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Original Research Articles

The use of sesame oil in sea bream feeds and its effects on growth and body chemical composition

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As fish oil availability declines worldwide and its price rises, there is a growing need to engage in scientific investigations into alternative oil sources for incorporation into fish feeds. This study aimed to determine the effects of dietary sesame oil on the growth performance, feed utilization, and nutritional composition of sea bream (*Sparus aurata*). Twenty-five individual fish (initial mean weight: 32.38±0.27 g) were placed in each tank in triplicate. Four experimental fish meal-based (iso-proteic 49% and iso-lipidic 20%) diets were formulated; the control (C) group contains 100% of fish oil (FO) and varying amounts (20, 40, 60%) of sesame oil (SO). During the 75-day experiment, the fish were fed 3 times a day, and the mean ambient temperature and dissolved oxygen values were measured as 22.5±0.5°C and 6.8±0.3 mg/L, respectively. At the beginning of the experiment, 20 fish were sampled to determine their nutrient composition and somatic indexes. In the end, 4 fish were collected for the same procedures and 4 for each tank's muscle and liver fatty acid compositions. At the end of the study, the S60 group exhibited the lowest final weight (FW) and feed utilization parameters. On the other hand, there were no statistical differences between FO, SO20, and SO40 in terms of FW. In addition, the SO40 group had the best feed conversion ratio (FCR) among the groups ($P<0.05$). The whole-body lipid compositions of the groups were different. The highest lipid level was found in SO40 with 15.83±0.36%. Muscle and liver fatty acid composition was significantly affected by the fatty acid profile of experimental feeds. While total ω-6 fatty acids were higher in the SO groups than in group C, total ω-3 fatty acids were higher in the C group compared to the SO groups ($P<0.05$). The ω-3/ω-6 ratios in the SO20 and SO40 groups showed similarity, while the highest ratio was observed in the control group ($P<0.05$). As a result, according to data obtained from our study, it is predicted that 40% SO could be added to sea bream feed instead of FO in terms of growth performance, feed utilization, and nutritional composition.

INTRODUCTION

The aquaculture industry has grown rapidly at an average annual rate of 6.7% between 1990 and 2020. Fish produced through aquaculture now nearly match the quantity of fish caught in the wild. FAO-OECD predicts that the total global seafood production will rise to 202 million tonnes per year by 2032, up from 181 million tonnes from 2020 to 2022. A significant 96% of this additional growth is expected to come from the expansion of aquaculture production, which is projected to reach 111 million tonnes per year by 2032.[1]

Fish farming, especially fish cultivation, relies on a specific oil source in their diets to enhance growth performance, feed consumption, and protein utilization.[2,3] While feeding marine fish, the quantity and utilization of fats in their diets play a crucial role in their growth. On the other hand, fish oil prices are increasing yearly. According to FAO data, while the prices of fish meal (Peruvian fish meal 65% crude protein) were roughly constant at 1600 USD (per tonne) in April 2023, this situation shows that the increase of 3700 USD (per tonne) for fish oil continues.[4] Despite the low supply of fish oil and the high demand, it is inevitable to be faced with a constant price increase. For this reason, over the past decade and still, the most important issue has been the use of an alternative oil source instead of fish oil in finfish feeds.[5-9] Vegetable oils have an

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almost limitless supply, making them the sole, easily accessible, and cost-effective substitute for fish oils.[10]

Throughout scientific research, numerous vegetable oil sources have been investigated as potential substitutes for fish oil, either in partial or complete replacement. Among the explored alternatives are canola, linseed, soybean, sunflower, cottonseed, sesame, palm, and olive oil.[2,3,7-9,11-17] It is observed that C18 series fatty acids are more dominant in vegetable oils in general, and they have a lower profile in terms of EPA and DHA.[5,13,18] While freshwater fish convert Linoleic acid (LO) to Arachidonic acid (AA) and Linolenic acid (LNO) to eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) very easily, marine fish do not have this ability, and especially C20 and C22 series HUFAs are needed in fish such as sea bream, sea bass and turbot.[13,18,19] On the other hand, in many marine fish, vegetable oil source was replaced with fish oil in certain proportions and results were obtained without any negative effects. In these studies where partial replacements were made, it was found that positive results were obtained in both growth, feed evaluation and body fatty acid compositions of the fish.[3,7,9,11,13-15,20-24] Some studies showed positive growth results when the diet completely replaced fish oil. However, this replacement did not have the same impact on the levels of ω-3 fatty acids and the ω-3/ω-6 ratio in the fish.[7,14,15]

Sesame oil generally exhibits a rich oleic acid (OA) and linoleic acid (LO) profile. In addition, sesame and linseed oils are recognized for their high resistance to oxidative rancidity owing to their tocopherol content. Furthermore, sesame oil is enriched with endogenous phenolic antioxidants like sesamin, sesamolin, and sesamol.[16,25-28]

The use of sesame oil instead of fish oil in fish feeds has been observed in a limited number of studies conducted on sea bass and rainbow trout.[16,17,29]

Therefore, this study aims to investigate the effects of sesame oil, used in certain proportions in feeds of sea bream, a preferred marine fish species in Turkey and Europe, on the fish's growth performance, feed evaluation, nutritional composition, and muscle and liver fatty acid profiles.

MATERIAL AND METHODS

FISH AND EXPERIMENTAL DESIGN

The EU Directive 2010/63/EU's guidelines for animal welfare and experimental ethics were followed in this investigation. Fish (*Sparus aurata*) were obtained from Akuvatur Aquaculture Company (Adana, TR) and acclimated at Cukurova University, Fisheries Faculty's research station. Prior to the setup of the study, the stock population (2000 individuals) was placed in stock tanks two weeks in advance and fed with the control group diet. At the beginning of the experiment, the average initial weight of gilthead sea bream was 32 g, and they were stocked into each tank (500 L) in three replicates of 25 randomly selected fish.

Throughout the experimental period (75 days), the tanks were supplied with filtered water at a flow rate of 3 L/min, aerated with oxygen, and subjected to a light period of 12 hours light: 12 hours dark (12L:12D). Water parameters were measured, and the average values during the trial were found to be 22.5±0.5°C for water temperature, 39±0.8 g/L for salinity, 6.8±0.3 mg/L for dissolved oxygen, and a pH of 7.8±0.1. Throughout the study, the fish were fed by hand thrice daily to apparent satiation.

EXPERIMENTAL FEEDS

Four different feed groups were used in the study: iso-proteic (49%) and iso-lipidic (20%). These groups were formulated as follows: Control (C) group with 100% fish oil (FO) and 20%, 40%, and 60% sesame oil (SO) designated as SO20, SO40, and SO60, respectively (**Table 1**). Raw materials were sourced from local producers within the country. All raw materials were thoroughly mixed and processed into pellets using a laboratory-scale pellet machine during feed preparation. Subsequently, the prepared feeds were vacuum-sealed and stored in the freezer (-20°C) for use throughout the study. Furthermore, the fatty acid composition of the experimental feeds was also analyzed (**Table 2**).

SAMPLE COLLECTION AND ANALYTICAL METHODS

At the beginning of the study 20 fish samples were taken from the stock population for whole body proximate composition and calculated body indices (hepatosomatic index; HSI, viscerosomatic index; VSI) At the end of the experiment, 4 fish were sampled from each tank for the same procedures. In addition, 4 fish were taken from each tank for muscle and liver fatty acid analysis. Fish weight measurements were taken at the beginning and end of the study, and daily feed consumption was recorded throughout the experimental period. These measurements were used to determine the growth performance and feed evaluations. Nutritional composition analyses of the feeds and fish samples followed the AOAC (Association of Official Analytical Chemists) standards.[30]

The fatty acid methyl esters of the experimental diets and the fish's muscle and liver samples were prepared following the method described by Ichiara et al.[31] with a minor modification. Transmethylation was carried out using 2 M KOH in methanol and n-heptane. Fatty acid analysis was conducted using a GC Clarus 500 with a flame ionization detector and a fused silica capillary SGE column (30 m × 0.32 mm, ID × 0.25 µm, BP20 0.25 UM, USA). The oven temperature was programmed to rise from 140°C to 200°C at a rate of 4°C/min and then to 220°C at a rate of 1°C/min, while the injector and detector temperatures were set at 220°C and 280°C, respectively. A 1 µl sample size was injected into the system, and helium (16 psi) was used as the carrier gas with a split ratio of 1:100. Fatty acids were identified by comparing the retention times of FAME with a Standard 37-component FAME mixture (Supelco). All analyses were performed in triplicate.

STATISTICAL ANALYSIS

All data were analyzed using one-way analysis of variance (ANOVA) in the SPSS 15.0 Windows software package. To assess the differences between means were tested for sig-

Table 1. Ingredients and proximate composition of the diets

Feed ingredients (g/kg)	C	SO20	SO40	SO60
Fish meal	510	510	510	510
Corn Gluten	230	230	230	230
Dextrin	65	65	65	65
Fish oil	90	72	54	36
Sesame oil	0	18	36	54
CMC	45	45	45	45
DCP	20	20	20	20
Vit Mix[a]	20	20	20	20
Min Mix[b]	20	20	20	20
Proximate composition (% of dry matter)				
Crude protein	49.18	49.08	48.79	48.75
Crude fat	20.02	19.87	20.03	20.03
Ash	12.11	12.02	11.92	11.97

[a]Vitamin mixture (g kg_1 vitamin mix): retinyl acetate, 1; cholecalciferol, 2.5; dl-a-tocopheryl acetate, 5; menadione, 1; thiamin–HCl, 0.1; riboflavin, 0.4; d-calcium panthothenate, 2; pyridoxine–HCl, 0.3; cyanocobalamin, 1; niacin, 1; choline, 200; ascorbic acid (ascorbyl polyphosphate), 5; folic acid, 0.1; d-biotin, 1; mesoinositol, 30. All ingredients were diluted with a-cellulose.
[b]Mineral mixture (g kg_1 mineral mix): KCl, 90; KI, 0.04; $CaHPO_4.2H_2O$, 500; NaCl, 40; $CuSO_4.5H_2O$, 3; $ZnSO_4.7H_2O$, 4; CoSO4, 0.02; FeSO4.7H2O, 20; $MnSO_4.H_2O$, 3; CaCO3, 215; MgOH, 124; Na2SeO3, 0.03; NaF, 1.

nificance using Duncan's multiple range test.[32] The significance level was set at P<0.05, and the results are reported as mean ± standard deviation (SD).

RESULTS

GROWTH PERFORMANCE AND FEED UTILIZATION

Throughout the trial period, no mortality was observed. At the end of the experiment, the S60 group exhibited the lowest final weight (FW), which showed statistically significant variation from the other groups (P<0.05). However, no significant differences were observed between the control and the other two groups (S20 and S40). The control group demonstrated the highest specific growth rate (SGR), slightly different from the S20 group. Subsequently, S40 and S60 groups followed with decreasing SGR values (P<0.05).

Regarding feed evaluation, the S40 group exhibited the most favorable feed conversion ratio (FCR), with no significant difference observed between the control and S20 groups. The highest FCR value was recorded in the S60 group (P<0.05). In terms of protein utilization assessment, both the protein efficiency ratio (PER) and protein productive value (PPV) exhibited significant differences between the groups (P<0.05). The control group had the highest values for both parameters compared to the other groups. Conversely, the S20 and S40 groups displayed similar values, while the S60 group showed the lowest protein utilization (**Table 3**).

PROXIMATE COMPOSITION AND SOMATIC INDEXES

No significant differences were observed among the groups in terms of protein and moisture values (P>0.05). However, the dietary treatments affected both ash and lipid contents, with the S40 group showing the highest lipid content (P<0.05). Significant variations were observed among the groups in VSI and HSI values (P<0.05). The highest VSI value was determined in the S40 group, consistent with its elevated lipid content. Additionally, the HSI values in the S0 groups were significantly higher than those in the C group (**Table 4**).

FATTY ACID COMPOSITION OF MUSCLE AND LIVER

Muscle and liver fatty acid composition was significantly affected by the dietary fatty acid composition (**Table 5 and Table 6**). In the muscle tissue, the total saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), EPA, and DHA contents were significantly higher in group control compared to the SO groups (P<0.05). On the other hand, while total ω-6 fatty acids were higher in the SO group than in group C, total ω-3 fatty acids were higher in the C group than in the SO groups (P<0.05). The ω-3/ω-6 ratios in the SO20 and SO40 groups showed similarity, while the highest ratio was observed in the C group, and the lowest was found in the SO60 group. Regarding liver fatty acid composition, significant differences were observed in SFAs, MUFAs, and polyunsaturated fatty acids (PUFAs) (P<0.05). C16:0 and C22:6ω-3 were dominant in the control group, whereas total MUFAs and specifically C18:1ω-9 fatty acids were found at higher levels in the SO40 group compared to the other groups. The ω-3/ω-6 ratios in the liver were highest in the control group and decreased sequentially in the other groups.

DISCUSSION

In studies conducted on marine fish, it has been revealed that incorporating different vegetable oil sources in partial

Table 2. Fatty acid composition of the experimental diets (% of total fatty acids)

Fatty acids	C	SO20	SO40	SO60
C14:0	3.81±0.16	3.61±0.21	3.52±0.20	2.72±0.04
C15:0	0.41±0.06	0.44±0.02	0.45±0.03	0.38±0.00
C16:0	15.81±0.08	15.10±0.51	14.43±0.31	13.94±0.23
C17:0	0.19±0.00	0.29±0.01	0.29±0.02	0.25±0.00
C18:0	3.87±0.02	4.30±0.03	4.62±0.12	5.06±0.08
C20:0	0.54±0.02	0.54±0.01	0.61±0.08	0.55±0.04
C23:0	0.05±0.00	0.04±0.00	0.04±0.01	0.05±0.01
C24:0	1.53±0.01	1.24±0.05	1.24±0.09	0.96±0.01
∑SFA	26.21±0.23	25.56±0.72	25.20±0.12	23.92±0.31
C14:1ω9	0.05±0.05	0.02±0.00	0.02±0.00	0.02±0.00
C15:1	0.07±0.00	0.07±0.00	0.08±0.01	0.06±0.01
C16:1ω9	0.29±0.02	0.31±0.01	0.33±0.01	0.26±0.02
C16:1ω7	4.45±0.07	3.86±0.22	3.85±0.12	3.23±0.13
C17:1	0.15±0.01	0.16±0.01	0.17±0.01	0.15±0.00
C18:1ω9	22.66±0.09	22.44±0.50	18.50±0.31	21.72±0.45
C18:1ω7	5.39±0.09	5.10±0.39	3.31±0.09	3.65±0.04
C20:1ω9	4.49±0.09	3.90±0.08	3.52±0.42	2.31±0.39
C20:1ω7	0.49±0.01	0.36±0.11	0.32±0.09	0.29±0.01
C22:1ω9	4.11±0.07	3.58±0.39	3.30±0.09	2.42±0.07
C22:1ω7	0.18±0.09	0.19±0.01	0.19±0.01	0.16±0.00
C24:1ω9	1.64±0.16	1.28±0.07	1.09±0.17	0.84±0.15
∑MUFA	43.97±0.31	41.25±0.17	34.67±0.33	35.11±0.17
C18:2ω6	8.93±0.04	8.95±0.20	9.95±0.69	10.22±0.12
C18:3 ω6	0.19±0.01	0.10±0.06	0.06±0.01	0.06±0.01
C18:3ω3	2.18±0.08	7.20±0.25	13.37±0.54	16.71±0.23
C18:4ω3	1.14±0.06	1.14±0.04	1.26±0.04	1.10±0.03
C20:2ω6	0.14±0.01	0.14±0.01	0.14±0.01	0.11±0.01
C20:3ω6	0.47±0.03	0.49±0.01	0.54±0.10	0.52±0.01
C20:4ω6	0.22±0.03	0.19±0.01	0.23±0.00	0.17±0.00
C20:4ω3	0.66±0.02	0.57±0.01	0.54±0.04	0.44±0.01
C20:5ω3	5.46±0.09	4.97±0.14	4.94±0.18	4.29±0.07
C22:6ω3	6.95±0.25	6.31±0.32	6.43±0.12	5.56±0.27
∑PUFA	26.34±0.40	30.06±0.28	37.45±0.56	39.19±0.45
∑ω-6	9.95±0.08	9.86±0.26	10.92±0.80	11.09±0.13
∑ω-3	16.39±0.34	20.19±0.37	26.54±0.37	28.10±0.53
ω-3/ω-6	1.65±0.03	2.04±0.02	2.43±0.04	2.53±0.01

Table 3. Growth and feed utilization parameters

	C	SO20	SO40	SO60
Initial (g)	32.12±0.55	32.13± 0.42	32.30±0.12	32.38±0.27
FW (g)	60.95 ± 0.63^{a}	59.82 ± 1.09^{a}	59.76 ± 1.38^{a}	53.46 ± 1.03^{b}
SGR(%/day)	0.71 ± 0.03^{a}	0.69 ± 0.04^{ab}	0.68 ± 0.04^{b}	0.55 ± 0.09^{c}
FCR	1.42 ± 0.05^{b}	1.41 ± 0.01^{b}	1.35 ± 0.03^{c}	1.45 ± 0.05^{a}
PER	1.42 ± 0.1^{a}	1.34 ± 0.03^{b}	1.31 ± 0.02^{b}	1.14 ± 0.19^{c}
PPV	26.33 ± 1.75^{a}	26.08 ± 0.51^{a}	23.03 ± 1.66^{b}	20.87 ± 0.53^{c}

Different letters (a,b,c) indicate significant group differences.

Table 4. Proximate composition and somatic indexes of fish

	Initial	C	SO20	SO40	SO60
Protein	15.47±0.64	16.92±0.44	17.31±0.21	16.40±0.16	17.14±0.98
Moisture	73.27±4.09	66.71±0.34	66.96±0.35	61.87±0.25	66.38±0.86
Ash	4.89±0.60	3.57±0.43^{a}	3.12±0.08^{b}	3.10±0.12^{b}	2.77±0.43^{c}
Lipid	6.35±0.59	12.31±0.43^{b}	10.63±0.23^{c}	15.83±0.36^{a}	12.34±0.23^{b}
VSI	0.96±0.49	0.81±0.09^{b}	0.72±0.02^{c}	0.98±0.06^{a}	0.72±0.05^{c}
HSI	0.79±0.23	2.06±0.50^{c}	2.47±0.57^{a}	2.37±0.41^{b}	2.37±0.31^{b}

Different letters (a,b,c) indicate significant group differences.

proportions as a substitution for fish oil can lead to favorable outcomes.[3,14,15,19,23,24,33-40] In addition, fish meal-based feeds (average 400-500 g/kg) with 18-22% oil content are commonly used in these studies, similar to those used in the current study.

In previous studies, it has been observed that as the substitution ratio of vegetable oil increases, certain negative effects are observed in growth performance and feed utilization efficiency in fish. Also, it was observed that this negative situation was reflected in the composition of fish body and liver fatty acids.[15,38,41,42] Particularly, a significant decrease in growth was noted at substitution levels exceeding 50-60%, with adverse effects becoming more pronounced at substitution rates around 70-80%.[14,23,24,35-37,39] On the other hand, in some studies, the complete substitution of fish oil with vegetable oils did not result in negative effects on growth and feed utilization.[7,14,15]

In the present study, similar to the previous partial substitution studies (SO40 group), positive results were obtained in terms of both growth and feed utilization. However, as the substitution rate increased (SO60 group), significant reductions in growth, feed utilization, PER and PPV were observed.

Evaluating the nutritional composition and somatic index parameters, it is evident that fish fed with vegetable oil feeds exhibited notable enhancements in body lipid content, hepatosomatic index (HSI), and viscerosomatic index (VSI).[12,14,15,24,39,42] Additionally, lipid accumulations were documented in both muscle and liver lipid content and increased visceral adiposity.[15,24,37,39] In the data obtained from our study, there was a notable increase in body lipid content and somatic indexes, especially in the sesame oil group (particularly SO40). This increase, observed in our study and other studies, has been previously attributed to the high presence of C18:2ω6 fatty acid in vegetable oils, which is known to enhance lipid accumulation.[14,15,33]

The current study's sea bream muscle fatty acid composition reflects the experimental diets' fatty acid profile. Thus, the clear effect of substituting fish oil with sesame oil in the diets on the fish's muscle and liver fatty acid profiles has been determined. This similar profile reflection has been reported in many studies.[3,7,12,13,24,35,42]. In addition, it is known that specific fatty acids accumulate in muscle and liver tissues or are used effectively in these tissues.

The muscle and liver compositions showed a similar tendency in total SFA and MUFA levels with the experimental feeds. Palmitic acid (C16:0) was the predominant SFA, followed by stearic acid (C18:0). Our findings have demonstrated consistent trends. Moreover, previous studies conducted using vegetable oils and various fish species have reported similar results.[7,15,40,42-44]

Considering the muscle and liver DHA levels, it is seen that the levels are higher than the levels in the feed. Therefore, this finding further supports the hypothesis that certain selected fatty acids are utilized for deposition and retention. Previous studies have reported similar observations on sea bream, sea bass, and turbot.[19,20,24,42]

The potential reasons behind this selective deposition can be attributed to the strong affinity of fatty acyl transferases for DHA and the relatively limited breakdown of DHA through β-oxidation, which is due to the intricate catabolic pathway governing this highly unsaturated fatty acid (HUFA).[2,12,19,24]

The use of sesame oil particularly appears to significantly impact the ω-3/ω-6 ratio in fish. A significant reduction observed in the ω-3/ω-6 levels when comparing the dietary levels with those in muscle and liver tissues. Concurrently, total ω-3 levels exhibit a similar trend. This finding shows how important ω-3 fatty acids are for marine fish species.[18] On the other hand, in fish, it is desirable to maintain a balanced ω-3/ω-6 ratio and use ω-3 fatty acids that promote growth. An increase in HSI values regarding fish growth performance can be expected, indicating a positive growth pattern.[14,18] It was determined that the results of our study were consistent with the high HSI values and the effective use of ω-3 fatty acids, especially in the sesame oil groups. Previous studies have reported similar findings (Bell et al., 2002; Regost et al.[20]; Mourente et al.[19]; Piedecausa et al.[14]).

In conclusion, when incorporating three different levels of sesame oil (20%, 40%, 60%) as replacements for fish oil in a feed formulation comprising 49% protein (fish meal based) and 20% lipid, the group with 40% sesame oil (SO40) showed positive performance in terms of growth, feed efficiency, nutrient composition, somatic indexes, and fish muscle and liver fatty acid compositions. However, when the substitution rate exceeded this level, negative effects were observed in the mentioned parameters.

Table 5. Fatty acid composition of sea bream muscle (% of total fatty acids)

Fatty acids	C	SO20	SO40	SO60
C14:0	3.27±0.02^{a}	3.07±0.02^{b}	3.24±0.03^{a}	2.55±0.02^{c}
C15:0	0.34±0.01	0.34±0.01	0.36±0.01	0.32±0.01
C16:0	13.82±0.23^{a}	13.78±0.01^{a}	13.28±0.02^{a}	12.73±0.03^{b}
C17:0	0.42±0.01^{a}	0.17±0.02^{b}	0.17±0.02^{b}	0.15±0.01^{b}
C18:0	3.22±0.03^{c}	3.48±0.01^{b}	2.96±0.02^{d}	3.78±0.01^{a}
C20:0	0.23±0.01	0.26±0.01	0.31±0.01	0.31±0.01
C23:0	0.23±0.01	0.21±0.01	0.22±0.02	0.21±0.01
C24:0	2.99±0.01^{a}	2.46±0.03^{b}	2.55±0.02^{b}	2.13±0.02^{c}
∑SFA	24.52±0.03^{a}	23.77±0.05^{b}	23.09±0.06^{b}	22.17±0.02^{c}
C14:1ω9	0.01±0.00	0.01±0.00	0.03±0.01	0.01±0.00
C15:1	0.05±0.00	0.06±0.01	0.06±0.01	0.05±0.00
C16:1 ω9	0.82±0.03	0.75±0.01	0.71±0.02	0.72±0.02
C16:1 ω7	5.86±0.06^{a}	5.42±0.01^{b}	4.87±0.01^{bc}	4.16±0.02^{c}
C17:1	0.15±0.00	0.19±0.02	0.18±0.01	0.16±0.01
C18:1 ω9	24.34±0.31^{ab}	23.96±0.02^{b}	24.47±0.06^{ab}	26.11±0.01^{a}
C18:1 ω7	3.27±0.01^{a}	3.17±0.02^{ab}	2.93±0.03^{b}	3.03±0.02^{ab}
C20:1 ω9	2.32±0.02^{a}	2.18±0.01^{ab}	2.05±0.02^{b}	1.63±0.01^{c}
C20:1 ω7	0.43±0.00	0.43±0.02	0.50±0.02	0.43±0.01
C22:1 ω9	0.06±0.01	0.07±0.01	0.08±0.01	0.08±0.01
C22:1 ω7	0.27±0.01	0.21±0.01	0.21±0.02	0.30±0.01
C24:1 ω9	0.88±0.02	0.81±0.01	0.82±0.05	0.74±0.03
∑MUFA	37.99±0.09^{a}	37.06±0.02^{b}	36.70±0.05^{c}	37.12±0.04^{b}
C18:2 ω6	10.11±0.01^{d}	13.44±0.02^{c}	14.58±0.02^{b}	17.48±0.02^{a}
C18:3 ω6	0.13±0.01	0.13±0.01	0.09±0.05	0.15±0.01
C18:3 ω3	2.20±0.02^{a}	2.28±0.01^{a}	1.78±0.01^{b}	1.54±0.01^{c}
C18:4 ω3	1.05±0.01	1.15±0.01	1.16±0.01	1.04±0.03
C20:2 ω6	0.54±0.03	0.50±0.01	0.49±0.02	0.55±0.02
C20:3 ω6	0.21±0.01	0.10±0.01	0.14±0.01	0.14±0.01
C20:4 ω6	4.53±0.01^{a}	4.36±0.02^{a}	4.34±0.01^{a}	3.56±0.02^{b}
C20:4 ω3	0.09±0.00	0.09±0.01	0.13±0.01	0.09±0.01
C20:5 ω3	2.06±0.02^{a}	1.22±0.01^{b}	1.35±0.03^{b}	0.61±0.01^{c}
C22:6 ω3	10.55±0.04^{a}	9.87±0.01^{b}	9.49±0.01^{b}	9.46±0.03^{b}
∑PUFA	31.12±0.61^{b}	33.14±0.05^{a}	33.54±0.06^{a}	34.62±0.05^{a}
∑ω-6	15.52±0.04^{d}	18.53±0.05^{c}	19.64±0.05^{b}	21.88±0.04^{a}
∑ω-3	15.95±0.57^{a}	14.61±0.00^{b}	13.91±0.01^{c}	12.74±0.02^{d}
∑ω-3/∑ω-6	1.02±0.03^{a}	0.79±0.00^{b}	0.71±0.00^{b}	0.58±0.00^{c}

Different letters (a,b,c,d) denote significant group differences.

Table 6. Fatty acid composition of sea bream liver (% of total fatty acids)

Fatty acids	C	SO20	SO40	SO60
C14:0	4.12±0.01^{a}	3.09±0.01^{b}	2.86±0.05^{c}	3.09±0.03^{b}
C15:0	0.41±0.01^{a}	0.33±0.01^{b}	0.29±0.01^{c}	0.34±0.02^{b}
C16:0	15.01±0.01^{a}	14.49±0.01^{b}	13.03±0.01^{c}	13.84±0.02^{c}
C17:0	0.16±0.00^{b}	0.18±0.00^{a}	0.16±0.00^{b}	0.13±0.01^{c}
C18:0	4.36±0.05^{b}	5.34±0.05^{a}	4.83±0.02^{b}	4.93±0.02^{ab}
C20:0	0.31±0.01^{a}	0.23±0.01^{b}	0.22±0.01^{b}	0.32±0.01^{a}
C23:0	0.19±0.00^{a}	0.17±0.02^{b}	0.15±0.00^{c}	0.17±0.00^{b}
C24:0	2.82±0.03^{a}	2.26±0.01^{b}	2.15±0.03^{c}	1.92±0.03^{d}
∑SFA	27.37±0.01^{a}	26.08±0.06^{b}	23.69±0.07^{d}	24.75±0.08^{c}
C14:1ω9	0.01±0.01	0.01±0.00	0.01±0.00	0.01±0.00
C15:1	0.06±0.00	0.06±0.00	0.06±0.00	0.06±0.00
C16:1 ω9	0.93±0.01^{a}	0.62±0.01^{b}	0.58±0.00^{c}	0.57±0.01^{c}
C16:1 ω7	5.27±0.02^{a}	4.46±0.02^{b}	4.27±0.02^{b}	3.89±0.02^{c}
C17:1	0.15±0.01^{a}	0.09±0.01^{b}	0.10±0.01^{b}	0.11±0.02^{ab}
C18:1 ω9	24.93±0.04^{d}	27.48±0.03^{b}	30.18±0.03^{a}	26.33±0.04^{c}
C18:1 ω7	3.61±0.01^{b}	3.87±0.02^{a}	3.55±0.03^{c}	3.54±0.03^{c}
C20:1 ω9	2.75±0.02a	2.09±0.01^{b}	1.86±0.02^{c}	1.82±0.02^{c}
C20:1 ω7	0.48±0.01	0.54±0.01	0.55±0.01	0.50±0.01
C22:1 ω9	0.08±0.01	0.12±0.01	0.13±0.01	0.08±0.01
C22:1 ω7	0.31±0.01	0.13±0.01	0.13±0.01	0.12±0.01
C24:1 ω9	1.03±0.02^{c}	1.42±0.01^{a}	1.33±0.02^{b}	1.11±0.01^{c}
∑MUFA	39.32±0.04^{c}	40.75±0.06^{b}	42.60±0.01^{a}	38.02±0.04^{d}
C18:2 ω6	9.48±0.04^{d}	10.52±0.02^{c}	13.35±0.01^{b}	16.36±0.03^{a}
C18:3 ω6	0.15±0.01	0.14±0.00	0.13±0.00	0.15±0.01
C18:3 ω3	1.81±0.00^{a}	1.53±0.03^{b}	1.32±0.01^{c}	1.36±0.01^{c}
C18:4 ω3	0.89±0.02^{a}	0.63±0.01^{c}	0.65±0.01^{c}	0.75±0.02^{b}
C20:2 ω6	0.70±0.01^{b}	0.76±0.03^{a}	0.52±0.02^{d}	0.63±0.02^{c}
C20:3 ω6	0.20±0.01^{a}	0.21±0.01^{a}	0.17±0.01^{b}	0.19±0.02^{ab}
C20:4 ω6	3.06±0.04^{a}	3.01±0.02^{a}	2.54±0.03^{c}	2.74±0.02^{b}
C20:4 ω3	0.08±0.01^{c}	0.13±0.01^{a}	0.13±0.01^{a}	0.11±0.00^{b}
C20:5 ω3	1.02±0.02^{b}	1.13±0.05^{a}	1.00±0.02^{c}	0.66±0.03^{d}
C22:6 ω3	8.67±0.02^{b}	9.12±0.02^{a}	7.95±0.04^{c}	8.96±0.01^{b}
∑PUFA	26.05±0.06^{c}	27.18±0.11^{b}	27.75±0.04^{b}	31.91±0.01^{a}
∑ω-6	13.59±0.05^{d}	14.64±0.04^{c}	16.71±0.04^{b}	20.07±0.02^{a}
∑ω-3	12.46±0.02^{a}	12.54±0.09^{a}	11.04±0.06^{b}	11.84±0.01^{ab}
∑ω-3/∑ω-6	0.92±0.01^{a}	0.86±0.01^{b}	0.66±0.01^{c}	0.59±0.00^{d}

Different letters (a,b,c,d) denote significant group differences.

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