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RESEARCH ARTICLE

Impact of feeding juvenile pikeperch (*Sander lucioperca* (L.)) diets supplemented with vegetable oils on proximate body composition and fatty acid profile

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Abstract. Juvenile pikeperch, *Sander lucioperca* (L.) were reared in recirculating aquaculture systems for 55 days and fed a commercial trout diet (group CD) or diets supplemented with the following vegetable oils (VO): rapeseed (group RO), soy (group SO), sunflower (group SFO). The level of feed supplementation with VO was 84% of the total crude fat (CF), which was achieved by adding 160 g VO kg^{-1} feed to the commercial feed base that contained 30 g CF kg^{-1} feed. The diets tested did not have a significant impact on the proximate composition of the whole fish, fillets, or viscera ($P > 0.05$). Significant differences were noted in the protein and fat contents of the pikeperch livers; these were significantly higher in the groups fed diets supplemented with VO ($P < 0.05$). The fatty acid (FA) profiles of the pikeperch body parts (whole fish, fillets, viscera, liver) analyzed reflected the proximate composition of the diets applied. The FA profiles of pikeperch muscles were the most stable. The diets tested did not have a significant impact in the fillets of fish from the VO groups on the value of summed products of polyunsaturated FA from the n-3 family (n-3 PUFA) to the PUFA from the n-6 family (n-6 PUFA) (n-3/n-6 ratio) ($P > 0.05$). They were, however, significantly lower than the values noted in group CD ($P < 0.05$) (1.03-2.07 vs. 3.50).

Keywords: fillet, fatty acids, vegetable oil, Percidae, proximate composition of body, viscera, liver

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Introduction

In light of limited resources of fish meal and fish oil (FO) coupled with rising costs and growing demand, vegetable oils are being used widely as substitutes for these components in the manufacture of fish feed (Tacon 2004). Vegetable oils (VO) can be a source of essential fatty acids (EFA) for many species of fish. Unlike fish oils, global supplies of vegetable oils are increasing, and the most widely produced oils include soy (SO), rapeseed (RO), and sunflower (SFO) (Turchini et al. 2009). These oils are rich in C18 fatty acids (FA) such as oleic acid (C18:1 cis 9; OA; rapeseed oil), α-linolenic (18:3 n-3; ALA; rapeseed and flax seed (LO) oils), and linoleic (18:2 n-6; LA; soy and sunflower oils). One of the disadvantages of vegetable oils is their lack of highly unsaturated fatty acids from the n-3 family (n-3 HUFA), e.g.,

eicosapentaenoic acid (20:5 n-3; EPA) and docosahexaenoic acid (22:6 n-3; DHA), which play decisive roles in many physiological processes and have a significant impact on, among other things, fish health (Turchini et al. 2009).

Fish species differ in their ability to bioconvert (elongate and desaturate) ALA to n-3 HUFA (Sargent et al. 2002). The metabolic effectiveness of this process in freshwater fish species is usually greater than it is in marine species (Steffens 1997, Rodriguez et al. 2002, Sargent et al. 2002). Fish that are capable of converting C18 FA, especially ALA, into EPA and DHA, include the Percidae, of which pikeperch, *Sander lucioperca* (L.), is one (Jankowska et al. 2003a). Substituting FO with VO with consequent increases in OA, LA, and ALA contents and decreases of EPA and DHA contents in the feed is reflected in the proximate composition of whole fish bodies, livers, viscera, and fillets. The magnitude of these shifts is specific to species, and even to given tissues, and depends on the proportion of the neutral and polar lipid content of the oils (Turchini et al. 2009). The composition of neutral lipids, the so-called deposit lipids (mainly triacylglycerols (TAGs)), is largely dependent on diet. The impact on polar lipids (phospholipids) might be less significant. In species with fatty meat that store fats (mainly TAGs), the impact of feed on the muscles is decidedly more pronounced than in fish with lean meat that store energy reserves in the viscera, for example (Jobling 2001). Pikeperch belongs to the second group of fish. Although feeding these fish commercial feed increases the fillet fat content, no change is noted in the value of the summed products of polyunsaturated FA from the n-3 series (n-3 PUFA) to the PUFA from the n-6 family (n-6 PUFA) (% total FA – tFA), including DHA, which is essential in human nutrition (Jankowska et al. 2003b).

The aim of the current study was to determine the impact feeding juvenile pikeperch diets supplemented with VO (specifically RO, SO, and SFO,) or commercial trout feed (with a similar fat content of 19%) had on the proximate composition and fatty acid profiles of whole fish bodies, fillets, viscera, and livers.

Materials and methods

Fish, rearing conditions, feed and feeding

The experimental material with an initial body weight (BW) of 102 g and total length (TL) of 24.5 cm was reared for 55 days in recirculating aquaculture systems at the Department of Aquaculture, Inland Fisheries Institute in Olsztyn (Poland). Rearing tanks with a volume of 0.2 m^3 were stocked with 31 individuals each. Water temperature was maintained at a constant level of 22.1 ± 0.2°C. Water oxygen saturation at the tank inflows and outflows did not decrease below 7.8 and 5.0 mg O_2 dm^{-3}, respectively. Concentrations of total ammonia nitrogen (TAN = NH_4^+-N + NH_3-N) at the inflows and outflows of the tanks did not exceed 0.10 and 0.34 mg TAN dm^{-3}, respectively. The water pH ranged from 7.8 to 8.1. The photoperiod applied was constant (24L:0D), and the light intensity at the tank water surface ranged from 20 to 22 lx.

The diets tested were prepared using a commercial feed base (Aller Safir XS, Aller-Aqua, Golub-Dobrzyń, Poland) containing 510 g protein kg^{-1} feed and 30 g fat kg^{-1} feed (dry matter (d.m.)). Each 1000 g of feed base was supplemented with 160 g (84% total fat content) of one of the following vegetable oils: rapeseed (ZPT Warszawa, Warsaw, Poland; diet RO), soy (WZT ADM Szamotuły, Szamotuły, Poland; diet SO), or sunflower (ZPT Warszawa, Warsaw, Poland; diet SFO). The vegetable oil was mixed well into the base feed, and then sealed with a vacuum pump (AGA Labor, Lublin, Poland). The control group of fish was fed Aller Safir XS commercial feed (Aller-Aqua, Golub-Dobrzyń, Poland) that had a proximate composition that was similar to that of the experimental feed (diet CD; Table 1). The fatty acid profiles of the experimental diets were similar to those of the oils with which they had been supplemented. In comparison to the experimental diets supplemented with VO, the control diet (CD) had a higher content of saturated fatty acids (SFA) and a lower content of unsaturated fatty acids (USFA) (Table 1). The highest content of monounsaturated

Table 1
Proximate composition (in dry matter (d.m.)) and share of chosen fatty acids in the commercial diet (CD) and the experimental diets supplemented with rapeseed oil (RO), soy oil (SO), and sunflower oil (SFO)

	Diet			
	CD	RO	SO	SFO
Proximate composition				
Crude protein (CP; g kg^{-1} d.m.)	450.3	449.0	452.1	452.0
Crude fat (CL; g kg^{-1}d.m.)	190.3	189.1	191.1	190.5
Nitrogen-free extract (NFE; g kg^{-1} d.m.)(1)	285.3	287.4	282.9	283.0
Crude ash (CA; g kg^{-1} d.m.)	74.1	74.5	73.9	74.5
Gross energy (MJ kg^{-1} d.m.)(2)	23.08	23.04	23.11	23.09
Fatty acids (% sum of all fatty acids)				
C14:0	8.21	1.83	1.85	1.88
C16:0	16.11	8.79	13.15	10.41
C18:1 cis9	26.22	46.64	25.60	21.73
C18:2 n-6	9.01	16.56	36.66	45.53
C18:3 n-3	3.11	5.62	2.63	1.21
C20:4 n-6	0.28	0.15	0.13	0.13
C20:5 n-3	4.64	2.36	2.10	2.25
C22:5 n-3	0.48	0.21	0.21	0.19
C22:6 n-3	5.07	3.42	3.26	3.29
Σ SFA(3)	27.18	13.59	19.22	15.96
Σ USFA(4)	72.82	86.41	80.78	84.04
Σ MUFA(5)	45.69	56.06	33.97	29.98
Σ PUFA(6)	27.13	30.35	46.81	54.05
Σ n-3 PUFA(7)	13.76	11.78	8.38	7.11
Σ n-6 PUFA(8)	9.29	16.86	36.78	45.66
Σ n3 PUFA/Σ n6 PUFA	1.28	0.70	0.23	0.16

(1) NFE = 100 – (CP + CL + CA), NFE with fiber;
(2) calculated based on the following conversion factors: CP – 24 kJ g^{-1}, CL – 39 kJ g^{-1}, NFE – 17 kJ g^{-1} (Jobling 1994);
(3) ΣSFA – saturated fatty acids: 14:0, 15:0, 16:0, 18:0, 20:0;
(4) ΣUSFA – sum of unsaturated fatty acids, monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA);
(5) ΣMUFA – sum of monounsaturated fatty acids: 14:1, 16:1, 17:1, 18:1cis9, 18:1cis11, 20:1n-9, 20:1n-7, 22:1n-11, 22:1n-9;
(6) ΣPUFA – sum of polyunsaturated fatty acids: 16:2, 16:4, 18:2 n-6, 18:3 n-3, 18:3 n-4, 18:4, 20:2, 20:3 n-6, 20:4 n-6, 20:3 n-3, 20:4 n-3, 20:5 n-3, 22:5 n-6, 22:5 n-3, 22:6 n-3;
(7) Σn-3 PUFA – PUFA from the n-3 family: 18:3 n-3, 20:3 n-3, 20:4 n-3, 20:5 n-3, 22:5 n-3, 22:6 n-3;
(8) Σn-6 PUFA – PUFA from the n-6 family: 18:2 n-6, 20:3 n-6, 20:4 n-6, 22:5 n-6.

fatty acids (MUFA) was in diet RO, and PUFA in diets SO and SFO. The highest content of n-3 PUFA was noted in diet CD, while that of n-6 PUFA was the highest in diet SFO. The n-3/n-6 fatty acid ratio ranged from 0.16 (diet SFO) to 1.28 (diet CD). In all of the diets tested, the dominant SFA was palmitic acid (C16:0; PA), and the highest values were noted in the control diet. Among the MUFA and PUFA, OA and LA dominated, respectively. The content of LA in the diets tested was as follows: CD < RO < SO < SFO. In comparison with the diets supplemented with VO, diet CD contained the most HUFA, e.g., arachidonic (20:4 n-6; ARA), EPA, and DHA (Table 1).

The feed was delivered for 16 h d^{-1} (09:00-03:00) with an automatic band feeder (FIAP, Fishtechnik GmbH, Ursensollen, Germany). The daily ration ranged from 1.2% of the stock biomass (beginning of rearing) to 1.0% of the stock biomass (last two weeks of rearing). Each group of fish was reared in three repeats.

Material collection and chemical analysis procedures

On the first and final days of the experiment all fish were weighed (BW ± 0.1 g) and measured (TL ± 0.1 cm). Additionally, samples of fish were taken for the analysis of the proximate composition of the bodies. The fish were deheaded after they had been anesthetized in a solution of etomidate (4.0 cm^3 dm^{-3}) (Propiscin, IFI Olsztyn, Olsztyn, Poland; Kazuń and Siwicki 2001). The number of the initial sample for analysis was 15 individuals (proximate composition of whole bodies – 5 fish; fillets – 6 fish; viscera – 10 fish). On the final day of the experiment 25 fish were sampled from each rearing tank (5 fish – analysis of the proximate composition of whole bodies; 6 fish – fillets; 20 fish – viscera and livers). After the fish had been deheaded with a simple cut, the fins were removed and the fish were skinned and then dissected, the fillets and viscera were weighed (to the nearest ± 0.01 g). Whole fish, fillets, viscera, and livers were ground (3 mm mesh size) and the contents of the primary components and the fatty acid profiles were determined. Samples from the same tanks (repeats) were combined and analyzed together (n = 3). The data collected was used to determine the value of the viscerosomatic index, VSI = 100 × (viscera weight (g) × body $weight^{-1}$ (g)).

The water content was determined by drying the samples at a temperature of 105°C to a constant weight. Total protein was determined with the Kjeldahl method using a multiplier of 6.25. Fat was determined with the Soxhlet method using petroleum ether for the solvent. Ash was determined by mineralizing the samples at a temperature of 550-600°C (AOAC 1975).

The fatty acid profiles were analyzed quantitatively and qualitatively after the muscle lipids had been cold extracted as described in Folch et al. (1957). The fatty acids were methylated with a mixture of chloroform, methanol, and sulfuric acid (100:100:1) (Peisker 1964). Chromatographic separation was performed in a gas chromatograph (Agilent Technologies 6890 N) with flame-ionizing detection (FID) and a capillary column 30 m in length with an internal diameter of 0.32 mm; the liquid phase was Supelcowax 10, with a film thickness of 0.25 μm. The separation conditions were as follows: carrier gas – helium; flow rate 1 mm^3 min^{-1}, detector temperature – 250°C; injector temperature – 225°C; column temperature – 180°C. Detector signals were recorded on a Phillips recorder scaled at 1 mV and at a tape speed of 10 mm min^{-1}. The various fatty acids were identified by comparing retention times with those of standards from Supelco (Bellefonte, PA, USA).

Statistical analysis

The statistical analysis of the data was performed with STATISTICA (StatSoft®, Kraków, Poland). Single factor analysis of variance (ANOVA) was applied, and the variance homogeneity was checked with Levene's test. When statistically significant differences were confirmed ($P \leq 0.05$), Tukey's test was applied. Percentage data was transformed with the *arcsin* function prior to statistical analysis.

Results

Proximate composition

The experimental diets supplemented with various vegetable oils did not have a significant impact on the growth rates or the condition of the juvenile pikeperch. After 55 days the fish attained a body weight of approximately 170 g ($P > 0.05$). No fish mortality was noted during rearing. The proximate composition of the whole fish, fillets, and viscera (water, protein, fat, ash) of the pikeperch were similar. Consequently, the energy concentration did not differ significantly statistically ($P > 0.05$; Table 2). The analysis of the proximate composition of the livers indicated that the protein content in the fish from groups RO and SO was significantly lower than that in the fish from groups CD and SFO ($P < 0.05$). The fat contents of the livers in fish from the VO groups was higher than that in group CD, and in groups RO

Table 2
Proximate composition (% wet weight) and energy value of the whole fish, fillets, viscera, and livers of pikeperch fed the tested diets (mean values (±SE); n = 3). Dietary treatments are discussed in detail in the Materials and Methods section. *calculated using the following conversion factors: protein – 24 kJ g^{-1}, fat – 39 kJ g^{-1} (Jobling 1994). Groups with different letter indexes in the same row are statistically significantly different (P < 0.05); na – not analyzed

	Beginning of experiment	Treatment groups			
		CD	RO	SO	SFO
Whole fish					
Water	72.34	68.77 (±0.52)	68.67 (±0.30)	68.12 (±0.37)	69.70 (±0.44)
Crude protein	17.16	17.48 (±0.25)	17.54 (±0.05)	17.08 (±0.25)	16.97 (±0.08)
Crude fat	6.44	9.65 (±0.28)	9.73 (±0.40)	10.69 (±0.20)	9.18 (±0.36)
Crude ash	4.06	4.12 (±0.01)	4.07 (±0.06)	4.11 (±0.07)	4.16 (±0.01)
Energy (kJ g^{-1})*	6.63	7.96 (±0.17)	8.00 (±0.15)	8.27 (±0.13)	7.65 (±0.16)
Fillets					
Water	79.50	77.78 (±0.07)	77.66 (±0.40)	77.88 (±0.02)	77.53 (±0.14)
Crude protein	18.52	20.33 (±0.06)	20.66 (±0.28)	20.28 (±0.14)	20.58 (±0.03)
Crude fat	0.79	0.78 (±0.12)	0.60 (±0.12)	0.75 (±0.14)	0.80 (±0.11)
Crude ash	1.19	1.12 (±0.00)	1.10 (±0.01)	1.10 (±0.02)	1.10 (±0.00)
Energy (kJ g^{-1})*	4.75	5.18 (±0.03)	5.19 (±0.11)	5.16 (±0.02)	5.25 (±0.05)
Viscera					
Water	28.57	17.52 (±0.96)	16.78 (±0.35)	14.90 (±1.02)	15.06 (±1.39)
Crude protein	7.36	8.17 (±1.69)	7.06 (±0.59)	5.56 (±0.94)	5.43 (±1.33)
Crude fat	63.91	74.15 (±2.65)	75.98 (±0.94)	79.36 (±0.07)	79.31 (±0.07)
Crude ash	0.16	0.17 (±0.01)	0.19 (±0.01)	0.19 (±0.01)	0.21 (±0.01)
Energy (kJ g^{-1})*	24.92	30.88 (±0.63)	31.32 (±0.22)	32.28 (±0.25)	32.23 (±0.35)
Livers					
Water	na	65.24 (±0.37)	61.97 (±1.50)	63.89 (±0.59)	63.38 (±0.78)
Crude protein	na	16.42^{a} (±0.34)	15.22^{b} (±0.18)	15.20^{b} (±0.12)	16.76^{a} (±0.08)
Crude fat	na	13.38^{a} (±0.31)	19.34^{b} (±1.19)	18.94^{b} (±0.72)	17.40^{ab} (±0.21)
Crude ash	na	0.97 (±0.01)	0.98 (±0.01)	0.98 (±0.01)	0.97 (±0.01)
Energy (kJ g^{-1})*	na	9.16^{a} (±0.20)	11.19^{b} (±0.42)	11.03^{b} (±0.25)	10.81^{b} (±0.10)

and SO these differences were statistically significant (P < 0.05; Table 2).

Fatty acid profiles

Whole fish – the fatty acid composition of pikeperch fed diets supplemented with various vegetable oils reflected the proximate composition of these feeds (Tables 1 and 3). Statistically significant differences among groups were noted in all of the fatty acid groups analyzed (SFA, USFA, MUFA, PUFA; P < 0.05; Table 3). The highest level of MUFA was noted in group RO, and the highest level of PUFA was in group SFO (P < 0.05). Diet was noted to have a significant impact on the contents of n-3 PUFA and n-6 PUFA (P < 0.05). The highest content of n-3 PUFA was confirmed in the bodies of pikeperch from group CD, while that of n-6 PUFA was noted in group SFO (Table 3). In effect, the n-3/n-6 ratios differed significantly and ranged from 0.39 (group SFO) to 1.91 (group CD) (P < 0.05). The contents in pikeperch bodies of fatty acids such as PA, OA, LA, and ALA corresponded to those in the feeds tested, and the differences among groups were statistically significant

Table 3

Fatty acid composition (% of the sum of all fatty acids) in bodies (whole fish) of pikeperch fed tested diets (mean values (±SE); n = 3). Dietary treatments are discussed in detail in the Materials and Methods section. Groups with different letter indexes in the same row are statistically significantly different (P < 0.05); SFA – saturated fatty acids; USFA – unsaturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids; n-3 PUFA – polyunsaturated fatty acids from the n-3 family; n-6 PUFA – polyunsaturated fatty acids from the n-6 family (see Table 1)

Fatty acids	Beginning of experiment	Treatment groups			
		CD	RO	SO	SFO
C14:0	5.78	5.86^{b} (±0.47)	3.54^{a} (±0.09)	3.72^{a} (±0.37)	3.16^{a} (±0.10)
C16:0	15.53	15.79^{c} (±0.54)	12.56^{a} (±0.09)	15.19^{bc} (±0.57)	13.00^{ab} (±0.38)
C18:1 cis 9	18.33	23.20^{a} (±1.69)	37.10^{b} (±0.55)	26.26^{a} (±0.13)	24.70^{a} (±0.02)
C18:2 n-6	14.08	10.73^{a} (±0.07)	15.57^{b} (±0.37)	26.79^{c} (±0.28)	32.57^{d} (±0.23)
C18:3 n-3	2.29	2.46^{b} (±0.06)	4.05^{d} (±0.01)	3.40^{c} (±0.10)	1.69^{a} (±0.01)
C20:4 n-6	0.81	0.64^{b} (±0.03)	0.38^{a} (±0.02)	0.32^{a} (±0.01)	0.35^{a} (±0.00)
C20:5 n-3	8.26	7.93^{b} (±0.42)	4.49^{a} (±0.30)	3.74^{a} (±0.28)	4.04^{a} (±0.05)
C22:5 n-3	1.56	1.38^{b} (±0.05)	0.85^{a} (±0.05)	0.70^{a} (±0.04)	0.74^{a} (±0.00)
C22:6 n-3	10.11	10.44^{b} (±0.46)	6.83^{a} (±0.44)	5.62^{a} (±0.36)	6.23^{a} (±0.19)
Σ SFA	23.72	23.89^{b} (±0.98)	17.94^{a} (±0.04)	21.24^{ab} (±1.00)	18.49^{a} (±0.44)
Σ USFA	76.28	76.11^{a} (±0.98)	82.06^{b} (±0.04)	78.76^{ab} (±1.00)	81.51^{b} (±0.44)
Σ MUFA	34.92	38.17^{c} (±0.27)	47.39^{d} (±0.53)	35.78^{b} (±0.10)	33.43^{a} (±0.05)
Σ PUFA	41.36	37.39^{ab} (±1.25)	34.67^{a} (±0.57)	42.98^{bc} (±1.09)	48.07^{c} (±0.49)
Σ n-3 PUFA	22.82	22.74^{b} (±1.02)	16.59^{a} (±0.84)	13.77^{a} (±0.80)	13.01^{a} (±0.25)
Σ n-6 PUFA	15.32	11.88^{a} (±0.01)	15.99^{b} (±0.31)	27.17^{c} (±0.24)	33.18^{d} (±0.30)
Σ n3/Σ n6	1.49	1.91^{c} (±0.08)	1.04^{b} (±0.07)	0.51^{a} (±0.02)	0.39^{a} (±0.00)

(P < 0.05). The contents of ARA, EPA, and DHA in the fish bodies were twice as high as those in the feeds tested. The content of HUFA in the fish from group CD was significantly higher than that in the VO groups. No statistically significant differences were noted, however, in the contents of ARA, EPA, or DHA in the bodies of fish fed the diets supplemented with VO (P > 0.05; Table 3).

Fillets – the fatty acids profiles of the fillets of pikeperch were more stable than those of the whole bodies. No statistically significant differences among groups were noted for SFA or USFA (P > 0.05; Table 4). The content of MUFA in the fillets of fish from group RO was significantly higher than in the other groups (36.8% vs. 26-28% tFA; P < 0.05; Table 4). The content of n-3 PUFA in group CD was significantly higher than that in the VO groups. In turn, the highest content of n-6 PUFA was noted in groups SO and SFO. Diet was not noted to significantly impact the value of the n-3/n-6 ratio in the fillets of the fish from the VO groups (P > 0.05), which was, nevertheless, significantly lower than that calculated for group CD (P < 0.05). The content of OA in group RO was significantly higher than that of the other dietary groups (P < 0.05), while the content of LA in the fillets of fish from groups SO and SFO was significantly higher than that in the fish from groups CD and RO (P < 0.05). The contents of OA and LA in the fillets of fish were lower than that determined in the feeds tested, and ARA and DHA were several-fold higher than the content in the feeds (Tables 1 and 4).

Viscera – significantly significant differences among groups were confirmed in the contents of the groups of fatty acids analyzed, e.g., SFA, USFA, MUFA, PUFA, n-3 PUFA, and n-6 PUFA (P < 0.05; Table 5). The contents of SFA, PUFA, and n-3 PUFA in the viscera of all the dietary groups was lower than in the fillets, while MUFA and n-6 PUFA contents

Table 4
Fatty acid composition (% of the sum of all fatty acids) in fillets of pikeperch fed tested diets (mean values (±SE); n = 3). Dietary treatments are discussed in detail in the Materials and Methods section. Groups with different letter indexes in the same row are statistically significantly different (P < 0.05); SFA – saturated fatty acids; USFA – unsaturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids; n-3 PUFA – polyunsaturated fatty acids from the n-3 family; n-6 PUFA – polyunsaturated fatty acids from the n-6 family (see Table 1)

		Treatment groups			
Fatty acids	Beginning of experiment	CD	RO	SO	SFO
C14:0	3.70	3.49^{b} (±0.04)	2.51^{a} (±0.22)	2.28^{a} (±0.14)	2.06^{a} (±0.16)
C16:0	19.23	18.20 (±1.27)	14.69 (±0.69)	17.26 (±0.72)	16.41 (± 0.05)
C18:1 cis 9	13.75	15.86^{a} (±0.74)	29.09^{b} (±0.45)	18.99^{a} (±0.31)	18.66^{a} (±1.18)
C18:2 n-6	11.29	8.09^{a} (±0.88)	11.58^{a} (±1.12)	19.23^{b} (±0.77)	23.35^{b} (±0.78)
C18:3 n-3	1.74	1.74^{ab} (±0.17)	2.60^{b} (±0.29)	2.29^{ab} (±0.12)	1.29^{a} (±0.13)
C20:4 n-6	1.30	1.24 (±0.09)	0.90 (±0.14)	0.88 (±0.03)	0.58 (±0.32)
C20:5 n-3	9.84	8.82^{b} (±0.28)	6.04^{a} (±0.21)	5.77^{a} (±0.12)	5.37^{a} (±0.27)
C22:5 n-3	1.59	1.56^{b} (±0.04)	0.99^{a} (±0.13)	1.13^{ab} (±0.01)	1.06^{a} (±0.06)
C22:6 n-3	18.71	21.61 (±0.82)	16.78 (±0.74)	18.47 (±0.76)	17.37 (±1.50)
Σ SFA	26.89	25.98 (±1.67)	21.99 (±0.58)	23.91 (±0.93)	23.03 (±0.04)
Σ USFA	73.11	74.02 (±1.67)	78.01 (±0.58)	76.09 (±0.93)	76.97 (±0.04)
Σ MUFA	25.48	27.82^{a} (±0.96)	36.81^{b} (±0.10)	25.96^{a} (±0.73)	25.72^{a} (±1.43)
Σ PUFA	47.63	46.20^{b} (±0.71)	41.20^{a} (±0.48)	50.13^{bc} (±0.19)	51.25^{c} (±1.40)
Σ n-3 PUFA	32.29	34.13^{b} (±0.31)	26.70^{a} (±0.50)	27.96^{a} (±0.52)	25.22^{a} (±1.82)
Σ n-6 PUFA	13.07	9.84^{a} (±0.83)	12.98^{a} (±0.93)	20.57^{b} (±0.57)	24.63^{b} (±0.49)
Σ n3/Σ n6	2.47	3.50^{b} (±0.33)	2.07^{a} (±0.19)	1.36^{a} (±0.06)	1.03^{a} (±0.09)

were higher (Tables 4 and 5). The ratio of n-3/n-6 ranged from 0.34 (group SFO) to 1.81 (group CD) (P < 0.05). The level of the C18 fatty acids analyzed (OA, LA, ALA) in the viscera of the fish from all the experimental groups was higher than that in the fillets, contrary to the contents of ARA, EPA, and DHA (Tables 4 and 5).

Livers – the shares of all the fatty acid groups analyzed was determined significantly by the diet applied (P < 0.05; Table 6). The highest contents of SFA and n-3 PUFA, and the lowest content of n-6 PUFA (P < 0.05) were noted in group CD. The livers of the fish from group RO had the highest content of MUFA and the lowest content of PUFA. The highest content of PUFA (43.46% tFA), which was decisive in determining the high content of n-6 PUFA (31.43% tFA), was confirmed in group SFO. The value of the n-3/n-6 ratio ranged from 0.33 (group SFO) to 2.06 (group CD) (P < 0.05). These values were comparable to those calculated for the viscera of the fish from the dietary groups analyzed, but decidedly lower than those estimated for the fish fillets (Tables 4, 5, and 6). The content of PA was similar to that noted in the fillets (Tables 4 and 6), while the contents of OA, LA, and ARA were similar to those confirmed in the viscera (Tables 5 and 6). The content of EPA was lower in the livers than it was in the viscera or fillets, while that of DHA was higher than that in the viscera, but two- to threefold lower than the content in the fillets (Tables 4, 5, and 6). No significant differences were noted in the contents of ARA, EPA, or DHA in the livers of fish fed diets supplemented with VO (P > 0.05). The shares of these fatty acids, were, however, lower than those confirmed in group CD (P < 0.05; Table 6).

Table 5
Fatty acid composition (% of the sum of all fatty acids) in viscera of pikeperch fed tested diets (mean values (±SE); n = 3). Dietary treatments are discussed in detail in the Materials and Methods section. Groups with different letter indexes in the same row are statistically significantly different (P < 0.05); SFA – saturated fatty acids; USFA – unsaturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids; n-3 PUFA – polyunsaturated fatty acids from the n-3 family; n-6 PUFA – polyunsaturated fatty acids from the n-6 family (see Table 1)

		Treatment groups			
Fatty acids	Beginning of experiment	CD	RO	SO	SFO
C14:0	6.59	5.77^{b} (±0.27)	3.36^{a} (±0.01)	3.40^{a} (±0.02)	3.53^{a} (±0.05)
C16:0	15.59	14.53^{b} (±0.27)	11.74^{a} (±0.17)	13.54^{b} (±0.05)	12.46^{a} (±0.18)
C18:1 cis 9	20.28	25.66^{a} (±0.23)	40.68^{c} (±0.35)	27.05^{b} (±0.14)	25.16^{a} (±0.06)
C18:2 n-6	15.65	11.34^{a} (±0.00)	16.27^{b} (±0.08)	28.79^{c} (±0.13)	33.55^{d} (±0.12)
C18:3 n-3	2.36	2.72^{b} (±0.01)	4.24^{d} (±0.02)	3.57^{c} (±0.04)	1.69^{a} (±0.01)
C20:4 n-6	0.61	0.59^{b} (±0.02)	0.29^{a} (±0.01)	0.28^{a} (±0.00)	0.29^{a} (±0.00)
C20:5 n-3	7.24	8.19^{b} (±0.31)	3.72^{a} (±0.08)	3.66^{a} (±0.09)	3.94^{a} (±0.05)
C22:5 n-3	1.33	1.39^{b} (±0.06)	0.69^{a} (±0.01)	0.71^{a} (±0.00)	0.72^{a} (±0.00)
C22:6 n-3	7.15	9.58^{b} (±0.61)	4.38^{a} (±0.33)	4.73^{a} (±0.02)	4.91^{a} (±0.04)
Σ SFA	24.42	22.22^{c} (±0.55)	16.79^{a} (±0.13)	19.04^{b} (±0.11)	17.89^{ab} (±0.28)
Σ USFA	75.58	77.78^{a} (±0.55)	83.21^{c} (±0.13)	80.96^{b} (±0.11)	82.11^{bc} (±0.28)
Σ MUFA	37.62	39.44^{b} (±0.55)	51.16^{c} (±0.50)	36.66^{a} (±0.11)	34.57^{a} (±0.07)
Σ PUFA	37.96	38.33^{b} (±1.10)	32.05^{a} (±0.63)	44.30^{c} (±0.01)	47.54^{c} (±0.21)
Σ n-3 PUFA	18.58	22.46^{b} (±0.98)	13.35^{a} (±0.45)	12.99^{a} (±0.08)	11.60^{a} (±0.09)
Σ n-6 PUFA	16.27	12.41^{a} (±0.12)	16.74^{b} (±0.17)	29.27^{c} (±0.03)	33.98^{d} (±0.14)
Σ n3/Σ n6	1.14	1.81^{c} (±0.06)	0.80^{b} (±0.02)	0.44^{a} (±0.00)	0.34^{b} (±0.00)

Discussion

Pikeperch fed commercial feeds have higher fat content in their bodies than do individuals feeding on natural feed (Jankowska et al. 2003a). However, providing these fish with diets that have similar fat contents but different FA sources (e.g., VO and/or FO) does not impact the content of this nutrient in either the whole bodies or the fillets (Schulz et al. 2005, Molnár et al. 2006, current study). It is worthwhile noting that the fat content of the diets applied in the current study was 19%, which differed from those applied in Molnar et al. (2006) at 12 or 18% and in Schulz et al. (2005) at 12-13%. Diets supplemented with FO and/or VO was also not noted to have impacted the proximate composition in other fish species, e.g., turbot, *Psetta maxima* (L.) (Regost et al. 2003), European seabass, *Dicentrarchus labrax* L. (Mourente et al. 2005), or tench, *Tinca tinca* (L.) (Zakęś et al. 2009).

Fats are metabolized in the liver, and feeding fish diets with different quantitative and/or qualitative fat contents can often impact the proximate composition of this organ. This phenomenon has also been confirmed in pikeperch (Schulz et al. 2005; current study), and in rainbow trout, *Oncorhynchus mykiss* (Walbaum) (Caballero et al. 2002). The fat content in the livers of pikeperch fed diets with VO was significantly higher than in fish from the control group (diet with FO). In the current study, changes were also noted in the protein content of the fish livers, which was significantly lower in the fish from groups RO and SO than in those from group CD (commercial feed). The impact of diets supplemented with VO on the livers is species specific. Izquierdo et al. (2003) found that feeding gilthead seabream, *Sparus aurata*

Table 6
Fatty acid composition (% of the sum of all fatty acids) in livers of pikeperch fed tested diets (mean values (±SE); n = 3). Dietary treatments are discussed in detail in the Materials and Methods section. Groups with different letter indexes in the same row are statistically significantly different (P < 0.05); SFA – saturated fatty acids; USFA – unsaturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids; n-3 PUFA – polyunsaturated fatty acids from the n-3 family; n-6 PUFA – polyunsaturated fatty acids from the n-6 family (see Table 1)

	Treatment groups			
Fatty acids	CD	RO	SO	SFO
C14:0	4.79^{b} (±0.05)	3.18^{a} (±0.00)	3.08^{a} (±0.02)	3.19^{a} (±0.15)
C16:0	17.04^{b} (±0.25)	15.43^{a} (±0.08)	16.62^{b} (±0.24)	16.47^{b} (±0.01)
C18:1 cis 9	27.83^{b} (±0.47)	40.16^{c} (±0.35)	26.75^{ab} (±0.05)	25.25^{a} (±0.03)
C18:2 n-6	9.30^{a} (±0.38)	13.64^{b} (±0.36)	27.13^{c} (±0.23)	30.74^{d} (±0.18)
C18:3 n-3	2.20^{b} (±0.08)	3.40^{d} (±0.04)	2.92^{c} (±0.00)	1.10^{a} (±0.02)
C20:4 n-6	0.54^{b} (±0.01)	0.24^{a} (±0.01)	0.25^{a} (±0.00)	0.25^{a} (±0.02)
C20:5 n-3	5.37^{b} (±0.32)	2.36^{a} (±0.04)	2.49^{a} (±0.06)	2.34^{a} (±0.06)
C22:5 n-3	1.56^{b} (±0.03)	0.74^{a} (±0.05)	0.73^{a} (±0.02)	0.72^{a} (±0.02)
C22:6 n-3	10.66^{b} (±0.26)	6.17^{a} (±0.01)	6.20^{a} (±0.09)	6.10^{a} (±0.09)
Σ SFA	24.03^{c} (±0.26)	20.42^{a} (±0.03)	22.19^{b} (±0.28)	22.11^{b} (±0.21)
Σ USFA	75.97^{a} (±0.26)	75.98^{c} (±0.03)	77.81^{b} (±0.28)	77.89^{b} (±0.21)
Σ MUFA	43.11^{b} (±0.76)	51.12^{c} (±0.35)	35.83^{a} (±0.30)	34.43^{a} (±0.07)
Σ PUFA	32.87^{b} (±1.02)	28.46^{a} (±0.38)	41.98^{c} (±0.02)	43.46^{c} (±0.13)
Σ n-3 PUFA	20.37^{c} (±0.57)	12.99^{b} (±0.08)	12.67^{b} (±0.12)	10.50^{a} (±0.03)
Σ n-6 PUFA	9.88^{a} (±0.35)	14.00^{b} (±0.35)	27.58^{c} (±0.20)	31.43^{d} (±0.16)
Σ n3/Σ n6	2.06^{d} (±0.01)	0.93^{c} (±0.02)	0.46^{b} (±0.02)	0.33^{a} (±0.00)

L., and European seabass diets supplemented with FO, SO, RO, LO, or a mixture of these oils had an significant impact on the contents of fat in the livers of these species. Similar observations were reported for turbot (Regost et al. 2003). The changes in the concentration of the basic nutrients (protein and fat) in the livers observed in the current study might indicate disruption in fat metabolism processes. The highest liver fat content noted was in the pikeperch from groups RO and SO. This was also apparent in the histological structure of this organ (Zakęś et al., unpublished data).

In the current study, the diets tested did not have a significant impact on the proximate composition of the pikeperch viscera, which had a fat content of 74-80% wet weight (w.w.). These results are confirmed by the fact that Percidae store a significant portion of energy in the viscera (Xu et al. 2001, Zakęś et al. 2004, 2008). Concentrations of energy in the viscera are reflected by a fat content that is several-fold higher than that in other organs or body parts. In the current study, however, the diets fed to the pikeperch had a significant impact on the quality composition of the viscera fats. Generally, the fatty acid profile of the viscera reflected that of the diets tested. This referred, among others, to acids that pikeperch prefer as their source of energy, e.g., PA and OA (Xu et al. 2001, Kowalska and Zakęś, unpublished data). The content of fatty acids in the viscera was similar to that of the feeds (the ratio of the fatty acid content in the viscera compared to the content in the feeds ≈ 1.0). Also noteworthy was the contents of HUFA (e.g., ARA, EPA, DHA), which was higher than those in the feeds. The main fraction of fats stores in the viscera are TAGs, which are dominated by SFA and MUFA (Jobling 2001). It should be underscored, however, that with arachidonic acid the ratio of ARA in the viscera to the content in the feeds ranged from 1.9 (group RO) to 2.3 (group SFO). The values of the DHA content confirmed were not

much lower at a ratio of 1.3 to 1.9. However, Xu et al. (2001) noted the level of OA in the viscera of perch, *Perca fluviatilis* L., to be higher than in the formulated feed, the content of ARA to be similar, and that of DHA to be slightly higher.

The fatty acid composition of the fillets and livers of pikeperch were also determined by the composition of the feed, but the tissues utilized the oils in the feeds and the individual fatty acids differently. In all the groups, the content of SFA in the fillets was higher than in the livers. In the case of the fillets, in contrast to the livers, the differences in SFA content among the groups was statistically insignificant. The content of SFA in both the fillets and the livers was higher than that in the diets tested, and in the fillets of the fish fed diets supplemented with VO it increased sufficiently so that it was comparable to the values noted in group CD. Thus, it appears that the quantitative and qualitative content of SFA in the experimental feeds supplemented with VO was sufficient to maintain this group of fatty acids at a level comparable to that noted in the fish from group CD. This is a significant finding since SFA in the muscle tissues is an important component of the polar lipids. Changes in the content of palmitic acid, which is the dominant of the SFA group and plays a key role in the synthesis of phospholipids, can be of significant physiological consequence (Olsen et al. 2003). Marine fish species fed diets supplemented with VO are often noted to have lowered SFA values in muscle tissue in comparison to fish fed diets with FO (Izquierdo et al. 2003, Montero et al. 2005). This was also reported by Molnár et al. (2006), who fed juvenile pikeperch feeds supplemented with flax seed oil, which was not tested in the current study.

Feeding fish diets containing VO, which are rich in C18 FA (OA, LA, ALA), results in increased contents of these in fish bodies (Mourente et al. 2005). The content of OA in the fillets of the fish tested, regardless of the dietary treatment, was significantly lower than in the diets. The ratio of OA in the fillets to that in the diets ranged from 0.6 (group CD) to 0.8 (group SFO). It is noteworthy that only in the group of fish fed feed supplemented with rapeseed oil (which had the highest content of OA among the feeds with VO) was the content of this FA significantly higher than that noted in group CD. It appears that pikeperch utilize OA well as a source of metabolic energy. Lowered levels of this FA in the muscle tissues might signal highly active mitochondrial enzymes oxidizing FA (Gavino and Gavino 1991). LA and ALA were stored in the pikeperch livers proportionally to their content in the feeds. The relative liver content of LA (the dominant FA among n-6 PUFA) in the groups of fish tested can be classified as follows: SFO > SO > RO > CD. In all of the groups analyzed, the contents of LA and ALA in the muscles of pikeperch were lower than in the livers (with the exception of ALA in the SFO group), and the ratio of the content of LA and ALA in the muscles to that in the feeds was similar to that noted for OA. This can be linked to the fact that mitochondrial β-oxidation is of particular significance to muscle tissues (Froyland et al. 2000). This is most likely also why the content of C18 FA in the livers of pikeperch was higher than that in the fillets. It should, however, be kept in mind that because of the high contents of LA in the diets supplemented with SO and SFO, the content of that FA in the fillets of the fish from these groups was significantly higher in comparison to groups CD and RO. In groups SO and SFO the relative content of LA was 140 and 190% higher, respectively, than in group CD. Higher contents of LA and ALA in the fillets of pikeperch fed feeds with VO were also noted by Molnár et al. (2006) and Schulz et al. (2005), as well as by other authors who studied both freshwater and marine fish species (Caballero et al. 2002, Izquierdo et al. 2003, Regost et al. 2003, Montero et al. 2005).

The supplementation with VO resulted in a significant decrease in the HUFA (ARA, EPA, DHA) content in whole bodies, viscera, and livers of fish in comparison to that in group CD. The contents of these FA corresponded to the lowered contents in the feed in comparison to that in the CD feed. The contents of ARA, EPA, and DHA in the livers of fish from the VO groups were about 50% lower than in group CD. The situation in the fillets was quite different, especially with regard to DHA. The content of this FA in the muscles of pikeperch from the VO groups was

lower than in group CD, but the differences were not statistically significant (21.6% tFA in group CD and 16.8-18.5% tFA in the VO groups). Some FA can be stored selectively in fish bodies. This often applies to DHA, which, because of its particularly significant function, is accumulated in bodies, especially in the muscles, and the content of it is higher than that in the feed (Caballero et al. 2002, Ng et al. 2003, Regost et al. 2003, Turchini et al. 2007). The mechanism for the selective storage of this fatty acid might be linked to DHA being less susceptible to the β-oxidation process (Bell et al. 2001). The higher content of n-3 HUFA in the fillets of pikeperch might also be explained by the bioconversion of C18 FA to C20-22 derivatives. A study by Jankowska et al. (2003b) indicated that pikeperch are capable of metabolic transformation – mainly ALA to EPA and DHA. Molnár et al. (2006) and Schulz et al. (2005) also drew similar conclusions. The share of ALA in the fillets of pikeperch from group CD, as in the VO groups, were lower, and its long-chain derivatives were several fold higher in comparison to the feeds. The efficiency of the bioconversion of n-3 PUFA measured as the ratio of DHA/EPA in the fillets of pikeperch from the dietary treatments analyzed ranged from 2.45 to 3.20. This indicates that pikeperch is capable of bioconverting ALA to n-3 HUFA. It is also noteworthy that the main consequence of higher DHA and lower LA contents in the fillets of the fish from all the dietary groups was the increased value of the n-3/n-6 ratio (in comparison to the values of this indicator in the diets and the whole bodies and livers of the pikeperch). However, in the case of the groups of fish fed diets supplemented with VO, it was significantly lower than that confirmed in group CD (3.5 in group CD vs. 1.0-2.1 in group VO).

In summation, it can be concluded that feeding juvenile pikeperch diets supplemented with RO, SO, and SFO that comprised over 80% of the total fat did not determine the proximate composition of the whole fish or the muscles. In comparison to the fillets of fish fed the commercial trout feed, those from fish fed VO exhibited a significantly higher content of C18 fatty acids, e.g., OA and ALA in group RO and LA in groups SO and SFO. In turn, the relative content of DHA in the pikeperch fillets in all the dietary groups was similar. The n-3/n-6 ratio in the fillets of fish fed diets with VO was, however, significantly lower than that in the fish fed commercial feed, and the dietary groups can be classified as follows: CD>RO>SO>SFO.

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References

AOAC 1975 – Official methods of analysis of the association of official analytical chemists – Washington DC, 20044.

Bell J.G., McEvoy J., Tocher D.R., McGhee F., Campbell P.J. Sargent J.R. 2001 – Replacement of fish oil with rapeseed oil in diets of Atlantic salmon (*Salmo salar*) affects tissue lipid composition and hepatocyte fatty acid metabolism – J. Nutr. 131: 1535-1543.

Caballero M.J., Obach A., Rosenlund G., Montero D., Gisvold M., Izquierdo M.S. 2002 – Impact of different dietary lipid sources on growth, lipid digestibility, tissue fatty acid composition and histology of rainbow trout, *Oncorhynchus mykiss* – Aquaculture 214: 253-271.

Folch H., Less M., Stanley H.A. 1957 – A simple method for isolation and purification of total lipids from animal tissues – J. Biol. Chem. 226: 497-499.

Froyland L., Lie O., Berge R.K. 2000 – Mitochondrial and peroxisomal beta-oxidation capacities in various tissues from Atlantic salmon *Salmo salar* – Aquacult. Nutr. 6: 85-89.

Gavino G.R., Gavino V.C. 1991 – Rat liver outer mitochondrial carnitine palmitoyltransferase activity towards long-chain polyunsaturated fatty acids and their CoA esters –- Lipids 26: 266-270.

Izquierdo M.S., Obach A., Arantzamendi L., Montero D., Robaina L., Rosenlund G. 2003 – Dietary lipid sources for seabream and seabass: growth performance, tissue

composition and flesh quality – Aquacult. Nutr. 9: 397-407.

Jankowska B., Zakęś Z., Żmijewski T., Szczepkowski M. 2003a – Fatty acid profile and meat utility of wild and cultured zander, *Sander lucioperca* (L) – EJPAU 6(1), http://www.ejpau.media.pl/volume6/issue1/fisheries/art-02.html.

Jankowska B., Zakęś Z., Żmijewski T., Szczepkowski M. 2003b – A comparison of selected quality features of the tissue and slaughter field of wild and cultivated pikeperch *Sander lucioperca* (L.) – Eur. Food Res. Technol. 217: 401-405.

Jobling M. 1994 – Fish bioenergetics – Chapman and Hall, London, 309 p.

Jobling M. 2001 – Nutrient partitioning and influence of feed composition on body composition – In: Food intake in fish (Eds) D. Houlihan, T. Boujard, M. Jobling, Blackwell Science, Oxford, UK: 354-375.

Kazuń K., Siwicki A.K. 2001 – Propiscin - a new safe anesthetic – Arch. Pol. Fish. 12: 123-136.

Molnár T., Szabó A., Szabó G., Szabó C., Hancz C. 2006 – Effect of different dietary fat content and fat type on the growth and body composition of intensively reared pikeperch *Sander lucioperca* (L.) – Aquacult. Nutr. 12: 173-182.

Montero D., Robaina L., Caballero M.J., Ginés R., Izquierdo M.S. 2005 – Growth, feed utilization and flesh quality of European seabass (*Dicentrarchus labrax*) fed diets containing vegetable oils: a time-course study on the effect of a re-feeding period with a 100% fish oil diet – Aquaculture 248: 121-134.

Mourente G., Good J.E., Bell J.G. 2005 – Partial substitution of fish oil with rapeseed, linseed and olive oils in diets for European sea bass (*Dicentrarchus labrax* L.): effects on flesh fatty acids composition, plasma prostaglandins E2 and F2α, immune function and effectiveness of fish oil finishing diet – Aquacult. Nutr. 11: 25-40.

Ng W.-K., Lim P.-K., Boey P.-L. 2003 – Dietary lipid and palm oil source affects growth fatty acid composition and muscle α-tocopherol concentration of African catfish, *Clarias gariepinus* – Aquaculture 215: 229-243.

Olsen R.E., Dragnes B.T., Myklebust R., Ringř E. 2003 – Effect of soybean oil and soybean lecithin on intestinal lipid composition and lipid droplet accumulation of rainbow trout, *Oncorhynchus mykiss* Walbaum – Fish Physiol. Biochem. 29: 327-329.

Peisker K. 1964 – Rapid semi-micro method for methyl esters from triglycerides using chloroform, methanol, sulphuric acid – J. Am. Oil Chem. Soc. 11: 87-90.

Regost C., Arzel J., Robin J., Rosenlund G., Kaushik S.J. 2003 – Total replacement of fish oil by soybean or linseed oil with a return to fish oil in turbot (*Psetta maxima*): I. Growth performance, flesh fatty acids profile, and lipid metabolism – Aquaculture 217: 465-482.

Rodriguez C., Perez J.A., Henderson R.J. 2002 – The esterification and modification of n-3 and n-6 polyunsaturated fatty acids by hepatocytes and liver microsomes of turbot (*Scophthalmus maximus*) – Comp. Biochem. Physiol. B132: 559-570.

Sargent J.R., Tocher D.R., Bell J.G. 2002 – The lipids – In: Fish nutrition (Eds) J.E. Halver, R.W. Hardy, Academic Press, San Diego, CA, USA: 181-257

Schulz C., Knaus U., Wirth M., Rennert B. 2005 – Effects of varying dietary fatty acid profile on growth performance, fatty acid, body and tissue composition of juvenile pike perch (*Sander lucioperca*) – Aquacult. Nutr. 11: 403-413.

Steffens W. 1997 – Effects of variation in essential fatty acids in fish feeds on nutritive value of freshwater fish for humans – Aquaculture 151: 97-119.

Tacon A.G.J. 2004 – Use of fish meal and fish oil in aquaculture: a global perspectives – Aquat. Resour. Cult. Develop. 1: 3-14.

Turchini G.M., Moretti V.M., Mentasti T., Orban E., Valfré F. 2007 – Effects of dietary lipid source on fillet chemical composition, flavour volatile compounds and sensory characteristics in the freshwater fish tench (*Tinca tinca* L.) – Food Chem. 102:1144-1155.

Turchini G.M., Torstensen B.E., Ng W.-K. 2009 – Fish replacement in finfish nutrition – Rev. Aquacult. 1: 10-57.

Xu X.L., Fontaine P., Mélard C., Kestemont P. 2001 – Effects of dietary fat levels on growth, feed efficiency and biochemical composition of Eurasian perch *Perca fluviatilis* – Aquacult. Int. 9: 437-449.

Zakęś Z., Jankowska B., Jarmołowicz S., Żmijewski T., Partyka K., Demska-Zakęś K. 2009 – Effects of different dietary fatty acids profiles on the growth performance and body composition of juvenile tench (*Tinca tinca* (L.)) – Rev. Fish Biol. Fish. 20: 389-401. doi: 10.1007/s11160-009-9146-x.

Zakęś Z., Kowalska A., Demska-Zakęś K., Jeney G., Jeney Z. 2008 – Effect of two medicinal herbs (*Astragalus radix* and *Lonicera japonica*) on growth performance and body composition of juvenile pikeperch [*Sander lucioperca* (L.)] – Aquacult. Res. 39: 1149-1160.

Zakęś Z., Przybył A., Woźniak M., Szczepkowski M., Mazurkiewicz J. 2004 – Growth performance of juvenile pikeperch, *Sander lucioperca* (L.) fed graded levels of dietary lipids – Czech J. Anim. Sci. 49: 156-163.

Streszczenie

Wpływ żywienia juwenalnego sandacza (*Sander lucioperca* (L.)) paszami suplementowanymi olejami roślinnymi na podstawowy skład chemiczny ciała i profile kwasów tłuszczowych

Młodocianego sandacza (początkowa masa ciała ok. 100 g) podchowywano w obiegach recyrkulacyjnych przez 55 dni i żywiono komercyjną paszą pstrągową (grupa CD) lub paszami suplementowanymi następującymi olejami roślinnymi (VO): rzepakowym (grupa RO), sojowym (grupa SO) lub słonecznikowym (grupa SFO). Poziom suplementacji pasz VO wynosił 84% całkowitego tłuszczu surowego (CF) – do komercyjnej mieszanki bazowej zawierającej 30 g CF kg^{-1} paszy dodawano 160 g VO kg^{-1} paszy. Podstawowy skład chemiczny pasz był podobny, a profile kwasów tłuszczowych (FA) w nich zawartych odzwierciedlały skład chemiczny olejów, którymi były suplementowane (tabela 1). Żywienie testowanymi paszami nie wpłynęło istotnie na wartości wskaźników wzrostu ryb i podstawowy skład chemiczny całej ryby, filetów i trzewi ($P > 0,05$; tabela 2). Odnotowano natomiast istotne różnice w zawartości białka i tłuszczu w wątrobie sandacza. Stwierdzono, że zawartość białka w grupach RO i SO była istotnie niższa niż u ryb z grup CD i SFO ($P < 0,05$). Poziom tłuszczu w wątrobie ryb z grup VO był wyższy od stwierdzonego w grupie CD, a w przypadku grup RO i SO różnice te były istotne statystycznie ($P < 0,05$; tabela 2). Profile FA analizowanych części ciała sandacza (cała ryba, filet, trzewia i wątroba) odzwierciedlały skład chemiczny stosowanych pasz (tabela 1, 3, 4, 5, 6). Udział wszystkich analizowanych grup FA, tj. nasyconych (SFA), nienasyconych (USFA), monoenowych (MUFA), polienowych (PUFA), polienowych z rodziny n-3 (n-3 PUFA) i polienowych z rodziny n-6 (n-6 PUFA) w całym ciele, trzewiach i wątrobie był istotnie determinowany stosowaną dietą ($P < 0,05$; tabela 3, 5, 6). Najbardziej stabilny był skład FA mięśni sandacza (tabela 4). W filetach ryb z grup VO nie stwierdzono istotnego wpływu żywienia testowanymi paszami na wartości ilorazów n-3 PUFA do n-6 PUFA (stosunek n-3/n-6) ($P > 0,05$). Były one jednak istotnie niższe niż w grupie CD ($P < 0,05$) (1,03-2,07 *vs* 3,50).