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RESEARCH ARTICLE

Impact of diets supplemented with rapeseed, soy, and sunflower oils on growth rates and the histological picture of the livers of juvenile pikeperch, *Sander lucioperca* (L.)

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Abstract. Juvenile pikeperch (120 g initial body weight) were fed a commercial diet (group CD) or experimental diets supplemented with rapeseed (group RO), soy (group SO), or sunflower (group SFO) oils for 55 days. The experimental diets were made by adding the given vegetable oil (VO) in quantities of 160 g kg^{-1} feed (84% of the total raw lipid in the diet) to a base of an extruded, commercial diet (containing 30 g kg^{-1} raw lipid). The dietary treatments had no significant influence on fish growth rates, apparent net protein retention (ANPR), or apparent net energy retention (ANER) ($P > 0.05$). The apparent lipid retention (ALR) in group SO was significantly higher than in the other groups ($P < 0.05$). The dietary treatments tested had a significant impact on the size of the hepatocytes and their nuclei, as well as on the nucleocytoplasmic index values ($P < 0.05$). No significant differences were noted in the overall image of the hepatocytes (degree of vacuolization or hepatocyte degeneration ($P > 0.05$)).

Keywords: liver histology, vegetable oils, Percidae, rearing parameters, nutrition

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Introduction

European aquaculture is becoming increasingly interested in pikeperch, *Sander lucioperca* (L.), as is evidenced by the creation of several farms that produce commercial-sized pikeperch (body weight > 1 kg) in recirculating systems using commercial diets (Philipsen 2008). Studies have indicated that this species can be fed commercial diets for salmonids (Zakęś et al. 2001, Jankowska et al. 2003, Molnar et al. 2006). The nutritional requirements of the species are not well known, and few scientific studies have investigated these issues (Zakęś et al. 2004, Nyina-Wamwiza et al. 2005, Schulz et al. 2007, 2008).

Recently, increasing attention has been drawn to the application of vegetable oils (VO) in fish diets (Turchini et al. 2009), and studies have indicated that substituting as much as 60% of the fish oil (FO) used in the diets for vegetable oil has no negative impact on the basic rearing indexes of Percidae fish such as European seabass, *Dicentrarchus labrax* L., or gilt-head bream, *Sparus aurata* L. (Izquierdo et al. 2003, Mourente et al. 2005). However, at higher levels of substitution (over 80%) decreases in growth rates were observed in both of these species (Montero et al. 2003, 2005, Izquierdo et al. 2005). This phenomenon has not been observed in salmonid fish (Torstensen et al. 2004). The response of pikeperch

to diets containing VO has been investigated. Schulz et al. (2005) analyzed the impact of feeding this species diets supplemented with linseed (LO) or soy (SO) oils, while Molnar et al. (2006) tested the effects on the fish of supplementing their diets with various amounts of LO. The diets tested had no significant impact in comparison to those supplemented with FO on growth rate or on the feed conversion ratio. Rearing indexes are influenced not only by the level of VO supplementation, but also by the type of oil used. For example, the final body weights of European seabass fed diets supplemented with rapeseed oil (RO) were significantly lower than those of individuals that received diets supplemented with SO or LO (Montero et al. 2005).

The aim of the current study was to identify the impact diets supplemented with RO, SO, and sunflower oil (SFO) (supplementation level > 80% total raw lipid) and a commercial trout diet with a similar lipid level (19%) had on the growth rate, feed conversion ratio, histological picture of the liver, and protein, lipid, and energy retention in juvenile pikeperch.

Materials and methods

Fish and rearing conditions

The 55-day feeding experiment was conducted at the Department of Aquaculture Inland Fisheries Institute in Olsztyn (IFI Olsztyn, Poland). The initial body weight (BW), body length (BL), and total length (TL) of the juvenile pikeperch was 102 g, 21.5 cm, and 24.5 cm, respectively. The fish were reared in recirculating systems. Thirty-one fish (initial stocking density of approximately 15 kg m^{-3}) were stocked into each rearing tank (volume 0.2 m^3). The physical and chemical parameters of the water were monitored continually throughout the rearing period: water temperature and oxygen content were measured daily, and total ammonia nitrogen (TAN = NH_4^+-N + NH_3-N), nitrite (NO_2-N), and pH were measured weekly. Water temperature was maintained at 22.1 ± 0.2°C. The water flow rate was 4.0 dm^3 min^{-1} (1.2 exchange h^{-1}), and water oxygen concentration at tank inflow and outflow were not lower than 7.8 and 5.0 mg O_2 dm^{-3}, respectively. The concentration of total ammonia nitrogen at tank inflow and outflow did not exceed 0.10 and 0.34 mg TAN dm^{-3}, respectively. The nitrite level did not exceed 0.09 mg NO_2-N dm^{-3} (inflow) or 0.01 mg NO_2-N dm^{-3} (outflow). The water pH ranged from 7.8 to 8.1. The photoperiod applied was constant (24L:0D), and the light intensity at the surface of the rearing tanks ranged from 20 to 22 lx.

Diets and feeding

The base diet (Aller Safir XS, Aller-Aqua, Golub-Dobrzyń, Poland) used to prepare the experimental diets was a commercial diet without added lipids, and its fat content was derived only from the lipids in fish meal. The extruded base diet contained 510 g crude protein kg^{-1} feed and 30 g crude lipids kg^{-1} feed (dry matter (d.m.)). This diet was supplemented with the following oils: rapeseed (ZPT Warszawa, Warszawa, Poland; diet RO), soy (WZT ADM Szamotuły, Szamotuły, Poland; diet SO), or sunflower oil (ZPT Warszawa, Warszawa, Poland; diet SFO). A measure of the given oil (160 g kg^{-1}; 84% of the total crude lipid) was added to 1000 g of the base diet, mixed precisely, and vacuum packed with a vacuum pump (AGA Labor, Lublin, Poland). The diets obtained had a similar proximate composition: crude protein 449.0-452.1 g kg^{-1} d.m., crude lipid 189.1-191.1 g kg^{-1} d.m., crude ash 73.9-74.5 g kg^{-1} d.m. (Table 1). The control group of fish were fed the commercial diet Aller Safir XS (Aller-Aqua, Golub-Dobrzyń, Poland) with a proximate composition that was similar to that of the experimental diets (diet CD; Table 1). Each dietary treatment was tested in three repeats. The feed was delivered for 16 h d^{-1} (09:00-03:00) by an automatic band feeder (FIAP, Fishtechnik GmbH, Ursensollen, Germany). The daily feed ration ranged from 1.2% of the stock biomass (beginning of rearing) to 1.0% of the stock biomass (final two weeks of rearing).

Table 1

Proximate composition (dry matter (d.m.)) of the commercial diet (CD) and experimental diets supplemented with rapeseed (RO), soy (SO), and sunflower (SFO) oils. [1] NFE = 100 – (CP + CL + CA), NFE contains fiber; [2] energy calculated with the following conversion factors: CP – 24 kJ g^{-1}, CL – 39 kJ g^{-1}, NFE – 17 kJ g^{-1} (Jobling 1994)

	Diet			
Specification	CD	RO	SO	SFO
Crude protein (CP; g kg^{-1} d.m.)	450.3	449.0	452.1	452.0
Crude lipid (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

Data collection procedure

Individual measurements of pikeperch body weight (BW ± 0.1 g), total body length (TL ± 0.1 cm), and body length (BL ± 0.1 cm) were taken on the first and final days of the experiment. The fish were anesthetized with a solution of etomidate at a dose of 1.0 mm^3 dm^{-3} (Propiscin, IFI Olsztyn, Poland; Kazuń and Siwicki 2001) prior to the measurements. Additionally, the fish biomass was determined weekly in each tank by weighing the entire stock (± 1.0 g).

On the first and final days of the experiment, samples of fish were taken for liver histopathology testing. After the fish were anesthetized in an etomidate solution (4.0 mm^3 dm^{-3}) they were headed. The samples from both the first and final days of the experiment comprised seven individuals from each dietary treatment group (4 × 7 fish). The fish and the livers were weighed (± 0.01 g), and the hepatosomatic indexes were calculated – HSI (%) = 100 × (liver weight (g) × body $weight^{-1}$ (g)).

To determine the proximate composition of the fish bodies, five fish were taken from each tank (15 fish from each dietary treatment). The pikeperch body water content was determined by drying the samples to a constant weight at a temperature of 105°C. Protein was determined using the Kjeldahl method (using a multiplier of 6.25), lipid – with the Soxhlet method (with a petroleum ether solvent), and ash – by sample mineralization at a temperature of 550-600°C (AOAC 1975). The proximate composition of the diets tested in the experiment was also determined.

The following were calculated using the data collected:

- daily growth rate, DGR (g d^{-1}) = (final body weight (g) – initial body weight (g)) × $rearing\ time^{-1}$ (d);
- specific growth rate, SGR (% d^{-1}) = 100 × (ln final body weight (g) – ln initial body weight (g)) × $rearing\ time^{-1}$ (d);
- condition coefficient, K = 100 × (body weight (g) × body length BL^{-3} (cm));
- feed conversion ratio, FCR = weight of feed consumed (g) × (final stock biomass (g) – initial stock biomass (g))$^{-1}$;
- apparent net protein retention, ANPR (%) = ((final body weight (g) × final protein content in fish (%)) – (initial body weight (g) × initial protein content in fish (%)) × total weight of protein delivered in $feed^{-1}$ (g)) × 100;
- apparent lipid retention, ALR (%) = ((final body weight (g) × final lipid content in fish (%)) – (initial body weight (g) × initial content of lipid in fish (%)) × total weight of lipid delivered in feed (g)) × 100;
- apparent net energy retention, ANER (%) = ((final body weight (g) × final energy value of fish (kJ)) – (initial body weight (g) × initial energy value of fish (kJ) × energy value of feed $consumed^{-1}$ (g)) × 100. Energy value calculated assuming: 24 kJ g^{-1} protein, 39 kJ g^{-1} lipid, 17 kJ g^{-1} carbohydrate (Jobling 1994).

Table 2
Description of cytological indicators used during the analysis of the livers of juvenile pikeperch fed different diets

Cytological parameter	Evaluation criteria
Hepatocyte diameter (± 1 μm)	Mean size of 50 cells
Mean hepatocyte nucleus diameter (± 1 μm)	Mean size 50 cells
Nucleocytoplasmic index (ratio of nucleus diameter to hepatocyte diameter)	Mean size 50 cells
Degree of hepatocyte vacuolization	0 = low degree of vacuolization in few cells; 1 = moderate degree of vacuolization in few cells; 2 = high degree of vacuolization in few cells; 3 = low degree of vacuolization in many cells; 4 = moderate degree of vacuolization in many cells; 5 = high degree of vacuolization in many cells; mean from 50 cells
Hepatocyte necrosis	0 = none; 1 = some; 2 = many; mean from 50 cells
Degeneration of liver parenchyma	0 = none; 1 = some; 2 = many; mean from 50 cells

Histological testing

Liver samples were fixed in Bouin's soultion, dehydrated in ethanol, and embedded in paraffin. Liver sections 5 μm thick were sliced with a rotary microtome (RM 2225 Leica, Germany) and stained with hematoxylin and eosin (H&E). These samples were analyzed using a Nikon E600 light microscope (Tokyo, Japan) coupled with a Nikon 4300 digital camera and a computer system running MultiScanBase (Computer Scanning System Ltd., Warsaw, Poland) and NIS-Elements (Nikon, Tokyo, Japan) image analysis programming. The analysis focused on the basic parameters of the hepatocytes, their nuclei, and cytoplasmic indexes (Table 2).

Statistical analysis

The data was analyzed statistically with Statistica (StatSoft Inc., Tulsa, OK, USA). Single-factor analysis of variance (ANOVA) was used and the equality of variances was tested with Levene's test. When statistically significant differences were noted ($P \leq 0.05$), Tukey's test was applied. Prior to statistical analysis, percentage data were transformed using the *arcsin* function, while liver data (degree of hepatocyte vacuolization, necrosis) was transformed using the Kruskal-Wallis test.

Results

Fish growth rate, retention of protein, lipid, and energy

The diets supplemented with different oils did not significantly influence the growth rates (DGR, SGR) or condition of the juvenile pikeperch ($P > 0.05$; Table 3). They also did not have a significant impact on the values of the FCR, or on protein (ANPR) and energy (ANER) retention ($P > 0.05$). However, the value of the lipid retention (ALR) in group SO was significantly higher (91.13 vs. 60.54-77.17; $P < 0.05$).

Histological analysis

The values of the hepatosomatic indexes (HSI) in all the experimental groups were similar and ranged from 1.12 (group RO) to 1.19 (group CD) ($P > 0.05$; Table 4). The livers of fish in groups RO and CD comprised hepatocytes with the largest diameter, the smallest nucleus size, and the lowest nucleocytoplasmic index value ($P < 0.05$; Table 4). The liver parenchyma in pikeperch from groups CD and RO was generally homogenous. The cell nuclei were thickened and were often shifted to the edge of the cells. The cytoplasm contained glycogen and lipid droplets. The degree of hepatocyte vacuolization

Table 3
Growth, condition, diet feed conversion ratio, and protein, lipid, and energy retention in juvenile pikeperch fed a commercial diet and diets supplemented with vegetable oil (mean value (±SE); N = 3). Dietary treatments described in Materials and methods section. Groups with different letter indexes in the same row differ significantly statistically (P < 0.05)

	Treatment group			
Specification	CD	RO	SO	SFO
Initial body weight (g)	102.1 (±1.00)	101.7 (±2.20)	100.0 (±0.98)	103.2 (±1.85)
Final body weight (g)	174.1 (±1.64)	169.0 (±0.80)	167.7 (±2.40)	167.8 (±4.08)
Daily growth rate (DGR (g d^{-1}))	1.30 (±0.01)	1.22 (±0.05)	1.23 (±0.03)	1.18 (±0.04)
Specific growth rate (SGR (% d^{-1}))	0.94 (±0.02)	0.93 (±0.05)	0.94 (±0.01)	0.88 (±0.01)
Initial condition factor (K)	1.03 (±0.01)	1.05 (±0.01)	1.02 (±0.02)	1.03 (±0.01)
Final condition factor (K)	1.19 (±0.02)	1.24 (±0.02)	1.23 (±0.01)	1.20 (±0.01)
Feed conversion ratio (FCR)	1.04 (±0.02)	1.09 (±0.10)	1.06 (±0.03)	1.12 (±0.02)
Apparent net protein retention (ANPR (%))	38.25 (±0.15)	37.06 (±2.44)	34.54 (±1.61)	32.15 (±0.07)
Apparent net lipid retention (ALR (%))	77.17^{ab} (±1.44)	72.20^{ab} (±7.62)	91.13^{b} (±3.94)	60.54^{a} (±3.86)
Apparent net energy retention (ANER (%))	47.70 (±0.42)	43.66 (±3.86)	47.39 (±2.11)	38.61 (±1.36)

Table 4
Cytological and histological indexes of the livers of juvenile pikeperch fed diets supplemented with different vegetable oils (mean values (± SE); n = 7). Dietary treatments described in Materials and methods section. Groups compared statistically using (1) ANOVA and Tukey's test or (2) the Kruskal-Wallis test. Groups with different letter indexes in the same row differ significantly statistically (P < 0.05)

	Treatment group			
Specification	CD	RO	SO	SFO
Hepatosomatic index (HSI (%))(1)	1.19 (± 0.08)	1.12(± 0.04)	1.14(± 0.02)	1.14(±0.02)
Hepatocyte size (μm)(1)	15.44^{bc} (± 0.56)	15.48^{c} (± 0.76)	13.27^{ab} (± 0.36)	12.69^{a} (± 0.46)
Diameter of hepatocyte nucleus (μm)(1)	4.27^{a} (± 0.08)	4.52^{ab} (± 0.07)	4.61^{b} (± 0.09)	4.66^{b} (± 0.04)
Nucleocytoplasmic index(1)	0.29^{a} (± 0.02)	0.30^{ab} (± 0.02)	0.37^{b} (± 0.02)	0.38^{b} (± 0.01)
Degree of hepatocyte vacuolization (low = 0 to high = 5)(2)	3.43 (± 0.57)	4.00 (± 0.44)	4.00 (± 0.22)	3.00 (± 0.31)
Hepatocyte necrosis (none = 0 to many = 2)(2)	0.29 (± 0.18)	0.57 (± 0.20)	0.71 (± 0.28)	0.43 (± 0.20)
Degeneration of liver parenchyma (none = 0 to many = 2)(2)	0.14 (± 0.14)	0.57 (± 0.20)	0.71 (± 0.29)	0.57 (± 0.20)

varied among individuals and ranged from 0 to 5. The first symptoms of parenchyma degeneration and necrosis were observed sporadically. Additionally, some of the fish from group RO exhibited some congestion and bile duct swelling.

Somewhat more advanced pathological changes were noted in the pikeperch from groups SO and SFO (Table 4). The liver parenchyma was usually non-homogeneous. Changes were noted in the shape of the hepatocytes, the cell nuclei, and the plasma did not stain well and was often granular and thickened. Additionally, fatty vacuolization of the hepatocytes was observed. Increased numbers of large lipid drops and spreading necrosis and degeneration were noted, especially in fish from group SO (Table 4).

Discussion

Pikeperch is a species that does not readily accept experimental, commercial diets. The effective utilization of this type of diet can be reduced as is indicated by relatively high values of the FCR coefficient (Zakęś et al. 2004, Schulz et al. 2007). It is also known that this species assimilates commercial diets manufactured for salmonids quite effectively (Zakęś et al. 2001, Molnar et al. 2006). When testing, for example, the effects of diet VO supplementation, one convenient solution might be to use so-called commercial base mix (which is obtained during the final phase of manufacture before oils are added). However, when using these procedures for preparing VO supplemented diets, the effective utilization by juvenile pikeperch can differ significantly, with values of the FCR coefficient ranging from about 1.0 (current study) to over 3.0 (Schulz et al. 2005). The highly effective utilization of the diets used in the current study was also indicated by the values of the basic nutrient (ANPR and ALR) and energy (ANER) retention coefficients. The values obtained in the current study were similar to those noted with regard to juvenile carp, *Cyprinus carpio* L., reared on a commercial diet (Sadowski et al. 2000), or turbot, *Psetta maxima* (L.), fed diets supplemented with FO, SO, and LO (Regost et al. 2003). The advantageous values of FCR, ANPR, ANER, and ALR indicated that the diets tested were highly assimilable for the juvenile pikeperch. It should also be underscored that the content of protein and lipid was within the range of values recommended for juvenile pikeperch (Nyina-Wamwiza et al. 2005).

When supplementing diets with vegetable oils, it is crucial that they do not have a negative impact on fish growth rates or effective feed utilization, and that the results are comparable to those obtained on diets in which the main source of fatty acids (FA) is FO (Izquierdo et al. 2003). The oils tested in the current study (RO, SO, SFO; approximately 84% total lipid) did not have a significant influence on either fish growth rates or the values of the feed conversion ratio (FCR). The values of these indexes in the groups that received VO supplemented diets were similar to those of the fish fed commercial diets (group CD) in which the main lipid source was FO and fish meal. They also did not differ from results obtained in other studies in which juvenile pikeperch of similar body weights were reared on commercial diets (Zakęś et al. 2001, 2008, Nyina-Wamwiza et al. 2005). Schulz et al. (2005), who fed juvenile pikeperch (initial BW approximately 15 g; feeding test time 57 days) diets supplemented with FO, SO, or LO, did not note any significant differences in growth rate or feed utilization effectiveness among groups. Similarly, Molnar et al. (2006), who used diets supplemented with FO and LO (initial BW approximately 64 g; test time 42 days), did not observe that the feeds had any impact on the same rearing indexes mentioned above. It should be underscored that the level of vegetable oil supplementation in these studies varied: in the study by Schulz et al. (2005) it was about 50% of total lipids, while Molnar et al. (2006) substituted VO for either 50 or 65% of total lipids. In the current study, VO comprised more than 80% of the total lipid content, and despite such a substantial increase in the level of supplementation, no adverse impacts on fish growth were noted. It is also worth mentioning that, except for SO, the current study tested different vegetable oils (RO and SFO) than did Schulz et al. (2005) and Molnar et al. (2006). Thus, it is impossible to draw far reaching conclusions. It should also be noted that when applying VO supplementation in excess of 80% of total lipids, decreased growth rates have been noted in other fish species (Montero et al. 2003, 2005, Izquierdo et al. 2005).

Since lipids are metabolized in the liver, the size of this organ (HSI) and its histological structure can often be influenced by the quantitative and/or qualitative lipid profile compositions of the diets fish consume. The diets tested in the current study did not have a significant impact on the values of HSI. However, Schulz et al. (2005) confirmed just such an influence in fish fed diets with SO, in which the HSI values were lower than in the LO or FO groups. Feeding pikeperch diets supplemented with VO was reflected in the morphological structure of the liver and the degree of vacuolization of the hepatocytes. Although no statistically significant differences were confirmed, the highest

degree of lipid vacuolization (mainly 4 and 5) and the most advanced pathological changes such as liver parenchyma degeneration, necrosis, and congestion occurred in the pikeperch from group SO. Bac et al. (1983) also observed hepatocyte degeneration in European seabass and gilt-head bream that were fed diets supplemented with SO. Such changes were less pronounced in the pikeperch fed the diets supplemented with RO, and the size of the hepatocytes and their nuclei and the nucleocytoplasmic index was similar to that of the group fed the commercial diet. RO supplementation at 46% of total dietary lipids was noted to have a similar effect on the liver morphology in juvenile tench, *Tinca tinca* (L.). The changes noted in the histological structure of the liver were less pronounced than in the group fed the diet supplemented with LO and peanut oil (Demska-Zakęś et al. 2008). In turn, Caballero et al. (2002) reported that the livers of rainbow trout, *Oncorhynchus mykiss* (Walbaum), fed a diet supplemented with SO presented a lower degree of degeneration than did fish that were fed diets supplemented with RO or olive oil. Contrary findings were reported by Parpoura and Alexis (2001), who observed increased pathological changes in European seabass that were fed diets supplemented with SO and olive oil. These results indicate that the impact on fish livers of diets supplemented with VO depends not only on the type of supplement but also on the species of fish.

In summation, it can be concluded that feeding juvenile pikeperch diets supplemented with RO, SO, and SFO at more than 80% of total lipids did not have a negative impact on the growth rate, the nutritional coefficients of the diets, or on nutrient or energy retention. However, the disadvantageous impact of the diet supplemented with SO on the histological picture of the liver is striking. Although this was not reflected in either the growth rate or condition, it cannot be ruled out that these could be affected with longer exposure to this diet. The preceding observations draw into question the suitability of SO-supplemented diets for this species. However, in order to draw firm conclusions, it is essential to conduct studies that focus on gaining an understanding of the metabolism of FA from various sources.

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Streszczenie

Wpływ żywienia paszami suplementowanymi olejem rzepakowym, sojowym i słonecznikowym na tempo wzrostu i obraz histologiczny wątroby juwenalnego sandacza *Sander lucioperca* (L.)

Juwenalnego sandacza o początkowej masie ciała 102 g podchowywano w obiegu recyrkulacyjnym i żywiono przez 55 dni paszą komercyjną (grupa CD) lub paszami eksperymentalnymi suplementowanymi olejem rzepakowym (grupa RO), sojowym (grupa SO) lub słonecznikowym (grupa SFO). Pasze doświadczalne uzyskiwano dodając do

ekstrudowanej, komercyjnej paszy bazowej (zawierającej 30 g kg^{-1} tłuszczu surowego) dany olej roślinny (VO) w ilości 160 g kg^{-1} paszy (84% całkowitego tłuszczu surowego w paszach). W efekcie otrzymano pasze o porównywalnym składzie chemicznym: białko surowe 449,0-452,1 g kg^{-1} paszy (sucha masa (d.m.)), tłuszcz surowy 189,1-191,1 g kg^{-1} paszy (d.m.), popiół surowy 73,9-74,5 g kg^{-1} paszy (d.m.). Kontrolną grupę ryb żywiono komercyjną paszą pstrągową o składzie chemicznym zbliżonym do pasz eksperymentalnych (pasza CD; tabela 1). Analizowano wpływ stosowania ww. pasz na wskaźniki wzrostu ryb, retencji nutrientów i energii oraz budowę histologiczną wątroby (tabela 2). Nie stwierdzono istotnego wpływu żywienia na tempo wzrostu ryb, w tym również na współczynniki retencji białka (ANPR) i energii (ANER) ($P > 0,05$; tabela 3). Współczynnik retencji tłuszczu (ALR) w grupie SO przyjął istotnie wyższą wartość niż w pozostałych grupach ($P < 0,05$). Wartość indeksu hepatosomatycznego (HSI) była zbliżona. Stwierdzono natomiast istotny wpływ testowanych pasz na wielkość hepatocytów i ich jąder, a także wartość indeksu nukleocytoplazmatycznego ($P < 0,05$). Nie odnotowano natomiast istotnych różnic w ogólnym obrazie hepatocytów (stopniu wakuolizacji i degeneracji komórek wątrobowych) ($P > 0,05$; tabela 4).