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RESEARCH ARTICLE

# Impact of feeding pikeperch *Sander lucioperca* (L.) feeds of different particle size on the results of the initial on-growing phase in recirculation systems

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**Abstract.** Two experiments were performed to analyze the impact of applying two formulated feeds of different particle sizes (feed 1 – particle length – 2.8 mm; feed 2 – 4.5 mm) on the results of on-growing pikeperch in recirculating aquaculture systems (RAS). Two pikeperch size classes were used: in experiment I the mean body weights (BW) were 74 and 102 g, and in experiment II the BW were 125 and 170 g. The fish in both size groups in experiment I that were fed feed 1 achieved significantly quicker growth and better values of the feed conversion ratio (FCR) values ($P < 0.05$). Larger intragroup differences in final BW and condition coefficients were noted in the fish groups receiving feed 2. No significant differences in growth, condition, or FCR values were noted in either of the two pikeperch size groups fed experimental feed in experiment II. Pikeperch prefers feed of smaller particle size. In the initial on-growing phase, and particularly for fish of BW 70-125 g, it is recommended to use feed with the smallest particle size.

**Keywords:** pikeperch, recirculation systems, feed particle size, feeding

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## Introduction

Developing and implementing comprehensive methods for rearing species new to aquaculture requires identifying their environmental requirements, and this includes feeding preferences. The priority in feeding studies is usually to optimize the nutritional quality of the feed (i.e., the qualitative and quantitative composition of the basic nutrients). The results of cultivating fish, especially under intense rearing conditions, are not only determined by the quantity and quality of feed, but also by whether the feed is delivered manual or automatically and the feeding frequency (Brännäs and Linnér 2000, Alanärä et al. 2001, Petursdottir 2002, Ronyai and Csengeri 2008). Less attention is focused during feeding trial on the physical parameters of the feed, including feed particle size, shape, color, and consistency. Studies indicate that these factors can have a significant impact on determining the results of rearing fish (Stradmeyer et al. 1988, Smith et al. 1995, Helland et al. 1997, Higuera 2001, Sonmez et al. 2009).

Pikeperch, *Sander lucioperca* (L.) is one of the new, promising species in European aquaculture. It has been demonstrated that this species can be fed commercial feed used in salmonid culture (Zakęś et al. 2001, 2012, Molnár et al. 2006). However, knowledge of the nutritional requirement of this species refers primarily to the proximate composition of the diet (Zakęś et al. 2004, Nyina-Wamwiza et al. 2005, Schulz et al. 2007, 2008). In practice, since pikeperch assimilate the commercial feed used in salmonid culture well, analogous feeding strategies, for example using the same particle size, are applied during attempts to on-grow this species (Z. Zakęś, personal observation). Feeding rainbow trout, *Oncorhynchus mykiss* (Walbaum), with body weights (BW) of about 20 g feeds with particle sizes of 3-4 mm results in improved growth rates in comparison to fish fed feeds of a smaller particle size (Sonmez et al. 2009). Feeding pikeperch this particle size only appears to be justified when body weights exceed 20 g (Z. Zakęś, personal observation). The impact of formulated feed particle size on the rearing of pikeperch in the initial on-growing phase in recirculating aquaculture systems (RAS) has not yet been confirmed experimentally (Zakęś 2009).

The aim of the current experiment was to determine the impact feeds of differing particle sizes have on juvenile pikeperch (initial body weight 74-175 g) reared in RAS.

## Materials and Methods

The study material was obtained through out-of-season reproduction and then rearing the material obtained in RAS (Zakęś 2009). Two experiments were performed: in experiment I the fish were divided into two size groups: group SI (mean BW approximately 74 g; 138 fish) and group LI (BW approximately 102 g; 138 fish). Each size group was divided at random into six sub-groups (2 size groups × 6 sub-groups) and stocked into 12 rearing tanks (23 specimens tank$^{-1}$), with volumes of 200 l each. Two feeding treatments were created respectively for sub-groups SI-1 and SI-2 and for LI-1 and LI-2 (each sub-group was in 3 replicates). In experiment II, the fish were divided into two size groups: group SII (BW approximately 125 g; 120 specimens) and group LII (BW approximately 170 g; 120 specimens). As was done in experiment I, the fish of each size group were stocked into six tanks (20 fish tank$^{-1}$) and two feeding sub-groups were created (i.e., SII-1 and SII-2 and LII-1 and LII-2; each sub-group was in 3 replicates).

Throughout the experiment, water temperature (± 0.1°C), and oxygen concentration at the water inlets and outlets were measured daily (YSI 58 dissolved oxygen meter, YSI, Inc., USA; ± 0.05 mg $O_2$ l$^{-1}$). The contents of total ammonia nitrogen (TAN = $NH_4^+$-N + $NH_3$-N), nitrite nitrogen ($NO_2$-N), and pH were measured weekly. The concentration of ammonia compounds determined with the colorimetric method (Bower and Holm-Hansen 1980). Water flow was maintained at 4 l min$^{-1}$ (1.2 water exchanges h$^{-1}$). The water temperature during both of the experiments was maintained at 22.0 ± 0.1°C, and dissolved oxygen saturation at the tank outflows did not decrease below 55%. Ammonia nitrogen concentrations at the tank outflows did not exceed 0.1 mg TAN l$^{-1}$, and those of nitrites did not exceed 0.03 mg $NO_2$-N l$^{-1}$. The water pH fluctuated within a range of 7.9-8.1. The production hall was lit for 24 h day$^{-1}$, and the light intensity at the water surface in the rearing tanks was 20-34 lx.

The fish were fed for 27 days with two fully extruded formulated feeds (Skretting, Norway) in both experiment I and II. Feeds 1 and 2 had similar proximate compositions, but differed in particle size (Table 1). Each fish size group in both experiments were fed feed 1 (sub-groups SI-1, LI-1 (experiment I) and SII-1, LII-1 (experiment II)) or feed 2 of a larger particle size (sub-groups SI-2, LI-2 (experiment I) and SII-2, LII-2 (experiment II)) (Tables 1, 2, 3). The feed was delivered by an automatic band feeder (FIAP, Fish Technic Gmbh, Germany) for 18 h d$^{-1}$ (10:00-04:00). The daily ration in experiment I was 1.2% of the stock biomass, and in experiment II – 1.0% of the stock biomass. The proximate composition of the feed was determined using standard methods (Skulmowski 1974). Dry mass was determined with the drying method at 105°C for 15 h, total protein content by multiplying the amount of nitrogen determined by a coefficient of 6.25, and raw fat with the Soxlet method. The gross energy of the feed was determined based on its proximate composition using the following energy calculators: 39 kJ $g^{-1}$ fat, 24 kJ $g^{-1}$ protein, 17 kJ $g^{-1}$ carbohydrates (Jobling 1994). The content of nitrogen-free extract (NFE) was calculated based on the differences of (100 – (water + fat + protein + ash) (Shearer 1994). The length of the feed particles (L) and their diameter (D) were determined using a Nikon SMZ-U stereo microscope (Japan) and the NIS-Elements F2.30 v. 2.21 program (Nikon, Japan). The L and D were determined for 30 particles of each feed (± 0.01 mm). Three samples from each feed were examined (3 × 30 particles). The speed at which the particles sank through the water was also determined using a glass cylinder with a volume of 1 l and a height of 46 cm. The cylinder was filled with water from the RAS (22.0°C), and then single particles were submerged 1.0 cm below the surface of the water with a tweezers and then released. The sink path of the particles (s) was 30 cm. The sink time (t) was measured to ± 0.01 s. The sink speed of the feed particles (V) was determined using the formula V (cm $s^{-1}$) = s × $t^{-1}$.

Monitoring measurements were taken of the fish on the initial and final days of each experiment. Body weight (BW ± 0.01 g), total length (TL ± 1 mm), and body length were (SL ± 1 mm) were measured. During the measurements the fish were anesthetized in a etomidate solution (1.0 ml $l^{-1}$, IFI Olsztyn, Poland). Additionally, the biomass of the fish in each tank was determined weekly by weighing the entire stock (± 1.0 g). The results of these were used to determine the daily feed ration in subsequent weeks of rearing. The tanks were cleaned daily in the morning (07:00-09:00). The quantities of feed consumed and fish deaths were monitored. The following performance indicators were calculated:

- body weight daily growth rate; DGR (g $d^{-1}$) = $(BW_f - BW_i) \times t^{-1}$,
- body weight specific growth rate; SGR (%) = $100 \times (\ln BW_f - \ln BW_i) \times t^{-1}$,
- condition coefficient; $F = (BW \times 100) \times SL^{-3}$,
- feed conversion ratio; $FCR = TFS \times (B_f - B_i)^{-1}$,
- stock survival; S (%) = $100 \times (N_f \times N_i^{-1})$,

where: $BW_f$ and $BW_i$ – final and initial fish body weight (g), t – rearing time (days), SL – fish body length (cm), $B_f$ and $B_i$ – final and initial stock biomass (g), TFS – total feed supply (g), $N_f$ and $N_i$ – final and initial stock density (specimens).

Additionally, values of the coefficient of variation (CV) for body weight and condition at the beginning ($CV_{BWi}$ and $CV_{Fi}$) and end ($CV_{BWf}$ and $CV_{Ff}$) of each experiment (CV (%) = 100 × (standard deviation × means value of a given character$^{-1}$) were calculated. The values of the final and initial CV ratios were determined for BW and F, accordingly, as $CV_{BWf}/CV_{BWi}$ and $CV_{Ff}/CV_{Fi}$.

The data was analyzed statistically with the program STATISTICA (StatSoft®, Kraków, Poland). Variance was tested simultaneously with Levene's test. Further, single factor analysis of variance (ANOVA) was performed, and when statistically significant differences were confirmed ($P \leq 0.05$), Tukey's test was applied. Percentage data were transformed with the *arcsin* function prior to statistical analyses.

## Results

### Feed characteristics

The weight of single particles of feed 2 were nearly four times that of feed 1, and the number of particles in 1 g of feed 2 was significantly lower. The energy contents of the feeds were similar, but the raw energy in single particles of feed 2 was four times higher (Table 1). The lengths of the particles of feeds 1 and 2 were 2.85 and 4.55 mm, respectively. The length to diameter (L/D) ratios of the tested feed particles were similar at approximately 1.1. The speed at which the particles sank in the water were also similar at approximately 9.0 cm $s^{-1}$ (Table 1).

### Performance indicators

In experiment I feeding the fish feeds with different particle sizes had a significant impact on most of the performance indicators analyzed. The values of SGR and DGR of the fish in sub-groups SI-1 and LI-1 were several higher than those of specimens fed feed

**Table 1**
Proximate composition and physical parameters of the experimental feed tested (for explanation see Materials and methods)

| Specification | Tested feed | |
|---|---|---|
| | feed 1 | feed 2 |
| Total protein (% dry mass (d.m.)) | 46.0 | 45.5 |
| Raw fat (% d.m.) | 20.8 | 21.8 |
| Nitrogen-free extract (NFE; % d.m.) | 16.0 | 15.8 |
| Raw ash (% d.m.) | 9.0 | 9.0 |
| Raw fiber (% d.m.) | 1.2 | 1.1 |
| Gross energy of feed (kJ $g^{-1}$ feed) | 22.07 | 22.29 |
| Particle length (L; mm) | 2.85 ± 0.30 | 4.55 ± 0.67 |
| Particle diameter (D; mm) | 2.56 ± 0.19 | 4.01 ± 0.33 |
| L/D ratio | 1.12 ± 0.14 | 1.15 ± 0.21 |
| Number of particles (number $g^{-1}$ feed) | 67.1 ± 0.6 | 17.0 ± 0.2 |
| Particle mass (mg $particle^{-1}$) | 14.9 ± 0.1 | 58.9 ± 0.1 |
| Gross energy of feed particles (kJ $particle^{-1}$) | 0.33 ± 0.00 | 1.31 ± 0.01 |
| Speed of particles sinking in the water (cm $s^{-1}$) | 8.58 ± 0.58 | 9.87 ± 0.98 |

**Table 2**
Growth index, condition coefficient, feed conversion ratio, and survival in two juvenile pikeperch groups (SI and LI) fed feeds with different particle sizes (feed 1 – sub-group SI-1 and LI-1, feed 2 – sub-group SI-2 and LI-2) – experiment I (mean values ± SD; n= 3)

| Specification | Group SI | | Group LI | |
|---|---|---|---|---|
| | sub-group SI-1 | sub-group SI-2 | sub-group LI-1 | sub-group LI-2 |
| Initial body weight – $BW_i$ (g) | 74.59 ± 1.02 | 73.97 ± 0.99 | 102.07 ± 3.56 | 102.35 ± 1.33 |
| Coefficient of variation of $BW_i$ – $CV_{BWi}$ (%) | 9.46 ± 2.03 | 10.86 ± 3.63 | 8.23 ± 1.16 | 8.16 ± 1.12 |
| Final body weight – $BW_f$ (g) | $91.23^b$ ± 1.12 | $77.23^a$ ± 1.67 | $122.90^b$ ± 4.86 | $109.59^a$ ± 2.62 |
| Coefficient of variation of $BW_f$ – $CV_{BWf}$ (%) | $12.72^a$ ± 2.38 | $18.02^b$ ± 0.75 | 10.18 ± 3.23 | 15.93 ± 1.70 |
| $CV_{BWf}/CV_{BWi}$ | 1.35 ± 0.12 | 1.80 ± 0.64 | $1.23^a$ ± 0.27 | $1.96^b$ ± 0.08 |
| Initial condition coefficient value – $F_i$ | 1.19 ± 0.02 | 1.19 ± 0.01 | 1.24 ± 0.02 | 1.23 ± 0.00 |
| Coefficient of variation of $F_i$ – $CV_{Fi}$ (%) | 5.21 ± 0.24 | 5.23 ± 1.57 | 4.56 ± 0.64 | 4.97 ± 1.17 |
| Final condition coefficient value – $F_f$ | $1.24^b$ ± 0.04 | $1.13^a$ ± 0.01 | $1.26^b$ ± 0.01 | $1.18^a$ ± 0.00 |
| Coefficient of variation of $F_f$ – $CV_{Ff}$ (%) | $5.62^a$ ± 2.16 | $9.21^b$ ± 1.49 | $4.95^a$ ± 2.00 | $8.60^b$ ± 0.04 |
| $CV_{Ff}/CV_{Fi}$ | 1.07 ± 0.36 | 1.83 ± 0.32 | 1.06 ± 0.27 | 1.81 ± 0.48 |
| Daily growth rate – DGR (g $d^{-1}$) | $0.62^b$ ± 0.03 | $0.12^a$ ± 0.03 | $0.77^b$ ± 0.05 | $0.27^a$ ± 0.07 |
| Specific growth rate – SGR (% $d^{-1}$) | $0.75^b$ ± 0.03 | $0.16^a$ ± 0.03 | $0.69^b$ ± 0.03 | $0.25^a$ ± 0.06 |
| Feed conversion ratio – FCR | $1.5^a$ ± 0.07 | $7.3^b$ ± 1.63 | $1.6^a$ ± 0.06 | $4.6^b$ ± 1.05 |
| Survival – S (%) | 100 | 100 | 100 | 100 |

Sub-groups within a given fish size group (SI and LI) with different letter indexes differ significantly statistically ( $P \leq 0.05$)

2 ($P < 0.05$). The final values of the body weight coefficient of variation ($CV_{BWf}$) in sub-group SI-2 was significantly higher than in sub-group SI-1 (Table 2). In turn, statistically significant differences were noted between the values of final and initial CV ($CV_{BWf}/CV_{BWi}$; $P < 0.05$) in the group of larger fish (group LI; Table 2). The condition of the fish in both size groups fed feed with a smaller particle size was higher than in sub-groups SI-2 and LI-2. The final value of the coefficient of variation ($CV_{Ff}$) in sub-groups SI-2 and LI-2 was nearly two times higher than that in the sub-group fed feed 1 ($P < 0.05$; Table 2). The FCR coefficient in the sub-groups fed feed 1 was significantly lower than in the sub-groups fed feed 2 ($P < 0.05$; Table 2). No fish deaths were noted in the stocks.

No significant differences were noted in growth or condition in the two pikeperch size groups (SII and LII) in experiment II fed feeds of different particle sizes. The FCR value for all sub-groups was about

**Table 3**
Growth index, condition coefficient, feed conversion ratio, and survival in two juvenile pikeperch groups (SII and LII) fed feeds with different particle sizes (feed 1 – sub-group SII-1 and LII-1, feed 2 – sub-group SII-2 and LII-2) – experiment II (mean values ± SD; n= 3)

| | Group SII | | Group LII | |
|---|---|---|---|---|
| Specification | sub-group SII-1 | sub-group SII-2 | sub-group LII-1 | sub-group LII-2 |
| Initial body weight – $BW_i$ (g) | 125.55 ± 2.46 | 124.99 ± 0.41 | 173.72 ± 1.17 | 170.91 ± 2.71 |
| Coefficient of variation of $BW_i$ – $CV_{BWi}$ (%) | 11.45 ± 0.68 | 12.03 ± 0.55 | 9.29 ± 1.60 | 8.81 ± .080 |
| Final body weight – $BW_f$ (g) | 138.70 ± 4.34 | 138.87 ± 2.15 | 191.85 ± 4.33 | 189.42 ± 2.05 |
| Coefficient of variation of $BW_f$ – $CV_{BWf}$ (%) | 12.84 ± 1.13 | 13.16 ± 1.19 | 10.08 ± 2.17 | 9.83 ± 1.45 |
| $CV_{BWf}/CV_{BWi}$ | 1.12 ± 0.11 | 1.09 ± 0.09 | 1.08 ± 0.11 | 1.11 ± 0.08 |
| Initial condition coefficient value – $F_i$ | 1.17 ± 0.02 | 1.16 ± 0.03 | 1.22 ± 0.01 | 1.22 ± 0.02 |
| Coefficient of variation $F_i$ – $CV_{Fi}$ (%) | 5.77 ± 1.68 | 6.46 ± 1.09 | 4.87 ± 1.65 | 6.18 ± 2.07 |
| Final condition coefficient value – $F_f$ | 1.20 ± 0.02 | 1.18 ± 0.04 | 1.23 ± 0.02 | 1.21 ± 0.01 |
| Coefficient of variation of $F_f$ – $CV_{Ff}$ (%) | 7.05 ± 2.17 | 8.34 ± 1.78 | 4.97 ± 0.86 | 5.92 ± 0.15 |
| $CV_{Ff}/CV_{Fi}$ | 1.23 ± 0.10 | 1.29 ± 0.18 | 1.06 ± 0.16 | 1.05 ± 0.42 |
| Daily growth rate – DGR (g $d^{-1}$) | 0.49 ± 0.07 | 0.51 ± 0.10 | 0.67 ± 0.12 | 0.69 ± 0.12 |
| Specific growth rate – SGR (% $d^{-1}$) | 0.37 ± 0.04 | 0.39 ± 0.07 | 0.37 ± 0.06 | 0.38 ± 0.07 |
| Feed conversion ratio – FCR | 2.5 ± 0.27 | 2.4 ± 0.40 | 2.5 ± 0.40 | 2.5 ± 0.50 |
| Survival – S (%) | 100 | 98.33 ± 2.89 | 100 | 98.33 ± 2.89 |

No significant differences were noted within the given fish size groups (SII and LII) (P > 0.05)

2.5 (P > 0.05; Table 3). Only single fish deaths were noted.

## Discussion

The feed particle sizes in experiment I had a significant impact on the results. The performance indicators were lower for the pikeperch in both size groups (BW 74 and 102 g) that were fed the feed with the larger particle size. It is likely that only some of the specimens fed feed 2 consumed it, which is indicated by the significantly higher final values of $CV_{BWf}$ and $CV_{Ff}$ in these groups. The pikeperch were observed daily while the tanks were being cleaned, and it was noted that a significant portion of the feed in groups SI-2 and LI-2 was not consumed (approximately 30-50% of the daily ration). Importantly, the degree of feeding did not increase throughout rearing. Conversely, only single particles were noted during tank cleaning in the groups that were fed feed 1. Notably, the feeding intensity of the fish was in the sub-optimal range (Zakęś 2009). The reason for this was not a barrier imposed by the snout size of the pikeperch in relation to particle size. Presumably, the pikeperch snout size is about 10% of TL (for fish of a TL of 70-776 mm; Dörner et al. 2007). In experiment I, the TL of the fish from the smaller size group was about 216 mm, which means that the snout size of these pikeperch was about 22 mm. Particles measuring 4.5 mm in length, which is 20.4% of snout size, is within the size range of food that can be potentially consumed by pikeperch (Brylińska 2000). There is no information on the particle size of commercial feed that would guarantee optimal pikeperch growth. It has been noted that for Atlantic salmon, *Salmo salar* L. this size is 25% of snout size (Wańkowski and Thorpe 1979), and in European eel, *Anguilla anguilla* (L.) it is 40-60% (Knights 1983). Importantly, pikeperch have smaller snouts in comparison to other species of similar body lengths; however, most of its prey does not differ from that caught by species with larger snouts, such as perch, *Perca fluviatilis* L. (Dörner et al. 2007). It has been confirmed that under natural conditions pikeperch prefer and actively seek out smaller prey (Turesson et al. 2002).

Pikeperch is one of the species that only feed from the water column (Z. Zakęś, personal observations). One explanation for the poorer results obtained when feeding the fish feed 2 could be the lower availability stemming from the different times at which the particles sank in the water. The present study indicated, however, that the sink times of the particles in feeds 1 and 2 were similar to each other and to those noted in other salmonid commercial feeds with similar particle sizes (Tabachek 1988, Chen et al. 1999).

Applying these same feeds in experiment II (BW 125 and 170 g) did not significantly determine any of the performance indicator values. In these groups, it was possible that the growth rate of the fish fed feed 1 with smaller particle size would be lower as a consequence of the higher energy costs expended by the fish to consume this type of feed. The energy value of the particles in feed 1 was four times lower than that in feed 2, but the energy expenditure to capture them was similar. Feeding fish feed with particles sizes that are too small can lead to lowered growth rates, which can be explained by, among other things, the less advantageous energy balance (Tabachek 1988). The size of feed consumed can also impact gastrointestinal evacuation time, thus affecting the absorption of nutrients in the food (Jobling 1987, Sveier et al. 1999). No differences in growth rate or FCR values were noted in the current study of fish fed feeds 1 and 2 in experiment II; thus, the effectiveness of assimilating these feeds by pikeperch with body weights ranging from 125-170 g did not differ.

To sum up, pikeperch is a species that willingly consumes and effectively assimilates feed of smaller particle sizes. In the beginning of the on-growing period (BW 70-100 g) it is advised to use feeds with particle sizes of 2.8 mm. Feeds with larger particles (length 4.5 mm) can be fed to fish with BW > 125 g. Fish with BW in the 125-190 g range can, however, be fed with feed that has a particle size of 2.8 mm without lowering performance indicator values. Since the physical parameters of the feed have a large impact on the results of on-growing pikeperch in RAS, it is recommended to conduct feeding tests that focus not only on the chemical parameters but also the physical characters of formulated feeds.

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**Author contributions.** Z.Z. designed the research, M.H., K.P., A.K., K.S. and Z.Z., performed the research, Z.Z. and M.H analyzed the data, Z.Z. and M.H. wrote the paper.

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