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RESEARCH ARTICLE

Impact of feed rations on growth, selected body parameters and maturation of vendace, *Coregonus albula* L., reared in RAS

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Abstract. Vendace, *Coregonus albula* L., was reared to commercial size in a recirculating system. Three different feed rations were applied during the ten-month-long experiment. The feed rations impacted fish growth rates, and fish in the different groups achieved body weights of 26.6 g to 57.5 g. The final survival in all groups was similar from 44.3% among the fish fed the smallest feed ration to 53.2% in the group receiving the largest feed ration. No differences were noted in the share of viscera, peritoneal fat, or in the hepatosomatic indexes, but there were differences in the gonadosomatic indexes. After thermal stimulation, only males achieved sexual maturity. The number of mature fish was similar in all groups and ranged from 17.8 to 21.3% of all fish. The results of the present study indicated that vendace can achieve commercial size in an intensive rearing period of ten months in RAS.

Keywords: feed ration, maturation, RAS, vendace, growth

Introduction

Disadvantageous changes in natural ecosystem environments and overfishing of fish stocks have rendered aquaculture increasingly important (Asche et al. 2009). Thanks to the development of rearing technologies, more and more freshwater and marine fish species, both thermophilic and cryophilic, are being produced under controlled conditions, and one of the fastest growing sectors of aquaculture is recirculating aquaculture systems (RAS). Recirculating systems permit maintaining optimal environmental conditions thanks to which even fish with relatively specific environmental requirements can be reared successfully (Martins et al. 2010).

Vendace, *Coregonus albula* L., is potentially an interesting species for rearing. It inhabits cold lakes in northern Europe and Eurasia. It is a schooling fish that is caught en masse with set or hauled gears (Szczerbowski 1993), and it is of significant commercial interest in its areas of occurrence (Sandlund 1992, Sipponen 1998, Kaupinis and Bukelskis 2004, Wołos et al. 2009) thanks to the organoleptic properties of its meat, which, among other things, is smoked and even used to produce caviar, despite its disappearance from many areas because of its sensitivity to disadvantageous changes in the environment (Winfield et al. 2004). In natural waters, vendace can reach commercial size in the second or third year of life (Czerniejewski and Filipiak 2002). The environmental requirements of vendace are similar to those of other species from the genus *Coregonus*, which are reared in many countries including Finland, Russia, Poland, Estonia, and Kazakhstan (Tournay 2006, Timirkhanov et al. 2010); however, basic information regarding the possibilities of rearing this species to commercial size is still lacking. The aim of the present study was to determine the impact of feed

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ration size on the results of rearing, selected body parameters, and vendace maturation when reared in RAS.

Materials and methods

Introductory rearing in RAS

The study was performed at the Department of Sturgeon Breeding, IFI, Olsztyn. The study material was obtained from the artificial reproduction of vendace caught in Lake Mamry (Mazurian Lakeland, northeast Poland), in which there is a strong population exploited by the fisheries (Wołos et al. 2009). After incubation and initial rearing, the fry obtained had a mean body weight of 0.54 g and a mean body length of 3.9 cm. Fish age on the initial day of the experiment was 67 days post hatch (DPH), and rearing lasted for 237 days (until 304 DPH).

The fish were reared in a recirculating system with a volume of 70 m^3 equipped with square tanks made of artificial material with a working volume of 1 m^3 each. The fish were divided into three groups, each of them was fed a different feed ration. Because there is a lack of data on vendace nutrition, the feed rations were using a table designed for rainbow trout, *Oncorhynchus mykiss* (Walbaum) (Goryczko 2001). The following feed rations were applied: 50% of the trout rations – group S; 75% – group M; 100% – group H. The daily feed ration was decreased gradually throughout the experiment and at the end it was 20% for group S, 30% for group M, and 40% for group H of the rations recommended for trout. The daily feed ration was calculated based on fish biomass and varied at the beginning and end of the experiment from 10 to 0.6% in group S, 15 to 0.72% in group M, and 20 to 0.8% in group H. There were three replicates for each group of fish. Initially, the stock in each tank comprised 1,000 individuals, but from day 105 of rearing (172 DPH), the fish stock was reduced to 400 individuals selected at random.

During the rearing, the fish were fed commercial salmonid fish feeds (Skretting, France): Nutra 2.0, Nutra 1.1, Nutra 1.5, Nutra 1.9, which contained 52.0% protein; 20.0% fat; 8.5% carbohydrates; 11.0% ash, and 19.9 MJ kg^{-1} digestible energy (manufacturer's data). Feed was delivered 18 h per day (07:00-01:00) by an automatic band feeder (FIAP, Germany). The tanks were illuminated 24 h per day. The mean water temperature was 18.0°C (range 13.0-21.5°C). Oxygen concentration at the outflow was higher than 6.2 mg O_2 l^{-1}, and water pH ranged from 7.20 to 7.67. These parameters were measured with a Cyber Scan 5500 (Eutech Instruments, USA). Ammonia nitrogen (CAA = NH_4^+-N + NH_3-N) at the outflow did not exceed 0.35 mg CAA l^{-1}, and the content of nitrites did not exceed 0.25 mg NO_2- l^{-1}. These parameters were determined with a spectrophotometer (Carl Zeiss 11, Germany) (Hermanowicz et al. 1999). Every morning the tanks were cleaned of excrement and unconsumed feed, and any fish deaths were noted.

Analysis of selected body parameters

Ten individuals from each tank, or replicate, were selected at random for a total of 30 from each feed ration group. The fish were sacrificed in an aqueous solution of the anesthetic Propiscin (active ingredient – etomidate, Kazuń and Siwicki 2001) at a concentration of 20 ml l^{-1} water. Next, the fish were gutted and the analyzed body parts were weighed to the nearest 1 mg and their percentage shares of the whole body weights were calculated. The sex ratio was determined, with males comprising from 53.3 to 56.7% of all individuals, and the following indicators were calculated:

- share of viscera (% BW) = viscera weight (g) × BW^{-1} × 100%
- hepatosomatic index HSI (% BW) = liver weight (g) × BW^{-1} × 100%
- gonadosomatic index GSI (% BW) = W_g × BW^{-1} × 100%
- share of peritoneal fat (% BW) = peritoneal fat weight (g) × BW^{-1} × 100%

where: BW – total fish weight (g),
W_g – gonad weight (g)

Body deformities were also noted.

Fish maturation

At the end of rearing, 45 fish were selected at random from each feed ration group (15 from each replicate) and placed in a recirculating system equipped with a water cooling system. The sexual maturity of the fish was determined by lowering the water temperature gradually over 12 days from 12.0 to 5.0°C, which is the natural spawning temperature for vendace. After the temperature reached 6.0°C, all the fish were examined daily. Mature specimens, (those which released sex products) were removed from the tanks. The maturation procedure concluded after a temperature of 5.0°C had been maintained for 12 days; after three days, no new individuals matured.

Measurement procedures and statistical analysis

In order to determine fish growth rate and condition, the feed conversion ratio and the daily feed ration were performed every 14 to 28 days individual measurements of fish body length and total length (± 1 mm) and body weight (± 0.1 g). The fish were measured and under the anesthetic Propiscin at a concentration of 1 ml l^{-1} water.

The data collected were used to determine the following rearing parameters:

- daily growth rate, DGR (g d^{-1}) = (final body weight (g) – initial body weight (g)) × rearing $time^{-1}$ (days);
- specific growth rate, SGR (% d^{-1}) = 100 × (ln final body weight (g) – ln initial body weight (g)) × rearing $time^{-1}$ (days);
- Fulton's condition coefficient, CF = 100 × (body weight (g) × body length Lc^{-3} (cm));
- stock survival, S (%) = 100 × (final abundance (individual) × initial $abundance^{-1}$ (individual));
- feed conversion ratio, FCR = weight of feed consumed (g) × (final stock biomass (g) – initial stock biomass $(g))^{-1}$;
- Protein efficiency ratio, PER = (final fish biomass (g) – initial fish biomass (g)) × quantity of protein fed^{-1} (g).

The results were analyzed statistically with Statistica 5.0 PL. The homogeneity of variance was verified with Levene's test, and one-way analysis of variance (ANOVA) and Tukey's test (HSD) ($P \leq 0.05$) were used to determine the significance of differences in the groups analyzed. The calculations were performed with the mean values from the replicates of the different groups.

Results

The final body weights ranged from 26.6 g in group S to 57.5 g in group H, and it was statistically higher in group H than in the other two groups (Table 1). The daily (DGR) and specific (SGR) growth rates were also the highest in the fish from group H, and they differed statistically from the fish growth in group S ($P < 0.01$). Fish body length at the end of the experiment ranged from 13.1 cm (group S) to 16.5 cm (group H; $P < 0.001$). The body lengths in these groups and in group M also differed significantly statistically (Table 1). The values of the condition coefficients were similar from 1.18 in group S to 1.28 in group H. The final survival in all the groups was similar from 44.3% in group M to 53.2% in group H. Differences were noted in the values of the feeding coefficients, with the lowest noted in group S (1.64) and the highest in group M (2.03).

The share of viscera in the total fish body weight in the groups analyzed was similar and ranged from 10.12% in group S to 11.38% in group M. The value of the hepatosomatic index was also similar and ranged from 1.01% in group S to 1.16% in group H. Differences were noted in the values of the gonadosomatic index which was higher in the groups of fish fed larger feed rations: in group S it was 2.11%, in group M – 3.35%, and in group H – 3.60% of body weight (Table 2). Differences in the GSI among groups M and H and group S were statistically significant. The quantity of peritoneal fat ranged from 1.45% of body weight in group S to 1.82% in group M ($P > 0.05$). A high share of fish body deformities, mainly shortened gill covers, was noted in all the groups. Fish

Table 1
Results of rearing vendace (*C. albula*) fed different feed rations (details of the groups in the Materials and methods section, mean values ± SD, n=3)

Parameters	Group S	Group M	Group H
Initial body weight (g)	0.5 ± 0.2	0.5 ± 0.2	0.5 ± 0.2
Final body weight (g)	26.6 ± 2.4[a]	40.6 ± 6.2[a]	57.5 ± 9.1[b]
Daily growth rate DGR (g d^{-1})	0.11 ± 0.01[a]	0.17 ± 0.03[a]	0.24 ± 0.04[b]
Mean specific growth rate SGR (% d^{-1})	1.65 ± 0.04[a]	1.82 ± 0.07[b]	1.97 ± 0.07[b]
Initial body length (cm)	3.9 ± 0.1	3.9 ± 0.1	3.9 ± 0.1
Final body length (cm)	13.1 ± 0.3[a]	14.8 ± 0.4[b]	16.5 ± 0.7[c]
Final Fulton's condition coefficient	1.18 ± 0.03[a]	1.24 ± 0.10[a]	1.28 ± 0.04[a]
Survival (%)	48.6 ± 4.9[a]	44.3 ± 4.5[a]	53.2 ± 1.9[a]
Feed conversion ratio FCR	1.64 ± 0.16[a]	2.03 ± 0.21[b]	1.89 ± 0.07[ab]
Protein efficiency ratio PER	1.18 ± 0.12[a]	0.95 ± 0.10[a]	1.02 ± 0.04[a]

Values in rows with the same letter index do not differ significantly statistically (P > 0.05)

Table 2
Final values of selected body and maturation parameters of vendace (*C. albula*) fed different feed rations (explanations in the Material and methods section; means ± SD, n=3)

Parameters	Group S	Group M	Group H
Viscera weight (% BW)	10.12 ± 0.49[a]	11.38 ± 0.65[a]	11.33 ± 0.62[a]
Hepatosomatic index HSI (% BW)	1.01 ± 0.04[a]	1.14 ± 0.08[a]	1.16 ± 0.08[a]
Gonadosomatic index GSI (% BW)	2.11 ± 0.35[a]	3.35 ± 0.37[b]	3.60 ± 0.56[b]
Share of peritoneal fat (% BW)	1.45 ± 0.45[a]	1.82 ± 0.18[a]	1.68 ± 0.10[a]
Frequency of body deformities (%)	40.3 ± 1.9[a]	32.4 ± 3.4[a]	40.0 ± 6.9[a]
Share of mature fish (%)	21.3 ± 3.3[a]	18.3 ± 4.3[a]	17.8 ± 3.3[a]

Values in rows with the same letter index do not differ significantly statistically (P > 0.05)

with deformities accounted for 32.4% in group M to 40.3% in group S of the total number of fish.

After thermal stimulation, the females did not achieve sexual maturity and no eggs were obtained from them, but the males matured. The percentage of mature fish of all the fish in the different groups was similar at 21.3% in group S, 18.3% in group M, and 17.8% in group H (Table 2).

Discussion

Vendace growth rate during rearing in RAS was substantially faster than under natural conditions. Individuals aged ten months attained body weights corresponding to values of fish aged 1+ and even 2+ in natural ecosystems (Kaupinis and Bukelskis 2004, Czerniejewski et al. 2006). The fish fed the largest feed ration reached the minimum commercial size during the experiment (Szczepkowski and Stabiński 2011). The fish reared in RAS had a different body shape compared to fish from natural populations. The condition coefficient among individuals from the group fed the smallest feed ration was higher (1.18) than in wild fish of the same size or even larger (mean body weight of 111 g), in which the mean condition coefficient ranged from 0.70 to 0.90 (Czerniejewski et al. 2006, Przybył et al. 2010). This is evidence that even the lowest feed ration tested in the experiment fully met the nutritional requirements of the fish.

No differences in growth rates were noted between females and males, even though females require a greater share of food for gonadal development. Under natural conditions, faster growth is noted among females, but these fish are aged 2+ and older (Ciepielewski and Hornatkiewicz-Żbik 2006, Golski et al. 2010). Thus, it is plausible that differences in growth rates occur at ages more advanced that at ten months.

The effectiveness of vendace feed use in RAS was relatively low. The high feeding coefficients were impacted by the relatively low survival of the fish during the experiment, which did not exceed 55%. This could have also stemmed from the feeds used not fully meeting vendace nutritional requirements. Confirmation of this could be the large share of fish with body deformities (30-40%). Although these feeds have been used successfully to rear European whitefish, *Coregonus lavaretus* (L.) (Szczepkowski et al. 2006), but the nutritional requirements of these two species can differ substantially. It is also noteworthy that vendace feeds exclusively on zooplankton throughout its life, while, in addition to this type of food, the European whitefish also consumes a variety of small benthic organisms, and even preys on other fish (Szczerbowski 1993).

Another factor that led to the high FCR ratios, especially in the groups fed the largest feed rations (groups M and H), could have been the reduction in feed use effectiveness linked to gonad formation since fish use substantially more energy developing gonads during sexual maturation (Kamler 1992). Confirmation of this could be the fact that during the initial rearing phase until a body weight of about 10 g was reached the FCR in all groups was at a similar level (1-1.2), and substantial increases were noted after the fish exceeded this size.

Only male vendace achieved sexual maturation during the experimental period. The values of the gonadosomatic index in the males from all groups were similar to those noted in mature fish from natural conditions; for example, the GSI of male vendace from Lake Luterskie (northeast Poland) just prior to spawning was 2.35% (Długosz and Worniałło 1985). Females aged ten months and reared in RAS were not yet ready to spawn even though their body weights were equivalent to those of mature fish (Czerniejewski and Wawrzyniak 2008). During pond rearing, eggs were obtained from fish with body weights of 42 g (Wziątek et al. 2009), but these fish were older (aged 1+) than those in our study. The size of the gonads of the females reared in the RAS were significantly smaller than those of mature wild fish. The GSI was the highest in the group fed the largest feed ration, but it was still just approximately 5.3%, while mature wild females from different lakes had GSI values just before spawning of 13.3 to 29.9%, with most exceeding 20% (Długosz and Worniałło 1985, Lahti and Muje 1991, Golski et al. 2010). This might indicate that achieving sexual maturity in a recirculating system could require more time and/or different environmental conditions, foremost regarding thermal regime.

The hepatosomatic index is linked with metabolic activity and the energy reserves contained in the liver. It has been confirmed that the value of this index is impacted by the type of food (Hung et al. 1990). No differences in this index were noted among the groups fed different feed rations in the current study, and this could indicate that the energy supplied was not stored only in the liver. This could be confirmed by the small degree of variation in values of the HSI in vendace from 1.01 to 1.16. Other fish species present a substantially wider range of variation, for example in white sturgeon, *Acipenser transmontanus* Richardson, HSI values range from 1.99 to 3.71. Seasonal variability can also affect HSI values, as it does with the gonadosomatic index (Lenhardt et al. 2009). Significantly, excessive food was not stored in the body cavity as peritoneal fat, which is evidence of its similar share that is independent of the level of feeding. This also indicates, that similarly to salmonids, fat can be stored primarily in the muscles (Macrae et al. 1993), which is advantageous in terms of slaughter yield.

The results of the current experiment indicate that vendace can reach commercial size when reared intensively in RAS for ten months. The main challenge is the low effectiveness of feed use (values in excess of 1.5) and the occurrence of numerous body deformities, which, when combined, decrease economic performance. Further studies are necessary to develop a better understanding of proper rearing conditions and to optimize feeds to permit increasing final survival and the feed efficiency ratio. Additionally, the substantial variability in growth rates observed in vendace from various lakes (Kaupinis and Bukelskis 2004) needs to be considered, as this would affect the results of rearing including, among other factors, survival (Mamcarz 1994), which could also serve to identify the various potential and suitability of different populations for intensive rearing.

Autor contribution. B.S. designed and performed the research, M.S. performed reseach and wrote the manuscript, I.P. performed the reseach.

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