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Research Article

Effect of Different Feeding Rates for the Growth and Body Composition of Manchurian Trout, *Brachymystax lenok*

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A 50-day feeding trial was conducted to investigate the effects of feeding rates (FRs) on the growth, feed utilisation, and body composition of *Brachymystax lenok*. Juveniles of *B. lenok* (initial body weight of 7.6 ± 0.2 g) were fed a commercial diet at the different FRs of 1, 2, 3, 4, and 5% of their body weight. The results indicated that weight gain (WG) and specific growth rate (SGR) were first increased and then decreased with an increase in the FR. The WG and SGR of the 4% group were 299.78% and 3.96%, respectively. The feed conversion ratio (FCR) and protein efficiency ratio (PER) were also significantly affected by the FR ($P < 0.05$). Furthermore, the condition factor (CF) did not differ significantly among the treatment groups ($P > 0.05$). However, the FR significantly affected the hepatosomatic index (HSI) and visceral somatic index (VSI) ($P < 0.05$). With an increase in the FR, the moisture content of the fish decreased, but the ash content changed irregularly. The protein content increased significantly with increasing FR ($P < 0.05$). The lipid content showed a trend similar to protein in the body. Based on the SGR and FCR data, the optimal FR range was 2.4 to 3.1% for *B. lenok* (7–30 g body weight) at a water temperature of 16°C.

1. Introduction

Aquaculture can be a viable strategy to restore depleted fish populations and endangered fish species, preserve them, and balance the supply and demand of seafood [1, 2]. The efficiency of aquaculture operations is influenced by several interconnected factors, including the aquatic environment, nutrition, and farmed stock [3, 4]. Maximising these factors is the foundation of sustainable aquaculture [5]. Improving feeding efficiency in aquaculture can maximise the reproduction and growth potential of aquatic organisms. Fish growth at all stages is largely governed by the type of food, feeding rate (FR), feeding frequency, food intake, and ability to absorb nutrients [6, 7]. Among these factors, the FR is one of the most important aspects of commercial fish farming [8, 9]. An optimum daily FR is helpful for reducing feed waste, minimising water pollution, and decreasing the economic costs of aquaculture production.

The Manchurian trout, *Brachymystax lenok*, is distributed in rivers and lakes throughout eastern Siberia, including portions of Kazakhstan, Mongolia, China, and Korea [10]. The lenok population, as an endangered species, has declined in China [11, 12], and in recent years, a recovery plan has been implemented to protect this species from further losses. Accordingly, their biology, ecology, artificial propagation, and cultivation techniques have been studied [13–15]. The traditional culture of Manchurian trout mainly relies on chopped or minced trash fish, which can easily lead to the deterioration of water quality and the spread of diseases. Therefore, studies on feeding strategies should be conducted to develop cost-effective and nutritionally balanced diets for this species. A previous study showed that a diet containing 450 g/kg of proteins and 160 g/kg of lipids is suitable for better growth and utilisation of Manchurian trout in a recirculating water system [15]. Moreover, when the lipid content of the diet exceeds 250 g/kg, the antioxidant status is affected during the larvae stage [16]. In addition to determining proper feeds, an appropriate feeding regiment is also essential for aquaculture practices. However, no information is available on the effect of FR on Manchurian trout larvae cultured under controlled conditions. Given the interest in developing intensive aquaculture methods for this species, this study aimed at determining the optimum FR for cultured species under the controlled conditions.

2. Materials and Methods

2.1. Ethics Statements. All experiments were performed in accordance with the European Communities Council Directive (86/609/EEC). All fish involved in this research were bred following the guidelines of the Animal Husbandry Department of Heilongjiang, China. All efforts were made to minimise animal suffering.

2.2. Supply and Maintenance of Fish. This study was conducted at the hatchery (Heilongjiang River Fishery Research Institute, China). The fish were hatchery-reared from eggs of the same cohort obtained from a captive broodstock in the Heilongjiang region. The fish were acclimated to laboratory conditions and fed three times per day with a commercial diet (161, Beijing Hanye Science & Technology Co., Ltd., China) containing 52% crude protein, 20% crude fat, 10.7% ash, and 0.4% crude fiber, at around 8:00, 12:00, and 16:00 for three weeks under constant conditions. The tanks use a recirculation system to maintain water temperature at 16 ± 1°C, dissolved oxygen at 8.0–8.5 mg/L, and pH 7.0–7.3.

2.3. Feeding Management and Experimental Design. At the start of the experiment, 15 groups of 30 fish of approximately equal size (mean weight (SD), 7.6 ± 0.2 g) were stocked into 15 circular tanks of 150 L capacity. Triplicate groups of fish were fed at five different rates: 1, 2, 3, 4, and 5% of body wet weight/day for a 50 days period. Fish were given daily rations during daylight hours (8:00–16:00 h), and daily rations were divided into three equal meals per day at 8:00, 12:00, and 16:00 h. Fish in each tank were collectively weighed every 10 days, and then the quantity of feed supplied was readjusted according to the measured weight.

2.4. Sampling and Growth Index Measurements. At the end of the experiment, fish from each tank were captured and euthanised with a 0.9 mL/L 2-phenoxyethanol solution. The moisture, crude protein, lipid, and ash contents of the experimental diets and samples were determined using standard AOAC methods [17] procedures at the Heilongjiang River Fishery Research Institute. Protein levels were determined using a Tecator Kjeltec system, and the fat content analysis was performed using a Tecator Soxtec system with petroleum ether according to AOAC [18]. Moisture content was determined by heating the samples at 105°C for 24 h, and ash content was determined by burning the samples at 500°C for 12 h. The relevant parametric formulae are as follows:

$$\text{Weight gain (WG, \%)} = \frac{(\text{final fish weight} - \text{initial fish weight})}{(\text{initial fish weight})} \times 100\%,$$
$$\text{Specific growth rate (SGR, \%)} = \frac{(\ln W_t - \ln W_0)}{t \times 100\%}, \qquad (1)$$

where W_t and W_0 represent the initial body mass (g) and final body mass (g) of the fish at a certain experimental stage, respectively, and t represents the number of breeding days.

$$\text{Protein efficiency ratio (PER, \%)} = \frac{\text{weight gain } (g)}{\text{protein intake } (g)},$$
$$\text{Feed conversion ratio (FCR, \%)} = \frac{\text{feed consumed } (g)}{\text{weight gain } (g)},$$
$$\text{Fulton's condition factor } \left(\text{CF}, g\,\text{cm}^{-3}\right) = \frac{100 \times \text{body weight } (g)}{(\text{body length, cm})^3}, \qquad (2)$$
$$\text{Hepatosomatic (HSI, \%)} = 100\% \times \left(\frac{\text{liver weight}}{\text{whole body weight}}\right),$$
$$\text{Viscerosomatic index (VSI \%)} = 100\% \times \left(\frac{\text{viscera weight}}{\text{whole body weight}}\right).$$

2.5. Statistical Analysis. All data were subjected to variance normality and homogeneity checks using the Shapiro–Wilk and Levene tests. The least significant difference test and one-way ANOVA were used to analyse differences between groups. Results are expressed as the mean ± SD. Statistical analyses were performed using SPSS version 13.0. Statistical significance was set at $P < 0.05$. A quadratic regression analysis method was used to analyse the SGR and FCR.

3. Results

The effects of the FR on the WG, SGR, PER, and FCR are shown in Table 1. All of these indices were significantly affected by the FR ($P < 0.05$). Both WG and SGR increased significantly ($P < 0.05$) as the FR increased from 1% to 4%, but they decreased as the FR increased to 5%. There was no significant difference in the growth of fish at 2% and 3% FRs ($P > 0.05$). The PER decreased significantly as the FR increased ($P < 0.05$), and the FCR was significantly affected by an increase in the FR ($P < 0.05$). Quadratic regression analysis of the SGR and FCR indicated that the optimum FRs for *B. lenok* were 3.1% and 2.4% BW/day, respectively (Figure 1). Therefore, the SGR and FCR values were combined to determine the optimal FR range between 2.4% and 3.1%.

The CF showed no significant effect among the treatment groups ($P > 0.05$) (Table 2). However, the HSI and VSI were significantly affected by the FR ($P < 0.05$). Specifically, the highest HSI and VSI were obtained with 5% BW/day.

Body composition results are shown in Table 3. The moisture decreased with an increase in the FR. Meanwhile, the ash content in the 5% FR treatment group was the highest among all treatments, and there were significant differences among the five treatments ($P < 0.05$). The protein content in the 2%-3% treatment groups was significantly higher than in the other treatment groups ($P < 0.05$). Moreover, the lipid content increased with an increase in the FR, and there was no significant difference in the 3%–5% groups ($P > 0.05$).

4. Discussion

4.1. Growth. In the present study, based on SGR and FCR data, a feeding rate ranging from 2.4% to 3.1% BW/day can be recommended for Manchurian trout fingerlings fed a 52% protein diet. The FR had a significant effect on all variables, and the amount of food supplied was the main growth-limiting factor. In addition, higher growth was observed when the fish were fed at higher FRs (1%–4% BW/day) compared to those fed at lower rates. Similar results were observed for juvenile cobia fish, which had a higher SGR at 7% BW/day, compared to 3% BW/day [19]. Other studies on different species have revealed that with increasing FRs, growth increases at higher ratio levels and decreases at lower ratio levels [20–22]. However, fish fed with diets containing 5% BW/day exhibited limited growth. Notably, growth does not increase after the FR exceeds the optimum level [23, 24].

Feed efficiency is not lacking when the FR is less than the maintenance level of the fish, and the highest feed efficiency is achieved with a ratio greater than the maintenance level [25]. Eroldogan et al. [20] reported that the fish subjected to low FRs tend to exhibit optimised digestion to extract more nutrients efficiently and increase nutrient absorption from their feed. In this study, we found that under low FRs, fish tended to exhibit optimised digestion to extract more nutrients more efficiently, resulting in a decreased PER and increased FCR. It is may be due to the low FR group (1.0%–4.0%) having an appropriate or insufficient feed abundance, resulting in intense competition for food among the fish. However, the high feeding rate group (5.0%) has led to a decrease in competition, leading to significant anorexia behavior.

The FR is an important aspect for studying the energy associated with fish breeding and growth [26]. When the FR is low, the feed remains in the digestive tracts of fish for a longer time, and feed absorption efficiency can be improved to meet the needs of growth and immunity. With a high ingestion rate, metabolism is reduced by increasing gastrointestinal speed, and energy is lost with faeces [27]. Moreover, rhythmic changes in fish digestive enzymes have been observed during regular feeding [28, 29]. Studies on trout have shown a positive correlation between trypsin activity in the intestine and the digestion coefficient, and excess nutrition might reduce the activity of enzymes [30]. Moreover, in Brazilian sardines, *Sardinella brasiliensis,* enzyme activity decreases with an increase in the FR [31]. It has been speculated that this could be the reason for the initial decrease and then increase in the FCR value, whereas the SGR value followed the opposite trend, which requires further verification.

4.2. Body Condition. Indices of body conditions, such as the CF, HSI, and VSI, are often used to assess the nutritional status of fish and indicate physiological conditions [32]. In this study, the feeding ratio affected HSI and VSI but not CF. An increase in the FR was significantly reflected by HSI (1.3%–2.7%) and VSI (8.0%–19.9%) for both groups. Studies have shown that if fish consume more food than is required to maintain body functions, the excess energy is mainly stored in the muscle and visceral tissues in the form of lipids [33]. However, in some fish, such as spadefish, energy is accumulated in the gonadal adipose tissues [34]. Therefore, determining the optimal FR is a key factor for successful aquaculture. At a low FR, fish must use the deposited energy in the viscera to meet their energy requirement, which decreases visceral weight. Our results agree with those of Storebakken and Austreng [35] and Ballestrazzi et al. [36]. According to Phillips et al. [37], a balanced amount of nutrients influences the liver size, and fish can transfer excessive energy to the viscera. The marked differences among fish fed at rates of 1.0 to 4.0% BW/day suggest that all fish in these treatment groups were adequately fed, but the results of fish fed at a rate of 5% were significantly higher than those of the others. Therefore, the present study demonstrated that 5% FR led to oversatiation, which may cause health issues.

Table 1: WG, SGR, PER, and FCR of *Brachymystax lenok* fed with diets with various feeding ratios.

Feeding ratio (%)	Survival rate (%)	Final weight (g/fish)	WG (%)	SGR (%)	PER (%)	FCR (%)
1	90	13.32 ± 0.23	74.52 ± 3.15[d]	1.59 ± 0.00[d]	2.63 ± 0.10[a]	0.96 ± 0.00[b]
2	93	24.91 ± 0.91	227.14 ± 6.5[b]	3.38 ± 0.10[b]	2.51 ± 0.10[ab]	0.89 ± 0.00[c]
3	97	26.18 ± 0.56	243.87 ± 6.8[b]	3.53 ± 0.00[b]	2.27 ± 0.00[bc]	0.95 ± 0.00[b]
4	100	30.43 ± 0.64	299.78 ± 8.06[a]	3.96 ± 0.50[a]	2.01 ± 0.00[c]	0.91 ± 0.00[c]
5	100	15.38 ± 0.45	102.09 ± 5.93[c]	2.01 ± 0.80[c]	0.73 ± 0.00[d]	1.91 ± 0.10[a]

Values were presented as means ± SD. In the same row, values that are not followed by the same letter are significantly different ($P < 0.05$). WG, weight gain; SGR, specific growth rate; PER, protein efficiency ratio; FCR, feed conversion ratio.

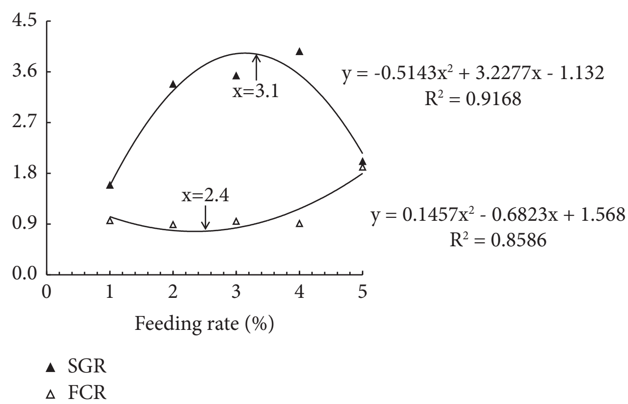

Figure 1: Quadratic regression analysis of SGR and FCR indicated the optimum feeding rate of *Brachymystax lenok*.

Table 2: CF, HSI, and VSI of *Brachymystax lenok* fed with diets with various feeding ratios.

Feeding ratio (%)	Final length (cm)	CF (g cm^{-3})	HSI (%)	VSI (%)
1	11.41 ± 0.27	0.90 ± 0.08[a]	1.34 ± 0.07[d]	8.06 ± 0.03[d]
2	13.53 ± 0.22	1.01 ± 0.09[a]	1.67 ± 0.05[bc]	11.91 ± 0.36[c]
3	13.75 ± 0.14	1.01 ± 0.04[a]	1.79 ± 0.08[b]	14.60 ± 0.25[b]
4	14.25 ± 0.22	1.05 ± 0.06[a]	1.62 ± 0.05[c]	13.06 ± 0.36[c]
5	11.82 ± 0.14	0.93 ± 0.05[a]	2.70 ± 0.05[a]	19.92 ± 0.99[a]

Values were presented as means ± SD. In the same row, values that were not followed by the same letter were significantly different ($P < 0.05$). CF, condition factor; HSI, hepatosomatic index; VSI, viscerosomatic index.

Table 3: Effects of feeding rate on body composition in *Brachymystax lenok*.

Feeding ratios (%)	Moisture (%)	Ash (%)	Protein (%)	Lipid (%)
1	77.81 ± 0.21[a]	2.79 ± 0.02[b]	15.31 ± 0.01[c]	0.79 ± 0.01[c]
2	76.95 ± 0.15[b]	2.35 ± 0.03[c]	19.03 ± 0.02[a]	1.11 ± 0.01[b]
3	76.13 ± 0.13[c]	2.01 ± 0.02[d]	18.96 ± 0.02[a]	1.33 ± 0.01[a]
4	76.24 ± 0.25[c]	2.75 ± 0.02[b]	17.91 ± 0.02[b]	1.38 ± 0.02[a]
5	74.98 ± 0.20[d]	3.68 ± 0.03[a]	17.65 ± 0.01[b]	1.42 ± 0.03[a]

Values were presented as means ± SD. In the same row, values that are not followed by the same letter are significantly different ($P < 0.05$).

4.3. Body Composition. The moisture content of the fish decreased significantly with the increasing FRs. In this study, the crude protein content of the whole body was significantly affected by the feeding ratio. Generally, under suboptimal feeding conditions (2%–5%), fish retain more protein in the muscle. Similar results have been reported by Ng et al. [21]. However, the body protein content appeared to be affected by the lowest FR (1% BW/day), because of the suboptimal feed due to which the protein is converted to energy and consumed, suggesting that a rate substantially above the maintenance level did not provide sufficient protein or energy to support growth. Therefore, in the 1% FR group, the body protein content of fish was lower than in other groups. Moreover, lipid levels in fish increase with increasing feeding ratios, whereas moisture levels decrease. Previous studies on the white sturgeon *Acipenser transmontanus* [23], rainbow trout [38], and tropical bagrid catfish [21] have also reported similar observations in terms of body lipids. Taken together, these results suggest that a suitable feeding ratio can save feed costs and improve meat quality by improving protein retention.

5. Conclusions

In summary, the present study showed that FR could significantly affect growth, feed efficiency, body conditions, and body composition of Manchurian trout. The results of this study indicated that the optimal FR range to improve growth and feed utilisation under the experimental conditions was

2.4%–3.1% for Manchurian trout (7–30 g body weight). Further studies on the FR range to examine different developmental stages are crucial for its production.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Enhui Liu coordinated and performed experiments and prepared the manuscript. Tianqing Huang collected the data. Wei Gu checked the manuscript. Gaochao Wang cultured the fish. Bingqian Wang submitted and revised the manuscript. Xiulan Shi analysed the data. Gefeng Xu reviewed the manuscript. All authors contributed to the manuscript at various stages. All authors have read and approved the manuscript.

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