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The influence of feeding rate on growth, feed efficiency and body composition of juvenile grass carp (*Ctenopharyngodon idella*)

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Abstract. An 8 weeks growth study was conducted to estimate the optimal feeding rate for juvenile grass carp (3.08 ± 0.03 g, mean ± SD). Fish were fed with a casein purified diet (360 g protein, 56 g lipid and 3000 kcal total energy/kg dry diet) at six feeding rates: 1.0, 1.5, 2.0, 2.5, 3.0, 3.5% body weight per day (BW d^{-1}). Each feeding rate was randomly assigned to three tanks of fish with 30 fish per tank ($50W \times 50H \times 100L$, cm). Fish were maintained in recirculating systems at a water temperature of 24.97 ± 2.23 °C and were fed four times per day. After 2 weeks, fish fed on 3.5% BW d^{-1} could not finish the diet and this treatment was cut-off. Analysis of variance showed that growth performance was significantly ($p < 0.05$) affected by different feeding rates. The nutrient compositions of whole body, muscle and liver were also significantly different among treatments. The body weight gain (WG), specific growth rate (SGR), feed efficiency (FE), protein efficiency ratio (PER), apparent digestibility coefficiency (ADC), retention of protein (PR), mesenteric fat index, body moisture and protein content were significantly ($p < 0.05$) affected by feeding rate. The WG, SGR and digestion rate were highest at 2% BW d^{-1}, although the FE and PER decreased with increasing feeding rate. Broken line analysis on specific growth rate indicated that the optimum feeding rate of juvenile grass carp is 1.97% body weight day^{-1}.

Introduction

Feeding rate is important for the growth, feed conversion, nutrient retention efficiency and chemical composition of fish (Huisman 1976; Reinitz 1983a; Henken et al. 1985; Hung and Lutes 1987; Storebakken and Austreng 1987a, b). Determination of the nutrient requirement is also affected by feeding rate (Tacon and Cowey 1985; Talbot 1985). A restricted feeding rate will cause impaired health (Storebakken and Austreng 1987a) or slow growth (Hung and Lutes 1987; Hung et al. 1989; Fontaine et al. 1997). Conversely, over-feeding of fish will cause the overload of stomach and intestine, and decrease the efficiency of digestion and absorption (Jobling 1986), and thus reduces feed efficiency (Hung and Lutes 1987; Storebakken and Austreng 1987a). An

optimum feeding rate is helpful to minimize the feed loss, reduce water pollution and decrease cost of aquaculture production.

Estimation of an optimum feeding rate is affected by fish size, water temperature, feeding strategy, and rearing condition (Storebakken and Austreng 1987a; Hung et al. 1993; Ballestrazi et al. 1998). Vahl (1979) suggested that only two parameters were necessary to design an optimal feeding regime in aquaculture system, the maximum voluntary feed intake in one meal and the evacuation rate of the stomach. Some studies, however, show acclimation of fish is also important (Ishiwata 1968) and short-term feed intake has a limited value in assessing the optimum feeding rate (Storebakken 1986).

Grass carp (*Ctenopharyngodon idella*) is a very popular economic fish species cultured in China. There is little information about nutrient requirement and optimum feeding rate of grass carp (Dabrowski 1977; Dabrowski and Kozak, 1979; Lin et al. 1989; Lin 1991; Carter and Brafiled 1991, 1992a, b; Cui et al. 1992). Our previous study (Du and Liu, unpublished data) have found that in juvenile grass carp, the intestinal evacuation time is 12 h and the maximum daily consumption of a formulated diet is $3.64 \pm 0.23\%$ BW d^{-1} when fish cultured in a recirculating system at 27.5–28.5 °C during a short-term study (22 days). In this study, fish were fed on the same purified diet as previous study for 56 days at six feeding rates. The effects of feeding rate on growth, feed efficiency, digestion rate, nutrient retention and body chemical composition were determined and the optimum feeding rate was assessed.

Materials and methods

Diet preparation

The same purified diet in former study (Du and Liu, unpublished data) was used and the formulation is shown in Table 1. All the ingredients were from mainland of China, except fish oil was from New Zealand (Bakels Edible Oils Ltd., Mt Macnganui). All the dry ingredients were mixed (A-200T Mixer Bench Model unit, Russell Food Equipment Ltd., Ottawa, Ontario, Canada) for 15 min, and then fish oil and corn oil was added, and then mixed for another 15 min. Water (300 ml kg^{-1} dry ingredients mixture) was added and mixed for another 15 min. The wet mixture was pelleted into 1.5 mm size and the pellets were air-dried at room temperature for 24 h, and then stored at −20 °C until used. The available dietary energy was calculated using physiological fuel value of 4.0, 4.0 and 9.0 kcal g^{-1} (16.7, 16.7 and 37.7 kJ g^{-1}) for protein, carbohydrate and lipid, respectively (Lee and Putnam 1973; Garling and Wilson 1977).

Supply and maintenance of fish

Juvenile grass carp were obtained from local fish farm and maintained in a 18 circular fiberglass tanks ($50W \times 50H \times 100L$) system. The 18 tanks were

Table 1. Formulation and composition of experiment diet fed to juvenile grass carp.

Ingredients	g kg^{-1} diet (dry)
Casein	320
Gelatin	80
Corn starch	250
Fish oil	30
Corn oil	30
Cellulose	18.49
Vitamin mix[A]	10
Mineral mix[B]	80
Ascorbic phosphate ester	10
Choline chloride	5
Y_2O_3	0.1
Composition (%)	
Moisture	9.5
Crude protein	35.85
Crude lipid	5.6
Ash	5.64
Crude energy (kcal kg^{-1})	3000

[A]Vitamin mix contained (mg 100 g^{-1} of diet): thiamine HNO3, 5; riboflavin, 5; vitamin A, 2500 IU; vitamin E, 40; vitamin D3, 2400 IU (Roche Taishan (Shanghai) Vitamin Products Ltd., Shanghai, P.R. China); menadione, 4 (Zhejiang Brother chemical Company Ltd., Zhejiang Province, P.R. China); pyridoxine HCl, 4 (Hubei Xian ning Second Pharmaceutical Factory, Xian ning, Hubei Province, P.R. China); cyanocobalamin, 0.01 (Junchi Biological Technology Co., Ltd., Tianjing, P.R. China); biotin, 0.6 (Sumitomo chemical Co., Ltd., Osaka Japan); calcium pantothenate, 10 (Dahchi Pharmaceutical Co., Ltd., Tokyo, Japan); folic acid, 1.5 (Jinan Xinfa Pharmaceutical Co., Ltd., Jinan, Shandong Province, P.R. China); niacin, 20 (Lonza Guangzhou Ltd., Co., Guangzhou, Guangdong Province, P.R. China); inositol, 200 (Shanghai Yiran Industrial Limited Company, Shanghai, P.R. China); and cellulose was used as a carrier.
[B]Mineral mix: (g 100 g^{-1} diet): calcium biphosphate, 0.98; calcium lactate, 3.79; sodium chloride, 0.26; potassium sulfate, 1.31; potassium chloride, 0.53; ferrous sulfate, 0.09; ferric citrate, 0.31; magnesium sulfate, 0.35; zinc sulfate, 0.004; manganese sulfate, 0.003; cupric sulfate, 0.002; cobalt chloride, 0.003; potassium iodide, 0.0002; and cellulose 4.2. All minerals were supplied by Guangzhou Chemical Reagent Factory, except that calcium Lactate was supplied by Yinchuan Jintaiyang Calcium lactate Co. Ltd., Yinchuan, Ningxia Province, P.R. China.

arranged in two rows with nine tanks each and were connected as a closed recirculating system containing freshwater in Laboratory of Fish Nutrition, Sun Yat-sen university (Guangzhou, P.R. China). The fish were acclimated to experimental condition and diet for 2 weeks. During acclimating period, fish were fed experimental diet about 1% body weight per day (BW d^{-1}).

When the experiment began, all the fish in tanks were pooled together. Five hundred and fourty health fish with similar body weight were selected from them and distributed randomly into the 18-tank system with 30 fish per tank. The fish were weighed and the differences of total weight among tanks were less than 5%. The initial weight of fish is 3.08 ± 0.03 g (mean $\pm$ SD). Natural light cycle was used in whole experimental period.

Six feeding rates were used in this study (1.0, 1.5, 2.0, 2.5, 3.0, 3.5% BW d^{-1}) with three replicates for each treatment. Fish were fed four times per day (9:00 AM, 12:00 AM, 3:00 PM, 6:00 PM) by hand. Fish were weighed once every 2 weeks and the daily rations were adjusted accordingly. The waste diet and feces were siphoned out from every tank every morning before feeding. During the last 2 weeks, feces from each tank were collected daily. Feces from each tank were pooled and dried at 105 °C for 12 h, and then kept at −20 °C for future analysis. The experiment lasted for 56 days. During the experimental period, the water temperature, dissolved oxygen, pH and ammonia were 24.97 ± 2.23 °C, 7.09 ± 0.24 mg l^{-1}, 7.29 ± 0.03 and 0.13 ± 0.04 mg l^{-1}.

Sample collection and chemical analysis

After the final weighing and were fasted for 24 h, three fish were randomly captured from each tank for whole body chemical analysis. Another five fish were randomly captured and killed by immediate spinal destroying. The body weight, body length, liver weight and mesenteric fat were measured, respectively. Back muscle was dissected without skin. Muscle and liver were stored at −20 °C until analysis. The moisture, protein, lipid and ash of diets and samples were analyzed by dried at 105 °C for 24 h, the Kjeldhal method with Tecator Kjelte (1030-Auto-analyzer, Tecator AB, Höganäs, Sweden), Soxhlet Extraction with Tecator Soxtem (HT6, Tecator AB, Höganäs, Sweden) and combustion at 550 °C for 16 h, respectively. The Y_2O_3 concentration of diets and feces were determined by inductively-coupled plasma atomic spectrometry (model: IRIS Advantage (HR), Thermo Jarrel Ash Corporation, Boston, USA) after 0.15 mg of sample was transferred to a dry 100 ml Kjeldhal flask and 10 ml of concentrated nitric acid was added. The flask was heated over an electric heater to about 350 °C to allow the sample to be digested until no brown smoke was coming out. The flask was cooled, 1 ml of perchloric acid added, and reheated until white precipitate occurred. Cool the flask to room temperature and transfer solution to a 25 ml volumetric flask, and the solution was diluted to fixed volume with distilled water for analysis.

Statistical analysis

The data were expressed as mean ± SD. The data of different treatments were subjected to one-way ANOVA. When significant ($p < 0.05$) difference was found, a Duncan's multiple range test was used to estimate the difference. Optimal feeding rate was determined using specific growth rate by the broken line model (Robbins et al. 1979).

Results

Only three fish died during the experiment and it was unrelated to treatments. Two weeks after experiment began, fish fed on 3.5% BW d^{-1} couldn't finish all the diet and some symptom of anorexia appeared. It was obvious that the 3.5% BW d^{-1} feeding rate was too high for the fish, and 4 weeks later, this treatment was cut-off.

The influence of feeding rate on weight gain (WG), specific growth rate (SGR), feed efficiency (FE), protein efficiency ratio (PER), apparent digestibility (ADC) and retention of protein (PR) were shown in Table 2. All these indexes were affected significantly ($p < 0.05$) by feeding rate. Both WG and SGR increased significantly ($p < 0.05$) with the increasing feeding rate from 1 to 2%, and then decreased as the feeding rate increased from 2 to 3%. No significant difference was found on growth rate of fish fed 2.5 and 3% BW d^{-1}. Broken line analysis of SGR indicated that the optimum feeding rate of juvenile grass carp is 1.97% BW d^{-1} (Figure 1). Feed efficiency and protein efficiency ratio decreased significantly ($p < 0.05$) as the feeding rate increased. Similarly, lower ADC and PR values were found in fish fed up to 2.5% BW d^{-1}.

The slaughter variables at the end of experiment were show in Table 3. The feeding rate did not affect hepatosomatic index (HSI) significantly in this study. The condition factor and viscera index, however, significantly differed between fish fed 1 and 3% BW d^{-1}. The mesenteric fat index (MFI) increased significantly as the feeding rate increased, but no differences were found among treatments of 2, 2.5 and 3% BW d^{-1}.

The chemical compositions of whole body, muscle and liver were shown in Table 4. Protein and ash contents of the whole body were not affected by feeding rate ($p > 0.05$). Moisture in whole body decreased significantly ($p < 0.05$) with the increasing feeding rate, and conversely, lipid increased significantly ($p < 0.05$) with the increasing feeding rate. Moisture content of muscle from fish fed 1% feeding rate was highest in all treatments and there had no significant differences among the other five treatments. Protein content of fish fed 1% feeding rate was lowest in all treatments and there was no significant differences among the other treatments. The lipid content of muscle was lowest in 1% and highest in 3% feeding rate treatment, and no significant differences were found among 1.5, 2 and 2.5% feeding rate treatments. Liver lipid content increased with the increase of feeding rates, and especially when feeding rate exceeded 2%, liver lipid increased sharply and was even about three times more than lower feeding rate (1 and 1.5% BW d^{-1}).

Discussion

Our previous study (Du and Liu, unpublished data) found that the maximum daily diet consumption was 3.64% BW d^{-1} in short term (22 days). However, in present study, fish could not eat up the diet and the symptom of anorexia

Table 2. The growth rate, feed efficiency, apparent digestibility coefficient of diet and protein retention of juvenile grass carp fed the purified diet for 8 weeks.

	Feeding rate (%BW d^{-1})				
	1	1.5	2	2.5	3
WG[A]	46.25 ± 2.65^{a}	70.61 ± 5.72^{b}	92.73 ± 2.37^{d}	83.95 ± 8.78^{c}	80.21 ± 9.19^{bc}
SGR[B]	0.67 ± 0.03^{a}	0.94 ± 0.06^{b}	1.15 ± 0.02^{c}	1.07 ± 0.08^{c}	1.03 ± 0.09^{bc}
FE[C]	0.78 ± 0.04^{d}	0.74 ± 0.04^{cd}	0.69 ± 0.02^{c}	0.48 ± 0.04^{b}	0.37 ± 0.03^{a}
PER[D]	2.41 ± 0.12^{d}	2.28 ± 0.12^{cd}	2.12 ± 0.06^{c}	1.47 ± 0.13^{b}	1.14 ± 0.10^{a}
ADC[E]	74.06 ± 0.89^{bc}	74.18 ± 0.14^{bc}	75.48 ± 0.55^{c}	72.89 ± 0.84^{b}	71.36 ± 1.17^{a}
PR[F]	30.52 ± 4.35^{b}	32.68 ± 1.92^{b}	31.40 ± 1.41^{b}	21.61 ± 2.13^{a}	16.70 ± 2.25^{a}

The 3.5% BW d^{-1} feeding rate was too high for the fish because 2 weeks after experiment was begun, fish couldn't eat up the diet and 4 weeks later, this treatment was cut-off.

Values were presented as means ± SD. Average initial body weight of the juvenile grass carp was 3.08 ± 0.03 g.

In the same row, values that are not followed by the same letter are significantly different ($p < 0.05$).

[A]Weight gain (WG) = (final weight − initial weight) × 100/(initial weight).

[B]Specific growth rate (SGR) = (ln final weight − ln initial weight) × 100/days.

[C]Feed efficiency (FE) = (Fish weight gain)/(feed intake).

[D]Protein efficiency ratio (PER) = (Fish weight gain)/(protein intake).

[E]Apparent digestibility coefficient (ADC) = (1−Y_2O_3 concentrate in diet/Y_2O_3 concentrate in feces)×100.

[F]Protein retention (PR) = (Fish protein gain) × 100/(protein intake).

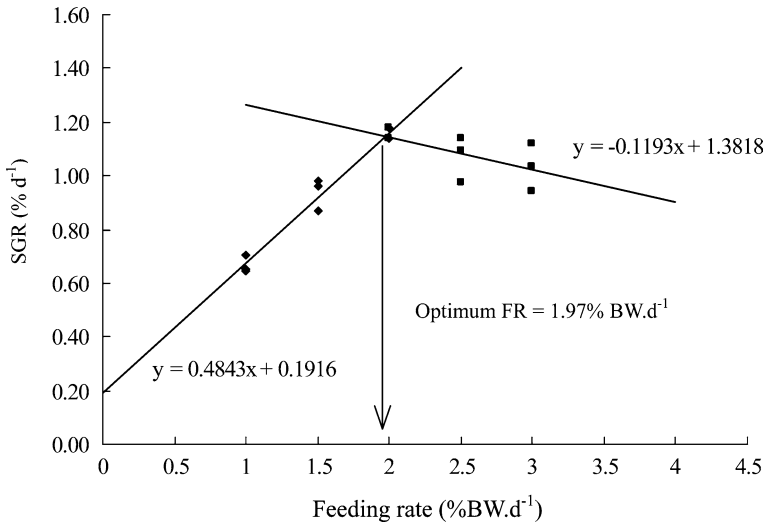

Figure 1. Optimum feeding rate (FR) based on specific growth rate (SGR) as determined by the broken line model.

Table 3. Slaughter variables of juvenile grass carp fed the purified diet for 8 weeks.

	Feeding rate (%BW d^{-1})				
	1	1.5	2	2.5	3
CF[A]	2.02 ± 0.22^{b}	1.90 ± 0.10^{a}	1.96 ± 0.11^{ab}	1.92 ± 0.14^{ab}	1.85 ± 0.13^{a}
VSI[B]	10.59 ± 0.83^{a}	11.14 ± 0.89^{ab}	11.57 ± 0.86^{b}	11.16 ± 0.96^{ab}	11.38 ± 0.78^{b}
HSI[C]	2.57 ± 0.44^{a}	2.78 ± 0.50^{a}	2.86 ± 0.48^{a}	2.92 ± 0.28^{a}	3.00 ± 0.47^{a}
MFI[D]	1.66 ± 0.35^{a}	2.23 ± 0.65^{b}	2.61 ± 0.62^{bc}	2.72 ± 0.62^{c}	2.86 ± 0.75^{c}

Values were presented as means ± SD. In the same row, values that are not followed by the same letter are significantly different ($p < 0.05$).
[A]Condition factor (CF) = Fish weight (g) × 100/body length (cm).
[B]Viscera Index (VSI) = Viscera weight × 100/fish weight.
[C]Hepatosomatic index (HSI) = Liver weight × 100/fish weight.
[D]Mesenteric fat index (MFI) = Mesenteric fat weight × 100/fish weight.

Table 4. Chemical composition of whole body, muscle and liver in juvenile grass carp the purified diet for 8 weeks.

	Feeding rate (%BW d^{-1})				
	1	1.5	2	2.5	3
Whole body					
Moisture (%)	80.13 ± 1.40^{c}	76.78 ± 0.74^{b}	76.21 ± 0.31^{ab}	75.44 ± 0.89^{ab}	74.76 ± 0.47^{a}
Protein (%)	11.88 ± 0.72^{a}	12.67 ± 0.43^{a}	13.11 ± 0.38^{a}	12.97 ± 0.21^{a}	12.89 ± 0.52^{a}
Lipid (%)	3.55 ± 0.72^{a}	6.09 ± 0.21^{b}	6.39 ± 0.73^{b}	7.38 ± 0.91^{bc}	8.29 ± 0.66^{c}
Ash (%)	2.94 ± 0.09^{a}	2.82 ± 0.03^{a}	2.73 ± 0.13^{a}	2.71 ± 0.02^{a}	2.69 ± 0.03^{a}
Muscle					
Moisture (%)	80.32 ± 0.22^{b}	79.79 ± 0.23^{a}	79.53 ± 0.39^{a}	79.90 ± 0.22^{ab}	79.91 ± 0.20^{ab}
Protein (%)	16.62 ± 0.14^{a}	17.13 ± 0.25^{b}	17.34 ± 0.29^{b}	17.24 ± 0.19^{b}	17.21 ± 0.20^{b}
Lipid (%)	0.89 ± 0.06^{a}	1.08 ± 0.11^{b}	1.06 ± 0.01^{b}	1.12 ± 0.06^{b}	1.28 ± 0.16^{c}
Liver					
Moisture (%)	70.20 ± 0.63^{b}	67.96 ± 0.53^{b}	62.44 ± 1.79^{a}	60.07 ± 1.77^{a}	60.43 ± 2.10^{a}
Lipid (%)	3.54 ± 0.15^{a}	5.71 ± 0.74^{a}	13.46 ± 1.57^{b}	17.08 ± 1.95^{c}	15.55 ± 2.08^{bc}

Values were presented as means ± SD. In the same row, values that are not followed by the same letter are significantly different ($p < 0.05$).
Initial body proximate composition (%) were: moisture 80.38 ± 0.76, crude protein 11.51 ± 0.29, crude lipid 4.25 ± 0.46, ash 2.90 ± 0.20.

appeared after they were fed 3.5% BW d^{-1} for 2 weeks, at a similar water temperature used in the previous study. The result agrees with the suggestion by Storebakken (1986) that short-term feed intake study has limitation in assessing an optimum ration level. It should point out that the water temperature in the whole study was ranged relative widely, and it mainly because of the decrease of temperature in the last few weeks in November. But it was the real condition in grass carp aquaculture from October to November in south China. So the results of this study are still helpful for practical aquaculture during this period.

In sturgeon, the percent body weight increase (% BWI) increased significantly ($p < 0.05$) with the increasing of feeding rate from 0.5 to 2% and there were no significant differences in feeding rates from 2 to 4% (Hung and Lutes 1987). The curve showed obvious breakpoints at feeding rate 2% BW d^{-1}. At same time, the food gain rate (FGR) also formed a typical U-shaped curve and the breakpoint was also at 2% BW d^{-1}. Based on the maximum %BWI and minimum FGR, Hung and Lutes (1987) suggested that the optimum feeding rate of hatchery-produced juvenile white sturgeon (30–100 g) held at 20 °C was 2.0% BW d^{-1}. In the current study, WG and SGR increased with the feeding rate increasing from 1 to 2% and their highest values were both at 2% BW d^{-1} among all treatments. The results of the increasing growth with increasing submaximal rations have been repeated by Huisman (1976), Staples and Nomura (1976), Wurtsbaugh and Davis (1977a, b), Reinitz (1983a) and Storebakken and Austreng (1987b). When feeding rate exceeds optimum level, no increased growth and feed efficiency are achieved (Hung and Lutes 1987; Storebakken and Austreng 1987a; Hung et al. 1989). In present study, the results are similar with the above reports. As for feed efficiency, it always increased with the increasing of feeding rate when the feeding rate was under the maintenance level of the fish, and however, decreased as feeding rate increased when feeding rate was above the maintenance level of the fish (Storbakken and Austreng 1987a, b; Hung et al., 1989). In present study, feed efficiency decreased linearly with the increasing feeding rate from 1 to 3% BW d^{-1}. It possibly can be explained that the minimum feeding rate in this study, 1% BW d^{-1}, exceeded the maintenance ration level of juvenile grass carp, because even in 1% BW d^{-1} feeding rate group, there still existed weight gain (46.25%). Similarly, the trend of PER in this study is like FE. This result is same as the report of Ballestrazzi et al. (1998).

The effect of feeding rate or ration level on apparent digestibility can be concluded into three types, positive effect (Davies 1963; Cui and Wootton 1988; Xie and Suns 1993), negative effect (Elliott 1976; Henken et al. 1985) and no significant effect (Kelso 1972). Davies (1963) believed that there exists an optimum ration level for apparent digestibility in fish, and by this level, the ratio of utilizable energy is highest. In present study, the ADC in feeding rates 1, 1.5 and 2% had no significant differences ($p > 0.05$) and the highest was at 2%. When feeding rate exceeded 2%, ADC decreased quickly. This result agrees with the suggestion of Davies (1963).

Except 1% BW d^{-1} feeding rate, the protein retention decreased with increasing of feeding rate. Thinking about the constant protein content in fish, unaffected by feeding rate and the decreasing protein retention, it suggests the protein utilization decreased, and however, the nitrogen loss increased with the increasing feeding rate. It agrees with the results of Ballestrazzi et al. (1998), Storebakken and Austreng (1987b).

The highest CF was observed at feeding rate 1% BW d^{-1} and the lowest value was at 3% BW d^{-1}. It's abnormal and contradicts the results of Reinitz (1983b), Storebakken and Austreng (1987b), Hung and Lutes (1987). The explanation for this is still unclear exactly. Except 1% BW d^{-1}, the viscera

percentage in other four treatments seemed unaffected by feeding rate. It is explained that at 1% BW d^{-1} feeding rate, fish must use the deposit energy in viscera to fit its energy requirement and this leaded to the decrease of viscera weight. Liver and mesenteric fat tissue are both important energy deposit place in fish. There was the obvious trend that both liver and mesenteric fat ratio increased with the increasing feeding rate and the increasing of mesenteric fat ratio is significant ($p < 0.05$). This result agrees with Storebakken and Austreng (1987b) and Ballestrazzi et al. (1998). It is well documented that the amount of nutrients and their balance influence the liver size (Phillips et al. 1966; Lee and Putnam 1973) and fish can transfer excessive energy to deposit in viscera. One possible reason for the increased liver and mesenteric fat ratio in fish may also be the acclimation to increasing food intake.

The body compositions of fish were affected by the feeding rate. Protein and ash remained at a relatively stable level in whole body. Body moisture decreased with increasing feeding rate, but body lipid increased with increasing feeding rate. In muscle and liver, the similar trends of compositions were found. It agrees with the results of Hung and Lutes (1987), Storebakken and Austreng (1987a) and Hung et al. (1993). Reinitz (1983a) believed previous nutritional history (diet and feeding rate) and fish size (individual weight) were the primary determinations of body composition of non-starving young rainbow trout. Storebakken and Austreng (1987b) believed the variations in the contents of fat and dry matter were mainly a direct result of ration level. Shimeno et al. (1997) found activities of pentose phosphate cycle dehydrogenases, glucose-6-phosphate dehydrogenase (G6PDH) and phosphogluconate dehydrogenase (PGDH), were most sensitive to feeding rate, and these activities together with the body fat content markedly increased as feeding rate increased. In this study, body protein content wasn't affected by feeding rate. It means even at lowest feeding rate, 1% BW d^{-1}, the supply of dietary protein can make fish maintain body protein level. But in muscle, protein content at 1% feeding rate was lower than others. It suggests that at 1% BW d^{-1}, the supply of dietary protein is only slightly above the maintenance level.

Optimum feeding rate expressed as percent body weight have been shown to decrease with increased fish size and decreased water temperature in some species of fish (Brett 1979). Hung and Lutes (1987) believed the optimum feeding rate of white sturgeon was 2% BW d^{-1} at 20 °C, based on the maximum % BWI and minimum FCR. In present study, the optimum feeding rate of juvenile grass carp is defined as 1.97% BW d^{-1}, according to the broken line model based on specific growth rate.

References

Ballestrazzi B., Lanari D. and D'Agaro E. 1998. Performance, nutrient retention efficiency, total ammonia and reactive phosphorus excretion of growing European sea-bass (*Dicntrarchus labrax*, L.) as affected by diet processing and feeding level. Aquaculture 161: 55–65.

Brett J.R. 1979. Environmental factors and growth. In: Hoar W.S., Randall D.J. and Brett J.R. (eds) Fish Physiology. Bioenergetics and Growth, Academic Press, New York, NY, pp. 599–675.
Carter C.G. and Brafield A.R. 1991. The bioenergetics of grass carp *Ctenopharyngodon idella* (Val.): energy allocation at different planes of nutrition. J. Fish Biol. 39: 873–887.
Carter C.G. and Brafield A.R. 1992a. The bioenergetics of grass carp *Ctenopharyngodon idella* (Val.): the influence of body weight, ration and dietary composition on nitrogenous excretion. J. Fish Biol. 41: 533–543.
Carter C.G. and Brafield A.R. 1992b. The relationship between specific dynamic action and growth in grass carp *Ctenopharyngodon idella* (Val.). J. Fish Biol. 41: 895–907.
Cui Y. and Wootton R.J. 1988. Bioenergetics of growth of a cyprinid, *Phoxinus phoxinus*: the effect of ration, temperature and body size on food consumption, faecal production and nitrogenous excretion. J. Fish Biol. 33: 431–443.
Cui Y., Liu X.F., Wang S.M. and Chen S.L. 1992. Growth and energy budget in young grass carp *Ctenopharyngodon idella* Val. fed plant and animal diets. J. Fish Biol. 41: 231–238.
Dabrowski K. 1977. Protein requirement of grass carp fry (*Ctenopharyngodon idella* Val.). Aquaculture 12: 63–73.
Dabrowski K. and Kozak B. 1979. The use of fish meal and soybean meal as a protein source in the diet of grass carp fry. Aquaculture 18: 107–114.
Davies P.M.C. 1963. Food input and energy extraction efficiency in *Carassius auratus*. Nature, (Lond.) 198: 707.
Elliott J.M. 1976. Energy losses in the waste products of brown trout (*Salmo trutta* L.). J. Anim. Ecol. 45: 561–580.
Fontaine P., Gardeur J.N., Kestemont P. and Georges A. 1997. Influence of feeding level on growth, intraspecific weight variability and sexual growth dimorphism of Eurasian perch *Perca fluviatilis* L. reared in a recirculation system. Aquaculture 157: 1–9.
Garling D.L. and Wilson R.P. Jr. 1977. Effect of dietary carbohydrate to lipid ratio on growth and body composition of fingerling channel catfish. Prog. Fish Cult. 39: 43–47.
Henken A.M., Kleingeld D.W. and Tijssen P.A.T. 1985. The effect of feeding level on apparent digestibility of dietary dry matter, crude protein and gross energy in the African catfish *Clarias gariepinus* (Burchell, 1822). Aquaculture 51: 1–11.
Huisman E.A. 1976. Food conversion efficiencies at maintenance and production levels for carp, *Cyprinus carpio* L., and rainbow trout *Salmo gairdneri* Richardson. Aquaculture 9: 259–276.
Hung S.S.O. and Lutes P.B. 1987. Optimum feeding rate of hatchery-produced juvenile white sturgeon (*Acipenser transmontanus*): at 20 °C. Aquaculture 65: 307–317.
Hung S.S.O., Lutes P.B., Conte F.S. and Storebakken T. 1989. Growth and feed efficiency of whit sturgeon (*Acipenser transmontanus*) sub-yearling at different feeding rates. Aquaculture 80: 147–153.
Hung S.S.O., Lutes P.B., Shqueir A.A. and Conte F.S. 1993. Effect of feeding rate and water temperature on growth of juvenile white sturgeon (*Acipenser transmontanus*). Aquaculture 115: 297–303.
Ishiwata N. 1968. Ecological studies on the feeding of fishes. Satiation curve. Bull. Jpn. Soc. Sci. Fish. 34: 691–693.
Jobling M. 1986. Gastrointestinal overload – a problem with formulated feed? Aquaculture 51: 257–263.
Kelso J.R.M. 1972. Conversion, maintenance, and assimilation for walleye *Stizostedion vitreum*, as affected by size, diet, and temperature. J. Fish. Res. Board Can. 29: 1181–1192.
Lee D.J. and Putnam G.B. 1973. The response of rainbow trout to varying protein/energy ratio in a test diet. J. Nutr. 103: 916–922.
Lin D., Mao Y.Q. and Liao X.H. 1989. Improvement of meat quality of grass carp (*Ctenopharyngodon idellus*). Fish Nutrition Research in Asia. Proceeding of the Third Asian Fish Nutrition Network Meeting, pp. 148–152.
Lin D. 1991. Grass carp, *Ctenopharyngodon idella*. In: Wilson R.P. (ed) Handbook of Nutrient Requirement of Finfish, CRC Press, Boca Raton, FL, pp. 89–96.

Phillips A.M., Livingston D.L. and Poston H.A. 1966. The effect of changes in protein quality, calorie sources, and calorie levels upon the growth and chemical composition of brook trout. Fish. Res. Bull. (New Zealand) 29: 6–14.

Reinitz G. 1983a. Relative effect of age, diet, and feeding rate on the body composition of young rainbow trout (*Salmo gairdneri*). Aquaculture 35: 19–27.

Reinitz G. 1983b. Influence of diet and feeding rate on the performance and production costs of rainbow trout. Trans. Am. Fish. Soc. 112: 830–833.

Robbins K.R., Norton H.W. and Baker D.H. 1979. Estimation of nutrient requirements from growth data. J. Nutr. 109: 1710–1714.

Shimeno S., Shikata T., Hosokawa H., Masumoto T. and Kheyyali D. 1997. Metabolic response to feeding rate in common carp, *Cyprinus carpio*. Aquaculture 151: 371–377.

Staples D.J. and Nomura M. 1976. Influence of body size and food ration on the energy budget of rainbow trout, *Salmo gairdneri*, Richardson. J. Fish Biol. 9: 29–43.

Storebakken T. 1986. Reduction of feed-loss from salmonids by optimizing the rations and using dietary binders. Dr. Scient. Thesis, Agric. Univ. Norway, 153 pp.

Storebakken T. and Austreng E. 1987a. Ration level for salmonids Growth, survival, body composition, and feed conversion in Atlantic salmon fry and fingerlings. Aquaculture 60: 189–206.

Storebakken T. and Austreng E. 1987b. Ration level for salmonids. Growth, feed intake, protein digestibility, body composition, and feed conversion in rainbow trout weighing 0.5–1.0 kg. Aquaculture 60: 207–221.

Tacon A.G.J. and Cowey B.C. 1985. Protein and amino acid requirements. In: Tytler P. and Calow P. (eds) Fish Energtics: New Perspectives, The Johns Hopkins University Press, Baltimore, MD, pp. 155–183.

Talbot C. 1985. Laboratory methods in fish feeding and nutritional studies. In: Tytler P. and Calow P. (eds) Fish Energtics: New Perspectives, The Johns Hopkins University Press, Baltimore, MD, pp. 125–154.

Xie X. and Sun R. 1993. The faecal production and digestibility of the southern catfish (*Silurus meridionalis* Chen), in relation to ration level, body weight an temperature. Oceanol. Limnol. Sin. (in China) 24: 627–633.

Vahl O. 1979. An hypothesis on the control of food intake in fish. Aquaculture 17: 221–229.

Wurtsbaugh W.A. and Davis G.E. 1977a. Effects of temperature and ration level on the growth and food conversion efficiency of *Salmo gairdneri*, Richardson. J. Fish Biol. 11: 87–98.

Wurtsbaugh W.A. and Davis G.E. 1977b. Effects of fish size and ration level on the growth and food conversion efficiency of rainbow trout, *Salmo gairdneri*, Richardson. J. Fish Biol. 11: 99–104.