Effects of Different Feeding Rate on the growth, plasma biochemistry, and Body composition of common carp (Cyprinus carpio Linnaeus 1758) in a recirculating system

Firas M. AlKhafaji

Department of Animal Production, College of Agriculture, Al-Qasim Green University, Hilla, Babylon, Iraq

* Corresponding author: Firas M. AlKhafaji

ORCID : 0000-0002-1223-6366

Email address: alkhafajifiras@agre.uoqsim.edu.iq

Abstract

Feeding rate optimization is an important factor affecting growth performance and feed efficiency in aquaculture. The effects of feeding rates (2.5–8.5% body weight day) on growth, feed utilization, body composition, and physiological responses of juvenile Cyprinus carpio were evaluated. The results showed consistently high survival (>95%) with no significant differences among treatments. The growth performance improved with feeding rate, with the highest weight gain at an 8.5% feeding rate and the optimum specific growth rate (SGR) at a 5.5% feeding rate. The feed utilization efficiency was reflected by the lower feeding rates (2.5–4.5%), which resulted in better feed conversion ratio (FCR) and protein efficiency ratio (PER). Higher feeding rates, on the other hand, led to higher lipid deposition and hepatosomatic and viscerosomatic indices. At the lowest feeding rate, biochemical analysis indicated high levels of ALT and AST and low electrolyte balance, indicating physiological stress under restricted feeding conditions. As a conclusion, a moderate feeding rate (around 5.5% BW day) is the most optimal feeding rate for growth performance, feed efficiency, and physiological stability of juvenile common carp.

Keywords: Feeding rates, common carp, RAS, body composition, growth performers, aquaculture nutrition.

Introduction

Aquaculture's rapid expansion has raised demand for environmentally friendly production methods that maximize feed use (78). The biggest operating expense in fish farming is feed, which is also a significant source of nitrogenous waste. When feed is supplied in excess, it deteriorates water quality and is economically inefficient (32). Therefore, Improving feed management without sacrificing resilience to stress, growth, or health is one of the primary goals of modern aquaculture systems(69).

In recirculating aquaculture systems, feeding rate is a crucial management factor that can directly affect fish welfare and nutrient availability (90).

Feed management is one of the most important factors influencing the feasibility and productivity of any industrial aquaculture operation since feed costs make up the majority of aquaculture production costs. The effects of changing the feeding rate on the growth performance of White Sturgeon Acipensertransmontanus have been documented in a number of research (23), European Bass (30), and Nile Tilapia *Oreochromisniloticus* (10). As a result, determining the ideal feeding rate is essential for fish culture feeding management strategies (29). According to (88) and (20), diet costs can account for 30–70% of an aquaculture enterprise's overall production costs, with the percentage rising as the operation becomes more intensified. Fish growth performance and vestige are negatively impacted by both overfeeding and underfeeding, which also compromise the success of an aquaculture endeavor. A number of variables, including Fish species, fish size, feeding frequency, feed nutrient content, and water temperature, have been found to influence optimal feeding rates in a variety of fish species and sizes (6; 47; 48; 87; 55; 37; 38; and 39). The optimal feeding rates are determined by a number of elements, including fish growth performance, feed utilization, proximate composition of the entire body, serological traits, and histological changes (16; 42; 65) .

One of the most significant freshwater species that is frequently raised in a variety of aquaculture systems is the common carp (Cyprinus carpio), including recirculating aquaculture systems (RAS). In recent years, intensive production of this species has increasingly relied on controlled artificial environments due to their high productivity and efficient resource utilization. However, because such systems operate under fully artificial conditions, successful culture depends on a comprehensive understanding of optimal rearing parameters, including water quality, feeding strategies, stocking density, and system management. These factors are essential for designing efficient, sustainable, and economically viable aquaculture operations (53; 87; 28; 25).

Currently, no research has been carried out on the effect of feeding rates on juveniles of common carp with this rates in RAS. Thus, the objective of this study was to determine the effects of different feeding rates of 2.5 %, 4.5 %, 6.5 % or 8.5 % body weight per a day to *Cyprinus carpio* early juveniles over 100 days on the proximate makeup of the entire body, muscle cholesterol, plasma biochemistry, growth performance, and feeding efficiency.

Materials and Methods

Source of experimental animals and set-up

After being bought from Al-Hilla for a fish hatchery, 30-day-old common carp fingerlings were sent to the Al-Mussaib region of Iraq. They were given floating pellets with a crude protein content of 32% and a fat content of 8% after being acclimated for 14 days in a fiberglass tank. The GBL-800YZ recirculating system provided the freshwater for this tank, that was manufactured and acquired from Goldbill (Fujian, China) Aquaculture Technology Co, Ltd. A trickling biofilter, two foam fractionators, and a mechanical belt filter (80 × 200 × 100 cm), a blower/gas exchanger, and UV sterilization were all included in this 40-ton system.

A total of 600 fingerlings with starting lengths and weights of 6.70 ± 0.09 g and 6.85 ± 0.14 cm, respectively, were randomly distributed into twelve fiberglasstanks (1×1×1 m^3) which yielded a stocking density of 50 juveniles/m^3. The water supplied from each tank was from a recirculating system, This had a foam fractionator, biofilter, and mechanical sand filter. Every four hours, the flow rate was high enough to replenish the whole tank volume while each tank was gently aerated. A partial water exchange (≈40%) was carried out every 14 days.

After an initial 14 days acclimation period, 4 different feeding rate treatments were randomnly assigned in triplicate that included 2.5 %, 4.5 %, 6.5 %, or 8.5 % body weight per a day, respictivly, for 100 days. Fish were given their daily rates divided into three equal meals per day at 08:00, 13:00 and 18:00 hours (5), from a Yinsheng T8800 automatic feeder that was inspected at least twice daily.To accomplish this, a sample of the fish (n = 10) were weighed every 14 days, and the amount of food provided was adjusted accordingly. The feeds were floating contains 32% crude protein and 8% crude fat.

A multi-digital probe from each tank was used to measure the temperature, pH, and dissolved oxygen (DO) twice a day. A commercial test kit (API® freshwater master test kit, Chalfont, USA) was used once a week to measure the total ammonia-nitrogen and nitrite-nitrogen before the water reached the biofilter and before water exchanges. Ammonia-N and nitrite-N were 0.3 ± 0.2 and 0.2 ± 0.1 mg l-1, respectively, and the mean DO was 4.9 ± 0.4 mg l-1. In the meantime, the pH was 7.4 ± 3 and the temperature was 27 ± 1ºC.

On the day the trial concluded, no food was served. The Animal Ethics Committee states that after 100 days, Every fish was put to sleep with an excess of clove oil (around 150 ppm). Once the fish stopped responding, the final size and weights were individually measured from all fish to calculate the specific growth rates for length and weight as well as weight gain. The condition factor (K) was calculated as K = W/L3 × 100, where L is the body length (in centimeters) and W is the weight of the body (in grams). The CV was computed by dividing the length SD by the average length of the fish in each treatment. A blood sample was obtained, each fish was measured and weighed, and the animal was dissected for additional analysis.

Plasma biochemistry

In order to produce triplicate samples/treatment, Syringes were used to draw blood samples (at least 1.5 ml) from ten fish in each replication that had previously been coated with a saturated EDTA solution. Owing to the fish's comparatively tiny size, the samples were combined to guarantee the smallest volume required for examination. The plasma was extracted, put in a fresh vial, and kept at -20°C after the blood was centrifuged for 10 minutes at 5,000 rpm. Within two days of sampling, An automated Hitachi 902 analyzer was used to measure the amounts of plasma cholesterol, glucose, triglycerides, phosphate, sodium, potassium, calcium, chloride, aspartate aminotransferase (AST), and alanine aminotransferase (ALT).

Body indices

After taking the blood samples, a total of 10 fish were dissected for the viscera and liver to calculate the hepatosomatic index (HSI) and viscerosomatic index (VSI), respectively. The viscera and liver were divided by the final body weight and then multiplied by 100 to determine the VSI and HSI, respectively.

Each treatment's surviving fish were kept at -20°C after their final weights and sizes were determined. For cholesterol, muscle lipid peroxidation, or whole-body proximate composition, In each treatment, half of the fish were mixed.

Muscle cholesterol, lipid peroxidation, and proximate composition of the entire bodyEach treatment consisted of fifty fish, which were split evenly to evaluate muscle cholesterol, lipid peroxidation, or proximate composition. The entire body's moisture, crude protein, fat, and ash contents were determined using the standard (7) procedures. Initially, the fish samples were processed so that only the muscle could be used to measure lipid peroxidation or cholesterol. (72) state that in order to determine the amount of cholesterol in the muscle (both red and white), the heads and fins were removed first, then the skin and bones. To put In short, 3 ml of 95% ethanol was added after 1 g of the fish muscle was carefully chopped with a knife and 2 ml of 50% KOH were added. After ten minutes of digestion at 60°C and cooling to room temperature, five milliliters of hexane were added. This mixture was vortexed, followed by the addition of three milliliters of distilled water, phase separation, removal of the upper hexane layer (1.5 milliliters), evaporation under nitrogen gas, and resuspension using four milliliters of o-phthalaldehyde reagent. Six milliliters of pure water were then added after two milliliters of strong sulfuric acid. A reagent blank was used to measure the absorbance at 550 nm, and the results were stated in µg ml-1.

Thiobarbituric acid-reactive substances (TBARS) were used to detect lipid peroxidation in accordance with (51) approach, which (52) modified. Ultraturrax was used to homogenize meat samples (one g) in 4 mL of 0.15 M KCl + 0.1 mM BHT at a medium speed for a minute. Following homogenization, 200 µL of the material was combined with TBRAS solution and heated for 60 minutes at 95 °C in a water bath until a pink hue developed. Following chilling, the extracts were mixed with one milliliter of distilled water and three milliliters of n-butyl alcohol. For ten minutes, the mixtures were centrifuged at 5000 rpm. Using a spectrophotometer (Secomam, Domont, France), the absorbance of the supernatant was measured at 532 NM against a suitable blank. A standard curve of 1, 1, 3, 3-tetraethoxypropane was used to compute the TBARS, which were then represented as mg malondialdehyde Assay (MDA)/kg sample.

Statistical analysis

Each replicate's data was evaluated using a one-way ANOVA, Chi-square analysis was used to examine just survival, and repeated measure MANCOVA was used to examine K. Tukey's post-hoc test was used to determine treatment differences if significant differences ($P<0.05$) were found. The SPSS statistical software version 31.0.2.0 was utilized for all statistical analyses.

Results

Survival, growth and feeding efficiencies

Throughout the trial, survival remained high (95.69–97.02%), and there were no discernible differences ($P>0.05$) across the various feeding rate treatments (Table 1). However, compared to all other treatments, fish fed 8.5% body weight per day gained a lot more weight. In contrast to the other treatments, fish fed 5.5% body weight per day had a considerably greater specified growth rate (SGR) for both length and weight (Table 1). Fish with 2.5% or 4.5% body weight per day had considerably lower feed conversion ratios (FCR) and higher protein efficiency ratios (PER) than fish with 6.5% or 8.5% body weight per day (Table 1).

Body indices and whole-body proximate composition

Table 2 displays the fish's body indices, muscle cholesterol, lipid peroxidation (MDA), and whole-body proximate composition for each feeding treatment. Crude lipid levels were highest in fish given 8.5% body weight daily, and they differed

TABLE 1. Mean (±SE) growth performance, feeding efficiencies and survival (%) of early juvenile Common Carp (Cyprinus carpio) fed at different Rates body weight per a day after 100 days.

Parameters	2.5%	4.5%	6.5%	8.5%
Initial weight (g)	6.67 ± 0.03	6.74 ± 0.12	6.78 ± 0.05	6.63 ± 0.11
Final weight (g)	28.09 ± 1.07^{d}	57.42 ± 0.32^{c}	80.11 ± 0.83^{b}	122.40 ± 0.83^{a}
Initial length (cm)	6.73 ± 0.20	6.89 ± 0.17	6.94 ± 0.05	6.82 ± 0.08
Final length (cm)	11.23 ± 0.26^{d}	13.84 ± 0.09^{c}	15.25 ± 0.13^{b}	17.13 ± 0.11^{a}
SGR weight (% day^{-1}) [1]	1.41 ± 0.03^{d}	2.12 ± 0.02^{c}	2.44 ± 0.01^{b}	2.88 ± 0.02^{a}
SGR length (% day^{-1}) [2]	0.50 ± 0.04^{d}	0.68 ± 0.03^{c}	0.77 ± 0.01^{b}	0.91 ± 0.01^{a}
Weight gain % [3]	288.71± 13.48^{d}	676.75 ± 18.52^{c}	973.58 ±18.88^{b}	1568.70 ± 40.35^{a}
FCR[4]	0.89 ± 0.06^{b}	0.95 ± 0.09^{b}	1.14 ± 0.04^{a}	1.23 ± 0.04^{a}
PER[5]	2.11 ± 0.15^{a}	2.00 ± 0.21^{a}	1.63 ± 0.06^{b}	1.52 ± 0.05^{b}
Survival [6]	96.36 ± 1.15	95.69 ± 1.15	97.02 ± 0.00	96.36 ± 1.15

Different superscripted letters within each row indicate significant differences ($p < 0.05$)

[1] SGR weight (% day^{-1}) = ((LN (final body weight) – LN (initial body weight))/number of days) × 100

[2] SGR length (% day^{-1}) = ((LN (final body length) – LN (initial body length))/number of days) × 100

[3] WG (%) = (final body weight – initial body weight)/initial body weight × 100

[4] FCR = (weight gain/feed intake)

[5] PER = protein efficiency ratio=wet weight gain (g)/total protein intake (g)

[6] Survival (%) = (total remaining fish – initial amount of fish) × 100

TABLE 2.Mean (±SE) whole-body proximate composition (% wet weight), muscle cholesterol (µg ml^{-1}), hepatosomatic index (HSI), viscerosomatic index (VSI) and condition factor (K) of early juvenile Common Carp (Cyprinus carpio) fed at different Rates body weight per a day after 100 days.

Parameters	2.5%	4.5%	6.5%	8.5%
Moisture	57.70 ± 0.99^{a}	56.12 ± 1.36^{b}	54.63 ± 0.50^{c}	53.68 ± 0.31^{c}
Crude protein	17.41 ± 0.76^{a}	16.81 ± 1.42^{a}	15.82 ± 0.37^{ab}	14.69 ± 0.59^{b}
Crude lipid	10.17 ± 0.87^{c}	11.28 ± 1.17^{c}	13.91 ± 1.38^{b}	16.64 ± 1.64^{a}
Crude ash	4.30 ± 0.20^{a}	3.76 ± 0.21^{b}	3.29 ± 0.33^{c}	3.10 ± 0.14^{c}
Cholesterol	0.40 ± 0.03	0.41 ± 0.07	0.36 ± 0.09	0.43 ± 0.05
MDA	0.07 ± 0.01	0.11 ± 0.06	0.12 ± 0.03	0.13 ± 0.02
HSI [1]	1.99 ± 0.09^{bc}	1.79 ± 0.14^{c}	2.28 ± 0.28^{ab}	2.56 ± 0.15^{a}
VSI [2]	10.06 ± 1.70^{c}	10.78 ± 0.32^{bc}	12.52 ±0.53a^{b}	13.05 ± 0.33^{a}
K [3]	1.44 ± 0.06^{c}	1.58 ± 0.03^{b}	1.64 ± 0.04^{b}	1.77 ± 0.04^{a}

Different superscripted letters within each row indicate significant differences ($p < 0.05$)

[1] HSI, hepatosomatic index = [100 × liver weight (g)]/body weight (g).

[2] VSI, viscerosomatic index = [100 × visceral weight (g)]/body weight (g).

[3] K, condition factor = [100 × length ^{3} (cm)]/body weight (g)

considerably from the other treatments. As feed rates increased, muscle cholesterol and MDA rose as well, but there was no discernible difference between the treatments (Table 2). Fish fed 8.5% or 6.5% body weight per day had considerably higher HIS, VSI, and K than fish fed 4.5% or 2.5% body weight per day (Table 2).

Plasma biochemistry

The plasma biochemistry results are shown in Table 3 designate that plasma ALT and AST were significantly higher in fish fed 2.5% body weight per a day compared to those fed 8.5% body weight per a day. Plasma sodium and Chloride levels were considerably lower in fish fed 2.5% body weight per a day compared with 4.5% body weight per a day. In the meantime, there were no discernible variations in plasma levels of potassium, phosphate, triglycerides, glucose, or cholesterol.

TABLE 3.Mean (±SE) plasma biochemistry, enzymes and mineral content of Common Carp (Cyprinus carpio) early juveniles when fed at different Rates body weight per a day after 100 days.

Parameters	2.5%	4.5%	6.5%	8.5%
ALT	20.39 ± 2.88a	10.20 ± 2.51b	9.00 ± 1.00b	12.29 ± 1.15b
AST	333.00±7.21a	225.00±10.14c	242.69±8.38c	262.00±4.58b
Cholesterol	4.55 ± 0.47	5.00 ± 0.75	5.04 ± 1.11	4.26 ± 0.98
Glucose	5.90 ± 1.06	5.94 ± 0.85	6.21 ± 0.87	5.49 ± 0.51
Triglycerides	2.59 ± 0.75	2.42 ± 0.44	3.27 ± 2.17	2.24 ± 0.69
Phosphate	2.84 ± 0.23	3.02 ± 0.61	2.93 ± 0.15	2.73 ± 0.20
Na	122.99 ± 4.04b	141.60 ± 2.64a	125.69 ± 6.02b	130.80 ± 3.05b
K	6.33 ± 0.51	6.53 ± 1.62	7.29 ± 2.69	6.53 ± 1.38
Cl	98.10 ± 3.60c	115.20 ± 2.00a	102.00 ± 2.62bc	104.70 ± 1.52b

Different superscripted letters within each row indicate significant differences ($p < 0.05$)

DISCUSSION

One of the most important variables influencing fish growth is feeding rate. Different rates are needed for each species at the various stages of growth. Growth retardation is typically seen when improper feeding rates are used (54; 61). As a result, determining the proper feeding rates for fish is crucial. Different feeding rates had a substantial impact on the juvenile Common Carp's (Cyprinus carpio) development performance and feed consumption in the current study (2). In other words, according to our study, juvenile Common Carp generally grew faster as feeding rates increased. (22; 9; 80; 36; 91; 2) were comparable to earlier research on other species (5).

In addition, weight gain of juvenile Common Carp was significantly affected by feeding rates, such as Common Carp fed the highest percentage of body weight per day gained significantly more weight than those fed at the lowest feeding rates. Similar trends were obtained for polyculture Nile tilapia, common carp and silver carp (1), olive flounder (16; 17) and cuneate drum (86); blackspotseabream, Pagellusbogaraveo (21); European sea bass, Dicentrarchuslabrax L. (30); gilthead sea bream, Spurusaurata (54); and white sturgeon, Acipensertransmontanus (23) amongst others .

In addition to all of that, determining weight increase is crucial in aquaculture since it determines the feed conversion ratio, which gauges how successfully fish convert food mass into body mass, in conjunction with the amount of food supplied (33) .The fish's SGR and weight gain rate were the best. This implied that fish will grow poorly at low rates of size. There are two possible explanations for the growth retardation observed in fish exposed to lower feeding rates, according to the earlier study. First, fish with low rates may not be able to meet their energy needs for growth and maintenance, which could lead to poor growth rates (24). Second, fish housed at low rates typically showed more swimming activity for food contests, which resulted in higher energy costs and slower growth rates (40).

The feeding rate had no discernible effect on the survival rate of young Common Carp. Over 95% of people survived on average. These outcomes are comparable to those documented for young gilthead sea bream, European sea bass, O. niloticus, and yellowtail flounder, juvenile olive flounder and cuneate drum (66; 67; 54; 30; 16; 86). Meanwhile, (1); and (73) highlight a markedly reduced survival rate for the lowest feeding rates in studies on silver carp, polycultured Nile tilapia, common carp, and O. niloticus fry, respectively.

Fish quality has been demonstrated by body composition, which is impacted by diet and feeding practices (92). Fish body composition has been demonstrated to be significantly impacted by feeding rates (4; 3). As feeding rates rise, fat levels rise (1; 35; 16; 92) and nitrogen retention falls (23; 86). Fish fat may be produced from more dietary energy at high rates, which is one of the likely causes of this (75). In this study, feeding rates were favorably correlated with body contents and nutrient retention rates. This could be due to the fact that young fish at reduced feeding rates used more energy to compete for scarce food, which could increase protein and fat metabolism. Consequently, rather than being deposited in the fish's body, more protein and fat were metabolized to provide energy.

Fish development, physical condition, energy storage, and resilience to environmental stressors can all be inferred from the hepatosomatic index and condition factor. Fish typically have smaller livers under poor, stressful, and unfavorable environments, which implies the liver has less energy stored in it. In the current investigations, as feeding rates increased, so did HSI, VSI, and K. These findings are comparable to those of juvenile black rockfish Sebastesschlegeli (64), olive flounder (15), juvenile mirror carp (Cyprinus carp) (26), and juvenile Korean rockfish (56).

References

[1] Abdelghany, A. E., & Ahmad, M. H. (2002).Effects of feeding rates on growth and production of Nile tilapia, common carp and silver carp polycultured in fertilized ponds. Aquaculture Research, 33(6), 415-423.

[2] Adebayo, O. T., Balogun, A. M., &Fagbenro, O. A. (2000).Effects of feeding rates on growth, body composition and economic performance of juvenile clariid catfish hybrid (female Clariasgariepinus× male Heterobranchusbidorsalis). Journ al of Aquaculture in the Tropics, 15(2), 109-117.

[3] Afzal Khan, M., Jafri, A. K., &Chadha, N. K. (2004). Growth

and body composition of rohu, Labeorohita (Hamilton), fed compound diet: winter feeding and rearing to marketable size. Journal of Applied Ichthyology, 20(4), 265-270.

[4] Ahmed, I. (2007). Effect of ration size on growth, body composition, and energy and protein maintenance requirement of fingerling Indian major carp, Labeorohita (Hamilton). Fish Physiology and Biochemistry, 33(3), 203-212.

[5] Amin, S. A., Abdulrahman, N. M., Ahmed, V. M., Ibrahim, P. B., Ismail, R. R., Ahmed, M. B., & HamaGareeb, N. M. (2018). Effects of feeding frequency on common carp (Cyprinuscarpio L.) growth rate. *Iraqi Journal of Veterinary Sciences*, *32*(1).

[6] Andrews, J. W., & Page, J. W. (1975).The effects of frequency of feeding on culture of catfish. Transactions of the American Fisheries Society, 104(2), 317-321.

[7] AOAC (Association of Official Analytical Chemists), 1997.In: Cunniff, P.A. (Ed.), Official methods of analysis of AOAC International, 16th edition AOAC International, Arlington, Virginia, USA.

[8] AOAC, 1990. Official Methods of Analysis of AOAC International. In Association of Official Analysis Chemists International. pp. 1058–1059

[9] Arzel, J., Metailler, R., Le Gall, P., & Guillaume, J. (1998).Relationship between ration size and dietary protein level varying at the expense of carbohydrate and lipid in triploid brown trout fry, Salmotrutta. Aquaculture, 162(3) , 259-268.

[10] Bhujel, R. C., Little, D. C., &Hossain, A. (2007).Reproductive performance and the growth of pre-stunted and normal Nile tilapia (Oreochromisniloticus) broodfish at varying feeding rates. Aquaculture, 273(1), 71-79.

[11] Biswas G., Thirunavukkarasu A.R., Sundaray J.K., Kailasam M., 2010. Optimization of feeding frequency of Asian seabass (Lates calcarifer) fry reared in net cages under brackishwater environment. Aquaculture 305, 26-31.

[12] Booth M.A., Tucker B.J., Allan G.L., Fielder D.S., 2008. Effect of feeding regime and fish size on weight gain, feed intake and gastric evacuation in juvenile Australian snapper Pagrus auratus. Aquaculture 282, 104-110.

[13] Carlos M.H., 1988. Growth and survival of bighead carp (Aristichthys nobilis) fry fed at different intake levels and feeding frequencies. Aquaculture 68, 267-276.

[14] Charles P.M., Sebastian S.M., Raj M.C.V., Marian M.P., 1984. Effect of feeding frequency on growth and food conversion of Cyprinus carpio fry. Aquaculture 40, 293-300.

[15] Cho, S. H. (2005). Compensatory growth of juvenile flounder Paralichthysolivaceus L. and changes in biochemical composition and body condition

indices during starvation and after refeeding in winter season. Journal of the World Aquaculture Society, 36(4), 508-514.

[16] Cho, S. H., Lee, S. M., Park, B. H., & Lee, S. M. (2006). Effect of feeding ratio on growth and body composition of juvenile olive flounder Paralichthysolivaceus fed extruded pellets during the summer season. Aquaculture, 251(1), 78-84.

[17] Cho, S. H., Lee, S. M., Park, B. H., Ji, S. C., Choi, C. Y., Lee, J. H., ... & Oh, S. Y. (2007). Effect of daily feeding ratio on growth and body composition of subadult olive flounder, Paralichthysolivaceus, fed an extruded diet during the summer season. Journal of the World Aquaculture Society, 38(1), 68-73.

[18] Clements, K.D., 1991. Endosymbiotic communities of two herbivorous labroid fishes, Odaxcyanomelas and O. pullus. Mar. Biol. 109, 223-229.

[19] Costa-Bomfim, C.N., Pessoa, W.V.N., Oliveira, R.L.M., Farias, J.L., Domingues, E.C., Hamilton, S., Cavalli, R.O. 2014. The effect of feeding frequency on growth performance of juvenile cobia, Rachycentroncanadum (Linnaeus, 1766). J. Appl. Ichthyol. 30, 135-139.

[20] Davies, O. A., Inko-Tariah, M. B., &Amachree, D. (2006). Growth response and survival of Heterobranchuslongifilis fingerlings fed at different feeding frequencies. African Journal of Biotechnology, 5(9): 778-787.

[21] De Almeida Ozório, R. O., Andrade, C., Freitas Andrade Timóteo, V. M., da Conceição, C., Eugénio, L., &Pinheiro Valente, L. M. (2009). Effects of feeding levels on growth response, body composition, and energy expenditure in blackspotseabream, Pagellusbogaraveo, Juveniles. Journal of the World Aquaculture Society, 40(1), 95-103.

[22] De Silva, S. S., Gunasekera, R. M., &Keembiyahetty, C. (1986).Optimum ration and feeding frequency in Oreochromisniloticus young.In 1. Asian Fisheries Forum, Manila (Philippines), 26-31 May 1986.

[23] Deng, D. F., Koshio, S., Yokoyama, S., Bai, S. C., Shao, Q., Cui, Y., & Hung, S. S. (2003). Effects of feeding rate on growth performance of white sturgeon (Acipensertransmontanus) larvae. Aquaculture, 217(1), 589-598.

[24] Desai, A. S., & Singh, R. K. (2009). The effects of water temperature and ration size on growth and body composition of fry of common carp, Cyprinuscarpio. Journal of thermal Biology, 34(6), 276-280.

[25] Dragomir, C., Nica, A., & Cristea, V. (2020). Health status and environmental conditions of common carp (*Cyprinus carpio*) reared in recirculating aquaculture systems. *Current*

Trends in Natural Sciences, 9(17), 132–138.

[26] Du, Z. Y., Liu, Y. J., Tian, L. X., He, J. G., Cao, J. M., & Liang, G. Y. (2006). The influence of feeding rate on growth, feed efficiency and body composition of juvenile grass carp (Ctenopharyngodonidella). Aqua culture International, 14(3), 247-257.

[27] Ebrahimi, M., Rajion, M. A., Goh, Y. M., &Sazili, A. Q. (2012). Impact of different inclusion levels of oil palm (ElaeisguineensisJacq.) fronds on fatty acid profiles of goat muscles. Journal of Animal Physiology and Animal Nutrition, 96(6), 962-969.

[28] Eljasik, P., Nowosad, J., Kucharczyk, D., & Targońska, K. (2022). Comparison of growth performance of common carp (*Cyprinus carpio*) reared in recirculating aquaculture systems and pond systems. *Sustainability, 14*(7), 3724. https://doi.org/10.3390/su14073724

[29] Elmessery, W. M., Abdallah, S. E., Oraiath, A. A. T., Espinosa, V., Abuhussein, M. F. A., Szűcs, P., ... & Elwakeel, A. E. (2025). A deep deterministic policy gradient approach for optimizing feeding rates and water quality management in recirculating aquaculture systems. *Aquaculture International*, *33*(4), 253.

[30] Eroldoğan, O. T., Kumlu, M., &Aktaş, M. (2004).Optimum feeding rates for European sea bass Dicentrarchuslabrax L. reared in seawater and freshwater. Aquaculture, 231(1), 501-515.

[31] Folch, J., Lees, M., & Sloane Stanley, G. H. (1957).A simple method for the isolation and purification of total lipids from animal tissues. J biolChem, 226(1), 497-509.

[32] Ghaedi, A., & Khanjani, M. H. (2025). The effect of different dietary protein levels on the water quality and reproductive performance of Nile tilapia (Oreochromis niloticus) broodstock in biofloc system. *Journal of Fisheries*, *13*(3), 133206-133206.

[33] Goddard, S. (1996). Feed rations and schedules. In Feed management in intensive aquaculture (pp. 139-158).Springer US.

[34] Greaves, K., Tuene, S., 2001.The form and context of aggressive behaviour in farmed Atlantic halibut (Hippoglossushippoglossus L.). Aquaculture 193, 139-147.

[35] Han, D., Xie, S., Lei, W., Zhu, X., & Yang, Y. (2004).Effect of ration on the growth and energy budget of Chinese longsnout catfish, LeiocassislongirostrisGünther. A quaculture Research, 35(9), 866-873.

[36] Hung, S. S., & Lutes, P. B. (1987). Optimum feeding rate of hatchery-produced juvenile white sturgeon (Acipensertransmontanus): at 20 C. Aquaculture, 65(3-4), 307-317.

[37] Hung, S. S., Conte, F. S., & Lutes, P. B. (1995).Optimum feeding rate of white sturgeon, Acipensertransmontanus, yearlings under commercial production conditions. Journal of Applied Aquaculture, 5(1), 45-51.

[38] Hung, S. S., Lutes, P. B., Conte, F. S., &Storebakken, T. (1989).Growth and feed efficiency of white sturgeon (Acipensertransmontanus) sub-yearlings at different feeding rates. Aquaculture, 80(1-2), 147-153.

[39] Hung, S. S., Lutes, P. B., Shqueir, A. A., & Conte, F. S. (1993).Effect of feeding rate and water temperature on growth of juvenile white sturgeon (Acipensertransmontanus). Aqua culture, 115(3-4), 297-303.

[40] Johansen, S. J. S., &Jobling, M. (1998). The influence of feeding regime on growth and slaughter traits of cage-reared Atlantic salmon. Aquaculture international, 6(1), 1-17.

[41] Kelly, A.M., Heikes, D., 2013. Sorting and grading warmwater fish. Southern Regional Aquaculture Center.SRAC Publication No. 391.March. http://www.aces.edu/dept/fisheries/aquaculture/documents/srac391.pdf

[42] Kim, K. D., Kang, Y. J., Kim, K. W., & Kim, K. M. (2007).Effects of feeding rate on growth and body composition of juvenile flounder, Paralichthysolivaceus. Journal of the World Aquaculture Society, 38(1), 169-173.

[43] Lawrence, C., Best, J., James, A., Maloney, K., 2012. The effects of feeding frequency on growth and reproduction in zebrafish (Daniorerio). Aquaculture 368, 103-108.

[44] Lee S.M., Hwang U.G., Cho S.H., 2000. Effects of feeding frequency and dietary moisture content on growth, body composition and gastric evacuation of juvenile Korean rockfish (Sebastes schlegeli). Aquaculture 187, 399-409.

[45] Lee S.M., Pham M.A., 2010. Effects of feeding frequency and feed type on the growth, feed utilization and body composition of juvenile olive flounder, Paralichthys olivaceus. Aquacult. Res. 41, e166-e171.

[46] Leenhouwers, J.I., Pellikaan, W.F., Huizing, H.F.A., Coolen, R.O.M., Verreth, J.A.J., Schrama, J.W., 2008. Fermentability of carbohydrates in an in vitro batch culture method using inocula from Nile tilapia (Oreochromisniloticus) and European sea bass (Dicentrarchuslabrax).Aquac.Nutr. 14, 523-532.

[47] Li, M., & Lovell, R. T. 1992a.Comparison of satiate feeding and restricted feeding of channel catfish with various concentrations of dietary protein in production ponds. Aquaculture, 103(2), 165-175.

[48] Li, M., & Lovell, R. T. 1992b. Effect of dietary protein concentration on nitrogenous waste in intensively fed catfish ponds. Journal of the World

Aquaculture Society, 23(2), 122-127.

[49] Liu, Y. H., Luo, G. Z., Sun, P. Y., Tan, H. X., & Zhu, X. B. (2003). The culture effects of Scortumbarcoo recirculating system. Journal of Shanghai Fisheries University, 6, 130-134.

[50] Luo, G., Zhang, N., Tan, H. 2012. Effect of low salinity on jade perch Scortunbarcoo performance in a recirculating aquaculture system.North Am. J. Aquacult. 74, 395-399.

[51] Lynch, S. M., &Frei, B. (1993). Mechanisms of copper-and iron-dependent oxidative modification of human low density lipoprotein. Journal of Lipid Research, 34(10), 1745-1753.

[52] Mercier, Y., Gatellier, P., Viau, M., Remignon, H., &Renerre, M. (1998).Effect of dietary fat and vitamin E on colour stability and on lipid and protein oxidation in turkey meat during storage. Meat Science, 48(3), 301-318.

[53] Mihály-Karnai, Z., Kovács, B., & Nagy, S. A. (2025). Sustainability in intensive aquaculture: Common carp production in recirculating aquaculture systems. *Animals*, *15*(7), 1055. https://doi.org/10.3390/ani15071055

[54] Mihelakakis, A., Tsolkas, C., &Yoshimatsu, T. (2002).Optimization of Feeding Rate for Hatchery-Produced Juvenile Gilthead Sea Bream Sparusaurata. Journal of the World Aquaculture Society, 33(2), 169-175.

[55] Minton, R. V. (1978). Responses of channel catfish fed diets of two nutrient concentrations at three rates in ponds (Doctoral dissertation, Auburn University).

[56] Mizanur, R. M., Park, G., Yun, H., Lee, S., Choi, S., &Bai, S. C. (2014). The effects of feeding rates in juvenile Korean rockfish,(Sebastesschlegeli) reared at 17° C and 20° C water temperatures. Aquaculture international, 22(3), 1121-1130.

[61] Ng, W. K., Lu, K. S., Hashim, R., & Ali, A. (2000).Effects of feeding rate on growth, feed utilizationand body composition of a tropical bagrid catfish. Aquaculture International, 8(1), 19-29.

[62] Ng, W.-K., Koh, C.B. 2016. The utilization and mode of action of organic acids in the feeds of cultured aquatic animals. Rev. Aquacult. in press. doi: 10.1111/raq.12141

[63] Ng, W.-K., Romano, N., 2013.A review of the nutrition and feeding management of farmed tilapia throughout the culture cycle. Rev. Aquacult. 5, 220-254.

[64] OH, S. Y., Noh, C. H., KANG, R. S., KIM, C. K., Cho, S. H., & JO, J. Y. (2008). Compensatory growth and body composition of juvenile black rockfish Sebastesschlegeli following feed deprivation. Fisheries science, 74(4), 846-852.

[65] Okorie, O. E., Bae, J. Y., Kim, K. W., Son, M. H., Kim, J. W., &Bai, S. C. (2013). Optimum feeding rates in juvenile olive flounder, Paralichthysolivaceus, at the optimum rearing

temperature. Aquaculture Nutrition, 19(3), 267-277.

[66] Pouomogne, V., &Mbongblang, J. (1993).EFFECT OF FEEDING RATE ON THE GROWTH OF TILAPIA (OREOCHROMIS-NILOTICUS) IN EARTHEN PONDS. ISRAELI JOURNAL OF AQUACULTURE-BAMIDGEH, 45(4), 147-153.

[67] Puvanendran, V., Boyce, D. L., & Brown, J. A. (2003). Food ration requirements of 0+ yellowtail flounder Limandaferruginea (Storer) juveniles. Aquaculture, 220(1), 459-475.

[68] Qingiun, S., Xiaofeng, S., Zirong, X., Miaoan, S., 2004. Effect of dietary protein levels on growth performance and body composition of jade perch Scortum barcoo. Acta Hydrobiologica Sinica 28, 367-373.

[69] Raza, B., Zheng, Z., & Yang, W. (2024). A review on biofloc system technology, history, types, and future economical perceptions in aquaculture. *Animals*, *14*(10), 1489.

[70] Riche, M., Haley, D.I., Oetker, M., Garbrecht, S., Garling, D.L., 2004.Effect of feeding frequency on gastric evacuation and return of appetite in tilapia Oreochromisniloticus (L.). Aquaculture 234, 657–673.

[71] Romano, N., Simon, W., Ebrahimi, M., Fadel, A.H.I., Chong, C.M., Kamarudin, M.S. 2016. Dietary sodium citrate improved oxidative stability in red hybrid tilapia (Oreochromis sp.) but reduced growth, health status, intestinal short chain fatty acids and induced liver damage. Aquaculture 458, 170-176.

[72] Rudel, L.L., Morris, M.D., 1973. Determination of cholesterol using o-phthalaldehyde. J. Lipid Res. 14, 364–366.

[73] Santiago, C. B., Aldaba, M. B., & Reyes, O. S. (1987). Influence of feeding rate and diet form on growth and survival of Nile tilapia (Oreochromisniloticus) fry. Aquaculture, 64(4), 277-282.

[74] Schnaittacher, G., William, K.V., Berlinsky, D.L., 2005. The effects of feeding frequency on growth of juvenile Atlantic halibut, Hippoglossushippoglossus L. Aquacult. Res. 36, 370–377.

[75] Shearer, K. D., Silverstein, J. T., &Dickhoff, W. W. (1997). Control of growth and adiposity of juvenile chinook salmon (Oncorhynchustshawytscha). Aq uaculture, 157(3-4), 311-323.

[76] Silva C.R., Gomes L.C., Brandão F.R., 2007.Effect of feeding rate and frequency on tambaqui (Colossomamacropomum) growth, production and feeding costs during the first growth phase in cages. Aquaculture 264, 135-139.

[77] Song, L.P., An, L., Zhu, Y.A., Li, X., Wang, A.Y., 2009. Effects of dietary lipids on growth and feed utilization of jade perch, Scortunbarcoo. J. World Aqucault. Soc. 40, 266-273.

[78] Soengas, J. L., Comesana, S., Blanco, A. M., & Conde-Sieira, M. (2025). Feed intake

regulation in fish: implications for aquaculture. *Reviews in Fisheries Science & Aquaculture*, *33*(1), 8-60.

[79] Titus, E., Ahearn, G.A., 1988. Short-chain fatty acid transport in the intestine of a herbivorous teleost. J. Exp. Biol. 135, 77-94.

[80] Van Ham, E. H., Berntssen, M. H., Imsland, A. K., Parpoura, A. C., Bonga, S. E. W., & Stefansson, S. O. (2003). The influence of temperature and ration on growth, feed conversion, body composition and nutrient retention of juvenile turbot (Scophthalmusmaximus). Aquaculture, 217(1), 547-558.

[81] Van Hoestenberghe, S., Fransman, C.A., Luyten, T., Vermeulen, D., Roelants, I., Saskia, B., Goddeeris, B.M., 2016. Schizochytrium as a replacement for fish oil in a fishmeal free diet for jade perch, Scortum barcoo (McCulloch & Waite). Aquacult. Res. 47, 1747-1760.

[82] Van Hoestenberghe, S., Roelants, I., Vermeulen, D., Goddeeris, B.M., 2013. Total replacement of fish oil with vegetable oils in the diet of juvenile jade perch Scortun barcoo reared in recirculating aquaculture systems. J. Agricult. Sci. Tech. B. 3, 385-398.

[83] Van Hoestenberghe, S., Wille, M., De Swaef, E., Goddeeris, B.M., Nevejan, N., 2015. Effect of weaning age and the use of different sized Artemia nauplii as first feed for jade perch Scortun barcoo. Aquacult. Int. 23, 1539-1552.

[84] Wang, N., Hayward, R.S., Noltie, D.B., 1998. Effect of feeding frequency on food consumption, growth, size variation, and feeding pattern of age-0 hybrid sunfish. Aquaculture 165, 261–265.

[85] Wang, N., Xu, X., Kestemont, P., 2009. Effect of temperature and feeding frequency on growth performances, feed efficiency and body composition of pikeperch juveniles (Sander lucioperca). Aquaculture 289, 70-73.

[86] Wang, Y., Kong, L. J., Li, K., & Bureau, D. P. (2007). Effects of feeding frequency and ration level on growth, feed utilization and nitrogen waste output of cuneate drum (Nibeamiichthioides) reared in net pens. Aquaculture, 271(1), 350-356.

[87] Wang, Y., Li, X., Zhang, H., & Chen, L. (2024). Effects of recirculating aquaculture systems on growth performance and flesh quality of common carp (*Cyprinus carpio*). *Aquaculture Reports*, *35*, 101500. https://doi.org/10.1016/j.aqrep.2024.101500

[88] Webster, C. D., Thompson, K. R., Morgan, A. M., Grisby, E. J., &Dasgupta, S. (2001). Feeding frequency affects growth, not fillet composition, of juvenile sunshine bass Moronechrysops× M. saxatilis grown in cages. Journal of the world aquaculture society, 32(1), 79-88.

[89] Wu Y., Han H., Qin J., Wang Y., 2015. Effect of feeding frequency on growth, feed

utilization, body composition and waste output of juvenile golden pompano (Trachinotus ovatus) reared in net pens. Aquacult. Res. 46, 1436-1443.

[90] Wu, Y., Chen, J., Jia, C., Gui, F., Xu, J., Yin, X., ... & Zhang, Q. (2025). Recent Advances in the Hydrodynamic Characteristics of Industrial Recirculating Aquaculture Systems and Their Interactions with Fish. *Sustainability (2071-1050)*, *17*(17).

[91] Xie, X. J., & Sun, R. (1992). The bioenergetics of the southern catfish(Silurusmeridionalis Chen): Growth rate as a function of ration level, body weight, and temperature. Journal of fish biology, 40(5), 719-730.

[92] Zhang, L., Zhao, Z., Xiong, D., Fang, W., Li, B., Fan, Q., ...& Wang, X. (2011). Effects of ration level on growth, nitrogenous excretion and energy budget of juvenile yellow catfish, Pelteobagrusfulvidraco (Richardson). Aquaculture research, 42(7), 899-905.