Effects of Different Dietary Carbohydrate-to-Lipid Ratios on Growth, Body Composition, and Digestive Enzyme Activity in Common Carp (Postprint)

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Abstract

This experiment was conducted to investigate the effects of different dietary carbohydrate-to-lipid ratios on growth, body composition, and digestive enzyme activities in common carp. A total of 1,050 common carp with an average body weight of (44.45$±$1.60) g were randomly divided into 5 groups (3 replicates per group, 70 fish per replicate) and fed diets with carbohydrate-to-lipid ratios of 5.2, 6.8, 9.6, 15.0, and 27.7 for a 63-day feeding trial. The results showed that: 1) The weight gain rate and specific growth rate of carp fed diets with a carbohydrate-to-lipid ratio of 6.8 were the highest, significantly higher than those of other groups (P<0.05). The feed conversion ratio at a dietary carbohydrate-to-lipid ratio of 27.7 was significantly higher than that at ratios of 5.2-15.0 (P<0.05), and the feed conversion ratio was the lowest at a carbohydrate-to-lipid ratio of 6.8. The protein efficiency ratio of the group with a carbohydrate-to-lipid ratio of 27.7 was significantly lower than that of other groups (P<0.05), but its condition factor was significantly higher than that of the group with a ratio of 6.8 (P<0.05). 2) The crude lipid content in whole fish and dorsal muscle was higher in the groups with carbohydrate-to-lipid ratios of 5.2 and 27.7, significantly higher than that in other groups (P<0.05); the crude ash content in dorsal muscle was significantly lower in the group with a ratio of 15.0 than in the group with a ratio of 5.2 (P<0.05), while no significant differences were observed among other groups (P>0.05). 3) Serum total cholesterol content showed a trend of first decreasing then increasing with increasing dietary carbohydrate-to-lipid ratio, reaching its lowest value at a ratio of 15.0, which was significantly lower than that at ratios of 5.2 and 27.7 (P<0.05), while serum triglyceride content reached its highest value in the group with a ratio of 6.8, significantly higher than that in other groups (P<0.05). Serum glucose con-

tent reached its highest value in the group with a carbohydrate-to-lipid ratio of 27.7, significantly higher than that in other groups (P<0.05). Hepatic glycogen content reached its highest value in the group with a ratio of 27.7, significantly higher than that in other groups except the group with a ratio of 15.0 (P<0.05). 4) Hepatopancreas and midgut protease activities reached their highest values in the group with a carbohydrate-to-lipid ratio of 6.8, significantly higher than those in other groups (P<0.05); foregut protease activity was significantly lower at a ratio of 15.0 than in other groups (P<0.05). Hepatopancreas and foregut amylase activities were highest in the group with a ratio of 15.0; midgut amylase activity showed a decreasing trend with increasing dietary carbohydrate-to-lipid ratio, with the group with a ratio of 27.2 being significantly lower than other groups (P<0.05); hindgut amylase activity was lowest in the group with a ratio of 15.0, significantly lower than other groups except the group with a ratio of 9.6 (P<0.05). The trends of lipase activity in all tissues were similar, showing an initial increase followed by a decrease with increasing dietary carbohydrate-to-lipid ratio, with the highest values all appearing at a dietary carbohydrate-to-lipid ratio of 15.0. Based on comprehensive consideration of growth, body composition, serum biochemical indices, and digestive enzyme activities, the optimal dietary carbohydrate-to-lipid ratio for common carp is 6.8–15.0.

Full Text

Effects of Different Dietary Carbohydrate-to-Lipid Ratios on Growth Performance, Body Composition, and Digestive Enzyme Activities of Common Carp (Cyprinus carpio)

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Abstract: This study investigated the effects of different dietary carbohydrate-to-lipid ratios on growth performance, body composition, and digestive enzyme activities of common carp (*Cyprinus carpio*). A total of 1,050 common carp with an average body weight of (44.45$±$1.60) g were randomly divided into 5 groups (3 replicates per group, 70 fish per replicate) and fed experimental diets with carbohydrate-to-lipid ratios of 5.2, 6.8, 9.6, 15.0, and 27.7 for 63 days. The results showed: (1) The highest weight gain rate (WGR) and specific growth rate (SGR) were observed in fish fed the diet with a carbohydrate-to-lipid ratio of 6.8, which were significantly higher than those in other groups (P<0.05). The feed conversion ratio (FCR) was significantly higher in the 27.7 carbohydrate-to-lipid ratio group compared to the 5.2–15.0 groups (P<0.05), with the lowest FCR occurring at a ratio of 6.8. The protein efficiency ratio (PER) in the 27.7 carbohydrate-to-lipid ratio group was significantly lower than in other groups (P<0.05), while its condition factor (CF) was significantly higher than that in the 6.8 ratio group (P<0.05). (2) Crude lipid content in whole body and dorsal muscle was highest in the 5.2 and 27.7 carbohydrate-to-lipid ratio groups, significantly higher than in other groups (P<0.05). Dorsal muscle ash content in the 15.0 ratio group was significantly lower than in the 5.2 ratio group (P<0.05), with no significant differences among other groups (P>0.05). (3) Serum total cholesterol content first decreased then increased with rising dietary carbohydrate-to-lipid ratios, reaching its lowest value at a ratio of 15.0, which was significantly lower than in the 5.2 and 27.7 groups (P<0.05). Serum triglyceride content showed the opposite trend, with the highest value in the 6.8 ratio group, significantly higher than other groups (P<0.05). Serum glucose content peaked in the 27.7 ratio group, significantly higher than other groups (P<0.05). Liver glycogen content was also highest in the 27.7 ratio group, significantly higher than all groups except the 15.0 ratio group (P<0.05). (4) Hepatopancreas and midgut protease activities peaked in the 6.8 carbohydrate-to-lipid ratio group, significantly higher than other groups (P<0.05). Foregut protease activity was significantly reduced at a carbohydrate-to-lipid ratio of 15.0 compared to other groups (P<0.05). Hepatopancreas and foregut amylase activities were highest in the 15.0 ratio group. Midgut amylase activity decreased with increasing dietary carbohydrate-to-lipid ratios, with the 27.2 ratio group significantly lower than others (P<0.05). Hindgut amylase activity was lowest in the 15.0 ratio group, significantly lower than all groups except the 9.6 ratio group (P<0.05). Lipase activities in all tissues showed similar trends, increasing initially then decreasing, with maximum values occurring at a carbohydrate-to-lipid ratio of 15.0. Based on comprehensive consideration of growth performance, body composition, serum biochemical indices, and digestive enzyme activities, the optimal dietary carbohydrate-to-lipid ratio for common carp is 6.8–15.0.

Keywords: common carp (*Cyprinus carpio*); carbohydrate-to-lipid ratio; growth performance; body composition; digestive enzyme activities

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Introduction

With the development of intensive aquaculture and soaring fishmeal prices, research on protein substitution and conservation in aquafeeds has continued unabated. Appropriate dietary carbohydrate or lipid levels can exert protein-sparing effects. Sun et al. [?] reported that optimal growth in common carp was achieved when dietary corn starch levels ranged from 0–13% and protein levels were 28.1–32%. Guo et al. [?] found that reducing dietary protein from 32% to 30% while increasing dextrin levels from 0 to approximately 4.5% did not affect growth but improved metabolic enzyme activities. Fan et al. [?] demonstrated that optimal growth occurred with 29.2% crude protein and 7.6% crude lipid. Wang et al. [?] observed that juvenile yellow catfish (*Pelteobagrus fulvidraco*) exhibited best growth performance at moderate carbohydrate-to-lipid ratios.

However, inappropriate proportions of carbohydrates, lipids, and proteins can lead to slow growth [?]. Studies have shown that excessive carbohydrate-to-lipid ratios in *Leiocassis longirostris* diets caused morphological changes and hepatic lesions [?], while Ali et al. [?] found that *Clarias gariepinus* fed diets with carbohydrate-to-lipid ratios of 0.74–3.42 showed significantly lower weight gain and protein efficiency at a ratio of 0.74, but no further improvement when ratios increased from 1.66 to 3.42.

Excessive dietary carbohydrates can cause hyperglycemia and fatty liver, compromising fish health [?], while excessive lipids adversely affect growth and flavor [?]. Thus, appropriate proportions of carbohydrates, lipids, and proteins promote fish growth and health, making the determination of optimal carbohydrate-to-lipid ratios crucial for aquaculture development.

Common carp, native to Asia and later introduced to Europe, North America, and other regions, is an omnivorous species widely cultured in northern China, valued for its rapid growth and delicious flesh. No previous studies have investigated the optimal carbohydrate-to-lipid ratio in low-protein diets for common carp. This experiment examined the effects of different dietary carbohydrate-to-lipid ratios on growth, body composition, blood indices, and digestive enzyme activities to identify optimal ratios for improving growth and reducing feed costs.

1.1 Experimental Fish and Culture Management

Experimental fish were obtained from Tianjin Huanxin Aquatic Breeding Farm and reared at Tianjin Ninghe County Tianxiang Aquaculture Company. After disinfection, foam floating boards were used to construct temporary rearing cages (1 m × 1 m × 2 m) divided into 15 submerged net cages within a large polyculture pond. Fish were acclimated with a basal diet (32% protein) for 14 days. Healthy common carp with average body length (12.31$±0.2)*cmandweight*(44.45±1.6)*gwererandomlyallocatedinto*5*groupswith*3*replicateseach*(70*fishperrep* *daytrial*, *watertemperaturewas*(28±3.1)°*C*, *pHwas*7.8±$0.2, dissolved oxygen exceeded 5.0 mg/L, and feeding rate was 3–6% body weight daily, administered twice daily (09:00 and 15:00).

1.2 Experimental Diet Formulation

Five experimental diets were formulated with fishmeal, soybean meal, peanut meal, and cottonseed meal as protein sources, dextrin as carbohydrate source, and soybean oil as lipid source, maintaining constant protein level (~30%) while achieving carbohydrate-to-lipid ratios of 5.2, 6.8, 9.6, 15.0, and 27.7. All ingredients were ground through a 40-mesh sieve, mixed uniformly, and processed into 2.00 mm sinking pellets using a Jiangsu Muyang MUZLM V4 pelletizer at Tianxiang Aquaculture Company. Pellets were air-dried at room temperature, sealed in plastic bags, and stored at -20 °C until use. Nutrient composition was analyzed before feeding. Dietary composition and nutrient levels are shown in

Table 1 .

1.3 Sample Collection and Processing

At the end of the trial, fish were fasted for 48 h. Twenty fish per cage were measured for body length and weight. After anesthesia with MS-222, blood was collected from the caudal vein and pooled from 3 fish per sample into 2 mL tubes. Serum was separated by centrifugation at 4,500 r/min for 10 min at 4 °C. Following blood collection, hepatopancreas and intestinal sections (foregut, midgut, hindgut) were excised. All samples were stored at -80 °C until analysis. Prior to analysis, tissues were homogenized in physiological saline (1:9, w/v), centrifuged at 4,000 r/min, and supernatants were collected for assays (lipase was measured in 20% homogenate, others were diluted according to kit requirements). Serum samples were analyzed directly after thawing.

1.4.1 Calculation of Growth and Physical Indices

Weight gain rate (WGR, %) = 100 × (Wt - W0)/W0
Specific growth rate (SGR, %/d) = 100 × (ln Wt - ln W0)/t
Feed conversion ratio (FCR) = F/(Wt - W0)
Protein efficiency ratio (PER) = (Wt - W0)/(F × CP)
Condition factor (CF, %) = 100 × Wt/Lt^3
Hepatosomatic index (HSI, %) = 100 × Wg/Wt
Survival rate (SR, %) = 100 × Nt/N0

Where: Wt = final body weight (g); W0 = initial body weight (g); Lt = final body length (cm); t = experimental duration (d); F = total feed intake (dry weight, g); Wg = hepatopancreas weight (g); CP = dietary crude protein content; Nt = final fish number; N0 = initial fish number.

1.4.2 Body Composition Analysis

Nutrient composition of experimental diets, dorsal muscle, and whole body were determined according to AOAC methods [?]. Moisture content was measured by oven-drying at 105 °C; crude ash by combustion at 550 °C; crude lipid by Soxhlet extraction; crude protein by Dumas combustion; and total carbohydrate by 3,5-dinitrosalicylic acid method.

1.4.3 Serum Biochemical Indices and Tissue Digestive Enzyme Activities

Serum total cholesterol, triglycerides, glucose, liver glycogen, and tissue lipase and amylase activities were measured using commercial kits from Nanjing Jiancheng Bioengineering Institute. Tissue protease activity was determined by the Folin-phenol method.

1.5 Data Processing and Statistical Analysis

All data are expressed as mean ± standard deviation (SD). Excel 2003 and SPSS 17.0 were used for data analysis. Standard curves were constructed using Excel to calculate enzyme activities or metabolite concentrations. One-way ANOVA was performed using SPSS 17.0, and Duncan' s multiple range test was applied when significant differences were detected (P<0.05).

2.1 Effects of Dietary Carbohydrate-to-Lipid Ratios on Growth Indices of Common Carp

As shown in Table 2 , WGR and SGR increased initially then decreased with rising dietary carbohydrate-to-lipid ratios, peaking at a ratio of 6.8, which was significantly higher than other groups (P<0.05). No significant differences in FCR were observed among fish fed diets with carbohydrate-to-lipid ratios of 5.2–15.0 (P>0.05), but all were significantly lower than the 27.7 ratio group (P<0.05). PER increased initially then decreased, with the 27.7 ratio group significantly lower than others (P<0.05), while no significant differences existed among remaining groups (P>0.05). Dietary carbohydrate-to-lipid ratio had no significant effect on survival rate (P>0.05).

2.2 Effects of Dietary Carbohydrate-to-Lipid Ratios on Physical Indices of Common Carp

As shown in Table 3 , condition factor decreased initially then increased with rising dietary carbohydrate-to-lipid ratios. The 6.8 ratio group had significantly lower condition factor than the 27.7 ratio group (P<0.05), with no significant differences among other groups (P>0.05). Hepatosomatic index did not differ significantly among groups (P>0.05).

2.3 Effects of Dietary Carbohydrate-to-Lipid Ratios on Body Composition of Common Carp

As shown in Table 4 , dietary carbohydrate-to-lipid ratio had no significant effect on moisture, crude protein, or ash content of whole body, nor on moisture and crude protein content of dorsal muscle (P>0.05). However, it significantly affected crude lipid content in whole body and dorsal muscle, and ash content in dorsal muscle (P<0.05). Crude lipid content in whole body and dorsal muscle was highest in the 5.2 and 27.7 ratio groups, significantly higher than other groups (P<0.05). Dorsal muscle ash content in the 15.0 ratio group was significantly lower than in the 5.2 ratio group (P<0.05), with no significant differences among other groups (P>0.05).

2.4 Effects of Dietary Carbohydrate-to-Lipid Ratios on Serum Biochemical Indices and Liver Glycogen Content of Common Carp

As shown in Table 5 , serum total cholesterol content decreased initially then increased with rising dietary carbohydrate-to-lipid ratios, reaching its minimum at a ratio of 15.0, which was significantly lower than in the 5.2 and 27.7 ratio groups ($P<0.05$). Serum triglyceride content showed the opposite trend, peaking in the 6.8 ratio group, significantly higher than other groups ($P<0.05$). Serum glucose content increased with dietary carbohydrate-to-lipid ratios, reaching its maximum in the 27.7 ratio group, significantly higher than other groups ($P<0.05$). Liver glycogen content also increased with dietary carbohydrate-to-lipid ratios, peaking in the 27.7 ratio group, significantly higher than all groups except the 15.0 ratio group ($P<0.05$).

2.5 Effects of Dietary Carbohydrate-to-Lipid Ratios on Digestive Enzyme Activities of Common Carp

As shown in Table 6 , hepatopancreas and midgut protease activities increased initially then decreased with rising dietary carbohydrate-to-lipid ratios, peaking in the 6.8 ratio group, significantly higher than other groups ($P<0.05$). Foregut protease activity was significantly reduced at a carbohydrate-to-lipid ratio of 15.0 compared to other groups ($P<0.05$), while no significant differences existed among remaining groups ($P>0.05$). Dietary carbohydrate-to-lipid ratio had no significant effect on hindgut protease activity ($P>0.05$). Hepatopancreas and foregut amylase activities were highest in the 15.0 ratio group, with hepatopancreas amylase activity not significantly different from the 6.8 ratio group ($P>0.05$) but significantly different from other groups ($P<0.05$). Midgut amylase activity decreased with increasing dietary carbohydrate-to-lipid ratios, with the 27.2 ratio group significantly lower than others ($P<0.05$). Hindgut amylase activity was lowest in the 15.0 ratio group, significantly lower than all groups except the 9.6 ratio group ($P<0.05$). Lipase activities in all tissues showed similar trends, increasing initially then decreasing, with maximum values occurring at a carbohydrate-to-lipid ratio of 15.0.

Discussion

3.1 Effects of Dietary Carbohydrate-to-Lipid Ratios on Growth of Common Carp

In this study, the highest WGR and SGR were observed at a dietary carbohydrate-to-lipid ratio of 6.8, while PER did not differ significantly among ratios of 5.2–15.0 but was significantly higher than in the 27.7 ratio group. These results indicate that when carbohydrates and lipids are maintained at appropriate proportions, their synergistic effects can be fully realized [?], enhancing fish growth and feed utilization [?]. Conversely, excessive carbohydrate-to-lipid ratios adversely affect growth and feed efficiency [?]. Wang et al. [?] reported optimal growth performance in juvenile yellow catfish at moderate carbohydrate-to-lipid ratios. He et al. [?] found that appropriate carbohydrate-to-lipid ratios could spare protein when dietary protein levels were reduced in gibel carp (*Carassius auratus gibelio*), while excessive carbohydrate or lipid levels inhibited growth, consistent with our findings. Similar results have been reported for *Clarias gariepinus* [?], *Leiocassis longirostris* [?], *Pelteobagrus vachelli* [?], and grass carp (*Ctenopharyngodon idella*) [?]. However, some studies found no significant differences in growth performance of *Rhamdia quelen* with varying carbohydrate-to-lipid ratios [?], possibly due to differences in species, culture conditions, diet formulation, or feeding strategies. Although FCR was generally high in this study, likely due to feeding methods and feed processing, the highest FCR and lowest WGR and SGR occurred in the high carbohydrate-to-lipid ratio group, suggesting that high carbohydrate intake may impede growth in common carp, consistent with findings in topmouth culter (*Erythroculter ilishaeformis*) [?].

3.2 Effects of Dietary Carbohydrate-to-Lipid Ratios on Physical Indices of Common Carp

Although dietary carbohydrate-to-lipid ratio did not significantly affect hepatosomatic index, the 27.7 ratio group exhibited higher values than other groups. This may occur because when dietary carbohydrate levels are excessive, some carbohydrates are converted to fat and deposited in the hepatopancreas. The range of carbohydrate-to-lipid ratios tested in this study remained within the tolerance limits of common carp, not causing excessive fat deposition or hepatomegaly, though excessively high ratios could impair liver function. Similar results have been reported in Chinook salmon [?]. Additionally, increased condition factor in fish fed high carbohydrate-to-lipid ratio diets suggests that high-carbohydrate, low-lipid diets more readily promote nutrient accumulation.

3.3 Effects of Dietary Carbohydrate-to-Lipid Ratios on Body Composition and Serum Biochemical Indices of Common Carp

As a food fish, flesh quality and flavor significantly affect marketability. This study examined body composition while ensuring fish health. Previous research indicates that elevated dietary lipid levels increase fat deposition in fish tissues [?], and ingested carbohydrates may also be converted to fat and deposited in hepatopancreas and mesentery [?]. In this study, whole body and dorsal muscle crude lipid content were highest in the 5.2 and 27.7 carbohydrate-to-lipid ratio groups, indicating that some ingested carbohydrates were converted to fat deposited in tissues, and suggesting that common carp possess relatively high carbohydrate utilization capacity. Similar results have been reported in spotted rabbitfish [?] and longfin rabbitfish (*Siganus canaliculatus*) [?]. However, Li et al. [?] found that increasing dietary carbohydrate levels did not significantly affect dorsal muscle composition in black seabream, possibly due to species-specific differences in carbohydrate absorption and utilization capacities and varying carbohydrate inclusion levels. Dietary carbohydrate-to-lipid ratio did not significantly affect crude protein content in dorsal muscle or whole body of common carp, consistent with findings in blunt snout bream (*Megalobrama amblycephala*) [?].

Approximately 70–80% of blood cholesterol originates from the liver, with the remainder from the digestive tract; liver damage elevates serum cholesterol levels [?]. In this study, serum total cholesterol decreased with increasing dietary carbohydrate-to-lipid ratios, with higher values at ratios of 5.2 and 27.7 and no significant differences among 6.8–15.0 ratios, indicating that both excessively high and low carbohydrate-to-lipid ratios impose metabolic burdens on common carp, consistent with crude lipid content results. Although aquatic animals possess glycolytic enzymes that can convert some carbohydrates to lipids and other metabolites, this capacity is insufficient relative to carbohydrate intake, leading to continuously elevated serum glucose with increasing dietary carbohydrate levels [?, ?]. In this study, serum glucose and liver glycogen contents increased with dietary carbohydrate-to-lipid ratios, consistent with findings in gibel carp [?] and Jian carp (*Cyprinus carpio* var. Jian) [?], indicating that excessive carbohydrate levels increase metabolic burden and negatively affect health. Triglycerides are stored energy sources readily utilized by most tissues, with serum triglycerides primarily derived from food. In this study, serum triglyceride content increased initially then decreased with rising dietary carbohydrate-to-lipid ratios, peaking at a ratio of 6.8, suggesting that carbohydrate and lipid addition promotes triglyceride synthesis. Similar results have been reported in *Sohilbe intermedius* [?] and rainbow trout (*Oncorhynchus mykiss*) [?].

3.4 Effects of Dietary Carbohydrate-to-Lipid Ratios on Digestive Enzyme Activities of Common Carp

In this study, protease activities in all tissues were relatively high at a carbohydrate-to-lipid ratio of 6.8, but decreased when ratios exceeded 6.8, indicating that this ratio promotes protease activity while higher ratios inhibit it. Liu et al. [?] reported that trypsin activity in hepatopancreas decreased with increasing dietary dextrin levels in obscure pufferfish, while intestinal trypsin activity was unaffected, suggesting that high carbohydrate intake may cause liver damage and metabolic disorders. Cahu et al. [?] found that increasing dietary carbohydrate levels decreased protease activity in European seabass (*Dicentrarchus labrax*), while Gao et al. [?] reported increased protease activity in southern catfish (*Silurus meridionalis*). These discrepancies may relate to species-specific feeding habits and nutrient utilization capacities.

Under our experimental conditions, hepatopancreas and foregut amylase activities were highest in the 6.8 and 15.0 carbohydrate-to-lipid ratio groups, indicating that dextrin addition stimulates amylase activity as a self-regulatory response to high carbohydrate intake, consistent with findings in obscure pufferfish [?], freshwater black seabream [?], and Nile tilapia [?]. Conversely, higher amylase activities in midgut and hindgut occurred at lower carbohydrate-to-lipid ratios, suggesting that lipid addition also promotes intestinal amylase activity.

Wang et al. [?] reported that intestinal amylase activity in red seabream (*Pagrus major*) was induced by food, while lipase activity was negatively correlated with dietary lipid level.

Changes in lipase activity reflect fat utilization capacity. In this study, lipase activities in all tissues peaked at a carbohydrate-to-lipid ratio of 15.0, suggesting that excessive carbohydrates may be converted to fat deposited in hepatopancreas or mesentery, thereby affecting lipase activity. Some studies indicate that dietary lipid level does not significantly affect lipase activity [?, ?], while Han et al. [?] reported that high dietary lipid levels significantly inhibited foregut and midgut lipase activity in GIFT tilapia. The effects of dietary carbohydrate-to-lipid ratios on lipase activity remain controversial and require further investigation.

Conclusion

The optimal dietary carbohydrate-to-lipid ratio for growth in common carp was 6.8, while digestive enzyme activities remained high at ratios of 6.8–15.0. Based on comprehensive evaluation of growth performance, body composition, blood indices, and digestive enzyme activities, the appropriate dietary carbohydrate-to-lipid ratio for common carp is 6.8–15.0.

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