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Influence of Dietary Protein Content on Growth Performance, Feed Efficiency, Condition Factor, and Length-Weight Relationship in *Cyprinus carpio* during the Summer Season

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ABSTRACT

An investigation was carried out to explore the effect of dietary protein on growth, feed utilization efficiency, condition factor, and length-weight relationships in common carp (*Cyprinus Carpio*). 3600 *C. carpio* were sourced from a Mosul fish hatchery and transported to a private farm in Khanki township, where they were divided into four groups of 900 each. Following a day of acclimation, the fish were placed in 4× 4× 3m water culture ponds and fed diets with different protein concentrations (T1: 30%, T2: 28%, T3: 30%, and T4: 35%) for 90 days. From each group, twenty fish were selected for data collection. Results indicated that the growth parameters, such as daily weight gain, total weight gain, weight gain rate, relative growth rate, metabolic growth rate, and specific growth rate, were higher in fish fed a 28% protein diet (T1) compared to other protein concentrations (T1: 30%, T3: 26%, and T4: 35%). Nutrient utilization parameters, including daily feed consumption, total feed consumption, daily protein consumption, and total protein consumption, were elevated in fish fed with 35% protein (T3). T2 exhibited a significantly higher feed efficiency ratio and protein productive value compared to other diets. The feed conversion ratio was markedly decreased in fish fed a 28% protein diet (T2). Fulton condition factor and modified condition factor were significantly elevated ($P< 0.05$) with a 28% protein diet (T2), while the relative condition factor decreased. The length- weight relationships indicated isometric growth in T3 (26, 35%), allometric positive growth in T2 (28%), and negative growth in T1 (30%). In conclusion, the study highlighted the superior growth performance and nutrient utilization efficiency in common carp when fed a 28% protein diet (T2).

INTRODUCTION

Following decades of rapid expansion, aquaculture has emerged as the fastest-growing sector in animal food production globally. In 2022, the worldwide production of aquaculture, reaching 87.5 million tons, exceeded marine capture (78.8 million tons), and identified itself as the main source of aquatic animals for human consumption **(Yuan *et al.*, 2023)**. In Iraq, the agricultural sector remains a significant source of sustenance for the impoverished and those facing food insecurity, serving as the primary generator of rural employment. Although its contribution to the gross domestic product has decreased from approximately 9% in 2002 to 3.3% in 2008 and 3.6% in 2009, making it the second-largest contributor after oil revenues, agriculture still accounts for 20% of employment. With a population of around 32 million, of which one-third reside in rural areas relying on agriculture for their livelihoods, the national population growth rate is about 3% **(Mahmud, 2021)**. Investing in fish farming projects is considered one of the most favorable investment opportunities in Iraq, especially contributing to food security **(Al-Qudsi & Alamili, 2023)**.

Common carp (*Cyprinus carpio*) is a resilient fish known for its rapid growth and ability to endure challenging environments **(Mizory & Altaee, 2023)**. The cost of feed constitutes approximately 50- 80% of the total cultivation expenses in aquaculture. As a result, ensuring an adequate nourishment becomes an important aspect of achieving a well-balanced diet while reducing production costs **(Hasan & Soto, 2017)**. Researchers have endeavored to decrease this percentage by exploring alternatives to diet ingredients. They have investigated the inclusion of cost-effective food additives, readily available, as partial or complete substitutes for components in the diet **(Maaruf & Akbay, 2020)**. Protein, a significant component in aquafeeds for fish growth and energy source, is getting more attention to control its supplementation due to the adequate supply of protein sources **(Wang *et al.*, 2022)**. An elevated intake of protein in the diet adds to the difficulties of nitrogen excretion in aquatic organisms, leading to water pollution in aquaculture farms. This, in turn, hinders the growth of farmed animals and substantially raises the expenses associated with aquaculture **(Yuan *et al*., 2023)**.

As a result, determining the appropriate amount of dietary protein is critical from both biological and economic perspectives. However, the diversity of proteins in terms of amino acid content causes physical variances in the protein’s properties of different origins **(Hua *et al.*, 2019)**. The primary purpose of this study was to explore the adverse effects of reduced dietary protein consumption on fish production. Likewise, the research attempted to identify the feed with the best economic and ecological performance.

MATERIALS AND METHODS

Study area

The Tigris River stands as one of the most pivotal rivers in western Asia, deriving its primary source from Hazar Lake in the southeastern part of Turkey. The total catchment area upstream of the Mosul Dam reservoir is estimated to be approximately 54,900 square kilometers, with shared contributions from Turkey, Syria, and Iraq **(Al-Ansari *et al*., 2015)**. Mosul Dam (Chambarakat Dam) is located in western Mosul. The selected site for fish farming using cage fish culture is in the Khanki Township, Sumel District, Duhok Governorate, Kurdistan Region. This location was chosen due to its recognized status as the primary area for circular cage fish farms. Numerous fish farms have been established in this region **(Ahmed, 2023)**.

Designing experiments and crafting dietary composition

A total of 3,600 *C. carpio,* all of the same age, were obtained from a dedicated fish hatchery in Mosul. The fish had an average body weight (BW) of 150.9± 2.34 grams, a total length (TL) of 23.28± 1.055cm, fork length (FL) of 21.85± 0.89cm, and standard length (SL) of 19.86± 0.66cm. These fish were transported from Mosul under suitable conditions in the early morning to secure their transportation during the long distance to an aquaculture site, specifically in a plastic rectangular pond located in the southwestern part of Dohuk Governorate in Khanki Township, Sumel district. The fish were checked again and acclimated one day before being released to the water culture pond (4× 4× 3m). The fish were divided into four groups, and each pond contained nine hundred fish. The first group (T1), second group (T2), third group (T3), and final group (T4) were all provided with a commercial extruded floating diet, each containing varying concentrations of crude protein (T1: 30%, T2: 28%, T3: 26%, and T4: 35%). The feed was procured from the aquatic feed production complex, in Arak, Iran through the *Kimiyagran-e-taghziyeh* company. The feed underwent examination using a specialized instrument from Perten (PerkinElmer Company), as shown in Table (1). This feeding regimen was administered for 90 days, with a daily feeding amount equivalent to 3% of the estimated fish weight based on the total biomass of the fish **(Soliman *et al*., 2022)**. The feed quantity was modified based on the average body weight of the sample, adjusting it to correspond with the new fish biomass.

Table 1. The composition and nutritional elements (%) of the four test diets

Type of food	T1	T2	T3	T4
Minimum amount of protein	**30%**	**28%**	**26%**	**35%**
Minimum amount of carbohydrate	**40**	**45**	**45**	**45**
Maximum amount of fat	**6**	**6**	**6**	**6**
Maximum amount of fiber	**8**	**8**	**8**	**8**
Maximum amount of ash	**10**	**10**	**10**	**10**
Humidity	**10**	**10**	**10**	**10**

The parameters of the water in the aquaculture pond aquarium were assessed using various instruments and a multimeter. These parameters included temperature (25.3 C^{o}), pH (7.9), electrical conductivity (453µS/ cm), total dissolved solids (290ppm), turbidity (3.4), dissolved oxygen (5.9mg/ l), total hardness (238mg/ l), biological oxygen demand measured over 5 days (2.7mg/ l), total alkalinity (135mg/ l), and salinity (0.31ppt). Over 90 days of feeding, twenty fish were randomly collected from each group to measure the length and weight, while the remaining fish were sold in a designated aquatic marketplace.

Morphological indicators

Dimensions and mass of the fish

The fish's length was determined using a slide caliper. The measurements included three different lengths: total length (TL) (measured from the snout to the caudal fin), standard length (SL) (measured from the snout to the end of the tail), and fork length

(FL) (measured from the snout to the middle of a concave tail) **(Ullah *et al.,* 2022)**. The body weight was assessed using a digital balance adventure **(Al Sulivany *et al.,* 2024)**.

Measurement of growth performances

Daily weight gain (DWG) applies to the measure of weight acquired by the fish in one day; whereas total weight gain (TWG) applies to the entirety of the amount of weight collected by fish during a given period **(Hassan *et al*., 2021)**. Weight growth rate (WGR), calculates the percentage increase in weight of the fish over a specified period, relative to its initial weight **(Guo *et al*., 2021)**. The relative growth rate (RGR) is a measure of the proportional increase in the size of fish relative to its time **(Lieke *et al*., 2021)**. Metabolic growth rate (MGR) is the relationship between an individual fish's growth and its metabolic rate **(White *et al*., 2022)**. Specific growth rate (SGR) refers to the percentage increase in the body weight of an individual fish per unit of time **(Mizory & Altaee, 2023)**.

DWG (g) = [(FW – IW)/t] × 100.
TWG (g/day) = (FW – IW).
WGR (%) = [(FW-IW) / IW] × 100.
RGR (%) = [(In (FW) – In (IW))/ IW] × 100.
MGR (gkg$^{0.8}$ day^{-1}) = (TWG) / [{(IW/1000)$^{0.8}$ + (FW/1,000)$^{0.8}$}] /2.
SGR (%) = [(ln (FW)-ln (IW))/ t] ×100.
Where, IW and FW are the mean initial and final fish weights, and t is the duration of the experimental period.

Metrics fish feeding efficiency

Total feed consumed (TFC) represents the quantity of feed consumed by a group of fish during a specified time frame, as defined by **Folorunso *et al.* (2017)**. Total protein consumed (TPC) quantifies the overall protein intake by a group of fish over a specific duration, as outlined by **Colombo *et al*. (2023)**. The feed efficiency ratio (FER), described by **Gabriel *et al* (2021)** measures fish growth through the amount of feed consumed. The protein efficiency ratio (PER), as defined by **Singh *et al.* (2011)** signifies the growth in body mass relative to protein intake. The protein productive value (PPV), introduced by **El-Dahhar *et al.* (2016)** is an indicator evaluating the efficiency of protein utilization in fish. Net protein utilization (NPU) offers a metric for the efficiency of protein utilization. Feed conversion ratio (FCR), calculated according to **Singh *et al.* (2011)** is determined as the kilograms of feed required to produce one kilogram of whole fish. All these metrics were computed using the following equation:

TFC (g/day) = Number of fish× Average feed intake per fish × t.
DFC (g/day) = TFC/t.
TPC (g/day) = TFC × Protein content of the diet.
DPC (g/day) = TPC/t.
FER (%) = WG/Dry weight of the diet.

PER (%) = WG/Dry weight of protein.
PPV (%) = (WG/TPC) ×100.
NPU (%) = WG/ Total protein intake.
FCR = Feed consumed/WG.

Length- weight relationship and condition factor

The length- weight relationship in fish is a mathematical correlation that helps express the connection between the length and weight of a fish **(Chang *et al*., 2022)**. The Fulton's condition factor (*K*) is a morphometric index used to assess the overall health and well-being of a fish based on its weight and length **(Hvas *et al*., 2022)**. The modified condition factor (*Kb*) is a variation of Fulton's condition factor that incorporates the cube root of fish weight to provide a more sensitive measure of condition **(Mrdak *et al*., 2023)**. The relative condition factor (*Kn*) is another adaptation of Fulton's condition factor, taking into account the expected relationship between weight and length for a healthy population **(Dietz *et al*., 2019)**. The following equation was used to calculate the length-weight relationship and condition factor:

LWR (g/cm) = $a \times L^b$.
K = $100 \times W/L^3$.
Kb = $100 \times W/L^b$.
Kn = $W/ {}^{\wedge}W$.

Where, W is the weight of fish in gr; L is the length of fish in centimeters; a is the rate of change in weight with length (intercept); b is the weight at unit length (slope), and ${}^{\wedge}W$ denotes the anticipated weight.

Statistical analysis

Statistical analyses were conducted using the Graph Pad Prism program (version 8) from Graph Pad Prism Software in Finland. Morphological performance and feed utilization were assessed using Kruskal-Wallis tests (ANOVA). The results were expressed as means ± SEM. The length- weight relationship (LWR) between length and body weight was determined by connecting log-transformed data with fish length and analyzing it through linear regression.

RESULTS

The current investigation discloses that the incorporation of protein at a concentration of 28% (T2) over 90 days, amidst diverse environmental conditions characteristic of the hot summer in the northern region of Iraq, leads to a substantial enhancement ($P< 0.01$) in growth performance and metabolic rate (DWG, TWG, WGR, RGR, MGR, and SGR). The results, exhibiting a mean SE of 18.53± 0.138, 1668± 12.48, 1106± 12.08, 49.63± 0.267, 20.21± 0.058, and 3.235± 0.003, manifest a noteworthy improvement compared to fish nourished with pellets containing protein concentrations of 30% of T1, 26% of T3, and 35% of T4, as illustrated in Table (2) and Fig. (1A, B, C, D, E, and F).

Table 2. Growth performance of *Cyprinus carpio* over 90 days when subjected to four different experimental diets.

Parameter	T1 (30%)	T2 (28%)	T3 (26%)	T4 (35)
ITL (cm)	23.7±0.127	23.8±0.137	24±1.317	23.9±1.332
FTL (cm)	33.9^{b}±0.22	32.85^{a}±0.26	33.94^{b}±0.28	33.06^{b}±0.3076
IFL (cm)	21.73±0.123	21.82±0.145	21.98±0.173	21.93±0.124
FFL (cm)	31.4^{b}±0.228	30.35^{a}±0.22	31.4b^{c}±0.38	30.56^{b}±0.31
ISL (cm)	19.7±0.127	19.8±0.134	20.1±0.199	19.9±0.123
FSL (cm)	28.4^{c}±0.228	27.35^{b}±0.24	28.61^{a}±0.32	27.56^{bc}±0.32
IBW (g)	151.1±1.018	151±2.77	150.5±2.23	151.4±2.821
FBW (g)	1400^{a}±21.72	1819^{b}±14.62	1356^{a}±33.4	1655^{c}±14.77
DWG (g/day)	13.87^{a}±0.237	18.53^{b}±0.138	13.39^{a}±0.312	16.7^{c}±0.232
TWG (g/day)	1249^{a}±21.34	1668^{b}±12.48	1205^{a}±28.77	1503^{c}±18.44
WGR (%)	826.7^{a}±13.43	1106^{bc}±12.08	802.5^{a}±21.2	994.4^{c}±11.14
RGR (%)	44.34^{a}±0.31	49.63^{bc}±0.267	43.79^{a}±0.521	47.66^{c}±0.281
MGR (gkg$^{0.8}$ day^{-1})	18.13^{a}±0.1164	20.21^{b}±0.058	17.87^{a}±0.177	19.45^{c}±0.059
SGR (%)	3.121^{a}±0.0068	3.235^{d}±0.003	3.106^{a}±0.0094	3.194^{c}±0.0032

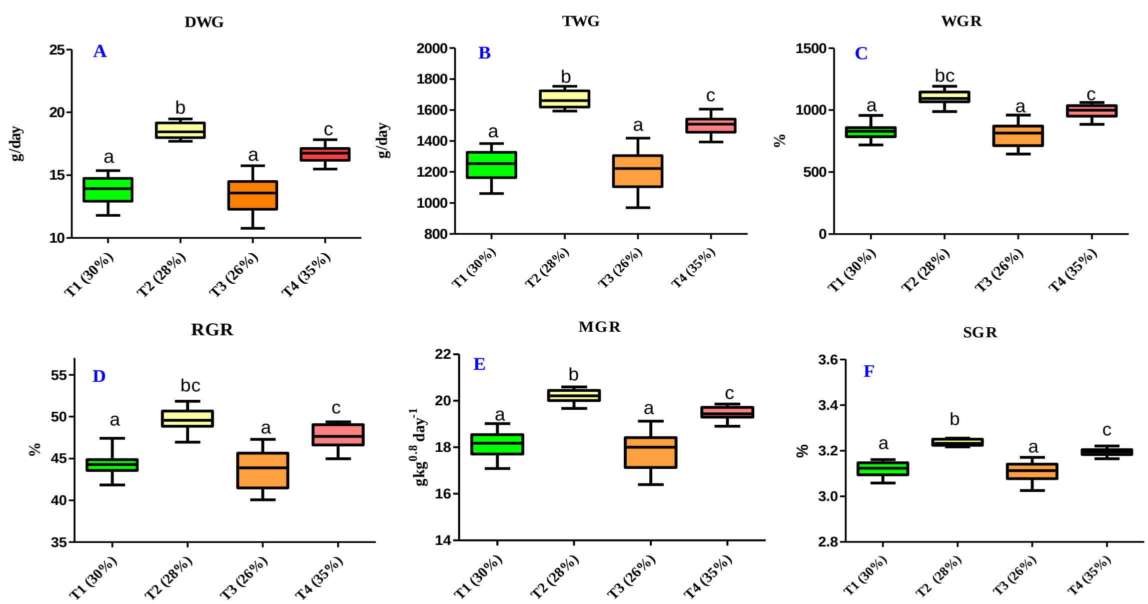

Fig. 1. The effect of varying levels of dietary protein on the growth performance of *Cyprinus carpio*. Note, data are displayed as means with standard error (SE). Significant differences *(P*< 0.05- 0.01) are indicated by distinct superscripts (a, b, and c). The abbreviations used include DWG for daily weight gain, TWG for total weight gain, WGR for weight growth rate, RGR for relative growth rate, MGR for metabolic growth rate, and SGR for specific growth rate

Measurement of feed utilization

The examination of the influence of varying dietary protein levels on feed utilization reveals a comprehensive array of parameters encompassing daily feed consumption (DFC), total feed consumption (TFC), daily protein consumption (DPC), total protein consumption (TPC), feed efficiency ratio (FFR), protein efficiency ratio (PER), protein productive utilization (PPV), NPU and feed conversion ratio (FCR) in fish (Table 3 & Fig. 2A, B, C, D, E, F, G, H, and I). Remarkably, fish feed pellets containing 28% protein (T2) exhibited heightened levels of DFC and TFC in comparison to T1 (30%), T3 (26%), and T4 (35%) fish *(P*< 0.05). This distinction is substantiated by mean and standard error (SE) values of 0.466± 0.0076 and 41.99± 0.65, respectively. Conversely, a discernible elevation *(P*< 0.01-0.05) in protein consumption was noted in the fish-fed diets with 35% of T4 and 28% of T2 protein, relative to groups T1 and T3.

The augmentation in feed efficiency was statistically significant *(P*< 0.05) when fish were subjected to diets with 28% protein (T2), while PER and NPU experienced a decline with the escalating dietary protein intake, particularly evident in fish T4 and T2. However, the PPV of fish in the T2 group surpassed that of T1, T3, and T4, attaining statistical significance at a lower level *(P*< 0.05). The optimal fish farming performance was shown in the T2 group, indicated by an FCR rate of 2.945± 0.0027, in contrast to T1 (3.03±0.0053), T3 (3.041±0.0092), and T4 (2.972c±0.0031).

Table 3. The feeding utilization of *Cyprinus carpio* over 90 days when subjected to four different experimental diets

Parameter	T1 (30%)	T2 (28%)	T3 (26%)	T4 (35)
DFC (g/day)	0.466^{c}± 0.0076	0.6^{a}±0,004	0.452^{c}±0.0095	0.55^{b}±0.004
TFC (g/day)	41.99^{a}±0.65	54.57^{b}±0.77	40.67^{a}±2.54	49.64^{c}±1.33
DPC (g/day)	0.14^{a}±0.0021	0.16^{ab}±0.0011	0.11^{b}±0.0015	0.19^{c}±0.0015
TPC (g/day)	12.6^{a}±0.195	15.28^{b}±0.11	10.57^{a}±0.22	17.37^{c}±0.13
FER (%)	0.33^{b}±0.0005	0.33^{a}±0.0003	0.32^{b}±0.0009	0.33^{c}±0.0003
PER (%)	1.33^{a}±0.007	1.32^{ac}±0.007	1.423^{c}±0.011	1.06^{b}±0.005
PPV (%)	0.042^{a}±0.009	0.044^{c}±0.003	0.042^{a}±0.0005	0.032^{b}±0.00027
NPU (%)	47.86^{a}±0.176	47.64^{a}±0.114	51.32^{c}±0.111	38.08^{b}±0.19
FCR	3.03^{a}±0.0053	2.94^{bc}±0.0027	3.04^{a}±0.0092	2.97^{c}±0.0031

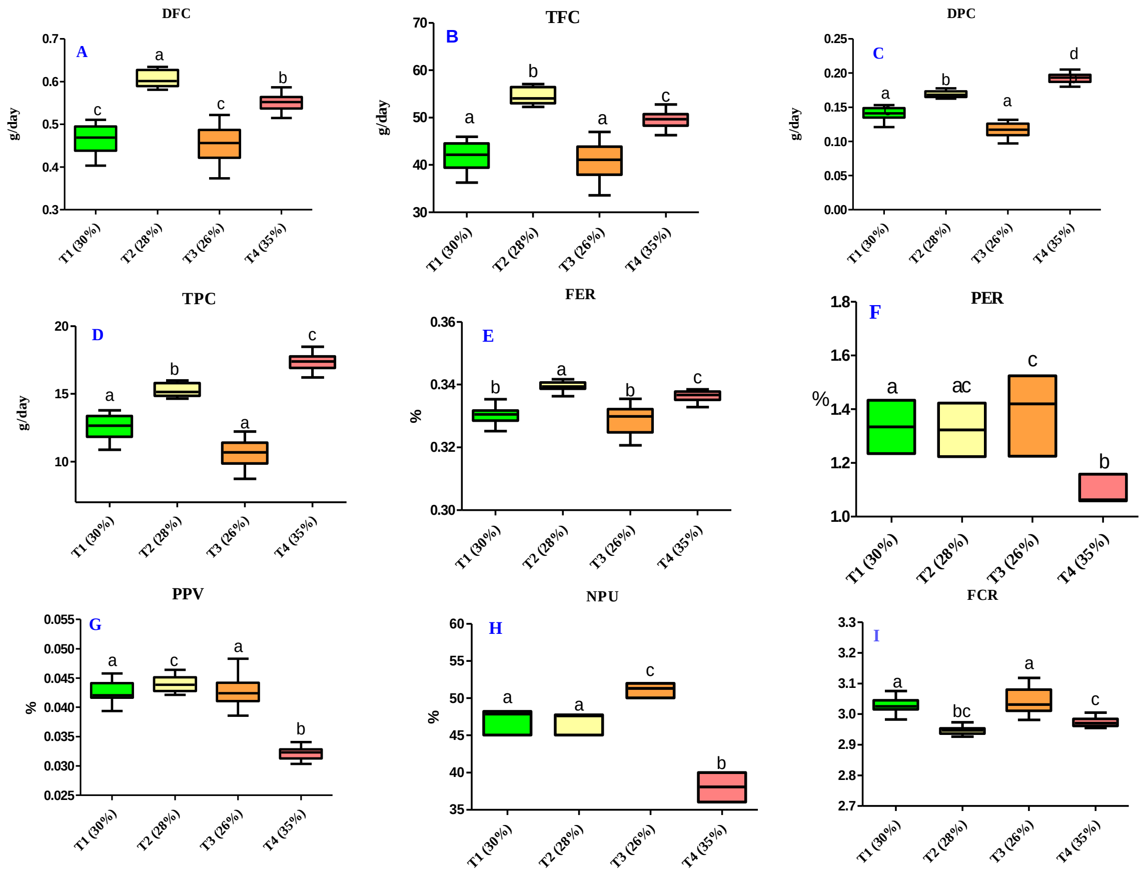

Fig. 2. The effect of varying levels of dietary protein on the feed utilization of *Cyprinus carpio*. Note, data are displayed as means with standard error (SE). Significant differences *(P*< 0.05- 0.01) are indicated by distinct superscripts (a, b, and c). The abbreviations used include DFC for daily feed consumed, TFC for total feed consumed, DPC for daily protein consumed, TPC for total protein consumed, FER for feed efficiency ratio, PER protein efficiency ratio, PPV for protein productive value, NPU for N=net protein utilization, and FCR for feed conversion ratio

Length weight relationships (LWR)

A comprehensive presentation of descriptive statistics and evaluated parameters about weight and length in fish-fed diets with different protein concentrations (T1: 30%, T2: 28%, T3: 26%, and T4: 35%) is provided. This includes essential information such as regression parameters (a and b) of the length- weight relationship (LWR), and their 95% confidence limits, along with the coefficient of determination (r^2) are present in Table (4) and Fig. (3A, B, C, D, E, F, G, H, and I) All relationships were revealed enhanced but statistically non-significant *(P*≥ 0.05) with r^2 values of the species. In the current study, the calculated growth coefficient of the (a) value of LWRs ranged from 0.34± 0.03 in the T2 (28%) group at the beginning of the experiment to 3.76± 0.34 in the same fish at the final experiment. The coefficients of determination (r^2) ranged from 0.0000048 in the fish fed diets with T1 (30%) of protein to 0.178 in the same fish at the final experiment. The LWRs indicated an isometric growth in the fish fed diets with T3 (26%) and T4 (35%) of protein (3.04± 0.028, 3.21± 0.0058), negative allometric growth appeared in the fish-fed diets with T1 (30%) of protein (2.47± 0.045), and positive allometric growth *(P*≤ 0.01) showed in the fish fed diets with T2 (28%) of protein (4.32± 0.025) when compared with all other groups.

Table 4. The length-weight relationships (LWR) of *Cyprinus carpio* over 90 days when subjected to four different experimental diets

Length weight relationship							
Treatment	**Mean±SE**	**a**	**b**	**95% CI a**	**95% CI b**	**r2**	**P value**
Before experiment							
T1	2.18^{a}±0.02	2.18 ± 0.4	-0.0027± 0.2	1.33 to 3.03	4.88 to +infini	0.0000048	0.99
T2	0.83^{b}±0.01	0.34 ± 0.03	-0.07 ± 0.21	0.28 to 0.41	0.78 to +infini	0.006273	0.73
T3	1.55^{c}±0.08	1.24 ± 0.28	0.67 ± 0.20	0.64 to 1.84	-7.7 to -0.57	0.3698	0.004
T4	2.44^{d}±0.05	2.34 ± 0.59	-0.12 ± 0.43	1.08 to 3.60	3.48 to +infini	0.004336	0.78
After Experiment							
T1	2.47^{a}±0.045	1.62± 0.77	0.99 ± 0.50	0.002to 3.2	Infini to 0.001	0.178	0.0639
T2	4.32^{d}±0.025	3.76 ± 0.34	-0.33 ± 0.23	3.02 to 4.49	5.51 to +infini	0.1021	0.1697
T3	3.04^{c}±0.028	2.6 ± 0.71	0.28 ± 0.46	1.19 to 4.18	infini to -0.9	0.02076	0.5445
T4	3.21^{b}±0.0058	3.16 ± 0.16	0.036 ± 0.10	2.8 to 3.5	infini to -10.8	0.0064	0.7357

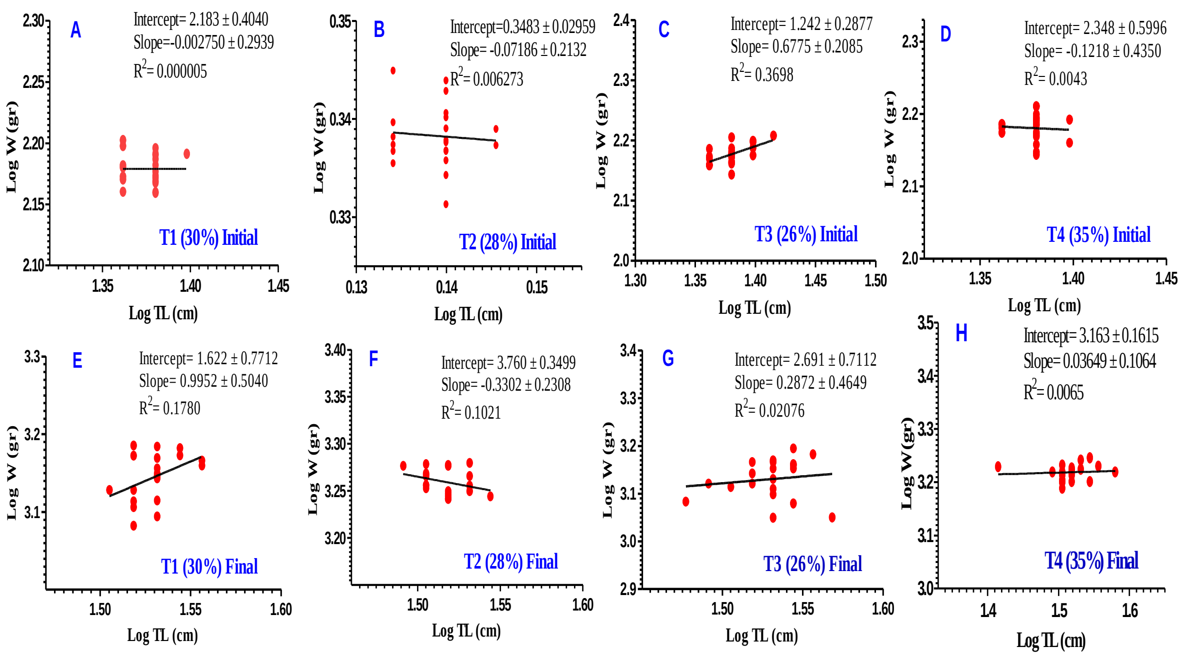

Fig. 3. The effect of varying levels of dietary protein on the length- weight relationship of *Cyprinus carpio* at the beginning and final of the experiment

Condition factor

Table (5) and Fig. (4A, B, C, D, F, and F) reveal highly significant elevation differences *(P*≤ 0.01) in the *K* values. Specifically, fish subjected to diets with 28% protein content (T2) exhibited a *K* value of 5.2± 0.11, sharply contrasting with those in groups (T1, T3, and T4), where K values were 3.6± 0.071, 3.5± 0.12, and 4.5± 0.13, respectively.

Furthermore, a remarkable observation was made concerning the *Kb*, where a high value is generally considered indicative of robust health and optimal condition in fish, signifying adequate nourishment and sufficient energy reserves. By this, a high *Kb* value *(P*≤ 0.05) was identified in fish subjected to diets with 28% protein (T2, 2.84± 0.0036). Additionally, elevated *Kb* values were evident in fish receiving diets with 26% protein (T3, 2.77c± 0.0083), whereas a lower value was observed in the group with 30% protein content (T1, 2.06± 0.0045). The relative condition factor (*Kn*) provided further insights, with the expected value appearing in fish-fed diets with 28% protein (T2, 0.99b± 0.008, *P*≤ 0.001). Conversely, an excessive condition of Kn was evident in fish exposed to diets containing 30% protein (T1, 2.96± 0.01). These findings collectively underscore the impact of protein content on the condition factors of common carp, shedding light on the intricate relationship between dietary composition and the health parameters of the studied fish population.

Table 5. Fulton's (K), modified (Kb) and relative (Kn) condition factors of *Cyprinus carpio* over 90 days when subjected to four different experimental diets

Treatment	**Condition factor**		
	K	***Kb***	***Kn***
Before experiment			
T1	1.139±0.021	2.177^{a}±0.0029	0.999^{a}±0.0013
T2	1.125±0.021	2.088^{b}±0.0036	0.962^{b}±0.0017
T3	1.094±0.023	1.991^{bc}±0.05	0.981^{bc}±0.035
T4	1.113±0.021	2.086^{b}±0.0042	0.962^{ac}±0.002
After experiment			
T1	3.6^{a}±0.071	2.06^{a}±0.0045	2.96^{a}±0.01
T2	5.2^{b}±0.11	2.84^{b}±0.0036	0.99^{b}±0.008
T3	3.5^{a}±0.12	2.77^{c}±0.0083	1.32^{c}±0.004
T4	4.5^{bc}±0.13	2.76^{c}±0.0054	1.19^{d}±0.002

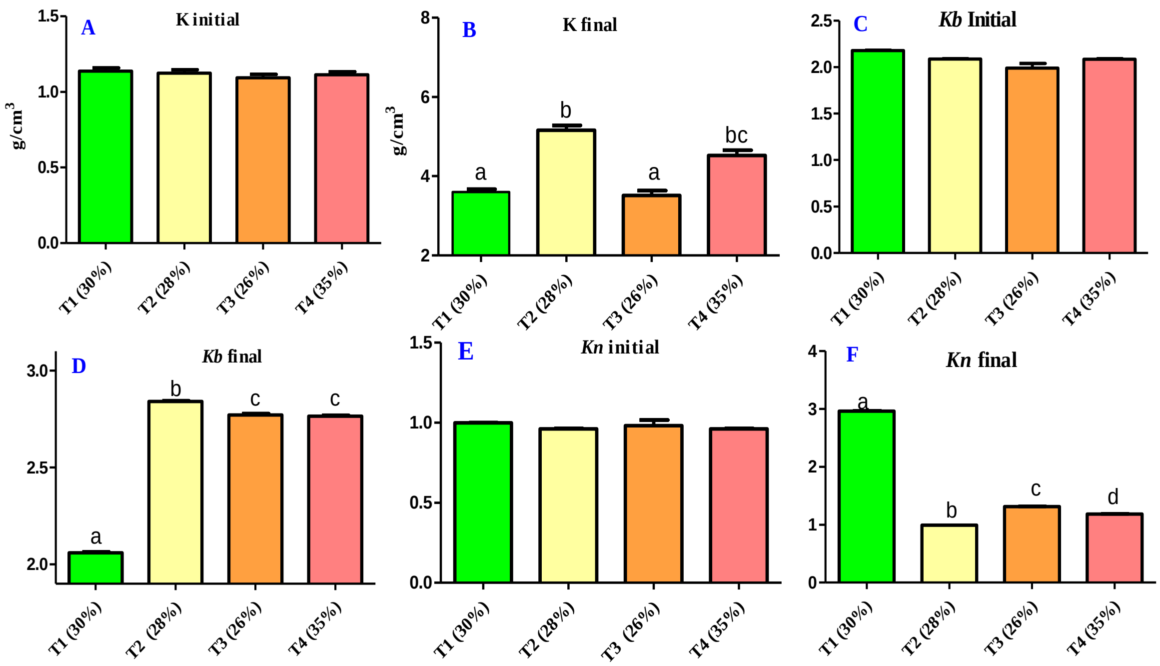

Fig. 4. The effect of varying levels of dietary protein on the condition factor of *Cyprinus carpio*. Note, data are displayed as means with standard error (SE). Significant differences (*P*< 0.05- 0.01) are indicated by distinct superscripts (a, b, c, and d). The abbreviations used include *K*, Fulton condition factor, *Kb* for modified condition factor, and *Kn* for relative condition factor

DISCUSSION

Protein nutrition stands out as the most extensively researched domain within fish nutrition **(Gebauer *et al.*, 2023)**. In the initial forays into employing compound diets for fish culture, numerous endeavors have been dedicated to delineating the optimal protein content in the diet **(Bullon *et al.*, 2023)**. Protein in fish diets is acknowledged as an essential yet costly nutrient, exerting a direct influence on feed consumption, fish development, and associated feed expenditures **(Radhakrishnan *et al.*, 2020)**. **Kamalam *et al.* (2020)** asserted that fish necessitate a higher amount of dietary protein compared to other vertebrates.

The present study showed significant effects of dietary protein levels on the growth performance of carp. DWG, TWG, WGR, RGR, MGR, and SGR were improved after dietary protein levels at a concentration (T2, 28%). A study on the Yellow River Carp demonstrated that the fish's WG and SGR were significantly influenced by the dietary protein level, with an ascending trend up to 250g/ kg **(Wang *et al.*, 2023)**. Another study found that increased dietary protein improved the growth of both growth hormone gene (GH) transgenic and non-transgenic carp **(Guo *et al.*,**

2021). Additionally, the growth parameters were shown to increase with dietary protein levels up to 35% in another study **(Barlaya *et al.*, 2022)**. However, it is important to note that the relative GH expression of carp muscle significantly decreased with the increasing dietary protein level up to 310g/ kg in the Yellow River Carp study, and then it significantly increased **(Wang *et al*., 2023)**.

The elevation in DFC, TFC, DPC, TPC, FFR, and PPV in fish obtained diets containing 28% protein (T2) compared to the fish feeds (T1: 30%, T3: 26%, and T4: 35% of protein) can be attributed to several factors supported by existing research. The observed augmentation in feed efficiency in fish-fed diets with 28% protein is consistent with research on the optimization of protein in supplementary feeds for pond-raised cyprinids, which showed that net fish yield is enhanced as the level of digestible protein in the supplementary diets increased and plateaued at 28% dietary protein level **(Zeb & Javed, 2018)**. Additionally, a study on the Far Eastern catfish (*Silurus lotus*) showed that DFC and DPC were significantly affected by dietary protein levels, with the final mean weight improved with increasing dietary protein levels, indicating a positive correlation between protein levels and feed consumption **(Kim *et al.*, 2012)**.

The decline in PER and NPU with escalating dietary protein intake, particularly evident in fish-fed diets with 35 and 28% protein, can be explained by when insufficient non-protein energy is available in the diet, part of the dietary protein will be catabolized to supply energy, leading to a decline in PER and NPU **(Sankian *et al.*, 2017)**. This is in agreement with other studies showing that the PER was significantly decreased with increasing dietary protein levels **(Kim *et al.*, 2012)**. Additionally, the use of high-fat diets in aquaculture to save protein and reduce feed costs can cause lipid deposition and impair flesh quality in fish, leading to a decrease in PER **(Welker *et al*., 2017)**.

Alam *et al.* (2019) observed that surplus amino acids from a protein-rich diet cannot be directly stored in the fish body; they are deaminated and transformed into compounds used for energy, resulting in a decrease in NPU. The decrease in FCR was also observed in fish feed diets with T2 (28% of protein). The decrease in FCR with increasing dietary feed consumption can be linked to the fact that fish tend to consume more protein when it is available in excess, which can lead to higher growth rates and improved feed utilization, ultimately contributing to a lower FCR **(Kim *et al.*, 2012)**.

The LWRs of fish are important for assessing the condition of fish and are widely used in fish stock assessments and biomass estimation **(Li *et al.*, 2023)**. Understanding the factors that influence these relationships, such as diet composition, is valuable for informing sustainable fishery practices and aquaculture management. The observed LWRs in this study provide valuable insights into the growth patterns of fish in response to varying dietary protein levels. The isometric growth observed in fish-fed diets with 26 (T3) and 35% (T4) protein implies a proportional increase in length and weight. This suggests that these protein levels may meet the nutritional requirements for balanced growth in the studied fish species. **Jisr *et al.* (2018)** found that the isometric growth patterns have been recognized as indicative of optimal nutritional conditions in various fish species including *Liza ramada*, *Oblada melanura*, and *Epinephelus costae*. Conversely, the occurrence of negative allometric growth in fish fed a 30% protein diet (T1) suggests that this protein concentration may not be optimal for balanced growth. Negative allometry, where length increases at a slower rate than weight, has been associated with suboptimal nutritional conditions in fish **(Jisr *et al.*, 2018)**. This finding emphasizes the importance of considering the specific dietary needs of fish to achieve optimal growth. The positive allometric growth observed in fish-fed diets with 28% protein (T2) indicates an accelerated length growth compared to weight gain. This may suggest that the 28% protein concentration is conducive to stimulating length development in the studied fish. Positive allometry has been linked to enhanced growth performance and can be indicative of favorable nutritional conditions **(Muchlisin *et al*., 2010; Nazeemashahul *et al*., 2020)**.

The elevated protein level of 28% in fish feeds has been found to have a significant impact on the models of condition factors (*K*, *Kb*, and *Kn*) of the fish. These results are in disagreement with those supported by **Yang *et al.* (2002)**, which indicates that juvenile silver perch fed diets containing 43% dietary protein had significantly higher condition factors than those fed lower dietary protein levels. Additionally, a higher dietary protein level could lead to poor feed utilization and a decrease in PER and protein retention efficiency (PRE) **(Kim *et al.*, 2016; Lu *et al.*, 2021)**. Moreover, the protein-to-energy (P/E) ratio in the diet plays a crucial role in fish growth and feed utilization, with an unbalanced ratio leading to suboptimal growth and feed efficiency **(Taj *et al.*, 2023)**. Therefore, the elevated protein level of 28% in fish feeds may have led to changes in the condition factors due to its impact on feed utilization, protein efficiency, and protein-to-energy ratio.

CONCLUSION

In conclusion, the study demonstrated that a dietary protein concentration of 28% (T2) significantly enhanced growth performance and nutrient utilization efficiency in common carp. This finding suggests the potential for optimizing feeding strategies for improved aquaculture outcomes during the summer season.

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