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Evaluation of Commercial Fish Feeds: Nutrient and Pollutant Contents, Growth and Flesh Quality Implications for Carp Fish Cultured in Bangladesh

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Abstract

As aquaculture based on commercial feed continues to grow substantially in Bangladesh, the study evaluated five widely used commercial fish feeds—Lili, One, Quality, Nabil, and ACI by analyzing their nutrient and heavy metal (Pb, Co, Cr, Cd, Ni) contents, and their impacts on the growth rate and muscle composition of four carp species: *Catla catla*, *Hypophthalmichthys molitrix,* *Labeo rohita*, and *Cirrhinus cirrhosus*. Proximate parameters and heavy metal contents of the feeds were analyzed using standard methods. A 90-day cage-based feeding trial was conducted to assess the growth and nutrient utilization of the fish, measuring mean weight gain (MWG), specific growth rate (SGR), survival rate, feed conversion ratio (FCR), and carcass nutrient composition. Although all the feeds exceeded allowable heavy metal concentrations, the ACI feed had lower heavy metal concentrations and higher protein content (23.63±0.32). Fish fed with ACI feed exhibited better MWG (288.44±4.81), SGR (0.82±0.01), and FCR (2.25±0.08), whereas fish fed with Nabil feed performed the poorest results. No significant difference was found in carcass nutrients among the fish, but those fed ACI feed exhibited relatively higher protein content. The study identified ACI feed as a superior commercial feed that enhances carp growth in the northwestern part of Bangladesh.

Introduction

Aquaculture, recognized as the most dynamic sectors of global food production, with Bangladesh showing one of the highest growth rates in this field. Freshwater aquaculture has emerged as the most prominent form of aquaculture, with fish being the leading product in freshwater systems (Olsen, 2011). Over the past two decades, the extensive use of commercial fish feeds has prominently contributed to aquaculture productivity in Bangladesh. In a few years, the aquaculture production of the country rose from 124,000 metric tons to 2,730,000 metric tons, primarily due to the application of commercial feeds (Ali et al., 2025). The increasing need for commercial fish feeds, which is driven by the intensification of aquaculture operations, considerably promotes the development and growth of several fish feed industries in Bangladesh, such as Nourish, Provita, Quality, Alo, Nilsagor, Lili, ACI, Astha, Nabil, Biswas, Mission, Saudi-Bangla, Aftab, Paragon, and Oriental Feed Ltd. The successful production of aquaculture relies on the use of well-balanced commercial feeds (Nunes et al., 2022). The nutrient content of the ingredients incorporated in feed formulation and the overall nutritional profile of feeds are important aspects of fish growth and nutrition (Rombenso, 2022). The quality of the feeds, which provide the essential nutrients for optimal growth, is

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also decisive for determining the carcass quality of fish (Mohapatra and Patra, 2013). However, due to the rising market demand for larger-sized carp fish, farmers are increasingly turning to various brands of commercial feeds to produce bigger fish. Many farmers use these commercial feeds without fully understanding their original quality and must rely solely on the nutritional information provided on the feed bag by the manufacturer.

Unfortunately, many manufacturing companies are unable to provide quality fish feed because of the limited supply of good-quality feed components, the use of substandard alternative raw materials, the inclusion of contaminated ingredients, and variable cost of ingredients (Khatun et al., 2017). The labeled nutritional value of commercial fish feeds often misleads the farmers (Rahman et al., 2014). Contaminants like toxic metals in feed can be moved in cultured fish and subsequently enter the human food chain. The ingestion of heavy metal-contaminated fish can result in their bioaccumulation in humans, potentially causing serious health risks, including cardiovascular problems, neurological complications, kidney damage, and even cancer (Almashhadany et al., 2025). Additionally, a majority of manufacturers have relied on substandard feed constituents to boost protein levels in feed, which may enhance growth but compromise the fish flesh quality. Commercial feed producers have highlighted their products from multiple perspectives, and despite their investigation findings, there is still a lack of scientific laboratory evidence in Bangladesh comparing and justifying the impacts of these feeds on fish growth and body composition. Therefore, assessing the quality of commercial feeds is essential for promoting sustainable and high-quality fish production.

However, the assessment of fish feed quality primarily considers fish growth, feed utilization efficiency, and other relevant parameters (Hernández and Roman, 2016). Several researchers (Rahman et al., 2014; Sarker et al., 2015; Hossain et al., 2017; Islam et al., 2021) investigated feed quality and their impacts on the growth and development of diverse fish species around the world. But scientific investigations regarding the assessment of commercial feeds used in carp polyculture by evaluating the proximate composition and heavy metal concentrations, along with their effects on growth and carcass composition, are few. Since feed-based carp polyculture in semi-intensive or intensive systems is commonly adopted in the Rajshahi region of Bangladesh due to its high productivity and market demand, polyculture was applied in this investigation to determine growth performance and to closely resemble the effects of polyculture of carps fed with commercial feeds. Therefore, this investigation was conducted to evaluate the quality of commercial feeds commonly used by fish farmers in the Rajshahi region of Bangladesh by analyzing their proximate compositions, heavy metal contents, and their impacts on the growth and nutrient contents of candidate carp species.

Materials and Methods

Feed Sample Collection

A survey was conducted to identify the popular commercial feeds used by farmers for carp fish farming in the Rajshahi region. Upon finishing the survey, five frequently used carp feeds (Lili, One, Quality, Nabil, and ACI Feed) were chosen and collected from dealers at different locations in Rajshahi.

Analysis of Feeds' Proximate Composition

The collected feed samples were analyzed to assess proximate content following the Association of Official Analytical Chemists (2005) methods in the Quality Control Laboratory, Faculty of Fisheries. The crude protein was determined using a micro-Kjeldahl (VELP Scientica, Italy), multiplying nitrogen by 6.25, and lipids were extracted and measured through Soxhlet apparatus (Wincom, Hunan, China). In addition, moisture and ash content were assessed by oven-drying at temperature of 105°C 91 for 24 hours and incineration at 550°C using a muffle furnace (Nabertherm GmbH, Germany) for 12 hours, respectively. The carbohydrate content was estimated by deducting the percentages of crude protein, lipid, moisture, and ash from 100, following the method described by Onyeike et al. (2000).

Determination of Heavy Contents in the Feeds and Fish Muscles

Representative feed and experimental fish muscle samples were dried in an oven and then cooled, ground, and homogenized. Then the ground samples were placed in previously cleaned and dried plastic containers and desiccated for 24 hours. In a muffle furnace, each sample was digested at 600°C over six hours. After cooling to room temperature, the resulting ash was mixed with 20 mL of 1N HCl and diluted with distilled water to a total volume of 100 mL. Subsequently, the solution was filtered using filter paper (Whatman 42) to isolate the solids for later testing. Heavy metal contents (Pb, Co, Cd, Cr, and Ni) in the digested feeds were estimated using an atomic absorption spectrophotometer with an acetylene-air flame. Calibration curves from standard solutions were used for quantification, with each sample measured three times. Absorption wavelengths and detection limits for Pb (217.0 nm, 0.001 ppm), Co (247.7 nm, 0.02 ppm), Cr (357.9 nm, 0.01 ppm), Cd (228.8 nm, 0.002 ppm), and Ni (232.0 nm, 0.01 ppm) were determined. To reduce bias, samples were coded and evaluated blindly. The amounts of each metal in the samples were computed using the formulas described by Kundu et al. (2017).

Actual metal concentration in sample (mg/kg) = AAS reading of digest x dilution factor

Dilution factor = Digest volume ⁄ Digested sample weight

Evaluation of Growth Performance of Fish

Experimental Site

The study was carried out by evaluating five commercial feeds, each administered to fish in three replicate cages, resulting in a total of 15 experimental cages that were placed in an earthen pond at the Faculty of Fisheries, University of Rajshahi, Bangladesh. The cages, measuring 2.72 m³, were made from iron rods and covered with synthetic nylon net with a mesh size of 5 mm. An opening was created on the top side of the cage to facilitate the feeding and handling of the fish.

Selection and Collection of Fish Species

Four carp species (*C. catla*, *H. molitrix, L. rohita*, and *C. cirrhosus*) were chosen for the investigation. Fish juveniles were sourced from a local farm with oxygen. The juveniles were then stocked in the cages for acclimatization.

Experimental Design

The experiment was performed using five treatments (viz., T_1, T_2, T_3, T_4, and T_5) that incorporated five types of commercial feeds (Lili, One, Quality, Nabil, and ACI) along with four carp fish species over three months (from June to August 2023). Following acclimatization, twenty-eight juveniles of each of the four carp species, appropriate to the cage volume, were stocked in each cage, maintaining a uniform density (Table 1). Throughout the experimental trial, the selected feeds were fed daily at a rate of 5% the fish's body weight, split equally between morning and evening feedings. The ration size of the fish was regulated based on their weight gain, which was monitored on a fortnightly basis.

Water Quality Monitoring

Different parameters, including pH, water temperature, dissolved oxygen (DO), carbon dioxide (CO_2), total alkalinity, and ammonia-nitrogen (NH_3-N), were measured fortnightly throughout the experimental trial. Measurements of water pH and temperature were taken using a Hanna HI-98128 digital pH meter and a Celsius thermometer, respectively. The concentrations of DO, CO_2, total alkalinity, and NH_3-N were measured with HACH Kit (Model: DR/2010). No significant differences were observed in the measured parameters, and the values remained within the fish culture productive ranges (Table 2).

Sampling and Analysis of Growth and Feed Utilization

At the start of the trial, fish from each cage were sampled and weighed. Then, measurements were taken fortnightly throughout the culture period (a total of 7 times) to record the fish weight. Growth and nutrient utilization were assessed via mean weight gain (MWG), specific growth rate (SGR), survival rate (SR), and feed conversion ratio (FCR) following the frequently used formulas (Paray et al., 2020).

$$\text{Mean weight gain} = \text{Mean final body weight} - \text{Mean initial body weight}$$

$$\text{Specific growth rate (\%/day)} = 100\ \{\ln(\text{final body weight}) - \ln(\text{initial body weight})\} / \text{Culture period}$$

$$\text{Survival rate (\%)} = (\text{Number of harvested fish}/\text{Number of stocked fish}) \times 100$$

$$\text{Feed conversion ratio (FCR)} = \text{Dry feed fed}/\text{Live weight gain}$$

Table 1. Mean stocking weight and density of the experimental fish

Species	Mean initial weight (g)	Stocking density (number/cage)
L. rohita	277.68±3.90	8
C. catla	450.15±4.03	7
C. cirrhosus	131.93±5.13	7
H. molitrix	205.28±3.01	6

Table 2. Water quality parameters in the experimental treatments

Parameters	Treatments				
	T_1	T_2	T_3	T_4	T_5
Temperature (°C)	34.56±0.62^a	33.78±1.52^a	34.42±0.40^a	33.54±0.78^a	32.54±0.70^a
DO (mg/l)	6.12±0.35^a	6.42±0.34^a	6.61±0.22^a	6.10±0.58^a	6.20±0.51^a
pH	7.42±0.08^a	7.37±0.051^a	7.42±0.86^a	7.45±0.12^a	7.48±0.12^a
Alkalinity (mg/l)	151.45±3.74^a	156.83±4.06^a	153.17±7.08^a	152.68±5.54^a	151.68±5.54^a
NH_3-N (mg/l)	0.033±0.004^a	0.034±0.003^a	0.036±0.006^a	0.035±0.006^a	0.036±0.006^a

*There was no significant ($P>0.05$) difference among the water quality parameters in the experimental site.

Collection and Analysis of Carcass Compositions of Fish

Six fish were retrieved from individual cages and euthanized upon completion of the experimental feeding. After gutting and cleaning the fish, muscle samples were taken from various body portions and kept in frozen conditions for subsequent examination. The proximate compositions (crude protein, crude lipid, moisture, ash, and carbohydrate of the carcass were determined using the method of AOAC (2005).

Economic Feasibility of the Feeds

An economic assessment was conducted based on all the costs of feed, seed, and other expenses, as well as the estimated return obtained from selling the harvested fish. The following formulas were used to assess the economics of the treatments:

Net benefit (BDT) = Total return – Total cost

Cost–Benefit Ratio (CBR) = Net benefit/Total cost

Data analysis

Normality of the data was verified prior to analysis. One-way ANOVA was conducted, followed by Duncan's multiple-range test to compare means. A P value<0.05 was considered statistically significant. All analyses were carried out through SPSS version 22 (Statistical Package for Social Sciences, USA).

Results

Proximate Compositions of Feeds

Table 3 and Table 4 present the nutrient composition found for the selected commercial fish feeds and the composition declared by the manufacturer, respectively (Figure 1). The present findings showed that all feeds contained lower levels of

Table 3. Analyzed data of proximate composition (%) of different feeds

Feed Brand	Crude Protein	Crude Lipid	Carbohydrate	Moisture	Ash
Lili	22.48±0.37^b	5.70±0.16^c	39.77±1.02^b	12.27±0.25^b	12.10±0.27^b
One	22.31±0.45^b	6.10±0.18^b	38.30±1.36^b	13.97±0.16^a	12.12±0.22^b
Quality	19.56±0.48^c	5.45±0.14^c	42.58±1.32^a	12.55±0.31^b	11.01±0.34^c
Nabil	19.20±0.35^c	5.60±0.11^c	41.73±1.10^a	12.16±0.63^b	13.05±0.44^a
ACI	23.63±0.32^a	6.67±0.17^a	38.16±1.05^b	12.64±0.48^b	11.27±0.29^b

*Values in the same column with different superscripts are significantly different (P<0.05).

Table 4. The manufacturer's stated proximate composition (%) of different feeds

Feed Brand	Crude Protein	Crude Lipid	Carbohydrate	Moisture	Ash
Lili	24	5	35	12	15
One	22	5	35	11	12
Quality	22	6	40	10	10
Nabil	24	4	40	12	21
ACI	24-25	4-5	35-40	10	10-15

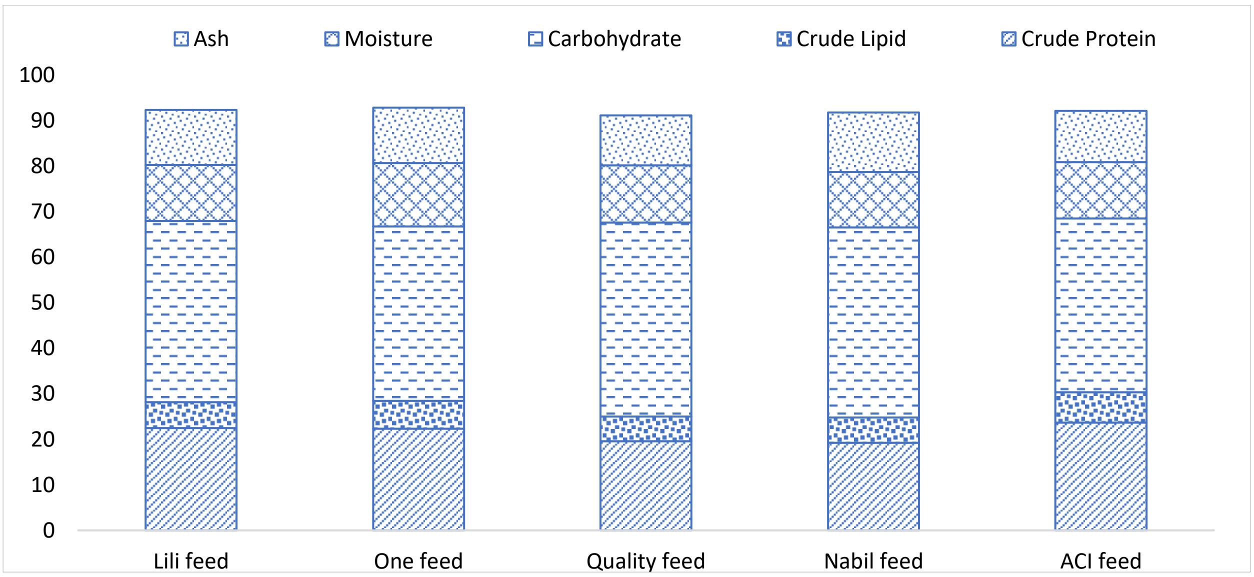

Figure 1. Comparative proximate composition of the tested fish feeds.

protein and lipid than those declared by the manufacturer. The fish (*C. catla*, *H. molitrix, L. rohita*, and *C. cirrhosus*) were given pelleted carp grower feeds formulated to suit their feeding habits. The analyzed data exhibited that ACI feed contained significantly (P<0.05) greater amounts of crude protein (23.63±0.32%) compared to both Lili and One feed, whereas Quality feed (19.56±0.48%) and Nabil feed (19.20±0.35%) showed lower crude protein levels. In One feed, the predicted protein value nearly matched the company's declared protein value. In contrast, the protein content of Quality and Nabil feed was less than 2.5–5.0 %, and the protein content of Lili and ACI feed was less than 1.0–1.5%, as indicated by the manufacturers. The ACI feed had a significantly (P<0.05) greater crude lipid level (6.67±0.17%), while the Quality feed had lower crude lipid content (5.40±0.14%). In contrast to Quality feed, which had a lipid level of less than 0.55% below the company's stated values, ACI, Nabil, One, and Lili feed had lipid contents greater than approximately 2.0, 1.5, 1.1, and 0.7%, respectively. One feed had the lowest carbohydrate content (37.3±0.36%), whereas the Quality feed had the highest (43.58±0.32%). The moisture percentages in the examined feed samples were more or less the same as those listed on the manufacturer's label. According to the feeds' moisture content analysis, one feed had the maximum moisture content (13.97±0.16%), while the Nabil feed had the lowest (12.16±0.63%). Ash content in the feed samples was found to range between 11.01 and 13.05%. Quality feed had the least amount of ash, while Nabil feed had the highest ash content.

Heavy Metal Content in Feeds

The estimated levels of heavy metals, including Pb, Co, Cd, Cr, and Ni, in the selected feeds are shown in Table 5 (Figure 2). Pb concentration varied among the feeds, with the maximum being 12.82 mg/kg in Nabil feed and the minimum being 9.47 mg/kg in ACI feed, and One feed exhibited significantly (P<0.05) higher Pb levels. Both Lili and Quality feeds showed notably increased concentrations of Co. Additionally, the highest Cr content was found in the Quality feed, whereas the

Table 5. Heavy metal content (mg/kg) in the fish feeds

Feed Brand	Heavy Metal (mg/kg)				
	Pb	Co	Cr	Cd	Ni
Lili	10.66±0.88[b]	4.53±0.62[a]	2.38±0.08[c]	2.38±0.16[ab]	3.74±0.38[a]
One	12.61±0.25[a]	2.41±0.78[b]	2.36±0.37[c]	3.22±0.44[a]	3.04±0.11[ab]
Quality	9.75±0.89[c]	4.69±0.69[a]	3.45±0.18[a]	2.30±0.27[b]	3.67±0.14[a]
Nabil	12.82±0.85[a]	2.26±0.42[b]	2.92±0.08[b]	2.68±0.33[ab]	3.57±0.57[a]
ACI	9.47±0.48[c]	1.19±0.18[c]	2.22±0.08[c]	1.33±0.34[c]	2.75±0.20[b]
Mean value	11.06±0.72	3.02±0.58	2.67±0.19	2.38±0.32	3.35±0.33
Safe limit (mg/kg)					
FAO	2.0	1.0	1.0	2.0	2.0
WHO	2.0	1.0	1.0	2.0	2.0
EU	5.0	1-5	1.0	2.0	0.1-8

*Values in the same row with different superscripts are significantly different (P<0.05).

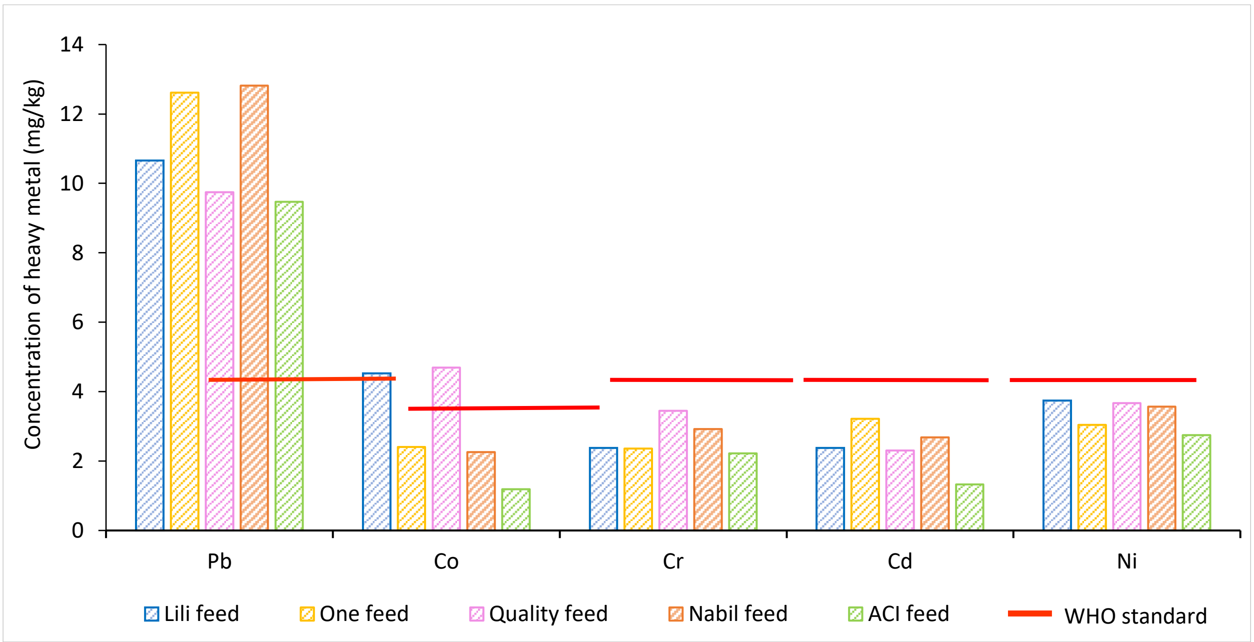

Figure 2. Concentrations of heavy metals in commercial fish feed, along with WHO-recommended values.

greatest Cd concentration was detected in the One feed. ACI feed had significantly lower concentrations of the estimated heavy metals.

Growth and Nutrient Utilization of Fish

The findings on growth and nutrient utilization parameters of the selected carps are depicted in Table 6. From the results, it was noted that, for *L. rohita*, significantly (P<0.05) higher weight gain, SGR, and better FCR were observed in T_5, whereas T_4 exhibited poorer performance in these parameters (Figure 3). Regarding *C. catla* and *C. cirrhosus*, T_5 showed noticeably greater weight gain, SGR, and better FCR than the remaining treatments. The weight gain, SGR, and FCR of *H. molitrix* were superior in T_5, followed by T_2 and T_1. Throughout the trial, survival rates of *C. catla*, *H. molitrix*, *L. rohita*, and *C. cirrhosus* ranged from 92.86% to 100%, with no significant variations observed among treatments (P>0.05).

Carcass Composition of the Fish

The data analyzed regarding the carcass composition of the fish muscle are summarized in Table 7. According to the results, the nutrient composition of the flesh showed no significant variations (P>0.05) among the experimental fish. However, all fish species fed ACI feed exhibited relatively elevated levels of crude protein in their flesh. The lipid deposition in the flesh of all experimental fish subjected to various feeds demonstrated no notable differences.

Heavy Metal Content in Fish

Among the metals analyzed in the experimental fish, Pb was recorded as the most prevalent metal, followed in decreasing order by Co, Ni, Cr, and Cd (Table 8). Among the species studied, *C. catla* had the highest levels of Pb, Cr, and Ni, whereas *L. rohita* and *H. molitrix* showed the greatest accumulation of Co and Cd, respectively. Significant variations among all the treatments (P<0.05) were found for Cr in all the species, and for Pb in *C. cirrhosis* and *H. molitrix*, Co in *L. rohita*, *C. cirrhosis* and *H. molitrix*, and Cd in *C. catla* and *H. molitrix*. However, Ni levels did not differ significantly across treatments in any species. Additionally, a Pearson correlation matrix was developed to assess the association between the feed's heavy metal concentrations and their accumulation in fish tissues (Table 9). A significant positive correlation was noticed for each metal, indicating that higher metal contents in the feed were associated with increased concentrations in the respective fish tissues.

Table 6. Growth performance and feed utilization parameters of the fish among treatments

Parameters	Species	Treatments/Feeds				
		T_1	T_2	T_3	T_4	T_5
MIW (g)	*L. rohita*	277.68±3.9^{a}	268.55±9.97^{a}	278.78±5.13^{a}	276.63±2.65^{a}	275.05±3.46^{a}
	C. catla	450.15±4.03^{a}	442.34±5.85^{a}	451.75±6.29^{a}	443.35±4.45^{a}	451.13±6.54^{a}
	C. cirrhosus	131.93±5.13^{a}	125.84±2.25^{a}	127.99±6.31^{a}	125.51±4.16^{a}	132.93±6.46^{a}
	H. molitrix	205.28±3.01^{a}	201.98±5.34^{a}	207.40±3.96^{a}	204.40±2.69^{a}	209.88±3.36^{a}
MFW (g)	*L. rohita*	620.08±7.8^{b}	619.49±8.50^{b}	582.90± 6.22^{c}	547.53±6.97^{d}	659.88±3.71^{a}
	C. catla	789.30±8.06^{b}	779.95±5.30^{b}	728.80±13.18^{c}	729.60±9.76^{c}	884.58±8.31^{a}
	C. cirrhosus	276.37±8.46^{b}	269.66±4.36^{b}	244.90±11.71^{c}	231.3±10.13^{c}	306.5±11.07^{a}
	H. molitrix	350.5±6.65^{ab}	353.20±11.81^{a}	330.98±6.4^{bc}	320.42±7.24^{c}	370.42±5.99^{a}
MWG (g)	*L. rohita*	342.40±3.90^{b}	350.94±1.47^{b}	304.3± 11.35^{c}	270.90± 9.62^{d}	384.83±7.18^{a}
	C. catla	339.15±4.03^{b}	337.6± 11.16^{b}	277.13±6.89^{c}	286.25±5.30^{c}	434.73±3.57^{a}
	C. cirrhosus	144.44±3.33^{b}	143.82±6.60^{b}	116.94±5.40^{c}	105.84±5.96^{c}	173.65±4.60^{a}
	H. molitrix	145.28±9.65^{a}	151.18±6.47^{a}	123.58±2.44^{b}	116.02±9.93^{b}	160.54±2.63^{a}
SGR (bwd^{-1})	*L. rohita*	0.89±0.02^{b}	0.94±0.03^{ab}	0.82±0.03^{c}	0.76±0.02^{c}	0.97±0.02^{a}
	C. catla	0.62±0.00 ^{b}	0.63±0.02^{b}	0.53±0.01^{c}	0.55±0.01^{c}	0.75±0.01^{a}
	C. cirrhosus	0.82±0.01^{b}	0.85±0.04^{b}	0.72±0.00^{c}	0.68±0.01^{c}	0.93±0.01^{a}
	H. molitrix	0.59±0.04^{a}	0.62±0.01^{a}	0.52±0.00^{b}	0.50±0.04^{b}	0.63±0.01^{a}
FCR	*L. rohita*	2.28±0.06^{bc}	2.25±0.04^{bc}	2.43±0.07^{ab}	2.53±0.09^{a}	2.10±0.08^{c}
	C. catla	2.37±0.16^{b}	2.40±0.06^{ab}	2.68±0.12^{a}	2.57±0.12^{a}	2.28±0.08^{b}
	C. cirrhosus	2.43±0.16^{b}	2.41±0.03^{b}	2.52±0.07^{a}	2.68±0.08^{a}	2.27±0.07^{c}
	H. molitrix	2.48±0.06^{ab}	2.38±0.13^{b}	2.57±0.12^{ab}	2.71±0.06^{a}	2.33±0.09^{b}
SR (%)	*L. rohita*	100.00±0.00^{a}	97.77±8.84^{a}	100.00±0.00^{a}	100.00±0.00^{a}	100.00±0.00^{a}
	C. catla	100.00±0.00^{a}	100.00±0.00^{a}	100.00±0.00^{a}	100.00±0.00^{a}	100.00±0.00^{a}
	C. cirrhosus	100.00±0.00^{a}	100.00±0.00^{a}	92.86±10.10^{a}	100.00±0.00^{a}	100.00±0.00^{a}
	H. molitrix	100.00±0.00^{a}	100.00±0.00^{a}	100.00±0.00^{a}	97.67±7.79^{a}	100.00±0.00^{a}

*MIW = Mean Initial Weight, MFW = Mean final Weight, MWG = Mean Weight Gain, SGR = Specific Growth Rate, FCR = Food Conversion ratio, SR = Survival Rate. T_1, T_2, T_3, T_4, and T_5 were treated as fish groups fed with Lili feed, One feed, Quality feed, Nabil feed, and ACI feed, respectively. Values in the same row with different superscripts are significantly different (P<0.05).

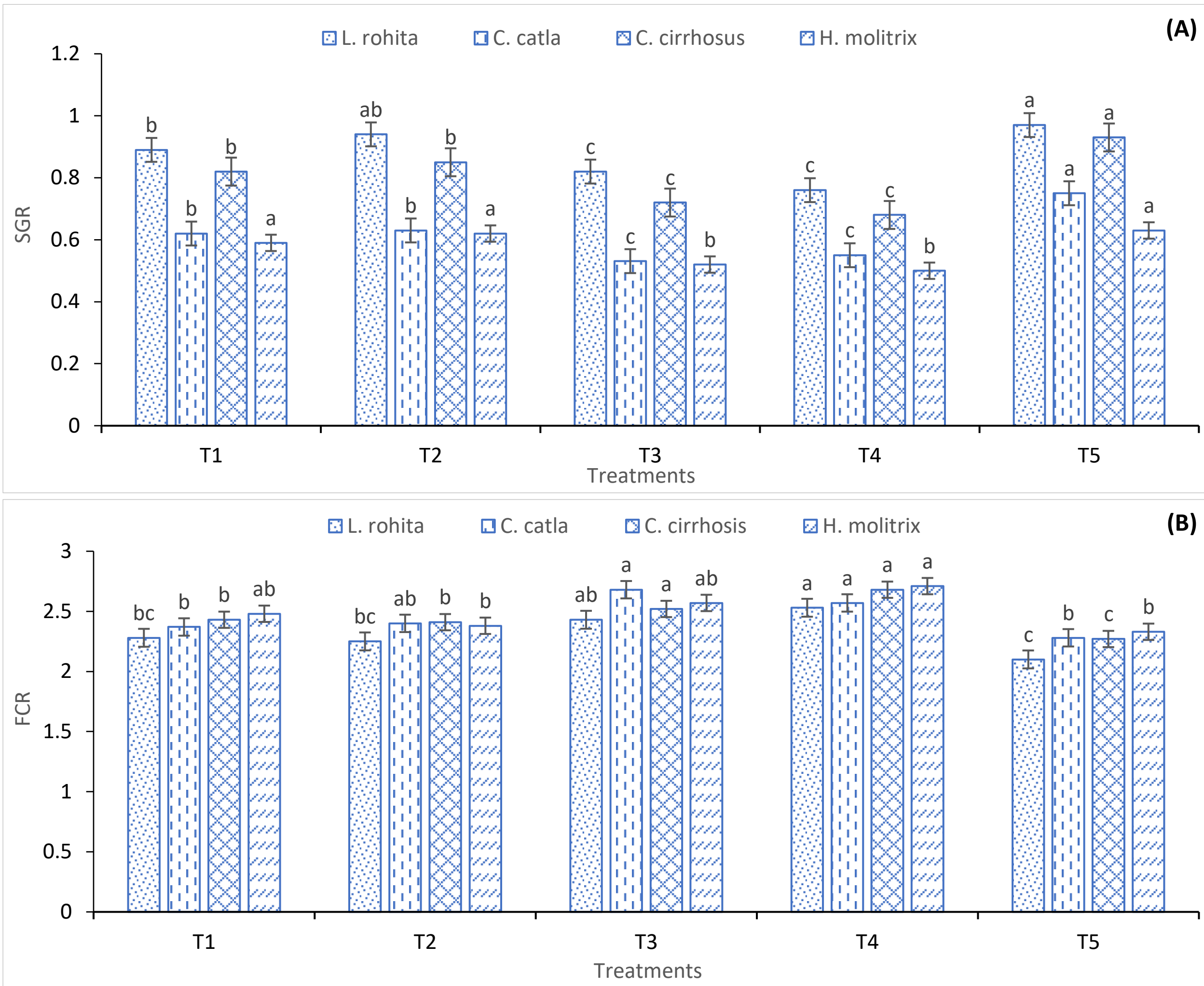

Figure 3. Comparison of (A) SGR, (B) FCR of the experimental fish species among the treatments.

Table 7. Carcass composition of the fish species among the treatments

Component (%)	Species	Treatments/Feeds				
		T_1	T_2	T_3	T_4	T_5
Crude Protein	*L. rohita*	18.39±0.64^{a}	18.18±0.57^{a}	17.95±0.71^{a}	17.89±0.84^{a}	18.78±0.51^{a}
	C. catla	18.48±0.21^{a}	17.76±1.09^{a}	17.69±0.66^{a}	17.43±0.78^{a}	18.94±0.42^{a}
	C. cirrhosus	18.03±1.20^{a}	18.19±0.33^{a}	17.39±0.78^{a}	17.46±1.03^{a}	18.58±0.36^{a}
	H. molitrix	18.09±0.62^{a}	17.98±0.43^{a}	17.49±0.64^{a}	16.73±1.20^{b}	18.21±0.74^{a}
Crude Lipid	*L. rohita*	2.57±0.44^{a}	2.21±0.33^{a}	2.48±0.37^{a}	2.71±0.61^{a}	2.51±0.50^{a}
	C. catla	2.59±0.33^{a}	2.47±0.49^{a}	2.68±0.37^{a}	2.86±0.68^{a}	2.46±0.43^{a}
	C. cirrhosus	2.54±0.11^{a}	2.40±0.45^{a}	2.78±0.23^{a}	2.54±0.71^{a}	2.66±0.29^{a}
	H. molitrix	1.97±0.41^{a}	1.95±0.66^{a}	2.08±0.20^{a}	2.03±0.26^{a}	2.44±0.40^{a}
Carbohydrate	*L. rohita*	2.60±0.33^{a}	2.98±0.50^{a}	2.28±0.21^{a}	2.43±0.42^{a}	2.78±0.11^{a}
	C. catla	3.25±0.45^{b}	5.53±0.56^{a}	5.13±0.42^{a}	3.38±0.48^{b}	4.37±0.71^{ab}
	C. cirrhosus	1.90±0.47^{a}	2.05±0.12^{a}	2.23±0.28^{a}	2.28±0.34^{a}	1.92±0.36^{a}
	H. molitrix	1.33±0.42^{b}	1.45±0.45^{b}	1.82±0.63^{a}	1.82±0.42^{b}	1.22±0.35^{b}
Moisture	*L. rohita*	74.16±1.11^{a}	74.28±0.81^{a}	75.91±1.04^{a}	74.75±1.13^{a}	74.21±0.66^{a}
	C. catla	72.81±1.04^{a}	72.28±0.6^{a}	71.81±0.90^{a}	72.25±0.99^{a}	72.41±1.04^{a}
	C. cirrhosus	76.51±1.22^{a}	76.54±0.72^{a}	74.81±0.52^{a}	76.32±0.90^{a}	74.61±0.66^{a}
	H. molitrix	77.56±1.15^{a}	77.09±0.65^{a}	76.13±1.26^{b}	75.54±1.25^{b}	76.56±0.69^{b}
Ash	*L. rohita*	1.24±0.23^{ab}	0.95±0.12^{b}	1.61±0.37^{a}	0.80±0.09^{b}	1.21±0.20^{ab}
	C. catla	1.76±0.1^{a}	1.25±0.30^{a}	1.91±0.62^{a}	1.25±0.40^{a}	1.11±0.06^{a}
	C. cirrhosus	0.76±0.11^{a}	1.17±0.20^{a}	1.06±0.16^{a}	1.12±0.23^{a}	1.26±0.30^{a}
	H. molitrix	0.86±0.11^{b}	1.86±0.21^{a}	1.16±0.30^{b}	1.07±0.16^{b}	0.96±0.16^{b}

*T_1, T_2, T_3, T_4, and T_5 were treated as fish groups fed with Lili feed, One feed, Quality feed, Nabil feed, and ACI feed, respectively. Values in the same row with different superscripts are significantly different (P<0.05).

Economic Feasibility of the Feeds

The data related to the economics of the treatments are summarized in Table 10. Among the treatments, T_5 demonstrated the highest fish yield, total return, net benefit, and CBR.

Discussion

Proximate Composition of Feeds

Fish's growth, health, and reproductive performance largely rely on adequate supply and proper quality of nutrients, irrespective of the type of aquaculture system. Nowadays, the use of commercial fish feeds is common for supplying nutrients to achieve higher production levels. Since protein is the main ingredient in feed that stimulates growth, feed producers place a strong emphasis on protein content as an indicator of quality. In the study, it was noted that the protein level in the commercial fish feeds ranged from 19.20 to 23.63%, with ACI feed having the highest value. The protein level in the studied feeds is lower than that reported by Rahman et al. (2014), who found protein levels ranging from 25.37 to 26.71% in commercial feeds. The current findings closely align with Nayeem et al. (2019), who recorded that the crude protein of different commercial fish feeds ranged between 21.65 and 34.40%, with Mega feed having the highest average crude protein content. Dietary lipids are significant sources of energy, which fish require for growth and development (Kim et al., 2012). Among the analyzed commercial fish feeds, lipid content varied between 5.45 and 6.67%, with ACI feed exhibiting the maximum value. Khatun et al. (2017) reported that the average crude lipid values of commercial feeds varied

Table 8. Heavy metal content (mg/kg) in the fish among the treatments

Heavy metal (mg/kg)	Species	Treatments/Feeds					Safe limit (mg/kg)		
		T_1	T_2	T_3	T_4	T_5	WHO	FAO	EU
Pb	*L. rohita*	2.08±0.94 [a]	5.04±2.37[a]	5.09±1.94[a]	5.97±1.70[a]	5.08±1.75[a]	0.01	2.5	0.1
	C. catla	6.12±1.20[a]	4.88±1.62[a]	5.86±2.47[a]	6.68±2.39[a]	4.38±2.27[a]			
	C. cirrhosus	0.83±0.18[b]	7.49±1.18[a]	5.00±1.71[ab]	7.48±1.89[a]	5.16±1.18[ab]			
	H. molitrix	0.68±0.59[b]	5.32±1.35[a]	5.82±0.53[a]	6.32±1.35[a]	5.82±1.18[a]			
Co	*L. rohita*	5.00±0.69[a]	4.38±1.21[a]	2.44±0.57[ab]	4.30±1.32[a]	0.88±0.06[b]	0.05	-	-
	C. catla	1.32±0.48[a]	2.10±0.64[a]	1.07±0.60[a]	1.38±0.62[a]	0.87±0.16 [a]			
	C. cirrhosus	2.83±1.08[a]	1.45±0.77[a]	2.44±0.48[a]	0.59±0.32[a]	0.68±0.15[a]			
	H. molitrix	5.02±1.13[a]	1.46±0.86[b]	1.40±0.23[b]	0.94±0.68[b]	0.64±0.23[b]			
Cr	*L. rohita*	0.68±0.06[b]	1.74±0.32[a]	1.17±0.13[ab]	1.40±0.45[ab]	0.58±0.20[b]	0.05	1.0	1.0
	C. catla	0.45±0.15[cd]	3.13±0.15[a]	1.03±0.20[bcd]	1.43±0.25[b]	0.36±0.05[d]			
	C. cirrhosus	0.45±0.51[b]	2.94±0.37[a]	1.25±0.38[b]	1.29±0.06[b]	0.49±0.44[b]			
	H. molitrix	0.53±0.38[a]	0.97±0.62[a]	1.02±0.31[a]	1.61±0.12[a]	0.67±0.06[a]			
Cd	*L. rohita*	0.76±0.56[a]	1.03±0.83[a]	1.57±0.75[a]	1.20±0.84[a]	1.19±0.60 [a]	0.03	0.2	0.05
	C. catla	0.07±0.04[c]	2.83±0.56[a]	1.46±0.21[b]	0.68±0.09[bc]	1.02±0.13 [b]			
	C. cirrhosus	0.40±0.28[a]	1.23±0.33[a]	0.98±0.03[a]	0.65±0.54[a]	0.28±0.03[a]			
	H. molitrix	1.50±0.21[a]	1.77±0.61[a]	1.16±0.66[a]	0.83±0.03[a]	1.02±0.22[a]			
Ni	*L. rohita*	1.10±0.09[a]	1.25±0.70[a]	1.09±0.34[a]	1.73±0.40[a]	1.06±0.03[a]	0.02	0.2	-
	C. catla	1.95±0.92[a]	2.20±0.97[a]	1.33±0.58[a]	0.76±0.27[a]	1.20±0.16[a]			
	C. cirrhosus	2.02±1.68[a]	0.66±0.36[a]	1.43±0.08[a]	1.17±0.14[a]	0.99±0.06[a]			
	H. molitrix	1.43±0.68[a]	1.79±0.34[a]	1.91±0.36[a]	1.27±0.11[a]	0.73±0.35[a]			

*Values in the same row with different superscripts are significantly different (P<0.05).

Table 9. Pearson correlation matrix of heavy metals in fish feeds and fish samples

	Feed (Pb)	Feed (Co)	Feed (Cr)	Feed (Cd)	Feed (Ni)	Fish (Pb)	Fish (Co)	Fish (Cr)	Fish (Cd)	Fish (Ni)
Feed (Pb)	1									
Feed (Co)	-0.225	1								
Feed (Cr)	-0.071	0.537	1							
Feed (Cd)	0.83	0.248	0.159	1						
Feed (Ni)	0.104	0.841	0.624	0.341	1					
Fish (Pb)	0.435	-0.515	0.385	0.219	-0.275	1				
Fish (Co)	0.274	0.688	-0.087	0.551	0.646	-0.666	1			
Fish (Cr)	0.776	-0.168	0.123	0.841	-0.119	0.614	0.039	1		
Fish (Cd)	0.291	-0.037	0.129	0.566	-0.299	0.426	-0.083	0.821	1	
Fish (Ni)	0.213	0.817	0.158	0.647	0.663	-0.522	0.925*	0.213	0.217	1

*Correlation is significant at the 0.05 level (2-tailed).

Table 10. Cost-benefit analysis of the feeds

Parameters	Treatments/Feeds				
	T_1	T_2	T_3	T_4	T_5
Total yield (kg/treatment/90 days)	14.52±0.36[b]	14.42±0.39[b]	13.45±0.40[c]	13.03±0.39[c]	15.85±0.73[a]
Total cost (BDT)	1605.33±20.60[b]	1544±27.07[b]	1335±33.87[c]	1316±32.60[c]	1475±27.02[a]
Total return (BDT)	2453±58.81[b]	2436±53.70[b]	2272±53.39[c]	2205±61.0[c]	2680±76.45[a]
Net benefit (BDT)	847.67±73.66[b]	892±80.67[b]	937±26.07[b]	888±69.15[b]	1205±104.4[a]
CBR	1:0.53	1.0.58	1:0.70	1:0.68	1:0.82

between 6.40 and 11.13%, which is more or less comparable to the estimated lipid values in the selected feeds. Sarker et al. (2015) documented that the crude lipid values of various carp feeds were in the range of 4.32 to 10.49%, which is also roughly supportive of the present findings. Similarly, Nayeem et al. (2019) found that the mean crude lipid levels ranged from 4.33 to 9.76%, consistent with the present outcomes. Adjusting moisture levels is essential for both economic efficiency and the quality of feed. In this study, the moisture content in all feeds was observed to be about 1-3% above the maximum values stated by the feed manufacturing companies. In the current study, the analyzed feeds showed moisture contents ranging from 12.16 to 13.97%. Sarker et al. (2015) observed similar outcomes, stating that the average moisture levels for starter and grower carp feeds from various fish feed mills ranged between 8.49 and 14.30%. Additionally, the present results regarding moisture content are also closely aligned with those of Rahman et al. (2014) and Khatun et al*.* (2017). Ash percentage in fish feed is important as it indicates the presence of minerals like potassium, calcium, magnesium, phosphorus, etc. In the fish feeds, the ash content ranged from 11.01 to 13.05%, with the Nabil feed showing the highest level. In a study, Rahman et al. (2014) recorded higher ash contents (17.10 to 18.94%) in the commercial feeds compared to the present results. Khatun et al. (2017) indicated that Aftab fish feed had the highest ash content (24.40%), while ACI fish feed had the lowest (8.51%), which is closely related to the present results. Aside from providing energy, soluble carbohydrates contribute significantly to enhancing the stability of the feed at low concentrations (Ng and Romano, 2013). In our study, the carbohydrate contents in the analyzed feeds were found to range between 38.16 and 42.58%, which aligns with the findings described by Rahman et al. (2014). However, findings regarding carbohydrate contents in commercial fish feeds are scarce.

Heavy Metal Contents in the Fish Feed

Contamination of fish feed from various pollutant sources can lead to the transfer of these pollutants to fish and ultimately to human consumers. Fish are a crucial part of the aquatic food chain and are vulnerable to contaminants, particularly heavy metals. Numerous studies have shown that fish feed contains varying concentrations of different heavy metals (Salawu et al., 2016; Saha et al., 2021; Sarkar et al., 2021). The present investigation revealed that the feeds used for carp culture had elevated levels of Pb (mean 11.06 mg/kg, ranging from 9.47 to 12.82 mg/kg), exceeding the standards of the European Union (2003). The Pb levels in the feeds were also higher than the recommended allowable limit (2 mg/kg) for animal feed products (FAO, 1984). Saha et al. (2021) reported a mean concentration of Pb measuring 5.79 mg/kg in the commercial fish feeds they analyzed, which is still lower than the current findings. The analyzed fish feeds had Cr concentrations in the range of 2.22 to 3.45 mg/kg, surpassing the acceptable limit of 1.0 mg/kg established by FAO (1984) and the European Union (2003). Munshi et al. (2018) reported a higher Cr level of 15.03 mg/kg in fish feed compared to this study. Comparable findings were presented by Sarkar et al. (2021), who indicated that several commercially manufactured fish feeds of Bangladesh had significantly elevated Cr levels (2.83 to 15.45 mg/kg). The average Cd concentration in most feeds (2.38±0.32 mg/kg) exceeded the 2 mg/kg limit recommended by the FAO (1984) and the EU (2003). Ikem and Egilla (2008) noted that the average Cd level in fish feeds is 2.37 mg/kg, aligning with these results and exceeding acceptable limits. Hossain et al. (2017) reported Cd levels in commercial fish feeds ranging from 0.19 to 0.42 mg/kg, which are lower than the values observed here. The average Co in the feeds was 3.02 mg/kg, with most samples having concentrations above 2 mg/kg, which falls within the internationally acceptable range (1-5 mg/kg) set by the EU (2003). The mean Ni level in the fish feeds was 3.35±0.33 mg/kg, with a range of 2.75 to 3.74 mg/kg. Islam et al. (2021) reported Ni levels in fish feeds ranging from 8.41 to 16.89 mg/kg, which are higher than these findings. The Ni levels in the feeds are not a concern, as maximum permissible limits for nickel in various foods for humans range from 0.1 to 8 mg/kg (EU, 2003). Although the FAO/WHO established a maximum limit of 2 mg/kg for Ni (FAO/WHO, 1984), long-term exposure to high Ni levels in feed could pose health risks to both fish and humans who consume them. Overall, this study indicates that heavy metal pollution in feeds used for carp culture in the study areas is relatively high. Nonetheless, attention should be directed toward the formulation of fish feeds, and ingredients with high heavy metal concentrations should be avoided.

Fish's Growth and Nutrient Utilization

Aquaculture productivity is influenced by three interconnected factors: the aquatic environment, diet, and farmed species (Teiba et al., 2020). Factors related to diet, such as the origin of dietary ingredients and their proportions in the diet, can affect the diet's chemical composition, which in turn influences feed consumption, nutrient utilization, and overall growth performance in aquaculture (Sorensen et al., 2012). In the current trial, all the selected fish species (*C. catla, H. molitrix, L. rohita,* and *C. cirrhosus*) fed with ACI feed demonstrated notably enhanced growth and better FCR compared to the other treatments. These results may be linked to the better nutritional composition of that feed, particularly the protein level. These results are consistent with Dinesh et al. (2010), who reported that feeds with higher protein content significantly increased weight gain and specific growth rates in *L. rohita.* According to Zulfiqar et al. (2023), carps (*L. rohita* and *C. catla*) that were given AMG feed with a higher protein content (26.2%) exhibited greater body weight gain compared to those that received other types of aquafeed, which agrees with the present findings. The outcomes of the present investigation are also in agreement with those of Abbas et al. (2023), who observed improved growth performance and FCR in *L. rohita* when fed a protein-rich diet. Moreover, the current findings are also consistent with Hossain et al. (2017), Ahir et al. (2023), and Zulfiqar et al. (2024), all of whom indicated that diets high in protein contribute to improved production performance in various fish species. The growth, development, and reproduction of aquatic organisms also depend on dietary lipids in both quantitative and qualitative ways (Wang et al., 2021). A lipid inclusion of 5–8% is suitable for freshwater carp, with appropriate essential fatty acid balance (Tacon, 1990). The crude lipid content in the analyzed feeds was within the optimal range, with the ACI feed being the highest (6.67%), which might be a reason for attaining superior growth in ACI feed-fed fish.

Carcass Composition of the Fish

Fish's flesh composition largely depends on the nutritional profile of their diet (Orban et al., 2007). Increasing the crude protein content in feed can enhance the protein levels in the body composition of fish (Ayub et al., 2021). In this investigation, the highest carcass crude protein was recorded in trial fish fed the ACI feed among the treatments. The outcomes of this study corroborate the findings of Zulfiqar et al. (2024), who obtained a higher crude protein level (28.66±0.24%) in *L. rohita* fed a diet rich in protein compared to the other experimental feeds. The carcass protein content (16.73–18.94 %) observed in the current research was comparatively lower than that (20.3–20.73%) reported for silver black porgy (*Sparidentex hasta*) by Hossain et al. (2017). Aligning with Siddiqui and Khan (2009), the present study findings also revealed that higher protein levels in the diet can elevate the overall crude protein content of fish. Dietary lipids are a vital source of energy for fish. Abbas et al. (2023) reported that increasing the crude fat content of the diet results in elevated crude lipid levels in fish. In this investigation, the carcass lipid level did not vary significantly among the treatments, which might be due to no notable variation in crude lipid level in the feeds. The carcass lipid content (1.95-2.86%) in the fish observed in this research was lower than that reported for *S. hasta* (3.64-5.81%) by Hossain et al. (2017), possibly due to variations in dietary lipid content or dietary lipid assimilation. The current results revealed no considerable deviation in the carcass moisture, ash, and carbohydrate contents across the treatments, which aligns with earlier studies performed by Paul et al. (2018), Abbas et al. (2023), and Zulfiqar et al. (2024).

Heavy Metal Content in the Fish

According to the results, heavy metal concentrations in the examined fish species exceeded the recommended safe limits for human consumption. Numerous studies have illustrated the alarming situation of heavy metal contamination in Bangladesh, involving an array of fish species and several harmful heavy metals. Hossain et al. (2016) and Das et al. (2017) documented the presence of different toxic metals such as Pb, Ni, Zn, Cu, As, and Cd in commercial aqua feeds, along with evidence of their accumulation in fish bodies. Ghosh et al. (2021) analyzed heavy metals in different cultured fish species, including *Pangasius pangasius*, *Heteropneustes fossilis*, *Anabas testudineus*, *Oreochromis niloticus*, and *Clarias batrachus*, and noticed excessive levels of Co and Cr, along with a hazardously high concentration of Pb, supporting the findings observed in the present study. Comparable results were obtained by Roy et al. (2025), who found unacceptable concentrations of different metals, including Cd, Cu, Pb, As, and Cr in *P. pangasius* and *C. catla* collected from a polyculture system, with Pb and Cd levels exceeding the maximum allowable limits recommended by the FAO and WHO (1984). Aktar et al. (2025) also found unsafe levels of heavy metals in *L. rohita* raised in a commercial feed-based culture system. Aski et al. (2023) also detected heavy metals in exotic carps such as *Cyprinus carpio*, *H. nobilis*, *H. molitrix*, and *Ctenopharyngodon idella*. These findings suggest that fish feed could be a potential contributor to heavy metal deposition in the experimental fish. The Pearson correlation matrix revealed a strong positive association between feed's heavy metal levels and their accumulation in fish, which coincides with the results of Aziz et al. (2022) and Ghosh et al. (2023). Remarkably, the significant positive correlation between fish (Co) and fish (Ni) indicates that Co and Ni are closely interrelated in fish tissues, possibly as a result of similar metabolic processes or sources that influence their accumulation.

Economic Feasibility of the Feeds

The highest fish production and CBR were achieved in T_5, demonstrating superior economic performance compared to the other treatments. Although T_1 produces higher fish yield, its elevated production costs reduce its overall economic efficiency, making it the least profitable treatment. On the contrary, despite having a lower yield in T_3, its low production cost and favorable CBR reflect good cost efficiency. As the price of feed and feed ingredients has been rising continuously, the cost of production can't be directly compared with previous literature.

Conclusions

The research findings revealed that ACI feed has relatively higher protein content and lower heavy metal levels, and it considerably enhances the growth and carcass protein of the selected fish. However, the measured nutrient levels of the tested feeds did not coincide with manufacturer-declared values, and all the studied feeds exhibited higher levels of heavy metals. Considering that there is a pressing need to monitor fish feed production to guarantee both sufficient nutrient content and the minimum level of heavy metals on a national scale. Regulatory bodies should enforce regulations and ensure compliance to produce high-quality fish feed. Nevertheless, the findings of this study will assist fish farmers in selecting appropriate feed and negotiating with feed suppliers for quality feeds to ensure healthier aquaculture farming.

Ethical Statement

Every step was carried out following institutional and national guidelines for the ethical handling of animals in research. The study protocol was reviewed and approved by the Institutional Animal, Medical Ethics, Biosafety, and Biosecurity Committee (IAMEBBC) of the University of Rajshahi, Bangladesh.

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Author Contribution

Md. Tariqul Islam: Conceptualization, Investigation, Methodology, Data Curation, Writing-original draft; Imon Kumar Shikdar: Formal Analysis, Data Curation, Visualization and Writing-original draft; Md. Mahedul Islam Murad: Investigation, Methodology, Data Curation; Md. Mahabubur Rahman: Fund collection, Supervision, Review and editing, Validation.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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