Iran. J. Ichthyol. (2025) 12(2): 147-161
P-ISSN: 2383-1561; E-ISSN: 2383-0964

ORIGINAL ARTICLE

Morphometry, dietary composition, and feeding patterns of *Clarius gariepinus* from the Chenab River, Punjab, Pakistan

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Article history:
Accepted 15 April 2025

Abstract
The African catfish, *Clarias gariepinus* (*C. gariepinus*), is a vital aquaculture species due to its resilience and high nutritional value. This study evaluates the morphometric and feeding characteristics of fifteen *C. gariepinus* specimens collected from the Chenab River, Pakistan, between November 2021 and May 2022. The morphometric analysis included total length, standard length, body depth, and eye diameter. The total length of the specimens ranged from 13 to 25cm (mean = 16.66±2.37cm), while body weight varied from 23 to 86g (mean= 41.32±13.08g). Significant correlations were observed between total length and fork length (r= 0.979, *P*<0.001) and between total length and body weight (r= 0.790, *P*<0.001). The Gastro-somatic Index and frequency of occurrence (%) were used to assess feeding habits. Zooplankton, small crustaceans, and benthic organisms were common prey items. Larger specimens (> 30cm) displayed increased consumption of plant material and fish remains. The study provides insights into the morphometric variability and feeding ecology of *C. gariepinus*, highlighting its adaptability to local environmental conditions. These findings contribute to understanding growth patterns, health indicators, and dietary preferences, crucial for fisheries management and sustainable aquaculture practices.

Keywords: *Clarias gariepinus*, Indus River, Morphometry, Feeding habits, Stomach content

INTRODUCTION

Clarias gariepinus (*C. gariepinus*), widely known as the African catfish, is a key species in aquaculture across Africa due to its adaptability, resilience to various environmental conditions, and high economic value (Alhassan et al. 2022; Tiamiyu et al. 2023). In many Asian countries, *C. gariepinus* plays a critical role as a primary food fish and is a major source of animal protein and essential micronutrients, owing to its excellent taste and high nutritional value (Fiaz et al. 2020; Nguyen et al. 2021). Morphometric analysis serves as a fundamental tool for assessing fish growth, development, and the relationships between different body parts, as well as for identifying variations that may arise due to environmental factors (Tah et al. 2021; Das et al. 2023). The characterization of fish using morphometric and meristic measurements is vital for identifying different strains or stocks, particularly by detecting shape variations (Martinez et al. 2020). While molecular approaches delve into the genetic and biochemical variations within and between populations, morphometric differences, such as growth rates, body length, and age patterns, remain essential for stock identification and management (Aguilar-Medrano et al. 2022). Morphometry involves the quantitative analysis of biological shape, with applications in developmental biology, systematics, and taxonomy (Patwary et al. 2021; Munir et al. 2022). Significant isolation among populations can result in notable morphometric and meristic differences, which can be used to differentiate and manage species populations (Singh et al. 2021). Dietary composition and feeding behavior are equally crucial for the growth and health of *C. gariepinus*. As an omnivorous species, it consumes a wide variety of natural and artificial diets, which affects its feed conversion ratio (FCR) and overall productivity (Agboola et al. 2023; Adewumi et al. 2023). Optimizing the diet composition, including the balance of proteins, lipids, and carbohydrates, is vital for enhancing fish growth, reducing feed waste, and lowering production costs in aquaculture systems (Ahmed 2023; Akinbile et al. 2023). The formulation of balanced diets that meet the nutritional needs of *C. gariepinus* is essential for maximizing growth rates, improving feed conversion efficiency, and reducing waste outputs, which are critical for the sustainability of aquaculture operations (El-Sayed 2021).

Analyzing stomach contents provides critical insights into the diet, feeding behaviors, and selective feeding patterns of fish, making it a valuable method for developing artificial diets and understanding feeding habits in aquaculture (Nguyen et al. 2020; Sharma & Singh 2022). For *C. gariepinus*, feeding habits are essential for optimizing farming and ensuring sustainable management practices (Langi et al. 2024). Despite the economic importance of this species in aquaculture, there is a significant lack of detailed information on its feeding ecology, particularly in regions such as the lower Indus River (Little et al. 2016). This gap is exacerbated by environmental changes caused by the construction of hydroelectric dams, which disrupt natural feeding patterns and habitats (Soomro et al. 2021). Studies focusing on the gastrointestinal tracts of this species provide insights into nutrient intake and utilization, which are critical for enhancing growth and health in aquaculture systems (Ali et al. 2021). Moreover, these studies contribute to a broader understanding of community dynamics and ecosystem interactions, revealing the role of the species within the aquatic food web (Bako et al. 2022). Research by Robert et al. (2019) highlighted the importance of analyzing gut contents to identify natural prey items and optimize formulated feeds for better growth performance. Similarly, studies by Ovie & Eze (2019) emphasized the role of seasonal variations in diet composition, revealing how environmental factors influence feeding patterns in freshwater ecosystems. Additionally, work by Iheanacho et al. (2018) demonstrated the use of stomach content analysis to assess the impact of invasive species on native fish

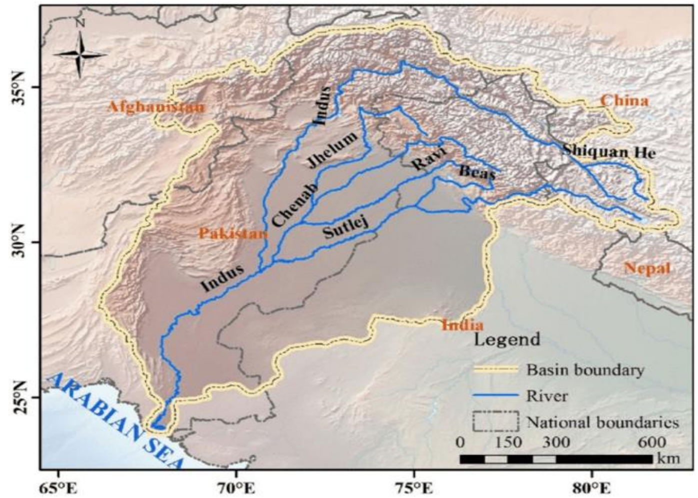

Fig.1. Indicates the sites along the Indus River in Pakistan, from which catfish samples were obtained (Braulik et al. 2015).

diets, providing insights into competitive interactions and resource partitioning in aquatic habitats.

This study aims to evaluate the external morphometric features of *C. gariepinus* in the Chenab River, focusing on body size and condition factors to provide crucial insights for stock management, selective breeding, and optimizing aquaculture practices in Pakistan. Additionally, the study aims to compare the gastrointestinal characteristics of *C. gariepinus* to understand its feeding habits and nutrient absorption patterns. By analyzing stomach contents, the research seeks to generate valuable data to inform optimal feeding strategies and promote sustainable fish farming practices.

MATERIALS AND METHODS

Study Area: The sampling site is situated along the River Chenab, approximately 25 kilometers from Multan, a city in the Punjab province of Pakistan (Fig. 1). Significance, supporting various freshwater species, including the catfish targeted in this study (Owais et al. 2024).

Morphometric analysis: From November 2021 to May 2022, fifteen specimens of *C. gariepinus* were collected from the Chenab River using drag nets based on the availability and size of the fish (Fig. 2). The samples varied in body size and weight. Immediately after collection, the fish were preserved in ice and transported to the fisheries laboratory in the

Fig.2. Indicate the African catfish, *Clarias gariepinus* during measuring the length parameters.

Department of Zoology, Emerson University, Multan, Punjab, Pakistan. Various morphometric parameters were measured, including standard length (SL), total length (TL), head length (HL), eye diameter (ED), pre-dorsal length (PDL), dorsal fin base (DFB), pectoral fin length (PtFL), pectoral fin base (PFB), pelvic fin length (PvFL), pelvic fin base (PvFB), forked length (FL), anal fin length (AFL), anal fin base (AFB), body depth (BD), caudal fin length (CFL), snout length, caudal fin base (CFL), dorsal fin length (DFL), and dorsal fin base (DFB). Measurements were taken in centimeters using a biometry ruler with 1 mm accuracy. A digital balance (AND Model FX300I) with a precision of 0.1g was used for weight measurement. Other tools included a dissection kit, formalin, water, and a microscope. Gender was identified visually through macroscopic examination of the gonads after dissection.

Examination of the stomach contents: After transporting the fish into the laboratory, the fish was caught by a dip net, killed by a sharp blow to the head, and dissected with scissors. The whole stomach was carefully cut and preserved in an 8% formalin solution for subsequent content analysis. The samples were removed from their containers, and to neutralize the formalin odor, the stomach contents were diluted with 100 ml of water per gram of material. The contents were then filtered using 100-µm and 500-µm mesh sieves. To prevent sample decay, the contents were not kept in water for more than 48 hours (Hyslop 1980; Saba et al. 2020).

The Gastro-somatic Index (%) and Frequency of Occurrence (%) were utilized to analyze the food and feeding habits of *Clarias gariepinus*. Prey items were identified and classified based on their systematic status using the frequency of occurrence, numerical counts, and the gravimetric method for quantitatively assessing stomach contents (Gogoi et al. 2020). An attempt was made to match the food items to their respective species (Gupta & Banerjee 2013). Polychaetes, small crustaceans, and some fish were especially difficult to identify because they were quickly digested and rarely in good form. The taxonomic classification of phytoplankton was performed by examining microscopic preparations from each filtrate under a microscope.

Feeding behavior was analyzed using the Gastro-somatic Index (GaSI) and the Frequency of Occurrence (%). The Gastro-somatic Index of food items was calculated following the method described by Kurbah & Bhuyan (2018).

GaSI= Weight of Stomach of Examined Fish/Total Body Weight of Fish×100

Feeding intensity is evaluated by comparing the percentage of food content with the fish's length class and calculating the Gastro-somatic Index (GaSI) for adult specimens. The Frequency of Occurrence (%) determines the presence or absence of various prey

Table 1. Descriptive Statistics of morphological characters in *Clarias gariepinus.*

Specimens	N	Range	Min	Max	Mean	S. E	S. D	Variance
	50	49	2	50	30.5	1.94	12.68	146.677
Weight	50	60	23	86	41.32	1.78	13.081	144.812
Head length	50	3	1	3	4.04	0.188	0.9	0.74
Head width	50	3	3	4	3.88	0.18	0.883	0.798
Eye diameter	50	3	1	3	0.7	0.08	0.378	0.143
Upper jaw length	50	1	3	3	3.68	0.089	0.545	0.370
Lower jaw length	50	2	2	4	3.55	0.07	0.605	0.645
Dorsal fin base	50	2	2	1	2.16	0.058	0.643	0.134
Dorsal fin length	50	3	2	4	1.36	0.12	0.794	0.385
Anal fin base	50	3	4	6	4.88	0.093	0.600	0.380
Anal fin length	50	2	2	1	1.9	0.074	0.504	0.163
Gap of mouth	50	3	1	1	0.96	0.03	0.317	0.3
Pectoral fin length	50	3	3	7	3.66	0.143	0.847	0.726
Pectoral fin base	50	2	1	2	0.66	0.067	0.483	0.243
Caudal fin length	50	3	3	7	2.44	0.120	0.745	0.544
Caudal fin base	50	2	2	1	2.86	0.063	0.338	0.118
Body depth	50	4	3	11	7.88	0.166	1.056	1.113
Interorbital length	50	2	2	1	2.73	0.087	0.48	0.26
Postorbital length	50	2	2	1	2.88	0.044	0.268	0.079
Total length	50	10	13	25	16.66	0.773	2.369	5.566
Fork length	50	11	13	23	16.88	0.309	1.948	3.786
Standard length	50	9	13	22	16.06	0.275	1.680	2.717
Pelvic fin length	50	3	1	3	0.8	0.182	0.743	0.553
Pelvic fin base	50	2	1	2	0.30	0.074	0.455	0.206
Stomach weight	50	3	1	1	0.35	0.083	0.578	0.334
Liver weight	50	2	1	2	0.17	0.075	0.363	0.123
Gut length	50	15	3	21	6.99	0.845	3.073	9.373

items across all individuals, providing a simple yet effective measure of the relative importance of different prey types and quantifying the overall food composition within a fish population. The relevance of each prey item is determined by the fraction of intestines containing it. This traditional method relies on accurately identifying some part of the prey's body to deliver reliable data on dietary composition. It reveals the variability in fish diets based on the prey consumed. The number of stomachs containing each prey item is recorded and expressed as a percentage of the fish examined. The frequency of all prey components is then aggregated and scaled down to represent the diet's percentage composition. The following equation calculates the frequency of occurrence:

Frequency of occurrence (%)= Fi= Ni/N × 100

In this context, % 'F' represents the frequency of occurrence of a given item 'i,' 'Ni' refers to the number of stomachs where the specific item 'i' is found, and 'N' denotes the total number of stomachs examined.

The calculation formula of the condition factor was as follows (Al Sulivany *et al.*, 2024).

$$\text{Condition factor} = 100 \times W/L^3$$

The weight-length relation is in an exponential form as described by the succeeding formula (Azam & Naeem 2021):

$$W = aL^b$$

The equation in the form of a log is as follows:

$$\text{Log}W = \log a + b \log L$$

Statistical relations between fish body weight and total length were derived using linear transformation as reported in the study of Azam & Naeem (2021).

RESULTS

The descriptive statistics for various morphological and physiological parameters of *C. gariepinus* sampled from the Chenab River are in (Table 1). The total length of the specimens ranged from 13 to 25cm, with a mean and SD of 16.66±2.37cm. The weight of the fish had a more comprehensive range, from 23 to 86g, and the mean and SD of weight was 41.32±13.08g. Head-related parameters also displayed differences: the head length averaged

4.04cm, with minimal variation (SD= 0.9), while the head width averaged 3.88cm. Eye diameter was the smallest parameter measured, with an average of 0.7cm. Fin-related measurements, such as dorsal fin base and length, showed a wide range of values, with the dorsal fin base averaging 2.16cm and the length averaging 1.36cm.

Interestingly, body depth exhibited a mean of 7.88cm. The pectoral and caudal fins presented consistent measurements with averages of 3.66 and 2.44cm, respectively. Other critical parameters, like the gut length, had the highest variability, with a mean and SD of about 6.99± 3.07cm.

Based on Fulton's condition factor (K), the length-weight relationship of this type of fish reveals significant variations. The highest K was observed in specimen 34, with a K value 0.95. In contrast, specimen 6 had the lowest K value of 0.39, indicating a potentially poorer health state or an elongated body than its weight. The average condition factor hovered around 0.6. Larger fish did not always have higher condition factors; for example, specimen 4, which had the greatest weight (87.8g) and total length (27.4cm), had a low K value of 0.43, pointing to a relatively slender body. Conversely, smaller fish like specimen 15, weighing only 34g and measuring 15.5cm, exhibited a much higher condition factor of 0.91 (Table 2).

The regression analysis, correlating total length with various morphological parameters, reveals significant relationships between body size and other traits (Table 3). The strongest correlation was observed between TL and FL ($r= 0.979$), with a coefficient of determination ($r^2= 0.944$). Similarly, snout length ($r= 0.916$, $r^2= 0.831$) also displayed a strong correlation, reflecting its consistent growth to body size. Body depth (BD) correlated highly with total length ($r= 0.831$, $r^2= 0.671$). The weight regression against total length ($r= 0.790$, $r^2= 0.893$) suggests a robust relationship, though with some variation, as the confidence intervals for the regression coefficients were broad. Fins showed varied relationships; the anal fin base (AFB) was highly correlated with TL ($r= 0.841$), while the pectoral fin base (PtFB) and dorsal fin length (DFL) also demonstrated strong correlations. Conversely, the interorbital length (IeOL) and gape of mouth (GOM) exhibited weaker correlations, with R-values of 0.200 and 0.288.

The regression analysis of *C. gariepinus* reveals significant relationships between total body weight and various morphological parameters. The strongest correlations were observed in total length (TL) and fork length (FL), with correlation coefficients (r) of 0.889 and 0.890, respectively, both explaining approximately 79% of the total variation ($r^2 \approx 0.79$). Body depth (BD) also showed a strong positive correlation ($r= 0.781$, $r^2= 0.590$). The standard length (SL) demonstrated a robust relationship with body weight ($r= 0.802$, $r^2= 0.643$), while anal fin base (AFB) showed a moderate to strong correlation ($r= 0.700$, $r^2= 0.480$). Interestingly, some parameters showed weaker correlations, such as eye diameter (ED) with $r= 0.391$ and $r^2= 0.159$, and notably, specific measurements like gonadal maturity (GOM), inter-orbital length (IeOL), and pelvic fin base (PvFB) showed weak or non-significant correlations ($r= 0.241$, 0.145, and 0.081 respectively) with corresponding low r^2 values. The regression equations consistently showed positive slopes (b values) for most parameters, except for upper jaw length (UJL), lower jaw length (LJL), inter-orbital length (IeOL), and pelvic fin base (PvFB), which displayed negative slopes. All significant correlations were marked with consistently low P-values (0.000-0.003) for most significant relationships, indicating statistically solid reliability of the observed correlations.

The logarithmic regression analysis of this species revealed complex relationships between TL, and various morphological parameters (Table 5). The most robust correlation was observed in FL with a highly positive correlation coefficient ($r= 0.972$) and the highest coefficient of determination ($r^2 = 0.951$), indicating that 95.1% of the variation in fork length can be explained by total length. Standard length (SL) also demonstrated a powerful correlation ($r = 0.910$, $r^2 = 0.830$), followed by BW, showing a significant positive correlation ($r= 0.880$, $r^2= 0.781$). Body depth

Table 2. Length-weight relationship by Fulton's condition factor K= 100×W/L^3.

Specimen	Body weight (W)	Total length (L)	Condition factor K (%)
1	49	19.8	0.63
2	41	19.9	0.52
3	42.2	20.8	0.47
4	87.8	27.4	0.43
5	44.3	17.7	0.80
6	37.5	21.3	0.39
7	75.2	21	0.81
8	48	23.5	0.37
9	39	18	0.67
10	55.6	22	0.52
11	57.5	22.5	0.50
12	43.5	18.1	0.73
13	44	17	0.90
14	29	16.5	0.65
15	34	15.5	0.91
16	36	17.3	0.70
17	33	17.5	0.62
18	35.7	18	0.61
19	36	18.1	0.61
20	33	17	0.67
21	34.5	17.5	0.64
22	26	17.5	0.49
23	27	17	0.55
24	25	14.5	0.82
25	27	15	0.80
26	28	15	0.83
27	26	17.6	0.48
28	27.4	17.1	0.55
29	40	18	0.69
30	28	16	0.68
31	35	17	0.71
32	37	17	0.75
33	38	18	0.65
34	39	16	0.95
35	36.8	17	0.75
36	30	19	0.44
37	36.9	18	0.63
38	36	17.6	0.66
39	35	19	0.51
40	35	18.5	0.55
41	35	18.5	0.55
42	35	18.5	0.55
43	35	19.5	0.47
44	43	20	0.54
45	44	23	0.36
46	32	21	0.35
47	34	20	0.43
48	45	19	0.66
49	43	18	0.74
50	42	19	0.61

exhibited a strong relationship ($r= 0.791$, $r^2= 0.640$), while anal fin base (AFB) showed a notable correlation ($r= 0.850$, $r^2= 0.720$). The analysis revealed moderate correlations for parameters such as head length (HL) and pectoral fin length (PtFL) with correlation coefficients of 0.710 and 0.730, respectively. Interestingly, some morphological features showed weak or non-significant correlations, particularly gonadal maturity (GOM, $r= 0.120$, $r^2= 0.042$), inter-orbital length (IeOL, $r= 0.171$, $r^2= 0.030$), and notably, pelvic fin base (PvFB) and lower width (LW) both showed extremely weak correlations ($r= 0.003$, $r^2= 0.620$). The regression equations generally showed positive slope values (b), except for

Table 3. Descriptive statistics and Regression analysis of *Clarius gariepinus*: Total length against various morphological parameters.

Formula	Parameter relation		95% CI of	95% CI of	Correlation coefficient	Coefficient determination	*P*
Y= a + bx	a	b	A	b	r	r^2	
W= a+bTL	-39.88	3.588	-53.35 to -26.42	4.631 to 6.345	0.790**	0.893	0.000
HL= a+bTL	-0.132	0.179	-1.111to 0.852	0.130 to 0.237	0.740**	0.545	0.000
HW= a+bTL	-1.699	0.269	-3.08 to -0.36	0.195 to 0.347	0.758**	0.569	0.000
ED= a+bTL	-0.133	0.045	-0.75 to 0.48	0.017 to 0.088	0.445	0.198	0.015
UJL= a+bTL	3.597	-0.112	3.45 to 5.77	-0.178 to 0.05	0.488**	0.233	0.003
LJL= a+bTL	4.135	-0.096	3.15 to 5.16	-0.157 to -0.047	0.509**	0.258	0.002
DFB= a+bTL	-0.318	0.087	-1.03 to 0.35	0.044 to 0.133	0.572**	0.315	0.000
DFL= a+bTL	-1.061	0.198	-2.14 to 0.03	0.135 to 0.259	0.732**	0.531	0.000
AFB= a+bTL	2.421	0.182	1.65 to 3.14	0.16 to 0.23	0.841**	0.600	0.000
AFL= a+bTL	-0.217	0.119	-0.81 to 0.47	0.06 to 0.18	0.679**	0.468	0.000
GOM= a+Btl	0.340	0.035	-0.38 to 0.91	-0.005 to 0.08	0.288	0.078	0.142
PtFL= a+bTL	-1.005	0.207	-2.44 to 0.45	0.16 to 0.29	0.640**	0.410	0.002
PtFB= a+bTL	-0.410	0.060	-0.77 to -0.74	0.03 to 0.08	0.730**	0.531	0.000
CFL= a+bTL	-0.569	0.220	-1.74 to 0.60	0.16 to 0.29	0.739**	0.549	0.000
CFB= a+bTL	0.551	0.071	-0.18 to 1.31	0.03 to 0.2	0.492**	0.251	0.016
BD= a+bTL	1.698	0.379	0.31 to 3.81	0.31 to 0.49	0.831**	0.671	0.000
IeOL=a+bTL	1.762	-.017	0.88 to 2.71	-0.07 to 0.04	0.200	0.012	0.381
POL= a+bTL	0.609	0.071	0.12 to 1.12	0.04 to 0.09	0.571**	0.341	0.000
FL= a+bTL	2.872	0.741	1.87 to 3.98	0.68 to 0.81	0.979**	0.944	0.000
SnL= a+bTL	3.871	0.641	2.22 to 5.51	0.59 to 0.74	0.916**	0.831	0.0001
PvF= a+bTL	-1.532	0.140	-2.92 to -0.13	0.07 to 0.23	0.502**	0.260	0.003
PvFB= a+bTL	0.480	-0.006	-0.13 to 1.07	-0.040 to 0.06	0.041	0.003	0.663
SW= a+bTL	-1.088	0.083	-2.98 to -0.18	0.040 to 0.16	0.501**	0.248	0.002
LW= a+bTL	-1.330	0.087	-2.97 to -0.67	0.06 to 0.14	0.630**	0.388	0.002
GL= a+bTL	-3.921	0.679	-9.25 to 1.46	0.31 to 1.04	0.530**	0.280	0.001

Intercept (a), Regression coefficient (b), Correlation coefficient (r), Coefficient of determination(r^2), Confidence intervals (CI), Significant ***P<0.001, Non-significant P>0.05.

upper jaw length (UJL), lower jaw length (LJL), inter-orbital length (IeOL), pelvic fin base (PvFB), and lower width (LW), which displayed negative slopes, suggesting an inverse relationship with total length. Most correlations were statistically significant, as indicated by *P*-values predominantly at 0.001 or lower.

The regression equations showcase a range of correlation coefficients (r) and determination coefficients (r²), indicating varying levels of predictive power across different parameters (Table 6). For instance, the relationship between log total length and log weight demonstrates a strong correlation coefficient of 0.880, with an r² value of 0.781. Similarly, log head length shows a moderate correlation (r= 0.630) but with a less significant r² of 0.393, reflecting a weaker predictive capacity. Notably, the log eye diameter exhibits a significant relationship with a *p*-value of 0.002, indicating strong statistical significance, while parameters like log dorsal fin base and log anal fin base also present noteworthy correlations with p-values below 0.001. Conversely, some parameters, such as log gill opening measurement (GOM), show weaker correlations and higher *P*-values.

The results presented in Table 7 illustrate the percentage frequency of occurrence of different food items consumed by *C. gariepinus*, offering significant insights into the dietary preferences of this species, for individuals measuring between 15 and 20cm, zooplankton and small crustaceans dominate their diet, with frequencies as high as 79% for crustaceans. As the size increases to the 20 to 25cm range, there is a notable shift where the consumption of insects and benthic organisms becomes more pronounced, with frequencies around 59% for both categories. In the 25 to 30 cm category, the frequency of occurrence for fish scales and debris material also rises significantly, reflecting a broader dietary scope that includes opportunistic feeding behaviors. Notably, larger individuals, particularly those in the 30 to 35cm range, exhibit a marked increase in the consumption of plant

Table 4. Descriptive statistics and Regression analysis of *Clarius gariepinus*: Total body weight against various morphological parameters.

Formula	Relation Parameters		Confidence Intervals	Confidence Intervals	Correlation coefficient	Correlation determination	*P*
Y= a+bx	A	b	a	B	r	r^2	
TL= a+bW	9.88	0.177	9.693 to12.084	0.149 to 0.208	0.889**	0.792	0.000
HL= a+ b W	1.898	0.041	2.396 to 3.399	0.020 to 0.045	0.641**	0.406	0.000
H = a+bW	1.385	0.044	0.651 to 2.131	0.025 to 0.051	0.609**	0.371	0.002
ED= a+bW	0.407	0.010	0.141 to 0.678	0.003 to 0.016	0.391*	0.159	0.013
UJL= a+bW	3.481	-0.022	2.960 to 3.991	-0.036 to 0.009	0.468**	0.220	0.003
LJL= a+bW	3.134	-0.020	2.677 to 3.588	-0.034 to 0.09	0.496**	0.0245	0.001
DFB= a+bW	0.544	0.017	0.227 to 0.881	0.08 to 0.032	0.539**	0.289	0.001
DFL= a+bW	1.103	0.032	0.558 to 1.671	0.022 to 0.048	0.641**	0.391	0.000
AFB= a+bW	4.541	0.033	4.123 to 4.953	0.021 to 0.043	0.700**	0.480	0.000
AFL= a+bW	0.953	0.024	0.631 to 1.279	0.015 to 0.030	0.641**	0.404	0.000
GOM= a+bW	0.710	0.008	0.417 to 1.008	-0.003 to 0.031	0.241	0.059	0.141
PtFL= a+bW	1.366	0.031	0.551 to 2.091	0.019 to 0.059	0.520**	0.272	0.002
PtFB= a+bW	0.255	0.012	0.080 to 0.431	0.007 to 0.019	0.630**	0.399	0.000
CFL= a+bW	1.760	0.042	1.192 to 1.290	0.026 to 0.058	0.691**	0.481	0.002
CFB= a+bW	1.351	0.013	1.016 to 1.691	0.002 to 0.020	0.388*	0.161	0.019
BD= a+bW	5.689	0.070	4.949 to 6.420	0.048 to 0.091	0.781**	0.590	0.003
IeO= a+bW	1.651	-0.006	1.32 to 1.234	-0.016 to 0.007	0.145	0.031	0.378
POL= a+bW	1.230	0.014	1.004 to 1.460	0.007 to 0.016	0.570**	0.331	0.001
FL= a+bW	10.81	10.781	9.860 to10.710	0.113 to 0.160	0.890**	0.787	0.001
SL= a+bW	10.90	0.112	9.809 to11.009	0.089 to 0.140	0.802**	0.643	0.000
PvFL= a+bW	0.078	0.0230	-0.719 to 0.548	0.012 to 0.046	0.486**	0.230	0.001
PvFB= a+bW	0.457	-0.002	0.179 to 0.722	-0.009 to 0.009	0.081	0.006	0.671
SW= a+bW	0.190	0.019	-0.609 to 0.209	0.007 to 0.030	0.510**	0.252	0.002
LW= a+bW	0.309	0.019	-0.630 to 0.022	0.009 to 0.029	0.530**	0.259	0.003
GL= a+bW	3.467	0.125	0.510 to 6.430	0.049 to 0.196	0.487**	0.229	0.003

Table 5. Descriptive statistics and Regression analysis of *Clarius gariepinus*: log of Total length against various morphological parameters.

Formula	Relation Parameters		Confidence Intervals	Confidence Intervals	Correlation coefficient	Correlation determination	*P*
LogY= log a+b log x	A	B	A	B	r	r^2	
Log W= log a + b log TL	-0.77	1.88	-1.120 to -0.310	1.512 to 2.171	0.880**	0.781	0.001
Log HL= log a + b log TL	-0.89	1.09	-1.320 to -0.420	0.732 to 1.445	0.710**	0.510	0.001
Log HW= log a+b log TL	-1.36	1.44	-1.950 to -0.710	0.940 to 1.937	0.689**	0.477	0.001
Log ED= log a+b log TL	-1.60	1.16	-2.499 to -.688	.430 to 1.878	0.470**	0.216	0.002
Log UJL= log a+b log TL	1.48	-0.89	0.820 to 2.073	-1.330 to -0.36	0.478**	0.227	0.001
Log LJL= log a+b log TL	1.49	-0.86	0.841 to 2.012	-1.322 to -0.39	0.512**	0.263	0.000
Log DFB= log a+b log TL	-1.69	1.335	-2.354 to -0.878	0.740 to 1.930	0.596**	0.359	0.000
Log DFL= log a+b log TL	-1.26	1.280	-1.940 to -0.518	0.709 to 1.851	0.590**	0.360	0.001
Log AFB= log a+b log TL	-0.02	0.620	-1.76 to 0.146	0.499 to 0.748	0.850**	0.720	0.860
Log AFL= log a+b log TL	-1.20	1.146	-1.730 to -0.660	0.714 to 1.579	0.660**	0.434	0.000
Log GOM= log a+b log TL	-0.70	0.520	-1.735 to 0.340	-0.319 to 1.348	0.120	0.042	0.181
Log PtFL = log a+b log TL	-1.30	1.360	-1.810 to -0.765	0.944 to 1.777	0.730**	0.534	0.000
Log PtFB= log a+b log TL	-2.21	1.620	-2.890 to -1.550	1.074 to 2.163	0.710**	0.499	0.000
Log CFL= log a+b log TL	-0.79	1.021	-1.233 to -0.293	0.650 to 1.412	0.674**	0.449	0.001
Log CFB= log a+b log TL	-0.69	0.737	-1.265 to -0.095	0.251 to 1.222	0.456**	0.206	0.026
Log BD= log a+b log TL	-0.03	0.760	-0.265 to 0.209	0.572 to 0.950	0.791**	0.640	0.819
Log IeOL= log a+b log TL	0.619	-0.40	-0.280 to 1.487	-1.081 to 0.350	0.171	0.030	0.177
Log POL= log a+b log TL	-0.69	0.690	-1.056 to -0.234	0.350 to 1.026	0.570**	0.321	0.002
Log FL= slog a+b log TL	0.150	0.850	0.067 to 0.238	0.780 to .916	0.972**	0.951	0.001
Log SL= log a+b log TL	0.240	0.760	0.099 to 0.379	0.648 to .870	0.910**	0.830	0.002
Log PvFL= log a+b log TL	-4.27	3.270	-5.209 to -2.210	1.671 to 4.880	0.560**	0.310	0.001
Log PvFB= log a+b log TL	-0.50	-0.02	-2.389 to 1.437	-1.546 to 1.527	0.003	0.620	0.001
Log SW= log a+b log TL	-3.88	2.770	-5.970 to -1.780	1.089 to 4.450	0.480**	0.230	0.001
Log LW= log a+b log TL	-0.50	-0.02	-2.389 to 1.440	-1.548 to 1.530	0.003	0.620	0.001
Log GL= log a+b log TL	-3.90	2.770	-5.971 to -1.770	1.089 to 4.450	0.479**	0.230	0.001

matter and fish, with plant material occurring in over 61% of instances, highlighting a shift towards more diverse and complex feeding patterns as they mature. Finally, in the largest size class (35 to 40cm), fish remains are frequently observed, with occurrences reaching up to 82%, indicating a predatory behavior

Table 6. Descriptive statistics and Regression analysis of *Clarius gariepinus*: log of Weight against various morphological parameters.

Formula	Relation Parameters		Confidence Intervals	Confidence Intervals	Correlation coefficient	Correlation determination	*P*
LogY= log a+b log x	A	b	A	B	r	r^2	
Log TL= log a+b log W	0.580	0.430	0.460 to 0.720	0.350 to 0.490	0.880**	0.781	0.000
Log HL= log a+b log W	-0.30	0.460	-0.530 to 0.09	0.270 to 0.650	0.630**	0.393	0.110
Log HW= log a+b log W	-0.40	0.550	-0.830 to 0.06	0.273 to 0.830	0.550**	0.299	0.070
Log ED= log a+b log W	-0.91	0.512	-1.480 to -0.40	0.160 to 0.860	0.431**	0.180	0.002
Log UJ = log a+b logW	1.071	-0.420	0.680 to 1.437	-0.68 to -0.179	0.496**	0.244	0.000
Log LJL= log a+b log W	1.008	-0.410	0.660 to 1.366	-0.69 to -0.188	0.520**	0.270	0.001
Log DFB=log a+b logW	-0.89	0.593	-1.351 to -0.44	0.299 to 0.880	0.550**	0.320	0.001
Log DFL=log a+b log W	-0.49	0.510	-0.882 to 0.02	0.220 to 0.789	0.520**	0.257	0.060
Log AFB=log a+b log W	0.360	0.260	0.240 to 0.481	0.177 to 0.336	0.730**	0.524	0.001
Log AFL= log a+b log W	-0.60	0.520	-0.920 to -0.30	0.307 to 0.740	0.621**	0.389	0.001
Log GOM= log a+blog W	-0.30	0.150	-0.930 to 0.31	-0.259 to 0.560	0.120	0.366	0.011
Log PtFL= log a+blog W	-0.45	0.540	-0.820 to -0.07	0.310 to 0.780	0.610**	0.369	0.023
Log PtFB= log a+b log W	-1.30	0.670	-1.710 to -0.80	0.377 to 0.960	0.610**	0.368	0.001
Log CFL= log a+b log W	-0.20	0.440	-0.486 to 0.10	0.246 to 0.641	0.596**	0.354	0.271
Log CFB= log a+b log W	-0.29	0.296	-0.591 to 0.15	0.061 to 0.530	0.382*	0.143	0.224
Log BD= log a+b log W	0.420	0.323	0.242 to 0.580	0.220 to 0.430	0.709**	0.508	0.000
Log IeOL= log a+b log W	0.463	-0.197	-0.080 to 0.91	-0.537 to 0.145	0.189	0.036	0.089
Log POL= log a+b log W	-0.30	0.338	-0.550 to -0.06	0.177 to 0.498	0.568**	0.323	0.024
Log FL= log a+b log W	0.64	0s.379	0s.520 to 0.82	0.320 to 0.441	0.894**	0.799	0.001
Log SL= log a+b log W	0.69	0.330	0.556 to 0.797	0.241 to 0.410	0.805**	0.649	0.001
Log PvF= log a+b log W	-2.64	1.570	-3.820 to -1.40	0.800 to 2.340	0.557**	0.312	0.001
Log PvFB=log a+b log W	-0.20	-0.200	-1.330 to 0.91	-0.930 to 0.536	0.091	0.754	0.003
Log SW= log a+b log W	-2.44	1.280	-3.712 to -1.20	0.467 to 2.090	0.463**	0.210	0.001
Log LW= log a+b log W	-4.32	2.631	-6.520 to -3.50	1.655 to 3.590	0.670**	0.450	0.001
Log GL= log a+b log W	-0.30	0.720	-0.770 to 0.30	0.383 to 1.053	0.579**	0.332	0.363

Table 6. Percentage of frequency of occurrence of different food items according to size (cm) in *Clarius gariepinus.*

Food items	15-Nov	15-20	20-25	25-30	30 -35	35-40
	-10	-8	-7	-7	-3	-5
Zooplankton Spirostone Vorticella	40	30	72.41	30.51	101	62
Insects Regimbartia Hemiptera	62	0	59.14	59.13	0	0
Crustacean	79	39.5	30.5	60.14	34.3	59
Plants	21	0	0	0	61.5	82
Fish Chipila Mowa	39	76	41.88	30.5	31.3	39
Debris material						
Fish scales, *Channa* spp	78	79	60.14	103	104	59
Mollusca	-	-	-	-	110	-

characteristic of adult *C. gariepinus*.

DISCUSSION

The findings of this study provide a comprehensive overview of the morphological and physiological variability in *Clarias gariepinus*, reflecting not only the inherent growth patterns of the species but also the effects of environmental conditions specific to the Chenab River ecosystem. This species is well known for its phenotypic plasticity, enabling it to adapt to various ecological niches, thus enhancing its survival in diverse habitats (Ekelemu et al. 2018). The observed range in morphological traits such as body depth, head length, and fin measurements align with previous studies indicating that environmental factors like water flow, substrate composition, and nutrient availability significantly influence the growth and development of *C. gariepinus* (Oyugi et al. 2020). For instance, variations in body depth can be attributed to different hydrodynamic conditions, where individuals in faster currents may develop deeper bodies for improved stability and maneuverability. At the same time, those in slower waters may exhibit shallower profiles (Dunlop et al. 2020). Such morphological diversity is particularly crucial in fluctuating or challenging environments, where individuals with different body shapes may have varying abilities to exploit available resources or evade predation. This adaptability is essential for individual fitness and the population's resilience to environmental changes, such as habitat degradation or climate change. Study by Fagbuaro et al. (2015), investigated the morphometric characteristics of *C. gariepinus* in Nigeria. The study found significant variations in body weight, total length, and standard length, which were influenced by environmental factors such as water quality and food availability. It would suggest that environmental conditions in Pakistan also play a significant role in shaping the morphometric traits of *C. gariepinus*. Differences in measurements could be attributed to habitat-specific factors like river flow, temperature, and nutrient availability. Study by Dadebo et al. (2014). Conducted in Ethiopia, this research reported that *C. gariepinus* primarily consumed fish, insects, and crustaceans, with a preference for animal-based food sources.

The variation in K values provides critical insights into the nutritional status and environmental conditions (Seçer et al. 2021). Lower K values in larger specimens could indicate seasonal food availability, often affecting body condition (Otieno 2019). For example, larger fish may experience a drop in condition factor during spawning seasons due to the energy demands associated with reproduction. Furthermore, the inverse relationship between fish size and K value in some specimens might be attributed to energy allocation strategies, where larger fish invest more energy in reproduction rather than somatic growth, thus appearing leaner (Kadye & Booth 2015). Conversely, smaller fish with higher K values could indicate better access to food resources or less energy being diverted to reproductive processes. This suggests monitoring condition factors across life stages could provide valuable insights into population dynamics and health. The strong correlation between total length and fork length, with a high coefficient of determination, further confirms the reliability of fork length as a proxy for total length in assessing fish growth. This relationship benefits fisheries managers and aquaculturists, who often rely on fork length as a quick and non-invasive measure for estimating fish size and biomass in wild populations and cultured stocks (Silva et al. 2015). Additionally, the positive correlation between body depth and total length emphasizes the role of body depth in improving swimming efficiency, which is critical for predator evasion and foraging in riverine environments (Dunlop et al. 2020). Understanding these relationships can inform management practices aimed at optimizing growth conditions for aquaculture while ensuring sustainable practices that consider ecological balance. Moreover, the variation in fin-related traits such as dorsal fin base length and pectoral fin base suggests that these traits are highly adaptable and influenced by environmental factors like water current and substrate type. Fins play a crucial role in stabilization and propulsion; their variability may indicate differing ecological roles among individuals within the population. For instance, fish inhabiting fast-flowing river sections may develop longer dorsal and pectoral fins to improve stability and control. In contrast, those in slower-moving waters may not require such adaptations (Adebayo & Solarin 2021).

This morphological flexibility supports the hypothesis that *C. gariepinus* populations are highly responsive to localized environmental pressures, leading to micro-adaptations within populations even across relatively small geographic areas (Olufeagba et al. 2017). Such adaptability enhances individual fitness and contributes to the resilience of populations facing environmental fluctuations. Furthermore, the weaker correlations observed for parameters such as eye diameter and interorbital length suggest that these features are less directly related to overall body size and may be more reflective of individual feeding strategies or habitat preferences. As an opportunistic feeder capable of adjusting its diet based on prey availability, *C. gariepinus* may exhibit less consistent growth patterns in traits related to vision and prey detection (Adebayo & Solarin, 2021). This variability could respond to differing water clarity or prey availability across various river sections. For example, catfish inhabiting turbid waters may develop large, enormous eyes to enhance their ability to detect prey under low visibility conditions (Olufeagba et al. 2017). Conversely, those residing in clearer waters might not face similar predation pressures or competition for food resources; hence, their eye morphology may reflect less pronounced adaptations. Moreover, the logarithmic regression analysis highlights the complexity of growth patterns in *C. gariepinus*, with some traits showing extremely high predictive power for overall growth. In contrast, others display weak or even negative correlations. The negative slopes observed for parameters like interorbital length may reflect functional trade-offs where increased growth in one area may come at the expense of other traits that are less critical for survival or reproduction in specific environments (González-Tizón et al. 2020). These findings underscore the importance of multi-trait analyses when studying fish growth; focusing solely on one parameter may overlook important ecological and functional relationships influencing overall fitness. Additionally, understanding how morphological variations interact with behavioral ecology can provide deeper insights into how *C. gariepinus* navigates its environment. For instance, behavioral adaptations such as feeding strategies can be closely linked with morphological traits like jaw structure and fin configuration. Fish that exhibit more efficient feeding behavioral tend to have specific adaptations that allow them to exploit available resources effectively (Ezenwa et al. 2021). The interplay between morphology and behavior is particularly relevant when considering how these fish respond to anthropogenic pressures such as pollution or habitat alteration. Overall, this study enhances our understanding of the intricate relationship between morphology and environmental adaptation in *C. gariepinus*, offering valuable insights for ecological research and aquaculture development. The findings suggest that growth and morphology are influenced by genetics and a wide range of environmental factors that shape physical characteristics in ways that optimize survival and reproduction. As we continue to face challenges such as climate change, habitat degradation, and overfishing, understanding these relationships becomes increasingly important for developing sustainable management practices to preserve this ecologically significant species.

CONCLUSION

This study provides valuable insights into the morphological and ecological variability of *Clarias gariepinus* in the Chenab River. The strong correlations between body size, fin dimensions, and other morphometric traits highlight the species' adaptability to diverse environmental conditions. Additionally, the Gastro-somatic Index and Frequency of Occurrence analyses reveal key dietary patterns, emphasizing the species' opportunistic feeding behavior. Variations in Fulton’s condition factor further suggest the influence of seasonal and reproductive factors on fish health. Overall, the findings enhance our understanding of the species' ecological resilience and its implications for fisheries management and aquaculture.

ACKNOWLEDGMENT

We would like to express my sincere appreciation to Assist. Prof Dr. Khalid Ibrahim for his valuable comments on this manuscript.

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Iran. J. Ichthyol. (2025) 12(2): 147-161
P-ISSN: 2383-1561; E-ISSN: 2383-0964
http://www.ijichthyol.org

doi: 10.22034/iji.v12i2.1066

مقاله کامل

ریخت‌سنجی، ترکیب غذایی، و الگوهای تغذیه‌ای *Clarius gariepinus* از رودخانه چناب، پنجاب، پاکستان

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چکیده: گربه‌ماهی آفریقایی، *Clarias gariepinus* (*C. gariepinus*)، به‌دلیل انعطاف‌پذیری و ارزش غذایی بالا، یکی از گونه‌های حیاتی آبزی‌پروری است. این مطالعه ویژگی‌های ریخت‌سنجی و تغذیه پانزده نمونه *C. gariepinus* جمع‌آوری‌شده از رودخانه چناب، پاکستان، بین نوامبر ۲۰۲۱ و مه ۲۰۲۲ را ارزیابی می‌کند. آنالیز ریخت‌سنجی شامل طول کل، طول استاندارد، عمق بدن و قطر چشم بود. طول کل نمونه‌ها از ۱۳ تا ۲۵ سانتی‌متر (میانگین= ۱۶/۶۶±۲/۳۷ سانتی متر)، در حالی‌که وزن بدن از ۲۳ تا ۸۶ گرم (میانگین= ۴۱/۳۲±۱۳/۰۸ گرم) متغیر بود. بین طول کل و طول چنگال (r=۰/۹۷۹، P<۰/۰۰۱) و بین طول کل و وزن بدن (r=۷۹۰، P<۰/۰۰۱) همبستگی معنی‌داری مشاهده شد. برای ارزیابی عادات تغذیه از شاخص گاسترو-سوماتیک و فراوانی وقوع (٪) استفاده شد. زئوپلانکتون‌ها، سخت‌پوستان کوچک و موجودات اعماق دریا اقلام طعمه رایج بودند. نمونه‌های بزرگتر (بیش از ۳۰ سانتی‌متر) بیشتر مصرف مواد گیاهی و بقایای ماهی را داشتند. این مطالعه بینش‌هایی را در مورد تنوع ریختی و بوم‌شناسی تغذیه *C. gariepinus* ارائه می‌دهد و سازگاری آن را با شرایط محیطی محلی برجسته می‌کند. این یافته‌ها به درک الگوهای رشد، شاخص‌های سلامتی و ترجیحات غذایی کمک می‌کنند که برای مدیریت شیلات و شیوه‌های آبزی‌پروری پایدار حائز اهمیت هستند.

کلمات کلیدی: *Clarias gariepinus*، رودخانه ایندوس، ریخت‌سنجی، عادات تغذیه، محتوای معده