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CONSTITUTIONAL AND GROWTH INDICES, HEMATOLOGICAL AND METABOLIC PROFILES IN CARP (*Cyprinus carpio* Linnaeus, 1758), DUE TO THE ADMINISTRATION OF BREWERY YEAST (*Saccharomyces cerevisiae*)

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Abstract

This work aimed to determine the influence of brewer`s yeast (Saccharomyces cerevisiae) on the growth dynamics, health and physiological status of common carp (Cyprinus carpio Linnaeus, 1758). An experimental device was installed with four groups of carp in summer I. The control group was fed with classic feed. Groups II, III and IV are the experimental groups to which brewer`s yeast was added to the feed in a proportion of 3% (Group II), 5% (Group III) and 7% (Group IV). At the end of the experiment conducted over a period of 30 days, total weight gain (TWG) and average daily gain (ADG) as growth indices and the Fulton index (K) as a constitutional index were calculated, as well as the following physiological indices: hemogram and metabolic profiles. A 3% dietary supplementation of brewer's yeast produced the highest growth performance (TWG 69.58 g; ADG 2.32 g/day) and significantly improved Fulton's condition factor, while higher inclusion levels (5-7%) reduced growth performance and induced signs of metabolic stress. Hematological parameters remained stable across treatments, whereas moderate supplementation improved protein metabolism and physiological status without disrupting homeostasis. The addition of brewer`s yeast to the feed structure proved beneficial both in terms of growth dynamics and the health of the fish.

Key words*: yeast, physiological status, growth indices, constitutional indices, cyprinids.*

INTRODUCTION

Brewer's yeast (*Saccharomyces cerevisiae*) is a unicellular, eukaryotic yeast belonging to the phylum *Ascomycota* and the order *Saccharomycetales*. It is widely used in the baking, winemaking, and brewing industries (Walker & Stewart, 2016; Maicas, 2020). Due to its genetic and biochemical characteristics, it represents one of the main model organisms in molecular biology, possessing a genome organized into 16 linear chromosomes and functioning as a facultatively anaerobic chemoorganotrophic organism (Vanderwaeren et al., 2022). It has an active capacity to metabolize carbohydrates through glycolysis and alcoholic fermentation. As a result of these metabolic processes, ethanol and CO_2 are produced; these features are defined by the Crabtree effect, which involves the avoidance of complete oxidation via mitochondrial respiration and the inhibition of the activity of competing microorganisms (Pfeiffer & Morley, 2014). These particular characteristics have significant technological and industrial implications.

Biochemically, brewer's yeast synthesizes a wide range of biologically active compounds. It contains a high level of proteins with high biological value, B-complex vitamins (thiamine, riboflavin, pyridoxine, niacin, folic acid), nucleotides and nucleotide derivatives, and structural polysaccharides such as β-1,3/1,6-glucans and mannans (Badia et al., 2012; Bertolo et al., 2019; Grigore et al., 2025). The immunomodulatory effects attributed to

brewer's yeast are mainly due to the cell wall, which is largely composed of β-glucans and mannoproteins.

Nutritionally, brewer's yeast represents an important source of microbial protein, characterized by a favorable amino acid profile, with a high lysine content as well as a significant contribution of minerals and trace elements (Jach et al., 2022). Due to the presence of mannan oligosaccharides (MOS) as components of the cell wall, brewer's yeast reduces the adhesion of pathogenic bacteria such as *Escherichia coli* and *Salmonella* spp. to the intestinal mucosa (Alvarez et al., 2024). Although brewer's yeast in its inactive form is not considered a probiotic, its components can exert prebiotic and immunomodulatory functions. Following the administration of brewer's yeast, intestinal absorption functions are improved as intestinal villi are stimulated and increase in height (Jiang et al., 2015), the villus-to-crypt ratio is improved, and the activity of digestive enzymes is stimulated.

From an immunological and immunomodulatory perspective, β-glucans - recognized as ligands for receptors on phagocytic cells - stimulate the activity of macrophages and neutrophils, leading to increased phagocytic activity, enhanced lysozyme production, and improved resistance to bacterial infections (Ciszek-Lenda et al., 2024; Chattaraj et al., 2024).

Brewer's yeast has an increasingly wide range of applications in the field of farm animal nutrition (Ciurescu et al., 2021; Grigore et al., 2022) and in aquaculture (Mareš et al., 2023). The nutritional supplementation of brewer's yeast in ruminants leads to increased fiber digestibility, a reduced risk of acidosis, and improved milk production. In monogastric animals, studies have demonstrated a reduction in the incidence of diarrhea in piglets, improved growth rates, and optimization of feed conversion (Sampath et al., 2023).

In aquaculture, the inclusion of brewer's yeast plays a dual role: reducing the use of antibiotics and, more importantly, partially replacing fish meal, whose price has been steadily increasing and whose production volumes fluctuate on agricultural commodity markets. For this reason, various agricultural products as well as living organisms are being tested with the aim of replacing fish meal (Vrabec et al., 2015; Kulma et al., 2019). Due to its high protein content (40-50% of dry matter), brewer's yeast can partially substitute fish meal in the diets of carp, trout, salmon, or tilapia. However, it cannot fully replace fish meal because of its limited methionine content and the relatively low digestibility of its cell wall at high inclusion levels in feed. From the perspective of immunostimulatory effects in fish, the β-glucans and nucleotides present in yeast have been shown to increase phagocytic activity, elevate plasma lysozyme levels, and reduce mortality caused by bacterial infections (e.g., *Aeromonas hydrophila*).

Thus, brewer's yeast represents a valuable source of microbial protein and a functional ingredient with multiple applications in animal nutrition. Its metabolic properties, well characterized in numerous studies conducted over time, together with its content of bioactive compounds and its effects on intestinal health and immunity, justify its use in modern production systems. In aquaculture, the role of brewer's yeast extends beyond its strictly nutritional value, exerting immunomodulatory effects and promoting intestinal health, thereby contributing to the sustainability and efficiency of aquaculture production (Nicolae et al., 2012; Dobre et al., 2024).

In order to improve and increase the efficiency of cyprinid production, particularly that of common carp (*Cyprinus carpio*), new technologies for the exploitation of this species have been implemented (Filep et al., 2016; Bucur et al., 2016; Arcade et al., 2024), including genetic selection programs (Nicolae et al., 2013). The structural and functional methods underlying these technologies (Costache et al., 2021) are complemented by innovations in the field of nutrition. The common carp is an omnivorous species and, under intensive culture conditions and in various climatic environments (Dobrotă et al., 2024), readily accepts formulated feeds that include cereal-based ingredients, fish meal, plant protein sources, and vitamin-mineral premixes to ensure a balanced nutrient supply at all stages of development. In addition to the basic nutritional components, recent research emphasizes the use of functional additives with more complex roles, such as probiotics,

prebiotics, plant extracts (phytogenics), and other bioactive compounds that can stimulate digestion, improve nutrient utilization, strengthen the immune system, and reduce stress in fish (Cristea et al., 2012; Crețu et al., 2022). Plant extracts, essential oils, herbs, and certain bioactive substances are incorporated into diets at low inclusion levels in order to support both growth performance and overall health.

The aim of this study was to determine the influence of brewer's yeast (*Saccharomyces cerevisiae*) on growth performance indices and the physiological status of common carp (*Cyprinus carpio* Linnaeus, 1758).

MATERIALS AND METHODS

The experiment was conducted over a 30-day period, from May to June 2025, at the Mărtinești fish farm in Cluj County. Four cages were installed and four groups were formed, each consisting of 50 common carp specimens whose initial body weight (BW) and total length (TL) were recorded, at the start and at the end of the experiment. Group 1 (C) was considered the control group, while Group 2 (G2), Group 3 (G3) and Group 4 (G4) represented the experimental groups. Feeding was carried out according to an established schedule, with the specification that fish were not fed on Sundays, which were considered fasting days. Feed was administered once daily on a sliding feeding tray that could be immersed and lifted, allowing monitoring of feed consumption. Group 1 (control) was fed a conventional carp diet produced within the farm (Table 1). For Group 2, the feed was supplemented with 3% brewer's yeast, for Group 3 with 5% brewer's yeast and for Group 4 with 7% brewer's yeast. Each group received a daily ration equivalent to 1.5% of the total biomass of the group.

Growth performance indices were calculated, including total weight gain (TWG) and average daily gain (ADG), as well as Fulton's condition factor (K) (Lațiu et al., 2022). At the end of the experiment, blood samples were collected to assess the physiological status of the fish. Blood samples required for the analyses were obtained from the caudal vein, from five individuals in each experimental group. Sampling was performed using syringes with a usable volume of 3 mL. The collected blood was subsequently transferred into vacutainers containing anticoagulant (heparin) for hematological determinations, and into vacutainers with sodium citrate (Clot Activator) for serum separation required for biochemical analyses. Hematocrit (Hct) was determined by centrifugation at 12,000 rpm for 3 minutes. Hemoglobin concentration (Hb) and erythrocyte count (RBC) were determined using spectrophotometric techniques (UV-VIS Screen Master Touch). Hemoglobin determination was performed using the End-Point colorimetric reaction. Readings were carried out in the NIS spectral range using 0.4% ammonium hydroxide (NH_4OH) in distilled water as reagent. The erythrocyte count was determined using a turbidimetric and colorimetric EP-type reaction with visible reading, employing a sodium sulfate (Na_2SO_4) acetic solution in distilled water (Gowen reagent). The mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH) and mean corpuscular hemoglobin concentration (MCHC) were calculated.

The biochemical profile was obtained through spectrophotometric techniques (UV-VIS Screen Master Touch) (Table 2).

All statistical analyses were performed using GraphPad Prism (version 8.0.1, GraphPad Software, USA). Data were initially tested for normality using the Shapiro-Wilk test. When the assumption of normal distribution was met, differences among groups were evaluated using analysis of variance (ANOVA), followed by Tukey's Honestly Significant Difference (HSD) test for post hoc multiple comparisons. For datasets that did not meet the assumption of normality, the non-parametric Kruskal-Wallis test was applied, followed by Dunn's test for pairwise comparisons. The level of statistical significance was set at $p < 0.05$. Results are presented as mean ± standard deviation (SD), and the number of replicates (n) for each parameter is reported in the corresponding tables or figures. Parameters that could not be determined using the available analytical methods or that were below the limit of detection (LOD) were recorded as below detection limit (BDL). In certain cases, the possibility of a Type II error cannot be

excluded due to limitations related to sample size or analytical sensitivity; such instances are acknowledged and discussed in the Results and Discussions section.

Table 1. Composition of the feed administered to common carp specimens

Ingredients	%	DM, %	OM, %	ME kcal, %	CP, %	CL, %	CDF, %	Ash, %	NFE, %	TP, %
FM	5	4.55	99.23	162.50	3.50	0.40	0.00	0.77	0.24	0.10
MM	7	6.30	98.45	213.50	4.58	1.83	0.00	1.55	0.35	0.28
SM-C1	15	13.20	99.10	510.00	6.93	0.24	1.83	0.90	4.56	0.10
SM-G2	12	10.56	99.28	408.00	5.54	0.19	0.66	0.72	3.65	0.08
SM-G3	10	8.80	99.40	340.00	4.62	0.16	0.55	0.60	3.04	0.07
SM-G4	8	7.04	99.52	272.00	3.70	0.13	0.44	0.48	2.43	0.05
SFM	5	4.49	99.70	127.50	1.75	0.06	1.09	0.30	1.22	0.06
BY-C	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BY-E2	3	2.72	99.77	65.10	1.29	0.04	0.04	0.23	1.00	0.03
BY-E3	5	4.54	99.62	108.50	2.15	0.07	0.06	0.38	1.67	0.05
BY-E4	7	6.35	99.47	151.90	3.01	0.10	0.08	0.53	2.34	0.07
CF	30	25.98	99.58	1050.00	2.67	2.83	0.30	0.42	20.97	0.14
WF	30	26.28	99.49	975.00	3.39	2.83	0.30	0.51	20.97	0.08
BM	7	13.58	99.64	227.50	6.23	0.38	0.00	0.36	0.06	0.07
VMP	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Total-C	100	94.37	95.19	3266.00	29.05	8.56	2.51	4.81	48.36	0.83
Total-G2	100	91.74	95.15	3229.10	28.96	8.56	2.38	4.85	48.45	0.85
Total-G3	100	89.98	95.12	3204.50	28.89	8.55	2.30	4.88	48.51	0.85
Total-G4	100	88.22	95.09	3179.90	28.83	8.55	2.21	4.91	48.57	0.86

DM-dry matter; **OM**-organic matter; **ME**-metabolizable energy; **CP**-crude protein; **CL**-crude lipids; **CDF**-crude dietary fiber; **NFE**-nitrogen free-extract; **TP**-total phosphorus; **FM**-fish meal; **MM**-meat meal; **SM**-soybean meal; **SFM**-sunflower meal; **BY**-brewer's yeast; **CF**-corn flour; **WF**-wheat flour; **BM**-blood meal; **VMP**-vitamin-mineral premix; **C**-control group; **E**-experimental groups.

Table 2. Biochemical parameters of blood analyzed in this study

Blood parameter	λ (nm)	Usual method
TP - total proteins (g/dL)	546 nm	Burette
ALB - albumins (g/dL)	628 nm	BCG
ɣ-GLOB - gamma globulins (g/dL)	405 nm	Indirectly Computation
CHOL - cholesterol (mg/dL)	500 nm	CHOD-PAP (Enzymatic)
TRY - triglycerides (mg/dL)	550 nm	GPO-PAP (Enzymatic)
GLU - blood glucose (mg/dL)	500 nm	GOD-PAP (glucose oxidase-peroxidase)
TC - total calcium	575 nm	OCPC (o-cresolftalein complexon)
Fe^{3+} - serum iron (mg/L)	560 nm	Ferrozine
Na^{+} - sodium (mmol/L)	405 nm	ISE (ion selective electrode)
K^{+} - poatassium (mmol/L)	380 nm	ISE (ion selective electrode)
GGT - gamma-glutamyl transpeptidase (U/I)	405 nm	Enzymatic-Kinetic
ASAT - aspartate aminotransferase (U/I)	340 nm	Kinetic UV (IFCC)
ALAT - alanine aminotransferase (U/I)	340 nm	Kinetic UV (IFCC)
LDH - lactate dehydrogenase (U/I)	340 nm	Kinetic UV
DB - direct bilirubin (mg/dL)	546 nm	Diazo
TB - total bilirubin (mg/dL)	540 nm	Diazo with accelerator

RESULTS AND DISCUSSIONS

The mean body weight values of the specimens are presented in Table 3. The initial body weight of fish in the four groups was homogeneous, with values ranging from 123.00 ± 1.02 g (C) to 124.84 ± 0.96 g (G3). At the end of the experiment, the mean body weight values ranged between 185.88 ± 1.21 g (G4) and 193.14 ± 1.18 g (G2). The highest TWG (69.58 g) and ADG (2.32 g/day) were recorded in G2, which received a dietary supplementation of 3% brewer's yeast. Similar values to those in C were observed in G3, which

received a 5% supplementation of brewer's yeast. The lowest growth performance was recorded in G4, with 7% inclusion of brewer's yeast in the diet.

The results confirm those of other studies indicating that the optimal inclusion level of brewer's yeast ranges between 2.5 and 5% for optimal growth performance (Mihai et al., 2023). When this range is exceeded, inhibition of certain metabolic processes may occur (Mareš et al., 2023), resulting in reduced growth dynamics, potential nutritional imbalances, and alterations in the intestinal microbiota (Tao et al., 2025). This may appear paradoxical, considering the high protein content of brewer's yeast; however, its amino acid profile is not fully compatible with the nutritional requirements of fish. At high inclusion levels, brewer's yeast may "dilute" other more balanced protein sources in the feed, contribute to increased excretion of ammonia or uric acid (Jaeger et al., 2020), and may significantly reduce overall digestibility.

Regarding the constitutional indices, Fulton's condition factor (K) was calculated for all four groups, both at the beginning and at the end of the experiment (Figure 1). Fulton's condition factor represents an important indicator of the physiological status and the degree of somatic development in fish and is frequently used to evaluate feeding efficiency and growth conditions in common carp. The statistical analysis was performed using Dunn's test for multiple comparisons, with a significance threshold of $\alpha = 0.05$, comparing the initial and final values of Fulton's condition factor for each experimental group (Table 4).

Table 3. Initial and final mean body weight values of common carp specimens from the experimental groups and the growth performance indices of the four groups

GI	**C**	**G2**	**G3**	**G4**
IBW (g)	123.00 ± 1.02	123.56 ± 1.13	124.84 ± 0.96	123.42 ± 1.07
FBW (g)	189.43 ± 1.26	193.14 ± 1.18	190.15 ± 1.17	185.88 ± 1.21
TWG (g)	66.43	69.58	65.31	62.46
ADG (g/day)	2.21	2.32	2.18	2.08

GI-growth indices; **IBW**-initial body weight; **FBW**-final body weight; **TWG**-total weight gain; **ADG**-average daily gain; **C**-control group; **G2**-experimental group 2; **G3**-experimental group 3; **G4**-experimental group 4.

Table 4. Statistical differences in Fulton's condition factor (K) among the four experimental groups, comparing the initial and final values

Number of families	1			
Number of comparisons per family	4			
α	0.05			
Dunn's multiple comparisons test	Mean rank diff.	Significant?	Summary	Adjusted P Value
Group C Initial vs. Group C Final	-40.67	Yes	*	0.0318
Group G2 Initial vs. Group G2 Final	-75.73	Yes	***	0.0002
Group G3 Initial vs. Group G3 Final	-37.41	No	ns	0.1077
Group G4 Initial vs. Group G4 Final	-25.18	No	ns	0.4641

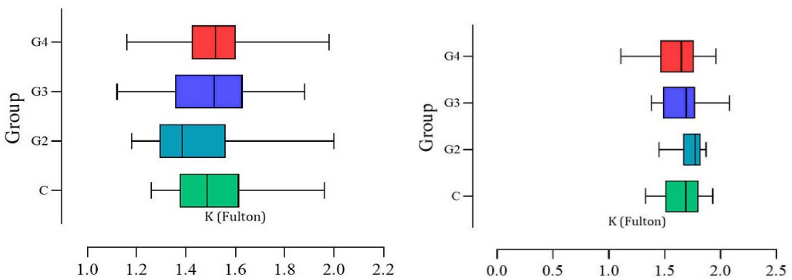

Figure 1. Fulton's condition factor (K) for the four experimental groups at the beginning of the experiment (left) and at the end of the experiment (right)

The control group showed a statistically significant difference between the initial and final values of Fulton's condition factor (Mean rank diff. = −40.67; $p = 0.0318$; $p < 0.05$). This result indicates a significant change in the body condition status of the fish during the experimental period. G2 (supplemented with 3% brewer's yeast) recorded the most pronounced statistical difference between the initial and final values (Mean rank diff. = −75.73; $p = 0.0002$; $p < 0.001$). This highly significant difference suggests a strong influence of brewer's yeast supplementation on the body condition of the carp specimens. G3 (supplemented with 5% brewer's yeast) did not show statistically significant differences between the initial and final values of Fulton's condition factor (Mean rank diff. = −37.41; $p = 0.1077$; $p > 0.05$), indicating that the observed changes were not sufficiently pronounced to be considered statistically significant. Similarly, G4 (supplemented with 7% brewer's yeast) showed no statistically significant differences between the beginning and the end of the experiment (Mean rank diff. = −25.18; $p = 0.4641$; $p > 0.05$), suggesting that the high level of brewer's yeast supplementation did not produce relevant changes in Fulton's condition factor.

Overall, the results indicate that moderate supplementation with brewer's yeast (particularly in G2) produced the greatest change in the condition index, whereas higher supplementation levels (5% and 7%) did not result in statistically significant differences during the experimental period. These observations may suggest the existence of an optimal inclusion level of brewer's yeast in the diet for improving the body condition of common carp.

Fulton's condition factor (K) is commonly used to assess the nutritional status, somatic development, and the relationship between weight and length in fish (Nash et al., 2006), being influenced by feed quality, nutrient conversion efficiency, and growth conditions. A higher Fulton's condition factor generally indicates a better body condition and a greater accumulation of body mass.

In the analyzed experiment, statistically significant differences were observed only in the control group and in the group supplemented with a moderate level of brewer's yeast, whereas the groups receiving higher yeast inclusion levels did not show significant differences. These results may be explained by several biological mechanisms (Zhou et al., 2024). The obtained results suggest that moderate supplementation of feed with brewer's yeast may positively influence the condition status (Fulton's condition factor K) of common carp (Mareš et al., 2023; Mihai et al., 2023), by improving nutrient digestibility and protein utilization efficiency. Brewer's yeast, particularly *S. cerevisiae*, represents a valuable source of proteins, B-complex vitamins, and bioactive compounds that can stimulate metabolism and the immune system of fish (Rhema, 2022; Sumbal et al., 2024). However, high inclusion levels do not necessarily lead to a further increase in Fulton's condition factor, as increases in length and weight may occur proportionally, thereby maintaining this body condition indicator relatively constant.

The physiological status and health condition of the common carp specimens from the four experimental groups are characterized by the hematological analyses and biochemical analyses performed at the end of the experiment (Tables 5, 6, 7, 8, 9).

Hematological parameters (Table 5) represent important indicators of the physiological and health status of fish, reflecting processes such as oxygen transport, energy metabolism, nutritional status, and immune response. In aquaculture, these parameters are frequently used to evaluate the effects of various dietary supplements on fish physiology. In the analyzed experiment, common carp were fed diets supplemented with brewer's yeast at different inclusion levels: 3, 5, and 7%, compared with the control group without supplementation. Statistical analysis of the hematological values determined at the end of the experiment showed that no significant differences were observed among the groups for any of the analyzed parameters. From a biological perspective, the absence of significant differences suggests that the administration of brewer's yeast at the tested inclusion levels did not produce major hematological changes, indicating that supplementation of the feed with this additive did not induce physiological stress or disrupt the homeostasis of the organism

(Boonanuntanasarn et al., 2019). This stability of hematological parameters may be interpreted as an indicator of the good tolerance of common carp to the inclusion of brewer's yeast in the diet, even at relatively high levels (Figure 2).

Table 5. Mean values of hematological parameters and erythrocyte indices in specimens from the four groups at the end of the experiment

Parameter	Group	Hb (g/dL)	Hct (%)	RBCx10^{12}	MCV (fL)	MCH (pG)	MCHC (g/dL)
Mean ± SEM	C	5.844 ± 1.726	37.200 ± 7.662	3.312 ± 0.532	111.7 ± 6.337	17.39 ± 2.752	8.977 ± 0.5223
	G2	7.200 ± 1.856	39.400 ± 11.800	3.500 ± 0.396	110.6 ± 22.20	20.35 ± 3.438	9.369 ± 2.029
	G3	6.712 ± 0.736	44.400 ± 1.140	3.532 ± 0.195	126.1 ± 8.643	19.03 ± 2.082	7.962 ± 0.5519
	G4	6.786 ± 1.038	41.200 ± 1.304	3.532 ± 0.128	116.7 ± 2.378	19.19 ± 2.644	8.573 ± 0.1714

Table 6. Mean values of plasma protein constituents in specimens from the four groups at the end of the experiment

Parameter	Group	TP (g/dL)	ALB (g/dL)	γ-GLOB (g/dL)
Mean ± SEM	C	3.592 ± 0.338	1.068 ± 0.105	0.138 ± 0.040
	G2	4.390 ± 0.157	1.324 ± 0.084	0.121 ± 0.015
	G3	4.310 ± 0.482	1.364 ± 0.125	0.120 ± 0.013
	G4	4.480 ± 0.376	1.252 ± 0.109	0.110 ± 0.013

Table 7. Mean values of lipid and carbohydrate constituents in the blood plasma of specimens from the four groups at the end of the experiment

Parameter	Group	TRY (mg/dL)	CHOL (mg/dL)	GLU (mg/dL)
Mean ± SEM	C	283.000 ± 21.360	213.300 ± 23.240	107.200 ± 15.180
	G2	305.700 ± 48.300	187.300 ± 24.410	106.500 ± 24.880
	G3	280.800 ± 14.550	185.200 ± 4.823	122.300 ± 3.984
	G4	241.700 ± 22.790	187.800 ± 11.730	184.700 ± 42.720

Table 8. Mean values of mineral constituents in the blood plasma of specimens from the four groups at the end of the experiment

Parameter	Group	Fe^{3+} (mg/L)	Na^{+} (mmol/L)	K^{+} (mmol/L)
Mean ± SEM	C	43.980 ± 12.570	154.200 ± 3.197	2.814 ± 0.249
	G2	40.400 ± 9.301	151.500 ± 2.205	3.216 ± 0.268
	G3	36.600 ± 7.570	160.800 ± 2.044	2.880 ± 0.212
	G4	38.860 ± 7.237	164.200 ± 4.257	2.706 ± 0.080

Table 9. Mean values of enzymatic constituents in the blood plasma of specimens from the four groups at the end of the experiment

Par.	Group	ASAT (U/l)	ALAT (U/l)	LDH (U/l)	GGT (U/l)	DB (mg/dL)	TB (mg/dL)
Mean± SEM	C	51.940 ± 7.89	25.300 ± 10.24	224.900 ± 28.61	3.340 ± 0.42	0.001 ± 0.01	0.054 ± 0.08
	G2	43.160 ± 13.18	17.400 ± 2.45	204.000 ± 12.80	8.000 ± 1.27	0.000 ± 0.00	0.006 ± 0.01
	G3	57.280 ± 4.24	14.320 ± 3.95	293.200 ± 8.25	3.676 ± 0.62	0.007 ± 0.01	0.231 ± 0.25
	G4	49.300 ± 1.49	21.620 ± 4.60	267.700 ± 4.77	3.144 ± 0.33	0.002 ± 0.01	0.019 ± 0.03

The increase in TP observed in all experimental groups compared with the control suggests stimulation of protein synthesis or a metabolic adaptation to the experimental conditions. G4 shows the highest increase, which may indicate a more pronounced physiological response of the organism to the treatment or to the experimental conditions. The significant increase in albumin in G2 and G3 suggests enhanced and efficient hepatic activity, since albumin is the principal marker of hepatic protein synthesis and plays an important role in maintaining colloid osmotic pressure and in the transport of various molecules. The absence of a significant difference in G4 may reflect either a physiological adaptation or stabilization of albumin concentration at the level of this experimental group (Gokulakrishnan et al., 2022).

The stability of γ-GLOB indicates that the humoral immune response was not significantly affected by the experimental factor, as γ-globulins represent the main component of plasma immunoglobulins (Table 6).

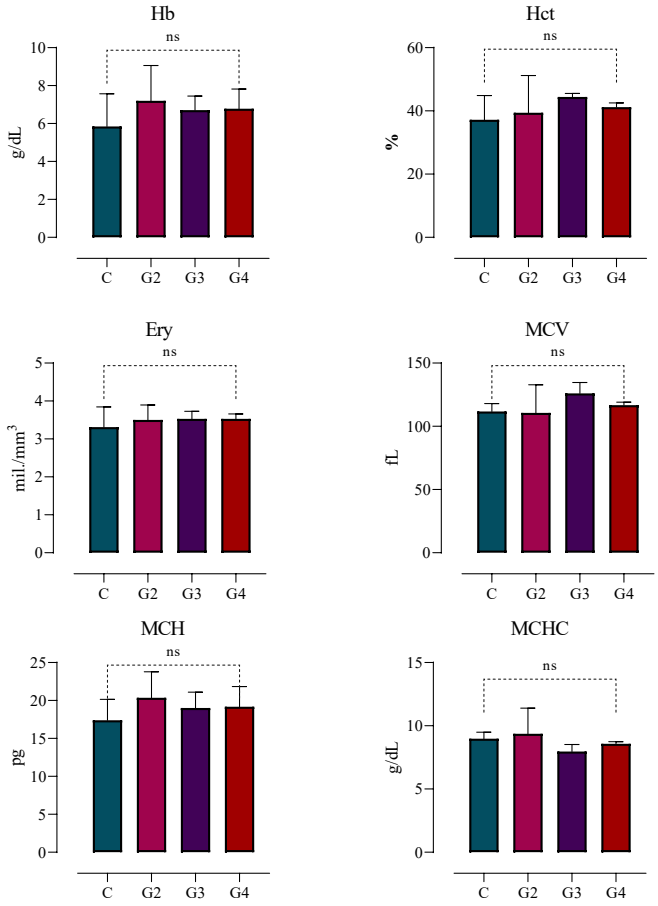

Figure 2. Significance of the differences in hematological parameters (Hb, Hct, RBC) and erythrocyte indices (MCV, MCH, and MCHC) among the four experimental groups

Triglyceride levels reflect lipid metabolism and energy storage (Table 7). The increase observed in G2 may indicate mobilization of energy reserves or metabolic adaptation, whereas the decrease in G4 suggests increased energy expenditure or inhibition of lipid synthesis. The decrease in cholesterol levels in all experimental groups indicates possible alterations in hepatic metabolism, reduced lipoprotein synthesis, or increased lipid catabolism (Hassaan et al., 2018).

The balance of blood glucose levels in G2 indicates the absence of a major effect (Goran et al., 2017), whereas the increases observed in G3 and especially G4 suggest metabolic stress and possible disturbances in glucose regulation (hyperglycemia), which may reflect effects on glycogenolysis, gluconeogenesis, or insulin sensitivity.

The decrease in Fe^{3+} values observed in all experimental groups suggests possible effects on iron metabolism, either through reduced absorption or through redistribution among different compartments (plasma, liver, tissue reserves) (Table 8). The lower values recorded in G3 and G4 may indicate increased utilization or mobilization for the synthesis of hemoproteins (e.g., hemoglobin, cytochromes) (Huyben et al., 2016).

The significant increases in Na^{+} levels in G3 and G4 suggest modifications in hydroelectrolytic balance, possibly through effects on renal or hormonal function (aldosterone, vasopressin). The slight decrease observed in

G2 may reflect an initial physiological adaptation to the treatment (Sutthi & Thaimuangphol, 2020). The stable or only slightly modified K^+ values indicate that the intracellular/extracellular potassium balance was largely maintained, although the slight decrease observed in G4 may signal minor renal loss or cellular redistribution (Figure 3).

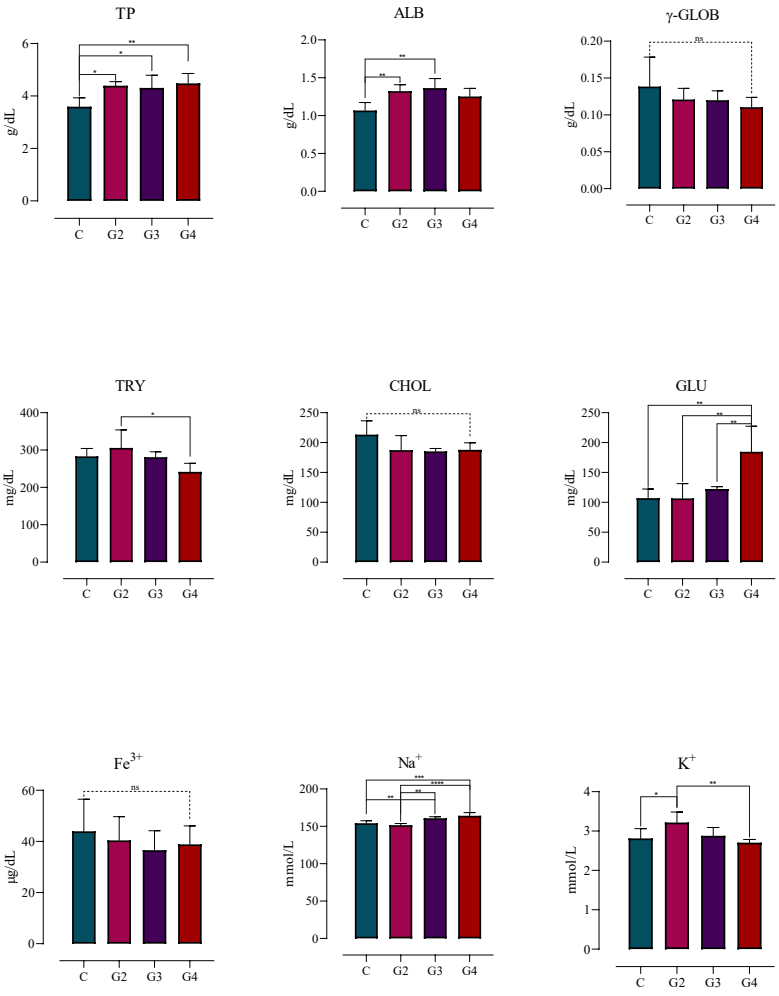

Figure 3. Significance of the differences in protein metabolic profiles (TP, ALB, γ-GLOB), lipid profiles (TRY, CHOL), carbohydrate profile (GLU), and mineral profiles (Fe^{3+}, Na^+, K^+) among the four experimental groups

ASAT and ALAT are markers of hepatic cytolysis. The decrease in ALAT observed in G2 and G3 may indicate metabolic adaptation or reduced hepatic enzymatic activity, whereas variations in ASAT may reflect influences on both muscular and hepatic metabolism (Table 9). The significant increase in LDH in G3 and G4 indicates tissue stress or cellular damage, as LDH is a nonspecific marker of cellular injury.

The marked increase in GGT in G2 suggests stimulation of the biliary pathways or cholestasis, while the normal values recorded in G3 and G4 indicate the absence of biliary canalicular impairment (Figure 4).

The nearly normal values of DB and TB indicate the maintenance of hepatic excretory function, with the exception of a slight increase observed in G3.

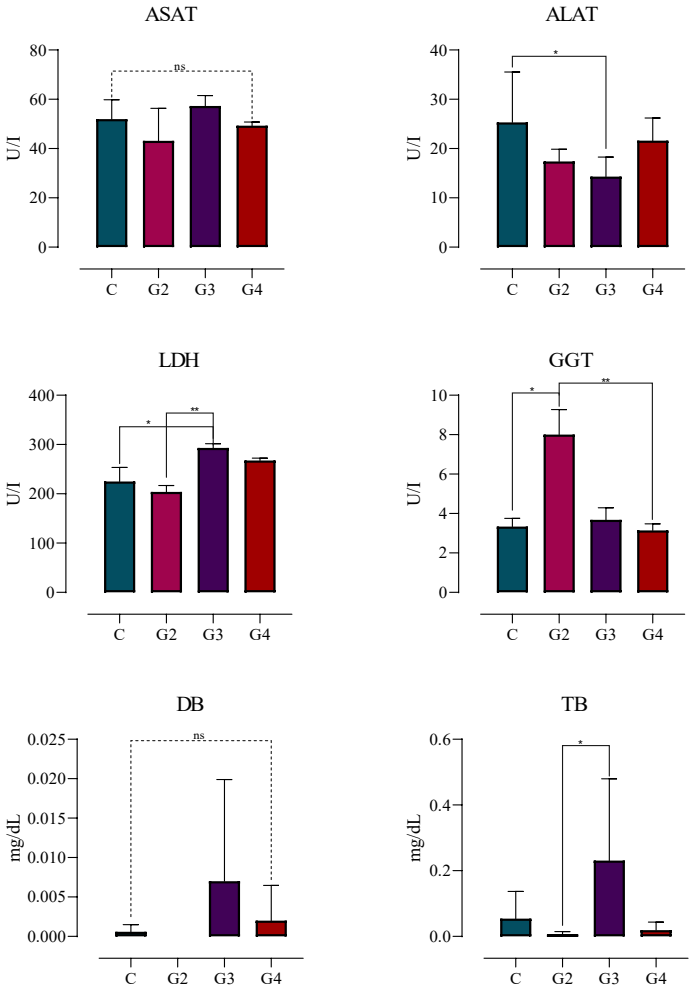

Figure 4. Significance of the differences in enzymatic metabolic profiles (ASAT, ALAT, LDH, GGT, DB, TB) among the four experimental groups

CONCLUSIONS

Brewer's yeast may be considered as an additive in common carp feeds, although only to a limited extent. Its high protein content recommends this product as an additive; however, the different amino acid profile may lead to inhibition of metabolic processes and, consequently, reduced growth of common carp when included at excessively high levels. Our results demonstrated that a 3% supplementation level is beneficial both in terms of growth performance and immunomodulatory effects. From a hematological perspective, no significant changes were observed in the experimental groups compared with the control group. Regarding metabolic profiles, an increase in biochemical protein indicators was observed, suggesting stimulation of protein synthesis and an adaptive response of metabolic processes in the experimental groups. However, at high inclusion levels, brewer's yeast may lead to an imbalance of the intestinal microbiota, generating digestive dysfunctions, specifically a reduction in digestibility. The increased level of lipid fractions observed in G2 (3% brewer's yeast supplementation) suggests mobilization of energy reserves, whereas at higher inclusion levels, as in G4 (7% brewer's yeast supplementation), inhibition of

lipid synthesis was observed. The levels of mineral fractions showed certain variations, particularly in the case of sodium, which produced alterations in the hydroelectrolytic balance and affected renal functions. Enzymatic fractions also exhibited some differences between the control group and the experimental groups, indicating tissue stress and stimulation of biliary function. Overall, brewer's yeast can be considered a suitable partial substitute for fish meal, but only when included in relatively low amounts in the diet.

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