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Original Article

Effects of dietary supplementation of peppermint (*Mentha piperita*) on growth, survival and haemato-biochemical profile of common carp (*Cyprinus carpio*) fingerlings

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Abstract
Herbal feed additives are increasingly explored in aquaculture as natural alternatives to synthetic growth promoters and immunostimulants. Peppermint (*Mentha piperita*), known for its bioactive phytochemicals and antioxidant properties, has shown potential benefits for fish health and metabolism. A 60-day feeding trial was conducted using 120 fingerlings (initial mean weight: 10.2±0.02 g; length: 9.63±0.03 cm) randomly distributed into four experimental groups, each with three replicates, following a completely randomized design. Experimental diets were prepared by incorporating peppermint leaf powder at 0% (control), 1%, 2%, and 3% per kg of feed weight (designated as T1, T2, and T3, respectively). After 60 days, fish fed the diet containing 3% peppermint (T3) exhibited significantly higher ($p < 0.05$) weight gain, protein efficiency ratio, average daily growth, and specific growth rate compared to other treatments. A significant increase ($p < 0.05$) in white blood cell (WBC) count was also recorded in the T3 group, indicating enhanced immune response. No significant differences were observed in red blood cell count, haemoglobin, packed cell volume, platelets, lymphocytes, monocytes, mean corpuscular hemoglobin concentration, mean corpuscular hemoglobin, or mean corpuscular volume among treatments. No mortality was observed in any group throughout the experimental period. Overall, dietary supplementation with 3% peppermint leaf powder improved growth performance, stimulated immune function, and maintained normal hematobiochemical parameters in common carp, supporting its potential as a safe and effective natural additive in sustainable aquaculture.

Keywords: *Cyprinus carpio*; growth parameters; haemato-biological parameters; *Mentha piperita*

1 | INTRODUCTION

The fisheries and aquaculture sector plays a vital role in global food security, nutrition, and rural livelihood development, while also contributing significantly to foreign exchange earnings (Ngasotter *et al.* 2020; Meinam *et al.* 2025). As capture fisheries plateau, aquaculture has emerged as the fastest-growing food production sector, offering a sustainable means to meet the rising global demand for animal protein (FAO 2014). In 2020, global fish production reached 177.8 million tonnes, with India ranking as the third-largest fish-producing country, contributing 14.75 million tonnes, approximately 8% of global output, and holding the top position in inland aquaculture production (FAO 2022). Per capita fish consumption has risen steadily, from 20.2 kg in 2020 to a projected 21.4 kg by 2030, underscoring the increasing reliance on aquatic foods for nutritional security (FAO 2022).

Among aquaculture species, the common carp (*Cyprinus carpio*) is one of the most widely cultivated freshwater fishes worldwide, valued for its rapid growth, omnivorous feeding habit, and adaptability to a range of environmental conditions (Rahman *et al.* 2015; Mohammed *et al.* 2024). In India and across Asia and Europe, it represents a cornerstone species for inland aquaculture, accounting for about 8.6% of global finfish aquaculture production (FAO 2022).

In recent years, the aquaculture industry has increasingly focused on natural feed additives and herbal supplements as sustainable alternatives to antibiotics and synthetic growth promoters (Zhu 2020; Barad *et al.* 2024; Hassan *et al.* 2025). Peppermint (*Mentha piperita* L.), a natural hybrid of *Mentha aquatica* and *Mentha spicata*, has long been recognized for its therapeutic, antimicrobial, and antioxidant properties (Shalayel *et al.* 2017; Gholamipourfard *et al.* 2021; Hudz *et al.* 2023). Traditionally referred to as “hierba buena” or “good herb,” peppermint is rich in biologically active compounds such as menthol, menthone, menthyl acetate, cineole, and limonene, which have demonstrated digestive, immunomodulatory, and hepatoprotective effects in various species (Rita and Animesh 2011; Balakrishnan 2015; Loolaie *et al.* 2017). Despite extensive studies on peppermint’s pharmacological benefits in humans and livestock, its effects on fish growth and haematobiochemical health remain insufficiently explored.

Peppermint is a very popular herb. Peppermint exerts growth-promoting and immunomodulatory effects in fish primarily through the physiological actions of its major bioactive compounds, menthol and menthone. Menthol is known to stimulate digestive enzyme secretion (protease, amylase, and lipase), enhance bile flow, and improve intestinal motility, which collectively increase nutrient digestibility and feed utilization, ultimately supporting improved growth performance (Adel *et al.* 2015). In addition, menthol exhibits strong antimicrobial properties by disrupting bacterial cell membranes, thereby reducing pathogenic load in the gut and promoting a healthier intestinal microbiota, which further enhances nutrient absorption and growth (Talpur 2014). From an immunological perspective, menthol and menthone possess antioxidant and anti-inflammatory activities, scavenging reactive oxygen species and stabilizing cell membranes, which protect immune cells from oxidative stress (Zaia *et al.* 2016). These compounds have been reported to upregulate innate immune responses, including increased phagocytic activity, lysozyme levels, respiratory burst activity, and complement system activation in fish, indicating enhanced nonspecific immunity (Paknejad *et al.* 2020; Kolygas *et al.* 2025). Furthermore, peppermint bioactives have been associated with modulation of stress- and growth-related endocrine pathways, including growth hormone (GH) and insulin-like growth factor-1 (IGF-1), as well as reduced expression of stress markers such as heat shock proteins under suboptimal conditions, thereby supporting both growth and immune resilience (Adel *et al.* 2015; Paknejad *et al.* 2020).

Common carp (*Cyprinus carpio*) belongs to the order Cypriniformes and the Cyprinidae family, it generally inhabits freshwater environments, especially ponds, lakes, rivers and also rarely inhabits brackish-water environments (Rahman 2015). Common carp is considered to be a very important species in Indian aquaculture and in many Asian and European countries. It is a popular culture fish due to its hardy nature, omnivorous habit, and easy breeding in confined water. Therefore, the present study was undertaken to evaluate the effects of dietary peppermint supplementation on the growth performance, survival, and haematobiochemical parameters of common carp fingerlings. The findings aim to provide insights into the potential application of peppermint as a natural growth promoter and immunostimulant in sustainable aquaculture.

2 | METHODOLOGY

2.1 Site of the experiment

The experimental work was conducted at the live fish laboratory (wet lab) latitude 22.027314 and longitude 81.210155 of the Department of Aquaculture, LSPN College of Fisheries, Kawardha, Chhattisgarh. The experiment was carried out from the month February to April 2022.

2.2 Procurement of fingerlings

Fingerlings of common carp were procured from a private fish hatchery located in Arjunda Village, Durg District, Chhattisgarh. A total of 120 healthy fingerlings were carefully packaged, transported to the live fish laboratory (wet lab) of the college, and stocked in 700L FRP tanks. The initial average body weight and length of disease-free fingerlings were 10.2±0.02 g and 9.63±0.03 cm, respectively. Prior to the experiment, fish were treated with 0.3% NaCl and $KMnO_4$ solutions for disinfection and acclimatized for 15 days. During acclimatization, fish were fed a basal diet (with peppermint) at 5% of body weight, administered twice daily at 10:00 a.m. and 5:00 p.m. Water quality was maintained through 30% water exchange on alternate days, and parameters such as temperature, pH, dissolved oxygen, alkalinity, and hardness were monitored weekly to ensure optimal rearing conditions.

2.3 Procurement of peppermint (*Mentha piperita*)
Fresh peppermint leaves identified by botanical authemtication were collected from the premises of the College of Fisheries, Kawardha, for experimental use. The leaves were thoroughly washed, air-dried at room temperature for 1 week until the moisture content dropped below 10%, and then finely ground into powder form. The proximate composition of peppermint (per 100 g) diets were analysed after 1 week of drying according to method outlined by The Association of Official Analytical Chemists (AOAC 2005; Table 1).

TABLE 1 Nutritional composition of the peppermint (per 100 g).

Composition	Nutritional composition
Total fat (g)	0.9
Protein (%)	3.8
Total carbohydrate (g)	15
Dietary fiber (g)	8
Potassium (mg)	569
Sodium (mg)	31

2.4 Procurement of other feed ingredients
Feed ingredients, including groundnut oil cake, mustard oil cake, fish meal, rice bran, wheat bran, tapioca, vitamin premix, and vegetable oil, were procured from the local market of Kawardha. All ingredients were finely ground into powder form and thoroughly mixed with the required proportions of peppermint (Table 2). The prepared feed was stored in airtight containers at 4°C for 1 week before feeding to maintain its freshness and nutritional quality.

2.5 Feed preparation
All feed ingredients were thoroughly mixed with water to form a uniform dough, which was then cooked in a pressure cooker 115°C for 30 minutes. The cooked dough was cooled to room temperature, after cooling which the required quantity of vitamin–mineral premix was added, mixed, and blended thoroughly. The dough was extruded through a hand pelletizer with a 2 mm die to produce uniform pellets. The pellets were air-dried at room temperature until the moisture content fell below 10%. Peppermint leaf powder was incorporated at concentrations of 1%, 2%, and 3% per kg of feed for treatments T1, T2, and T3, respectively (Table 2).

2.6 Proximate analysis of experimental diet
The proximate composition of the basal and peppermint-supplemented diets, including moisture content, crude fat or ether extract (EX), crude protein (CP), crude fibre (CF), and ash content on the basis of dry matter (DM) of formulated feed were determined following the standard procedures of the Association of Official Analytical Chemists (AOAC 2005). All proximate and biochemical analyses of the feed were carried out at the Department of Aquaculture Laboratory. The proximate composition of the experimental diets is presented in Table 3.

TABLE 2 Details of percentage composition of the diets used in the experiment.

Ingredients	g/100g of feed			
	C	T1	T2	T3
Mustard oil cake	32	32	32	32
Fish meal	8	8	8	8
Groundnut oil cake	30	30	30	30
Rice bran	10	10	10	10
Wheat flour	12	11	10	9
Tapioca	5	5	5	5
Vegetable oil	2	2	2	2
Vitamin premix	1	1	1	1
Peppermint leaf powder	0	1	2	3
Total	100	100	100	100

C, Control– no peppermint; Treatments (peppermint per kg feed): T1, 1% peppermint; T2, 2% peppermint; T3, 3% peppermint.

TABLE 3 Proximate composition of the different experimental diets.

Treatments	Protein (%)	Fat (%)	Fiber (%)	Ash (%)	Moisture (%)	NEF (%)
C	30.0 ± 0.05	7.10 ± 0.027	6.32 ± 0.011	7.22 ± 0.01	8.08 ± 0.057	40.10 ± 0.05
T_1	29.91 ± 0.06	7.03 ± 0.005	6.31 ± 0.010	7.72 ± 0.026	8.01 ± 0.015	41.25 ± 0.07
T_2	29.80 ± 0.02	7.09 ± 0.027	6.41 ± 0.012	7.55 ± 0.043	8.03 ± 0.009	41.01 ± 0.08
T_3	29.05 ± 0.05	7.12 ± 0.012	6.52 ± 0.015	7.73 ± 0.027	8.10 ± 0.273	41.27 ± 0.09

C, Control– no peppermint; Treatments (peppermint per kg feed): T1, 1% peppermint; T2, 2% peppermint; T3, 3% peppermint. Value are means ± SD, n = 3 per treatment group.

2.7 Experimental design and set-up of the experiment
The experiment was conducted over a period of 60 days. The experimental setup comprised twelve glass aquaria (0.6 × 0.3 × 0.45 m^3) with a water capacity of 81-L each, covered with green nets to prevent fish escape and contamination. Prior to stocking, all aquaria were thoroughly cleaned and disinfected using potassium permanganate (4 mg L^{-1}) and sodium chloride (NaCl) solutions. After cleaning, tanks were filled with borewell water, and continuous aeration was maintained throughout the experimental period to ensure adequate oxygenation.

The experiment followed a completely randomized design (CRD) with four dietary treatments and three replicates per treatment, each containing ten fingerlings per aquarium. The treatments were as follows: C (Control)– basal diet without peppermint supplementation; T1– diet containing 1% peppermint leaf powder; T2– diet containing 2% peppermint leaf powder; T3– diet containing 3% peppermint leaf powder. This design allowed for the assessment of growth performance and haematobiochemical responses of common carp under varying levels of dietary peppermint supplementation.

2.8 Feeding and cleaning of faecal matter

During the experimental period, fish were fed either the control diet (C) or diets containing different concentrations of peppermint (T1, T2, and T3) for two months. Feeding was carried out twice daily, at 09:00 a.m. and 04:00 p.m. Each morning, before feeding, the tanks were carefully cleaned, and any uneaten feed, waste, and fecal matter were removed by siphoning to maintain optimal water quality throughout the experiment.

2.9 Growth performance parameters

To assess growth performance, the body weight (g) in weighing balance and length (cm) in scale of common carp was recorded at 15-day intervals throughout the experimental period. Fish from each tank were gently netted and weighed carefully to minimize handling stress. Growth performance was evaluated based on parameters such as weight gain, specific growth rate (SGR), average daily gain (ADG), feed conversion ratio (FCR), and protein efficiency ratio (PER), were determined according to the standard formula (Kumar *et al.* 2014; Lal *et al.* 2022, 2023a).

Weight gain (g) = Final average weight gain-Initial average weight gain

SGR (%) = [(In final weight – In initial weight) / No. of days] × 100

ADG (g / day) = (Final weight (g) – Initial weight (g)) / Culture period (days)

FCR (g) = (Feed given (g dry weight)) / Body weight gain (g wet weight)

PER (g) = (Net weight gain) / Protein fed

2.10 Haemato-immunological parameters

Haematological and biochemical analyses were performed after the 60-day feeding trial. Fish from each replicate were anesthetized using clove oil at a concentration of 0.20 ml per 500 ml of water to minimize handling stress. Blood samples were collected from the caudal vein using a 1 ml syringe pre-rinsed with 10% EDTA and immediately transferred into EDTA-coated vials to prevent coagulation (Lal *et al.* 2025a).

Haematological parameters, including haemoglobin concentration, erythrocyte count, leucocyte count, haematocrit (%), mean corpuscular haemoglobin (MCH), mean corpuscular haemoglobin concentration (MCHC), mean corpuscular volume (MCV), platelet count, neutrophils, lymphocytes, and monocytes, were analyzed at the Hi-Tech Pathology Laboratory, Kawardha, Chhattisgarh. An automatic haematology analyzer (Benesphera H33s Next Gen Haematology Analyzer, Mumbai India) was employed to determine key blood parameters such as erythrocyte count, haemoglobin concentration, and total leucocyte count.

2.11 Physico-chemical parameter of water

Water quality parameters, including dissolved oxygen (titration method), pH (pH meter), temperature (thermameter), alkalinity (titration method), and hardness (titration method) were recorded morning and evening monitored fortnightly throughout the study following the standard procedures outlined by APHA (2005).

2.12 Data analysis

Data analysis was performed using IBM SPSS Statistics version 26. A one-way analysis of variance (ANOVA) was applied to assess differences among treatment means for all measured parameters, and Duncan's Multiple Range Test (DMRT) was used for post-hoc comparison between treatments. Statistical significance was determined at $p < 0.05$. All results presented in the text, tables, and figures are expressed as mean ± standard error (SE).

3 | RESULTS

3.1 Proximate composition of experimental diet

The crude protein content of the diets ranged from 29.05 to 30.00%, while the crude fat content varied between 7.03 and 7.10%. The ash content ranged from 7.22 to 7.73%, and the moisture content was between 8.01 and 8.10%. The crude fibre content varied from 6.32% to 6.52%. Minor variations in nutrient composition among the diets were attributed to differences in the proximate composition of the individual feed ingredients used.

3.2 Growth performance parameters

The growth performance parameters of *C. carpio* are illustrated in Figure 1. For growth parameters, a statistically significant difference ($p < 0.05$) was observed among the various treatment groups. The highest weight gain (280.69±2.49 g) was recorded in the T3 group, which received 3% peppermint inclusion in the feed, while the lowest (166.48±3.22 g) was observed in the control group. Similarly, the highest specific growth rate (1.47±0.01 g) was noted in the T3 group, whereas the control group exhibited the lowest (1.07±0.02 g). The average daily gain followed a similar trend, with the T3 group showing the highest value (0.32±0.005 g) and the control group the lowest (0.19±0.005 g). The feed conversion ratio was highest in the control group and lowest in the T3 group, indicating better feed utilization in the latter. Furthermore, the protein efficiency ratio was significantly higher in the T3 group (3% peppermint inclusion) and the lowest in the control group (0% peppermint inclusion).

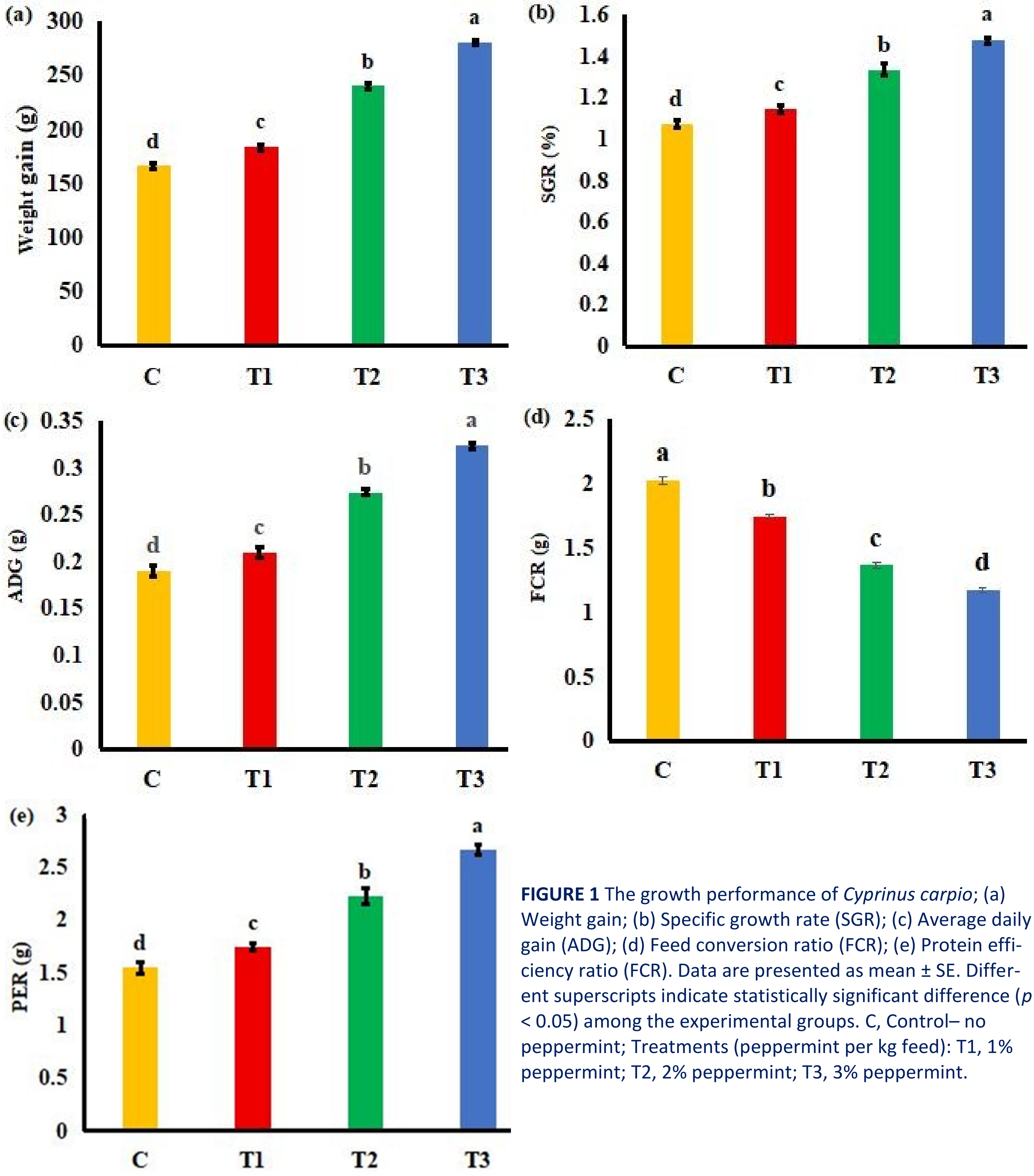

FIGURE 1 The growth performance of *Cyprinus carpio*; (a) Weight gain; (b) Specific growth rate (SGR); (c) Average daily gain (ADG); (d) Feed conversion ratio (FCR); (e) Protein efficiency ratio (FCR). Data are presented as mean ± SE. Different superscripts indicate statistically significant difference ($p < 0.05$) among the experimental groups. C, Control– no peppermint; Treatments (peppermint per kg feed): T1, 1% peppermint; T2, 2% peppermint; T3, 3% peppermint.

3.3 Haemato-biochemical parameters

The haematological and biochemical parameters of *C. carpio* are shown in Table 4. A statistically significant difference ($p < 0.05$) was observed among the treatment groups. The highest red blood cell (RBC) count was recorded in the T3 group, while the lowest was observed in the control group. Similarly, the white blood cell (WBC) count was highest in the T3 group fed with a 3% peppermint-supplemented diet and lowest in the control group. The platelet count followed the same trend, with the highest value (mean±SD: 1.53±0.02) in T3 and the lowest in the control.

The packed cell volume (PCV) was also found to be highest in the T3 group and lowest in the control group. The haemoglobin concentration showed a similar pattern, with the highest level in T3 and the lowest in the control group. The mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), and mean corpuscular haemoglobin concentration (MCHC) were all highest in the T3 group and lowest in the control group. Additionally, the lymphocyte count was significantly higher in T3 (94.26±0.79) fed with 3% peppermint inclusion, whereas the control group showed the lowest count. The monocyte level was also highest in T3 (3.24±0.06) and lowest in the control group, indicating an overall improvement in haematological parameters with peppermint supplementation.

TABLE 4 Effect of experimental diets on haematological parameters (%) in *Cyprinus carpio* fingerlings.

Parameters	Group			
	Control	**T1**	**T2**	**T3**
RBC (%)	26.3 ± 1.08^{c}	30.68 ± 1.05^{b}	32.38± 1.48^{b}	38.73±1.50^{a}
WBC (%)	1.4 ± 0.02^{c}	1.49 ± 0.02^{c}	1.54 ± 0.02^{b}	1.65 ±0.02^{a}
Platelets	1.19 ± 0.02^{c}	1.26 ± 0.03^{bc}	1.35 ± 0.02^{b}	1.53 ±0.02^{a}
PCV (%)	20.36 ± 0.36^{c}	21.94 ± 0.27^{b}	22.54 ± 0.32^{b}	24.89 ±0.43^{a}
Haemoglobin (%)	6.73 ± 0.14^{c}	7.99 ± 0.06^{b}	8.32 ± 0.06^{b}	8.41 ±0.04^{a}
MCV	164.35± 2.51^{c}	223.62 ± 4.16^{b}	245.4 ± 2.57^{a}	268.59 ±3.34^{a}
MCH	66.99 ± 1.42^{c}	74.63 ± 2.79^{b}	84.91 ± 2.74^{a}	85.56 ± 1.25^{a}
MCHC	26.29 ± 1.08^{c}	30.68 ± 1.04^{b}	32.38 ± 1.48^{b}	38.73 ± 1.49^{a}
Lymphocytes (%)	61.97 ± 1.25^{c}	75 ± 0.99^{bc}	84.37 ± 1.14^{b}	94.26 ± 0.79^{a}
Monocytes	2.03 ± 0.04^{b}	2.10 ± 0.03^{ab}	2.77 ± 0.05^{ab}	3.24 ±0.06^{a}

C, Control– no peppermint; Treatments (peppermint per kg feed): T1, 1% peppermint; T2, 2% peppermint; T3, 3% peppermint. Values are expressed as a mean ± standard deviation. Values with different superscripts in a row differ significantly ($p < 0.05$).

3.4 Physico-chemical parameter of water

The physicochemical parameters of the water are illustrated in Figure 2. Water quality was assessed based on parameters such as dissolved oxygen (DO), pH, temperature, alkalinity, and hardness. The water temperature during the study ranged between 26 and 29°C across the different treatment groups. Dissolved oxygen levels varied from 6.2 to 7.5 mg/L. The recorded pH values were within the optimal range of 6.5–9, as reported by Boyd (1982). Alkalinity values ranged from 113 to 124 mg/L among the treatments, while water hardness was observed to range between 230 and 251 mg/L.

4 | DISCUSSION

4.1 Proximate composition of feed

The proximate composition of fish feed serves as a vital indicator of its nutritional quality and its capacity to promote optimal growth and health in aquaculture species. The incorporation of natural feed additives, such as peppermint (*M. piperita*), into formulated diets can modify the feed's proximate composition, particularly its protein, lipid, moisture, and ash contents. Peppermint is abundant in essential oils, phenolic compounds, and nutrients that enhance both the nutritional and functional properties of fish diets (Dawood *et al.* 2022). When used at appropriate inclusion levels, peppermint can improve feed palatability, nutrient digestibility, and stability without disrupting the proximate balance.

The inclusion of peppermint leaves or oil has been reported to slightly elevate the crude protein content of fish feeds, attributed to the herb's inherent protein and amino acid composition. Talpur (2014) observed that supplementing fish feed with powdered peppermint leaves increased dietary crude protein levels, as peppermint contains considerable nitrogenous compounds. Elevated protein content in the feed promotes improved growth performance, as proteins are fundamental for muscle development and enzymatic activity in fish.

Beyond its impact on protein content, peppermint supplementation can also influence the crude lipid composition of fish feeds. Peppermint leaves and oil contain bioactive fatty acids, such as linoleic and α-linolenic acids, that enhance the lipid fraction of the feed (Kowalski *et al.* 2024). These unsaturated fatty acids increase the feed's energy density and contribute to a more favorable fatty acid profile in fish muscle. Nevertheless, the overall rise in lipid content remains modest, since peppermint is typically incorporated at low levels (0.5–2% of the diet) to maintain feed texture and prevent lipid oxidation.

Peppermint addition may further affect the feed's moisture and ash contents. Abdel-Tawwab *et al.* (2021) reported that incorporating peppermint oil slightly reduced feed moisture due to its hydrophobic and volatile components, which promote drying and improve shelf stability. Lower moisture levels also help minimize microbial spoilage, thereby extending feed longevity. Conversely, ash content may marginally increase as peppermint contains essential minerals such as calcium, magnesium, and potassium, which contribute to the overall inorganic fraction of the diet.

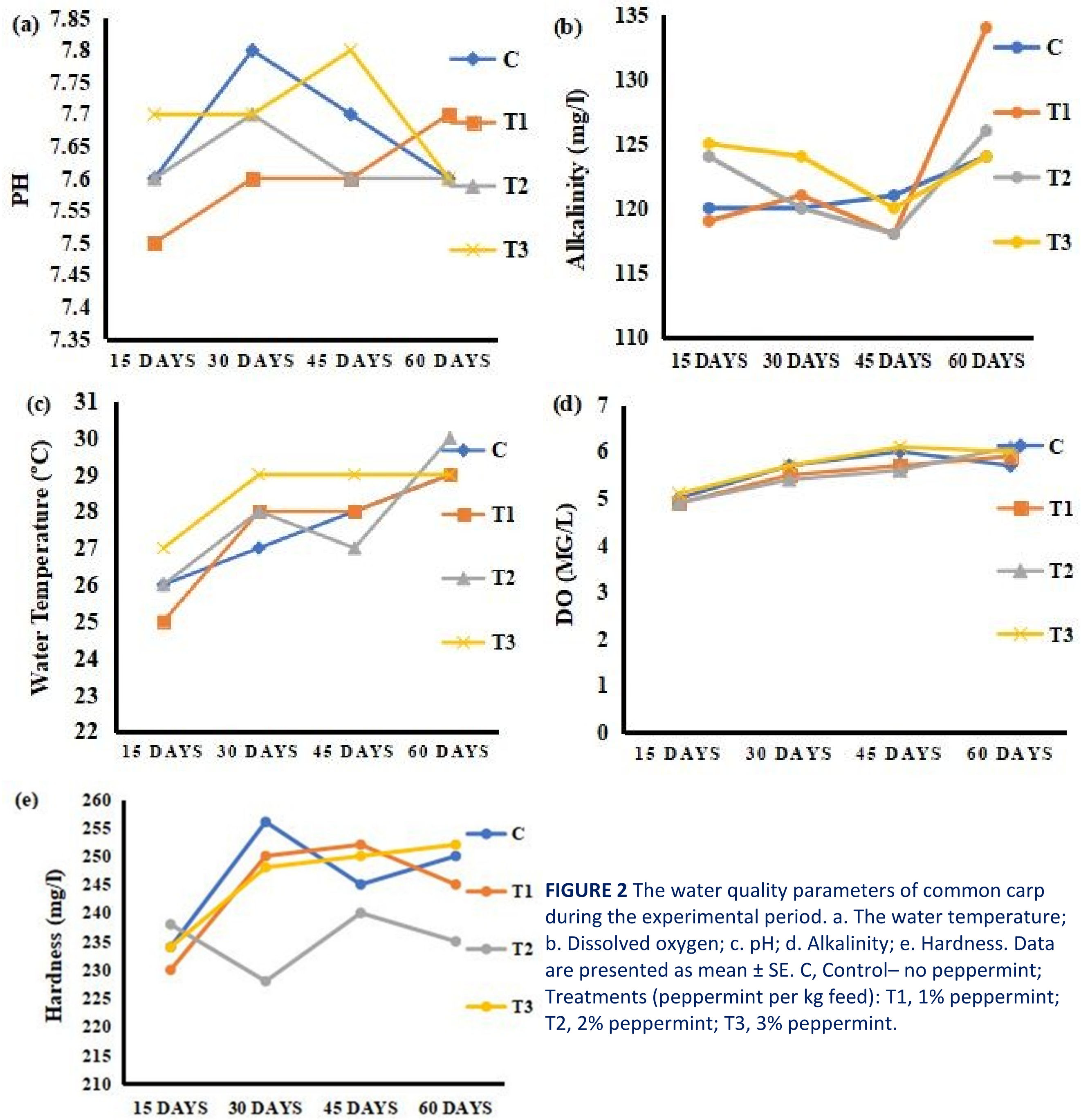

FIGURE 2 The water quality parameters of common carp during the experimental period. a. The water temperature; b. Dissolved oxygen; c. pH; d. Alkalinity; e. Hardness. Data are presented as mean ± SE. C, Control– no peppermint; Treatments (peppermint per kg feed): T1, 1% peppermint; T2, 2% peppermint; T3, 3% peppermint.

The incorporation of peppermint also influences the crude fiber content of fish feed, which plays a key role in nutrient digestibility. According to Cao *et al.* (2021), feeds supplemented with peppermint exhibited slightly elevated crude fiber levels due to the fibrous nature of the plant material. While excessive fiber can hinder nutrient absorption, moderate amounts are beneficial as they promote gut motility and enhance digestive efficiency. This effect is further supported by the presence of peppermint essential oils, which stimulate the secretion of digestive enzymes. Therefore, maintaining an optimal level of peppermint inclusion is crucial to achieve a favorable balance between fiber content and feed utilization efficiency.

Another important aspect of peppermint supplementation is its influence on the nitrogen-free extract (NFE), representing the carbohydrate fraction of the feed.

As peppermint contains relatively low carbohydrate levels, its direct contribution to NFE is minimal. Nonetheless, peppermint enhances feed utilization and energy metabolism in fish, indirectly improving the efficiency of carbohydrate use (Hosoda *et al.* 2005). This improved metabolic efficiency translates into better energy conversion, as reflected by enhanced FCR and overall growth performance.

4.2 Growth performance

The use of medicinal herbs as natural feed additives in aquaculture has gained increasing attention as sustainable alternatives to synthetic growth promoters and antibiotics. Among these, *M. piperita* has been extensively studied for its beneficial effects on fish growth and health. Peppermint is rich in bioactive compounds such as menthol, menthone, limonene, flavonoids, and phenolic acids, which collectively contribute to its antibacterial, antioxidant, and digestive-stimulating properties (Adel *et al.* 2015). These natural constituents enhance feed palatability, digestion, and metabolic efficiency, thereby promoting improved growth performance in various fish species.

In the present study, *C. carpio* fingerlings fed diets containing 3% peppermint (T3 group) exhibited a significantly higher percentage weight gain compared to the control group. Similar findings were reported by Talpur (2014), who observed increased weight gain in fish fed with 5 g/kg peppermint-supplemented diets. The growth-promoting potential of peppermint is attributed to its diverse bioactive compounds that enhance digestive enzyme activity and nutrient absorption (Citarasu 2010). In this study, the T3 group also showed the highest SGR, indicating a positive correlation between higher peppermint inclusion levels and growth performance. Talpur (2014) similarly reported that fish fed with 5 g/kg peppermint exhibited significantly higher SGR values compared to controls.

Several previous studies have confirmed that peppermint supplementation improves key growth performance indices such as FCR, SGR, and weight gain. For instance, Kolygas *et al.* (2025) demonstrated that *Oreochromis niloticus* fed peppermint oil–enriched diets showed marked improvements in growth metrics compared to control groups. The enhanced growth was attributed to increased feed intake and nutrient utilization, facilitated by the aromatic compounds in peppermint that improve feed attractiveness and digestibility. Consistent with these findings, the T3 group in the present study showed the highest average daily growth rate when fed with 3% peppermint. Similarly, Adel *et al.* (2015) reported significantly higher daily growth rates in fish receiving diets supplemented with 3% *M. piperita* compared to controls.

Optimal growth and health benefits are typically achieved at low to moderate peppermint inclusion levels (0.5–2% of diet or 100–300 mg/kg oil), while excessive doses may reduce palatability or cause mild toxicity (Talpur 2014). In this study, the FCR decreased with increasing peppermint inclusion, indicating improved feed utilization efficiency. Comparable results were reported by (Paknejad *et al.* 2020), who found that higher peppermint levels (up to 4 g/kg) in fish diets led to the lowest FCR values. According to (Reverter *et al.* 2017), the bioactive compounds in peppermint stimulate appetite and digestive processes, thereby improving feed intake and nutrient assimilation.

Furthermore, the PER was highest in the T3 group fed with 3% peppermint. A comparable trend was noted by (Bhatnagar and Saluja 2019), who reported that fish fed diets containing 6 g/kg *M. piperita* exhibited significantly higher PER values than the control group. Overall, the PER showed significant differences among all treatment groups, confirming the beneficial effect of peppermint supplementation on protein utilization and growth efficiency in *C. carpio*.

4.3 Haematological parameters

Haematological and biochemical parameters are key indicators of a fish's physiological condition and overall health and are often used to evaluate the effects of dietary additives. Previous studies have demonstrated that incorporating *M. piperita* into fish diets can significantly improve these parameters. The herb's bioactive constituents, such as menthol, menthone, rosmarinic acid, and flavonoids, possess potent antioxidant, antibacterial, and immunostimulatory properties that enhance haematopoiesis, support metabolic function, and protect against oxidative stress (Adel *et al.* 2015).

Several investigations have reported that peppermint supplementation increases red blood cell (RBC) count, haemoglobin concentration (Hb), and haematocrit (Hct) values in fish, reflecting enhanced oxygen transport capacity and stimulated erythropoietic activity. For instance, Elashry *et al.* (2024) found that *O. niloticus* fed with peppermint oil–enriched diets exhibited significantly higher RBC and Hb levels than control fish. These improvements in haematological indicators suggest enhanced physiological performance and a greater ability to cope with stress and maintain metabolic balance. Similarly, Sayed-Lafi and Sultan (2019) observed that *C. carpio* fed peppermint powder–supplemented diets showed elevated haematological parameters, including WBC counts. Higher WBC levels are generally associated with strengthened immune defense and improved disease resistance. The immunostimulatory effects of peppermint are attributed to its phenolic constituents, which enhance leukocyte proliferation and macrophage activation, thereby reinforcing innate immunity and overall resistance to infections.

In the present study, the T1 and control groups exhibited the highest haemoglobin levels, while the remaining treatment groups showed comparatively lower values. Similar findings were reported by (Adel *et al.* 2015), who observed that fish fed with 3% peppermint had significantly improved haematological parameters, including haemoglobin levels, compared to control fish. A comparable pattern was noted in Caspian white fish, where increasing peppermint concentration led to a rise in Hb content (Adel *et al.* 2015). Elevated haemoglobin levels are closely linked to improved oxygen delivery and growth performance, indicating better physiological adaptation. The enhancement of haematological parameters can be attributed to peppermint's bioactive compounds, which promote blood health and overall vitality in fish (Reverter *et al.* 2017).

In this study, the T3 group also exhibited higher MCV compared to the control group. Paknejad *et al.* (2020) reported a similar observation, where fish fed with a 4 g/kg *M. piperita* supplemented diet showed increased MCV values. The rise in MCV with increasing peppermint inclusion suggests improved erythrocyte size and oxygen-carrying capacity. Likewise, the T3 group demonstrated elevated MCH and MCHC values compared to other treatments. This observation aligns with the findings of Paknejad *et al.* (2020), who noted increased MCH and MCHC levels in fish receiving a 4 g/kg peppermint diet. These results indicate that peppermint supplementation enhances the synthesis and oxygen-binding efficiency of haemoglobin in red blood cells.

Furthermore, the T3 group exhibited the highest lymphocyte counts among all treatments. Padala *et al.* (2021) similarly reported that increasing peppermint inclusion levels resulted in elevated lymphocyte counts, with the highest values observed in fish fed 2% peppermint diets. Enhanced lymphocyte levels are vital for boosting immune competence by strengthening both specific and non-specific defence mechanisms. In the present study, the monocyte count was also highest in the T3 group (3% peppermint inclusion), while the lowest was recorded in the control group. (Padala *et al.* 2021) observed a similar trend, where increasing peppermint levels in the diet corresponded with elevated monocyte counts. Peppermint's bioactive components, including alkaloids, terpenoids, saponins, and flavonoids, are known to stimulate immune cell production and activity (Reverter *et al.* 2017). These findings collectively suggest that peppermint supplementation supports haematological and immunological enhancement, thereby improving fish health and resilience.

4.4 Water quality parameters

Water quality plays a vital role in determining the growth, health, and survival of cultured fish species, including *C. carpio*. Among the various parameters, water temperature is particularly influential, as it directly and indirectly affects growth rate, feed digestibility, and several physiological processes. The metabolic rate of fish is closely linked to temperature. It increases with rising temperature and decreases when the temperature drops. According to ICAR (2011), the metabolic rate of fish roughly doubles with every 10°C increase in temperature. These findings are consistent with those of Jhingran (1991), who reported that a temperature range of 18–38°C is suitable for carp culture, promoting optimal growth and metabolic activity (Lal *et al.* 2023b; 2025b).

Recent studies have also suggested that dietary supplementation with herbal additives such as *M. piperita* can positively influence fish physiology and indirectly improve water quality parameters by altering feed utilization, excretion patterns, and microbial balance in the aquatic environment (Abou Zaid *et al.* 2025). Peppermint supplementation enhances feed efficiency and digestion, thereby reducing organic waste accumulation and contributing to the maintenance of better water quality conditions in aquaculture systems.

DO is one of the most critical parameters for assessing water quality in fish culture. It significantly influences fish growth, feed intake, and metabolic activity. Bhatnagar and Garg (2000) emphasized that DO plays a vital role in regulating fish metabolism, survival, and feeding behavior. Low DO concentrations can lead to fish mortality, reduced feed conversion efficiency, and decreased feed intake. According to Jobling (1995), an oxygen concentration of approximately 5 mg/L is the minimum requirement for fish growth and survival, while Boyd (1982) reported an optimal range of 6–9 mg/L. In the present study, DO values varied between 7.6 and 8.5 mg/L across treatments, which falls within the ideal range for sustaining metabolic and physiological functions in fish.

The pH of water also exerts a significant influence on fish physiology. McDonald (1983) noted that low pH levels can disrupt ionic balance by altering gill structure and function, thereby impairing osmoregulation. In this study, the pH range observed across treatments was within 7.6–8.5, which is considered ideal for fish survival and metabolism. This finding aligns with the recommendations of Jhingran (1991) and Svobodova *et al.* (1993), who suggested that a pH range of 6.5–8.5 is optimal for carp culture.

Water alkalinity, which reflects the presence of carbonates, bicarbonates, hydroxides, phosphates, and dissolved minerals such as calcium and magnesium, also plays an important role in buffering capacity and nutrient availability. Santosh and Singh (2007) reported that the ideal alkalinity range for aquaculture is 50–300 mg/L, while Boyd and Lichtkoppler (1979) suggested that waters with alkalinity between 20 and 150 mg/L support high plankton productivity. In the present study, water alkalinity ranged from 113 to 124 mg/L across treatments, consistent with Sharma (2000), who indicated that alkalinity levels between 80 and 300 mg/L are suitable for carp culture.

Similarly, water hardness is another critical parameter influencing fish metabolism, feed efficiency, and stress tolerance. Romano *et al.* (2020) found that low hardness levels (50–100 mg/L as $CaCO_3$) reduced feed efficiency and stress resistance, while extremely low hardness (around 50 mg/L) increased ammonia-nitrogen excretion and oxygen consumption. In contrast, hardness values between 50 and 400 mg/L are considered optimal for aquaculture (Saraswathy *et al.* 2015). In this study, water hardness ranged from 230 to 251 mg/L among different treatments, which falls within the optimal range for supporting fish survival, growth, and physiological performance. Overall, the recorded physicochemical parameters, including temperature, DO, pH, alkalinity, and hardness remained within the ideal range for *C. carpio* culture, suggesting that the experimental conditions were conducive to optimal growth and health.

5 | CONCLUSIONS

Based on the findings of the present study, it can be concluded that the leaf powder of the medicinal herb peppermint (*M. piperita*) plays a significant role in enhancing the growth performance of common carp fingerlings. The incorporation of peppermint leaf powder into fish diets is simple and effective, offering a natural means to improve health and productivity. Supplementation with *M. piperita* notably enhanced haematological parameters and exhibited strong immunostimulatory effects in the experimental fish. Furthermore, fish fed with peppermint-supplemented diets showed increased WBC counts and experienced no mortality throughout the study period. Overall, these results demonstrate that peppermint leaf powder effectively stimulates immune responses and promotes significant improvements in growth performance and haematobiological parameters in *C. carpio* fingerlings.

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CONFLICT OF INTEREST

The authors have declared no conflict of interest.

AUTHORS' CONTRIBUTION

Conceptulation: YN, DKD, BND; Methodology: YN, DKD, BND, BS, JL; Data analysis: YN, BS, JL; Manuscript preparation: YN, BS, SN, T; Review & editing: DKD, BND, JL.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available within the article.

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