PREPRINT

Fishery Technology 63 (2026) : 1 - 14

Effects of Common Duckweed on Growth Performance, Survival, and Intestinal Morphology of Rohu, *Labeo rohita* (Hamilton, 1822) Fry in Biofloc System

Pratiksha V. Nimbarte, Raju M. Tibile, Anil S. Pawase, Gajanan S. Ghode, Sangita S. Wasave and Prathamesh J. Ade*

[a]*Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, College of Fisheries, Shirgaon, Ratnagiri-415629, Maharashtra, India*

Abstract

This study investigated the effects of incorporating varying levels of fermented common duckweed, *Lemna minor* (FLM), on the growth performance, survival, and intestinal morphology of rohu, *Labeo rohita* fry in a biofloc system for 90 days. The fry (2.6 ± 0.12 cm and 0.3 ± 0.03 g) were reared at a stocking density of 15 fry 100 L^{-1} in circular tanks following a completely randomised design. Five isonitrogenous (25% crude protein) diets were formulated by incorporating fermented common duckweed, *viz*., Control (0%), FLM10 (10%), FLM20 (20%), FLM30 (30%), and FLM40 (40%). No significant differences ($p > 0.05$) were observed in the growth performance of fish among treatments, and survival ranged from 96% to 98%. The FLM40 group showed significantly greater villus length ($p < 0.05$), which was similar to the control. No significant differences ($p > 0.05$) were observed in villus width, crypt depth, and muscularis thickness of rohu fed experimental diets. Incorporating higher levels of duckweed progressively reduced the cost of formulated feed. The study concluded that 5% wet yeast-fermented common duckweed can be incorporated up to 40% in the diet of rohu fry without adversely affecting growth performance or survival in a biofloc system.

Keywords: Biofloc, fermented *Lemna minor*, growth, intestinal morphology, *Labeo rohita*, nutrition

Received 22 November 2025; Revised 20 August 2026; Accepted 24 August 2026

Handling Editor: Dr. Shyne Anand P. S.

**Email: praveshade7@gmail.com*

Introduction

The global fisheries and aquaculture sector has reached a critical juncture, recognised for its indispensable role in ensuring food security and nutritional stability in the 21st century. According to the Food and Agriculture Organization (FAO, 2024), the sector maintains an annual growth rate of 3.2%, with aquaculture production in 2022 accounting for 51% of the 185 million tonnes of aquatic animals produced globally. Within this landscape, India holds a prominent position as the second-largest aquaculture producer, contributing approximately 8.92% to world fish production (Fisheries Statistics Division, 2023). Among the species driving this growth, the Indian major carp, rohu (*Labeo rohita*), remains a key species in freshwater aquaculture across the Indian subcontinent, representing 5.1% of global inland aquaculture fish production (FAO, 2022).

In conventional practices, fry are stocked at a density of 0.2-0.3 million per hectare, resulting in a survival rate of 60-70% (Jena & Das, 2019). Sustainable intensification of rohu culture depends on the availability of high-quality seed, prompting a shift toward nursery rearing systems that optimise water and land use. Biofloc Technology (BFT) has emerged as a promising nursery culture method, utilising microbial biomass to manage nitrogenous waste and provide supplemental nutrition *in situ* (Avnimelech, 1999). Studies have demonstrated that rohu fry can achieve optimal growth in biofloc systems, benefiting from the immunostimulatory properties of microbial flocs (Mahanand, Moulick, & Rao, 2013a). Biofloc technology (BFT) is one of the promising culture technologies where fish seed are reared at higher stocking densities with minimal water exchange (Das & Kamble, 2019; Mugwanya,

© 2025 Society of Fisheries Technologists (India)

FISHERY TECHNOLOGY

Dawood, Kimera, & Sewilam, 2021). Despite the biological advantages of BFT, the economic feasibility of such systems is often challenged by high operational costs, specifically the continuous energy required for aeration and the rising prices of commercial fish feed. To address this, there is an increasing interest in incorporating non-conventional, low-cost, easily available feed ingredients like duckweed.

The Lemnaceae family includes tiny green floating flowering plants known as duckweed. The plant has a high concentration of trace minerals, potassium, phosphorus, and a protein content of roughly 40–43% dry weight, and it grows well in a variety of conditions (Leng, Stambolie, & Bell, 1995). Duckweed's leaves are highly digestible (Chaturvedi, Langote, & Asolekar, 2003). Depending on the species, climate, available surface area, amount of nutrients, and management, duckweed can yield 10–30 tons of dry matter/ha annually (Tavares, Rodrigues, Fracalossi, Esquivel, & Rouback, 2008). While raw duckweed is nutrient-dense, its crude fibre content and anti-nutritional factors (ANFs), such as tannins and phytic acid, can limit its digestibility in carp fry (Bairagi, Ghosh, Sen, & Ray, 2002). Fermentation has been identified as a strategic processing technique to enhance the nutritional quality and digestibility of aquatic macrophytes by mitigating ANFs (Bairagi et al., 2002; Nout, 2009; Flores-Miranda et al., 2015).

Previous research has explored the use of fermented *Lemna* species in the diets of Nile tilapia and common carp, showing significant improvements in feed conversion ratios and cost-efficiency. However, the combined effect of feeding fermented *L. minor* to rohu fry within a biofloc-based nursery system remains under-researched. Given the potential for reducing feed costs without compromising water quality or fish health, this study was designed to evaluate the integration of these two technologies and to determine the impact of varying levels of fermented common duckweed (*L. minor*) on the growth, survival, and nutritional performance of *L. rohita* fry reared in a biofloc system.

Materials and Methods

The study was conducted in the Wet Laboratory, College of Fisheries, Shirgaon, Ratnagiri, Maharashtra (17°01'23.4'' N, 73°17'55.0'' E), for 90 days. Rohu fry were sourced from ICAR- Central Institute of Freshwater Aquaculture, Bhubaneswar, Odisha. Initially, fry were acclimatised for a week in 500 L biosecured fibreglass-reinforced plastic (FRP) tanks. The rohu fry with an average length of 2.6 ± 0.12 cm and average weight of 0.3 ± 0.03 g were stocked at a density of 15 fry 100 L^{-1}. The fry were fed twice a day at the rate of 10% of body weight day^{-1} from day 1 to day 30. Later on, from day 30 to 90, the feeding rate was reduced to 4% of their body weight day^{-1}.

An experiment was carried out following a completely randomised design (CRD). Five dietary treatments in which fermented *Lemna minor* was incorporated at different levels, *viz*., Control (0%) diet without fermented *L. minor*, FLM10 (fermented *L. minor* 10%), FLM20 (fermented *L. minor* 20%), FLM30 (fermented *L. minor* 30%), and FLM40 (fermented *L. minor* 40%), were incorporated used with four replicates each. Biofloc was prepared as per the methods described by Avnimelech (1999). 15 L of prepared biofloc and 85 L of clear freshwater were added to each experimental tank, and tanks were provided with vigorous and continuous aeration to maintain the microbial floc in suspension. The C/N ratio of 19:1 was maintained (Zhao et al., 2014) by adding sugar daily in the morning hours (Kute et al., 2022).

Freshly harvested and washed common duckweed was fermented as per the method given by Utomo, Nurfadhilah, and Ekasari (2015) and Rostika, Andriani, Abram, and Vinasyiam (2017). Duckweed was collected from seasonal paddy fields in Ratnagiri, which are naturally nutrient-rich and insecticide-free. To eliminate any kind of contamination, the collected biomass was cultured and propagated in 500 L FRP tanks. As duckweed propagated, the tanks were regularly harvested. The collected duckweed biomass was washed and solar-dried to produce a fine powder, then used for fermentation. The fermentation method involved the use of 5% wet yeast; specifically, 5 g of wet yeast (*Saccharomyces cerevisiae*) and 250 mL of water were added to 100 g of solar-dried duckweed powder to provide sufficient moisture. The mixture was kept in an airtight container in a dark environment for 96 hours. To ensure homogeneity and facilitate an evenly fermented product, the containers were subjected to systematic manual agitation every 24 hours. After 96 hours, the mixture was solar dried and ground using a domestic electric grinder and passed through a 0.2 mm mesh sieve to obtain a fine

FISHERY TECHNOLOGY

powder. The powdered fermented *L. minor* was incorporated into treatment diets at different levels (10, 20, 30, and 40%). The control diet was devoid of duckweed. All ingredients were procured from the local market. The proximate analysis of the feed ingredients and experimental diets was carried out as per standard procedures (AOAC, 2006) and is mentioned in Table 1. In this biofloc culture system, microbial floc acts as a natural supplementary feed source for rohu fry; therefore, five iso-nitrogenous diets with 25% crude protein levels were formulated (Sawant et al., 2020). The ingredients were mixed in the proportion shown in Table 2.

The growth parameters of the fish were recorded every 30 days. The survival was recorded at the end of the experiment by counting the surviving fish from each treatment.

The growth parameters and survival were calculated as follows:

$$\text{Length gain (\%)} = \frac{(\text{Final length} - \text{Initial length})}{\text{Initial length}} \times 100$$

$$\text{Weight gain (\%)} = \frac{(\text{Final weight} - \text{Initial weight})}{\text{Initial weight}} \times 100$$

$$\text{Survival (\%)} = \frac{\text{Total no of survived fishes}}{\text{Initial number of fishes}} \times 100$$

$$\text{Coefficient of variation (\%)} = \frac{\text{Standard deviation}}{\text{Mean}} \times 100$$

$$\text{Apparent feed conversion ratio} = \frac{\text{Total feed given}}{\text{Weight gain}}$$

$$\text{Condition factor (\%)} = \frac{\text{Weight of the fish (G)}}{\text{Length of the fish (cm)}^3} \times 100$$

$$\text{Protein efficiency ratio (PER)} = \frac{\text{Weight gain of fish (g)}}{\text{Total protein given (g)}}$$

$$\text{Specific growth rate} = \frac{\ln W_2 - \ln W_1}{T} \times 100$$

$$\text{Gastrosomatic index} = \frac{\text{Weight of fish gut}}{\text{Total weight of fish}} \times 100$$

Where:

W_1 = Natural log of initial weight

W_2 = Natural log of final weight

T = Duration in days

Water quality parameters such as pH and temperature were determined daily using a pH meter and

FISHERY TECHNOLOGY

Table 1. The proximate composition of the feed ingredients (% dry matter basis)

Nutrients	Maize meal	Soybean meal	Rice bran	Groundnut oil cake	Fishmeal	Fermented Duckweed	Raw duckweed
Crude Protein (%)	10.50	53.00	13.00	45.52	63.9	24.31	26.23
Crude Lipid (%)	4.25	1.72	5.14	7.86	8.48	2.31	2.8
Ash (%)	5.45	9.21	21.22	4.90	13.23	6.37	-
Crude Fiber (%)	18.92	4.31	22.41	5.68	3.15	11.05	13.6
Moisture (%)	4.65	6.20	5.10	8.30	2.66	8.91	-
*NFE (%)	56.23	25.56	33.13	27.74	8.58	47.05	-
Tannin	-	-	-	-	-	0.05	1.1
Phytic acid	-	-	-	-	-	0.07	1.4

*NFE= 100- (Crude protein + Crude Lipid + Ash + Crude Fiber + Moisture) (Bauer, Prentice-Hernandez, Tesser, Wasielesky, & Poersch, 2012)

Table 2. Ingredients and proximate composition of experimental diets

Ingredients	Ingredients used in diet formulation (g $100g^{-1}$)				
	Control	FLM10	FLM20	FLM30	FLM40
Fermented duckweed	-	10	20	30	40
Maize meal	40	33	30	25	22
Soybean meal	15	14	11	11	10
Rice bran	25	25	21	19	15
Groundnut oil cake	9	8	8	7	6
Fishmeal	9	8	8	6	5
Vitamin+ Mineral Mix*	2	2	2	2	2
Proximate composition of experimental diets (% dry matter basis)					
Crude Protein	24.9	23.31	24.21	24.96	25.10
Crude Lipid	4.8	5.7	5.9	6.2	4.9
Carbohydrate	56.65	56.45	54.23	54.66	53.87
Ash	8.19	7.38	8.8	8.18	9.08
Moisture	5.46	7.16	6.90	6.00	7.05
Gross Energy** (kcal/g)	4.19	4.17	4.15	4.24	4.09
Feed Formulation Cost***					
Cost of 1000 kg feed	Rs. 1,05,452	Rs. 99,649	Rs. 96,177	Rs. 89,351	Rs. 84,857

*Vitamin and mineral mixture (Dr. Katre Premix Lab Pvt Ltd., Nagpur, India)
**Gross Energy = (Protein x 5.64) + (Lipid x 9.44) + (Carbohydrate x 4.11) (Cho, Slinger, & Bayley, 1982)
**Feed Formulation Cost = Calculated based on the retailer price of each ingredient used

FISHERY TECHNOLOGY

thermometer, respectively. Ammonia-N (NH_3-N) was recorded daily using standard methods given in APHA (2005). The dissolved oxygen, total alkalinity, total hardness, nitrite-N (NO_2-N), and nitrate-N (NO_3-N) were recorded weekly using the standard methods given by Boyd (1981) and APHA (2005). The floc volume was measured after allowing the water samples to settle for 20 min in the Imhoff cone (Avnimelech & Kochba, 2009). Qualitative analysis of plankton in biofloc water was performed using the methodology described by Manan, Moh, Kasan, Suratman, and Ikhwanuddin (2017).

For intestinal morphology analysis, three fish samples were randomly selected from each treatment at the end of the experiment. Fish were anesthetised with 90 mg L^{-1} of clove oil (Simoes, Lombardi, Gomide, & Gomes, 2011) and dissected. After extraction and preservation in 10% neutral buffered formalin (NBF), the intestine was subsequently cleaned with ethanol and embedded in paraffin wax. Following sample fixation, hematoxylin and eosin staining was performed on 5 μm sections. Midgut cross-sections from each treatment were used for morphological examination (Younis, Abdel-Warith, Al-Asgah, Ebaid, & Mubarak, 2013). The slides were examined at 10X and 40X magnification using a light microscope (ZEISS Primo Star 2.0 with software) and TCapture imaging software to measure villi length, width, crypt depth, and number.

The mean values of the growth parameters such as length, length gain (%), weight, weight gain (%), specific growth rate, condition factor, coefficient of variation, apparent feed conversion ratio, and protein efficiency ratio were analysed using one-way analysis of variance (ANOVA) with SPSS version 16.0. Survival data were arc-sine transformed and subjected to ANOVA. Differences were deemed significant when $p < 0.05$, and the Tukey post-hoc method was used for further analysis.

Results and Discussion

The effect of incorporating fermented duckweed on the growth performance and survival of rohu fry is depicted in Table 3. At the end of the experimental duration, the growth parameters, *viz*., length, length gain %, weight, weight gain %, specific growth rate, condition factor, and coefficient of variation (CV) for weight were similar among treatments ($p > 0.05$). The CV of length was lower in FLM20 compared to the control group ($p < 0.05$), but statistically similar ($p > 0.05$) to FLM10, FLM30, and FLM40. The Gastro-Somatic Index (GSI) was significantly higher ($p < 0.05$) in FLM20 than in the control. The apparent feed conversion ratio, protein efficiency ratio, and survival (%) were statistically similar ($p > 0.05$) across all dietary groups. Various types of phytoplankton species of the genera *Nitzschia*, *Coscinodiscus*, *Rhizosolenia,* and zooplankton of copepod and calanoid groups were recorded across all experimental treatments.

The present study confirms the feasibility of incorporating fermented duckweed in the diet of rohu fry up to 40% without significantly affecting growth, survival, and feed efficiency in a biofloc rearing system. The amount of fermented duckweed that can be added to a fish's diet varies according to feeding habits and palatability of the diet. The fermented *Lemna* diet yields better performance than raw *Lemna* because of the lower antinutritional factors, resulting in better growth performance, PER, and FCR (Bairagi et al., 2002). The presence of antinutritional factors in macrophytes limits their direct use as a dietary ingredient, as there are reports of tannin toxicity to fish (Hossain & Jauncy, 1989; Mukhopadhyay & Ray, 1999). In the present study, fermented duckweed was incorporated in the diets of rohu fry due to its reduced antinutritional factors, phytic acid and tannin- compared to the raw duckweed (Table 1). The growth performance parameters of rohu showed insignificant differences between the fermented duckweed treatment groups and the control group. This outcome can be attributed to the decreased levels of antinutritional factors achieved through fermentation (Bairagi et al., 2002; Flores-Miranda et al., 2015) and combined with the biofloc rearing system, which provides easily accessible microbial floc as an additional nutrient source for the carps (Deb, Noori, & Rao, 2020). Similarly, no significant differences were observed in absolute growth and specific growth rate of Pacific white shrimp when fed fermented duckweed flour, and it can be utilised up to 35% in the diet (Flores-Miranda et al., 2015). In

Table 3. Growth performance and survival (%) of rohu (*Labeo rohita*) fed diet with different inclusion levels of fermented *Lemna minor* L. over 90 days

Parameters	Control	FLM10	FLM20	FLM30	FLM40
Average final length (cm)	4.77 ± 0.17	5.40 ± 0.20	5.42 ± 0.15	4.87 ± 0.17	5.22 ± 0.15
Length gain (%)	83.65 ± 6.54	107.68 ± 7.85	108.65 ± 5.74	87.49 ± 6.54	100.96 ± 5.95
Average final weight (g)	1.362 ± 0.13	1.885 ± 0.21	1.993 ± 0.16	1.440 ± 0.14	1.612 ± 0.14
Weight gain (%)	352.75 ± 43.83	528.75 ± 70.71	556.75 ± 52.17	382.00 ± 45.89	437.00 ± 45.89
SGR (% day^{-1})	1.642 ± 0.12	1.972 ± 0.13	2.014± 0.13	1.706 ± 0.08	1.814 ± 0.08
Condition factor	1.25 ± 0.04	1.18 ± 0.02	1.23 ± 0.02	1.22 ± 0.04	1.13 ± 0.02
$CV_{length\ (\%)}$	15.53 ± 2.43^{b}	10.5 ± 1.83^{ab}	8.13 ± 0.62^{a}	10.73 ± 1.0^{ab}	8.68 ± 1.28^{ab}
$CV_{weight\ (\%)}$	38.07 ± 5.68	29.77 ± 3.58	23.56 ± 4.55	30.22 ± 3.40	26.91 ± 2.89
AFCR	0.72 ± 0.08	0.58 ± 0.07	0.49 ± 0.04	0.72 ± 0.07	0.66 ± 0.05
PER	5.73 ± 0.58	7.17 ± 0.76	8.13 ± 0.57	5.71 ± 0.57	6.12 ± 0.51
Survival %	98.33 ± 0.91	96.66 ± 0.13	98.33 ± 0.09	96.66 ± 0.12	96.66 ± 0.12
Gastro-somatic Index	0.105 ± 0.02^{a}	0.157 ± 0.03^{ab}	0.210 ± 0.01^{b}	0.117 ± 0.02^{a}	0.140 ± 0.02^{ab}

The mean values are expressed as mean ± standard error

^{a,b} The values in a row with different superscripts vary significantly ($p < 0.05$). The values in row without any superscript indicate no significant difference among them ($p > 0.05$)

FISHERY TECHNOLOGY

carnivorous fish such as rainbow trout, incorporating *Lemna* up to 20% in the diet was effective, whereas reduced growth was seen at higher incorporation levels. Reduced growth with increasing dietary duckweed levels is attributed to decreased feed palatability (Fiordelmondo et al., 2022).

The condition factor reflects the relative robustness or degree of well-being of fish and varies according to age, maturity stage, and degree of nourishment (Williams, 2000). A condition factor greater than one indicates that the fish are in good health, and elevated condition factor values indicate an enhanced physical state (Mahmood, Mateen, & Hadyait, 2019). The condition factor was found to be statistically similar ($p > 0.05$) across all the groups, and was greater than one; this indicates the importance of the fermented diet as well as the biofloc system. Similarly, a condition factor above one was also observed in rohu fry (Kute et al., 2022) and common carp fingerlings (Bakhshi, Najdegerami, Manaffar, Tukmechi, & Farah, 2018; Minabi, Sourinejad, Alizadeh, Ghatrami, & Khanjani, 2020) cultivated in a biofloc system. Thus, results of the current study indicated that incorporation of fermented *Lemna* in the diet of rohu did not adversely affect the well-being of rohu fry. The coefficient of variation determined for fish length and weight indicates variation in size. The current study indicates a significant difference ($p < 0.05$) in the CV for length and insignificant differences in the CV for weight ($p > 0.05$) across treatments. This similarity in weight might be because of the continuous availability of food in the biofloc system (Ekasari et al., 2015). Dey et al. (2022) recorded the lowest CV for rohu spawn weight reared in the biofloc system compared to the clear water system, which justifies the role of continuous availability of live food in promoting uniform growth.

The apparent feed conversion ratio was statistically similar among all the groups in the present study. In this study, the observed feed conversion ratio (FCR) ranged between 0.49 and 0.72, although several studies documented FCR >2 when fed fermented duckweed in feed (Bairagi et al., 2002; Flores-Miranda et al., 2015). The continuous availability of floc produced in this biofloc system served as an additional source of natural food (Dey et al., 2022; Solanki et al., 2023), likely reducing the feed requirement. Also, the presence of antinutritional factors (Tacon, 1990) and high fibre content (De Silva, Shim, & Ong, 1990) within plant feedstuffs limits their incorporation in animal feeds. However, the use of fermented duckweed in the present study resulted in a decreased level of anti-nutritional factors (Bairagi et al., 2002; Flores-Miranda et al., 2015). The continuous availability of live food in the biofloc system and improved nutritional value of diets may be attributed to better FCR in all the experimental groups of the present study (Panigrahi et al., 2018). This shows the potential benefit of integrating both fermentation of plant ingredients and the biofloc system during nursery rearing of rohu. The protein efficiency ratio showed similarities ($p > 0.05$) between the control group and the fermented *L. minor* L. incorporated diets. This may be because of the improved digestibility of duckweed after fermentation and improved nutritional quality of the feed ingredient as reported by Bairagi et al. (2002) and Flores-Miranda et al. (2015).

Adding varying amounts of fermented *L. minor* L. to the diet of rohu fry during the rearing phase did not affect survival. The survival of rohu fry in the

FISHERY TECHNOLOGY

Table 4. Physicochemical parameters of water observed over the 90 days of experimental duration

Water quality parameters	Control	FLM10	FLM20	FLM30	FLM40
Temperature (!)	23.00 ± 0.19	23.08 ± 0.15	23.07 ± 0.16	22.06 ± 0.03	23.10 ± 0.15
pH	7.43 ± 0.007	7.43 ± 0.005	7.43 ± 0.004	7.44 ± 0.004	7.43 ± 0.002
Dissolved Oxygen (mg L^{-1})	6.76 ± 0.17	7.03 ± 0.31	6.97 ± 0.26	6.96 ± 0.08	6.48 ± 0.10
Total alkalinity (mg L^{-1})	67.9 ± 1.02	68.75 ± 1.51	68.41 ± 0.83	68.91 ± 0.51	69.52 ± 0.76
Total Hardness (mg L^{-1})	42.15 ± 0.72	41.76 ± 0.85	41.92 ± 0.84	42.61 ± 0.89	43.96 ± 0.97
Floc Volume (mL L^{-1})	16.24 ± 0.12	16.12 ± 0.13	16.23 ± 0.07	16.19 ± 0.02	16.27 ± 0.05

The mean values are expressed as mean ± standard error

present study ranged from 96% to 98% in the various treatments, which was greater than the 74% to 86% survival recorded by Yilmaz, Akyurt, and Gunal (2004) for carp fry when fed with raw duckweed. This lowered survival may be due to the presence of antinutritional components in raw duckweed (Bairagi et al., 2002). According to Flores-Miranda et al. (2015), Pacific white shrimp survival is unaffected by the addition of bacterially fermented *Lemna* sp. to their diet. A 100% survival rate was achieved when juvenile common carp were fed larger duckweed, *Spirodela polyrhiza* (Shrivastav et al., 2022). Better survival rates were yielded in numerous studies employing the biofloc system for carp rearing, whether using various stocking densities (Zhao et al., 2014) or carbon sources (Kute et al., 2022), or growing at various dietary protein levels (Sawant et al., 2020).

The physicochemical parameters of water observed throughout the experimental duration are depicted in Table 4. Average water temperature (23 °C, range 26 °C to 21 °C), pH (7.4, range 7.2-7.9), dissolved oxygen (6.8 mg L^{-1}, range 5 to 8.9 mg L^{-1}), total alkalinity (68 mg L^{-1}, range 40 to 85 mg L^{-1}), and floc volume (mean 16 mL L^{-1}) were within the range. The results of the ammonia-N (NH_3-N mg L^{-1}), nitrite-N (NO_2-N mg L^{-1}), and nitrate-N (NO_3-N mg L^{-1}) analysis are presented in Fig. 1. The proximate composition of the fish carcasses is given in Table 5. Dietary incorporation of fermented common duckweed did not affect the carcass composition of fish; it was similar in all the treatments.

The average temperature observed during the experimental study was 23 °C. The study was conducted from December to March when winter prevailed for the majority of the experimental duration. The seasonal changes in the atmospheric temperature may be the cause for the drop in water temperature levels seen in the current study during winter. The mean pH values fall within the ideal range of 6.5 to 8.5 (Meade, 1985) for rohu culture. The water's pH increased with little fluctuations in all experimental treatments during the present experiment. The pH of water in a biofloc system usually decreases due to the accumulation of organic matter and nitrification (Hargreaves, 2013;

FISHERY TECHNOLOGY

Table 5. Proximate carcass composition (% wet matter) of fish at the end of the experimental duration

Carcass composition (%)	Control	FLM10	FLM20	FLM30	FLM40
Moisture	74.75 ± 1.37	77.00 ± 0.57	75.70 ± 0.96	75.475 ± 0.48	75.60 ± 0.94
Protein	16.67 ± 0.44	16.82 ± 0.08	16.82 ± 0.43	16.00 ± 0.21	17.42 ± 0.17
Lipid	2.55 ± 0.06	2.38 ± 0.04	2.55 ± 0.02	2.65 ± 0.01	2.55 ± 0.06
Ash	4.62 ± 0.20	4.88 ± 0.23	4.71 ± 0.17	5.26 ± 0.15	5.36 ± 0.17

The mean values are expressed as mean ± standard error

Table 6. Histomorphometry measurements of mid intestine of rohu fed with different inclusion levels of fermented *Lemna minor* for 90 days

Parameters	Fermented *Lemna minor* (g kg^{-1} diet)				
	Control	FLM10	FLM20	FLM30	FLM40
Villus length (μm)	226.69 ± 26.14^{ab}	199.97 ± 23.41^{a}	158.83 ± 7.59^{a}	127.05 ± 15.24^{a}	306.45 ± 41.84^{b}
Villus width (μm)	150.32 ± 26.04	120.82 ± 20.56	137.72 ± 16.74	122.37 ± 12.24	139.90 ± 11.64
Crypt depth (μm)	71.90 ± 5.78	57.75 ± 1.04	54.00 ± 1.03	65.12 ± 0.7	64.52 ± 9.15
Muscularis thickness (μm)	51.22 ± 7.98	16.62 ± 1.45	30.90 ± 2.68	26.80 ± 5.47	50.30 ± 14.55
No. of villi	17.50 ± 1.04^{ab}	16.00 ± 0.91^{a}	22.50 ± 1.04^{c}	19.50 ± 0.86^{abc}	20.50 ± 0.95^{bc}

The mean values represent mean ± standard error (SE)

[a,b,c] The values in a row with different superscript vary significantly ($p < 0.05$). The values in row without any superscript indicate insignificant difference among them ($p > 0.05$)

Liu, Hu, Dai, & Avnimelech, 2014). Therefore, the lime-treated water with high pH was added whenever pH was found to be decreased to maintain it in the optimal range.

Carps grow best at dissolved oxygen levels greater than 5 mg L^{-1} (Adhikari, 2006). In all the experimental units, the average values were greater than 6 mg L^{-1}. Nevertheless, the variations in dissolved oxygen (DO) levels were noted; these might result from the growing microbial load in the experimental tanks, which consumes oxygen for respiration alongside the cultured animals (De Schryver, Crab, Defoirdt, Boon, & Verstraete, 2008). Fish culture water should have an alkalinity of 100 to 120 mg L^{-1} at the very least (Hargreaves, 2013). The total alkalinity in the present study ranged between 40 to 85 mg L^{-1}, which is comparable to the water alkalinity values found by Dey et al. (2022). The water used to fill the

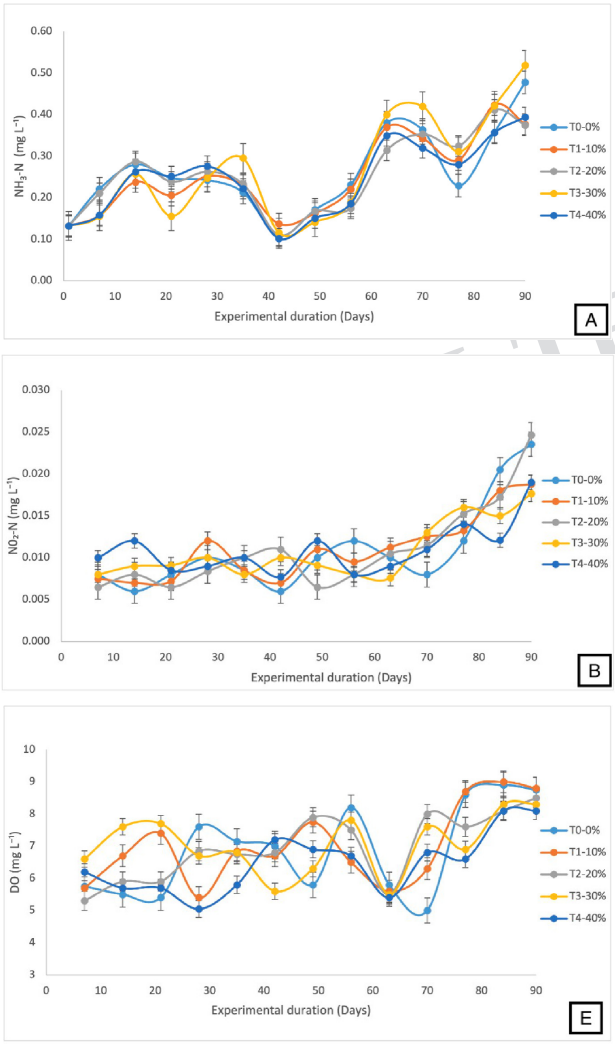


Fig. 1. Water quality parameters recorded during the experiment: A. NH_3-N (mg L^{-1}), B. NO_2-N (mg L^{-1}), and C. NO_3-N (mg L^{-1})

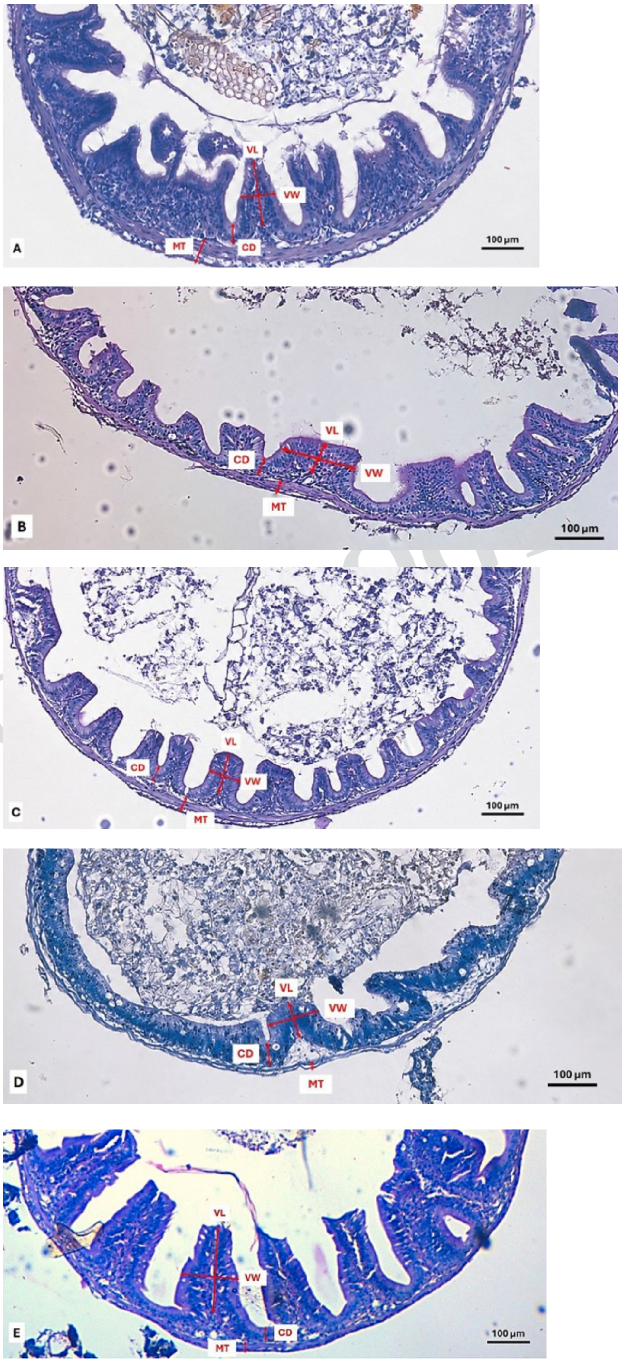


Fig. 2A. Histology of the mid intestine of *Labeo rohita* after 90 days. (ZEISS Primo Star 2.0 with software) at 10x magnification (A: Control (0%), B: FLM10, C: FLM20, D: FLM30, and E: FLM40). VL, villus length; VW, villus width; CD, crypt depth; MT, thickness of muscularis

experimental tanks initially had a total alkalinity of less than 40 mg L^{-1}. The water alkalinity of all the experimental units was raised by adding a supernatant of the lime-treated water. Further, a drop in water alkalinity was noticed after 56 days in the present study which was improved by adding a supernatant of the lime-treated water. The activity of nitrifying bacteria is responsible for most losses of alkalinity in nursery biofloc culture system (Hargreaves, 2013).

Aquatic animals raised for food are generally harmed by ammonia-N and nitrite-N concentrations in aquaculture that are more than 0.1 mg L^{-1} and 5 mg L^{-1}, respectively (Qiao, Liu, Jin, & Li, 2006; Wang et al., 2015). The current study's ammonia-N levels varied from 0.1 to 0.5 mg L^{-1}. Mahanand et al. (2013b) kept rohu's total ammonia nitrogen level below 1 mg L^{-1} while maintaining a 50% water exchange rate without having an impact on fish growth. According to Deb et al. (2020), fish can be raised in biofloc systems with total ammonia nitrogen concentrations as high as 0.7 mg L^{-1}. Likewise, total ammonia nitrogen levels higher than 0.1 mg L^{-1} were detected in the biofloc system for different fish species (Bakhshi et al., 2018; Minabi et al., 2020; Dey et al., 2022; Kute et al., 2022; Solanki et al., 2023). The nitrite-N levels in the current study varied from 0.005 to 0.025 mg L^{-1} and increased with the duration of the experiment. This rise may be attributed to the conversion of hazardous ammonia by nitrifying bacteria to nitrite-N and subsequently nitrate (Hargreaves, 2013). A similar nitrite-N level was observed by Solanki et al. (2023). Using various carbon sources, Bakhshi et al. (2018) noticed fluctuations in the nitrite-N levels in the biofloc system; the highest nitrite-N level was found to be 4 mg L^{-1}. Deb et al. (2020) found that the levels of nitrite-N in biofloc systems were lower than in clear water systems. Wang et al. (2015) stated that nitrate-N may also be hazardous, but only if animals are exposed to concentrations greater than 60 mg L^{-1} and for an extended period. In the current investigation, nitrate-N levels ranged from 5 mg L^{-1} to 25 mg L^{-1}. Accumulation of organic material in the culture environment and the ongoing nitrification process led to increased concentration of nitrate-N (Hargreaves, 2013). In the biofloc system, similar rising nitrate-N levels were noted by Bakhshi et al. (2018), Mahadik et al. (2024), and Dey et al. (2022).

The mean values of floc volume (16 mL L^{-1}) recorded in this study remained within an optimum level for carp. The average floc levels (35 mL L^{-1}) were observed by Aalimahmoudi and Mohammadiazarm (2019). The safe floc volume level of 25–50 mL L^{-1} for fish like tilapia and 10 to 15 mL L^{-1} for shrimp culture in the biofloc system has been suggested by Hargreaves (2013).

The intestinal wall of rohu consists of lumen, well-vascularised lamina propria, submucosa and muscularis with inner circular muscles and outer longitudinal muscles, and a thin serosa. Fig. 2B shows the well-developed submucosa and muscularis. The longitudinal muscle layer was normal in all dietary groups except FLM30 (Fig. 2B. D). Additionally, the lamina propria was clearly visible in all the dietary groups except the control and FLM30 groups. The columnar epithelium was properly arranged in the control, FLM20, and FLM30 groups. Furthermore, deformities in the villi

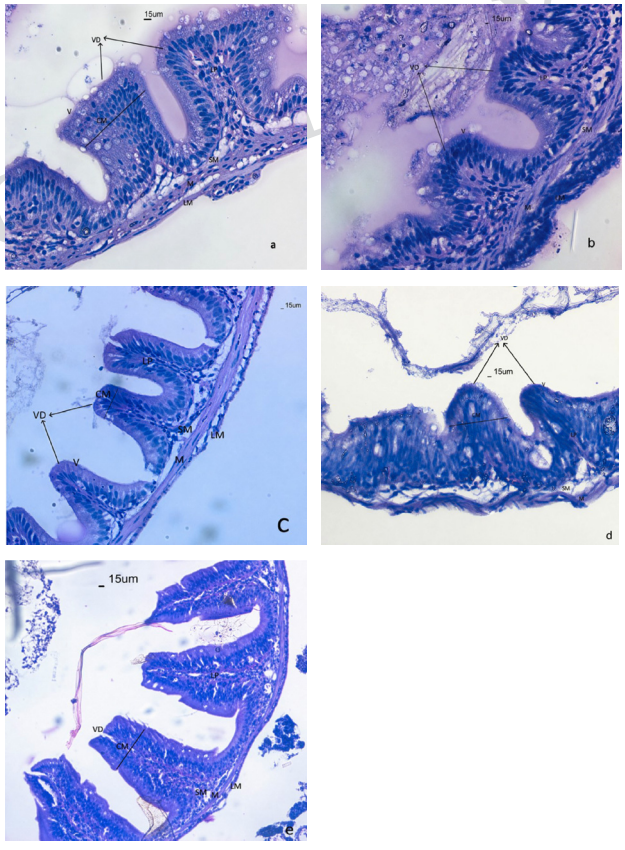


Fig. 2B. Histology of mid intestine of *Labeo rohita* after 90 days. (ZEISS Primo Star 2.0 with software) at 40 x magnification (A: Control (0%), B: FLM10, C: FLM20, D: FLM30, and E: FLM40). LP= Lamina propria, VD= Villi deformities, LM= Outer longitudinal muscle layer, M= Circular muscle layer, SM= Submucosa

shape were found more in the FLM10 group, followed by the FLM40 group. In case of the morphometric analysis of the treatment groups, the results revealed a significantly higher villus length ($p < 0.05$) in the FLM40 group compared to the FLM10, FLM20, and FLM30 groups, and was statistically similar to the control group. No significant differences ($p > 0.05$) were observed in the villus width, crypt depth, and muscularis thickness among all the treatments (Table 6). The increased number of villi was observed in FLM20, which was statistically similar to the FLM30 and FLM40 groups. However, significantly lower ($p < 0.05$) numbers of villi were observed in the FLM10 group, which were statistically similar to the control and FLM30 groups.

The nutritional absorption in the small intestine significantly influences fish growth (Elsabagh et al., 2018; Abdel-Latif, Abdel-Tawwab, Khafaga, & Dawood, 2020; Dawood et al., 2020). Certain macromolecular elements in the feed can be broken down by microorganisms into smaller molecules that fish can more easily absorb through their intestines (Zhang, Wang, Liu, Cao, & Zhu, 2020). Long intestinal villi are often linked to improved gut health and more effective nutritional absorption in fish, both of which improve growth performance (Zhang et al., 2020). In the context of the results of the present study, a significantly increased villus length was observed in FLM40 and was significantly similar to the control treatment. Also, no significant changes were observed in villus width, crypt depth, and muscularis thickness. Mahadik et al. (2024) reported a longer villus length than the control treatments due to the use of fermented rice bran with either probiotic or yeast. The beneficial effects of yeast on intestinal shape in this study may be due to the presence of mannooligosaccharides (MOS) in the yeast cell wall (Ran et al., 2015). Improved gut morphology of fish resulted in better feed utilisation (Dimitroglou et al., 2009). The increased villus length in the present study is suggested to increase the absorption area, which can result in more nutrient absorption through the gut wall of fish (Abdel-Tawwab, Adeshina, Jenyo-Oni, Ajani, & Emikpe, 2018; Zhou et al., 2019; Abdel-Latif et al., 2020).

Integrating wet yeast-fermented duckweed (*L. minor* L.) into a biofloc system addresses a critical bottleneck in sustainable aquaculture: reducing feed formulation costs without compromising fish health or growth performance. While previous studies have examined duckweed as a standalone feed ingredient or biofloc as a water-quality management tool independently, integrating both provides a dual benefit – reducing reliance on commercial feed ingredients while leveraging the natural productivity of biofloc. Because the trial demonstrated replacement feasibility rather than a performance gain, the primary practical value for small- and medium-scale farmers lies in direct feed cost reduction.

The feed formulation cost analysis reveals a progressive cost-saving trend as incorporation levels increase in the diet (Table 2). The FLM40 diet formulation achieved a raw ingredient formulation cost reduction of ₹ 20,595 per tonne (1000 kg) representing a 19.5% reduction compared to the control diet. This calculation accounts only for raw ingredient cost, excluding cost of duckweed collection, fermentation, drying, additional processing, and labour. Consequently, practical adoption by farmers can be optimised through strategic seasonal harvesting, aligning feed preparation with duckweed availability to maximise economic efficiency during nursery and fingerling rearing phases.

The present study aimed at evaluating the use of a local duckweed, collected from uncontaminated waters, as a cost-effective, non-conventional protein source in rohu fry diets. The results demonstrate that incorporation of wet yeast-fermented common duckweed, *L. minor* L., up to 40% in the diet does not adversely affect the growth performance, feed efficiency, intestinal morphometry, and survival of rohu fry reared in a biofloc system over a 90-day period. The combination of a fermented diet with available supplementary feed within the biofloc system resulted in a feed conversion ratio (FCR) of less than one. This feed utilisation confirms that the integration of fermented duckweed within the biofloc system is a viable strategy that significantly reduces feed formulation costs, thereby offering strong practical utility for farmers using locally available seasonal macrophyte resources.

Ethical Statement

The procedure for managing and collecting samples was carried out in accordance with the animal care protocols approved by the College of Fisheries, Ratnagiri (Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India) Committee on Animal Ethics.

FISHERY TECHNOLOGY

Acknowledgements

The authors thank the authorities of Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, and the Associate Dean, College of Fisheries, Ratnagiri, for providing all the necessary facilities for the research.

References

Aalimahmoudi, M., & Mohammadiazarm, H. (2019). Dietary protein level and carbon/nitrogen ratio manipulation in biofloc rearing of *Cyprinus carpio* juvenile: Evaluation of growth performance, some blood biochemical and water parameters. *Aquaculture*, *513*, Article 734408. https://doi.org/10.1016/j.aquaculture.2019.734408

Abdel-Latif, H. M. R., Abdel-Tawwab, M., Khafaga, A. F., & Dawood, M. A. O. (2020). Dietary oregano essential oil improved the growth performance via enhancing the intestinal morphometry and hepato-renal functions of common carp (*Cyprinus carpio* L.) fingerlings. *Aquaculture*, *526*, Article 735432. https://doi.org/10.1016/j.aquaculture.2020.735432

Abdel-Tawwab, M., Adeshina, I., Jenyo-Oni, A., Ajani, E. K., & Emikpe, B. O. (2018). Growth, physiological, antioxidants, and immune response of African catfish, *Clarias gariepinus* (B.), to dietary clove basil, *Ocimum gratissimum*, leaf extract and its susceptibility to *Listeria monocytogenes* infection. *Fish & Shellfish Immunology*, *78*, 346–354. https://doi.org/10.1016/j.fsi.2018.04.057

Adhikari, S. (2006). Soil and water quality management in aquaculture. In S. Ayyappan, J. K. Jena, A. Gopalakrishnan, & A. K. Pandey (Eds.), *Handbook of fisheries and aquaculture*. Indian Council of Agricultural Research.

AOAC. (2006). *Official methods of analysis of AOAC International* (18th ed.).

APHA. (2005). *Standard methods for the examination of water and wastewater* (21st ed.).

Avnimelech, Y. (1999). Carbon/nitrogen ratio as a control element in aquaculture systems. *Aquaculture*, *176*(3–4), 227–235. https://doi.org/10.1016/S0044-8486(99)00085-X

Avnimelech, Y., & Kochba, M. (2009). Evaluation of nitrogen uptake and excretion by tilapia in biofloc tanks, using 15N tracing. *Aquaculture*, *287*(1–2), 163–168. https://doi.org/10.1016/j.aquaculture.2008.10.009

Bairagi, A., Ghosh, K. S., Sen, S. K., & Ray, A. K. (2002). Duckweed (*Lemna polyrhiza*) leaf meal as a source of feedstuff in formulated diets for rohu (*Labeo rohita* Ham.) fingerlings after fermentation with a fish intestinal bacterium. *Bioresource Technology*, *85*(1), 17–24. https://doi.org/10.1016/S0960-8524(02)00067-6

Bakhshi, F., Najdegerami, E. H., Manaffar, R., Tukmechi, A., & Farah, K. R. (2018). Use of different carbon sources for the biofloc system during the grow-out culture of common carp (*Cyprinus carpio L.*) fingerlings. *Aquaculture*, *484*, 259–267. https://doi.org/10.1016/j.aquaculture.2017.11.036

Bauer, W., Prentice-Hernandez, C., Tesser, M. B., Wasielesky, W., & Poersch, L. H. S. (2012). Substitution of fishmeal with microbial floc meal and soy protein concentrate in diets for the Pacific white shrimp *Litopenaeus vannamei*. *Aquaculture*, *342–343*, 112–116. https://doi.org/10.1016/j.aquaculture.2012.02.023

Boyd, C. E. (1981). *Water quality in warm water fish ponds*. Auburn University.

Chaturvedi, K. M. M., Langote, D. S., & Asolekar, R. S. (2003). Duckweed-fed fisheries for treatment of low strength community waste water. *WWWTM Newsletter-Asian Institute of Technology*.

Cho, C. Y., Slinger, S. J., & Bayley, H. S. (1982). Bioenergetics of salmonid fishes: Energy intake, expenditure and productivity. *Comparative Biochemistry and Physiology Part B: Comparative Biochemistry*, *73*(1), 25–41. https://doi.org/10.1016/0305-0491(82)90198-5

Das, P. C., & Kamble, S. P. (2019). Optimising water requirement for nursery rearing of rohu *Labeo rohita* (Hamilton, 1822) in large outdoor concrete tanks: Influence of water depth on seed performance. *Indian Journal of Fisheries*, *66*(4), 151–156.

Dawood, M. A. O., Eweedah, N. M., Khalafalla, M. M., Khalid, A., El Asely, A., Fadl, S. E., Amin, A. A., Paray, B. A., & Ahmed, H. A. (2020). *Saccharomyces cerevisiae* increases the acceptability of Nile tilapia (*Oreochromis niloticus*) to date palm seed meal. *Aquaculture Reports*, *17*, Article 100314. https://doi.org/10.1016/j.aqrep.2020.100314

De Schryver, P., Crab, R., Defoirdt, T., Boon, N., & Verstraete, W. (2008). The basics of bio-flocs technology: The added value for aquaculture. *Aquaculture*, *277*(3–4), 125–137. https://doi.org/10.1016/j.aquaculture.2008.02.019

De Silva, S., Shim, K. F., & Ong, A. K. (1990). An evaluation of the method used in digestibility estimations of a dietary ingredient and comparisons on external and internal markers, and time of faeces collection in digestibility studies in the fish *Oreochromis aureus* (Steindachner). *Reproduction Nutrition Development*, *30*(2), 215–226. https://doi.org/10.1051/rnd:19900207

Deb, S., Noori, M. T., & Rao, P. S. (2020). Application of biofloc technology for Indian major carp culture (polyculture) along with water quality management. *Aquacultural Engineering*, *91*, Article 102106. https://doi.org/10.1016/j.aquaeng.2020.102106

FISHERY TECHNOLOGY

Dey, S. S., Tibile, R. M., Pawase, A. S., Meshram, S. J., Pathan, D. I., & Nayak, A. (2022). Evaluation of different stocking densities and carbon:nitrogen ratios on growth, body composition and production performance of *Labeo rohita* (Hamilton, 1822) spawn in biofloc based nursery system. *Aquaculture Research, 53*(14), 4989–5005. https://doi.org/10.1111/are.15985

Dimitroglou, A., Merrifield, D. L., Moate, R., Davies, S. J., Spring, P., Sweetman, J., & Bradley, G. (2009). Dietary mannan oligosaccharide supplementation modulates intestinal microbial ecology and improves gut morphology of rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Journal of Animal Science*, *87*(10), 3226–3234. https://doi.org/10.2527/jas.2008-1428

Ekasari, J., Rivandi, D. R., Firdausi, A. P., Surawidjaja, E. H., Zarin, M., Bossier, P., & De Schryver, P. (2015). Biofloc technology positively affects Nile tilapia (Oreochromis niloticus) larvae performance. *Aquaculture*, *441*, 72–77. https://doi.org/10.1016/j.aquaculture.2015.02.019

Elsabagh, M., Mohamed, R., Moustafa, E. M., Hamza, A., Farrag, F., Decamp, O., Dawood, M. A. O., & Eltholth, M. (2018). Assessing the impact of *Bacillus* strains mixture probiotic on water quality, growth performance, blood profile and intestinal morphology of Nile tilapia, *Oreochromis niloticus*. *Aquaculture Nutrition*, *24*(6), 1613–1622. https://doi.org/10.1111/anu.12797

Fisheries Statistics Division. (2023). *Handbook on Fisheries Statistics 2023*. Department of Fisheries, Government of India.

Food and Agriculture Organization of the United Nations. (2022). *The state of world fisheries and aquaculture: Towards blue transformation*. https://doi.org/10.4060/cc0461en

Food and Agriculture Organization of the United Nations. (2024). *The state of world fisheries and aquaculture: Blue transformation in action*. https://doi.org/10.4060/cd0683en

Fiordelmondo, E., Ceschin, S., Magi, G. E., Mariotti, F., Iaffaldano, N., Galosi, L., & Roncarati, A. (2022). Effects of partial substitution of conventional protein sources with duckweed (*Lemna minor*) meal in the feeding of rainbow trout (*Oncorhynchus mykiss*) on growth performances and the quality product. *Plants*, *11*(9), Article 1220. https://doi.org/10.3390/plants11091220

Flores-Miranda. M. C., Luna-González, A., Cortés-Espinosa, D. V., Álvarez-Ruiz, P., Cortés-Jacinto, E., Valdez-González, F. J., Escamilla-Montes, R., & González-Ocampo, H. A. (2015). Effects of diets with fermented duckweed (*Lemna* sp.) on growth performance and gene expression in the Pacific white shrimp, *Litopenaeus vannamei*. *Aquaculture International, 23*, 547–561. https://doi.org/10.1007/s10499-014-9835-x

Hargreaves, J. A. (2013). *Biofloc production systems for aquaculture* (SRAC Publication No. 4503). Southern Regional Aquaculture Center.

Hossain, M. A., & Jauncy, K. (1989). Nutritional evaluation of some Bangladeshi oilseed meals as partial substitutes for fish meal in the diet of common carp, *Cyprinus carpio* L. *Aquaculture Research*, *20*(3), 255–268. https://doi.org/10.1111/j.1365-2109.1989.tb00351.x

Jena, J. K., & Das, P. C. (2019). Carp culture. In S. K. Singh, A. T. Kumar, V. K. Bharti, & K. B. Gupta (Eds.), *Handbook of fisheries and aquaculture* (pp. 380–400). Indian Council of Agricultural Research, New Delhi.

Kute, A. S., Tibile, R. M., Pawase, A. S., Ghode, G. S., Ghuguskar, M. F., Sawant, K. S., Waghmode, R. P., & Dey, S. S. (2022). Growth and survival of rohu, *Labeo rohita* (Hamilton, 1822) fry using different carbon sources in biofloc system. *Journal of Experimental Zoology India*, *25*, 1503–1510.

Leng, R. A., Stambolie, J. H., & Bell, R. (1995). Duckweed - A potential high-protein feed resource for domestic animals and fish. *Livestock Research for Rural Development*, *7*(1), Article 5.

Liu, L., Hu, Z., Dai, X., & Avnimelech, Y. (2014). Effects of addition of maize starch on the yield, water quality and formation of bioflocs in an integrated shrimp culture system. *Aquaculture*, *418*–419, 79–86. https://doi.org/10.1016/j.aquaculture.2013.10.005

Mahadik, P. U., Wasave, S. S., Chavan, B. R., Meshram, S. J., Ghode, G. S., Wasave, S. M., Naik, S. D., & Shingare, P. E. (2024). Effect of fermented rice bran as a carbon source for rearing genetically improved farmed Tilapia, *Oreochromis niloticus* (Linnaeus, 1758), fry in biofloc system. *Aquaculture*, 592, Article 741246. https://doi.org/10.1016/j.aquaculture.2024.741246

Mahanand, S. S., Moulick, S., & Rao, P. S. (2013a). Optimum formulation of feed for rohu, *Labeo rohita* (Hamilton), with biofloc as a component. *Aquaculture International*, 21, 347–360. https://doi.org/10.1007/s10499-012-9557-x

Mahanand, S. S., Moulick, S., & Rao, P. S. (2013b). Water quality and growth of rohu, *Labeo rohita*, in a biofloc system. *Journal of Applied Aquaculture*, *25*(2), 121–131. https://doi.org/10.1080/10454438.2013.788898

Mahmood, T., Mateen, A., & Hadyait, M. A. (2019). Condition factor and length-weight relationship of pond reared *Labeo rohita*. *PSM Biological Research*, *4*(2), 89–96.

Manan, H., Moh, J. H. Z., Kasan, N. A., Suratman, S., & Ikhwanuddin, M. (2017). Identification of biofloc microscopic composition as the natural bioremediation in zero water exchange of Pacific white shrimp, *Penaeus vannamei*, culture in closed hatchery system. *Applied Water Science*, *7*, 2437–2446. https://doi.org/10.1007/s13201-016-0421-4

FISHERY TECHNOLOGY

Meade, J. W. (1985). Allowable ammonia for fish culture. *The Progressive Fish-Culturist, 47*(3), 135–145. https://doi.org/10.1577/1548-8640(1985)47%3C135:AAFFC%3E2.0.CO;2

Minabi, K., Sourinejad, I., Alizadeh, M., Ghatrami, E. R., & Khanjani, M. H. (2020). Effects of different carbon to nitrogen ratios in the biofloc system on water quality, growth, and body composition of common carp (*Cyprinus carpio* L.) fingerlings. *Aquaculture International, 28*, 1883–1898. https://doi.org/10.1007/s10499-020-00564-7

Mugwanya, M., Dawood, M. A. O., Kimera, F., & Sewilam, H. (2021). Biofloc systems for sustainable production of economically important aquatic species: A Review. *Sustainability, 13*(13), Article 7255. https://doi.org/10.3390/su13137255

Mukhopadhayay, N., & Ray, A. K. (1999). Utilization of copra meal in the formulation of compounded diets for rohu, *Labeo rohita* fingerlings. *Journal of Applied Ichthyology, 15*(3), 127–131. https://doi.org/10.1046/j.1439-0426.1999.00132.x

Nout, M. J. R. (2009). Rich nutrition from the poorest - Cereal fermentations in Africa and Asia. *Food Microbiology, 26*(7), 685–692. https://doi.org/10.1016/j.fm.2009.07.002

Panigrahi, A., Saranya, C., Sundaram, M., Kannan, S. R. V., Das, R. R., Kumar, R. S., Rajesh, P., & Otta, S. K. (2018). Carbon:Nitrogen (C:N) ratio level variation influences microbial community of the system and growth as well as immunity of shrimp (*Litopenaeus vannamei*) in biofloc based culture system. *Fish & Shellfish Immunology, 81*, 329–337. https://doi.org/10.1016/j.fsi.2018.07.035

Qiao, S., Liu, H., Jin, X., & Li, R. (2006). Harmful effects of ammonia nitrogen accumulation in aquaculture water and its bioutilization. *Hebei Fisheries*, (1), 20–22. https://doi.org/10.3969/j.issn.1004-6755.2006.01.009

Ran, C., Huang, L., Liu, Z., Xu, L., Yang, Y., Tacon, P., Auclair, E., & Zhou, Z. (2015). A comparison of the beneficial effects of live and heat-inactivated baker's yeast on Nile tilapia: Suggestions on the role and function of the secretory metabolites released from the yeast. *PLoS One, 10*(12), Article e0145448. https://doi.org/10.1371/journal.pone.0145448

Rostika, R., Andriani, Y., Abram, A. H., & Vinasyiam, A. (2017). The growth rate of Nile tilapia *Oreochromis niloticus* fry fed on fermented *Lemna* sp. meal. *Jurnal Akuakultur Indonesia, 16*(1), 101–106. https://doi.org/10.19027/jai.16.1.101-106

Sawant, K. S., Meshram, S. J., Dhamagaye, H. B., Chavan, B. R., Tibile, R. M., & Vartak, V. R. (2020). Growth and survival of *Labeo rohita* (Hamilton, 1822) fry in biofloc system using various dietary protein levels. *Journal of Experimental Zoology India*, 23, 765–769.

Shrivastav, A. K., Kumar, G., Mittal, P., Tocher, D. R., Glencross, B. D., Chakrabarti, R., & Sharma, J. G. (2022). Effect of greater duckweed *Spirodela polyrhiza* supplemented feed on growth performance, digestive enzymes, amino and fatty acid profiles, and expression of genes involved in fatty acid biosynthesis of juvenile Common carp *Cyprinus carpio*. *Frontiers in Marine Sciences, 9*, Article 788455. https://doi.org/10.3389/fmars.2022.788455

Simoes, L. N., Lombardi, D. C., Gomide, A. T. M., & Gomes, L. C. (2011). Efficacy of clove oil as anaesthetic in handling and transportation of Nile tilapia, *Oreochromis niloticus* (Actinopterygii: Cichlidae) juveniles. *Zoologia* (*Curitiba*), *28*(3), 285–290. https://doi.org/10.1590/S1984-46702011000300001

Solanki, S., Meshram, S. J., Dhamagaye, H. B., Naik, S. D., Shingare, P. E., & Yadav, B. M. (2023). Effect of C/N ratio levels and stocking density of Catla Spawn (*Gibelion catla*) on water quality, growth performance, and biofloc nutritional composition in an indoor biofloc system. *Aquaculture Research, 2023*(1), Article 2501653. https://doi.org/10.1155/2023/2501653

Tacon, A. G. J. (1990). *Standard methods for the nutrition and feeding of farmed fish and shrimp*. Argent Laboratories Press.

Tavares, F. A., Rodrigues, J. B. R., Fracalossi, D. M., Esquivel, J., & Rouback, R. (2008). Dried duckweed and commercial feed promote adequate growth performance of tilapia fingerlings. *Biotemas, 21*(3), 91–97.

Utomo, N. B. P., Nurfadhilah, & Ekasari, J. (2015). Fermentation of *Azolla* sp. leaves and the utilization as a feed ingredient of tilapia *Oreochromis* sp. *Jurnal Akuakultur Indonesia, 10*(2), 137–143. https://doi.org/10.19027/jai.10.137-143

Wang, G., Yu, E., Xie, J., Yu, D., Li, Z., Luo, W., Qiu, L., & Zheng, Z. (2015). Effect of C/N ratio on water quality in zero-water exchange tanks and the biofloc supplementation in feed on the growth performance of crucian carp, *Carassius auratus*. *Aquaculture, 443*, 98–104. https://doi.org/10.1016/j.aquaculture.2015.03.015

Williams, J. E. (2000). The coefficient of condition of fish. In J. C. Schneider (Ed.), *Manual of fisheries survey methods II: with periodic updates* [Fisheries special report 25, Chapter 13]. Michigan Department of Natural Resources, Fisheries Division.

Yilmaz, E., Akyurt, I., & Gunal, G. (2004). Use of duckweed, *Lemna minor*, as a protein feedstuff in practical diets for common carp, *Cyprinus carpio*, fry. *Turkish Journal of Fisheries and Aquatic Sciences, 4*(2), 105–109.

Younis, E. M., Abdel-Warith, A. A., Al-Asgah, N. A., Ebaid, H., & Mubarak, M. (2013). Histological changes in the liver and intestine of Nile tilapia, *Oreochromis*

FISHERY TECHNOLOGY

niloticus, exposed to sublethal concentrations of cadmium. *Pakistan Journal of Zoology*, *45*(3), 833–841.

Zhang, R., Wang, X. W., Liu, L. L., Cao, Y. C., & Zhu, H. (2020). Dietary oregano essential oil improved the immune response, activity of digestive enzymes, and intestinal microbiota of the koi carp, *Cyprinus carpio*. *Aquaculture*, 518, Article 734781. https://doi.org/10.1016/j.aquaculture.2019.734781

Zhao, Z., Xu, Q., Luo, L., Wang, C., Li, J., & Wang, L. (2014). Effect of feed C/N ratio promoted bioflocs on water quality and production performance of bottom and filter feeder carp in minimum-water exchanged pond polyculture system. *Aquaculture*, 434, 442–448. https://doi.org/10.1016/j.aquaculture.2014.09.006

Zhou, J. S., Guo, P., Yu, H. B., Ji, H., Lai, Z. W., & Chen, Y. A. (2019). Growth performance, lipid metabolism, and health status of grass carp (*Ctenopharyngodon idella*) fed three different forms of sodium butyrate. *Fish Physiology and Biochemistry*, *45*, 287–298. https://doi.org/10.1007/s10695-018-0561-6

FISHERY TECHNOLOGY