

Research Article

Effects of substitution of fishmeal with sesame meal in feeds for *Labeo rohita* fingerling

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Abstract

An eight-week feeding trial was conducted to assess the effects of fishmeal replacement with sesame meal in the diets of *Labeo rohita* fingerling ($2.34 \pm 0.02\text{g}$; $6.4 \pm 0.33\text{cm}$) on growth and carcass composition. Experimental diets containing 35% crude protein and 18 kJ g^{-1} gross energy were formulated by replacing fishmeal (FM) with sesame meal (SM) on a protein-to-protein basis at levels of 0%, 20%, 40%, 60%, 80%, and 100%. Fish were fed to near satiation. Substitution of FM with SM up to 40% did not cause any significant differences in live weight gain, specific growth rate, feed utilisation efficiency, protein efficiency ratio, protein retention efficiency and whole-body proximate composition, but these parameters declined significantly at 60%, 80% and 100% replacement levels. The findings suggest that FM can be substituted by SM up to 40% in formulating nutritionally balanced, cost-effective, sustainable, commercial feeds for *Labeo rohita* fingerling without hampering growth performance and carcass quality.

Keywords: Fishmeal replacement, *Labeo rohita*, nutritionally balanced, sustainable, cost-effective feeds

1. Introduction

The demand for animal-based protein is increasing due to population growth and changing dietary habits (Alagawany et al., 2021) and is expected 52% increase by 2050. Fish protein is regarded as a more affordable and easily digestible source of animal protein compared to other animal-derived proteins (Meena et al., 2022). As

one of the most reliable sources of protein production, aquaculture is positioned to play a vital role in meeting this demand (Murthy, 2022). With nearly half of the world's fish supply already coming from aquaculture, this share is likely to grow as traditional capture fisheries struggle to keep up with demand (Asche et al., 2022; Boyd

et al., 2022). However, the intensification of aquaculture is facing several challenges, particularly the shortage of fishmeal (FM) and its rising demand, as 70% of global fishmeal supplies is used in fish feed production (Gatlin et al., 2007; FAO, 2022; Wang et al., 2024). Fishmeal is a high-quality protein essential for many aquafeeds (Villanueva et al., 2020). Its limited availability due to stagnation in capture fisheries and rising costs is hampering the production of cost-effective and sustainable aquaculture feeds. Hence, there is a dire need to explore alternative protein sources. The by-products of agriculture, particularly oilseed meals, have emerged as strong candidates as they are plentiful, low-cost, easily stored, transported and nutritionally adequate for aquafeeds as opposed to the animal by-product meals (Akiyama, 1991; Lim and Dominy, 1991; Mukhopadhyay, 2001).

India, being an agricultural country, produces a number of oilseed meals, including soybean meal, groundnut meal, rapeseed meal, and sesame meal. These by-products are not only available in millions of tons annually but also offer an economical and sustainable alternative to fishmeal (USDA, 2021; Rajaram et al., 2023). Numerous studies have evaluated the impact of using various plant protein alternatives to FM such as cottonseed meal in *Hemibagrus wyckioides* (Li et al., 2023), *Procambarus clarkii* (Zhang et al., 2023), soybean meal in *Heteropneustes fossilis* (Howlader et al., 2023), *Dicentrarchus labrax* (Mohommady et al., 2025), groundnut meal in *Oreochromis niloticus* (Zehra et al., 2020), *Oncorhynchus mykiss* (Farooq et al., 2025) and rapeseed meal in *Lutjanus guttatus* (Hernández et al., 2020), *Megalobrama amblycephala* (Zhou et al., 2018), sunflower oil cake in *Oreochromis niloticus* (Hossain et al., 2018), *Cyprinus carpio* (Rahmdel et al., 2018), linseed protein concentrate in *Rhamdia quelen* (Pianesso et al., 2020) and linseed oil cake in *Labeo rohita* (Banerjee et

al., 2023), respectively. Out of all these ingredients, sesame meal is a promising alternative due to its high protein (42-50%) and lipid (11-12%) content. It is also rich in methionine and cysteine, which are often lacking in other plant-based proteins (Mahajan et al., 2025). Its low cost, long shelf life, good storage properties, and widespread availability in India make it a practical choice for inclusion in aquafeeds, especially for species like Indian major carps (Das et al., 2021).

This research explores the nutritional efficacy of sesame meal as a sustainable and locally available alternative to fishmeal in aquafeeds for fingerling *L. rohita*. By integrating sesame meal into aquafeeds, the industry can reduce its dependency on fishmeal in producing cost-effective commercial feeds, making fish farming more sustainable, affordable, and environmentally friendly. This study is a step toward building a more resilient aquaculture feed sector that meets the nutritional needs of a growing population.

2. Materials and Methods

2.1 Diet Formulation and Preparation

Six different isonitrogenous (35% CP), isocaloric (18.0 kJ g⁻¹) and isolipidic (7%) diets were formulated. Dietary ingredients were finely ground and sieved to obtain a uniform particle size. Half of the crude protein was contributed by FM, and the remaining half was contributed by other ingredients in the diet. Fishmeal was substituted with sesame meal at the replacement level of 0% (17.5% CP), 20% (14.0% CP), 40% (10% CP), 60% (7% CP), 80% (3.5% CP), and 100% (0% CP) and the diets were designated as SM0, SM20, SM40, SM60, SM80 and SM100, respectively. The required quantities of each ingredient were weighed using an electronic balance (Precisa 120A, 0.1 mg sensitivity; Oerlikon AG, Zurich, Switzerland) and mixed until a homogenous mixture was obtained. After that, the required amount of

distilled water was added, and the mixture was pressure-cooked for 20 minutes to form a dough. After the cooked mixture was cooled to room temperature, oil was added and mixed for 4 min in a blender (Hobart Corporation, Troy, OH, USA), followed by mixing vitamin and mineral premixes at 40°C. The resulting dough was forced through the extruder on a 2-mm die, and the strands were dried at 40°C to reduce the moisture content to 10%, crumbled, sieved (500 µm) and stored at -4 °C.

2.2 Fish acclimatization and experimental design

Induced-bred rohu fingerlings were sourced from KGF Aquaculture and Fish Hatchery, Aligarh. Prior to stocking, the fish received prophylactic treatment in a KMnO₄ solution (1:3000) and were then placed in circular tanks (600 L capacity; 0.91 m in height and 1.22 m in diameter). Before commencing the feeding trial, fish were acclimated for two weeks on the SM0 feed. The feeding trial was conducted in the wet lab of the Department of Zoology, Aligarh Muslim University, Aligarh.

2.3 Feeding trial

Fingerlings of rohu were randomly distributed into 18 circular polyvinyl tanks (55 L capacity) with three replicates per dietary treatment. The fish were stocked at a rate of 30 fish in tanks fitted with a continuous water flow (1–1.5 L min⁻¹). The experiment was conducted under a 12 h light and 12 h dark cycle. Fish were hand-fed two times daily (09:00 and 17:00 h) to satiety, and unconsumed ration was collected immediately, dried, and weighed to determine feed utilization. Body weight was measured weekly using a precision balance after anaesthetizing fish with MS-222 (100 mg L⁻¹; Sigma, St. Louis, MO, USA). The feeding trial lasted for eight weeks.

2.4 Sample collection and chemical analysis

Before the start of the experiment, 30 fish were randomly collected, sacrificed, segregated into 3 groups containing 10 fish each, pooled, and 6 subsamples (3×6) from each replicate were analysed for initial carcass composition. At the end of the feeding trial, ten fish from the replicates of each dietary group were sacrificed and pooled, and six subsamples (n=3×6) were taken for final carcass composition analysis. The remaining fish in each replicate were measured for length and body weight to estimate the condition factor (CF). The liver and viscera were excised and weighed to calculate the hepatosomatic index (HSI) and viscerosomatic index (VSI).

2.5 Proximate Composition Analysis

The proximate composition of the whole body at the start and end of the trial was evaluated following the procedures described by AOAC (2010). Crude protein (N×6.25) was quantified using an automatic analyser (Kjeltec Tecator TM Technology 2300, Hoganas, Sweden). Moisture content was measured by drying the samples in a hot-air oven at 102±1 °C (Yorko Instruments, New Delhi, India). Lipid content was estimated through solvent extraction method, while ash content was obtained by incinerating the samples in a muffle furnace at 650°C for 12 h. Gross energy was analysed using a ballistic bomb calorimeter.

2.6 Growth assessment

The growth of the fish was measured using the following indices:

Absolute weight gain (g fish⁻¹) = Final body weight (g fish⁻¹) - Initial body weight (g fish⁻¹).

Specific growth rate (SGR% day⁻¹) = (ln final body weight (g) - ln initial body weight (g) / No. of days of the experiment × 100.

Feed conversion ratio (FCR) = Dry feed fed (g) / Wet weight gain (g).

Protein efficiency ratio (PER) = Weight gain (g) / Protein intake (g).

Protein retention efficiency (PRE%) = Protein gain (g) / Protein intake (g) x 100.

Hepatosomatic index (HSI%) = Liver weight (g) / Body weight (g) x 100.

Viscerosomatic Index ratio (VSI) = Viscera weight (g) / Body weight (g) x 100.

Condition factor (CF) = Body weight (g) / Body length (cm)³ × 100.

2.7 Statistical analyses

Data were analysed using one-way ANOVA, with normality and variance homogeneity confirmed via Shapiro–Wilk and Levene’s tests, respectively. Tukey’s HSD test identified significant differences ($P < 0.05$). Broken-line regression was applied to model LWG, SGR, PER and PRE against the replaced level of FM with SM and selected for its superior fit ($R^2 > 0.90$) over linear or quadratic models. All statistical analyses were performed using Origin Software (v10.1.5.32).

3.0 Results

3.1 Growth Performance

Growth parameters of fingerling *L. rohita* fed diets with graded replacement of fishmeal (FM) by sesame meal (SM) are summarised in Table 2. Live weight gain (LWG%), specific growth rate (SGR), protein efficiency ratio (PER), and protein retention efficiency (PRE%) did not differ significantly ($P > 0.05$) up to 40% replacement, while further replacement at 60, 80 and 100% caused a significant reduction ($P < 0.05$). Feed conversion ratio (FCR) remained unaffected up to 40% FM replacement, beyond which it significantly increased ($P < 0.05$). Broken-line analysis of LWG, SGR, PER, and PRE against FM replaced levels indicated optimum

substitution at 39.35%, 40.00%, 40%, and 34.00% respectively (Fig.1, Fig.2, Fig.3 and Fig.4).

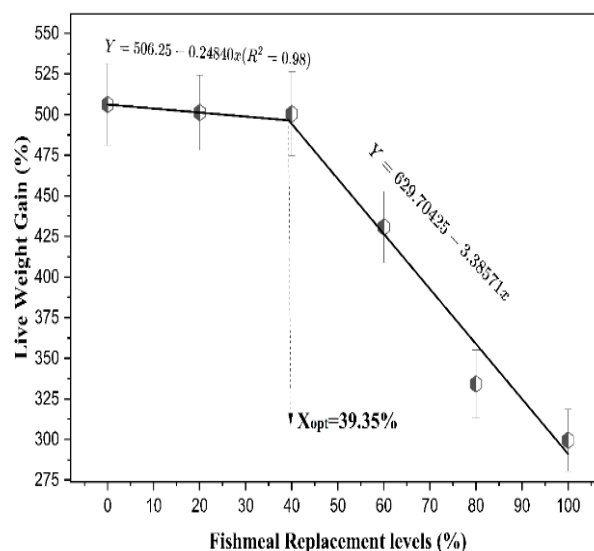


Figure 1: Broken-line relationship of live weight gain to dietary fishmeal replacement levels. Each point represents the mean of three replicates per treatment.

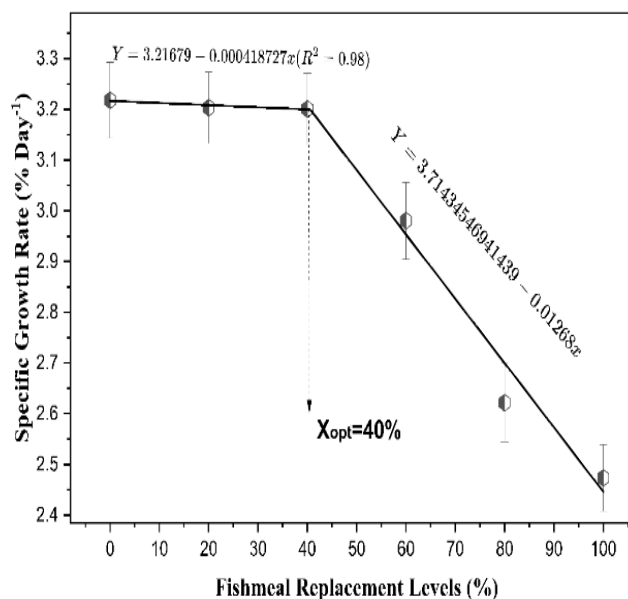


Figure 2: Broken-line relationship of specific growth rate to dietary fishmeal replacement levels. Each point represents the mean of three replicates per treatment.

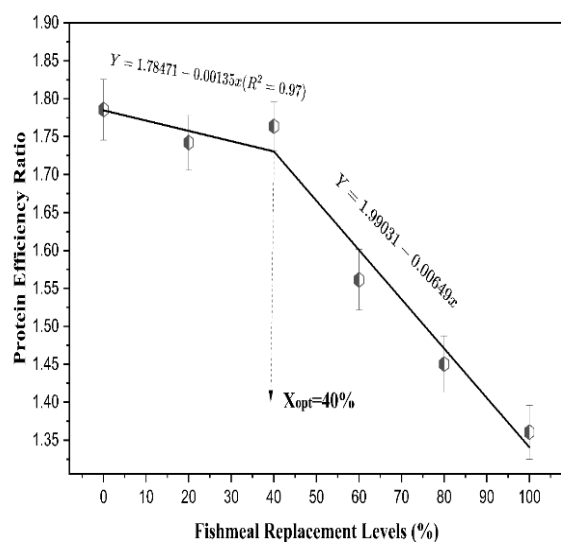


Figure 3: Broken-line relationship of protein efficiency ratio to dietary fishmeal replacement levels. Each point represents the mean of three replicates per treatment.

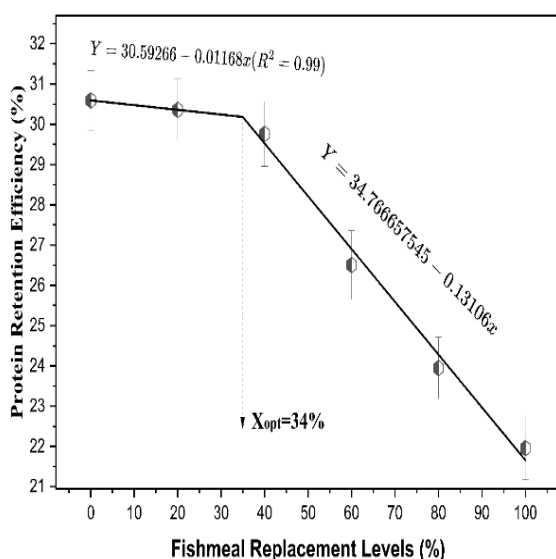


Figure 4: Broken-line relationship of protein retention efficiency to dietary fishmeal replacement levels. Each point represents the mean of three replicates per treatment.

Carcass composition of fish fed experimental diets is presented in Table 3. Whole-body protein and lipid content remained unchanged up to SM40 but declined significantly ($P < 0.05$) at SM60, SM80 and SM100. Carcass ash contents showed no significant differences ($P > 0.05$) in fish fed with all diets. No significant difference ($P > 0.05$) was observed in moisture content till SM40; however significant ($P < 0.05$) increase in moisture content was evident in fish fed with SM60, SM80 and SM100 diets. Somatic indices such as hepatosomatic index (HSI), viscerosomatic index (VSI), and condition factor (CF) did not differ significantly ($P > 0.05$) among all dietary treatments (Table 2).

4. Discussion

The present study evaluated growth performance and carcass composition of *L. rohita* fingerling fed FM-replaced diets with SM. Our results demonstrated that SM could replace up to 40 % of dietary FM protein without adversely affecting growth, feed utilization, or carcass composition. However, replacement beyond this threshold ($\geq 40\%$) progressively impaired growth, protein retention, and lipid deposition.

Growth performance and Feed utilisation

In the current experiment, growth parameters, including live weight gain, specific growth rate, were unaffected up to 40% FM replacement with SM, but declined significantly at higher levels. Similarly, Hasan et al. (1997) and Thu et al. (2011) reported that 50% FM could be replaced with SM in the diets of *Cyprinus carpio* fry and *Oncorhynchus mykiss* without severe depression in growth and survival levels while in rohu, Mukhopadhyay and Ray (1999, 2001) observed that raw sesame seed meal could not replace more than 30% of FM protein, though fermentation increased the safe replacement level to 50%.

3.2 Carcass Composition and Biometric Indices

Table 1 Dietary formulation and proximate composition of the experimental diets (g 100 g⁻¹).

INGREDIENTS (g 100 g⁻¹)	SM0	SM20	SM40	SM60	SM80	SM100
Fishmeal	28.22	22.58	16.93	11.92	5.64	0
Sesame	0	7.77	15.55	23.33	31.11	38.88
Rice Distillers Dried Grain	19.09	19.09	19.09	19.09	19.09	19.09
Mustard oil cake	13.33	13.33	13.33	13.33	13.33	13.33
Wheat middling	20.71	20.71	20.71	20.71	20.71	20.71
Tapioca starch	13.93	12	9.97	8.03	6.30	4.27
Mineral mix	1.5	1.5	1.5	1.5	1.5	1.5
Vitamin mix	2	2	2	2	2	2
Oil premix	1.2	1	0.9	0.7	0.3	0.2
Analysed crude protein	34.92	34.92	34.92	34.91	34.91	34.91
Analysed crude lipid	7.43	7.40	7.46	7.42	7.48	7.44
Gross Energy (kJ g⁻¹)	18.80	18.22	18.27	18.31	18.29	18.35

a Cod liver oil, Universal Medicare Private Limited, Mumbai, India and refined corn oil, Nashiel Chemical Private Limited, Ahmedabad, India. b Mineral mixture (g kg⁻¹): calcium biphosphate 135.7; calcium lactate 326.9; ferric citrate 29.7; magnesium sulphate 132.0; potassium phosphate (dibasic) 239.8; sodium biphosphate 87.2; sodium chloride 43.5; aluminium chloride. 6H₂O 0.154; potassium iodide 0.15; cuprous chloride 0.10; manganous sulphate. H₂O 0.80; cobalt chloride. 6H₂O 1.00; zinc sulphate. 7H₂O 4.0; Loba chemie, India. f Halver (2002). c Vitamin mixture (30 g kg⁻¹ of diet; 10 g vitamin mix +20 g α -cellulose): choline chloride 5.00; inositol 2.00; ascorbic acid 1.00; niacin 0.75; calcium pantothenate 0.5; riboflavin 0.2; menadione 0.04; pyridoxine hydrochloride 0.05; thiamine hydrochloride 0.05; folic acid 0.015; biotin 0.005; alphotocopherol 0.4; vitamin B12 0.0001; Loba chemie, India. d Estimated value of the basal diet on Gallenkamp ballistic bomb calorimeter.

Table 2: Growth performance of fingerling *Labeo rohita* fed diets containing varying replacement levels of fishmeal with sesame meal.

Parameter	SM0	SM20	SM40	SM60	SM80	SM100
Initial body weight/fish (g)	2.4±0.01	2.34±0.08	2.30±0.01	2.37±0.01	2.4±0.03	2.4±0.05
Final body weight/fish (g)	14.55±0.21 ^a	14.07±0.34 ^a	13.68±0.37 ^a	12.2±0.46 ^b	9.59±0.29 ^c	9.17±0.35 ^c
Absolute weight gain (g fish ⁻¹)	12.15±0.53 ^a	11.73±0.45 ^a	11.38±0.32 ^a	9.83±0.29 ^b	7.19±0.31 ^c	6.77±0.36 ^d
Live weight gain (%)	506.25±18 ^a	501.28±23 ^a	494.78±16 ^a	414.76±18 ^b	299.58±17 ^c	282.08±20 ^c
SGR (% day ⁻¹)	3.21±0.05 ^a	3.20±0.07 ^a	3.18±0.04 ^a	2.92±0.05 ^b	2.47±0.06 ^c	2.39±0.05 ^b
FCR	1.60±0.03 ^c	1.64±0.03 ^c	1.62±0.04 ^c	1.83±0.03 ^b	1.97±0.05 ^c	2.1±0.04 ^d
PER	1.78±0.03 ^a	1.74±0.04 ^a	1.76±0.04 ^a	1.56±0.03 ^b	1.45±0.06 ^c	1.36±0.04 ^d
PRE (%)	30.40±0.89 ^a	29.98±0.68 ^a	29.46±0.99 ^a	25.10±0.84 ^b	22.76±1.32 ^c	19.92±0.96 ^d
HSI(%)	2.26±1.21 ^a	2.42±1.33 ^a	2.31±1.39 ^a	2.29±1.84	2.35±1.52 ^a	2.46 ±1.62 ^a
VSI(%)	4.43±0.31 ^a	4.36±0.45 ^a	4.58±0.69 ^a	4.45±0.56 ^a	4.39±0.73 ^a	4.58±0.64 ^a
CF(g cm ³)	1.61±0.04 ^a	1.59±0.09 ^a	1.63±0.12 ^a	1.67±0.08	1.56±0.17 ^a	1.52±0.14 ^a

*Mean values of 3 replicates±SEM; **mean values sharing the different superscripts in the same column are significantly different (P<0.05)

Table 3 Carcass composition (wet basis) of fingerling *Labeo rohita* fed diets containing varying replacement levels of fishmeal with sesame meal.

Parameter (g 100 g ⁻¹)	SM0	SM20	SM40	SM60	SM80	SM100
PROTEIN	16.13±0.05 ^a	16.28±0.13 ^a	15.85±0.07 ^a	15.21±0.11 ^b	14.67±0.09 ^c	13.85±0.15 ^d
ASH	3.33±0.12 ^a	3.47±0.09 ^a	3.26±0.16 ^a	3.31±0.19 ^a	3.52±0.14 ^a	3.68±0.18 ^a
MOISTURE	73.68±0.03 ^a	73.02±0.06 ^a	73.52±0.02 ^a	74.75±0.07 ^b	75.41±0.05 ^c	75.69±0.5 ^d
LIPID	4.64±0.15 ^a	4.57±0.11 ^a	4.72±0.07 ^a	3.85±0.014 ^b	3.42±0.18 ^b	3.29±0.13 ^c

*Mean values of 3 replicates±SEM; **mean values sharing the different superscripts in the same column are significantly different (P<0.05)

The reduction in growth performance at high SM levels can be explained by several nutritional constraints. First, sesame meal is known to be deficient in lysine and threonine (Mukhopadhyay, 2001; Hasan et al., 1997), which restricts protein synthesis when FM is largely replaced. Second, anti-nutritional factors (ANFs), particularly phytic acid and tannins, reduce the digestibility and availability of proteins and minerals (Roy et al., 2014; Banerjee et al., 2023). Phytate binds phosphorus, zinc, calcium, and magnesium, while tannins form indigestible complexes with proteins, both leading to reduced nutrient utilisation. Third, SM has relatively poor palatability compared to FM, and wetted cake can acquire an unpleasant taste that reduces voluntary feed intake (Hasan et al., 1997). The combined effects of amino acid deficiency, ANFs, and reduced palatability may explain the growth depression observed in our study above 40% FM replacement. Feed conversion ratio (FCR) was not affected up to 40% replacement but increased significantly at higher levels, while protein efficiency ratio (PER) and protein retention efficiency (PRE) showed a parallel decline at levels above 40%. These results agree with Hasan et al. (1997), who documented an increase in FCR values as SM inclusion increased from 25% (FCR 2.82) to 75% (FCR 5.77) in *C. carpio* fry. In rohu, Mukhopadhyay and Ray (1999) similarly found reduced nutrient utilization at high sesame meal levels. The impaired feed efficiency may be attributed to ANFs binding proteins and minerals, thereby lowering digestibility (Hossain and Jauncey, 1989; Banerjee et al., 2023), as well as reduced feed intake due to low palatability.

Several studies have shown that processing methods improve SM utilization. Das and Ghosh (2015) reported that fermentation of SM enhanced PER and digestibility in rohu, with optimal performance achieved at 40% inclusion. Likewise, Roy et al. (2014) found that bioprocessed SM improved growth and nutrient utilization

compared with raw meal. The current findings emphasize that SM can replace only 40% of FM in its as-is form. However, improvement in the processing of SM, such as fermentation, inactivation of antinutritional factors, amino acid supplementation, etc, may substantially increase nutritional potential of SM.

Carcass composition and Somatic Indices

The carcass composition of *L. rohita* fingerlings in the present study was affected by replacement of FM with SM. Protein and lipid contents were not significantly changed up to 40% SM but declined significantly at higher replacement levels. Also, moisture content did not change significantly till 40% replacement level, but it increased at levels higher than 40%. This inverse relationship between lipid and moisture at levels high than optimum is well documented in fish and has been reported in rohu fed sesame diets (Mukhopadhyay and Ray, 1999) as well as in tilapia and other species (Alegbeleye et al., 2012; Olude et al., 2016). Banerjee (2023) and Das and Ghosh (2015) also observed decreased carcass protein and lipid in rohu fingerlings at high replacement levels of FM with SM. The observed decline may be due to reduced digestibility and nutrient deposition under conditions of amino acid imbalance and ANF interference.

Carcass composition of *L. rohita* fingerling in this study remained largely unaffected up to an optimal of SM40 and differed beyond, which is consistent with earlier reports on sesame and other oilseed meals (Mukhopadhyay, 2001; Badran et al., 2024). Carcass ash content remained unchanged in fish fed all the diets. This suggests that mineral deposition in the whole body was not drastically altered.

Hepatosomatic index (HSI), viscerosomatic index (VSI), and condition factor (CF) did not differ significantly among treatments, even at 100% FM replacement. Similar findings were reported in Nile tilapia, where the

replacement of FM with SM and cottonseed meal did not affect somatic indices (Badran et al., 2024). Yadav et al. (2025) also showed stable HSI and VSI in rohu fed plant protein meals. The outcomes of this study, along with previous study, suggest that SM can safely replace up to 40% of FM protein in diets of rohu fingerling. Reduced growth and carcass quality in fish fed with higher replacement levels of SM with FM may be due to amino acid imbalance, ANFs, and palatability issues. However, processing methods such as fermentation, soaking, or enzyme supplementation (e.g., phytase) have been shown to reduce ANFs and improve amino acid availability, thereby enabling higher inclusion levels of SM (Mukhopadhyay and Ray, 2001; Das and Ghosh, 2015; Roy et al., 2014). Successful incorporation of SM has been reported in rainbow trout, *O. mykiss*, up to 52% (Nang Thu et al., 2011), 20% (Emadi et al., 2014), and in beluga sturgeon, *Huso huso*, up to 48% (Jahanbakhshi et al., 2013), emphasising species-specific responses and the importance of processing.

5. Conclusion

Considering the abundant production and low cost of sesame meal in India, its partial use in aquafeeds represents a promising strategy to reduce dependence on fishmeal and produce cost-effective, sustainable feeds for the intensive culture of fingerling *L. rohita*. The present findings contribute to defining the optimum replacement level of FM with SM and highlight the need for further work on improving processing, digestibility, inactivating ANF, and amino acid balancing strategies to unlock the full potential of SM in aquaculture feeds.

6. Statements and Declarations

Ethical Approval: All the experimental procedures, including the animal experimentation, were approved by the institutional ethical committee of the Department of

Biochemistry, Aligarh Muslim University, Aligarh, India (registration no: CCSEA/BC/P-11/2024-2025).

Conflict of Interest Declaration: The authors declare that they have no conflict of interest.

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Author Contributions: The second author, Mukhtar Ahmad Khan, provided expert assistance and is a scientific advisor for designing this study. He also contributed to the drafting of the paper. The first author, Shigufta Ali, conducted the feeding trial and substantially contributed to the writing of the manuscript, statistical analysis and interpretation of the data.

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