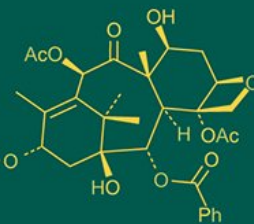
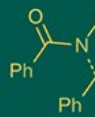
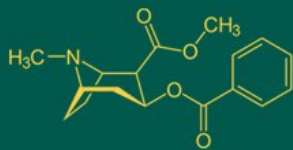


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Evaluation of raw and fermented sesame oil cake on growth performance and nutritional composition of Amur carp (*Cyprinus carpio haematopterus*) fingerlings

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Abstract

A 90-day feeding trial was conducted to evaluate the performance of raw and processed sesame oil cake (SOC) based diets on survival, growth, feed efficiency, nutrient gain and whole-body composition of Amur carp (*Cyprinus carpio haematopterus*) fingerlings. To reduce the ant nutritional factor (phytic acid), various processing methods were tested. Among these 48-hour solid-state fermentation (SSF) method proved to be the most effective, significantly lowering the phytic acid content ($0.534 \pm 0.009\%$ to $0.098 \pm 0.011\%$) and enhancing crude protein content ($33.06 \pm 0.68\%$ to $35.90 \pm 0.06\%$). For the feeding experiment, a total of 210 fingerlings were randomly distributed into seven treatment groups in triplicate FRP tanks (200 L) and fed with iso-nitrogenous and iso-caloric diets: T0 (control), T1–T3 (soybean oil cake, SBOC was replaced with raw SOC at 20%, 40%, 60%) and T4–T6 (SBOC was replaced with SSF SOC at 20%, 40%, 60%, respectively). Significantly higher ($p < 0.05$) carcass crude protein and crude fat content were recorded in the T6 group. Growth performance indicators, including body weight gain ($354.2 \pm 17.8\%$), daily weight gain (0.141 ± 0.002 g/day), and specific growth rate (1.678 ± 0.114), were highest in T6, followed by T5 and T4. Feed utilization parameters such as feed conversion ratio (FCR), protein efficiency ratio (PER), and protein productive value (PPV) were significantly improved in groups fed fermented SOC (T5 and T6) compared to other treatments. The study suggests that replacing 60% of soybean meal with SSF SOC can significantly enhance growth and feed efficiency in Amur carp fingerlings. Without fermentation, the inclusion of raw SOC at 20% soybean meal replacement level also yielded better growth and feed conversion than control and higher raw SOC inclusion levels.

Keywords: Amur carp, sesame oil cake, phytic acid, solid state fermentation

Introduction

With the rising population, the demand for a consistent supply of fish is increasing rapidly, as fish remains one of the most affordable and vital protein sources to combat malnutrition in developing nations (Maulu *et al.*, 2021) ^[21]. Intensive aquaculture, characterized by high stocking densities, relies heavily on formulated feeds, as natural productivity cannot meet the nutritional requirements. Formulating a low-cost, nutritionally balanced diet using agro-based materials is, therefore, essential for sustainable carp farming in India (Das *et al.*, 2016) ^[6]. Traditionally, fish meal has played a dominant role in aqua feed formulations due to its richness in essential amino acids like lysine and methionine, which are deficient in most plant proteins and its efficient energy contribution, since fish poorly utilize carbohydrates (De Silva and Anderson, 1994). However, the rising cost, uncertain availability and fluctuating quality of fish meal have widened the gap between demand and supply of formulated aqua feeds (Ayyappan and Ali, 2007). This necessitates a shift towards alternative, non-conventional plant protein sources to reduce dependency on fish meal and fish oil (Naylor *et al.*, 2000) ^[25]. One promising approach is the recycling of nutrients from underutilized agro-industrial by-products such as oilseed cakes, which offer eco-friendly and cost-effective alternatives. Sesame (*Sesamum indicum*), cultivated mainly for its oil (Lee *et al.*, 2010) ^[20], yields sesame oil cake (SOC) as a protein-rich by-product after oil extraction. SOC contains about 29% crude protein (Nandeesh, 1993) ^[23] and has been identified as a potential feed ingredient for livestock and fish (Guo *et al.*, 2011) ^[15]. Additionally, sesame

seeds are rich in essential and sulphur amino acids (Hahm, 2009) [16] essential fatty acids like linoleic and linolenic acid (Nzikou, 2009) [26] and vital micronutrients such as vitamins A, D, E, K and minerals including copper, magnesium, zinc, calcium, iron, and phosphorus (FAO, 2012) [10]. However, its broader use in aquafeeds is limited due to anti-nutritional factors like phytic acid and protease inhibitors (Francis, 2001) [11]. Phytic acid or myo-inositol hexakisphosphate, binds with mineral cations (Na, K, Mg, Ca, Zn, Fe, Cu, Mn, P), forming phytates that reduce nutrient bioavailability and digestibility by forming insoluble complexes with proteins and amino acids (Kumar *et al.*, 2011) [18]. As fish lack the enzyme phytase (Pointillart *et al.*, 1987) [28], they cannot digest phytates, leading to mineral excretion and contributing to environmental eutrophication (Persson, 1991) [27]. Therefore, reducing phytic acid is critical for improving SOC's nutritional value. Several processing techniques such as soaking, cooking, and fermentation have been shown to reduce phytic acid content (Hurrell *et al.*, 2004) [17], with solid-state fermentation using beneficial microbes emerging as one of the most effective and sustainable methods (Wang *et al.*, 2018) [32].

Amur carp (*Cyprinus carpio haematopterus*), a genetically improved strain of common carp, is gaining popularity due to its superior growth rate (approximately 27%), delayed sexual maturity, adaptability to supplementary feeding and resilience to adverse environmental conditions (Pavadi *et al.*, 2025) [29]. These traits make it a promising candidate for replacing species like mrigal and traditional common carp in composite fish farming systems. Despite the nutritional potential of sesame oil cake (SOC) as an alternative plant protein source, its application in aquafeeds remains limited due to the presence of anti-nutritional factors, particularly phytic acid. Although various processing methods have been explored to enhance the nutritive value of plant-based feed ingredients, there is limited research on the effect of raw and processed SOC, especially fermented forms, on the performance of Amur carp. Therefore, this study was undertaken to evaluate the efficacy of dietary supplementation of raw and solid-state fermented SOC on the growth performance, carcass composition, and survivability of Amur carp fingerlings thereby addressing a crucial knowledge gap in optimizing cost-effective and sustainable feed formulations for improved aquaculture productivity.

2. Materials and Methods

2.1 Processing of feed ingredients and diets preparation

2.1.1 Procurement of feed ingredients

Various conventional ingredients such as Soybean oil cake (SBOC), mustard oil cake, de-oiled rice bran and wheat flour were procured from the local market and were oven-dried (100 ± 5 °C) properly to remove moisture content followed by grinding to get their powder form. The fish meal was prepared in the Fish Nutrition Laboratory, College of Fisheries, Rangailunda, Berhanpur, India in dry rendering method following standard protocol (Gopakumar, 1997) [14]. Proximate composition of the conventional feed ingredients were analyzed following standard protocol (AOAC, 2005) [1]. The vitamin and mineral mixture (M/s Virbac Animal Health India Pvt. Ltd, Mumbai, India) procured from local market. The non-conventional experimental oil cake SOC was brought from local market, oven-dried for overnight (100 ± 5 °C), powdered and processed for solid state

fermentation method as described below. The phytic acid contents of raw, autoclaved, water soaked and solid-state fermented SOC was analyzed (Wheeler and Ferrel, 1971) [33]. Similarly, the proximate compositions of raw, autoclaved, water soaked and solid-state fermented SOC were also analyzed following the standard protocol (AOAC, 2005) [1].

2.1.2 Processing of soc

2.1.2.1 Water soaking

Raw sesame oil cake was kept in a plastic container and then clean water was added in sufficient quantity so that the cake completely remains soaked in water. Soaked sesame oil cake sample were collected at different time interval i.e. 6hr, 12hr, 18hr, and 24hr and then, kept in an oven at 60 ± 5 °C for drying. The samples were dried up to constant moisture level and then packed in air-tight plastic containers for proximate and phytic acid analysis.

2.1.2.2 Autoclaving

Raw sesame oil cake was autoclaved at 15 psi pressure and 121°C for 15-20 min. The sample was then kept in an oven at 60 ± 5 °C for drying. The samples were dried up to constant moisture level and then packed in air-tight plastic containers, for proximate and phytic acid analysis.

2.1.2.3 Solid state fermentation (ssf)

A commercially available feed probiotic in powder form, namely, Aqualact™ (M/s Biostadt India Ltd., Mumbai) was used as the convenient source of microbes for this fermentation. The substrates for SSF were prepared by mixing 5.0 kg of finely sieved (through 400-micron mesh) oil cakes with 3 L of tap water and made dough. The dough was placed in a stainless-steel vessel and autoclaved at 15 psi pressure for 15 min followed by cooling down to lukewarm temperature (approximately to 37°C). During autoclaving microbial suspension was prepared by taking approximately 800 ml of Aquaguard RO filtered tap water in a 1 L capacity beaker and about 25g of probiotic powder and 125 g of jaggery (1:5 parts) were added to it. It was then stirred thoroughly with a clean and dry glass rod for 5 min for proper mixing. Then it was allowed to stand for another 5 min to allow the fibres to settle down. The supernatant was poured out slowly to another beaker and added to the oil cake substrate prepared as above and mixed properly with a stainless-steel spatula. After this the mixture was allowed to undergo the fermentation process in an open fermentation chamber that is a plastic tray with the top covered with mosquito net, maintained at ambient temperature of 27-30 °C with periodical stirring once in about 12 h. Approximately 200 g fermented oil cake each was sampled out after 12 h, 24 h, 36 h and 48 h of fermentation for analysis.

2.1.3 Feed preparation

Seven iso-nitrogenous (crude protein 30%) and iso-caloric (395 kcal/100 g feed) pelleted diets were formulated by adding different ingredients as per the proximate composition of feedstuffs given in Tables 1 and 2 by replacing 20%, 40% and 60% of SBOC protein with either raw or processed SOC protein. Accordingly, the different experimental diets were T₀: control diet without SOC; T₁: 20% SBOC replaced with raw SOC; T₂: 40% SBOC replaced with raw SOC; T₃: 60% SBOC replaced with raw

SOC; T₄: 20% SBOC replaced with 48 hr SSF SOC; T₅: 40% SBOC replaced with 48 hr SSF SOC; T₆: 60% SBOC replaced with 48 hr SSF SOC (Table 3). Sinking pelleted feeds (1 mm dia) were then prepared in the laboratory following methods described by Pawar *et al* (2021) and stored in air tight containers for feeding the experimental fishes. The proximate composition of the feed was estimated (AOAC, 2005) [1].

2.2 Experimental set-up

The experiment was carried out in 21 FRP tanks of 200 L capacity each. Two hundred and ten fishes of uniform size (average initial weight of 3.51±0.13 g) were randomly distributed into seven experimental groups (named as T₀, T₁, T₂, T₃, T₄, T₅ and T₆) in triplicates following a completely randomized design with 10 fish per tank. The fishes were subjected to 90 days of feeding trial under the provision of continuous aeration for 24 h except the period of feeding (2 h). Initially fishes were fed @ 5% of the total biomass in two equal split dosages (10.00 hours and 16.00 hours) and subsequently feeding was adjusted according to the level of consumption. About 25% water from each experimental tank was siphoned out daily (2 h after the feed given) to remove the uneaten food and faecal matter separately followed by refilling of same amount of clean and seasoned bore well water. The siphoned water containing the leftover feed was passed through a strainer and dried to find out actual quantity of feed consumed by the experimental fishes. Batch weighing of fish was done in every 15 days interval to check the survival and growth of the experimental animals and to adjust the feeding ration accordingly. After completion of 90 days feeding trial, the DWG, PWG, SGR, FCR, PER, PPV, FI and carcass whole body composition of the fingerlings were estimated by using the formulae as given below:

$$\text{Daily weight gain (g) (DWG)} = \frac{\text{Final weight of fish(g)} - \text{Initial weight of fish(g)}}{\text{Total no. of experimental days}}$$

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

$$\text{Specific growth rate (SGR)} = \frac{\ln(\text{Final body weight}) - \ln(\text{Initial body weight})}{\text{Duration of the experiment (days)}} \times 100$$

$$\text{Feed conversion ratio (FCR)} = \frac{\text{Total dry food intake(g)}}{\text{Total live weight gain(g)}}$$

$$\text{Protein efficiency ratio (FER)} = \frac{\text{Total live weight gain (g)}}{\text{Total protein intake (g)}}$$

$$\text{Protein Productive Value (PPV)} = \frac{(\text{FW} \times \text{FP}) - (\text{IW} \times \text{IP})}{\text{P}} \times 100$$

Where, FW: Final weight of fish

IW: Initial weight of fish

FP: Final carcass protein% wet weight

IP: Initial carcass protein% wet weight

P: Protein fed (dry weight)

$$\text{Feed intake ratio (FI)} = \frac{\text{Feed consumption (g)}}{\text{Average final weight (g)} \times \text{Number of experimental days}} \times 100$$

2.3 Analysis of digestive enzymes

At the end of the experiment, the intestinal tissues of Amur carp were taken for digestive enzyme analysis after randomly sampling three fishes from each tank. The intestinal tissue was removed, pooled and kept at -80 °C

until the enzyme activity was analysed. Using and pestle, frozen pooled intestinal sample were hygienically ground in liquid nitrogen. A 5% crude enzyme extract was prepared using chilled 0.25 M sucrose (W/V). After centrifugation of homogenised tissue at 10000 g for 15 min at 4 °C, the supernatant was collected stored at -20 °C until use. The amylase, protease and lipase activity was assayed following Rick and Stegbauer (1974) [30], Moore and Stein (1948) and Bier (1955) [3] respectively. The enzyme activities were reported for amylase as micromoles of maltose produced min⁻¹g protein⁻¹ at 37 °C, for protease as µg of glycine released min⁻¹g protein⁻¹ and for lipase as µmole of free fatty acids liberated ml⁻¹ of enzyme extract min⁻¹.

2.4 Water quality parameters

The various physico-chemical parameters of water such as temperature, total alkalinity, free CO₂, DO₂ and hardness were analysed at 15 days interval following standard methods (Boyd *et al.*, 1992) [4].

2.5 Statistical analysis

The data were statistically analysed by statistical package SPSS version 20.0, in which data were subjected to one way ANOVA and Duncan's Multiple Range Test to determine the significance differences between mean values (*p*<0.05).

3. Results

3.1 Water quality

Throughout the trial, water conditions like temperature, alkalinity, dissolved oxygen, free CO₂, and hardness stayed within the ideal range for warm-water fish (Boyd and Tucker, 1992) [4] (Table 4).

3.2 Phytic acid and nutrient content in soc

The treatments viz., water soaking, autoclaving and especially solid-state fermentation (SSF) significantly reduced (*p*<0.05) phytic acid in raw sesame oil cake (SOC) (Table 5). The major reduction came after 48 hours of fermentation, bringing phytic acid down to just 0.098±0.011%. Fermentation also boosted crude protein levels i.e., 48-hour SSF resulted in the highest protein content (35.90±0.06%) compared to raw SOC (33.06±0.68%) (Table 2). In the other hand, water soaking and autoclaving didn't have much effect on protein content?

3.3 Fish whole body composition

At the end of the experiment, fish in the T₆ group had the highest crude protein levels in their bodies (69.63±0.39%), closely followed by those in T₅ (68.88±0.37%). Ether extract (fat) levels also followed a similar pattern. The highest ash content appeared in T₅ (9.32±0.82%), while T₃ had the lowest (7.7±0.85%) (Table 6).

3.4 Growth performance

At the end of the feeding trial of 90days, the survival was 100% in all groups. Fish that were fed fermented SOC diets gained more weight and grew faster than those on the control or raw SOC diets (Table 7). T₆ outperformed all others in every growth measure (Fig. 1).

3.5 Feed Efficiency

The T₆ group also had the most efficient feed usage, with the lowest feed conversion ratio (FCR) at 1.47±0.03. Protein efficiency ratio (PER) and protein productive value (PPV)

were also highest with fermented SOC diets. Interestingly, T3 had the highest feed intake ratio (1.891 ± 0.031), while T6 had the lowest (1.268 ± 0.038).

3.6 Digestive enzyme activity

Intestinal enzyme activities like amylase, protease and lipase were analysed for both treatment and control groups. All the enzyme activities were significantly ($p < 0.05$) varied with supplementation of fermented feed at the end of the experiment and is presented in (Table 8). Significantly higher ($p < 0.05$) amylase activity was seen in T₅ (16.41 ± 1.13) and T₆ (16.94 ± 0.78) groups whereas significantly higher ($p < 0.05$) protease and lipase activity (8.234 ± 1.13 and 18.71 ± 1.14 respectively) was seen in T₆ group.

4. Discussion

With the rising cost and demand for soybean meal in aquaculture, there's a clear need for alternative protein sources. Sesame oil cake (SOC) offers potential, but its use is limited by anti-nutritional factors especially phytic acid. Our findings show that solid-state fermentation (SSF) is highly effective at reducing phytic acid, in agreement with our earlier studies (Das and Ghosh, 2015) [5, 12]. Fermentation not only reduced phytic acid but also boosted protein levels, likely due to microbial protein synthesis, as noted by Roy *et al.* (2014) [31]. Unlike fermentation, water soaking and autoclaving didn't significantly change protein content, supporting previous results from Hurrell (2004) [17]. Fish fed fermented SOC diets showed better whole-body protein and fat levels, suggesting improved nutrient absorption. This makes sense, given that fermentation reduces phytates, which otherwise bind essential nutrients and limit their availability (Debnath *et al.*, 2005a, b) [8, 9]. Growth indices like weight gain and specific growth rate were significantly better in fish fed fermented SOC, matching trends seen in earlier studies (Nayak *et al.*, 2017) [24]. These improvements likely come from better nutrient availability and digestion after fermentation. Feed performance indicators like FCR, PER, and PPV were strongest in the fermented SOC groups. Interestingly, our Results differed slightly from Roy *et al.*

(2014) [31], who Raw SOC diets consistently underperformed. In our study, Raw SOC in T1 showed a slight improvement over the control. We also noticed that fish fed higher amounts of raw SOC (especially in T3) consumed more feed, which could SOC ate less but grew better, indicating better feed performance. The fact that all fish survived across treatments implies that both raw and fermented SOC are safe to use in diets for Amur carp. Overall, from this study We observed that 48-hour fermented SOC can replace up to 60% of soybean meal without sacrificing fish growth and nutrient utilization.

According to (Kuzmina, 1991) [19] the digestive enzymes of the GI tract may indicate adaptation to the dietary composition in fish and he found that inclusion of raw SOC in the diets led to a notable decrease in the activities of protease, amylase, and lipase in the GI tract of *L. rohita*. The current study aligns with these findings, where the reduction in the digestive enzyme activities was observed in the experimental groups fed with raw SOC, indicating that the enzymes could be highly vulnerable to plant-based ANFs (Kumar *et al.*, 2011; Ghosh and Mandal, 2015) [12, 18]. The gradual decrease in enzyme activity as the increased level of incorporation of raw SOC in the diets may be associated with the endogenous ANFs present in the oil cakes, such as tannins, phytic acid, and trypsin inhibitors (Ghosh *et al.*, 2019) [13]. However, treating the SOC by solid-state fermentation might decrease ANFs and enhance the digestive enzyme (protease, lipase and amylase) activities. In our study we observed significantly ($p < 0.05$) higher level of digestive enzymes with increased level of fermented SOC in the diets. This is in accordance with the findings of Banarjee *et al.* (2023), where they observed significantly higher digestive enzyme activities in GI tract of *L. rohita* fed with fermented LOC as compared to initial and raw LOC fed groups. In our study, the experimental groups fed bioprocessed SOC (T5 and T6) showed significantly higher digestive enzyme activities suggest more efficient absorption of the nutrients. This can be confirmed by the fact that these groups (T5 and T6) showed significantly higher growth as compared to other groups.

Table 1: Proximate composition of feed ingredients and experimental diets (%dry matter basis)

Ingredients	Moisture	Crude protein	Total carbohydrate	Ether extract	Total ash	Digestible energy (Kcal/ 100g)
Fish meal	5.59± 0.07	63.5± 1.12	9.33± 0.32	9.63± 0.75	17.54± 0.35	-
SBOC	6.35± 0.12	48.6± 0.98	42.12±0.56	1.74± 1.14	7.54± 0.47	-
Mustard oil cake	5.98± 0.42	34.33± 0.23	53.95± 0.08	6.14± 0.07	5.58± 0.52	-
De-oil rice bran	9.84± 0.45	17.40± 0.56	68.77± 0.47	1.05± 0.25	12.78± 0.08	-
Wheat flour	11.9± 0.09	14.5±0.28	76.2±0.007	3.7±0.36	5.6±0.24	-
Experimental diets						
T ₀	5.19±0.58	31.31±0.02	48.99±0.23	8.25±1.15	9.95±0.01	395.45±0.14
T ₁	3.96±1.12	29.54±0.04	47.34±0.58	10.24±0.57	12.88±0.66	399.68±0.69
T ₂	5.56±0.03	30.66±0.05	46.68±1.12	9.65±1.02	12.21±1.41	396.21±0.57
T ₃	5.87±0.13	30.89±0.03	46.81±0.65	9.42±0.73	12.88±0.89	395.58±0.56
T ₄	3.64±0.25	29.92±0.04	50.22±0.24	8.36±1.39	10.01±0.82	395.80±1.20
T ₅	4.87±1.00	31.10±0.02	47.00±0.87	8.75±1.72	11.55±0.98	391.15±0.87
T ₆	4.04±0.53	30.35±0.02	47.11±1.05	9.28± 0.41	13.26±1.34	393.36±1.41

Table 2: Proximate composition of raw and processed sesame oil cake (SOC) (%dry matter basis)

Ingredients	Moisture	Crude protein	Total carbohydrate	Ether extract	Total ash
Raw SOC	3.89± 0.13	33.06 ^a ± 0.68	43.68± 0.01	9.11± 0.48	14.15± 0.27
Water soaked SOC (6hrs)	3.54± 0.25	34.65 ^{ab} ± 0.54	42.51±0.25	8.56± 0.25	14.28± 0.65
Water soaked SOC (12hrs)	2.41± 0.32	34.69 ^{ab} ± 1.18	43.86± 0.68	7.87± 0.89	13.58± 0.28
Water soaked SOC (18 hrs)	2.45± 0.34	33.58 ^{ab} ± 0.87	41.90± 0.75	9.58± 0.75	14.94± 0.49
Water soaked SOC (24 hrs)	2.89± 0.56	35.16 ^{ab} ± 0.23	41.95± 0.65	9.85± 0.14	13.04± 1.25
Autoclaved SOC	4.25± 0.09	33.32 ^{ab} ± 0.78	44.25± 0.28	8.54± 0.62	13.89± 0.35
Fermented SOC (12 hrs)	3.25± 0.15	33.69 ^{ab} ± 0.69	44.55± 0.27	7.58± 0.01	14.18± 0.68
Fermented SOC (24 hrs)	3.85± 0.28	33.98 ^{ab} ± 0.58	42.46± 0.49	8.78± 0.06	14.78± 0.22
Fermented SOC (36 hrs)	2.94± 0.36	34.8 ^{ab} ± 1.15	41.36± 0.58	9.25± 0.85	14.59± 0.35
Fermented SOC (48 hrs)	3.28± 0.46	35.90 ^a ± 0.06	39.38± 0.25	9.85± 0.94	14.87± 0.97

Values sharing common superscript in a column did not differ significantly ($p>0.05$)

Table 3: Percentage composition of different ingredients in the experimental diet

Ingredients	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆
Fish meal	5	5	5	5	5	5	5
Soybean meal	32	26	19	12	26	19	13
Mustard oil cake	17	17	17	17	17	17	17
De-oiled rice bran	30	26	21	17	27	24	20
Wheat flour	10	10	10	10	10	10	10
Raw SOC	-	10	22	33	-	-	-
Processed SOC	-	-	-	-	9	19	29
Oil	4	4	4	4	4	4	4
Vit-Min Mixture	2	2	2	2	2	2	2

Table 4: Average water quality parameters of water during the experimental period

Parameters	T ₀	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆
Temperature (°C)	23.4-27.8	22.9-27.2	23.5-28.9	24.6-27.5	22.4-27.4	24.5-28.3	24.8-28.7
pH	7.8-8.1	7.7-8.3	7.2-8.1	7.4-8.3	7.9-8.5	7.8-8.3	8.2-8.5
DO ₂ (mgL ⁻¹)	5.7-7.2	5.5-8.1	5.9-7.2	6.1-7.9	5.8-7.5	5.6-8.2	7.3-7.9
Free CO ₂ (mgL ⁻¹)	ND	ND	ND	ND	ND	ND	ND
Total alkalinity (mgL ⁻¹)	126-142	123-140	136-145	122-136	125-138	123-142	138-146
Hardness (mgL ⁻¹)	227-240	223-242	238-245	224-237	231-245	233-247	225-242

Table 5: Phytic acid content (%) of raw and processed sesame oil cake (SOC)

	Phytic acid%
Raw SOC	0.534 ^a ±0.009
Autoclaved SOC	0.314 ^c ±0.008
Water soaked SOC (6hr)	0.528 ^a ±0.011
Water soaked SOC (12hr)	0.384 ^b ±0.008
Water soaked SOC (18hr)	0.374 ^b ±0.006
Water soaked SOC (24hr)	0.218 ^d ±0.011
Solid state fermented SOC (12hr)	0.518 ^a ±0.011
Solid state fermented SOC (24hr)	0.293 ^c ±0.011
Solid state fermented SOC (36hr)	0.173 ^e ±0.018
Solid state fermented SOC (48hr)	0.098 ^f ±0.011

Values sharing common superscript did not differ significantly ($p>0.05$)

Table 5A. Composition of Aqualact,

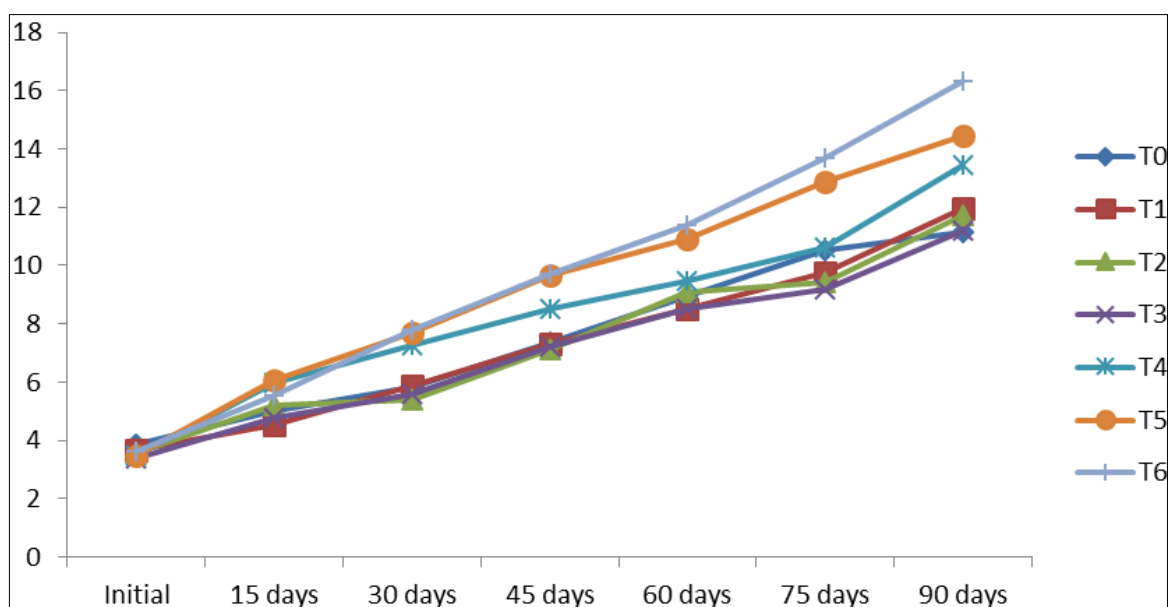
Name of the ingredients	Quantity per Kg.
<i>Bacillus coagulans</i>	45000 million cfu
<i>Lactobacillus acidophilus</i>	45000 million cfu
<i>Lactobacillus lacto</i>	30000 million cfu
<i>Bacillus licheniformes</i>	30000 million cfu
<i>Saccharomyces cerevisiae</i>	125000 million cfu
Sea weed extract	100 g
Enzyme complex contains	
1. Amylase	1. 24000 IU
2. Phytase	2. 11000 IU
3. Protease	3. 200000 IU
4. Cellulose	4. 150-250 IU
5. Beta- galactosidase	5. 800-1000 IU
6. Lipase	6. 50-100 IU

Coated Vitamin C	20 g
Vitamin B1	1 g
Vitamin B6	1 g
Sodium Benzoate	6 g

Table 6: Initial and final biochemical composition of Amur carp fingerlings (%dry matter basis)

Treatments	Moisture	Crude Protein	Ether extract	Total carbohydrate	Total Ash
Initial	73.86±1.22	67.49±0.79	8.25 ^b ±0.73	15.21± 0.54	9.05 ^a ±1.06
T ₀	73.08±0.94	67.55 ^c ±0.28	8.78 ^b ±0.16	13.72±0.34	8.95 ^a ±1.20
T ₁	72.67±1.22	67.58 ^c ±0.47	8.25 ^b ±0.27	15.56±0.57	8.61 ^a ±1.15
T ₂	72.46±1.56	65.31 ^d ±0.25	7.35 ^c ±1.17	18.71 ±0.25	8.63 ^a ±0.85
T ₃	72.45±0.75	64.46 ^e ±0.17	5.67 ^d ±0.05	22.17±1.02	7.7 ^b ±0.85
T ₄	72.97±1.19	67.95 ^c ±0.11	8.87 ^b ±0.47	14.29±0.45	8.89 ^a ± 0.85
T ₅	72.80±1.14	68.88 ^b ±0.37	10.58 ^a ±1.05	11.22± 0.15	9.32 ^a ±0.82
T ₆	74.86±1.22	69.63 ^a ±0.39	10.21 ^a ±0.84	11.01±0.89	9.15 ^a ±1.06

Mean values sharing a common superscript in a column did not differ significantly ($p>0.05$)

**Fig-1:** Body weight gain of Amur carp fingerlings at 15-day interval**Table 7:** Growth performance of fish fed with different experimental diets

Treatment	Initial Weight	Final Weight	Initial Length	Final Length	PWG*	DWG*	SGR*	FCR*	PER*	PPV*	FI*
T ₀	3.87±0.12	11.17±0.10	6.69±0.29	12.64±0.10	204.3 ^c ±83	0.088 ^e ±0.001	1.236 ^c ±0.030	2.39 ^a ±0.04	1.337 ^e ±0.024	24.655 ^f ±0.438	1.782 ^{bc} ±0.026
T ₁	3.66±0.20	11.98±0.11	6.53±0.17	12.67±0.44	227.9 ^c ±19.5	0.092 ^d ±0.003	1.318 ^c ±0.066	2.27 ^b ±0.08	1.494 ^d ±0.053	28.123 ^d ±0.957	1.751 ^c ±0.020
T ₂	3.57±0.11	11.70±0.17	6.51±0.16	13.09±0.12	227.6 ^c ±14.8	0.090 ^{de} ±0.003	1.318 ^c ±0.049	2.34 ^{ab} ±0.09	1.398 ^e ±0.057	27.004 ^{de} ±1.200	1.805 ^b ±0.039
T ₃	3.39±0.18	11.18±0.19	6.27±0.16	13.24±0.14	230.0 ^c ±18.7	0.086 ^e ±0.003	1.325 ^c ±0.063	2.45 ^a ±0.09	1.329 ^e ±0.047	25.759 ^{ef} ±0.868	1.891 ^a ±0.031
T ₄	3.48±0.16	13.43±0.20	6.37±0.26	13.82±0.15	286.2 ^b ±12.4	0.111 ^c ±0.001	1.501 ^b ±0.036	1.90 ^c ±0.01	1.756 ^c ±0.009	32.683 ^c ±0.191	1.568 ^d ±0.026
T ₅	3.47±0.45	14.47±0.20	6.43±0.29	14.52±0.25	319.6 ^{ab} ±9.2	0.122 ^b ±0.004	1.590 ^{ab} ±0.107	1.72 ^d ±0.05	1.866 ^b ±0.052	34.933 ^b ±0.924	1.455 ^e ±0.013
T ₆	3.63±0.45	16.33±0.48	6.73±0.52	15.39±0.16	354.2 ^a ±17.8	0.141 ^a ±0.002	1.678 ^a ±0.114	1.47 ^e ±0.03	2.252 ^a ±0.044	41.775 ^a ±0.806	1.268 ^f ±0.008

* NB: PWG= Percentage weight gain; DWG= Daily weight gain; SGR = Specific growth rate; FCR = Food

Table 8: Digestive enzyme activity of Amur carp fingerlings fed with different experimental diets at the end of the experiment

Treatments	Amylase ($\mu\text{g/min/gm of protein}$)	Protease ($\mu\text{g/min/gm of protein}$)	Lipase ($\mu\text{ mole/ min/ ml of enzyme extract}$)
T ₀	13.35 ^c ±1.23	4.25 ^c ±0.23	12.55 ^{cd} ±1.23
T ₁	14.05 ^{bc} ±0.85	3.85 ^d ±1.22	13.15 ^c ±0.27
T ₂	12.80 ^c ±1.02	4.01 ^c ±0.94	13.80 ^c ±1.45
T ₃	13.35 ^c ±0.67	3.62 ^d ±1.02	13.68 ^c ±0.60
T ₄	15.23 ^b ±0.82	6.21 ^b ±1.54	17.20 ^b ±0.22
T ₅	16.41 ^a ±1.13	6.97 ^b ±0.45	17.41 ^b ±1.33
T ₆	16.94 ^a ±0.78	8.23 ^a ±1.13	18.71 ^a ±1.14

Mean values sharing a common superscript in a column did not differ significantly ($p>0.05$)

4. Conclusion

The present investigation revealed that, incorporation of non-conventional feed ingredients like SOC after 48 h solid state fermentation showed significantly better growth performance, feed efficiency, digestive enzyme activities as well as nutrient (protein) retention in Amur carp fingerlings. Though fermented SOC proved to be more effective than raw SOC in replacing the soybean meal, the 20% inclusion level of raw SOC also resulted enhanced growth than control and the experimental groups fed with higher inclusion levels (40 and 60%) of raw SOC. Hence, 48 h solid state fermented SOC (Sesame oil cake) is a promising alternative protein source to partially replace the traditionally used expensive SBOC (Soybean oil cake) for formulating the cost-effective diet of Amur carp.

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