

Original Research Articles

Dietary Medium-Chain Triglycerides (MCTs) enhanced growth performance of nursery-reared milkfish *Chanos chanos* (Forsskål, 1775)

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Lipid quality plays a pivotal role in early milkfish nutrition, yet the potential of medium-chain triglycerides (MCTs) as productivity-enhancing lipid sources remains insufficiently characterized in milkfish aquaculture. The study evaluated the effects of dietary MCTs on growth performance, feed efficiency, nutrient retention, and carcass composition of juvenile *Chanos chanos*. An 8-week feeding trial was conducted using diets supplemented with 0%, 3%, 4%, and 5% MCTs in a flow-through seawater system. Growth parameters, feed conversion efficiency (FCE), protein efficiency ratio (PER), survival, carcass composition, and nutrient retention were assessed at the end of the trial. MCT supplementation significantly influenced fish performance. The highest weight gain (1217.7%) and specific growth rate (4.1) were observed in the 5% MCT group, while 3% and 4% inclusion improved protein retention (8.95%, 6.79%) and carcass crude protein content (84.45%, 83.60%). FCE and PER were also enhanced at 4-5% inclusion. However, excessive supplementation (5%) led to elevated lipid retention (43.35%) and body fat deposition, accompanied by reduced protein retention (2.77%). Survival (61-70%) did not differ significantly among treatments, indicating good tolerance. Overall, the results of this study indicate that dietary MCTs can be incorporated as functional lipid sources in milkfish diets, with a 4% inclusion level providing improvements in growth, feed efficiency, and protein utilization while limiting excessive fat deposition, thereby supporting enhanced juvenile milkfish production.

INTRODUCTION

The intensification of aquaculture has underscored the need for nutritionally optimized and cost-effective feeds, particularly during early developmental stages when nutrient demands are high. Among macronutrients, protein remains the most expensive component in aquafeeds, making its efficient utilization critical to both economic and biological sustainability.¹ In response, researchers have explored functional lipid alternatives that can provide metabolic energy, enhance feed efficiency, and spare dietary protein from catabolic use. One such promising group is the medium-chain triglycerides (MCTs), a class of saturated fatty acids composed of 6-12 carbon atoms. Unlike long-chain triglycerides (LCTs), MCTs are rapidly hydrolyzed, absorbed through the portal vein, and oxidized in the liver,

thereby providing immediate energy without accumulating in tissue.^{2,3} This rapid metabolism is believed to produce a protein-sparing effect, improving nitrogen retention and feed conversion ratios.⁴ However, the accelerated oxidation of dietary lipids may also reduce metabolizable energy and limit the availability of essential fatty acids, potentially compromising energy retention and redirecting metabolic resources from growth toward oxidative stress responses. Consequently, maintaining oxidative stability through careful feed formulation and lipid management is critical to ensure efficient energy utilization and optimal growth performance in aquaculture species.^{5,6}

In both terrestrial and aquatic nutrition studies, MCT supplementation has continued to demonstrate beneficial outcomes, including enhanced nutrient digestibility, improved nitrogen retention, and modulation of gut health.

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Recent findings highlight that MCTs can improve protein utilization and starch digestibility, thereby supporting growth performance and feed efficiency in aquaculture species.⁷ However, consistent with earlier observations, rapid oxidation of MCTs may compromise energy retention and reduce the availability of essential fatty acids, underscoring the need for balanced dietary formulations.⁸ Beyond their role in energy metabolism, MCTs have also been shown to enhance intestinal nutrient absorption and transport, contributing to improved bioavailability of dietary components and supporting immune and metabolic resilience in aquatic animals.⁷ Collectively, these recent studies reinforce the dual nature of MCT supplementation, providing immediate metabolic energy and functional benefits, while requiring careful management to avoid trade-offs in long-term energy retention and lipid balance.

Despite the recognized importance of lipid quality in larval and juvenile fish nutrition, the potential of MCTs as functional lipid additives remains largely unexplored in tropical aquaculture species. This gap is particularly evident in *Chanos chanos*, one of the most widely farmed marine finfish in Southeast Asia, where fry in the nursery phase are highly vulnerable to nutritional deficiencies, stress, and mortality often linked to suboptimal feed formulations. To address this gap, the major objective of this study is to evaluate the effects of dietary MCT inclusion on growth performance, feed utilization, and health indicators in nursery-reared milkfish fry. It is hypothesized that dietary supplementation with MCTs will significantly enhance growth performance, feed conversion efficiency, and nutrient utilization compared to conventional lipid sources, thereby offering a potential nutritional strategy to optimize early-stage milkfish production.

MATERIALS AND METHODS

FISH AND FACILITIES

The feeding trial was conducted at the University of the Philippines Visayas Multi-Purpose Fish Hatchery in Miagao, Iloilo, Philippines. *Chanos chanos* fry were procured from a commercial hatchery and acclimated for seven days in fiberglass tanks using filtered seawater under a controlled flow-through system. During acclimation, fry were fed ad libitum a standard commercial diet three times daily. Water temperature, salinity, pH, and dissolved oxygen were monitored and maintained within the optimal ranges for milkfish culture (temperature: 28–30°C; salinity: 30–32 ppt; pH: 7.8–8.3; DO: >5 mg/L). Following acclimation, uniformly sized fry were randomly distributed into twenty 90-L plastic containers arranged in a continuous flow-through system using filtered seawater. Each container stocked 20 fry and was covered with a black polyethylene mesh to minimize light stress and prevent escape. Daily maintenance included the siphoning of fecal waste and replenishment of seawater to maintain consistent water volume and quality. Aeration was provided continuously to maintain dissolved oxygen at optimal levels.

DIET FORMULATION AND FEEDING PROTOCOL

Four isonitrogenous and isolipidic diets were formulated to contain increasing levels of medium-chain triglycerides (MCTs): 0% (T1), 3% (T2), 4% (T3), and 5% (T4). For juvenile fish, dietary MCT inclusion is generally recommended at approximately 3–10% of the diet, or as a partial replacement of total dietary lipid, to enhance energy utilization and growth performance without compromising essential fatty acid balance.⁷ Diets were designed to be approximately isoenergetic based on ingredient composition, but actual energy content was not determined. The formulations (Table 1) included sardine fish meal, defatted soybean meal, copra meal, and corn gluten as protein sources, while rice bran and starch served as carbohydrate sources. Cod liver oil and soybean oil supplied long-chain lipids, and refined MCT oil (C6–C12 fatty acids) was incorporated according to treatment. All diets were supplemented with a commercial vitamin-mineral premix and soy lecithin to ensure micronutrient adequacy and proper emulsification.

Diets were pelleted using a laboratory-scale pelletizer, oven-dried to ~15% moisture, and stored in a refrigerator prior to use. Feed was hand-fed according to daily feed requirement per replicate three times daily (08:00, 12:00, and 16:00). Uneaten feed was siphoned 30 minutes after feeding to prevent nutrient leaching. Feeding rates were adjusted biweekly based on biomass assessments conducted at each sampling period.

EXPERIMENTAL DESIGN AND SAMPLING

A completely randomized design was employed, with each treatment replicated in three containers (n=3). Fish were sampled on days 0, 15, 30, 45, and 60 to assess growth and feed performance parameters. During each sampling, total stocked milkfish per replicate were measured for wet weight. Survival, daily feed intake, and mortalities were recorded throughout the 60-day feed trial. At the final sampling, all 25 milkfish per replicate were individually weighed, pooled per treatment and stored at -20°C for nutrient analysis.

$$WG(\%) = \frac{Fw(g) - Iw(g) \times 100}{Iw(g)}$$

$$SGR(\%) = \frac{\ln Fw - \ln Iw \times 100}{\text{Days of experiment}}$$

$$PER = \frac{WG(g)}{Pi \text{ (in decimal)}}$$

$$FCE(\%) = \frac{\text{Live WG (g)} \times 100}{\text{Feed consumed (g)}}$$

$$\text{Survival (\%)} = \frac{TNMe}{TNMs} \times 100$$

Note:

WG = Weight Gain

SGR = Specific Growth Rate PER = Protein Efficiency Ratio

FCE = Feed Conversion Efficiency Fw = Final weight

Iw = Initial weight WG = Weight gain Pi = Protein intake

TNMe = Total no. of milkfish at the end of culture period

TNMs = Total no. of milkfish stocked

Table 1. Test diet composition and MCT levels for each 100g formulation.

Ingredients (%)	Test Diets			
	1	2	3	4
Sardine fish meal	25	25	25	25
Copra meal	14.5	14.5	14.5	14.5
Soybean (Defatted)	35	35	35	35
Cod liver oil	1.5	1.5	1.5	1.5
Soybean oil	1.5	1.5	1.5	1.5
Rice bran	9	9	9	9
Corn/wheat starch	5	5	5	5
Gluten (corn)	6	6	6	6
Lecithin - soy (70%)	0.5	0.5	0.5	0.5
Vitamin premix	1	1	1	1
Trace mineral premix	1	1	1	1
MCTs	0	3	4	5
Proximate Composition (g.100 g -1 DM)				
Moisture	14.09	14.25	14.75	14.93
Ash	11.55	10.69	10.94	11.21
Lipid	4.59	6.30	6.70	6.99
Crude Protein	38.61	38.67	38.40	37.51

NUTRIENT RETENTION AND PROXIMATE COMPOSITION

Protein and lipid retentions of milkfish were computed using the following formula⁹:

$$NR(\%) = \frac{CNC_{final} - CNC_{initial}}{NI} \times 100$$

where:

NR = Nutrient retention

CNC_{initial} = carcass nutrient content; initial CNC_{final} = carcass nutrient content; initial NI = nutrient intake during the feed trial

Samples of test diets and fish carcasses were analyzed in triplicate for proximate composition following standard AOAC international¹⁰ 17th edition protocols:

ASH

Approximately 1 g of each sample (test diet & fish carcass) was placed in a porcelain crucible and incinerated in a muffle furnace at 600°C overnight. After ashing, the crucibles were removed from the furnace, cooled to room temperature in a desiccator, and immediately reweighed to obtain the final ash content. The ash content was calculated as:

$$\text{Ash } (\%) = \frac{\text{ash weight (g)}}{\text{sample weight (g)}} \times 100$$

MOISTURE

The moisture content of the diets and carcass samples was determined through the application of thermal drying to constant weight at 110°C for 24 hours. The diet samples were ground to a fine particle using a mortar and pestle then approximately 1-5g of sample was placed in a pre-

weighed dish followed by oven- drying at 110°C, allowing extended drying time until a constant weight is obtained. Immediately after oven-drying, samples were placed in a desiccator to cool down then reweighed. The moisture content of samples was calculated as:

$$\text{Moisture } (\%) = \frac{W_1 - W_2}{W_1} \times 100$$

where:

W₁ = weight (g) of sample before drying W₂ = weight (g) of sample after drying

LIPID CONTENT

The samples (20g) were homogenized with a 16ml of distilled water, 40ml of chloroform and 80ml of methanol at a speed of 9,500 rpm for 1min. at 40C. Chloroform (40ml) was added and homogenized for 30 sec, then 40ml of distilled water was added and homogenized again for 30 sec. After centrifugation of the homogenate at 2,000 rpm, at 40C for 20 min, the supernatant was transferred into a separatory funnel and allowed to separate. The lipid content was determined gravimetrically by measuring triplicate aliquots by the chloroform layer into tared containers, evaporating the solvent, and then weighing. The lipid content of the samples was calculated using the formula:

$$\text{Lipid content } (\%) = \frac{EL}{W_s} \times \frac{CL + AL}{3ml} \times 100$$

where:

EL = Extracted lipid (g) W_s = Weight of sample (g) CL = Chloroform layer (ml) AL = Amounts lost (ml)

TOTAL PROTEINS

Approximately 0.7g of the sample in a digestion flask was added with 1g of Copper sulphate, 10g of Potassium sulphate, and 20ml of Sulphuric acid. The content was transferred into a vessel after complete digestion. Sulfuric acid (25 ml of 0.2N) was pipetted out into beaker and begin the distillation. The distillate was allowed to collect in Sulphuric acid for a known volume and time. The collected distillate was titrated against 0.2N Sodium Hydroxide using Methyl red as an indicator. The percentage of protein was calculated with the following equation:

$$\% \text{ Nitrogen} = \frac{(\text{TB} - \text{TS}) \times 0.014 \times 1000}{\text{WS}}$$

$$\% \text{ of Protein} = \% \text{ of Nitrogen} \times 6.25$$

where:

TB = Titer blank TS = Titer sample

WS = Weight of sample

STATISTICAL ANALYSIS

All quantitative data were verified for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene's test. A one-way analysis of variance (ANOVA) was then performed to evaluate the effects of dietary MCT levels on growth performance and nutrient utilization indices. When significant differences ($p \leq 0.05$) were detected, post hoc comparisons were conducted using Tukey's HSD test was applied. Results are expressed as mean $\pm$ standard deviation (SD), and all statistical analyses were carried out using IBM SPSS Statistics for Windows, Version 27.0 (IBM Corp., Armonk, NY, USA).

RESULTS

GROWTH PERFORMANCE

The inclusion of MCTs in the diets of *Chanos chanos* had a positive effect on their growth performance over the 8-week feeding trial. Fish fed the MCT5 diet resulted in the highest WG value, which was significantly higher than the CTRL and MCT3 groups, as indicated in table 2. Similarly, SGR significantly improved with increasing MCT inclusion, with MCT5 and MCT4 treatments (4.1% and 4.1%, respectively) showing higher values compared to CTRL and MCT3. FCE and PER were also significantly enhanced in the MCT4 and MCT5 groups, with values of

49.4 % and 49.2% for FCE, and 0.021 and 0.025 for PER, respectively. These values were significantly higher than those observed in the CTRL and MCT3 groups, indicating improved feed and protein utilization efficiency at higher MCT levels.

Although TFI increased with higher MCT inclusion, the survival rates did not differ significantly among treatments, ranging from 61.7% to 70.0%. The results in Table 2 indicate that elevated dietary inclusion of MCTs (notably at MCT4 and MCT5 levels) noticeably improves growth performance, feed conversion efficiency, and protein utilization in juvenile milkfish, without adverse effects on survival.

CARCASS NUTRIENT COMPOSITION

The whole-body nutrient composition of *Chanos chanos* was significantly affected by dietary MCT inclusion (Table 3). Among the treatments, fish fed the MCT3 diet exhibited the highest crude protein content (84.45%), which was significantly greater than the CTRL (81.83%) and MCT5 (82.03%) groups ($P < 0.05$). Crude lipid content of the carcass increased significantly with higher MCT supplementation. Fish in the MCT5 group had the highest lipid content (5.28%), which was significantly greater than that in the CTRL and MCT3 groups. Ash content, indicative of mineral deposition and skeletal development, was significantly reduced in the MCT4 and MCT5 groups (13.70% and 14.11%, respectively), compared to CTRL and MCT3 ($P < 0.05$).

NUTRIENT RETENTION

The effects of dietary MCTs inclusion on nutrient retention in *Chanos chanos* are presented in Table 4. Significant differences were observed in both protein and lipid retention across treatments ($P < 0.05$), indicating that MCT supplementation distinctly influenced the metabolic fate of dietary nutrients. The highest protein retention value was observed in fish fed the MCT3 diet, which was significantly higher than the CTRL and MCT5 groups. In contrast, lipid retention increased dramatically at the highest MCT inclusion (MCT5), reaching 43.35%, which was significantly greater than all other treatments.

DISCUSSION

The present study demonstrated that dietary supplementation with MCTs positively influenced growth performance, feed utilization, and nutrient retention in juvenile *Chanos chanos*. Fish fed MCT-supplemented diets, particularly at higher inclusion levels (MCT4 and MCT5), showed significantly greater WG and SGR compared to those fed the control and lower MCT diets. These developments are attributed to the unique metabolic characteristics of MCTs, which are absorbed directly via the portal vein and rapidly oxidized in the liver, providing immediate energy that spares dietary protein for somatic growth.¹¹

The improvements observed in FCE and PER in the MCT4 and MCT5 groups further underscore the metabolic benefits of MCTs. This supports the concept of rapid MCT catabolism through hepatic β -oxidation. Odle¹² demonstrated that MCFAs undergo rapid hepatic oxidation, with acetate as an important product. Similarly, Marten et al.¹³ and Christensen et al.¹⁴ confirmed that MCFAs are preferentially oxidized compared to long-chain fatty acids, underscoring their role as an efficient energy source.

Experimental evidence from Tsujino et al.¹⁵ and Nosaka et al.¹⁶ shows MCT ingestion significantly increased fat oxidation during physical activity compared to long-chain triglycerides in overweight individuals (BMI 25–30). MCTs serve as an efficient energy source, thereby enhancing nutrient utilization and growth performance. Comparable findings have been reported in Japanese seabass (*Lateo-*

Table 2. Growth performance of milkfish *Chanos chanos* fed with MCT-added diets for 8 weeks.

Treatments	TFI (g)	WG (%)	SGR (%) FCE (%)	PER	Survival (%)
CTRL	17.3±1.45	668.0±74.74 ^a	3.7±0.09 ^a 35.1±2.92 ^a	1.40±0.0015 ^a	65.0±2.89
MCT3	18.9±1.71	700.3±91.46 ^{ab}	3.7±0.14 ^{ab} 33.7±3.41 ^a	1.48±0.0023 ^{ac}	61.7±1.67
MCT4	20.3±1.34	1073.7±120.72 ^{abc}	4.1±0.04 ^{bc} 49.4±2.71 ^b	2.07±0.0010 ^{bc}	66.7±4.41
MCT5	23.4±1.15	1217.7±76.15 ^c	4.1±0.02 ^c 49.2±1.46 ^b	2.50±0.0005 ^b	70.0±2.89

Values are mean ± SEM (n=3). Different superscript letters indicate significant differences among treatment (P< 0.05). TFI – total feed intake, WG – weight gain, SGR – specific growth rate, FCE – feed conversion efficiency, PER – protein efficiency ratio.

Table 3. Nutrient composition of the milkfish *Chanos chanos* carcass (% , dry weight).

Treatments	Crude Protein	Crude Lipid	Ash
Initial	80.99±0.52	2.25±0.43	17.73±0.05
CTRL	81.83±0.21 ^a	2.51±0.09 ^a	16.62±0.30 ^a
MCT3	84.45±0.59 ^b	3.53±0.21 ^{ab}	17.17±0.27 ^a
MCT4	83.60±0.60 ^a	3.49±0.24 ^{ab}	13.70±0.30 ^b
MCT5	82.03±0.38 ^{ac}	5.28±0.31 ^c	14.11±0.17 ^b

Values are mean ± SEM (n=3). Different superscript letters indicate significant differences among treatments (P<0.05).

Table 4. Nutrient retention in milkfish *Chanos chanos* fed with MCT-added diets for 8 weeks.

Treatments	Parameters	
	Protein retention	(%) Lipid retention (%)
CTRL	2.30±0.58 ^{a^}	5.65±1.96 ^{a^}
MCT3	8.95±1.52 ^{b^}	2.25±3.33 ^{a^}
MCT4	6.79±1.56 ^{a^}	18.53±3.62 ^{a^}
MCT5	2.77±0.51 ^{ac^}	43.35±4.37 ^{b^}

Values are mean ± SEM (n=3). Different superscript letters indicate significant differences among treatments (P<0.05).

labrax japonicus) and Nile tilapia (*Oreochromis niloticus*),^{17, 18} indicating that these benefits may extend across species.

Additionally, the increase in TFI observed with higher MCT inclusion, particularly in MCT5, did not compromise feed efficiency. This suggests that MCTs, through their rapid hepatic oxidation, may modulate feeding behavior by influencing endocrine and metabolic pathways, potentially enhancing appetite or energy-driven feed intake via mechanisms involving ghrelin activation and the regulation of satiety-related hormones.¹⁹⁻²¹ Enhanced palatability or altered metabolic cues, as previously described in studies involving lipid supplementation,²² may also contribute to increased intake.

Notably, survival rates were not significantly affected across treatments, suggesting that MCT inclusion up to 5% does not negatively impact fish health. This aligns with existing literature on the safety and tolerability of MCTs in aquafeeds for various finfish species,^{23,24} supporting their practical utility in nursery-stage diets.

Carcass nutrient analysis revealed that fish in the MCT3 group exhibited the highest crude protein content, indicating efficient lean tissue deposition and supporting the protein-sparing effect of MCTs, wherein lipid-derived energy reduces the need for protein catabolism to meet metabolic

demands. Fish in the MCT5 group showed elevated carcass lipid content, likely due to surplus dietary energy being stored as fat. This trend aligns with observations in other species, where high dietary MCT levels promote lipid deposition when energy intake exceeds the requirements for maintenance and growth.²⁴ Although MCTs are generally considered less lipogenic than long-chain fatty acids due to their rapid hepatic oxidation,²⁵ the increase in lipid content at the highest MCT inclusion level may be attributed to enhanced feed intake and energy surplus.

These findings highlight the importance of optimizing MCT inclusion levels to balance energy utilization and carcass composition. Ash content was observed to be lower in the MCT4 and MCT5 treatments, which may suggest a possible shift in nutrient allocation. While such reductions could indicate a tendency toward greater soft tissue accretion relative to mineral deposition, this interpretation should be made cautiously, as ash content alone does not provide a definitive measure of skeletal mineralization. Similar patterns have been reported in studies where high dietary lipid levels were associated with altered mineral deposition.^{23,26} Thus, the observed decline in ash may reflect a redistribution of metabolic resources; however, a limitation of this study is that ash content alone cannot be taken

as a definitive indicator of skeletal mineralization, as multiple dietary and physiological factors may influence mineral deposition. Future work should therefore include direct assessments of bone and scale mineralization, along with mineral profiling, to better clarify the relationship between MCT supplementation, nutrient allocation, and skeletal development.

Although the precise mechanisms remain unclear, it is plausible that increased lipid metabolism alters mineral absorption, retention, or utilization. This nutrient partitioning could reflect differential growth patterns between soft and hard tissues under lipid-rich conditions, potentially impacting skeletal integrity or overall body composition. While the biological significance of reduced ash content warrants further investigation, especially regarding long-term skeletal health, these findings highlight the need to balance energy-rich diets with adequate mineral support to ensure holistic growth in juvenile *Chanos chanos*. These results indicate that dietary MCTs influence carcass nutrient composition in *Chanos chanos*, with moderate inclusion (MCT3) enhancing protein deposition, while higher levels (MCT5) promote lipid accumulation and reduce mineral content. These findings provide valuable insights for optimizing carcass quality and nutrient partitioning in formulated diets for milkfish.

Nutrient retention values further clarified the variance effects of MCT inclusion. The MCT3 group achieved the highest protein retention, reinforcing its role in promoting lean tissue growth. This suggests that a moderate inclusion level of MCTs (3%) optimizes the protein-sparing effect, allowing more dietary protein to be retained for growth rather than catabolized for energy. This is consistent with previous findings indicating that MCTs, due to their rapid oxidation, serve as a readily available energy source, thereby increasing non-protein energy expenditure sparing amino acids utilization for anabolic processes.^{27,28}

Lipid retention was significantly higher in the MCT5 group, indicating an energy surplus that promoted fat storage. These divergent responses suggest that moderate MCT inclusion favors protein accretion, whereas excessive supplementation shifts nutrient partitioning toward lipid deposition. The MCT4 treatment produced a more balanced profile, supporting both protein retention and controlled lipid accumulation, while MCT3 achieved the highest protein retention with the lowest lipid retention (2.25%), implying that dietary energy at this level was primarily directed toward growth rather than storage. Although MCTs are generally considered less lipogenic than long-chain triglycerides due to their rapid hepatic oxidation, excessive intake particularly when coupled with increased feed consumption can still create an energy surplus that promotes fat deposition.^{29,30} Taken together, these findings indicate that moderate inclusion levels (3-4%) optimize protein utilization and nutrient allocation, whereas higher inclusion (5%) may predispose fish to undesirable lipid deposition and reduced mineral content. Such outcomes could have long-term implications for carcass quality, skeletal integrity, and market value, underscoring the need for cau-

tious application of higher MCT levels and further validation under commercial grow-out conditions.

This study demonstrated that dietary MCT supplementation significantly influenced growth, feed efficiency, and nutrient retention in juvenile *Chanos chanos*. The results support the hypothesis that a 4% inclusion level optimizes growth and protein utilization without compromising survival, whereas higher inclusion (5%) promotes lipid deposition at the expense of protein retention. Overall, these findings highlight the potential of MCTs as a functional lipid source, with 4% inclusion emerging as the most effective strategy to enhance production efficiency and sustainability in milkfish aquaculture.

CONCLUSION

Results of this study indicate that dietary MCT supplementation significantly affects growth performance, feed efficiency, and nutrient utilization in juvenile *Chanos chanos*. A 4% inclusion level provided the most favorable balance, enhancing growth and protein retention without compromising survival, whereas higher inclusion (5%) promoted lipid deposition at the expense of protein retention. Excessive fat accumulation is undesirable as it may reduce carcass quality and impair long-term health, underscoring the need for careful optimization of dietary lipid sources.

RECOMMENDATION

1. PRACTICAL RECOMMENDATIONS FOR FARMERS AND FEED PRODUCERS

A 4% dietary inclusion of MCTs is recommended to maximize growth, feed efficiency, and protein utilization in juvenile *Chanos chanos* while avoiding excessive fat deposition. If feed cost is a limiting factor, a 3% inclusion can still provide measurable benefits, though with slightly reduced efficiency. Inclusion above 4% (5%) should be avoided due to undesirable lipid accumulation that may compromise carcass quality and long-term health.

2. FUTURE RESEARCH DIRECTIONS

Further studies should assess long-term effects of MCT supplementation under commercial grow-out conditions. Research priorities include cost-effectiveness, nutrient digestibility, interactions with other feed ingredients, and direct measures of bone and scale mineralization to clarify the implications of reduced ash content.

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AUTHOR CONTRIBUTIONS

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COMPETING INTEREST{#COI}

The authors declare that there is no competing interest related to this study.

ETHICAL CONDUCT

All experimental procedures complied with internationally accepted standards for the humane treatment of research animals. Euthanasia was performed by rapid cooling followed by immersion in ice-chilled water, in accordance with the American Veterinary Medical Association (AVMA, 2013) Guidelines for the Euthanasia of Animals for small-bodied fishes. This procedure is recognized as a humane method for aquatic species and, under applicable regulations, does not require institutional ethical clearance or certification.

INFORMED CONSENT STATEMENT

All authors and their respective institutions have granted final approval for the publication of this manuscript.

DATA AVAILABILITY STATEMENT

The data in this research are confidential and handled in accordance with applicable privacy and ethical guidelines.

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