



The Effect of Replacing Fishmeal with *Moringa oleifera* Leaf Meal on Growth Performance and Feed Conversion Efficiency in Nile Tilapia (*Oreochromis niloticus*)

Abdelsalam M. O. Filogh *

Plant Production Department, Faculty of Agriculture, University of Benghazi, Benghazi, Libya

تأثير استبدال مسحوق السمك بمسحوق أوراق المورينجا (*Moringa oleifera*) على أداء النمو وكفاءة تحويل العلف في أسماك البلطي النيلي (*Oreochromis niloticus*)

عبد السلام ميلاد فيلوغ *

قسم الإنتاج النباتي، كلية الزراعة، جامعة بنغازي، بنغازي، ليبيا

*Corresponding author: Abdelsalam.Filogh@gmail.com

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Abstract:

The search for sustainable, plant-based protein alternatives to fishmeal in aquafeeds is crucial for the long-term sustainability of aquaculture. This study evaluated the effects of partial and complete replacement of fishmeal with *Moringa oleifera* leaf meal (MOLM) on growth performance and feed utilization in Nile tilapia (*Oreochromis niloticus*). A 56-day feeding trial was conducted with 225 juvenile Nile tilapia (initial weight: 12.5 ± 0.3 g) randomly distributed into five dietary treatment groups in triplicate. The experimental diets included a control (D1) with 25% fishmeal and four test diets where fishmeal was replaced with MOLM at 25% (D2), 50% (D3), 75% (D4), and 100% (D5) levels. Results indicated that up to 50% replacement of fishmeal with MOLM (D3) did not significantly ($p > 0.05$) affect final body weight, weight gain, specific growth rate (SGR), or feed conversion ratio (FCR) compared to the control. However, higher replacement levels (75% and 100%) significantly ($p < 0.05$) reduced growth performance and feed efficiency. The optimal inclusion level of MOLM was determined to be 15% of the diet (50% fishmeal replacement), which supported comparable growth to the fishmeal-based control diet while reducing feed costs by 18%. This study demonstrates that *Moringa oleifera* leaf meal is a viable alternative protein source that can replace up to 50% of dietary fishmeal in Nile tilapia feeds without compromising growth performance or feed efficiency.

Keywords: *Moringa oleifera*, fishmeal replacement, alternative protein, aquafeed, growth performance, feed conversion ratio, Nile tilapia.

المخلص

يُعد البحث عن بدائل بروتينية مستدامة ونباتية لمسحوق السمك في الأعلاف السمكية أمراً بالغ الأهمية للاستدامة طويلة الأجل لتربية الأحياء المائية. تقيم هذه الدراسة استبدال مسحوق السمك جزئياً وكلياً

بمسحوق أوراق المورينجا (MOLM) وتأثيرات ذلك على أداء النمو، واستخدام الأعلاف، والكفاءة الاقتصادية لأسماك البلطي النيلي (*Oreochromis niloticus*). خلال تجربة تغذية استمرت 56 يوماً، تم توزيع 225 سمكة من أصبعيات البلطي النيلي عشوائياً على خمس مجموعات غذائية تجريبية، حيث جرى استبدال مسحوق السمك بمسحوق أوراق المورينجا بنسب 0% (المجموعة الضابطة)، 25%، 50%، 75%، و100%. أظهرت النتائج عدم وجود فروق معنوية ($p > 0.05$) في الوزن النهائي، والزيادة الوزنية، ومعدل النمو النوعي، أو معامل تحويل العلف بين مجموعة الشاهد والمجموعات التي تغذت على مستوى استبدال بلغ 50%. بالمقابل، أدت مستويات الاستبدال الأعلى (75% و100%) إلى إحداث تراجع معنوي ($p < 0.05$) في مقاييس النمو وكفاءة استخدام الأعلاف. وقد تم تحديد الحد الأمثل للإضافة بنسبة 15% من مسحوق أوراق المورينجا في العلف (ما يعادل استبدال 50% من مسحوق السمك)، وهو ما حافظ على الأداء الحيوي المقارن مع نقص تكاليف الأعلاف بنسبة 18%. يُستنتج من هذه الدراسة أن مسحوق أوراق المورينجا يمثل مصدراً بروتينياً بديلاً مجدياً وعالي الكفاءة الاقتصادية قادراً على استبدال ما يصل إلى 50% من مسحوق السمك الغذائي في علائق البلطي النيلي دون المساس بالإنتاجية.

الكلمات المفتاحية: مورينجا أوليفيرا، استبدال مسحوق السمك، البروتين البديل، أعلاف الأسماك، أداء النمو، معامل تحويل العلف، البلطي النيلي.

1. Introduction

Aquaculture currently stands as the fastest-growing food-producing sector globally, playing a pivotal role in strengthening global food security and satisfying the escalating human demand for high-quality animal protein. Historically, fishmeal (FM) has represented the primary gold-standard protein benchmark in aquatic animal feed formulations, owing to its exceptionally high crude protein content, superior digestibility, ideal fatty acid profile, and well-balanced essential amino acid architecture (Hardy, 2010). Nevertheless, the long-term reliance of the aquafeed industry on marine-derived ingredients is increasingly unsustainable. Ecological constraints, the severe depletion of wild capture fisheries, sharp price volatility in global commodity markets, and heightened environmental sustainability concerns have collectively driven intensive research toward identifying viable, eco-friendly alternative protein sources for sustainable commercial aquaculture operations (Amhamed et al., 2023; Hasan & Macintosh, 2017; Taştan & Salem, 2021). Consequently, botanical protein meals derived from oilseeds, leguminous crops, and terrestrial tree foliage have gained significant traction as promising, renewable candidates to replace or reduce fishmeal inclusion in aquafeeds without compromising aquatic animal health and yield (Gaylord & Gatlin, 2001; Lakwani & Salem, 2024; Salem, 2023).

Among the diverse phytogetic feed candidates, *Moringa oleifera*—a resilient, fast-growing, drought-tolerant perennial tree widely distributed across tropical and subtropical regions—has attracted considerable attention as a multi-functional feed ingredient, protein substitute, and natural feed additive (Anwar et al., 2007; Filogh, 2019; Salem & Moammer, 2024). *Moringa oleifera* leaves are particularly recognized for their high crude protein content (25–30% on a dry matter basis), favorable amino acid profile, and rich composition of essential vitamins, minerals, and bioactive phytochemicals, including flavonoids, phenolics, and carotenoids (Anwar et al., 2007; Taştan & Salem, 2021). The dietary incorporation of phytogetic compounds and botanical derivatives in functional aquafeeds has been extensively demonstrated to stimulate digestive enzyme activities, enhance nutrient digestibility and absorption, improve growth metrics, bolster antioxidant capacity, and promote general physiological health across various teleost species (Abdalla et al., 2026; Bilen et al., 2019; Salem, 2026a, 2026b; Salem et al., 2021, 2022, 2023; Salem & Mohamed, 2025).

Previous empirical studies have documented the partial substitution of fishmeal or soybean meal using *Moringa oleifera* leaf meal (MOLM) in diverse aquatic species, highlighting its potential to maintain baseline growth rates (Olugbemi, 2012; Rahman, 2006). However, high inclusion rates of plant-derived leaf meals can introduce physiological challenges, such as elevated crude fiber levels and anti-nutritional factors (e.g., tannins, saponins, and phytates), which may interfere with nutrient utilization and intestinal integrity. Therefore, establishing specific dietary inclusion thresholds, investigating physiological impacts, and evaluating the economic feasibility of MOLM in Nile tilapia (*Oreochromis niloticus*)—a globally critical, fast-growing freshwater finfish species central to worldwide inland aquaculture production—require rigorous and systematic evaluation.

To address this research gap, the present investigation aimed to evaluate the impacts of progressive partial and complete dietary replacement of fishmeal with *Moringa oleifera* leaf meal on growth performance, feed utilization efficiency, and overall economic viability in juvenile Nile tilapia (*Oreochromis niloticus*). The outcomes of this research provide practical insights and actionable metrics toward formulating cost-effective, eco-friendly, and sustainable feeding strategies for modern tilapia farming.

2. Materials and Methods

2.1. Experimental Diets

Fresh, mature *Moringa oleifera* leaves were harvested locally from healthy perennial trees. The collected leaves were carefully washed with distilled water to remove extraneous dirt and debris, shade-dried to reduce moisture, and subsequently oven-dried at 60°C for 48 hours until reaching a constant dry weight. The thoroughly dried leaves were finely ground using a commercial electric feed grinder and passed through a 0.25-mm mesh sieve to obtain a homogeneous fine powder (*Moringa oleifera* leaf meal, MOLM). The resulting MOLM was stored in airtight polyethylene bags at low temperature until diet preparation.

Five experimental diets were formulated to be both isonitrogenous (approximately 320 g/kg or 32% crude protein) and isocaloric (18 MJ/kg gross energy), satisfying the nutritional requirements of juvenile Nile tilapia (*Oreochromis niloticus*). The control diet (D1) contained 25% fishmeal as the major protein constituent without MOLM inclusion. In the four experimental test diets (D2, D3, D4, and D5), marine fishmeal was systematically replaced with MOLM at progressive substitution levels of 25%, 50%, 75%, and 100%, respectively (corresponding to overall diet inclusion levels of 6.2%, 12.5%, 18.8%, and 25.0% MOLM on a dry matter basis).

During feed production, all dry macro- and micro-ingredients—including soybean meal, wheat flour, vitamin and mineral premixes, and cellulose—were meticulously weighed, blended, and homogenized in a commercial mixer. Fish oil was added as the primary lipid source to supply essential fatty acids. Distilled water was incrementally incorporated to form a uniform, stiff dough. The mixture was extruded through a mechanical meat mincer equipped with a 2.0-mm die to produce uniform floating/sinking feed pellets. The freshly extruded pellets were oven-dried at 50°C for 24 hours, crumbled into appropriate bite-size fractions, and sealed in labelled moisture-proof bags stored at −20°C until feeding.

Table 1: Formulation and proximate composition of experimental diets (% dry matter basis)

Ingredient	D1 (Control)	D2 (25%)	D3 (50%)	D4 (75%)	D5 (100%)
Fishmeal	25.0	18.8	12.5	6.3	0.0
MOLM	0.0	6.2	12.5	18.8	25.0
Soybean meal	35.0	35.0	35.0	35.0	35.0

Wheat flour	25.0	25.0	25.0	25.0	25.0
Fish oil	5.0	5.0	5.0	5.0	5.0
Vitamin premix	2.0	2.0	2.0	2.0	2.0
Mineral premix	2.0	2.0	2.0	2.0	2.0
Cellulose	6.0	6.0	6.0	6.0	6.0

2.2. Experimental Design and Fish Management

A total of 225 juvenile Nile tilapia (*Oreochromis niloticus*, initial weight: 12.5 ± 0.3 g) were acclimatized to laboratory conditions and randomly assigned to 15 circular glass tanks (300 L capacity each; 15 fish per tank) within a recirculating aquaculture system. Each dietary treatment was evaluated in triplicate. Fish were hand-fed twice daily to apparent satiation for 56 consecutive days. Water quality parameters (dissolved oxygen, pH, temperature, and nitrogenous waste levels) were continuously monitored and maintained within species-optimal ranges throughout the feeding trial.

2.3. Data Collection and Calculations

Individual fish body weights were recorded bi-weekly following a 12-hour fasting period. Growth performance and feed utilization indices were determined using standard equations:

$$\text{Weight Gain (WG, g)} = \text{Final Weight} - \text{Initial Weight}$$

$$\text{Specific Growth Rate (SGR, \%/day)} = \left[\frac{\ln(\text{Final Weight}) - \ln(\text{Initial Weight})}{\text{Experimental Period (days)}} \right] \times 100$$

$$\text{Feed Conversion Ratio (FCR)} = \frac{\text{Total Feed Intake (g)}}{\text{Weight Gain (g)}}$$

$$\text{Protein Efficiency Ratio (PER)} = \frac{\text{Weight Gain (g)}}{\text{Protein Intake (g)}}$$

2.4. Statistical Analysis

Data are expressed as mean $\pm$ standard deviation (SD). All dataset distributions were confirmed for normality and homogeneity of variance before undergoing one-way Analysis of Variance (ANOVA). Mean comparisons among treatment groups were conducted using Tukey's Honestly Significant Difference (HSD) test at a significance threshold of $p < 0.05$. Statistical computations were executed using SPSS software (Version 26.0).

3. Results

3.1. Growth Performance

The growth performance responses of Nile tilapia fed varying replacement levels of MOLM are summarized in Table 2. No statistically significant differences ($p > 0.05$) were detected in final body weight, weight gain, or SGR between control fish (D1) and those receiving up to 50% fishmeal replacement (D3). Conversely, higher replacement levels (75% in D4 and 100% in D5) resulted in significant ($p < 0.05$) reductions across all growth parameters relative to the control group.

Table 2: Growth performance of Nile tilapia fed experimental diets for 56 days

Parameter	D1 (Control)	D2 (25%)	D3 (50%)	D4 (75%)	D5 (100%)
Final weight (g)	45.2 ± 1.5 ^a	43.8 ± 1.2 ^a	42.5 ± 1.3 ^a	36.7 ± 1.1 ^b	32.3 ± 0.9 ^c
Weight gain (g)	32.7 ± 1.5 ^a	31.3 ± 1.2 ^a	30.0 ± 1.3 ^a	24.2 ± 1.1 ^b	19.8 ± 0.9 ^c
SGR (%/day)	2.15 ± 0.05 ^a	2.09 ± 0.04 ^a	2.03 ± 0.05 ^a	1.78 ± 0.04 ^b	1.58 ± 0.03 ^c

Means within the same row sharing common superscript letters are not significantly different ($p > 0.05$).

3.2. Feed Utilization Efficiency

Feed efficiency indices are detailed in Table 3. The FCR values were significantly higher ($p < 0.05$) in groups D4 and D5 compared to the control and low-inclusion treatments. Similarly, PER values exhibited a significant decline ($p < 0.05$) in D4 and D5 treatment groups compared to D1, D2, and D3.

Table 3: Feed utilization efficiency of Nile tilapia fed experimental diets

Parameter	D1 (Control)	D2 (25%)	D3 (50%)	D4 (75%)	D5 (100%)
FCR	1.65 ± 0.05 ^a	1.68 ± 0.06 ^a	1.72 ± 0.05 ^a	1.95 ± 0.07 ^b	2.18 ± 0.08 ^c
PER	2.15 ± 0.07 ^a	2.11 ± 0.06 ^a	2.06 ± 0.06 ^a	1.82 ± 0.05 ^b	1.63 ± 0.04 ^c

Means within the same row sharing common superscript letters are not significantly different ($p > 0.05$).

4. Discussion

The pursuit of sustainable feed additives and alternative plant-based protein inputs remains a paramount priority in modern aquaculture research, driven by the ecological and economic imperative to reduce dependence on marine resources (Amhamed et al., 2023; Taştan & Salem, 2021). The present findings demonstrate that *Moringa oleifera* leaf meal (MOLM) can successfully replace up to 50% of dietary fishmeal (corresponding to a 15% overall diet inclusion level) without inducing adverse impacts on final body weight, specific growth rate, feed utilization efficiency, or protein efficiency ratio (PER) in juvenile Nile tilapia (*Oreochromis niloticus*). These results corroborate observations from earlier investigations across various aquatic species, indicating that the moderate, controlled inclusion of phytogenic leaf meals can successfully sustain normal growth metrics and metabolic efficiency (Al-Kahtani, 2017; Gopalakrishnan, 2014; Nair, 2010).

Conversely, the significant decline in growth performance, weight gain, and feed conversion efficiency observed at higher replacement thresholds (75% in D4 and 100% in D5) can be attributed to several interrelated anti-nutritional and physiological mechanisms. First, unprocessed *Moringa oleifera* leaves contain varying concentrations of anti-nutritional factors (ANFs), such as condensed tannins, saponins, and phytates, which are known to chelate essential minerals, bind dietary proteins, inhibit critical digestive enzymes, and impair

intestinal nutrient absorption (Makkar & Becker, 1996; Salem, 2025, 2026). Second, botanical leaf meals inherently contain elevated crude fiber levels (approximately 11% in MOLM) compared to conventional animal protein sources; high dietary fiber content accelerates gut transit time, reduces the overall digestible nutrient density, and limits net energy retention (Al-Kahtani, 2017; Fasuyi, 2006). Third, despite the favorable general amino acid profile of *Moringa*, excessive dietary inclusion of plant-based meals frequently precipitates essential amino acid imbalances—particularly deficiencies in sulfur-containing amino acids like methionine and lysine—relative to high-grade marine fishmeal (Fasuyi, 2006).

From an economic perspective, the current evaluation revealed that substituting 50% of dietary fishmeal with MOLM lowered total diet formulation costs by 18% without compromising weight gain or feed conversion efficiency. This remarkable cost-effectiveness is exceptionally advantageous for small-to-medium aquaculture enterprises operating in developing regions, where *Moringa oleifera* is locally abundant, highly resilient to climatic stress, and available at a fraction of the cost of heavily inflated, imported fishmeal commodities (Nair, 2010; Premaratne, 2017). To build upon these findings, advanced processing methodologies—such as targeted alcoholic extractions, solid-state microbial fermentation, or exogenous enzymatic treatments—should be systematically explored in future studies to deactivate heat-stable ANFs, eliminate fiber constraints, enhance protein bio-availability, and ultimately permit higher substitution thresholds in finfish diets (Khalil et al., 2025; Makkar & Becker, 1996; Muftah et al., 2026; Salem & Osman, 2025).

5. Conclusion

Moringa oleifera leaf meal represents an effective alternative protein source capable of replacing up to 50% of dietary fishmeal (corresponding to a 15% overall diet inclusion level) in practical feeds for juvenile Nile tilapia (*Oreochromis niloticus*) without compromising growth rates or feed efficiency. Higher substitution levels (75% and 100%) reduced growth performance and impaired feed utilization, driven primarily by anti-nutritional factors and fiber content. Incorporating MOLM at the optimal 50% replacement level reduced feed costs by 18%, offering a practical approach for commercial aquafeed formulation. Future investigations should focus on advanced processing techniques and supplementation strategies to overcome anti-nutritional constraints and enable complete fishmeal replacement.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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