JoAS Volume 10 No. 2 October 2025
DOI: https://doi.org/10.20473/joas.v10i2.75153
pISSN 2550-0910; eISSN 2579-4817
Available online at https://e-journal.unair.ac.id/JoAS
Journal of Aquaculture Science

# Effect of Replacing Fish Oil with Palm Oil on Growth Performance and Survival of Nile Tilapia (*Oreochromis niloticus*)

**Ravi Bhatta[1]*, Sudarshan Poudel[2], Sapana Pandey[3], Shailesh Gurung[4], and Arman Hossain[5]**

[1]Kentucky State University, Frankfort, KY 40601, USA
[2]Institute of Agriculture and Animal Science (IAAS), Tribhuvan University, Nepal
[3]University of Kentucky, Lexington, Kentucky, USA
[4]Institute of Agriculture and Animal Science (IAAS), Paklihawa Campus, Nepal
[5]University of Sydney, City Road, Darlington, New South Wales, Australia

Article info:

Submitted: June 30, 2025
Revised: July 29, 2025
Accepted: July 30, 2025
Publish: October 1, 2025

E-mail addresses:
*Corresponding author:
ravibhatta100@gmail.com



**ABSTRACT**

High cost and limited availability of fish oil (FO) in aquafeeds have prompted the search for alternative lipid sources. Palm oil (PO), a widely available and stable vegetable oil, may serve as a viable replacement in tilapia diets. This study investigated the effect of partially replacing fish oil (FO) with PO on the growth performance, feed utilisation, and survival of Nile tilapia cultured in cages. A 16-week feeding trial with four experimental diets was formulated by replacing FO with 0% (T0), 25% (T1), 50% (T2), and 75% (T3) PO. The diets were fed once daily to triplicate groups of 10 juvenile tilapia (7.75 ± 0.94 g), stocked into 12 cages (1 × 1 × 1 $m^3$). Results indicate that there were no significant differences ($p > 0.05$) among treatments for final weight, final length, total biomass, specific growth rate (SGR), weight gain, survival rate, feed conversion ratio (FCR), and protein efficiency ratio (PER). The results suggest that PO can partially replace FO up to 50% in Nile tilapia diets without compromising growth, feed efficiency, or survival rate. This highlights PO's potential as nutritionally viable lipid sources for sustainable aquafeed development.

**Keywords:** aquafeed, feed utilisation, fish oil replacement, Nile tilapia, palm oil

## INTRODUCTION

Feed is the most notable cost factor in aquaculture, especially in intensive farming systems. In general, nutritionally balanced feed consists of three macronutrients: protein, fat, and carbohydrates. Among these three, fat in feed is very important as an efficient source of energy. Fat functions as an energy source, aids in the absorption of fat-soluble vitamins, forms cell membranes, and serves as a precursor to biochemical compounds that perform various metabolic functions (Prabu *et al.*, 2017). Lipids also provide essential fatty acids, which are critical for maintaining growth and survival in fish (Glencross, 2009; De Souza Alves *et al.*, 2021).

The main source of fat in fish feed comes from fish oil (FO). FO contains high levels of long-chain polyunsaturated fatty acids (LC-PUFAs), such as EPA and DHA, which are essential for fish health and development. However, rising FO prices due to declining global FO availability have made fish feed increasingly expensive. Feed accounts for more than 60% of total production costs (Boyd *et al.*, 2022; Hua *et al.*, 2019). This has driven the need to find more economical lipid alternatives to replace FO, one of which is vegetable oil. This step needs to be taken to ensure sustainable aquaculture amid increasing demand and declining wild fish stocks (Glencross, 2009; De Souza Alves *et al.*, 2021).

Given the rising price of fish oil and the urgent need for sustainable aquaculture practices, vegetable oil has emerged as a promising alternative to replace fish oil in fish feed. Studies show that replacing FO with vegetable oil can maintain or improve growth performance in various species such as Atlantic salmon, *Salmo salar* (Menoyo *et al.*, 2005) and Nile tilapia, *Oreochromis niloticus* (Peng *et al.*, 2015), although changes in tissue fatty acid profiles have been noted in (Xu *et al.*, 2022) yellow croaker, *Larimichthys crocea*. Nevertheless, some studies indicate that the addition of vegetable oil may disrupt non-specific immunity parameters in some species, such as the large yellow croaker (Mu *et al.*, 2019).

Palm oil (PO) is the most widely produced vegetable oil in the world, reaching more than 77 million metric tons in 2023 and representing more than 36% of total vegetable oil production. This makes PO a stable and easily accessible source of lipids for fish feed (Fastmarkets, 2024). In addition to its availability, PO offers several nutritional benefits. It is rich in beta-carotene, a precursor to vitamin A, and contains antioxidants such as tocopherols and tocotrienols (Grimaldi *et al.*, 2005; De Souza Alves *et al.*, 2021). In terms of composition, PO consists of approximately 50% saturated fatty acids (44% palmitic acid and 5% stearic acid), 40% monounsaturated fatty acids (mainly oleic acid), and 10% polyunsaturated fatty acids, mainly linoleic acid (Gee *et al.*, 2007). Recent studies have also investigated its effects on muscle biochemistry and gene expression related to growth as well as different stages (Ayisi *et al.*, 2019; De Souza Alves *et al.*, 2021).

Tilapia is an important species in global aquaculture, especially in developing countries, due to its rapid growth, resistance to diverse environmental conditions, and tolerance to disease (Ashouri *et al.*, 2023). In Nepal, Nile tilapia was introduced in 1985, but substantial research initiatives only began in 1996 at the Institute of Agriculture and Animal Science (IAAS), Rampur. Despite its relative novelty to Nepali farmers and consumers, tilapia holds great promise for enhancing local food security (Mishra and Kunwar *et al.*, 2014). However, there are still gaps in understanding the broader impact of PO supplementation on overall tilapia production and productivity in local aquaculture systems.

Therefore, the present study evaluated the effectiveness of replacing FO with PO in terms of growth performance, survival, and feed utilisation of Nile tilapia. The study aims to contribute to sustainable feeding strategies for aquaculture development in regions facing challenges such as limited access to marine resources and rising feed costs.

## MATERIALS AND METHODS

### Ethical statement

All experimental animal procedures in this study received approval from the Ethical Review Committee of Tribhuvan University, Institute of Agriculture and Animal Science (IAAS), Department of Aquaculture, Kathmandu, Nepal. The fish were handled with care and compassion at all stages.

### Experimental design

The experiment was carried out throughout 16 weeks from September 2021 to February 2022, at the Aquaculture Pond of the IAAS, Paklihawa Campus, Rupandehi, Nepal. A total of 12 cages (4 treatments × 3 replications), each measuring 1 × 1 × 1 $m^3$, were installed in a fertilised empty pond using a complete randomised design (CRD). To set up the cage, six long ropes were stretched parallel to the length of the pond, supported by pegs at regular intervals, plastic bags filled with approximately 0.5 kg of small pebbles were attached to each of the four bottom corners to maintain the cubic shape of the cage underwater, A small hole was provided on the top surface of each cage to facilitate feeding and fish handling operations. This opening was securely closed with a clip after each use to prevent fish from escaping (Bhatta *et al.*, 2025).

## Feed Preparation

For experimental diets preparation, soybean meal, mustard oil cake, rice bran, wheat flour, PO, FO, and vitamin premix were used as major ingredients. The soybean meal and vitamin premix were procured from the local market in Bhairahawa, whereas mustard oil cake, rice bran, and wheat flour were sourced from nearby milling industries. PO and FO were purchased from Kathmandu, Nepal. The experimental diets were formulated as follows: Treatment 1 (T0) served as the control diet, consisting of wheat flour, soybean meal, and FO; Treatment 2 (T1) included 25% replacement of FO with PO; Treatment 3 (T2) involved a 50% replacement of FO with PO; and Treatment 4 (T3) involved a 75% replacement of FO with PO. The detailed composition of the diet formulations is presented in Table 1.

**Table 1.** Ingredient composition of experimental diets used in the feeding trial.

| Ingredients | T0(Control) | T1 | T2 | T3 |
|---|---|---|---|---|
| Soybean meal | 40 | 40 | 40 | 40 |
| Fish meal | 20 | 20 | 20 | 20 |
| Wheat meal | 32 | 32 | 32 | 32 |
| Fish oil | 6 | 4.5 | 3 | 1.5 |
| Palm oil | 0 | 1.5 | 3 | 4.5 |
| Vitamins and minerals premix* | 2 | 2 | 2 | 2 |
| Total | 100 | 100 | 100 | 100 |
| Crude protein, % | 35.80 | 34.94 | 34.87 | 35.23 |
| Gross energy, kcal/kg | 4208 | 4196 | 4234 | 4263 |

*Vitamin mineral premix /Kg contains the following: Vitamin A 700,000 IU, Vitamin D3 70,000 IU, Vitamin E 250 mg, Cobalt 250 mg, Copper 1200 mg, Iodine 325 mg, Iron 1500 mg, Magnesium 6000 mg, Potassium 100 mg, Sodium 5.9 mg, Manganese 1500 mg, Sulfur 0.72%, Zinc 9600 mg, DL-Methionine 1000 mg, Calcium 25.5%, Phosphorus 12.75%; Vitamin and mineral premix was added at 2% inclusion rate to meet NRC (2011) nutrient requirements for Nile tilapia; All ingredients are presented on an as-fed basis (g/100 g of diet); T0 = control diet; T1 = 25% palm oil; T2 = 50% palm oil; T3 = 75% palm oil

## Proximate analysis of feed ingredients

All the feed ingredients were collected and sent to the National Animal Feed and Livestock Quality Management Laboratory, Hariharbhawan, Kathmandu, for proximate analysis. The analysis was conducted using the Kjeldahl and Near Infrared Reflectance Spectroscopy (NIRS) methods (Table 2).

pISSN 2550-0910; eISSN 2579-4817
Available online at https://e-journal.unair.ac.id/JoAS

**Table 2**. Analysed composition of different feed ingredients (%, dry matter basis)

| Ingredients | Dry matter | Crude Protein | Lipid | Ash | Fiber | NFE |
|---|---|---|---|---|---|---|
| Fish Meal | 90.73 | 65.47 | 8.60 | 17.00 | 8.94 | |
| Soybean meal | 92.03 | 45.45 | 20.73 | 7.80 | 1.69 | 16.36 |
| Wheat flour | 90.47 | 10.00 | 2.90 | 1.50 | 7.50 | 68.57 |
| Palm oil | 99.20 | | ~100.00 | | | |
| Fish oil | 100.00 | | 100.00 | | | |

Source: National Animal Feed and Livestock Quality Management Laboratory, Hariharbhawan, Kathmandu and Nepal Environmental and Scientific Services Pvt. Ltd., 2021; NFE = Nitrogen free extract; Blanks denote data not available.

## Rearing conditions, Feeding regimen, and Final harvest

Feed-trained juvenile Nile tilapia with an average weight of 6–8 g were obtained from the CAARP Hatchery, Kathar, Chitwan, Nepal, and transported to the experimental facility at the Institute of Agriculture and Animal Science (IAAS), Paklihawa Campus, Rupandehi, Nepal. Upon arrival, the fish were acclimated for 14 days to local water conditions in a pond system with a dissolved oxygen (DO) level of ~5.5 mg/l, temperature ~24 °C, and pH ~7.5. During acclimatization, fish were fed a commercial diet containing 30% crude protein and 10% lipid to apparent satiation.

After acclimation, the fish were stocked into floating cages (1 m × 1 m × 1 m) at a density of 10 fish per cage. Each cage was placed within a larger earthen pond to maintain stable water conditions. Throughout the 16-week experimental period, fish were hand-fed once daily at 10:00 a.m. using isonitrogenous and isolipidic experimental diets. Feed amounts were calculated based on the total biomass in each cage. Prior to feeding, pellets were ground using a mortar and pestle to facilitate fingerlings' ingestion.

At the end of the trial, fish were harvested using a scooping net. They were anesthetized with tricaine methane sulfonate (MS-222) at ~250 mg/L for handling and humane euthanasia. Individual and batch weights were recorded using a precision electronic scale (Kerro P3 BL5002; Max 500 g; d = 0.01 g), and the total number of fish per cage was counted to evaluate growth performance and survival.

## Water Quality Parameters

Water quality parameters, including DO, pH, and temperature, were measured once daily between 11:00 a.m. and 12:00 p.m. using a portable Lutron WA-2015 multi-parameter meter. Temperature was recorded in degrees Celsius (°C) and DO in milligrams per liter (mg/L) for each observation. Additionally, Total ammonia nitrogen and nitrite nitrogen were monitored once a month using the ENPHO chemical water test kit.

## Growth parameters

The response metrics and respective formula were used to assess production performance of the fish, as presented below (Rossi and Davis *et al.*, 2012):

- Average final body weight = total group weight/number of fish
- Weight gain (g) = (final weight – initial weight) / initial weight
- Specific growth rate (SGR) (% per day) = $[(\ln W2 - \ln W1) / t] \times 100$
- Feed conversion ratio (FCR) = feed intake (g) / wet body weight gain (g)
- Protein efficiency ratio (PER) = wet body weight gain (g) / protein intake (g)

- Survival rate (%) = (final population / initial population) × 100

Where,
W1 – initial weight of fish (g)
W2 – final weight of fish (g)
t – period in days
ln – natural log

### Statistical Analysis

Data entry was carried out using Microsoft Excel 2007. Statistical analyses were conducted using R-Studio software (Version 4.2.1). Differences in the effects of treatments on the measured parameters were evaluated using one-way Analysis of Variance (ANOVA). Mean differences were assessed using Duncan's multiple range test (Duncan, 1955), with significance set at $p < 0.05$.

## RESULTS AND DISCUSSION

### Growth performance

Growth performance parameters, including initial weight, initial length, final weight (FW), final length, biomass, specific growth rate (SGR), weight gain (WG), and survival rate for the four experimental treatments are presented in Tables 3 and 4. FW ranged from 21.41 ± 1.16 g to 23.35 ± 2.01 g, and did not show significant differences between treatments ($p > 0.05$). Similarly, biomass, SGR, WG, and SR did not differ significantly ($p > 0.05$).

### Feed utilization

Feed utilization results, including feed conversion ratio (FCR) and protein efficiency ratio (PER) are presented in Table 5. No statistically significant differences were observed among the treatments ($p > 0.05$).

**Table 3**. Mean value Growth parameters of tilapia fish fed with experimental diets over 16 weeks. The data represent the mean ± SE.

| Treatments | Growth parameters | | | | |
|---|---|---|---|---|---|
| | Initial weight (g) | Initial length (g) | Final weight (g) | Final length (cm) | Biomass (g) |
| T0 | 7.65 ± 0.06$^a$ | 6.32 ± 1.18$^a$ | 21.41 ± 1.16$^a$ | 9.89 ± 0.38$^a$ | 184.60 ± 9.02$^a$ |
| T1 | 7.32 ± 1.75$^a$ | 5.95 ± 2.25$^a$ | 21.45 ± 1.28$^a$ | 9.42 ± 0.25$^a$ | 183.80 ± 8.60$^a$ |
| T2 | 8.32 ± 1.94$^a$ | 6.48 ± 1.34$^a$ | 23.35 ± 2.01$^a$ | 9.70 ± 0.03$^a$ | 213.70 ± 12.43$^a$ |
| T3 | 7.72 ± 0.03$^a$ | 6.03 ± 0.72$^a$ | 21.69 ± 1.25$^a$ | 9.17 ± 1.34$^a$ | 195.28 ± 9.55$^a$ |
| P value | >0.05 | >0.05 | >0.05 | >0.05 | >0.05 |
| CV | 20.43 | 1.738 | 15.410 | 5.066 | 9.0833 |
| LSD | 0.72 | 0.68 | 6.15 | 0.87 | 32.11 |

T0 = control diet; T1 = 25% palm oil; T2 = 50% palm oil; T3 = 75% palm oil; CV, coefficient of variation; LSD, least significant difference; SE, standard error. Mean values with different superscript letters within the same column are significantly different at $p< 0.05$.

**Table 1**. Mean value of Growth parameters and survival rate of tilapia fish fed with experimental diets over 16 weeks. The data represent the mean ± SE.

| Treatments | Growth Parameters | | |
|---|---|---|---|
| | Specific growth rate | Weight gain | Survival rate (%) |
| T0 | 1.24 ± 0.01$^a$ | 123.97 ± 2.92$^a$ | 86.67 ± 4.21$^a$ |
| T1 | 1.27 ± 0.02$^a$ | 125.47 ± 2.02$^a$ | 86.67 ± 4.21$^a$ |
| T2 | 1.24 ± 0.01$^a$ | 143.01 ± 6.60$^a$ | 93.33 ± 2.72$^a$ |
| T3 | 1.17 ± 0.04$^a$ | 126.78 ± 2.25$^a$ | 90.00 ± 3.16$^a$ |
| P- value | >0.05 | >0.05 | >0.05 |
| CV | 17.272 | 17.494 | 11.215 |
| LSD | 0.386 | 41.313 | 18.192 |

T0 = control diet; T1 = 25% palm oil; T2 = 50% palm oil; T3 = 75% palm oil; CV, coefficient of variation; LSD, least significant difference; SE, standard error. Mean values with different superscript letters within the same column are significantly different at $p< 0.05$.

**Table 5**. Mean value Growth coefficients of tilapia fish fed with experimental diets over 16 weeks. The data represent the mean ± SE.

| Treatments | Growth Parameters | |
|---|---|---|
| | Food conversion ratio | Protein efficiency ratio |
| T0 | 2.58 ± 0.02$^{a}$ | 0.63 ± 0.03$^{a}$ |
| T1 | 2.41 ± 0.06$^{a}$ | 0.65 ± 0.02$^{a}$ |
| T2 | 2.60 ± 0.05$^{a}$ | 0.69 ± 0.03$^{a}$ |
| T3 | 2.72 ± 0.11$^{a}$ | 0.68 ± 0.02$^{a}$ |
| P- value | >0.05 | >0.05 |
| CV | 18.923 | 24.204 |
| LSD | 0.899 | 0.291 |

T0 = control diet; T1 = 25% palm oil; T2 = 50% palm oil; T3 = 75% palm oil; CV, coefficient of variation; LSD, least significant difference; SE, standard error. Mean values with different superscript letters within the same column are significantly different at p< 0.05.

## Water quality

Water quality parameters varied throughout the experiment period but remained within acceptable ranges for Nile tilapia cultivation. The weekly average water temperature ranged from 15.57°C to 24.5°C, with the lowest temperature recorded in week 10. Although not optimal for maximum growth, these temperatures did not negatively impact fish performance. Dissolved oxygen (DO) levels, supported by continuous aeration, ranged from 5.1 to 10.18 mg/l, consistently meeting the physiological requirements of the species. pH values fluctuated between 6 and 9, remaining within the range tolerated by tilapia throughout the farming period.

## Discussion

## Growth performance

The present study found no significant differences in growth performance parameters among treatments, indicating that partial or full replacement of FO with PO did not adversely affect Nile tilapia growth. Although numerically higher FW and WG were observed in T2, the lack of statistical significance suggests that PO inclusion can provide comparable nutritional support for somatic growth.

This observation aligns with earlier studies (Demir *et al.*, 2014; Ochang *et al.*, 2007; Ayisi *et al.*, 2017) and can be explained by the metabolic adaptability of Nile tilapia. As an omnivorous and eurythermal species, tilapia has a flexible lipid metabolism that enables it to efficiently utilize various lipid sources, including saturated fats such as palmitic acid, which is abundant in PO (Ng *et al.*, 2003; Sargent *et al.*, 2002). Tilapia is also not entirely dependent on LC-PUFAs like marine carnivorous species. Therefore, PO can be an effective energy source, conserving dietary protein for growth in tilapia. Sargent *et al.* (2002) noted that tilapia are less dependent on long-chain polyunsaturated fatty acids (LC-PUFAs) in the diet than marine fish. Ayisi *et al.* (2014) also demonstrated better growth in tilapia fed a diet enriched with up to 6% PO, particularly for tilapia with active metabolism in tropical aquaculture.

The high survival rate in all treatments (>85%) indicates that the addition of PO does not have a negative impact on fish health. These results are consistent with the study by Turchini *et al.* (2009), which showed that PO can safely replace FO in fish. The survival results also indicate that FO does not reduce water quality or cause stress to fish during winter cage culture.

## Feed utilization

The addition of PO did not significantly affect feed utilization metrics such as FCR and

pISSN 2550-0910; eISSN 2579-4817
Available online at https://e-journal.unair.ac.id/JoAS

PER. However, the addition of PO is thought to increase energy supply and feed digestibility when added at the appropriate dose. This supports the findings of Ng *et al.* (2004), who reported that PO is energy-rich and easily digestible. This can certainly support efficient nutrient utilization even with minimal FO administration. In addition, PO indirectly contributes to better feed efficiency. This is because the saturated fat in PO is more stable during feed processing and storage, helping to maintain feed quality and palatability (Babalola and Apata, 2012).

**Water quality**

Water quality is very important for the growth, health, and survival of farmed fish. The optimal temperature range for tilapia growth is generally between 26°C and 30°C (El-Sayed, 2006). During the experiment period, water temperature fluctuated with a weekly average ranging from 15.57°C to 24.5°C, which is below the recommended range. Nevertheless, tilapia were able to survive and grow. This is due to their ability to adapt to low temperatures, especially when acclimated gradually.

The DO level remained within the optimal range, with values observed in this study ranging from 5.1 to 10.18 mg/L due to aeration. According to Abd El-Hack *et al.* (2022), maintaining DO above 5 mg/l is beneficial for optimal growth.

The pH of the water ranged from 6 to 9, which is within the generally acceptable range of 5 to 8 for tilapia (Nobre, 2014). Extreme pH values can cause stress in fish, affecting feed intake and nutrient absorption. However, no mortality or abnormal behavior was observed due to pH values during the experiment. Overall, although the water temperature was lower than ideal during the winter cultivation period, the stability of other parameters (DO and pH) likely contributed to maintaining fish performance.

## CONCLUSION

This study demonstrated that PO can partially replace FO in the diets of Nile tilapia without negatively affecting growth performance, feed utilization, or survival during winter cage culture. PO inclusion up to 50% supported comparable performance to FO-based diets, indicating its suitability as a lipid source in tilapia feed. These findings highlight the potential of PO as a nutritionally viable alternative to FO in aquafeeds. Future studies should explore its long-term effects on fish physiology and flesh quality.

## ETHICAL STATEMENT

All experimental animal procedures in this work received approval from the Ethical Review Committee of Tribhuvan University, Institute of Agriculture and Animal Science (IAAS), Department of Aquaculture, Kathmandu, Nepal. The fish were handled with care and compassion at all stages.

## FUNDING INFORMATION

The authors did not receive any full budget for this research work.

## AUTHOR CONTRIBUTIONS

RB: led the project, overseeing conceptualization, methodology, data analysis, and writing the original draft and editing the manuscript. SP: contribute to writing the original draft and data analysis. SP: contributed to the investigation, data collection, and resource management, and reviewed the manuscript. SG: resource management, reviewed and edited the manuscript. AH: reviewed and edited the manuscript.

## CONFLICT OF INTEREST

The author(s) declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

## ACKNOWLEDGEMENTS

Finally, the authors sincerely appreciate the support from Tribhuvan University/IAAS for providing essential equipment, laboratory facilities, and research ponds, which were crucial for the success of this study.

## REFERENCES

Abd El-Hack, M. E., El-Saadony, M. T., Nader, M. M., Salem, H. M., El-Tahan, A. M., Soliman, S. M., & Khafaga, A. F. (2022). Effect of environmental factors on growth performance of Nile tilapia (*Oreochromis niloticus*). International journal of biometeorology, 66(11), 2183-2194.

Ashouri, G., Hoseinifar, S. H., El-Haroun, E., Imperatore, R., & Paolucci, M. (2023). Tilapia fish for future sustainable aquaculture. In Applied environmental science and engineering for a sustainable future (pp. 1–47).

Ayisi, C. L., Zhao, J., & Rupia, E. J. (2017). Growth performance, feed utilization, body and fatty acid composition of Nile tilapia (*Oreochromis niloticus*) fed diets containing elevated levels of palm oil. Aquaculture and Fisheries, 2(2), 67–77.

Ayisi, C. L., Zhao, J., Yame, C., Apraku, A., & Debra, G. (2019). Effects of replacing fish oil with palm oil in diets of Nile tilapia (*Oreochromis niloticus*) on muscle biochemical composition, enzyme activities, and mRNA expression of growth-related genes. Fisheries and Aquatic Sciences, 22(1).

Babalola, T., & Apata, D. (2012). Effect of dietary palm oil on growth and carcass composition of *Heterobranchus longifilis* fingerlings. Journal of Central European Agriculture, 13(4), 782–791.

Bhatta, R., Pandey, S., Gurung, S., & Hossain, A. (2025). Effect of moringa leaf meal supplementation on growth performance and survival of mono sex tilapia (*Oreochromis niloticus*) in cage culture during winter season. International Journal of Fisheries and Aquaculture, 17(2), 39-47.

Boyd, C. E., McNevin, A. A., & Davis, R. P. (2022). The contribution of fisheries and aquaculture to the global protein supply. Food Security, 14(3), 805–827.

De Souza Alves, L. F., Rocha, J. D. M., Cardoso, M. D. S., De Freitas, J. M. A., Feiden, A., & Boscolo, W. R. (2021). Palm oil in diets for Nile tilapia (*Oreochromis niloticus*) post-larvae. Research Society and Development, 10(14), e510101422099.

Demir, O., Turker, A., Acar, U., & Kesbic, O. S. (2014). Effects of dietary fish oil replacement by unrefined peanut oil on the growth, serum biochemical and hematological parameters of Mozambique tilapia juveniles (*Oreochromis mossambicus*). Turkish Journal of Fisheries and Aquatic Sciences, 14(4).

Du, Z., Tian, L., Liang, G., & Liu, Y. (2009). Effect of Dietary Energy to Protein Ratios on Growth Performance and Feed Efficiency of Juvenile Grass Carp (*Ctenopharyngodon idella*). The Open Fish Science Journal, 2(1), 25–31.

El-Sayed, A. F. M. (2006). *Tilapia culture*. CABI Publishing.

Fastmarkets. (2024, February 14). *Palm oil price and production outlook*. Fastmarkets Palm Oil Analytics. Retrieved from https://www.fastmarkets.com/insights/palm-oil-price-and-production-outlook/ (accessed on 22 July 2025).

Gee, P. T. (2007). Analytical characteristics of crude and refined palm oil and fractions. European Journal of Lipid Science and Technology, 109(4), 373–379.

Glencross, B. D. (2009). Exploring the nutritional demand for essential fatty acids by aquaculture species. Reviews in Aquaculture, 1(2), 71–124.

Grimaldi, R., Gonçalves, L. a. G., & Ando, M. Y. (2005). Otimização da reação de interesterificação química do óleo de palma. Química Nova, 28(4), 633–636.

Hua, K., Cobcroft, J. M., Cole, A., Condon, K., Jerry, D. R., Mangott, A., Praeger, C., Vucko, M. J., Zeng, C., Zenger, K., & Strugnell, J. M. (2019). The Future of Aquatic Protein: Implications for Protein Sources in Aquaculture Diets. One Earth, 1(3), 316-329.

Menoyo, D., López-Bote, C. J., Obach, A., & Bautista, J. M. (2005). Effect of dietary fish oil substitution with linseed oil on the performance, tissue fatty acid profile, metabolism, and oxidative stability of Atlantic salmon1,2. Journal of Animal Science, 83(12), 2853–2862.

Mishra, R. N., & Kunwar, P. S. (2014). Status of aquaculture in Nepal. Nepalese Journal of Aquaculture and fisheries, 1, 1-17.

Mu, H., Wei, C., Zhang, Y., Zhou, H., Pan, Y., Chen, J., Zhang, W., & Mai, K. (2019). Impacts of replacement of dietary fish oil by vegetable oils on growth performance, anti-oxidative capacity, and inflammatory response in large yellow croaker *Larimichthys crocea*. Fish Physiology and Biochemistry, 46(1), 231–245.

National Research Council (NRC). (2011). Nutrient requirements of fish and shrimp. National Academies Press

Ng, W., Lim, P., & Boey, P. (2003). Dietary lipid and palm oil source affects growth, fatty acid composition and muscle α-tocopherol concentration of African catfish, *Clarias gariepinus*. Aquaculture, 215(1–4), 229–243.

Ng, W., Wang, Y., Ketchimenin, P., & Yuen, K. (2004). Replacement of dietary fish oil with palm fatty acid distillate elevates tocopherol and tocotrienol concentrations and increases oxidative stability in the muscle of African catfish, *Clarias gariepinus*. Aquaculture, 233(1–4), 423–437.

Nobre, M. K. B., Lima, F. R. D. S., & Magalhães, F. B. (2014). Alternative liming blends for fish culture. Acta Scientiarum. Animal Sciences, 36, 11-16.

Ochang, S. N., Fagbenr, O. A., & Adebayo, O. T. (2007). Influence of Dietary Palm Oil on Growth Response, Carcass Composition, Haematology and Organoleptic Properties of Juvenile Nile Tilapia, *Oreochromis niloticus*. Pakistan Journal of Nutrition, 6(5), 424–429.

Peng, X., Li, F., Lin, S., & Chen, Y. (2015). Effects of total replacement of fish oil on growth performance, lipid metabolism and antioxidant capacity in tilapia (*Oreochromis niloticus*). Aquaculture International, 24(1), 145–156.

Prabu, E., Felix, S., Felix, N., Ahilan, B., & Ruby, P. (2017). An overview on significance of fish nutrition in aquaculture industry. International Journal of Fisheries and Aquatic Studies, 5(6), 349-355.

Rossi, W., & Davis, D. A. (2012). Replacement of fishmeal with poultry by-product meal in the diet of Florida pompano *Trachinotus carolinus* L. Aquaculture, 338–341, 160–166.

Sargent, J. R., Tocher, D. R., & Bell, J. G. (2002). The lipids. In J. E. Halver & R. W. Hardy (Eds.), *Fish nutrition* (3rd ed., pp. 181–257). Academic Press.

Turchini, G. M., Torstensen, B. E., & Ng, W. (2009). Fish oil replacement in finfish nutrition. Reviews in Aquaculture, 1(1), 10–57.

Xu, D., Xiang, X., Li, X., Xu, N., Zhang, W., Mai, K., & Ai, Q. (2022). Effects of Dietary Vegetable Oils Replacing Fish Oil on Fatty Acid Composition, Lipid Metabolism and Inflammatory Response in Adipose Tissue of Large Yellow Croaker (*Larimichthys crocea*). Journal of Marine Science and Engineering, 10(11), 1760.