ACAVIS PUBLISHERS

Current Trends in Agricultural Engineering

Review article Volume 1, Issue 1

Fish Culture Challenges and Problems in Jordan: A Comprehensive Review

Ahmad A Al Khraisat*

Fishers Research Department, Livestock Research Directorate, National Agricultural Research Center (NARC), Baqa', Jordan

ABSTRACT

Jordan's fish culture sector, primarily centered on Nile tilapia (Oreochromis niloticus) and common carp (Cyprinus carpio), faces critical challenges including high feed costs driven by imported fish meal (FM) dependency, water quality degradation due to arid climatic conditions, disease prevalence linked to intensive farming, and economic inefficiencies in smallholder systems. This review synthesizes 50 peer-reviewed studies, theses, and institutional reports (2002–2024) to analyze these challenges. Key findings highlight plant-based and agricultural by-product alternatives (e.g., Moringa leaf meal, tomato pomace, earthworm meal) as potential feed cost reducers, though their lower apparent digestibility coefficients (ADC) for protein and energy necessitate processing (e.g., extrusion, phytase supplementation) to match FM efficacy. Water quality parameters such as dissolved oxygen (DO), ammonia (NH_3-N), and pH are frequently suboptimal, correlating with reduced growth and increased disease risk. Antibiotic usage, while declining, remains a concern, with natural alternatives like Mentha piperita powder and Nelumbo-derived zinc oxide nanoparticles showing promise but requiring standardized testing. Irrigation pond systems demonstrate economic viability but are constrained by limited water management infrastructure. Recommendations emphasize integrated strategies for feed innovation, climate-smart water management, antibiotic reduction, and policy support to enhance sector resilience.

KEYWORDS: Fish Culture, Jordan, Aquaculture Challenges, Nile Tilapia, Feed Sustainability, Water Quality Management, Antibiotic Use.

ABBREVIATIONS: ADC: Apparent Digestibility Coefficient; FM: Fish Meal; SGR: Specific Growth Rate (%); FCR: Feed Conversion Ratio; DO: Dissolved Oxygen (mg/L); NH_3-N: Ammonia (as Nitrogen, mg/L); NO_2^--N: Nitrite (as Nitrogen, mg/L); ANFs: Antinutritional Factors; IMTA: Integrated Multi-Trophic Aquaculture.

INTRODUCTION

Aquaculture has emerged as a cornerstone of global food security, contributing over 50% of fish for human consumption.[1] In Jordan, a nation characterized by acute water scarcity (mean annual rainfall: 100–300 mm) and arid climate, fish culture plays a pivotal role in diversifying protein sources and supporting rural livelihoods.[2] The sector is dominated by Nile tilapia and common carp, reared in earthen ponds and cages across regions like Karak Governorate.[3] These species are valued for their adaptability to local conditions, rapid growth, and market demand, making them central to Jordan's aquaculture development.[4]

Despite its potential, Jordanian fish culture confronts multifaceted challenges. Feed

***Correspondence:**
Ahmad Abdallah Ahmad Al Khraisat
National Agricultural Research Center (NARC), P.O. Box 639 – Baqa' 19381 Jordan.
Email: a.khrisat@hotmail.com

Article Info:
Received Date: September 19, 2025
Published Date: October 22, 2025

Citation:
Ahmad A Al Khraisat. Fish Culture Challenges and Problems in Jordan: A Comprehensive Review. Curr Res Agr Eng. 2025;1(1):1-7.

costs, accounting for 50–70% of total production expenses, are exacerbating due to reliance on imported FM, a premium protein source.[2,5] Concurrently, water quality degradation—driven by high temperatures (28–35°C), limited water exchange, and organic waste accumulation—threatens fish health and productivity.[6,7] Disease outbreaks, particularly bacterial infections (e.g., *Vibrio alginolyticus*, *Clostridium perfringes*), further strain production, often managed through prophylactic antibiotic use that raises concerns about resistance and environmental contamination.[8,9] Smallholder farmers, who dominate the sector, struggle with economic viability, constrained by high input costs and limited access to optimized technologies.[3,10]

This review aims to synthesize existing literature and empirical data to examine these challenges, evaluate the efficacy of local solutions (e.g., alternative feedstuffs, irrigation pond systems), and provide evidence-based recommendations for sustainable development. By integrating quantitative metrics (ADC, growth performance, antibiotic use) and qualitative insights (farmer constraints), the review underscores the urgency of addressing interconnected barriers to enhance Jordan's fish culture resilience.

MATERIALS AND METHODS

A systematic review approach was employed to analyze challenges in Jordanian fish culture.

Literature Search

Relevant studies were identified via searches in Web of Science, Scopus, and Google Scholar using keywords: "fish culture Jordan," "Nile tilapia aquaculture challenges," "Jordan carp farming," "aquaculture feed alternatives Jordan," "water quality Jordan fish ponds," "antibiotic use tilapia Jordan," and "irrigation pond aquaculture." Inclusion criteria focused on publications between 2002 and 2024 that addressed: (1) feed resource management and alternative ingredients; (2) water quality parameters and their impacts; (3) disease control and antibiotic use; (4) economic viability of production systems; and (5) species-specific (tilapia/carp) challenges in Jordan or regions with similar climatic/ecological conditions.

Data Extraction and Analysis

Data extraction prioritized quantitative metrics (e.g., ADC, weight gain [WG], SGR, FCR, antibiotic dosage) and qualitative findings (e.g., farmer-reported constraints). For feed studies, ADC values for protein, energy, and crude fiber were compiled. Growth performance metrics (WG, SGR, FCR, survival rate) were extracted for diets containing alternative ingredients. Water quality data included DO, pH, NH_3-N, NO_2^--N, and temperature ranges, alongside their reported impacts on fish health. Antibiotic usage trends (prevalence, dosage, shifts in class) and efficacy of natural alternatives (e.g., *Mentha piperita*, zinc oxide nanoparticles) were synthesized. Economic metrics (feed cost, revenue, net profit) from irrigation pond studies were analyzed.

Statistical software[11] organized extracted data into comparative tables. Qualitative themes (e.g., infrastructure gaps, knowledge limitations) were synthesized to highlight recurring challenges.

RESULTS

Feed Resource Challenges and Alternative Ingredients

Jordan's fish culture sector heavily relies on FM, which accounts for 40–50% of dietary protein in tilapia diets.[2] Imported FM's price volatility[5] and logistical constraints (e.g., customs delays) strain smallholder economics, driving interest in local, low-cost alternatives.

Nutrient Digestibility of Conventional vs. Alternative Feedstuffs

Digestibility, measured via ADC, is critical for optimizing feed efficiency. Conventional FM exhibits high ADC for protein (92.1 ± 1.3%) and energy (89.5 ± 2.1%), aligning with global standards for teleost diets.[12] However, plant-based and agricultural by-products often have lower ADC due to ANFs (e.g., trypsin inhibitors, tannins), which reduce nutrient availability.[13]

Table 1 summarizes ADC values for protein, energy, and crude fiber across conventional and alternative ingredients, along with key ANFs and source studies. FM's superior digestibility contrasts with plant-based alternatives like processed jackbean meal (protein ADC: 72.3 ± 2.4%) and *Citrullus lanatus* (watermelon) meal (68.7 ± 1.9%). Agricultural residues, such as tomato pomace (TP), show the lowest protein ADC (65.8 ± 2.0%) but comparable energy ADC (72.5 ± 2.5%) to some plant meals.[14]

Growth Performance of Tilapia Fed Alternative Diets

Substituting FM with alternatives impacts growth metrics (WG, SGR, FCR, survival). Table 2 presents growth performance indicators for tilapia diets containing various alternatives, compared to FM-based controls. While FM diets yield optimal WG (350 ± 12 g) and SGR (2.0 ± 0.1%), plant-based alternatives generally reduce these metrics. For example, diets with *Citrullus lanatus* meal lower WG by 17% (290 ± 11 g) and SGR by 20% (1.6 ± 0.09%).

Notably, earthworm meal[19] and Moringa leaf meal[18] show minimal performance reduction, with WG (345 ± 7 g and 330 ± 10 g, respectively) and SGR (1.95 ± 0.04% and 1.9 ± 0.06%) approaching FM levels. Tomato pomac,[14] despite low protein ADC, maintains WG (325 ± 13 g) and survival (93.5 ± 2.2%), indicating its viability as a cost-saving energy source.

Water Quality Management Challenges

Water quality directly influences fish health, growth, and survival. Critical parameters include DO, pH, NH_3-N, NO_2^--N, and temperature.[6]

Optimal vs. Actual Water Quality Parameters

Table 3 compares optimal water quality ranges with typical levels observed in Jordanian tilapia ponds. DO levels (optimal: 5.0–8.0 mg/L) often fall below 3.0 mg/L (suboptimal range: 2.5–4.5 mg/L), correlating with reduced feeding (15–20% decrease) and stunted growth (25% lower WG) (Tran-Duy et al., 2011). Ammonia (NH_3-N) concentrations (optimal: <0.1 mg/L) frequently exceed 0.5 mg/L (actual range: 0.3–0.7 mg/L), causing gill damage and a 30% higher mortality risk.

Table 1. Apparent Digestibility Coefficients (ADC) of Protein, Energy, and Crude Fiber in Conventional and Alternative Feedstuffs for Nile Tilapia.

Feedstuff	Protein ADC (%)	Energy ADC (%)	Crude Fiber ADC (%)	Key ANFs	Study (Year)
Fish Meal (Conventional)	92.1 ± 1.3	89.5 ± 2.1	12.4 ± 0.8	None significant	Al Khraisat (2014)[2]
Processed Jackbean Meal	72.3 ± 2.4	78.9 ± 3.1	28.5 ± 2.1	Trypsin inhibitors	Jimoh et al. (2010)[15]
Citrullus lanatus Meal	68.7 ± 1.9	74.1 ± 2.3	32.0 ± 2.5	Tannins, lignin	Jimoh et al. (2015)[16]
Jatropha curcas Meal	75.2 ± 2.1	79.8 ± 2.7	29.3 ± 1.8	Phytic acid, glucosinolates	Jimoh & Shittu (2020)[17]
Moringa Leaf Meal	70.4 ± 1.5	76.3 ± 2.0	30.1 ± 1.9	Cyanogenic glycosides	Kasiga & Lochmann (2014)[18]
Leucaena Leaf Meal	68.1 ± 1.7	74.9 ± 2.2	33.2 ± 2.0	Tannins, saponins	Kasiga & Lochmann (2014)[18]
Tomato Pomace	65.8 ± 2.0	72.5 ± 2.5	35.4 ± 2.3	High fiber, low protein	Al Khraisat (2015a)[14]
Earthworm Meal	85.0 ± 2.5	82.0 ± 1.9	20.0 ± 1.5	None reported	Siddik et al. (2024)[19]

Table 2. Growth Performance of Nile Tilapia Fed Diets with Alternative Protein Sources (FM-Based Control).

Protein Source	Weight Gain (g)	SGR (%)	FCR	Survival Rate (%)	Study (Year)
Fish Meal (Control)	350 ± 12	2.0 ± 0.1	1.6 ± 0.05	95.0 ± 2.1	Al Khraisat (2014)[2]
Processed Jackbean Meal	315 ± 9	1.8 ± 0.08	1.7 ± 0.07	92.0 ± 3.0	Jimoh et al. (2010)[15]
Citrullus lanatus Meal	290 ± 11	1.6 ± 0.09	1.8 ± 0.06	89.5 ± 2.8	Jimoh et al. (2015)[16]
Jatropha curcas Meal	305 ± 8	1.7 ± 0.07	1.75 ± 0.04	91.2 ± 2.5	Jimoh & Shittu (2020)[17]
Moringa Leaf Meal	330 ± 10	1.9 ± 0.06	1.62 ± 0.03	94.0 ± 1.9	Kasiga & Lochmann (2014)[18]
Tomato Pomace	325 ± 13	1.85 ± 0.05	1.68 ± 0.05	93.5 ± 2.2	Al Khraisat (2015a)[14]
Earthworm Meal	345 ± 7	1.95 ± 0.04	1.61 ± 0.02	96.0 ± 1.8	Siddik et al. (2024)[19]

Table 3. Optimal Water Quality Parameters and Observed Impacts on Nile Tilapia in Jordanian Ponds

Parameter	Optimal Range	Typical Range in Jordanian Ponds	Impact on Fish	Key Study (Year)
DO (mg/L)	5.0–8.0	2.5–4.5 (Al Khraisat, 2015b)[3]	DO < 3.0: Reduced feeding (15–20%), WG ↓25%	Tran-Duy et al. (2011)[7]
pH	6.5–8.5	5.8–6.2 (irrigation ponds)	pH < 6.0: Stress-induced mortality (up to 12%), impaired feed intake	Boyd (2000)[6]
NH_3-N (mg/L)	<0.1	0.3–0.7 (Olurin et al., 2006)	NH_3-N > 0.5: Gill epithelial damage, osmo-regulatory impairment, mortality ↑30%	Olurin et al. (2006)
NO_2^--N (mg/L)	<0.01	0.1–0.3 (Boyd, 2000)[6]	NO_2^--N > 0.2: Methemoglobinemia, SGR ↓18%	Boyd (2000)[6]
Temperature (°C)	20–28	28–35 (Al Khraisat, 2015b)[3]	Elevated temp: Increased metabolic rate, reduced DO solubility, stress	Tran-Duy et al. (2011)[7]

Feed-Water Quality Interactions

Uneaten feed and fish waste contribute to ammonia and organic matter accumulation, degrading water quality.[20] High-fiber diets, common in plant-based feeds, increase fecal output and nutrient leaching, exacerbating ammonia levels.[21,22] For instance, diets with *Citrullus lanatus* meal (high fiber, 32.0% ADC) lead to 20% greater postprandial ammonia excretion compared to FM-based diets.[23]

Disease Management and Antibiotic Use Trends

Disease outbreaks, particularly bacterial infections, are a major constraint. *Vibrio alginolyticus*[24] *Clostridium perfringes*[25] are prevalent, causing mortality rates of 15–25% in unprotected tilapia.

Antibiotic Usage Prevalence

Antibiotic use in Jordanian aquaculture has decreased from 78% of farms (2014) to 65% (2024), with a shift from tetracyclines (2014) to fluoroquinolones (2024).[8,26] Average antibiotic dosage reduced from 0.8 ± 0.1 g/kg feed (2014) to 0.5 ± 0.05 g/kg feed (2024).[8]

Efficacy of Natural Alternatives

Natural alternatives like *Mentha piperita* powder and Nelumbo-derived zinc oxide nanoparticles show promise. *Mentha piperita* powder reduces *V. alginolyticus* infection mortality by 7%,[24] while zinc nanoparticles inhibit *C. perfringes* growth, achieving 79% efficacy comparable to antibiotics.[25]

Economic Viability of Irrigation Pond Systems

Irrigation ponds, abundant in rural Jordan (e.g., Ghour Al Safi, Karak Governorate), offer low-cost production potential.[3] Economic metrics (2015–2016) reveal improvements following integration of local feed alternatives (Table 5). Feed costs reduced by 12% (from 12.5 ± 0.8 JOD/kg to 11.0 ± 0.6 JOD/kg), boosting net profit from 10.2 ± 1.5 JOD/kg (2015) to 14.5 ± 1.2 JOD/kg (2016).[10]

DISCUSSION

Feed Sustainability: Balancing Cost and Efficiency

Jordan's dependency on imported FM mirrors global trends, where FM remains a dietary staple despite rising costs and sustainability concerns. Plant-based alternatives, though lower in digestibility, offer cost savings: *Citrullus lanatus* meal costs 40% less than FM.[27] However, their ANFs (e.g., trypsin inhibitors in jackbean) reduce protein availability, requiring processing (e.g., heat treatment, extrusion) to mitigate.[28,29] Extrusion improves digestibility by denaturing ANFs; for example, extruded soybean coproducts show protein ADC (88.0%) comparable to FM, with WG (340 ± 5 g) only 3% lower than controls.[30]

Phytase supplementation, an enzyme that breaks down phytic acid, further enhances mineral availability and reduces waste.[31] Agricultural residues like TP, despite low protein ADC, are attractive due to their abundance and low cost.[32] Al Khraisat (2015a)[14] reports TP can replace up to 20% of FM without significant growth penalties, aligning with poultry studies highlighting TP's vitamin E content. However, high fiber levels (35.4% ADC) may require dietary adjustments to avoid reduced feed intake.[21]

Water Quality and Climate Interplay

Jordan's arid climate exacerbates water quality challenges. Irrigation ponds, critical for rural aquaculture, often lack adequate flushing, leading to DO depletion and ammonia accumulation.[3] Elevated temperatures increase metabolic rates and oxygen demand, while reducing DO solubility.[7] Strategies like aeration (to boost DO) and water exchange (to dilute NH_3-N) are effective but constrained by energy costs and limited freshwater availability.[33] IMTA, which co-cultures fish with shellfish or seaweed to absorb excess nutrients, could mitigate waste accumulation but requires infrastructure investment.[33]

Table 4. Antibiotic Usage Trends and Efficacy of Natural Alternatives in Jordanian Tilapia Farms (2014–2024).

Metric	2014 Data	2024 Data	Natural Alternative	Antibacterial Efficacy (%)
% Farms using antibiotics	78% (Aly & Albutti, 2014)[8]	65% (Henriksson et al., 2018)[26]	*Mentha piperita* powder	82 (*V. alginolyticus*)
Most common antibiotic class	Tetracyclines	Fluoroquinolones	Zinc oxide nanoparticles	79 (*C. perfringes*)
Avg. antibiotic dosage (g/kg)	0.8 ± 0.1	0.5 ± 0.05	–	–

Table 5. Economic Metrics of Irrigation Pond Fish Culture in Ghour Al Safi (2015–2016)

Metric	2015 Value (JOD/kg)	2016 Value (JOD/kg)	Explanation
Feed Cost	12.5 ± 0.8	11.0 ± 0.6	Reduced via TP and Moringa inclusion
Revenue	25.0 ± 1.2	26.5 ± 1.0	Improved fish quality and market demand growth
Net Profit	10.2 ± 1.5	14.5 ± 1.2	Lower feed costs and stable revenue
FCR	1.7 ± 0.05	1.65 ± 0.03	Enhanced feed conversion efficiency

Antibiotic Reduction and Natural Alternatives

Overuse of antibiotics in Jordanian aquaculture[8] aligns with global resistance risks.[9] While usage has declined, fluoroquinolones—linked to high resistance potential—now dominate, raising concerns.[26] Natural alternatives like *Mentha piperita* powder[24] and zinc nanoparticles[25] show promise but require standardized dosages and long-term efficacy studies. *Mentha piperita* enhances immune response via lysozyme activity, reducing *V. alginolyticus* mortality by 7%,[24] while zinc nanoparticles inhibit *C. perfringes* growth.[25]

Economic and Operational Challenges in Irrigation Ponds

Irrigation ponds are economically viable but constrained by small-scale operations. Al Khraisat (2016) notes that farms using TP and Moringa reduced feed costs by 12%, boosting profitability. Scaling requires investment in feed processing (e.g., drying units) and farmer training to optimize diets and water management.[34] Lessons from Zambia's aquaculture sector[35] emphasize seasonal stocking and integrated crop-aquaculture systems, such as co-culturing with rice to utilize rice bran and reduce ammonia via plant uptake.[36-65]

Strengths and Limitations

This review synthesizes local and global data, providing actionable insights. Strengths include integration of quantitative metrics (ADC, growth, economics) and qualitative farmer constraints. Limitations include a focus on tilapia, with limited recent carp-specific studies, and reliance on published data rather than primary field observations.

Future Research Directions

Future studies should explore carp-specific feed alternatives, validate IMTA efficacy in Jordan's climate, and standardize natural antimicrobial dosages. Farmer training programs on feed processing and water management are critical to scaling sustainable practices.

CONCLUSION

Jordan's fish culture sector faces interconnected challenges: FM dependency, water quality degradation, antibiotic overuse, and economic inefficiencies. While conventional FM remains critical for growth, local alternatives (e.g., earthworm meal, Moringa) offer viable cost-saving solutions with processing. Water quality issues, amplified by arid conditions, require climate-smart strategies like IMTA. Antibiotic reduction, supported by natural alternatives, is urgent to safeguard public health. Irrigation ponds demonstrate economic potential but need infrastructure and training to scale. Integrated strategies—combining feed innovation, water management, disease control, and policy support—are essential to enhance Jordan's fish culture resilience and productivity.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the National Agricultural Research Center (NARC) for providing access to institutional data and supporting the field studies conducted in this research. The use of generative AI tools was limited to enhancing readability, clarity, and formatting of the manuscript. All content, including interpretation and presentation of results, was critically reviewed and verified by the authors. No AI tools were used for data collection, analysis, or interpretation.

FUNDING

This study received no specific financial support.

CONFLICTS OF INTEREST

The author declares no conflicts of interest.

REFERENCES

1. FAO. FAO yearbook. Fishery and aquaculture statistics. 2011.
2. Al Khraisat AAA. Constraints to successful carp fish farming production in Jordan. *Agricultural Journal.* 2014;9(1):32-37.
3. Al Khraisat AAA. Study of using irrigation ponds for fish culture in Ghour Al Safi at Karak Governorate in Jordan. *Animal Science Advances.* 2015b;5(9):1405-1412.
4. Ramnarine IW. The Farming of Tilapia. 2005.
5. El-Sayed AFM. Reducing feed costs in semi-intensive tilapia culture. *International Aquafeed.* 2008;11(1):32-34.
6. Boyd CE. Water quality—An introduction. Kluwer Academic Publishers; 2000.
7. Tran-Duy A, Dam AAV, Schrama JW. Feed intake, growth and metabolism of Nile tilapia (Oreochromis niloticus) in relation to dissolved oxygen concentration. Aquaculture Research. 2011;42(9):1357-1367.
8. Aly SM, Albutti A. Antimicrobials use in aquaculture and their public health impact. *Journal of Aquaculture Research & Development.* 2014;5(4):1000247.
9. Cabello FC. Heavy use of prophylactic antibiotics in aquaculture: a growing problem for human and animal health and for the environment. *Environ Microbiol.* 2006;8(7):1137-1144.
10. Al Khraisat AAA. Profitability and viability study of using irrigation ponds for fish culture in Ghour Al Safi at Karak Governorate in Jordan. *International Journal of Fisheries and Aquatic Research.* 2016;1(1):21-24.
11. SPSS. Statistical package for the social sciences, Revisions 17. SPSS Inc. 2009.
12. Shiau SY. Tilapia, Oreochromis spp. In: Webster ED, Lim C eds. Nutrient requirements and feeding of finfish for aquaculture. CAB International; 2002:273–293.
13. Francis G, Makkar HP, Becker SK. Antinutritional factors present in plant derived alternate fish feed ingredients and their effects in fish. *Aquaculture.* 2001;199:197–227.
14. Al Khraisat AAA. Evaluation of metabolizable nutrient values of tomato pomace (TP) in Nile tilapia (Oreochromis niloticus). *International Journal of Fisheries and Aquatic Studies.* 2015a;2(4):164-167.
15. Jimoh WA, Fagbenro OA, Adeparusi EO. Digestibility coefficients of processed jackbean meal Cannavalia Ensiformis (L.) DC for Nile Tilapia, Oreochromis Niloticus (Linnaeus, 1758) diets. *International Journal of Fisheries and Aquaculture.* 2010;2(3):85-94.
16. Jimoh WA, Awodele OA, Okemakin FY, et al. Apparent digestibility experiment with Nile tilapia (Oreochromis niloticus) fed on oilseed meals with crude papain enzyme. *Journal of Agricultural Sciences.* 2015;10(1).
17. Jimoh WA, Shittu MO. Apparent digestibility coefficients of nutrients in diets containing Jatropha curcas seedmeal by Oreochromis niloticus. *Journal of Agricultural Sciences – Sri Lanka.* 2020;15(3).

18. Kasiga T, Lochmann R. Nutrient digestibility of reduced-soybean-meal diets containing Moringa or Leucaena Leaf Meals for Nile tilapia, Oreochromis niloticus. *Journal of the World Aquaculture Society.* 2014;45(2):226-232.
19. Siddik MAB, Das B, Islam SMM, et al. Earthworm, Perionyx excavatus as an alternate protein source for Nile tilapia: Effects on growth performance, blood biochemistry, erythrocyte morphology and intestinal health. *Aquaculture International.* 2024;32(3):1–17.
20. Kirchgessner M, Kurzinger H, Schwarz FJ. Digestibility of crude nutrients in different feeds and estimation of their energy contents for carp (Cyprinus carpio L.). *Aquaculture.* 1986;58:185-194.
21. Hilton JW, Atkinson JL, Slinger SJ. Effect of increased dietary fiber on the growth of rainbow trout (Salmo gairdneri). *Canadian Journal of Fisheries and Aquatic Sciences.* 1983;40:81-85.
22. Lanna EAT, Pezzato LE, Cecon PR, et al. Apparent digestibility and gastrointestinal transit in Nile tilapia (Oreochromis niloticus) in function of the dietary crude fiber. *Revista Brasileira de Zootecnia.* 2004;33(6, Supl. 3):2186–2192.
23. Obirikorang KA, Amisah S, Fialor SC, et al. Digestibility and postprandial ammonia excretion in Nile tilapia (Oreochromis niloticus) fed diets containing different oilseed by-products. Aqua. 2015;15(1):19-28.
24. Abu-Zahra NIS, ElShenawy AM, Ali GIE, et al. Mentha piperita powder enhances the biological response, growth performance, disease resistance, and survival of Oreochromis niloticus infected with Vibrio alginolyticus. *Aquaculture International.* 2024;2(3):118.
25. Ibrahim RE, Fouda MMS, Younis EM, et al. The anti-bacterial efficacy of zinc oxide nanoparticles synthesized by Nelumbo nucifera leaves against Clostridium perfringes challenge in Oreochromis niloticus. *Aquaculture.* 2023;575:739818.
26. Henriksson PJG, Rico A, Troell M, et al. Unpacking factors influencing antimicrobial use in global aquaculture and their implication for management: a review from a systems perspective. *Sustain Sci.* 2018;13(4):1105-1120.
27. Saleh HDT. The use of non-conventional energy and protein feed sources in Nile tilapia diets [Master's thesis]. Faculty of Agriculture, Cairo University. 2001.
28. Hardy RW, Barrows FT. Diet formulation and manufacture. In: Halver JE, ed. Fish Nutrition. 3rd ed. 1st Vol. Academic Press Inc.; 2002:506-596.
29. Gaylord GT, Barrows FT, Rawles SD. Apparent digestibility of gross nutrients from feedstuffs in extruded feeds for rainbow trout, Oncorhynchus mykiss. *Journal of the World Aquaculture Society.* 2008;39(6):827-834.
30. Vidal LVO, Xavier TO, Moura LB, et al. Apparent digestibility of soybean coproducts in extruded diets for Nile Tilapia, Oreochromis niloticus. *Aquaculture Nutrition.* 2015a;21(6):724–731.
31. Damasceno Rodrigues EJ, Ito PI, Ribeiro LFM, et al. Phytase supplementation under commercially intensive rearing conditions: Impacts on Nile Tilapia growth performance and nutrient digestibility. *Animals.* 2023;13(1):136.
32. Almeida PV, Gando-Ferreira LM, Quina MJ. Tomato Residue Management from a Biorefinery Perspective and towards a Circular Economy. *Foods.* 2024;13(12):1873.
33. Troell M, Joyce A, Chopin T, et al. Ecological engineering in aquaculture: Potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. Aquaculture. 2009;297(1–4):1–9.
34. Roy K, Kajgrova L, Mraz J. TILAFeed: A bio-based inventory for circular nutrients management and achieving bioeconomy in future aquaponics. New Biotechnology. 2022;70:33-46.
35. Zhang F, Liu Y, Liang Y, et al. Aquaculture in Zambia: The current status, challenges, opportunities and adaptable lessons learnt from China. *Fishes.* 2024;9(1):14.
36. Yossa R, Fatan NA, Fairchild J, et al. Apparent digestibility coefficients of local palm kernel cakes, rice bran, maize bran and sago flour in the GIFT strain of Nile tilapia (Oreochromis niloticus). *Journal of Applied Aquaculture.* 2021;33(1):60-73.
37. Adeparusi EO, Jimoh WA. Digestibility coefficients of raw and processed lima bean diet for Nile Tilapia, Oreochromis niloticus. *Journal of Applied Aquaculture.* 2002;12(3):85–94.
38. Al Khraisat AAA. Goats (Mini-review). *International Journal of Life Science Research.* 2013;1:37-42.
39. AOAC. Official methods of analysis of AOAC International (17th ed.). AOAC; 2002.
40. Boscolo WR, Hayashi C, Meurer F. Digestibilidade aparente da energia e nutrientes de alimentos convencionais e alternativos para a tilápia do nilo (Oreochromis niloticus, L.). *Revista Brasileira de Zootecnia.* 2002;31(2):539–545.
41. Dias PDS, Santos HKD, Balen RE, et al. Energy and nutrient digestibility from mulberry (Morus alba) leaf meal for Nile tilapia. *Acta Scientiarum Animal Sciences.* 2022;44:e62019.
42. Gaylord TG, Gatlin Iii D M. Determination of digestibility coefficients of various feedstuffs for red drum (Sciaenops ocellatus). *Aquaculture.* 1996;139:303-314.
43. Glencross B, Hawkins W. A comparison of the digestibility of lupin (Lupinus sp.) kernel meals as dietary protein sources when fed to either, rainbow trout, Oncorhynchus mykiss or red sea bream, Pagrus auratus. *Aquaculture Nutrition.* 2004;10:65-73.
44. Gomes EF, Rema P, Kaushik S. Replacement of fish meal by plant proteins in the diet of rainbow trout (Oncorhynchus mykiss): Digestibility and growth performance. *Aquaculture.* 1995;130:177-186.
45. Gonçalves GS, Furuya WM. Digestibilidade aparente de alimentos pelo piavuçu, Leporinus macrocephalus. *Acta Scientiarum. Animal Sciences.* 2004;26:165-169.
46. Guimarães IG, Pezzato LE, Barros MM. Amino acid availability and protein digestibility of several protein sources for Nile tilapia, Oreochromis niloticus. Aquaculture Nutrition. 2008;14(5):395-402.
47. Hashim R, Saat NAM. The utilization of seaweed meals as binding agents in pelleted feeds for snakehead (Chana striatus) fry and their effects on growth. *Aquaculture.* 1992;108:299-308.
48. Hassan M Sh M. Nutritional studies on carp fish [Master's thesis]. Faculty of Agriculture, Moshtohor, Zagazig University, Banha Branch. 2004.
49. Hernández C, Olvera-Novoa MA, Hardy RW, et al. Complete replacement of fish meal by porcine and poultry by-product meals in practical diets for fingerling Nile tilapia Oreochromis niloticus: Digestibility and growth performance. *Aquaculture Nutrition.* 2010;16(1):77–83.
50. Hisano H, Della Flora MAL, Pilecco JL, et al. Apparent digestibility of nutrients, energy, and amino acid of nontoxic and detoxified physic nut cakes for Nile tilapia. *Pesquisa Agropecuária Brasileira.* 2015;50(9):849-856.
51. Hossain MA, Jauncey K. Nutritional evaluation of some Bangladeshi oilseeds meals as partial substitutes for fish meal in the diet of

common carp, Cyprinus carpio L. *Aquaculture and Fisheries Management*. 1989;20:225-260.

52. Koprucu K, Seven PT, Tuna G. Apparent digestibility coefficients of protein in selected feedstuffs for juvenile Nile Tilapia (Oreochromis niloticus Linnaeus, 1758). *Pakistan Journal of Biological Sciences*. 2004;7(11): 2173–2176.
53. Koprucu K, Ozdemir Y. Apparent digestibility of selected feed ingredients for Nile tilapia (Oreochromis niloticus). *Aquaculture*. 2005;250:308–316.
54. Kumar V, Akinleye AO, Makkar HPS, et al. Growth performance and metabolic efficiency in Nile tilapia (Oreochromis niloticus L.) fed on a diet containing Jatropha platyphylla kernel meal as a protein source. *Journal of Animal Physiology and Animal Nutrition*. 2011;95(1):89–98.
55. Luo F, Fu Z, Wang M, et al. Growth performance, tissue mineralization, antioxidant activity and immune response of Oreochromis niloticus fed with conventional and gluconic acid zinc dietary supplements. *Aquaculture Nutrition*. 2021;27(1):177-187.
56. Mizael WCF, Costa RG, Rodrigo Beltrão Cruz G, et al. Effect of the Use of Tomato Pomace on Feeding and Performance of Lactating Goats. *Animals (Basel)*. 2020;10(9):1574.
57. National Research Council. Nutrient requirements of fish. National Academy Press; 1993.
58. Persia ME, Parsons CM, Schang M, et al. Nutritional evaluation of dried tomato pulp. Poultry Science. 2003;82(1):141–146.
59. Pezzato LE, De Miranda EC, Barros MM, et al. Digestibilidade aparente de ingredientes pela tilápia do nilo (Oreochromis niloticus). *Revista Brasileira de Zootecnia*. 2002;31:1595–1604.
60. Senzui A, Masumoto T, Fukada H. Neuropeptide Y expression in response to sensory organ-detected fish meal soluble components and orally fed fish meal-based diet in yellowtail Seriola quinqueradiata. *Aquaculture*. 2020;514:734493.
61. Sklan D, Prag T, Lupatsch I. Apparent digestibility coefficients of feed ingredients and their prediction in diets for tilapia Oreochromis niloticus x Oreochromis aureus (Teleostei, Cichlidae). *Aquaculture Research*. 2004;35:358-364.
62. Vidal LVO, Xavier TO, Michelato M, et al. Apparent protein and energy digestibility and amino acid availability of corn and co-products in extruded diets for Nile Tilapia, Oreochromis niloticus. *Journal of the World Aquaculture Society*. 2015b;46(2):173-182.
63. Wylie MJ, Symonds JE, Setiawan AN, et al. Transcriptomic changes during previtellogenic and vitellogenic stages of ovarian development in wreckfish (Hāpuku), Polyprion oxygeneios (Perciformes). Fishes. 2019;4(1):16.
64. Zhang L, Maulu S, Hua F, et al. Aquaculture in Zambia: The current status, challenges, opportunities and adaptable lessons learnt from China. *Fishes*. 2023;9(1):14. Note: Potential duplication with Zhang et al. (2024), retained for completeness.
65. Zhang S, de Vries S, Gerrits WJJ. Quantifying the effects of dietary fibres on protein digestibility in pigs—A review. Animal Feed Science and Technology. 2024;300:115664.