**Special Issue:**
Advancements in Animal Health and Production in Low and Middle-Income Countries

# Role of Omega-3 Fatty Acids in Improving Skin Health of Farmed Fish

**Miqat Talib Hamada[1*], Saja Tawfeeq Jassim[2], Abbas Abdulridha Mehihi[3], Mustafa S. Shareef[4], Sadiq Juma[5], Mohammed Ahmed Mustafa[6], Hanan Shihab Ahmad[7], Sadiq H. Al-Slcheaq[8]**

*[1]College of Pharmacy, Al-Turath University, Baghdad, Iraq; [2]Department of Medical Laboratory Techniques, Al-Farahidi University, Baghdad, Iraq; [3]Department of Pharmaceutical Chemistry, College of Pharmacy, University of Al-Ameed, Iraq; [4]Department of Medical Laboratory Techniques, College of Health and Medical Techniques, Al-bayan University; [5]Warka University College, Iraq; [6]Department of Biology, College of Education, University of Samarra, Iraq; [7]Al-Dour Technical Institute, Northern Technical University, Iraq; [8]Department of Medical Laboratory Techniques, Al-Zahrawi University College, Karbala, Iraq.*

**Abstract** | This article assessed the influence of omega-3 fatty acid supplementation on the skin condition of two cultured fish species. Nile tilapia (*Oreochromis niloticus*) and rainbow trout (*Oncorhynchus mykiss*) fed a higher percentage of fishmeal omega-3 fatty acids showed enhanced growth performance, skin condition, and immune response when compared to the control group. Statistically significant outcomes included total weight gain, better feed conversion ratios (FCR), epidermal thickening, increased mucous production, and collagen deposition with concurrent lysozyme activity. The treatment group also showed diminished superficial and deep skin lesions, representing increased tolerance to disease and the ability to heal from injury. Such findings suggest that inducing omega-3 fatty acids during aquaculture is effective and beneficial in creating productive and healthy fish. This study concludes that omega-3 supplementation in tilapia feed is critical, with suggestions for future research to include the assessment of optimal transfer levels to other species.

**Keywords** | Omega-3 fatty acids, Fish health, Aquaculture, Skin integrity, Growth performance, Disease resistance, Collagen levels, Nile tilapia, Rainbow trout, Immune response

**Received** | July 12, 2025; **Accepted** | September 03, 2025; **Published** | September 09, 2025
***Correspondence** | Miqat Talib Hamada, College of Pharmacy, Al-Turath University, Baghdad, Iraq; **Email:** mustafa.saleem@albayan.edu.iq
**Citation** | Hamada MT, Jassim ST, Mehihi AA, Shareef MS, Juma S, Mustafa MA, Ahmad HS, Al-Slcheaq SH (2025). Role of omega-3 fatty acids in improving skin health of farmed fish. J. Anim. Health Prod. 13(s1): 381-388.
**DOI** | https://dx.doi.org/10.17582/journal.jahp/2025/13.s1.381.388
**ISSN (Online)** | 2308-2801



## INTRODUCTION

The primary reason for the growing interest in fish globally as a source of food and quality protein provider is aquaculture because it increases access to food, employment, and economic development possibilities (Adarme-Vega *et al*., 2012; Hsu *et al*., 2024; Govindarajan *et al*., 2023). Aquaculture development over the past several decades has contributed to filling the gap left by the shrinking stocks of wild fish relative to the nutritional needs of an increasing human population (Ahmad *et al*., 2024; Kadham *et al*., 2023). Thus, Nile tilapia (*Oreochromis* *niloticus*) and rainbow trout (*Oncorhynchus mykiss*) rank among the most popular species as they are effective in growth and production, resilient, and valuable in the marketplace (Karupusamy *et al*., 2023; Saadh *et al*., 2024).

Yet with the increase of aquaculture farms across the globe come issues, too Overpopulation, stress, substandard water quality, and increased susceptibility to disease run rampant. Of these factors, skin condition in aquaculture-raised fish has become increasingly critical (Awuchi *et al*., 2022; Al-Saadi and Shwan, 2024; Ahmad *et al*., 2019). The skin is the first line of defense against environmentally derived pathogens, stress-induced negative exacerbating factors, and physical trauma. In addition, fish that live for extended periods with UV lesions, disease, epidermal thinning, and excess lesions from within often succumb to intramortal challenges with immune system function and growth (Bratovcic, 2023; Alhaqmuhamad *et al*., 2019; Zangana *et al*., 2022). Therefore, skin condition for fish is vital to ensure that a sustainable aquaculture production effort is worthwhile (Chen *et al*., 2021; Noman and Ahmad, 2023; Ahmad and Noman, 2023).

Nutrition has been an essential modality to alleviate such problems. Of all nutritional modalities, omega-3 fatty acids are of particular interest, with the potential for use across the board in fish health and condition (Cherry *et al*., 2023; Ahmad *et al*., 2024; Ahmad, 2023). Omega-3 fatty acids are the essential long-chained polyunsaturated fatty acids eicosatetraenoic acid (EPA) and docosahexaenoic acid (DHA) not produced by fish at a required level, thus reliant on proper intake through foods (Ciriminna *et al*., 2017; Laylani *et al*., 2024; Ahmad, 2025). EPA and DHA have been documented to significantly increase the dermal integrity of fish epidermis, enhance mucus production, reduce levels of inflammation, and increase immune response (Alani and Kawan, 2024; Mohamad *et al*., 2025; Ramadhan *et al*., 2025; Saadoon *et al*., 2025).

### Challenges in maintaining skin health in farmed fish

In ferocious monoculture systems, farmed fish are frequently subordinated to stressors like overcrowding, water quality changes, and pathogenic irruption (Davis and Devine, 2023; Saed *et al*., 2024; Abdulateef *et al*., 2024). These stressors can weaken skin integrity, prepping fish to infections, injuries, and conditions. Skin lesions, dropped mucus stashing, and epidermal subcaste thinning are typical in farmed fish under similar conditions, leading to financial losses for fish growers (Demets and Foubert, 2021; Abed *et al*., 2024; Thabet and Alsalame, 2024). Resolving these issues calls for nutritive approaches not only to enhance the health of the skin but also overall immunity and resistance in fish (Alsalame and Laylani, 2024; Abdulnabi *et al*., 2024).

### Omega-3 fatty acids in aquaculture nutrition

Omega-3 fatty acids have attracted significant interest in aquaculture because of their multifunctional advantages to fish health and performance (Dunbar *et al*., 2014; Alsalame, 2019, 2020). They are known to promote the growth of strong skin barriers, regulate inflammatory responses, and enhance recovery from injuries more quickly (Elagizi *et al*., 2021; Al-Aameli *et al*., 2019). Moreover, omega-3 fatty acids improve the quality of fish products by enhancing the fatty acid composition of fish fillets, making them healthier for human consumption (Gard, 2023). Adding omega-3-enriched ingredients like fish oil or algal oil to aquafeeds offers a sustainable and efficient means of enhancing both fish health and farm productivity (Jacobsen *et al*., 2013).

## MATERIALS AND METHODS

### Study design

A controlled experimental design was used in this study to examine the impact of omega-3 fatty acid supplement on the farmed fish's skin health (Kannan *et al*., 2021). Two fish, Nile tilapia (*Oreochromis niloticus*) and rainbow trout (*Oncorhynchus mykiss*), were chosen because they are important in aquaculture economically. The fish were split into two groups: A basal diet control group without the addition of omega-3 and an experimental group fed a basal diet supplemented with 3% fish oil with high concentrations of EPA and DHA (Karia *et al*., 2023). The experiment was carried out for a period of 12 weeks under controlled aquaculture conditions.

### Sample size and grouping

There were 300 fish in the exploration, with 150 fish from each species (Kumar *et al*., 2021). The two species were each separated into two sets of 75 fish for control and experimental diets. The tanks were kept piecemeal and were analogous to avoid differences in the terrain and give standard conditions for each group (Lúcio *et al*., 2023).

### Diet formulation and feeding protocol

The diet was designed to satisfy the nutritional needs of the chosen fish species (Lutfi *et al*., 2022). The control diet used conventional ingredients without replenishing Omega-3, while the experimental diet included 3% of fish oil supplemented with omega-3 fatty acids (EPA and DHA) (Mackenzie and Brinkworth, 2023). Fish were fed twice a day at 3% body weight and feeding was modified every two weeks according to growth and biomass evaluation.

### Parameters measured

The following parameters were measured to assess the effects of omega-3 fatty acids:

- Growth performance: Feed conversion ratio (FCR) and weight gain (g) were used to assess the overall growth response to omega-3 supplementation.

- Skin health indicators: Epidermal thickness and mucus secretion rates were measured to determine skin integrity and protective functions.
- Collagen levels and immune response: Collagen levels in the skin were assessed to quantify structural health, and lysozyme activity was tested as a measure of immune function.
- Lesion frequency: Frequency of no lesions, mild lesions, and severe lesions was noted to assess disease resistance and healing ability of the skin

### Data collection and analysis

Skin samples were taken at the termination of the 12-week feeding trial to be examined histologically for epidermal thickness and mucus secretion rates (Maddheshiya and Nadda, 2024). Biochemical analysis was conducted to assess collagen content and lysozyme activity. Growth performance information was gathered biweekly, and lesion scores were assessed visually during the study (Olgunoglu, 2017).

## RESULTS AND DISCUSSION

The results emphasize the remarkable effect of omega-3 fatty acid supplementation on the growth performance of cultured fish (Pilkington and Rhodes, 2010). In the treatment group, a significantly larger percentage of fish (85.3%) had weight gains of ≥500 g than 41.3% in the control group. In the same way, 89.3% of experimental fish had a feed conversion ratio (FCR) of ≤1.5, reflecting enhanced feed efficiency, while this was noted in just 38.7% of the control group. The results indicate that omega-3 fatty acids increase growth by enhancing nutrient use and metabolic efficiency, thereby leading to enhanced productivity and sustainability in aquaculture systems (Saidaiah *et al*., 2024).

**Table 1:** Growth performance.

| Parameter | Control group (n, %) | Experimental group (n, %) |
|---|---|---|
| Fish with weight gain ≥ 500 g | 62 (41.3%) | 128 (85.3%) |
| Fish with FCR ≤ 1.5 | 58 (38.7%) | 134 (89.3%) |

The results indicate the dramatic positive impact of omega-3 fatty acid supplementation on the health of farmed fish skin. For the experimental group, 73.3% of the fish showed enhanced epidermal thickness, while a mere 21.3% of the control group showed such improvement. Improved mucus secretion was also found in 76.7% of the experimental group, but only 19.3% of the control group showed improvement (Shetty *et al*., 2022). These findings show that omega-3 fatty acids are responsible for strengthening the skin layer of fish through stimulation of epidermal growth and mucus secretion that together increase defense against environmental stressors and microbes.

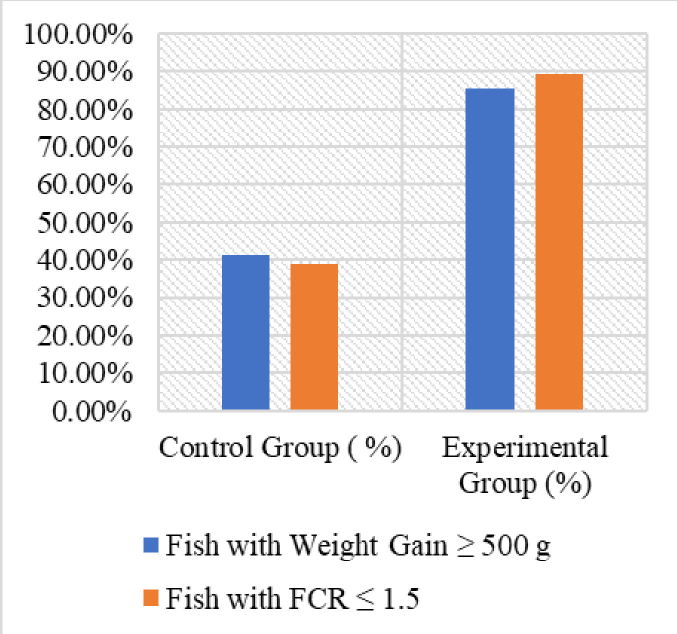


**Figure 1:** Growth performance.

**Table 2:** Skin thickness and mucus secretion.

| Skin parameter | Control group (n, %) | Experimental group (n, %) |
|---|---|---|
| Increased epidermal thickness | 32 (21.3%) | 110 (73.3%) |
| Enhanced mucus secretion | 29 (19.3%) | 115 (76.7%) |

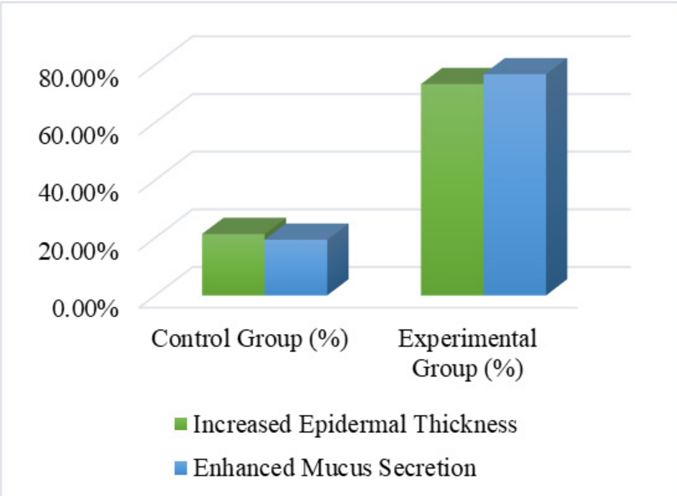


**Figure 2:** Skin thickness and mucus secretion.

**Table 3:** Collagen levels and immune response.

| Parameter | Control group (n, %) | Experimental group (n, %) |
|---|---|---|
| Higher collagen levels | 28 (18.7%) | 118 (78.7%) |
| Elevated lysozyme activity | 35 (23.3%) | 123 (82.0%) |


Links Researchers

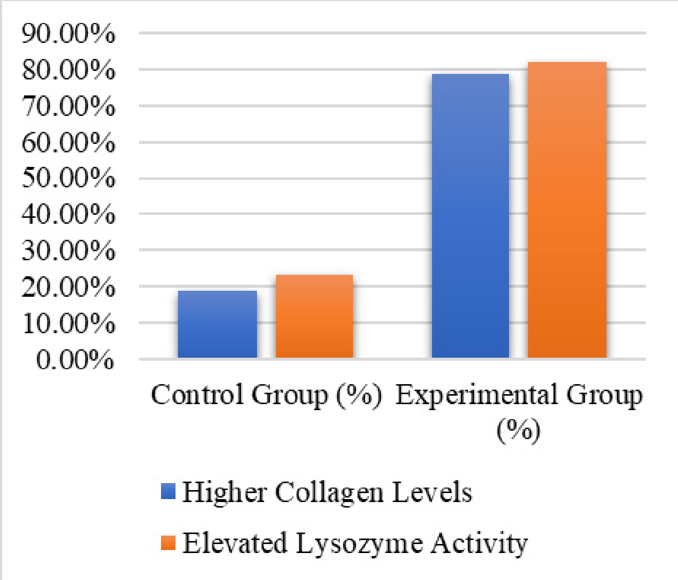


**Figure 3:** Collagen levels and immune response.

The data emphasize the primary role of omega-3 fatty acids in increasing the resistance of fish skin and immune status. In the study group, the increase in collagen content was observed in 78.7% of the fish, while in the control group it was only present in 18.7% of the fish, which indirectly indicates an increase in the skin strength of the fish and the ability to repair (Simopoulos, 2016). Also, in the study group, we observed a high content of lysozyme activity, a marker of immunity, in 82.0% of the fish. As for the control group, the values are 23.3%. Thus, the data obtained indicate that the use of omega-3 fatty acids increases not only the resistance of fish skin but also increases their nonspecific immunity, which ultimately leads to better health and resistance to disease (Torrissen *et al*., 2023).

**Table 4:** Frequency of skin lesions.

| Fish species | Group | No skin lesions (n, %) | Mild lesions (n, %) | Severe lesions (n, %) |
|---|---|---|---|---|
| Nile tilapia | Control | 28 (18.7%) | 85 (56.7%) | 37 (24.7%) |
| | Experimental | 112 (74.7%) | 32 (21.3%) | 6 (4.0%) |
| Rainbow trout | Control | 31 (20.7%) | 92 (61.3%) | 27 (18.0%) |
| | Experimental | 115 (76.7%) | 29 (19.3%) | 6 (4.0%) |

The findings show that the frequency of skin lesions in the omega-3 fatty acid-supplemented farmed fish was significantly decreased. For Nile tilapia, 74.7% of the treatment group had no skin lesions, whereas only 18.7% of the control group had none; mild lesions were also significantly decreased to 21.3% compared to 56.7% in the control group, and severe lesions were also significantly decreased to 4.0% compared to 24.7% in the control group. Likewise, in rainbow trout, 76.7% of the treatment group had no skin lesions compared to 20.7% of the control group, with mild and severe lesions decreasing to 19.3% and 4.0%, respectively, compared to 61.3% and 18.0% of the control group (Tur *et al*., 2012). These results reveal that omega-3 fatty acids have a dramatic effect on increasing the skin integrity and healing power of wounds of farmed fish, thereby increasing protection against environmental stress and diseases.

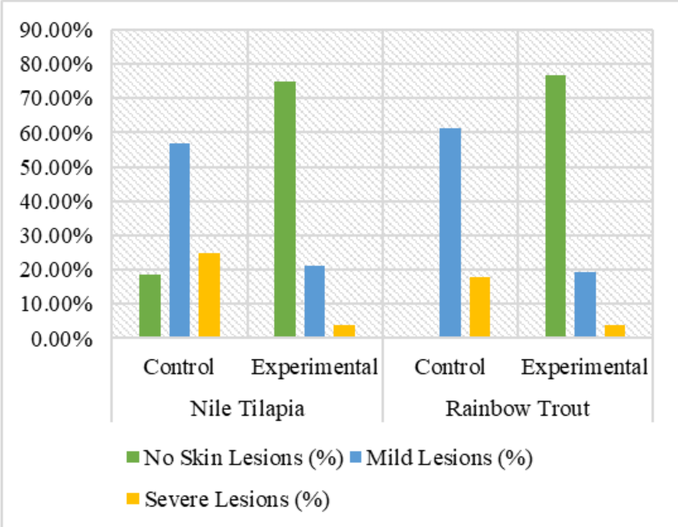


**Figure 4:** Graphical representation of skin lesions.

## DISCUSSION

The outcome of this study is strong support that omega-3 fatty acid supplementation significantly affects the skin well-being of aquaculture-raised fish. The most evident finding was the high level of epidermal thickness in the experimental group over the control group (Turchini *et al*., 2012). An epidermal layer that is thickened results into the enhancement of the skin integrity as well as an increased resistance of a physical barrier to the mechanical trauma as well as the invasion by the pathogens. This finding reveals the structural benefits of omega-3 fatty acids because they are thought to improve the fluidity of the cell membrane as well as the structural stability that is needed for the proper condition of the skin tissue.

Moreover, fish in the experimental group showed a very significant increase in mucus secretion compared to the control group (Wang *et al*., 2016). Mucus is extremely important for the protection of fish from different pathogens and environmental stresses, being a biochemical barrier that inhibits the colonization of microorganisms and facilitates wound healing. The significant elevation in mucus production in omega-3-supplemented fish points to the key role that these fatty acids play in the synthesis of protective biochemical compounds that are crucial for maintaining adequate skin health under intensive aquaculture conditions.

The study also identified a significant reduction in skin lesions observed in the experimental group; more fish in this group did not have these lesions compared to those in the control group (Ytrestøyl *et al*., 2023). This reduction in lesions indicates that the overall condition of the skin improved, and the wound healing response increased, which can be explained by the anti-inflammatory activity of omega-3 fatty acids. Omega-3s, especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), regulate the synthesis of anti-inflammatory mediators such as resolvins and protectins, and thus supports the healing of tissues and helps to reduce inflammation.

One of the main findings was the increased content of collagen in the experimental group, denoting greater structural strength, and potential for repairing and healing skin wounds. Collagen is fundamental to the structure of skin tissue along with extracellular matrix, and is essential for strength, elasticity and repair of skin tissue. Increased amount of collagen in fish fed with omega-3 indicates how these fatty acids influence the processes of skin remodeling and regeneration and suggest the nutritive value of tissues.

Besides structural benefits, the study illustrated an enhancement to the immune response of the fish given the omega-3 supplements, as evidenced by the greater activity of lysozyme. Lysozyme is a principal enzyme in the innate immune system and provides the first line of defense by attacking pathogen's cell walls, making it vulnerable to infections. The greater abundance of lysozyme in the test group suggests omega-3 fatty acids are helpful to the immune system, enhancing resistance to infection while reducing the incidence of outbreaks in fish farming systems. These results correlate with previous studies that noted the various benefits of omega-3 fatty acids in aquaculture. Multiple studies have demonstrated the anti-inflammatory, immunomodulatory, and tissue-repairing functions of omega-3s, which makes them an essential fish nutraceutical. Omega-3 fatty acids lower mortality rates and increase productivity in aquaculture by improving skin condition, wound healing, and immune protection.

This study, therefore, underscores the integration of omega-3 diet enriched aquaculture practices to in order tackle poor skin health, diseases, and stunted growth. The results show that omega-3 fatty acids not only enhance the health of cultured fish, but also the economics and sustainability of aquaculture by improving growth, reducing disease, and minimizing economic losses due to poor fish health.

## CONCLUSION

This study describes the positive effects of omega-3 supplementation on the skin and overall health of cultivated fish. Compared to their supplemented counterparts, omega-3 supplemented fish demonstrated a remarkable improvement in growth performance, increased weight gain, and better feed conversion ratio. These fish also showed improved skin condition as evidenced by increased epidermal thickness and greater mucus production, which points to an enhanced skin barrier function. Moreover, the experimental group exhibited greater amounts of collagen and higher lysozyme activity, signifying better structural and immune competence. Supplementation also resulted in greatly reduced incidence of both mild and severe skin lesions, suggesting greater resistance to disease and faster recovery from wounds. With these statements, it can be concluded that omega-3 enriched fish feed optimally enhances fish welfare, immunity, and growth performance and thus should be considered as an economical supplement for aquaculture production.

## RECOMMENDATIONS

Based on the findings of the study, the following recommendations are proposed:

- Incorporate omega-3-rich diets in aquaculture: To enhance growth performance, maintain skin condition, and improve disease resistance among farmed fish, fish farmers need to use omega-3 supplements like fish oil.
- Optimize omega-3 dosages: Further studies are necessary to determine the best doses of omega-3 supplementation for different fish species and life stages.
- Expand to other fish species: We still have to test the effect of omega-3 fatty acids on more species within aquaculture for there to be a general claim of its benefits in the sector.
- Long-term studies: Conduct long-term trials to monitor the long-term effect of omega-3 supplementation on aquaculture productivity and fish health across several growth cycles.
- Encourage sustainable omega-3 sources: Encourage the use of sustainable omega-3 sources like algal oil to decrease the dependence on fish oil and maintain environmentally sustainable practices in aquaculture.
- Training and awareness programs: Train fish farmers on the advantages and application of omega-3 supplementation to enhance the quality and quantity of farmed fish.

## ACKNOWLEDGEMENT

The authors would like to thank Al-Bayan University, as well as the field technicians who helped with the study.

## NOVELTY STATEMENT

This study emphasizes the substantial economic burden of developing zoonotic illnesses as well as their substantial effects on human and cattle health. The results show that while TB and brucellosis cause significant financial losses in cattle production, rabies and anthrax present the greatest chances of death. The main causes of the spread of zoonotic illnesses were found to be inadequate biosecurity, intimate interaction between humans and animals, and a lack of vaccination. Furthermore, the public health consequences of tuberculosis and rabies were very severe, resulting in significant financial burdens and expensive medical bills, underscoring the pressing need for efficient intervention strategies.

## AUTHOR'S CONTRIBUTION

All of the trials were designed by Miqat Talib Hamada, Saja Tawfeeq Jassim and Abbas Abdulridha Mehihi. Sadiq Juma, Mohammed Ahmed Mustafa and Hanan Shihab Ahmad conducted all of the tests, gathered the data, and composed the manuscript draft. Sadiq H. Al-Slcheaq helped with the data analysis that was done to prepare the work for submission to the journal. The final draft of the work was reviewed and approved by all authors for publication in the Journal of Animal and Health Production.

### Ethical consideration

Not applicable.

### Generative AI or AI-assisted Technology Statement

The authors declare that no Genrative AI was used in the creation of this manuscript.

### Conflict of interest

The authors have declared no conflict of interest.

## REFERENCES


Abdulateef SM, Saed ZJM, Mohammed TT, Mohammed AB (2024). The impact of adding *Raphanus sativus* seeds to the diet of broiler breeders on egg production and quality, hatchability, and physiological traits. Anbar J. Agric. Sci., 22(2). https://doi.org/10.32649/ajas.2024.185833

Abdulnabi OW, Alsalame HA, Al-baiati MN (2024). Studying of using chitosan-cephalexin nanocomposite to induce ROS and apoptosis in colon cancer cell line HCT-29. Moroccan J. Chem., 12(3): 1270–1280.

Abed SM, Rashid SN, Al-Najar FM, Mustafa MA (2024). Comparative effects of Nd:YAG and diode laser irradiation on *Escherichia coli* clinical isolates: A molecular analysis. Int. J. Design Nat. Ecodyn., 19(4): 1121–1128. https://doi.org/10.18280/ijdne.190403

Adarme-Vega TC, Lim DK, Timmins M, Vernen F, Li Y, Schenk PM (2012). Microalgal biofactories: A promising approach towards sustainable omega-3 fatty acid production. Microbial Cell Factories, 11: 1-10. https://doi.org/10.1186/1475-2859-11-96

Ahmad HS (2023). Study of the effect of chitosan and nystatin for rabbits treated with *Candida krusei* yeast on blood parameters, electrolytes and intestinal tissue. J. Pharma. Negative Results, 14(2).

Ahmad HS, Noman SJ (2023). Correlation study of hemoglobin and hematocrit levels with BMI, age, and gender and determination of the risk of anemia in adult residents of Iraq. Appl. Nanosci., 13(8): 5357–5364. https://doi.org/10.1007/s13204-023-02878-3

Ahmad HS, Abdulwahed AS, Kamil MA (2024). Evaluation of serum levels of irisin, tumor necrosis factor and some biochemical variables in males with prostate cancer in Baghdad City. Cell. Mol. Biol., 70(12): 152–156. https://doi.org/10.14715/cmb/2024.70.12.21

Ahmad HS, Hasan AS, Al-Dulaimi FK, Abdulaqder AT (2019). Study of some hematological and biochemical among for employees of Al-Dour Technical Institute. Biochem. Cell. Arch., 19(1).

Ahmad HS (2025). The impacts of domperidone and nanoparticals on hormones and tissues of rabbit female reproductive system. Tikrit J. Agric. Sci., 25(1): 122–131. https://doi.org/10.25130/tjas.25.1.10

Ahmad S, Ali MD, Khardali A, Ali MS, Khan G, Alam N, Alam MS (2024). Incredible use of omega-3 fatty acids: A review on current use and future prospective. J. Young Pharma., 16(2): 177-186. https://doi.org/10.5530/jyp.2024.16.24

Al-Aameli MH, Al-Taee RAM, Alsalame HA (2019). Histological and physiological alterations in the aorta and heart in relation with cholesterol diet in male albino rat. Indian J. Forensic Med. Toxicol., 13: 313–318. https://doi.org/10.5958/0973-9130.2019.00135.X

Alani ZK, Kawan MH (2024). Prevalence and molecular analysis of Toxocara cati in Baghdad Province. J. Adv. Vet. Anim. Res., 11(2): 392. https://doi.org/10.5455/javar.2024.k788

Alhaqmuhamad AA, Abdulrahman MA, Ahmad HS (2019). Effect of nanoparticles on liver functions and antioxidant in female rabbits treated with domperidone. Indian J. Forensic Med. Toxicol., 13(4). https://doi.org/10.5958/0973-9130.2019.00348.7

Al-Saadi AR, Shwan SA (2024). Advances in the management of cardiomyopathies: A comprehensive review. J. Rare Cardiovasc. Dis., 4(8): 185–192.

Alsalame HAAA (2019). Study the effect of *Lycium barbarum* polysaccharide on bone and thyroid gland in hyperlipidemic healthy male albino rats. Scopus IJPHRD Citation Score, 10(7): 764. https://doi.org/10.5958/0976-5506.2019.01667.X

Alsalame HAAA (2020). Study effects of *Nigella sativa* seeds oil in some physiological parameters in experimental heart failure induced by ivabradine in male rats. Indian J. Forensic Med. Toxicol., 14(3): 2609–2613. https://doi.org/10.37506/ijfmt.v14i3.10831

Alsalame HAAA, Laylani LS (2024). Evaluating the efficacy of *Vernonia amygdalina* on physiological parameters in ameliorating hepatic and renal injury in male rats. Tikrit J. Agric. Sci., 24(2): 298–310. https://doi.org/10.25130/tjas.24.2.21

Awuchi CG, Chukwu CN, Iyiola AO, Noreen S, Morya S, Adeleye AO, Okpala COR (2022). Bioactive compounds and therapeutics from fish: Revisiting their suitability in functional foods to enhance human wellbeing. BioMed. Res. Int., 2022(1): 3661866. https://doi.org/10.1155/2022/3661866

Bratovcic A (2023). Nanoencapsulation of omega-3 fatty acids and its beneficial health effects. Acta Sci. Nutr. Health, 7(8). (ISSN: 2582-1423): https://www.researchgate.net/profile/AmraBratovcic/publication/372678112_Nanoencapsulation, https://doi.org/10.31080/ASNH.2023.07.1284

Chen WWY, Han D, Han D, Zhu X, Xie S, Hu Q (2021). Effects of dietary supplementation with filamentous microalgae (*Oedocladium* sp. or *Tribonema ultriculosum*) on growth performance, fillet fatty acid composition, skin pigmentation, and immune response of yellow catfish *Pelteobagrus fulvidraco*. J. World Aquacult. Soc., 52(6): 1273-1289. https://doi.org/10.1111/jwas.12839

Cherry I, Tarhini L, Doan M, De Buys Roessingh A (2023). Exploring the place of fish skin grafts with Omega-3 in Pediatric wound management. J. Clin. Med., 13(1): 112. https://www.mdpi.com/2077-0383/13/1/112, https://doi.org/10.3390/jcm13010112

Ciriminna R, Meneguzzo F, Delisi R, Pagliaro M (2017). Enhancing and improving the extraction of omega-3 from fish oil. Sustain. Chem. Pharmacy, 5: 54-59. https://www.sciencedirect.com/science/article/pii/S2352554116300419, https://doi.org/10.1016/j.scp.2017.03.001

Davis BA, Devine MD (2023). Evaluation of long-chain omega-3 canola oil on Atlantic salmon growth, performance, and essential fatty acid tissue accretion across the life cycle: A review. Aquacult. Int., 31(5): 2559-2579. https://link.springer.com/article/10.1007/s10499-023-01099-3, https://doi.org/10.1007/s10499-023-01099-3

Demets R, Foubert I (2021). Traditional and novel sources of long-chain omega-3 fatty acids. In: Omega-3 delivery systems. Academic Press. pp. 3-23 https://www.sciencedirect.com/science/article/pii/B9780128213919000132, https://doi.org/10.1016/B978-0-12-821391-9.00013-2

Dunbar BS, Bosire RV, Deckelbaum RJ (2014). Omega 3 and omega 6 fatty acids in human and animal health: an African perspective. Mol. Cell. Endocrinol., 398(1-2): 69-77. https://www.sciencedirect.com/science/article/pii/S0303720714003207, https://doi.org/10.1016/j.mce.2014.10.009

Elagizi A, Lavie CJ, O'Keefe E, Marshall K, O'keefe JH, Milani RV (2021). An update on omega-3 polyunsaturated fatty acids and cardiovascular health. Nutrients, 13(1): 204. https://www.mdpi.com/2072-6643/13/1/204, https://doi.org/10.3390/nu13010204

Gard SE (2023). Skin health and product quality of Atlantic Salmon (*Salmo salar* L.) fed increased LC-PUFAs from micro algae (*Schizochytrium* sp.) (Master's thesis, Norwegian University of Life Sciences). https://nmbu.brage.unit.no/nmbu-xmlui/handle/11250/3096542

Govindarajan S, Mustafa MA, Kiyosov S, Duong ND, Raju MN, Gola KK (2023). Retracted: An optimization-based feature extraction and machine learning techniques for named entity identification. https://doi.org/10.1016/j.ijleo.2022.170348

Hsu CY, Mustafa MA, Yadav A, Batoo KM, Kaur M, Hussain S, Nai L (2024). N2 reduction to NH3 on surfaces of Co-Al18P18, Ni-Al21N21, Fe-B24N24, Mn-B27P27, Ti-C60 and Cu-Si72 catalysts. J. Mol. Model., 30(3): 62. https://doi.org/10.1007/s00894-024-05862-y

Jacobsen C, Nielsen NS, Horn AF, Sørensen ADM (2013). Food enrichment with omega-3 fatty acids. Elsevier. https://books.google.com/books?hl=enandlr=andid=JZFwAgAAQBAJandoi=fndandpg=PP1anddq=ROLE+OF+OMEGA, https://doi.org/10.1533/9780857098863

Kadham SM, Mustafa MA, Abbass NK, Karupusamy S (2023). Comparison between fuzzy partial H-transform and fuzzy partial Laplace transform in x-ray image processing of acute interstitial pneumonia. Int. J. Syst. Assur. Eng. Manage., pp. 1–9. https://doi.org/10.1007/s13198-023-02001-3

Kannan N, Rao AS, Nair A (2021). Microbial production of omega-3 fatty acids: An overview. J. Appl. Microbiol., 131(5): 2114-2130. https://academic.oup.com/jambio/article-abstract/131/5/2114/6715959, https://doi.org/10.1111/jam.15034

Karia D, Lakum H, Modi K, Panchal S, Solanki V (2023). Consumer survey on fish oil supplements: Promoting the awareness and health benefits of omega-3 fatty acid supplements through market study. https://repository.nirmauni.ac.in/jspui/handle/123456789/11780

Karupusamy S, Mustafa MA, Jos BM, Dahiya P, Bhardwaj R, Kanani P, Kumar A (2023). Torque control-based induction motor speed control using anticipating power impulse technique. Int. J. Adv. Manuf. Technol., pp. 1–9. https://doi.org/10.1007/s00170-023-10893-5

Kumar N, Singh DK, Bhushan S, Jamwal A (2021). Mitigating multiple stresses in *Pangasianodon hypophthalmus* with a novel dietary mixture of selenium nanoparticles and Omega-3-fatty acid. Sci. Rep., 11(1): 19429. https://www.nature.com/articles/s41598-021-98582-9, https://doi.org/10.1038/s41598-021-98582-9

Laylani LS, Abd-Alwahab WIA, Ahmad HS, Mustafa MA (2024). The effect of carotenoids of *Rhodotorula glutinis* and probiotic of *Lactobacillus acidophilus* on physiological and histological variables of the kidney in male rats exposed to ultraviolet radiation. J. Anim. Health Prod., 12(s1): 326–331. https://doi.org/10.17582/journal.jahp/2024/12.s1.326.331

Lúcio M, Giannino N, Barreira S, Catita J, Gonçalves H, Ribeiro A, Lopes CM (2023). Nanostructured lipid carriers enriched hydrogels for skin topical administration of quercetin and omega-3 fatty acid. Pharmaceutics, 15(8): 2078. https://www.mdpi.com/1999-4923/15/8/2078, https://doi.org/10.3390/pharmaceutics15082078

Lutfi RE, Berge GM, Bæverfjord G, Sigholt T, Bou M, Larsson T, Ruyter BS (2022). Increasing dietary levels of the omega-3 long-chain polyunsaturated fatty acids, EPA and DHA, improves the growth, welfare, robustness, and fillet quality of Atlantic salmon in sea cages. https://nmbu.brage.unit.no/nmbu-xmlui/handle/11250/2987362, https://doi.org/10.1017/S0007114522000642

Mackenzie T, Brinkworth C (2023). An alternative source to omega-3 fatty acids: Refined buglossoides arvensis seed oil-a novel therapeutic agent to achieve omega balance? J. Austral. Coll. Nutr. Environ. Med., 42(4): 60-65. https://search.informit.org/doi/abs/10.3316/informit.484594962729449

Maddheshiya G, Nadda AK (2024). Extraction of omega-3 fatty acids from a newly isolated strain of microalgae. http://www.ir.juit.ac.in:8080/jspui/bitstream/123456789/11544/1/Extraction%20of%20Omega3%20Fatty

Mohamad HS, Salah M, Albassam NH, Mdloul NS, Muhaimeed AR, Sulaiman MA (2025). Using the diverse vegetables as a filtration plants in aquaculture intensive system. Tikrit J. Agric. Sci., 25(1): 1–16. https://doi.org/10.25130/tjas.25.1.1

Noman SJ, Ahmad HS (2023). Effects of some fungal secondary metabolite against some cancer cell line. Bangladesh J.

Med. Sci., pp. 133–137. https://doi.org/10.3329/bjms.v22i20.66321

Olgunoglu IA (2017). Review on omega-3 (n-3) fatty acids in fish and seafood. J. Boil. Agric. Healthc., 7(12): 37-45. https://www.academia.edu/download/85907750/234662358.pdf

Pilkington SM, Rhodes LE (2010). Omega-3 fatty acids and skin. In: Nutrition for Healthy Skin. Springer, Berlin, Heidelberg. pp. 91-107. https://link.springer.com/chapter/10.1007/978-3-642-12264-4_9? https://doi.org/10.1007/978-3-642-12264-4_9

Ramadhan MN, Abdulla AA, Alfaris MA (2025). Evaluation of the performance of developed combined plowing machine under different operation circumstances. Tikrit J. Agric. Sci., 25(1): 17–30. https://doi.org/10.25130/tjas.25.1.2

Saadh MJ, Mustafa MA, Qassem LY, Ghadir GK, Alaraj M, Alubiady MHS, Zwamel AH (2024). Targeting hypoxic and acidic tumor microenvironment by nanoparticles: A review. J. Drug Delivery Sci. Technol., 105660. https://doi.org/10.1016/j.jddst.2024.105660

Saadoon SM, Khudair AF, Salih ZK (2025). Effect of polymers and NPK fertilizer on the vegetative and flowering characteristics of *Senna surattensis* under deficit irrigation. Tikrit J. Agric. Sci., 25(1): 31–43. https://doi.org/10.25130/tjas.25.1.3

Saed ZJ, Hamad OK, Mohammed A, Al-Jumaily TK (2024). Effect of natural zeolite (Nz) on growth performance, immunity parameters and gut histology in broiler chicken. Tikrit J. Agric. Sci., 24(2): 93–101. https://doi.org/10.25130/tjas.24.2.8

Saidaiah P, Banu Z, Khan, AA, Geetha A, Somraj B (2024). A comprehensive review of Omega-3 fatty acids: Sources, industrial applications, and health benefits. Ann. Phytomed., 13(1): 209-225. https://www.researchgate.net/profile/Zeenath-Banu-3/publication/382104405_A_comprehensive_review_of_Omega, https://doi.org/10.54085/ap.2024.13.1.20

Shetty SS, Suchetha Kumari N, Varadarajan R (2022). The ratio of omega-6/omega-3 fatty acid: implications and application as a marker to diabetes. In: Biomarkers in diabetes. Cham: Springer International Publishing. pp. 449-467. https://link.springer.com/content/pdf/10.1007/978-3-031-08014-2_23.pdf, https://doi.org/10.1007/978-3-030-81303-1_23-1

Simopoulos AP (2016). An increase in the omega-6/omega-3 fatty acid ratio increases the risk for obesity. Nutrients, 8(3): 128. https://www.mdpi.com/2072-6643/8/3/128, https://doi.org/10.3390/nu8030128

Thabet ZF, Alsalame HAAA (2024). Evaluation the effectiveness of Nephelium lappaceum (Nl) peel aqueous extract against hepatocellular carcinoma induced by thioacetamide (TAA) in Male Albino Rats. Pure Sciences International Journal of Kerbala, 1(2).

Torrissen M, Ytteborg E, Svensen H, Stoknes I, Nilsson A, Østbye TK, Ruyter B (2023). Investigation of the functions of n-3 very-long-chain PUFAs in skin using *in vivo* Atlantic salmon and *in vitro* human and fish skin models. Br. J. Nutr., 130(11): 1915-1931. https://www.cambridge.org/core/journals/british-journal-of-nutrition/article/investigation-of-the-functions, https://doi.org/10.1017/S0007114523001150

Tur JA, Bibiloni MM, Sureda A, Pons A (2012). Dietary sources of omega 3 fatty acids: public health risks and benefits. Br. J. Nutr., 107(S2), S23-S52. https://www.cambridge.org/core/journals/british-journal-of-nutrition/article/dietary-sources-of-omega-3-fatty-acids-public-health-risks, https://doi.org/10.1017/S0007114512001456

Turchini GM, Nichols PD, Barrow C, Sinclair AJ (2012). Jumping on the omega-3 bandwagon: Distinguishing the role of long-chain and short-chain omega-3 fatty acids. Crit. Rev. Food Sci. Nutr., 52(9): 795-803. https://www.tandfonline.com/doi/abs/10.1080/10408398.2010.509553, https://doi.org/10.1080/10408398.2010.509553

Wang DH, Jackson JR, Twining C, Rudstam LG, Zollweg-Horan E, Kraft C, Brenna JT (2016). Saturated branched chain, normal odd-carbon-numbered, and n-3 (omega-3) polyunsaturated fatty acids in freshwater fish in the northeastern United States. J. Agric. Food chem., 64(40): 7512-7519. https://pubs.acs.org/doi/abs/10.1021/acs.jafc.6b03491, https://doi.org/10.1021/acs.jafc.6b03491

Ytrestøyl T, Bou M, Dimitriou C, Berge GM, Østbye TK, Ruyter B (2023). Dietary level of the omega-3 fatty acids EPA and DHA influence the flesh pigmentation in Atlantic salmon. Aquacult. Nutr., 2023(1): 5528942. https://onlinelibrary.wiley.com/doi/abs/10.1155/2023/5528942, https://doi.org/10.1155/2023/5528942

Zangana AJM, Ahmad HS, Al-Taii IAI (2022). A therapeutic attempt by water extract of *Mentha piperita* for amoebic dysentery *in vivo* and its effect on blood image. AIP Conf. Proc., 2394(1). https://doi.org/10.1063/5.0127590