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Comparative Analysis of Nutritional Values of Fishmeals Produced From Whole Anchovy and Sprat and Farmed Salmon Viscera in the Black Sea Region

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ABSTRACT

Fishmeal is a nutrient-rich feed ingredient that is commonly used in commercial feed formulations for many species, primarily in the global aquaculture and pet food sectors. This study investigates the nutritional composition of fishmeals derived from whole anchovy, sprat, and salmon viscera, produced in Turkey during the 2023-2024 fishing season. A total of 91 samples were analyzed using a Bruker-type MPA brand spectrophotometer to determine crude protein, crude fat, moisture, and crude ash content. The carbohydrate content was calculated by difference, and energy content was derived using established conversion factors. Anchovy meal exhibited the highest crude protein content at 73.55%, followed by sprat meal at 70.08%, and salmon viscera meal at 63.58%. In terms of crude fat, salmon viscera meal had the highest concentration at 11.76%, compared to anchovy meal at 10.33% and sprat meal at 9.92%. Moisture content was highest in salmon viscera meal (10.45%), while anchovy and sprat meals had lower moisture levels of 6.53% and 7.15%, respectively. The crude ash content was also highest in salmon viscera meal at 11.96%. Carbohydrate content was most pronounced in sprat meal at 3.77%, with salmon viscera and anchovy meals containing 3.32% and 1.52%, respectively. Energy content was highest in anchovy meal at 393.26 kcal/100g. These findings highlight the distinct nutritional profiles of the fishmeals studied, allowing for the identification of the most suitable option for aquaculture nutrition. Specifically, anchovy meal emerges as the best choice due to its high protein content and energy efficiency.

INTRODUCTION

Seafood is an important source of protein, healthy fats, vitamins, and minerals. Fish contains significant amounts of energy and essential amino acids (Bayraklı, 2024). The polyunsaturated fats in fish have many health benefits and are a crucial source of long-chain omega-3 fatty acids, which are known to prevent heart diseases. Fish also contribute significantly to the body's production of protein, fats, and micronutrients (Ahmed et al., 2022; Lall & Dumas, 2022)

The importance of aquaculture is increasing as the demand for seafood grows. With wild fish stocks being overfished, aquaculture provides a sustainable alternative for meeting this demand (Einarsson & Óladóttir, 2020; Boyd et al., 2022). The growth of aquaculture has resulted in a higher need for high-quality fish feed, with fishmeal being a critical component. (Ansari et al., 2021; Alfiko et al., 2022). However, the demand for farmed fish is leading to challenges in the supply of fishmeal and fish oil, forcing the exploration of alternative sources of protein and new formulations for fish feeds (Bayraklı, 2023; Glencross et al., 2023; Eroldoğan et al., 2023). This need for affordable fishmeal is driven by the fact that fish feed accounts for nearly 70% of the costs of aquaculture operations. Fishmeal is essential for the rapid development of farmed fish, with about 30-40% fishmeal needed in fish feed to meet the necessary requirements (Hardy et al., 2022; Alfiko et al., 2022; Boyd et al., 2022).

Fishmeal is highly valued in aquafeeds due to its high protein content and well-balanced amino acid profile (Bayraklı et al., 2022). It is primarily produced from small pelagic fish such as ringa, anchovy and sprat, as well as leftovers from fish processing like salmon viscera. (Henriksen, 2020; Ahuja et al., 2020). As aquaculture continues to expand, the demand for fishmeal is also increasing, highlighting its importance in sustaining and boosting the industry (Campanati et al., 2022). To meet this growing need, a greater quantity of fish and by-products are expected to be used for fishmeal production each year (Sandström et al., 2022; Albrektsen et al., 2022). The fishmeal industry also faces challenges such as resource sustainability, price volatility, and public perceptions of its environmental impact (Bayraklı & Duyar, 2021; Gudbrandsdottir et al., 2021). The supply of used fish for fishmeal and fish oil production is not abundant. To ensure long-term viability, these issues must be addressed, including increasing the proportion of small pelagics for direct human consumption and improving fisheries and marine ecosystems (Lam et al.2020). To address this issue, it is important to move towards more eco-friendly production methods in feed production and make use of a wider range of fish.

The aim of this study was to compare the nutritional content and energy levels of fishmeals derived from whole anchovy, whole sprat, and salmon viscera in order to determine which of these fishmeals is superior. The assessment considered components such as crude protein, crude fat, crude ash, moisture, and carbohydrate values, in order to determine if salmon viscera fishmeal could be a viable alternative or additional feed ingredient in aquaculture. The results of this research could potentially improve the efficient use of locally sourced feed resources in Türkiye's aquaculture industry.

MATERIAL AND METHODS

The present study used a rigorous analytical method to assess the nutritional composition of fishmeals made from anchovy, sprat, and salmon internal organs. Samples were collected from fishmeal production facilities in Sinop, a region recognized for its fish processing industry. A total of 48 samples of anchovy meal were collected in December 2023, 27 samples of sprat meal in February 2024, and 16 samples of salmon internal organ meal in May 2024. Each sample underwent four independent measurements to ensure accuracy and reliability of the data.

A Bruker-type MPA brand spectrophotometer, located in the quality laboratory of a Sinop-based fishmeal factory, was utilized to analyze the primary nutritional components: crude protein, crude fat, moisture, and crude ash. This advanced spectrophotometric analysis provided high-resolution data essential for the accurate quantification of these components (Bayraklı et al, 2022).

The total amount of carbohydrates was determined by subtracting the combined amount of crude protein, crude fat, moisture, and crude ash from 100, as detailed in the methodologies by Ferris & Shanklin (1993) and Anonymous (2005). This calculation gave a thorough analysis of the carbohydrate content in the samples.

The energy content was measured in kilocalories per gram (kcal/g) and was calculated using the percentage of crude protein, total carbohydrate, and crude fat. The conversion factors used were 4.0 kcal/g for protein and carbohydrates, and 9.0 kcal/g for total fat, as determined by Ferris & Shanklin (1993) and Merrill & Watt (1973). The formula used to calculate total energy (TE) which provided an accurate estimate of the caloric value of each sample was given in Equation (1).

$$TE = (Crude\ protein \times 4) + (Carbohydrate\ \times 4) + (Crude\ fat \times 9) \tag{1}$$

The SPSS version 22 software (SPSS, Chicago, Illinois, USA) was used for the statistical analyses. A one-way analysis of variance (ANOVA) was used to find significant differences in the nutritional composition of the various fishmeals. Duncan's multiple range test was then used with a significance level of $P < 0.05$ to further assess the compositional differences.

RESULTS AND DISCUSSION

The present study provides a comprehensive analysis of the nutritional composition of fishmeals derived from anchovy, sprat, and salmon viscera, highlighting significant variations in their macronutrient profiles. The data, as presented in Table 1, reveal distinct differences in crude protein, crude fat, moisture, crude ash, carbohydrate content, and energy values among the three types of fishmeals.

The protein content of anchovy meal (73.55±1.50%) and sprat meal (70.08±1.36%) is higher than that of salmon viscera meal (63.58±1.85%), with anchovy meal exhibiting the highest protein content and salmon viscera meal showing the lowest. Differences among the three were significant ($p<0.05$). The significant differences observed in the nutritional analysis underscore that anchovy meal is a superior protein source for aquafeeds, offering higher protein content compared to sprat and salmon viscera meals. Anchovy meal typically contains a protein content that can exceed 70%, making it an excellent source of high-quality protein that is rich in essential amino acids (Guo et al., 2019). This high protein content is crucial for fish, as it promotes muscle development, enhances growth rates, and improves feed conversion efficiency. The amino acid profile of anchovy meal is also well-balanced, providing the necessary building blocks for protein synthesis in fish (Foroutani et al., 2018). In contrast, sprat meal, while still a good source of protein, generally has a slightly lower protein content compared to anchovy meal. However, it can still be a valuable ingredient in aquaculture feeds, especially when combined with other protein sources to achieve a balanced diet. Sprat meal can provide essential nutrients and contribute to the overall protein intake of the fish, but it may not be as nutritionally dense as anchovy meal (Litaay et al., 2022). Fishmeal derived from salmon viscera, although it has a respectable protein content, typically ranks lower than both anchovy and sprat meals in terms of protein quality and digestibility. While salmon viscera meal can provide a good source of protein, it may lack certain essential nutrients and amino acids that are more abundant in anchovy and sprat meals (Guo et al., 2019). Additionally, the digestibility of protein from salmon viscera may not be as high as that from anchovy or sprat, potentially leading to lower nutrient absorption and growth performance in fish (Suparmi et al., 2022). Given these considerations, it is advisable to prioritize anchovy meal as the primary protein source in aquaculture diets due to its superior protein content and nutritional profile. Sprat meal can be used as a supplementary protein source to enhance the overall diet, especially in formulations where cost or availability is a concern. Fishmeal from salmon viscera can be incorporated into diets, but it should be done with caution, ensuring that it is balanced with other high-quality protein sources to meet the nutritional needs of the fish effectively.

Table 1. Nutritional composition of fishmeals derived from anchovy, sprat, and salmon viscera

Nutritional Composition	Anchovy Meal	Sprat Meal	Salmon Viscera Meal
Crude Protein	73.55±1.50[c]	70.08±1.36[b]	63.58±1.85[a]
Crude Fat	10.33±0.86[ab]	9.92±0.33[a]	11.76±0.98[b]
Moisture	6.53±1.38[a]	7.15±1.43[a]	10.45±0.74[b]
Crude Ash	8.07±0.86[a]	9.07±0.87[a]	11.96±1.32[b]
Carbohydrate	1.52±0.55[a]	3.77±0.81[b]	3.32±0.69[b]
Energy	393.26±2.87[c]	384±3.68[b]	366.41±4.41[a]

Note: The difference between the means of the values indicated with different letters in the columns in each group is statistically significant ($p<0.05$).

Salmon viscera meal has the highest fat content at 11.76±0.98%, while both anchovy meal (10.33±0.86%) and sprat meal (9.92±0.33%) have lower but statistically similar ($p<0.05$) fat contents. The ideal crude fat ratio in fishmeal used in fish feed rations is a critical factor that influences the nutritional quality, growth performance, and overall health of fish. Generally, a crude fat content of around 10% is considered optimal for many aquaculture species, as it provides essential fatty acids while also contributing to the energy density of the diet (Mmanda et al., 2020; Chang, 2023). In this study, it was observed that the crude fat ratio determined was around 10% in three fishmeal types and was close to the crude fat ratio in ideal fishmeal. The specific ideal ratio can vary depending on the species being cultured, their life stage, and their dietary requirements. Having a higher crude fat content in fishmeal can be beneficial, as it enhances the energy content of the feed, which is particularly important for fast-growing species or those with high energy demands. Fish require lipids not only for energy but also for the absorption of fat-soluble vitamins and the provision of essential fatty acids, such as omega-3 and omega-6 fatty acids, which are crucial for growth, reproduction, and immune function (Mmanda et al., 2020). Moreover, higher fat content can improve the palatability of the feed, encouraging fish to consume more, which can lead to better growth rates and feed conversion ratios (Poczyczyński et al., 2014). However, excessively high crude fat levels can pose challenges, particularly concerning spoilage and rancidity. Fishmeals with high fat content are more susceptible to oxidative degradation, which can lead to the formation of off-flavors and harmful compounds that negatively impact fish health and feed quality (Zhu & He, 2011; Anuar, 2023). Therefore, while a certain level of fat is beneficial, it is essential to balance the fat content to avoid spoilage and ensure the feed remains fresh and nutritious.

Salmon viscera meal has the highest moisture content at 10.45%, whereas anchovy meal (6.53%) and sprat meal (7.15%) have comparatively lower levels. Statistical analysis revealed that salmon viscera meal was significantly different from both anchovy and sprat meals ($p<0.05$), while no significant differences were found between anchovy and sprat meals. The fishmeal used in fish feed rations is generally advised moisture under 10% to minimize bacterial growth and ensure better preservation. Maintaining a low moisture content is crucial for several reasons, primarily related to spoilage and the overall quality of the fishmeal. High moisture levels can create an environment conducive to microbial growth, leading to spoilage and the degradation of nutritional quality (Nyong, 2014). When moisture content exceeds the ideal range, the risk of mold and bacterial contamination increases, which can result in the loss of essential nutrients, including amino acids and fatty acids, as well as the production of harmful toxins (Hossen et al., 2013). Moreover, high moisture content can lead to the oxidation of lipids in fishmeal, which affects the flavor and palatability of the feed and compromises the health benefits associated with omega-3 fatty acids. This oxidation can result in rancidity, making the feed unpalatable and potentially harmful to fish health. Therefore, it is essential to ensure that fishmeal is processed and stored under conditions that minimize moisture absorption. Conversely, a low moisture content in fishmeal helps to enhance its shelf life and stability, allowing for longer storage without significant quality degradation. This is particularly important in aquaculture, where feed quality directly impacts fish growth and health outcomes (Samira & Mehrgan, 2015). Additionally, low moisture levels facilitate better handling and transportation of fishmeal, reducing the risk of spoilage during distribution. According to the findings of this study, the high moisture content present in fishmeal derived from salmon viscera may lead to deterioration during long-term storage. To prevent this, it is crucial to either rapidly convert the fishmeal into feed or implement processing techniques that effectively reduce its moisture content during production. These strategies are essential to maintain the quality and stability of the fishmeal over time.

The ash content of salmon viscera meal, anchovy meal, and sprat meal was analyzed, revealing that salmon viscera meal had the highest crude ash content at 11.96±1.32%. Meanwhile, anchovy meal and sprat meal, which have lower crude ash content, were found to be statistically similar to each other, with values of 8.07±0.86% and 9.07±0.87%, respectively. The observed differences in crude ash content were statistically significant ($p<0.05$). The ideal crude ash content in fishmeal used in fish feed rations typically ranges from 5% to 15%. This range is considered optimal for providing essential minerals while ensuring that the meal remains nutritionally balanced and effective for fish growth (Kokkali, 2023; Chang, 2023). Crude ash content reflects the mineral content of the fishmeal, which includes important elements such as calcium, phosphorus, magnesium, and trace minerals that are vital for various physiological functions in fish (Zaman et al., 2015). A lower crude ash content is generally preferred because excessively high crude ash levels can indicate a lower quality protein source or excessive mineral content, which may not be beneficial for fish health. High crude ash content can lead to an imbalance in the calcium-to-phosphorus ratio, potentially causing metabolic issues and affecting bone health in fish (Samira & Mehrgan, 2015). Moreover, high crude ash levels can negatively impact the digestibility of the feed, as excessive minerals can interfere with the absorption of nutrients (Zaman et al., 2015). Conversely, a certain level of crude ash is necessary to ensure that fish receive adequate minerals for growth and development. Minerals play crucial roles in skeletal development, enzyme function, and overall metabolic processes (Moazenzadeh et al., 2017). Therefore, while it is essential to maintain a balance, the goal should be to keep crude ash content within the recommended range to avoid spoilage and ensure optimal growth performance. According to the findings obtained in this study, three fishmeal types were found to have ideal crude ash content.

Sprat meal had the highest carbohydrate content (3.77±0.81%), followed by salmon viscera meal (3.32±0.69%), while anchovy meal had the lowest carbohydrate content (1.52±0.55%). Although no significant difference was found between sprat and salmon viscera meals, the difference between anchovy meal and the other two fish meals was statistically significant ($p<0.05$). This low carbohydrate content is particularly important for carnivorous fish species, such as salmonids, which are known to have limited ability to utilize carbohydrates effectively (Villasante et al., 2019). High carbohydrate levels can lead to metabolic issues, as these fish are not well adapted to digesting and metabolizing significant amounts of carbohydrates, often resulting in poor growth performance and health complications (Villasante et al., 2019). When considering which carbohydrate content in fishmeal should be preferred, it is essential to focus on the quality and digestibility of the carbohydrates present. Fishmeals with lower carbohydrate content are generally more beneficial, as they provide a higher concentration of protein and essential nutrients without the risks associated with excessive carbohydrate intake. For example, fishmeals that are high in protein and low in carbohydrates are more suitable for supporting the growth and health of carnivorous fish, as they align better with their natural dietary requirements (Villasante et al., 2019). In contrast, fishmeals with higher carbohydrate content may be appropriate for herbivorous or omnivorous species that can utilize carbohydrates more effectively. However, even for these species, it is crucial to ensure that the carbohydrate sources are digestible and do not contain anti-nutritional factors that could hinder nutrient absorption (Wade et al., 2013; Tadesse, 2023). Based on the findings of this study, it is recommended to use anchovy meal, which has a low carbohydrate content, in the feed for species like salmon that are widely farmed in the Black Sea. The lower carbohydrate levels in anchovy meal can offer nutritional advantages that support better growth and overall health in these fish.

Energy content analysis demonstrated that anchovy meal had the highest energy content at 393.26±2.87 kcal/100g, followed by sprat meal at 384±3.68 kcal/100g, and salmon viscera meal with the lowest at 366.41±4.41 kcal/100g. These differences were determined to be statistically significant ($p<0.05$). The ideal energy content in fishmeal used in fish feed rations typically ranges from 300 to 500 kcal per 100 grams. This range is considered optimal for providing sufficient energy to support the growth and metabolic needs of fish, particularly in aquaculture settings where energy demands can be high due to rapid growth rates and intensive farming practices (Nistor et al., 2021). Higher energy fishmeals are beneficial as they provide more calories per unit weight, which can enhance feed efficiency and growth performance in fish. This is particularly important for species with high energy requirements, such as salmon and other carnivorous fish, which benefit from energy-dense diets that support their growth and overall health (Tugiyono et al., 2020). Conversely, fishmeals with lower energy content, while still usable, may not be as effective in promoting optimal growth and feed conversion ratios. These lower energy meals might be more suitable for herbivorous or omnivorous species that can utilize a broader range of feed ingredients, including those with lower energy densities (El-Dakar et al., 2015). However, it is essential to ensure that even lower-energy meals are balanced with other ingredients to meet the overall dietary energy requirements of the fish. The anchovy, sprat, and salmon viscera flours analyzed in this study are well-suited for inclusion in fishmeal formulations due to their ideal energy content, which falls within the desirable range of 300-500 kcal. This energy range supports the nutritional needs of various aquaculture species effectively.

CONCLUSION

This study provides a comprehensive analysis of the nutritional composition of fishmeals derived from whole anchovy, sprat, and salmon viscera, highlighting significant variations in their macronutrient profiles. The results indicate that anchovy meal has the highest crude protein content (73.55±1.50%), making it a superior protein source for aquafeeds. In contrast, salmon viscera meal exhibited the lowest protein content (63.58±1.85%) and the highest moisture content (10.45±0.74%), which may affect its storage stability and nutritional quality.

Sprat meal had the highest carbohydrate content (3.77±0.81%), while anchovy meal had the lowest (1.52±0.55%). The energy content was highest in anchovy meal (393.26±2.87 kcal/100g), followed by sprat meal (384±3.68 kcal/100g) and salmon viscera meal (366.41±4.41 kcal/100g). These differences were statistically significant ($p<0.05$), underscoring the distinct nutritional profiles of the fishmeals studied.

Based on these findings, it is recommended that anchovy meal be prioritized as the primary protein source in aquaculture diets due to its high protein and energy content. Sprat meal can serve as a supplementary protein source, while salmon viscera meal should be used cautiously, ensuring it is balanced with higher-quality protein sources to meet the nutritional needs of fish effectively. Future research should focus on optimizing the processing and storage of fishmeals to enhance their nutritional quality and shelf life, as well as exploring alternative protein sources to meet the growing demands of the aquaculture industry.

Compliance with Ethical Standards

Authors' Contributions

BB: Conceptualization, Methodology, Supervision, Writing – review & editing

SY: Writing – original draft, Investigation, Formal analysis

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Not applicable.

Data Availability

The data that support the findings of this study are available from the corresponding author on request.

REFERENCES

Ahmed, I., Jan, K., Fatma, S., & Dawood, M. A. (2022). Muscle proximate composition of various food fish species and their nutritional significance: A review. *Journal of Animal Physiology and Animal Nutrition*, *106*(3), 690–719. https://doi.org/10.1111/jpn.13711

Ahuja, I., Dauksas, E., Remme, J. F., Richardsen, R., & Løes, A. K. (2020). Fish and fish waste-based fertilizers in organic farming–With status in Norway: A review. *Waste Management*, *115*, 95–112. https://doi.org/10.1016/j.wasman.2020.07.025

Albrektsen, S., Kortet, R., Skov, P. V., Ytteborg, E., Gitlesen, S., Kleinegris, D., Mydland, T., Hansen, J. Ø., Lock, J., Mørkøre, T., James, P., Wang, X., Whitaker, R. D., Vang, B., Hatlen, B., Daneshvar, E., Bhatnagar, A., Jensen, L. B., & Øverland, M. (2022). Future feed resources in sustainable salmonid production: A review. *Reviews in Aquaculture*, *14*(4), 1790-1812. https://doi.org/10.1111/raq.12673

Alfiko, Y., Xie, D., Astuti, R. T., Wong, J., & Wang, L. (2022). Insects as a feed ingredient for fish culture: Status and trends. *Aquaculture and Fisheries*, *7*(2), 166-178. https://doi.org/10.1016/j.aaf.2021.10.004

Anonymous (2005). Code of federal regulations. FDA, HHS, 21, part 101.9.

Ansari, F. A., Guldhe, A., Gupta, S. K., Rawat, I., & Bux, F. (2021). Improving the feasibility of aquaculture feed by using microalgae. *Environmental Science and Pollution Research*, *28*(32), 43234–43257. https://doi.org/10.1007/s11356-021-14989-x

Anuar, N. (2023). Nutritional properties evaluation of blowfly larvae from fish and chicken wastes for Asian sea bass feed formulation application. *Journal of Tropical Life Science*, *13*(3), 431–444. https://doi.org/10.11594/jtls.13.03.02

Bayraklı, B. (2023). Utilization of fish by-products for sustainable aquaculture: Nutritional analysis of fishmeal derived from the by-products of *Oncorhynchus mykiss*. *Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi*, *9*(2), 8–14. https://doi.org/10.58626/menba.1360875

Bayraklı, B. (2024). Impact of cooking processes on the toxic metals, macro, and trace elements composition of *Rapana venosa* meat. *Aquatic Research*, *7*(2), 74–82. https://doi.org/10.3153/AR24007

Bayraklı, B., & Duyar, H. A. (2021). Effect of freshness on fishmeal quality; anchovy meal. *Journal of Anatolian Environmental and Animal Sciences*, *6*(1), 57–65. https://doi.org/10.35229/jaes.824885

Bayraklı, B., Duyar, H. A., & Yıldız, S. (2022). Comparison of different analysis methods for determination of nutrient composition of fishmeal produced from anchovy (*Engraulis encrasicolus*). *Food Bulletin*, *1*(1), 7–10. https://doi.org/10.29329/foodb.2022.495.02

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. https://doi.org/10.1007/s12571-021-01246-9

Campanati, C., Willer, D., Schubert, J., & Aldridge, D. C. (2022). Sustainable intensification of aquaculture through nutrient recycling and circular economies: More fish, less waste, blue growth. *Reviews in Fisheries Science & Aquaculture*, *30*(2), 143–169. https://doi.org/10.1080/23308249.2021.1897520

Chang, V. (2023). Supplementation of *Kappaphycus alvarezii* solid waste (bioethanol production) in fish feed for *Barbonymus schwanenfeldii* growth. *Borneo Journal of Marine Science and Aquaculture*, *7*, 14–29. https://doi.org/10.51200/bjomsa.v7i.3757

Einarsson, Á., & Óladóttir, D. (2020). *Fisheries and aquaculture: The food security of the future*. Academic Press. https://doi.org/10.1016/C2019-0-02984-6

El-Dakar, Y., Shalaby, A., & Abd Elmonem, A. (2015). Growth performance and feed utilization of hybrid red tilapia, *Oreochromis niloticus* (Linnaeus) x *Oreochromis mosambicus* (Peters) fed different dietary protein and energy levels under rearing in seawater conditions. *Mediterranean Aquaculture Journal*, *7*(1), 12-21. https://doi.org/10.21608/maj.2015.4629

Eroldoğan, O. T., Glencross, B., Novoveska, L., Gaudêncio, S. P., Rinkevich, B., Varese, G. C., Carvalho, F., Tasdemir, D., Safarik, I., Nielsen, S. L., Rebours, C., Lada, L. B., Robbens, J., Strode, E., Haznedaroğlu, B. Z., Kotta, J., Evliyaoğlu, E., Oliveira, J., Girão, M., ... Rotter, A. (2023). From the sea to aquafeed: A perspective overview. *Reviews in Aquaculture*, *15*(3), 1028-1057. https://doi.org/10.1111/raq.12740

Ferris, D. A., & Shanklin, C. W. (1993). Cost of alternative methods of disposal of food waste in a university food service operation. *National Association of College and University Food Service Journal*, *26*(10), 49-56.

Foroutani, M., Parrish, C., Wells, J., Taylor, R., Rise, M., & Shahidi, F. (2018). Minimizing marine ingredients in diets of farmed Atlantic salmon (*Salmo salar*): Effects on growth performance and muscle lipid and fatty acid composition. *PLOS ONE*, *13*(9), e0198538. https://doi.org/10.1371/journal.pone.0198538

Glencross, B., Fracalossi, D. M., Hua, K., Izquierdo, M., Mai, K., Øverland, M., Robb, D., Roubach, R., Schrama, J., Small, B., Tacon, A., P. Valente, L. M., Viana, T., Xie, S., & Yakupityage, A. (2023). Harvesting the benefits of nutritional research to address global challenges in the 21st century. *Journal of the World Aquaculture Society*, *54*(2), 343–363. https://doi.org/10.1111/jwas.12948

Gudbrandsdottir, I. Y., Saviolidis, N. M., Olafsdottir, G., Oddsson, G. V., Stefansson, H., & Bogason, S. G. (2021). Transition pathways for the farmed salmon value chain: Industry perspectives and sustainability implications. *Sustainability*, *13*(21), 12106. https://doi.org/10.3390/su132112106

Guo, J., Swanepoel, A., Qiu, X., Reis, J., Rhodes, M., & Davis, D. (2019). Use of salmon by-product meals as a replacement for anchovy meal in practical diets for the Pacific white shrimp (*Litopenaeus vannamei*). *Aquaculture Nutrition*, *26*(2), 490–501. https://doi.org/10.1111/anu.13011

Hardy, R. W., Kaushik, S. J., Mai, K., & Bai, S. C. (2022). Fish nutrition—History and perspectives. *Fish Nutrition*. Academic Press. https://doi.org/10.1016/C2018-0-03211-9

Henriksen, A. (2020). Fishery by-products, *Calanus finmarchicus* and mesopelagic fish species as alternatives to fishmeal and fish oil in feeds for Atlantic salmon (*Salmo salar* L). [MSc. Thesis. Norwegian University of Science and Technology].

Hossen, M., Das, M., Sumi, K., & Hasan, M. (2013). Effect of storage time on fish feed stored at room temperature and low temperature. *Progressive Agriculture*, *22*(1–2), 115–122. https://doi.org/10.3329/pa.v22i1-2.16473

Kokkali, M. (2023). Optimisation of trace mineral supplementation in diets for atlantic salmon smolt with reference to holistic fish performance in terms of growth, health, welfare, and potential environmental impacts. *Frontiers in Physiology*, *14*, 1214987. https://doi.org/10.3389/fphys.2023.1214987

Lall, S. P., & Dumas, A. (2022). Nutritional requirements of cultured fish: Formulating nutritionally adequate feeds (pp. 65-132). In A. Davis (Ed.), *Feed and Feeding Practices in Aquaculture (Second edition)*. Woodhead Publishing. https://doi.org/10.1016/B978-0-12-821598-2.00005-9

Lam, V. W., Allison, E. H., Bell, J. D., Blythe, J., Cheung, W. W., Frölicher, T. L., Gasall, M. A., & Sumaila, U. R. (2020). Climate change, tropical fisheries and prospects for sustainable development. *Nature Reviews Earth & Environment*, *1*(9), 440–454. https://doi.org/10.1038/s43017-020-0071-9

Litaay, C., Indriati, A., Sriharti, N., Mayasti, N., Tribowo, R., Andriana, Y., & Andriansyah, R. C. E. (2022). Physical, chemical, and sensory quality of noodles fortification with anchovy (*Stolephorus sp.*) flour. *Food Science and Technology*, *42*, e75421. https://doi.org/10.1590/fst.75421

Merrill, A. L., & Watt, B. K. (1973). Energy value of foods, basis and derivation (No: 74-85). Human Nutrition Research Branch, Agricultural Research Service, US Department of Agriculture.

Mmanda, F., Mulokozi, D., Lindberg, J., Haldén, A., Mtolera, M., Kitula, R., & Lundh, T. (2020). Fish farming in Tanzania: The availability and nutritive value of local feed ingredients. *Journal of Applied Aquaculture*, *32*(4), 341–360. https://doi.org/10.1080/10454438.2019.1708836

Moazenzadeh, K., Islami, H., Zamini, A., & Soltani, M. (2017). Dietary zinc requirement of Siberian sturgeon (*Acipenser baerii*, brandt 1869) juveniles, based on the growth performance and blood parameters. *International Aquatic Research*, *9*(1), 25-35. https://doi.org/10.1007/s40071-017-0153-6

Nistor, V., Bocioc Sîrbu, E., Dima, F. M., Patriche, N., Athanasopoulos, L. B., Tenciu, M., & Popa, M. D. (2021). Optimization of food rations used for the pre-development of the species *Acipenser baerii* (J.F. Brandt, 1869) in recirculating aquaculture system. *Life Science and Sustainable Development*, 2(1), 68-74. https://doi.org/10.58509/lssd.v2i1.80

Nyong, E. (2014). Effect of storage and anti-nutritional components in stored pelleted fish feed. *International Journal of Science, Technology and Society*, 2(6), 186-189. https://doi.org/10.11648/j.ijsts.20140206.14

Poczyczyński, P., Gomułka, P., Woźniak, M., & Szostak, I. (2014). Preliminary study on the partial substitution of fish oil with amaranth oil in diets for rainbow trout (*Oncorhynchus mykiss*) fingerlings: Effects on body composition and fatty acids contents. *Turkish Journal of Fisheries and Aquatic Sciences*, *14*(2), 343–350. https://doi.org/10.4194/1303-2712-v14_2_16

Samira, H., & Mehrgan, M. (2015). The effect of replacing fishmeal in the diet with enzyme-treated soybean meal (HP310) on growth and body composition of rainbow trout fry. *Molecules*, *20*(12), 21058–21066. https://doi.org/10.3390/molecules201219751

Sandström, V., Chrysafi, A., Lamminen, M., Troell, M., Jalava, M., Piipponen, J., Siebert, S., van Hal, O., Virkki, V., & Kummu, M. (2022). Food system by-products upcycled in livestock and aquaculture feeds can increase global food supply. *Nature Food*, *3*(9), 729–740. https://doi.org/10.1038/s43016-022-00589-6

Suparmi, S., Sumarto, S., Afriana, U., & Hidayat, T. (2022). Utilization of biang fish flour (*Ilisha elongata*) as an enrichment material for sago noodles nutrient value. *International Journal of Biomaterials*, *2022*(1), 8746296. https://doi.org/10.1155/2022/8746296

Tadesse, A. (2023). Optimization of fish and plant production in tilapia-spinach aquaponics systems using black soldier fly larvae meal and mineral supplementation. *Helix*, *6*(1), 1–34. https://doi.org/10.59411/mvxf3229

Tugiyono, Febryano, I., Puja, Y., & Suharso. (2020). Utilization of fish waste as fish feed material as an alternative effort to reduce and use waste. *Pakistan Journal of Biological Sciences*, *23*(5), 701-707. https://doi.org/10.3923/pjbs.2020.701.707

Villasante, A., Catalán, N., Opazo, R., Dantagnan, P., & Romero, J. (2019). Effect of dietary carbohydrate-to-protein ratio on gut microbiota in Atlantic salmon (*Salmo salar*). *Animals*, *9*(3), 89. https://doi.org/10.3390/ani9030089

Wade, N., Skiba-Cassy, S., Dias, K., & Glencross, B. (2013). Postprandial molecular responses in the liver of the barramundi (*Lates calcarifer*). *Fish Physiology and Biochemistry*, *40*(2), 427–443. https://doi.org/10.1007/s10695-013-9854-y

Zaman, M. N., Naser, M. N., Abdullah, A. T. M., & Khan, N. (2015). Nutrient contents of some popular freshwater and marine fish species of Bangladesh. *Bangladesh Journal of Zoology*, *42*(2), 251-259. https://doi.org/10.3329/bjz.v42i2.23367

Zhu, F., & He, Y. (2011). Study on mid-infrared transmittance spectroscopy for fast measurement of crude fat content in fish feeds based on BPNN and LS-SVM. *Key Engineering Materials, 460–461*, 816–820. https://doi.org/10.4028/www.scientific.net/kem.460-461.816