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Preparation of Fish Meal from Various Fishery Sources For Use in Young Common Carp *Cyprinus carpio* L. Diets

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ABSTRACT

The purpose of the current research was to compare fishmeal produced from three distinct sources: marine fishmeal (MFM), freshwater fishmeal (FFM), and cartilaginous fishmeal (CFM), along with imported fishmeal (IFM). The study aimed to assess their biochemical properties and analyze their impact on the growth and nutritional performance of young common carp *Cyprinus carpio* L. The chemical composition revealed varying protein levels ranging from 70.6% to 65.12%. Regarding lipid content, the highest value was found in FFM at 9.97%. Moreover, ash content and nitrogen-free extract NFE ranged from 20.71% to 12.54% and 2.75% to 4.71%, respectively. Amino acid profile analysis revealed the presence of 18 essential and non-essential amino acids in varying proportions among the prepared fishmeal. The amino acid glutamic acid stood out with high levels in all prepared fishmeal, measuring 7.65, 7.57, 7.82, and 7.79mg/100-milligram protein for MFM, FFM, CFM, and IFM, respectively. Regarding the fatty acid composition in the oil extracted from the fishmeal, the FFM had the highest proportion of saturated fatty acids SFA at 29.96%. The highest proportion of monounsaturated fatty acids MUFA at 47.05% was found in CFM. Polyunsaturated fatty acids PUFA and unsaturated fatty acids UFA in MFM exhibited the highest percentages at 36.52% and 78.55%, respectively. The results showed that the highest values for the final weight (304.24g), total weight gain (171.23g), specific growth rate (4.82%), relative growth rate (123.62%), and feed conversion ratio (1.85) were recorded in diet T2 (using MFM) significantly ($P \leq 0.05$). The study showcased the potential use of these three prepared fishmeal types as viable local alternatives to imported fishmeal when formulating diets for feeding young common carp.

INTRODUCTION

Fishmeal is considered one of the most important commercial feed components in the field of aquaculture **(Qiu *et al.*, 2023)**. Fish feed industry utilizes approximately 87% of the global fishmeal production **(FAO, 2020)**. In order to meet the increasing demand for high-quality artificial feeds for aquatic organisms, there should be a corresponding advancement and expansion in fishmeal production **(Miles & Chapman, 2015)**. Fishmeal is generally produced from non-economically valuable and undesirable fish

species, as well as from bycatch or a mixture of various fish species **(Hendalia *et al*., 2019; Kim *et al*., 2021)**. Fishmeal plays a crucial role as a significant protein component in fish feed formulations. Its high protein content, ranging from 60 to 70%, along with its rich variety of quality amino acids and vitamins, notably vitamin D, B12, riboflavin, niacin and choline, make it invaluable. Additionally, fishmeal is a source of essential minerals, particularly calcium, phosphorus, manganese and iodine. Moreover, it contains beneficial lipids, including long-chain unsaturated fatty acids such as omega-3 and various other nutritional components in addition to essential trace elements necessary for growth, reproduction, body construction and tissue repair **(Ma *et al*., 2020)**. On the other hand, it still holds great significance in formulating feeds, especially plant-based feeds that are deficient in most essential amino acids and fatty acids, which can slow down fish growth **(Cho & Kim, 2011)**. This has led to its use as a balanced nutritional supplement that enhances feed palatability, reduces feeding costs, and improves digestion and nutrient absorption **(Lee *et al*., 2004; Olsen & Hasan, 2012)**. A well-balanced nutrition is paramount in aquaculture to enhance fish health, support optimal growth, and ensure survival. This balanced nutrition not only promotes the well-being of the fish but also contributes to increased economic production and high-quality yields, as noted by **Makode (2017)**.

MATERIALS AND METHODS

Fish meal preparation

A group of unwanted and economically non-viable fish species, known as bycatch, was utilized in the preparation of fish meal. Three distinct types of fish meal, namely freshwater fish meal (FFM), marine fish meal (MFM), and cartilage fish meal (CFM), were prepared. Upon arrival at the laboratory, the samples were thoroughly washed with tap water to remove any impurities and then manually cut into suitable size chunks. Fish pieces were placed in a pot and cooked at boiling temperature (100°C) for 20 minutes. Subsequently, the mixture was left to cool and transferred to meshed containers for filtration, and then it was pressed to remove excess water and oil. Consequently, the samples were spread out for air-drying at the laboratory temperature for 3 days, with continuous stirring to ensure homogenous drying. The resulting dried material was ground using an electric grinder and passed through a sieve with 0.5mm openings to eliminate any remaining unground parts for ease of use in feed formulation. Finally, the samples were stored in clean and dry glass containers until used for further tests.

Estimation of chemical composition

The percentage of moisture was determined using an electric drying oven at a temperature of 105°C until a constant weight was achieved. The percentage of ash was calculated after burning the samples in a muffle furnace at a temperature of 525°C for 16 hours or until the ash turned white. Total nitrogen was estimated using the semi-micro-

kjeldahl method and multiplying the result by a conversion factor for meat (6.25) to obtain the protein percentage. Lipid content was determined using Soxhlet extraction with organic solvent mixture (chloroform: methanol in a ratio of 1:2, v:v) following the method described by **Egan *et al*. (1988)**.

Estimation of amino acids

The amino acid content of the fish meal prepared samples was analyzed according to the method described by **Vidotti *et al*. (2003)**. An ion exchange column and post-column ninhydrin derivatization were used for analysis, utilizing the Visible-UV Detector -6 Av uv -Spd Shimadzu in an automatic analysis system. High-performance liquid chromatography (HPLC) equipment, operated under the supervision of the Ministry of Science and Technology in Baghdad, Iraq, was utilized for this purpose.

Estimation of total fatty acids

The total fatty acid content in the oils extracted from fish meal samples was analyzed using the method described by **Abdulkadir *et al*. (2010)**. The oils were examined using Gas Chromatography-Mass Spectrometry (GC-MS), a comprehensive spectral analysis technique, at the laboratories of the Chemistry Department, the Ministry of Science and Technology, Baghdad, Iraq.

Experimental system and fish

A fish rearing system was designed using 12 glass aquaria, each with a capacity of 30L. The aquaria were sterilized using a solution of sodium hypochlorite at a concentration of 200 parts per million for one hour **(Herwing, 1979)**. The tanks were equipped with perforated plastic covers to prevent fish from jumping out of the water. A ventilation system was installed to increase the dissolved oxygen levels in the water, and submerged heating devices with a thermostat were used to maintain the water temperature. The experiment consisted of four treatments, with three replicates for each treatment. Young common carp, *Cyprinus Carpio* L., with an average weight of 16.46 ± 0.067g, was used in the experiment. At the beginning of the experiment, ten fish specimens were distributed into each tank. The fish were acclimated to the experimental conditions for ten days and fed a standard diet during this period. The feeding trial lasted for 70 days, starting from March 14, 2021, until May 22, 2021. The investigational fish were fed at a rate of 3% of their body weight, divided into two meals per day. The daily feeding times were 8-9 am and 1-2 pm. Fish were weighed biweekly to adjust the amount of feed, accordingly. In addition, approximately 30% of aquaria water was replaced daily, and any remaining feed and waste were siphoned out using a siphon method.

Diet preparation

Four experimental diets were formulated using prepared fish meal. The diets were as follows: T1 (control diet containing commercial fish meal), T2 (diet containing marine fish meal), T3 (diet containing fresh fish meal) and T4 (diet containing cartilaginous fish meal). Upon establishing the proportions of the raw feed ingredients used in the production of the fish diets, as outlined in Table (1), the feed ingredients were finely ground and passed through a sieve with 2mm openings. These ingredients were then thoroughly mixed according to the calculated ratios to achieve homogeneity.

Approximately, 100ml of boiling water was added to every 250g of the mixture. Upon thorough mixing, the temperature of the mixture was raised to 80°C and then allowed to cool. Vitamins and minerals were added after the mixture of the feed dough was formed into discs using a commercial meat grinder with 4mm diameter holes. The compressed feed pellets were then air-dried in the laboratory for 48 hours with continuous stirring to remove excess moisture and ensure complete drying. Finally, the manufactured feed was stored in plastic containers with a capacity of 1kg and placed in the refrigerator until use.

Table 1. Proportions of feed ingredients used in feed manufacturing

Feedstuff	T1 IFM	T2 MFM	T3 FFM	T4 CFM
IFM	23	0	0	0
MFM	0	23	0	0
FFM	0	0	23	0
CFM	0	0	0	23
Soybean meal	20	20	20	20
Corn	15	15	15	15
Wheat bran	20	20	20	20
Wheat flour	18	18	18	18
Vit. and min.	2	2	2	2
Vegetable oil	2	2	2	2

Feeding experiment

Fish growth

Throughout the experiment, the fish were fed experimental diets at a daily rate of 3% of their body weight, divided into two meals (at 8-9 am and 1-2 pm). Fish were biweekly weighed to adjust the diet quantity, and approximately 25% of the aquarium water was daily changed, with siphoning of uneaten feed and waste. Fish growth parameters, namely total (TWG) and daily weight gains (DWG), were calculated following the method described by **Sevier *et al*. (2000)** as follows:

TWG (g/fish) = Final weight – Initial weight

DWG (g/fish/day) = TWG / time (day)

Relative (RGR) and specific (SGR) growth rates were calculated as described by

RGR (%) = TWG / Initial wt. X 100

SGR (%/day) = (ln final wt. – ln Initial wt.) / time (day) X 100

Feed conversion ratio (FCR), protein intake (PI) and protein efficiency ratio (PER) were calculated using the method applied by **Tacon (1990)** as follows:

FCR = Consumed feed (g) / TWG (g)

PI (g/fish) = Consumed feed (g) X Feed protein content (%)

PER (%) = TWG / PI

Feed apparent digestibility

To measure total apparent digestibility (TADC) and nutrient apparent digestibility (NADC) coefficients, the indirect method described by **Talbot (1985)** was applied using chromium oxide Cr_2O_3 as a marker. The marker content in experimental diets and

collected fish feces was assessed by measuring absorbance spectrophotometrically at 350nm as follows:

TADC (%) = 100 – [100 x (% marker in feed) / (%marker in feces)

NADC = 100 – [100 x {(% marker in feed) / (%marker in feces)}/ {(% marker in feces) / (%marker in feed)}]

RESULTS

Chemical composition

In this study, the chemical composition of different types of prepared fish meal was investigated, and it is detailed in Table (2). These analysis provide valuable insights into the nutritional profiles of the studied fish meal varieties. The results indicate variations in the chemical composition among the examined types. In regrads to the protein content, the IFM had the highest percentage of protein at 70.6%, followed by MFM at 69.19%. There was a significant difference (P<0.05) between the protein content in FFM at 58.43% and CFM at 65.12%. Hence, for the lipid content, the highest values were found in FFM at 9.97% and CFM at 9.11%. There was a significant difference (P<0.05) between these values and the percentage of lipid in IFM and MFM, which were 8.31% and 8.87%, respectively. The statistical analysis showed no significant difference between MFM and IFM (P>0.05).

On the other hand, FFM exhibited a high ash content of 20.71%, while the ash percentage in CFM was 16.87%, showing a significant difference (P<0.05), compared to the ash content in MFM and IFM, which recorded values of 13.44% and 12.54%, respectively. The moisture content was 5.11% for IFM, 5.75% for MFM, 6.18% for FFM, and 5.96% for CFM. The statistical analysis indicated significant differences (P<0.05) between MFM and FFM, as well as between IFM and CFM, while there was no significant difference between MFM and IFM (P>0.05). The results also revealed variations in non-nitrogenous compounds and energy content among the prepared fish meal types.

Table 2. Proximate composition (%) and metabolizable energy content (Kcal/100g) of imported and prepared fish meal

	IFM	MFM	FFM	CFM
CP	70.6 a±3.78	69.19 a±4.16	58.43 b±4.72	65.12 b±3.22
EE	8.31 a±1.86	8.87 a±1.24	9.97 b±1.87	9.11 b ±1.79
Ash	12.54 a± 2.85	13.44 a± 2.71	20.71 b± 3.24	16.87 b± 3.01
Moisture	5.11 a±1.01	5.75 a ±1.32	6.18 b ±1.82	5.96 b ±1.15
NFE	3.44 ±0.92	2.75 ±0.88	4.71 ±0.94	2.94 ±0.69
ME	477.420 ± 27.9	474.745± 25.1	424.346 ± 26.3	454.018 ± 25.7

IFM, Imported Fish Meal; MFM, Marine Fish Meal; FFM, Freshwater Fish Meal; CFM, Cartilaginous Fish Meal. ME was calculated according to **Henken *et al.* (1986)**.

The results shown in Table (3) illustrate the analysis of amino acids using high-performance liquid chromatography (HPLC) technique for fish meal prepared from marine fish, freshwater fish and cartilaginous fish. The results indicate the presence of 18 amino acids, with variations in their proportions. The amino acid glutamic acid stood out with high levels in all prepared fish meal, measuring 7.82, 7.79, 7.65, and 7.57mg/100

milligram protein for CFM, IFM, MFM and FFM, respectively. On the other hand, the amino acid tryptophan exhibited low levels in all samples, with values of 0.55, 0.54, 0.48 and 0.61mg/100 milligram protein for the respective fish meals. The remaining amino acids varied and differed in their proportions depending on the type of prepared fish meal.

Table 3. Amino acid profiles (µg/100 µg protein) of imported and prepared fish meal

Amino acid	IFM	MFM	FFM	CFM
Ala	3.71	3.54	3.64	3.88
Arg	3.81	4.05	3.53	4.11
Asp	6.07	5.82	5.94	5.76
Cys	0.69	0.70	0.59	0.64
Glu	7.79	7.65	7.57	7.82
Gly	5.22	5.07	5.11	4.96
His	1.61	1.42	1.07	1.91
Iso	2.16	2.75	1.95	2.67
Leu	4.43	4.29	4.08	3.85
Lys	4.65	4.48	4.29	4.14
Met	1.74	1.71	1.54	1.88
Phe	2.38	2.45	2.09	2.48
Pro	3.29	3.08	2.96	4.01
Ser	2.82	2.74	2.55	3.09
Thr	2.81	2.69	2.74	2.71
Trp	0.54	0.61	0.48	0.55
Tyr	1.89	2.01	1.76	2.12
Val	2.74	2.89	2.62	2.78
ΣEAA/Σ NEAA	0.854	0.893	0.810	0.840

EAA, Essential Amino Acids; NEAA, Non-Essential Amino Acids.

The total quantity and composition of individual fatty acids in the examined fish meal were determined using Gas Chromatography-Mass Spectrometry (GC-MS) technique. The results presented in Table (4) show the presence of 19 fatty acids with varying proportions in different prepared fish meals. All types of prepared fish meals were characterized by high levels of oleic acid (C18:1 w9), albeit with varying amounts. The percentages were 20.88%, 19.91%, 16.82% and 14.85% for CFM, FFM, MFM and IFM, respectively. Subsequently, the palmitoleic acid (C16:1 w7) had a percentage of 10.23% and 10.11% in CFM and MFM, respectively, while palmitic acid (C16:0) constituted 16.12% in FFM. Linoleic acid (C18:2 w6) was found in IFM at a percentage of 10.20%. On the other hand, behenic acid (C22:0) and myristoleic acid (C14:1 w5) had the lowest proportions relative to all the other fatty acids present in the oil composition. The results also demonstrated clear variations in the proportions and composition of the remaining fatty acids among different types of fish meal.

Table 4. Fatty acid profiles (µl/100 µl oil) of imported and prepared fish meal

Fatty acid	IFM	MFM	FFM	CFM
Myristic acid C14:0	3.38	3.55	5.78	4.33
Palmitic acid C16:0	9.41	8.72	16.12	8.25
Margaric acid C17:0	1.45	1.17	2.31	1.16
Stearic acid C18:0	2.85	2.66	3.38	4.78
Arachidic acid C20:0	1.77	1.98	0.97	2.22
Behenic acid C22:0	1.01	0.87	1.40	0.69
Myristoleic acid C14:1 w5	1.69	2.05	0.75	1.93
Palmitolenic acid C16:1 w7	9.78	10.11	8.44	10.23
Ginkgolic acid C17:1 w7	2.43	2.28	2.55	1.79
Oleic acid C18:1 w9	14.65	16.82	19.91	20.88
Gadoleic acid C20:1 w9	2.33	3.01	1.55	2.97
Erucic acid C22:1 w9	5.42	3.78	4.31	5.04
Nervonic acid C24:1 w9	5.16	3.98	2.69	4.21
Linoleic acid C18:2 w6	10.20	9.88	11.23	9.11
α-linolenic acid C18:3 w3	9.98	10.01	7.62	8.89
Eicosatrienoic acid C20:3 w3	4.98	5.11	3.05	3.88
Arachidonic acid C20:4 w6	2.67	2.85	1.63	2.39
Eicosapentaenoic acid (EPA) C20:5 w3	6.48	5.89	2.41	3.28
Docosapentaenoic acid (DHA) C22:6 w3	2.05	2.78	1.55	1.98
ΣSFA	19.87	18.95	29.96	21.43
ΣMUFA	41.46	42.03	40.20	47.05
ΣPUFA	36.36	36.52	27.49	29.53
ΣUFA	77.82	78.55	67.69	76.58

SFA, Saturated fatty acids; MUFA, Monounsaturated fatty acids; PUFA, Polyunsaturated fatty acids; UFA, Unsaturated fatty acids.

Fish growth experiment

Table (5) presents the initial weight (g), final weight (g), weight gain (g), total weight gain (g), specific growth rate (SGR), relative growth rate (RGR), feed conversion ratio (FCR) and protein efficiency ratio (PER) for the experimental fish. The results showed that the highest values for final weight, total weight gain, specific growth rate, and relative growth rate were recorded in diet T2 (using MFM), reaching 304.24g, 171.23g, 4.82%/day and 123.62%, respectively. The lowest values were observed in diet T4 (using CFM), with values of 274.34 g, 133.21 g, 4.45%/day and 94.38%, respectively. The results revealed that the use of (IFM, MFM, FFM) in diets T1, T2 and T3 improved the growth performance compared to the diet consisting of CFM (T4). Diet T2 showed superior growth performance compared to all other diets, and the difference was statistically significant ($P< 0.05$), indicating the quality of the MFM used in the diet.

It was observed that the best feed conversion ratio was achieved in diet T2, with a value of 1.85, and the difference was statistically significant ($P< 0.05$) compared to the other treatments, which showed conversion ratios of 2.62, 2.57, and 3.04 for diets T1, T3 and T4, respectively. Statistical analysis confirmed significant differences ($P< 0.05$) in feed conversion ratio between diet T4 and diets T1 and T3, which did not differ significantly from each other. The study also revealed that the highest protein efficiency ratio was observed in diet T2, with a value of 1.60, while the lowest ratio of 0.96 was recorded in

the control diet T4. The remaining ratios ranged between 1.15 and 1.27 for diets T1 and T3, respectively. Statistical analysis showed significant differences ($P< 0.05$) between diets T1 and T3 and the other treatments.

Table 5. Feeding and growth parameters of common carp *C. carpio* in growth experiment

Treatment	Initial weight (g)	Final weight (g)	Weight gain (g)	RGR (%)	SGR (%/day)	FCR	PER
T1	138.51a±3.52	304.24b±14.32	171.23b±20.22	4.82b±0.27	123.62b±16.74	2.62b±0.87	1.15b±0.12
T2	136.55b±3.64	395.16a±12.42	258.61a±16.46	5.36a±0.22	189.38a±13.96	1.85a±0.23	1.60a±0.21
T3	140.25a±3.57	314.16b±15.11	173.91b±20.43	4.84b±0.21	124.00b±17.63	2.57b±0.17	1.27b±0.12
T4	141.13a±4.78	274.34c±13.76	133.21c±17.26	4.45c±0.13	94.38c±10.41	3.04c±0.47	0.96c±0.11

Apparent digestibility

The results in Table (6) show the apparent digestibility coefficients of the nutritional components in the manufactured feeds containing different types of fish meal fed to common carp during the study period. The highest digestibility coefficient for protein was recorded in the IFM treatment with a value of 94.36, followed by the MFM feed with a value of 91.84. The digestibility coefficients for protein in the FFM and CFM feeds were 89.44 and 87.62, respectively. For the digestibility coefficient of the lipid component, the values were 91.45, 89.73, 86.66, and 84.64 for the IFM, MFM, FFM and CFM feeds, respectively. In terms of carbohydrate digestion, the value for digestibility of carbohydrates in the IFM feed was 90.16, while the value for the MFM feed was significantly lower at 88.26 ($P< 0.05$) compared to the other treatments. The values further decreased to 84.73 and 81.22 for the FFM and CFM feeds, respectively.

Table 6. Apparent digestibility coefficient of fish feed components

ADC	IFM	MFM	FFM	CFM
Protein	94.36a±0.33	91.84ab±0.28	89.44bc±0.11	87.62c ±0.09
Lipid	91.45a±0.09	89.73ab±0.05	86.66bc±0.04	84.64c±0.04
Carbohydrates	90.16a±0.08	88.26ab±0.06	84.73bc±0.06	81.22c±0.01

DISCUSSION

Chemical composition

The chemical composition of fish meal varies depending on various factors, including the type of fish used, sex, size, feeding habits, sexual maturity, fishing location, fish habitat and seasonal variations. Additionally, the manufacturing process of fish meal affects the protein, lipid, vitamins, and mineral content in the meal. The content of fish meal is influenced by the fishing location and fish habitat **(Liu, 2000; Dale, 2001)**. These results are consistent with a study by **Hossain *et al*. (2016)**, comparing the chemical composition of fifteen different types of fish meal, where protein values ranged from 31.3% to 61.2%, lipid content ranged from 0.8% to 23.5%, and ash content varied between 13.3% and 36.7%. Similarly, **Hendalia *et al*. (2019)** observed variations in the chemical compositions of fish meal derived from fish waste based on different preparation methods, with protein content ranging from 43.77% to 45.81% depending on the preparation method. Moreover, the results coincide with those of **Al-Hassoon *et al*. (2021)**, who observed slight differences in the chemical composition of fish meal based on the preparation method. They reported protein levels ranging from 82.33% to 84.25%,

lipid content ranging from 6.05% to 7.12%, ash content ranging from 3.41% to 6.67%, and moisture content ranging from 3.78% to 4.13%. In their study, **Khan *et al.* (2012)** revealed variations in the chemical composition of fish meal derived from 9 different sources of fish and their byproducts, depending on the raw material, preparation methods, and processing techniques. The protein content ranged from 37.43% to 66.57%; lipid content ranged from 9.9% to 29.2%; ash content ranged from 12.7% to 28.2%, and total energy ranged from 4118 to 4883 calories/g. In this context, **Jeyasanta and Patterson (2020)** observed significant variations in the chemical composition values among different types of prepared fishmeal. The moisture content ranged from 5.80% to 16.54%, protein content ranged from 32.95% to 69.75%, lipid content ranged from 4.83% to 9.9%, and ash content ranged from 11.48% to 14.68%. Furthermore, studies of **Rostagno *et al.* (2011)**, **Moghaddam *et al.* (2007)** and **Al-Dalawi (2018)** demonstrated variations in the chemical composition of prepared fish meal due to the differences in raw materials and the preparation methods.

The variation in the types and quantities of amino acids present in the fish meal depends mainly on the type of fish used in its production and the manufacturing method **(Hossain *et al.*, 2016)**. Many researchers have confirmed the variation in amino acid ratios according to the type of prepared fish meal. **Hendalia *et al.* (2019)** explained that the composition and proportions of amino acids in fish byproduct meal varied depending on the preparation treatment. They indicated that the prepared meal contained a complete set of essential amino acids, with arginine and methionine being the highest, along with high contents of valine and tryptophan. These findings are consistent with the observations made by **Jeyasanta and Patterson (2020)** in their study on the amino acid composition of fish meal prepared from different raw materials. They found significant variations in the ratios, where alanine, glutamic acid, aspartic acid, arginine and methionine had higher proportions compared to other amino acids. The results are also aligned with the findings of **Ween *et al.* (2017)** who analyzed amino acids in two types of fish meal and identified 12 essential amino acids crucial for growth and energy production. Lysine received particular attention due to its nutritional importance and limited content in plant protein. The results of the present study concur with several previous studies that highlighted the clear differences in the ratios and quantities of amino acids and their impact on growth based on variations in the prepared source and the preparation method **(Cho & Kim, 2011; Ghaly *et al.*, 2013; Prado *et al.*, 2016)**.

Some researchers attributed the variations in fatty acid ratios and composition to differences in chemical composition, as well as the influence of environmental factors, nutrition, sexual maturity, season, extraction methods and oil composition **(Jobling *et al.*, 2002; Al-Kanaani, 2014)**. This finding is consistent with a study conducted by **Lee *et al.* (2017)**, identifying differences in fatty acid values among protein sources. The results of **Jeyasanta and Patterson (2020)** also align with the presence of variations in fatty acid ratios and composition in two types of fish meal, with dominance observed in palmitic, oleic and palmitoleic acids, while the other fatty acids were present in varying proportions. **Ido and Kaneta (2020)** noticed that fish meal contained high and diverse levels of unsaturated fatty acids, including eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and both omega-3 fatty acids **(Ghaly *et al.*, 2013)**.

Fish growth performance

The use of weight gain, growth rates and feed conversion ratios as criteria for evaluating feed quality is important since they represent an assessment of the productivity of cultivated fish **(Lugert *et al*., 2016)**. It is necessary to determine the appropriate feeds for each type of cultivated fish to ensure a balanced diet that provides the necessary nutrients for their growth and maintains overall quality **(Joshi *et al*., 2021)**. The results of current experiment showed variation in growth parameters depending on the type of fish meal used in feed preparation. This result can be attributed to the variation in the components of fish meal and their impact on the growth of the fish being fed. Fish meal contains proteins, amino acids, vitamins, minerals, and essential lipids that fish require for growth and development. The composition of these types of fish meals can vary, potentially influencing the growth of the fish being fed **(Elshaer *et al*., 2022)**. **Bao *et al*. (2018)** demonstrated that complete fish meal is better for nutrition as it contains all the nutrients that fish need, while fish meal made from heads and viscera contains fewer components and is considered less effective in supporting fish growth. These findings are consistent with those of **Al-Bachry *et al*. (2020)** who found significant differences ($P<$ 0.05) in relative growth rates, specific growth rates, total weight gain, and daily weight gain in common carp fed on different levels of fish meal. It also aligns with **AL-Bachry *et al*. (2020)** study on the use of three levels of fish meal for feeding common carp, where they observed clear variations in growth parameters, feed conversion ratios, relative growth rates, and specific growth rates with different ratios. According to **Craig and Helfrich (2002)**, it is important to accurately determine the protein requirements for farmed fish. They stated that the ideal protein ratio for optimal growth of common carp is between 30-38%. Additionally, **Lee *et al.* (2017)** found that the highest survival rates, growth rates, and specific weight gain were observed in commercial juvenile abalone (*Haliotis duscus hannai*) fed with feed containing fish meal compared to other protein sources.

Apparent digestibility

The results indicate that the best digestibility values of the nutritional components were evident in the feed containing IFM. MFM is considered a rich source of proteins and essential amino acids, which are necessary for the synthesis and production of digestive enzymes in the fish's digestive system. This makes it easily digestible and absorbed better than other types of fish meal **(Olsen & Hasan, 2012)**. Additionally, MFM contains lower levels of saturated lipids and cholesterol compared to other fish meals, making it easier to promote the process of digestion and absorption **(López-Mosquera *et al*., 2011)**. Stimulating digestive enzymes of CHO, proteins and lipids in fish is important for achieving efficient digestion and better nutrient absorption, as well as inhibiting anti-digestive factors in food, resulting in higher digestibility coefficients compared to the control group **(EL-Haroun *et al*., 2006)**. **Bao *et al*. (2018)** mentioned that the digestibility rate of fish meal can reach between 80-95% in most fish species, leading to increased growth and protein efficiency ratio. Concequently, increasing the apparent digestibility coefficient of the feed and protein digestion **(Al-Dohail *et al*., 2009)** is recognized. The reason for the improved utilization of nutrients may be attributed to the improved intestinal function through the development of beneficial microorganisms and their rapid attachment to the mucosal layer, creating a suitable

environment for their growth and proliferation, which results in the secretion of digestive enzymes **(Amit *et al*., 2022)**. Consequently, this variation can result in an enhanced conversion of complex nutrients into simpler substances **(Djauhari *et al*., 2017)**.

CONCLUSION

In conclusion, the results of the current study confirmed the importance of different fishery sources as raw materials for feasible local fish meal production. Although marine fish meal proved to possess clearly superior specifications which make it the favorable candidate as protein component in fish diets, other studied sources may be also suitable if other factors were taken into consideration such as cost and seasonal availability. Aquaculture sustainability will still depend in the foreseen future on fish meal supplies for supporting aqua feed industry, and the above studied sources could be considered as inevitable components for the vitality of this industry.

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