Journal of Aquatic Research and Sustainability 1 (1): 21-28

Content available at Genesis Publishing Consortium Limited

Journal of Aquatic Research and Sustainability

Journal homepage: www.genesispcl.com/journals/jars

Original Research

Feather meal as a sustainable protein source for aquaculture in Bangladesh: Economic implications

A. M. Shahabuddin[1*], S. M. Al-Munim[2], Md. Foysul Hossain[3], Sauda Afrin Anny[2], Shahrear Hemal[1], Md. Abdur Rehan Rifat[1], Sawrup Sutrodhar[1]

[1] *Department of Aquaculture, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh*
[2] *Department of Agribusiness and Marketing, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh*
[3] *Department of Aquatic Environment and Resource Management, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh*

Check for updates

Article info

Article history
Received: 23 July 2024
Revised: 22 August 2024
Accepted: 24 September 2024
Published: 01 October 2024

Keywords
Alternative protein
Poultry waste
Hydrolysis
Feed ingredient
Revenue

Abstract

The aquaculture industry is primarily burdened by the costs associated with feed. It is fundamentally dependent on fish meal derived from wild-caught sources as the primary source of protein. With the widespread adoption of alternative feed ingredients for sustainable production, this study evaluated the use of poultry feathers as feed ingredients to produce hydrolyzed feather meal (HFM) and its economic implications in Bangladesh. Samples were collected from the poultry markets of Dhaka city and hydrolyzed using formic acid for nutritional analysis. A questionnaire survey was executed to evaluate the market dynamics associated with poultry waste. It was observed that the city generates approximately 1000 metric tons of poultry waste every day. Among them, 95% of the waste is thrown away. It was discerned that 0.5 metric tons of feather meal could be generated using one ton of raw feathers. Annually, 3000 metric tons of feather meal could be produced with a value of 0.9 million US$. The HFM contains a higher percentage of crude protein (86.53±0.02%) with crude fat (5.03±0.03%). It contains most of the important amino acids that are beneficial for the growth of fish. The price of the HFM was estimated at 0.27 to 0.30 US$ per kilogram, notably lower compared to fish meal (1.1 US$), and bone meal (0.7 US$). The physical properties of the HFM were found satisfactory. Thus, domestically sourced hydrolyzed feather meal could be used as a feed ingredients for aquaculture operations to reduce feed costs. HFM has the potential to be utilized as a cost-effective feed ingredient, thus lowering overall feed expenses, and presenting a substantial commercial potential.

© 2024 Shahabuddin et al. This is an open access article distributed under the **Creative Commons Attribution 4.0 International License** (www.creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

1. Introduction

Aquaculture plays a pivotal role in meeting the global imperative for food security and economic advancement (FAO, 2024), with estimations suggesting the necessity for an additional 60% by the year 2050 to accommodate an expanding population (Vorona and Iegorov, 2024). It was reported that global aquaculture production reached a record high of 130.9 million metric tons in the year 2022 (FAO, 2024). This sector bolsters local economies by generating employment opportunities and providing alternative sources of nutrition (Senina *et al.*, 2024). The aquaculture industry is increasingly acknowledged for its capacity to foster market development and advocate for sustainable practices (Tiutiunnyk, 2023).

Fish meal occupies a significant position in aquaculture owing to its elevated protein concentration, comprehensive amino acid composition, and superior digestibility, thereby rendering it a favored component in the dietary regimens of fish (Sabeeh *et al.*, 2021). The nutritional profile of fish meal is abundant in indispensable amino acids and fatty acids, which are critical for the development and well-being of aquatic organisms (Khan, 2018). It is characterized by its high palatability, which significantly enhances feed consumption, ultimately resulting in improved growth performance among piscine species (Mugwanya *et al.*, 2022). Nevertheless, the sustainability of fish meal is increasingly jeopardized by the depletion of wild fish populations and escalating costs, thereby necessitating the investigation of alternative protein sources. The escalation in fish meal prices compels the examination of sustainable substitutes, such as fermented plant proteins, and insect meals, which have demonstrated efficacy in sustaining growth performance (Hua, 2020; Mugwanya *et al.*, 2022). Although fish meal is essential for achieving optimal nutritional outcomes in aquaculture, the sector must reconcile its utilization with alternative protein sources to secure long-term sustainability, and hydrolyzed feather meal could be the substitution.

The use of feather meal in aquaculture feed is gaining attention due to the higher protein content and potential to reduce feed costs compared to fish meal. Feather meal is rich in essential amino acids, making it a viable alternative to traditional fish meal (Andriani *et al.*, 2024) compared to other plant ingredients. It was reported that fish-fed diets containing feather meal exhibit significant growth and survival rates (Mustapha and Adeniyi, 2022). However, effective processing methods are important to convert feather to feather meal. Breakdown of keratin of feathers through chemical treatment and hydrolysis enhances the digestibility of feather meal, which is crucial for aquaculture nutrition and use as feed ingredients for fish (Anggraeni *et al.*, 2023). Hydrolyzed feather meal (HFM) has been shown to improve protein digestibility significantly, making it a more

****Corresponding authors***
Email address: amsuddin@yahoo.com (A. M. Shahabuddin)

doi: https://doi.org/10.69517/jars.2024.01.01.0005

attractive feed ingredient (Fornari *et al*., 2023). It was reported that feather meal can replace up to 50% of fish meal in diets without compromising growth performance (Mustapha and Adeniyi, 2022). Feather meal inclusion at 8% improved the feed intake and growth rates of rainbow trout, demonstrating its potential as a fishmeal substitute (Jasour *et al*., 2017). Feather meal is rich in amino acids like glycine, serine, threonine, arginine, isoleucine, leucine, phenylalanine, and valine. The amino acid profile of feathers is comparable to that of fish meal (Sarmwatanakul and Bamrongtum, 2000) and the advancement of sustainable aquaculture is contingent upon the implementation of alternative feed sources to substitute for fish meal (Shahabuddin *et al*., 2017). Poultry by-product meal has been assessed in different types of fishes and exhibited high digestibility rates for protein (88%) and energy (82%), and these levels of digestibility indicate that PBM may be effectively incorporated into aquafeeds at quantities comparable to those of fish meal (Yang *et al*., 2005). It was observed that in Dhaka city, organic and biodegradable waste constitutes 70% of the total waste generated (Prodhan and Kaeser, 2019).

The City Corporation of Dhaka collects less than 50% of the waste generated in the city; the remainder accumulates in roadsides, drains, and low-lying areas. Predictions suggest a several-fold increase in waste over 10 years, with 70% being organic and biodegradable. The incorporation of feather meal in aquaculture formulations fosters sustainability by mitigating waste generated within the poultry sector. Rather than being disposed of, poultry feathers are converted into a highly valuable feed component, thereby, lessening the ecological footprint. It can be used as less expensive feed ingredients, making it an economically viable option for aquaculture. As the fishmeal price continues to rise, feather meal offers a cost-effective alternative that can help maintain profitability in the aquaculture industry. Additionally, integrating feather meal into feed formulations can reduce the dependence on imported feed ingredients, support local economies reduce feed costs for farmers. Hence the research was designed to explore the potential for using poultry byproduct meal as a substitute for fish meal to develop a more economical feed alternative.

2. Materials and Methods

2.1 Ethical approval

No ethical approval is required for this study.

2.2 Study area and sample collection for laboratory analysis

This study was conducted in Dhaka, Bangladesh, a highly populous urban area. The research focuses on transforming poultry waste from Dhaka's markets into valuable resources. The sampling area and sample size were determined according to the statistical sampling procedure. Registered markets of Dhaka North City Corporation were selected for the study (Figure 1). Poultry waste was collected from marketplaces for laboratory analysis. Samples were properly handled for laboratory testing.

2.3 Sample preparation

Feather meal was synthesized through the collection of poultry waste from commercial sources, followed by the meticulous separation of feathers from the amassed waste. Subsequently, the feathers underwent an extensive washing protocol and were thereafter subjected to a boiling process lasting one hour. Upon the completion of the boiling phase, the feathers were meticulously fragmented into diminutive portions, and the adipose material adhering to the base of the feathers was extracted. Thereafter, a specific volume of 8% formic acid was added to a glass bottle. The resultant mixture was permitted to undergo hydrolysis for a duration ranging from a minimum of 3 to 5 days at room temperature. Following the completion of the hydrolysis procedure, the feathers were desiccated in an oven maintained at 60 °C for 48 hours. Upon achieving the desired level of dryness, the feathers were pulverized into a fine powder, ultimately culminating in the product known as the hydrolyzed feather meal (Figure 2).

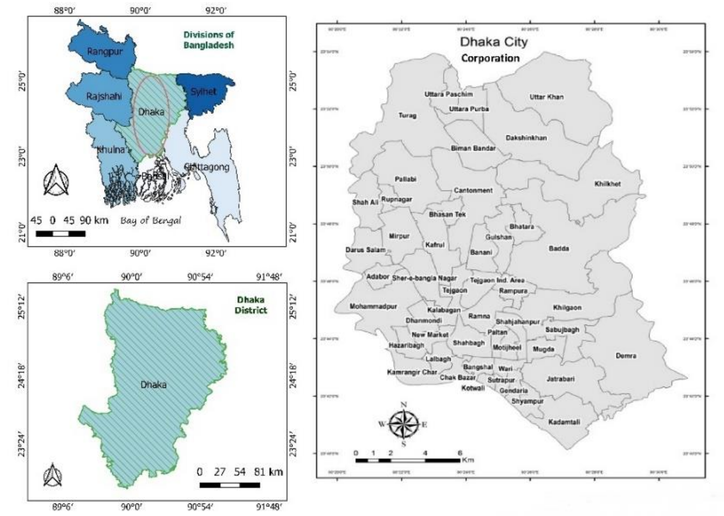

Figure 1. Map of the study area for the experiment.

2.4 Sample analysis

2.4.1 Proximate composition

Hydrolyzed poultry feather meal (HFM) was proximately analyzed for fish feed component suitability, including moisture content, dry matter, crude protein, crude fiber, crude fat, total ash, and acid-insoluble ash.

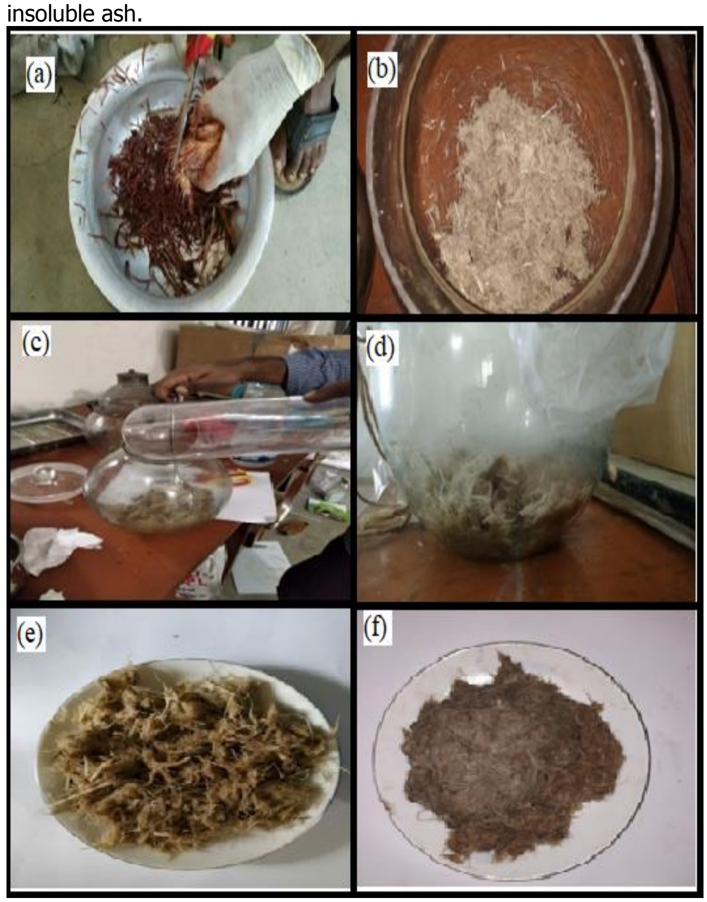

Figure 2. The images depict the various stages involved in the preparation of feather meal, including (a) separating feathers from poultry waste, (b)cutting, washing, and boiling the feathers, (c) adding acid for hydrolysis, (d) the process of hydrolyzing, (e) the final product of hydrolyzed feather meal, and (f) ground hydrolyzed feather meal.

2.4.2 Moisture determination

The moisture percentage of the supplied feed was assessed by the methodology delineated by (Nurnadia *et al*., 2011). The samples were subjected to drying for a duration of 24 hours at a temperature of 105°C in a pre-weighed porcelain crucible within a hot air oven

(Gallenkamp, Model OVB-305) until equilibrium in weight was attained. The weight reduction was quantified as a percentage of moisture content, calculated utilizing the following formula,

$$\text{Moisture (\%)} = \frac{\text{Original sample weight (g)} - \text{Dried sample weight (g)}}{\text{Original sample weight (g)}} \times 100$$

2.4.3 Protein determination

The Micro-Kjeldahl method was employed to quantify the crude protein content of the hydrolyzed feather meal by the methodology delineated by (Nurnadia *et al.*, 2011). BUCHI digestion mixture and micro-Kjeldhal distillation apparatus were applied for the process. The following formula was utilized to ascertain the proportion of nitrogen present in the samples,

$$\frac{\text{Milliequivalent of nitrogen } (0.014) \times \text{Titrant value(ml)} \times \text{Strength of HCl}}{\text{Weight of sample(g)}} \times 100$$

2.4.4 Lipid determination

The lipid composition of the dietary formulations was ascertained utilizing a protocol delineated by (Nurnadia *et al.*, 2011). The following formula was used to determine the fat content of the feather meal samples.

Total lipid (%) = [(Weight of lipid (g)/ Weight of sample (g)] × 100

2.4.5 Ash determination

The methodology delineated by (Nurnadia *et al.*, 2011) was employed to ascertain the ash content of the experimental feather meal. The quantity of ash present in the samples was evaluated by a muffle furnace (Philip Harris Ltd., England) at a temperature of 550 °C. The ash content was computed and represented as a percentage utilizing the following formula:

Ash (%) = [Weight of ash (g)/ Weight of sample (g)] × 100

2.4.6 Amino acids determination

The analysis of amino acids in hydrolyzed feather meal was followed by the method described by (AOAC, 2019). Separation of amino acids was achieved using a reverse-phase or ion-exchange column, with an appropriate gradient of solvents tailored for optimal resolution. Amino acids were detected using a fluorescence detector. The concentration of each amino acid was determined by comparing the peak areas or heights with those of the standard amino acid mix, using a calibration curve constructed from the standards. The results were analyzed to determine the amino acid composition of the hydrolyzed feather meal, expressed as a percentage of the total amino acids of the feather meal.

2.5 Physical examination

Hydrolyzed feather meal was visually inspected for its suitability as feed ingredients. The homogeneity of color was assessed to ensure processing (Mpofu and Ndlovu, 1994). The presence of odd or unpleasant smells was assessed to identify any signs of deterioration or contamination (Bureau *et al.*, 1999). The form (powdered, granulated, pelletized) was examined for its impact on feed formulation (Grisdale-Helland *et al.*, 2002). The samples were also examined for insect infestation and damage, which might potentially compromise the quality and safety of the meal (Kumar *et al.*, 2011). These findings were presented to confirm if hydrolyzed poultry feather meal met the standards as a feed ingredient.

2.6 Primary and secondary sources of information

Questionnaires, transect walks, key informant interviews, and reconnaissance surveys, transaction walks were used to collect primary data. Secondary data were obtained from the Dhaka city corporation office, its official website, a range of literary sources, newspapers, and academic research journals. A draft questionnaire had been reviewed in the field to ensure reliability. A draft questionnaire was prepared to address, problems and failures were corrected, and unnecessary items were removed to create a final questionnaire that met the research objectives. A definitive questionnaire intended for business proprietors was established after multiple rounds of assessment. The initial segment of the questionnaire examined the economic circumstances and household dynamics of farmers. The subsequent segment of the questionnaire delineated categories of poultry waste, their applications, daily output, methods of disposal, and recycling rates.

2.7 Sampling technique and sample size

A survey and direct interviews with market authorities reported that there were about 5000 shops. A random sampling method was utilized to select a sample of 5000 poultry shops for this study. The sample size for the questionnaire survey was determined using the following equation.

$n_0 = (z^2 pq)/d^2$ .... (1) (Berensen and Levine, 1992)

where,

z = Normal variety which has 2.005 for 95.5% confidence interval

p = Target proportion. In this case, I assumed the target proportion, p = 0.45

p + q = 1, therefore, q = 0.55 and

d = Desired error, here it is taken = 10% = 0.1

The initial sample size is therefore:

$n_0 = ((2.005)^2 \times 0.45 \times 0.55)/(0.1)^2 = 99.49$

This sample size is adjusted by using the following formula —

$n = n_0/(1 + n_0/N)$.................... (2)(Berensen and Levine, 1992)

Where,

n = required sample size, and

N = Size of total poultry shops in DCC = 5000

So, the sample size, $n = 99.49/(1 + 99.49/5000) = 98.50 \approx 99$

Out of the list of poultry markets, a random selection of 20 markets was made, and 100 poultry shop owners from those markets were randomly surveyed. On average, each market has 70 shops. A total of 100 questionnaire surveys were carried out.

2.8 Key informant interview and transact walk

Key informant interviews were conducted at research poultry marketplaces. The KII focused on poultry waste usage and disposal. Transact walking assisted in selecting a study site and collecting research data. Almost every field visit included a transact walk. Transact walking was done at poultry markets to ask, listen, detect, and take observations.

2.9 Data analysis

Primary and secondary data were classified and assessed the findings. Numerical and narrative data were transformed into tabular forms for accurate and indicative feedback. The data were analyzed using the SPSS statistical software package. All means for laboratory data were given with ± standard error (SE).

3 Results

3.1 Proximate composition and amino acids profile of hydrolyzed feather meal

The proximate composition of the hydrolyzed feather meal was determined. The proximate composition analysis of the tested ingredient showed that the moisture level was 11.25±0.15%, resulting in 88.75±0.09% dry matter. The sample showed 86.53±0.02% crude protein, suggesting greater protein content. Fat was found 5.03±0.03% and fiber was determined 0.73±0.07%. Ash content, which reflects mineral composition, was identified as 7.31±0.01% from the HFM. There was also 0.42±0.11% acid-insoluble ash, an indigestible mineral residue. A comprehensive analysis of hydrolyzed feather meal shows its high protein content and quality (Table 1).

Table 1. Proximate composition of hydrolyzed feather meal prepared in the laboratory conditions from the samples collected from poultry markets of Dhaka, Bangladesh (mean ± standard error, n=3).

Parameters	Proximate composition (% on DM basis)
Moisture	11.25±0.15
Dry matter	88.75±0.09
Crude protein	86.53±0.02
Crude fiber	0.73±0.07
Crude fat	5.03±0.03
Total ash	7.31±0.01
Acid insoluble ash	0.42±0.11

Hydrolyzed feather meal prepared from poultry waste, is characterized by a unique amino acid profile rich in arginine (5.69±0.03%), lysine (3.34±0.02%), phenylalanine (4.43±0.03%), threonine (3.54±0.02%) and valine (6.86±0.04%). Other abundant amino acids include histidine, isoleucine, methionine, and tyrosine contributing to its overall protein content. This hydrolyzed feather meal contained most of the essential amino acids including Arginine, Lysine, Phenylalanine, and Threonine. The percentage of Isoleucine, Methionine, and Tyrosine was found lower (Table 2). The hydrolysis process improves the digestibility of these amino acids, making them more available to the animal, but supplementation or combination with other protein sources is often necessary to achieve a balanced diet. Notably, the hydrolyzed feather meal contains a higher percentage of cysteine and proline, which are crucial for the structural integrity of keratin.

Table 2. Amino acids composition of hydrolyzed feather meal prepared in the laboratory conditions from the samples collected from poultry markets of Dhaka, Bangladesh (mean ± standard error, n=3).

Amino acids	Percentage
Arginine	5.69±0.03
Histidine	1.10±0.07
Isoleucine	0.19±0.06
Leucine	7.67±0.04
Lysine	3.34±0.02
Methionine	0.81±0.04
Phenylalanine	4.43±0.03
Threonine	3.54±0.02
Tyrosine	0.57±0.04
Valine	6.86±0.04
Methionine + Cystine	4.36±0.03
Proline + Threonine	7.21±0.04

3.2 Physical examination of Hydrolyzed Feather Meal (HFM)

Based on the examination, the sample had a "Normal" color (grade 5) and odor, suggesting no abnormalities (grade 4). Hydrolyzed feather meal was observed, confirming its composition and processing method. The sample also showed no insect infestation, indicating it was unspoiled and pest-free. The physical evaluation revealed that the hydrolyzed feather meal sample was of high quality, with no obvious faults or infestations (Table 3).

Table 3. Physical examination of hydrolyzed feather meal (HFM) prepared from poultry markets of Dhaka, Bangladesh.

Sample	Hydrolyzed feather meal	Grade (1 to 5, 1 indicating the lower grade and 5 indicating the higher grade)
Color	Normal	5
Odor (smell)	Normal	4
Sample type	Hydrolyzed feather meal	5
Insect infection	No	5

3.3 Socio-economic status of poultry sellers of Dhaka city

Age, familial composition, socioeconomic status, educational attainment, and professional engagement of individuals were determined to be relatively minimal. Nevertheless, these characteristics exert a considerable influence on the present research endeavor. The participants were categorized into three distinct groups. It was noted that 31% of the participants were under the age of 35, while the predominant majority (59%) of the participants fell within the age range of 36 to 50 years. A minor proportion (10%) of the participants were identified as being over 50 years of age (Table 4).

Most of the respondents' families had 2-6 family members (82%), whereas it was found 18% with the family members 4-6 persons. No family were identified with the family members more than 6. During the empirical investigation, the participants exhibited diverse educational attainments. Specifically, 51% of the respondents had enrolled in elementary education but did not achieve completion, 41% had pursued secondary education, and a minor fraction (8%) had completed high school and advanced to higher secondary education. The findings of the survey revealed that 49% of the participants had engaged in high school education, albeit not all had attained completion. In light of their educational experiences, these individuals demonstrate an inability to grasp the potential hazards associated with poultry waste and its conversion into aquaculture feed (Table 5).

Table 4. The age profile of the respondents of poultry sellers of Dhaka city, Bangladesh

Characteristics	Categories (years)	Distribution of respondents (%)
Age	Up to 35	31
	36 to 50	59
	above 50	10

Table 5. The educational background of participants of poultry sellers of Dhaka city, Bangladesh.

Educational levels	Percentage
Primary	51%
Secondary School Certificate (SSC)	41%
Higher Secondary Certificate (HSC)	8%

The research indicated that all participants were involved in poultry production within various markets of Dhaka city, which served as their exclusive means of livelihood. It was noted that the monthly earnings fluctuated between 167 and 400 US$. Specifically, 45% of the respondents reported earnings ranging from 167 to 250 US$ per month, while 41% earned between 250 to 330 US$, and the remaining individuals realized incomes exceeding 250 US$, thereby suggesting a middle-class socioeconomic status (Table 6).

Table 6. Average income levels of poultry sellers of Dhaka city, Bangladesh. The value expressed in US$ for each month

Income levels (US$/month)	Percentage (%)
167-250	45%
250-330	41%
330-400	14%

3.4 Current situation and state of poultry market waste generated in Dhaka city

The research area collected data on poultry sales, average daily sales, poultry waste, and weight of feathers. A total of 71% of poultry meat is edible and 28% is waste, mostly internal organs. The remaining 1% is composed of feathers. This 28 percent is discarded and a concern for environmental pollution (Figure 4).

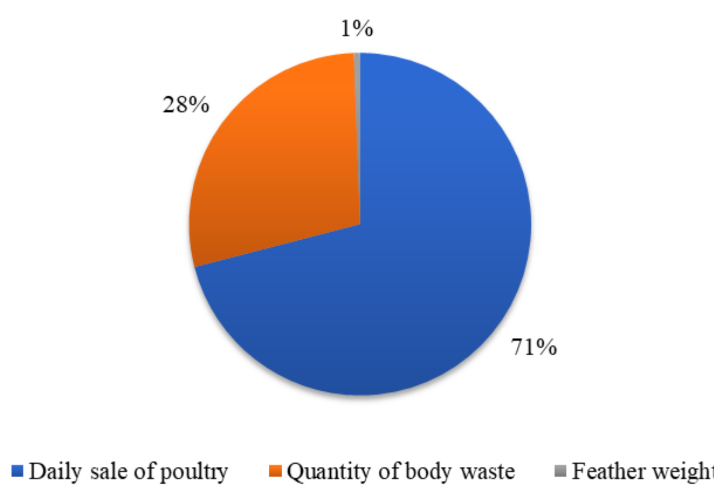

Figure 4. The percentage of poultry waste collected from the poultry market in Dhaka city, Bangladesh.

3.4.1 Poultry waste disposal and its use

The research findings indicated that a significant proportion of poultry establishments (95%) dispose of their market by-products to municipal waste management facilities or nearby dumping sites, with merely 4% opting to sell these by-products to aquaculture practitioners for utilization as feed for catfish. Furthermore, the feed manufacturing entity employs 1% of poultry by-products as a component in their feed formulations. The production of feed ingredients from the by-products has the potential to be economically advantageous for poultry sellers. A singular ton of feather waste could yield nearly 0.5 metric tons of the ultimate product, presenting a substantial commercial prospect. There is an opportunity to generate yearly revenue of more than 1 million US$ from the discarded feathers in Dhaka city. It was noted that the hydrolyzed feather meal comprises all requisite amino acids that are critical for the growth of fish. It was calculated that 0.23 US$ is required to produce per kilogram of hydrolyzed feather meal. With a minimum profit margin, the estimated price is around 0.27 to 0.30 US$, which is much lower than fish meal (1.1 to 1.4 US$) and bone meal (0.70 to 0.75 US$) available in the market (Table 7).

Table 7. Evaluated the expenses, earnings, and potential for business growth associated with hydrolyzed feather meal.

Cost components	Value (US$/Kg)
Feather collection from the market	0.0017
Transportation to the processing center	0.084
Processing of feather meal	0.13
Total cost	**0.23**
Approximate expected Profit (per kg)	0.033
Estimated sale price	**0.27-0.30**
Fish meal prices in the market	1.10-1.40
Bone meal prices in the market	0.70-0.75

4. Discussion

The methodical approach for the synthesis of feather meal underscores its viability as a sustainable feed ingredient, accentuating the importance of efficient collection, processing, and hydrolysis of avian feathers. Acid-based hydrolysis process successfully breaks down the keratin composition, leading to a rich in protein (86.5%) and amino acids, a substitute for conventional protein sources. The hydrolyzed feather meal (HFM) demonstrates significant levels of dry matter (DM) and crude protein (CP), consistent with earlier research findings (Boushy *et al.*, 1990; Kim and Patterson, 2000). Studies indicate that HFM contains protein levels ranging from 68% to 78%, depending on the specific processing techniques employed (Tursunova and Maksumova, 2024). Laboratory analysis showed that the hydrolysis process significantly enhances protein digestibility (Sinhorini *et al.*, 2020). It was found that the protein content in HFM was found to be 86%, falling within the documented range of 84.1% to 90.5% as reported by Morel *et al.* (2003). The protein content of the hydrolyzed feather meal derived from avian byproducts in Dhaka city was determined to be comparable to findings reported in prior research. It was also reported, that HFM derived from chicken feathers typically exhibits superior protein quality compared to that from turkey feathers (Sinhorini *et al.*, 2020). HFM is rich in essential amino acids, making it suitable for inclusion in diets for various animals, including poultry and fish. The utilization of HFM can replace traditional protein sources in animal feeds, although complete replacement may not always be effective (Fornari *et al.*, 2023).

The processing techniques and source of the feather have a major impact on the fat content of hydrolyzed feather meal (HFM). It was reported that the amount of fat in HFM may range from 1.8% to 12% (Dale, 1992), whereas the present research revealed an average of 5.03% lipid from the hydrolyzed feather meal. The percentage is suitable for the fish feed formulation. These investigations indicate that HFM exhibits variability based on plant sources and hydrolysis processes, such as temperature, pressure, and chemical treatments. Furthermore, other literature suggests that the nutritional value of HFM may differ, and their digestibility could be impacted by the processing techniques utilized during production (Boushy *et al.*, 1990).

HFM also offers important environmental benefits. Converting poultry feathers into HFM helps to mitigate environmental pollution by effectively managing poultry waste. This contributes to global sustainability goals by establishing a circular economy that transforms waste into valuable resources for other industries (Pieterse and Pretorius, 2014; Psofakis *et al.*, 2020; Novodworski *et al.*, 2023). Feathers contain high levels of protein and β-carotene, making them challenging to digest. However, through processes like autoclaving, these indigestible components can be transformed into feather meal. Protamine, produced by BCF Life Sciences, Inc., is an Extensively Hydrolyzed Poultry Feather (EHPF) created through acid hydrolysis of feathers. According to Eugenio and Duperray (2020), acid hydrolysis feather meal demonstrates superior nitrogen (99.6%) and amino acid (97%) digestibility compared to hydrolyzed feather meal (83.5% & 72.1%) and poultry by-products meal (89.7% & 88.3%).

The digestibility of amino acids in poultry feather meal is generally low due to the high content of keratin, which is resistant to enzymatic breakdown (Kumar, 2021). Various processing methods, such as hydrolysis (chemical, enzymatic, or thermal), have been studied to improve the digestibility of feather meal. Enzymatic hydrolysis, for instance, has been shown to increase the availability of amino acids by breaking down the keratin matrix (Wang and Parsons, 1997). Despite these improvements, the digestibility of some amino acids, such as lysine, remains relatively low even after processing. Though the hydrolyzed feather meal contained most of the amino acids, however, it was suggested that it could be used as the sole protein source rather use as a partial protein source along with other more digestible protein ingredients, so that it can contribute to a cost-effective feed formulation (Fornari *et al.*, 2023) mentioned that 20% HFM can be used as a protein source for the channel catfish diets. Hydrolyzed feather meal serves as a partial fishmeal replacement in European seabass diets. It was observed that up to 12.5% HFM is possible through the replacement of 76% fishmeal without impairing feed intake, growth, immune response of fish (Campos *et al.*, 2017). Moreover, utilizing poultry feather meal in animal diets not only helps to reduce waste but also offers an economically viable protein source. The HFM prepared from the poultry market of Dhaka city showed that the feed ingredient contained all the essential amino acids including Arginine, Phenylalanine, Threonine, Leucine, Lysine, Cystine, and Valine. A small percentage of Isoleucine, Methionine, Tyrosine, and Histidine were recorded. Though it was claimed that HFM is poorer in methionine, lysine, and histidine compared to fish meal, hence partial replacement of fish meal is suggested for better growth performance of aquatic animals (Psofakis *et al.*, 2020). In this experiment, it was also observed that the percentage of methionine, isoleucine and tyrosine percentage was found lower compared to other amino acids.

The HFM, which has the potential to reduce costs and promote sustainability, has become more popular than fish meal in aquaculture diets. HFM may successfully replace fish meal. HFM diets for Nile tilapia showed good palatability, indicating that they can take the place of fish meal without having an adverse effect on the feed conversion ratio (Santos *et al.*, 2023). HFM is an effective fish food since it promotes improved growth and nutrient utilization in African catfish-fed diets at 25% and 50% levels (Mustapha and Adeniyi, 2022). Research has revealed that HFM can be a viable alternative to fishmeal in aquafeed. A case study has shown that HFM can substitute for 25% of fishmeal in the diet of young gilthead seabream without affecting their growth, food consumption, or nutrient utilization. It becomes especially evident when incorporating vital amino acids like lysine and methionine as additional supplements (Psofakis *et al.*, 2020). The finding aligns with previous studies that indicate hydrolyzed feather proteins have a high crude protein content and improved digestibility, making them a practical and economical alternative for aquafeeds (Uushona *et al.*, 2019; Abou-El-Atta *et al.*, 2019; Novodworski *et al.*, 2023).

The nutritional composition of hydrolyzed feather meal as a feed ingredient can be used as an alternative protein source as well as a cheaper animal protein source. It was observed that the price of the HFM is much cheaper than the fish meal. Every year a significant volume of maize, soybean, meat and bone, and fishmeal were imported for the feed industry. It was reported that to import Maize 13% and soybean 7% duty tax was needed to pay increased feed price. Hence replacing of protein source through HFM is one of the best approaches that will fulfill the nutritional quality without compromising the growth performance (Policy Insights, 2021).

Hydrolyzed feather meal serves as a competitive and cost-effective protein source within animal nutrition, particularly when juxtaposed with other prevalent ingredients. With a valuation ranging from $400 to $600 per ton, it boasts a substantial protein composition (80-90%), thereby positioning itself as a more economical alternative to premium protein sources such as fish meal, which commands prices between $1,200 and $2,000 per ton. Although it is economically advantageous, hydrolyzed feather meal exhibits inferior digestibility and a deficiency in essential amino acids, such as lysine, in comparison to fish meal, which is lauded for its well-rounded amino acid composition. In contrast, soybean meal, which is similarly priced at $400 to $600 per ton, offers a reduced protein content (44-48%) and does not match the digestibility of protein derived from animal sources. Blood meal, another high-protein substitute, presents a comparable protein content of 80-90%; however, it is more costly, with prices ranging from $800 to $1,200 per ton. While the application of hydrolyzed feather meal may necessitate the supplementation of amino acids for optimal efficacy, its economic viability and high protein concentration render it a suitable option for feed formulations within the aquaculture and poultry sectors.

According to the report from the Bangladesh Bureau of Statistics, agriculture makes up 13.35% of the country's GDP, with poultry and fisheries contributing 4.95%. Feed mills provide high-quality feeds to meet the protein requirements of the nation. The commercial feed market in Bangladesh is projected to grow to 5.03 million metric tons and is valued at US$ 2.5 billion. Based on our study findings, poultry waste can be utilized to produce commercial fish feed with partial replacement of fish meal. Therefore, by using feather meal as a protein source, there is potential to generate a substantial quantity within Bangladesh. Hydrolyzed feather meal offers cost-effective protein and mineral content for fish diets. It is a cheaper alternative to fishmeal, meat and bone meal, and soybean meal, which are priced at 1.1, 0.7, and 0.45 US$/kg respectively. Its utilization in feed production can lead to reduced costs and positive economic outcomes.

Table 8. Comparison of feather meal ingredients with other feed ingredients (Source: Feed Industries Association Bangladesh, 2021).

Ingredient	Crude Protein %	Crude Lipid %	Carbohydrate %	Price per kg (US$)	Source	Export quantity (Thousand Metric tons)
Fishmeal	55-56	10-12	1-2	1.1	Own country	
Maize	8-10	3-4	65-70	0.27	Own + other country	2400
Meat and bone meal	45-55	10-15	1-2	0.7	Other country	
Mixed dried fish	30-40	5-8	2-4	0.33	Own country	
Mustard oilcake	28-35	8-14	30-40	0.31	Own country	
Rice bran	10-4	10-15	55-60	0.27	Own country	
Sesame oilcake	30-35	10-15	30-35	0.42	Own + Other country	
Soybean meal	40-45	10-15	30-35	0.45	Own + Other country	350
Wheat bran	12-16	3-6	70-80	0.25	Own Country	6700
Wheat flour	12-18	2-3	75-80	0.31	Own country	
Feather meal	86-87	5-6	--	0.56	Other country	

From a financial point of view, incorporating HFM into fish feed has the potential to greatly decrease the expenses associated with feed production. Bangladesh has a thriving aquaculture industry that can greatly benefit from adopting HFM. By reducing the need for imported fishmeal, the country can enhance the sustainability of its local fish production. The affordability of HFM in comparison to fishmeal makes it a compelling option, potentially boosting the profitability for fish farmers and contributing to the overall economic expansion of the aquaculture sector (Abou-El-Atta *et al.*, 2019; Novodworski *et al.*, 2023).

Although the HFM emerges as a potentially advantageous protein alternative in aquaculture feed formulations, it is accompanied by several significant constraints. The foremost challenge pertains to its digestibility; although hydrolysis enhances protein bioavailability, the intrinsic keratin configuration continues to present complications for specific ichthyological species (Fornari *et al.*, 2023; Andriani *et al.*, 2024). The digestibility of HFM exhibits considerable variability across different fish species, with studies indicating that juvenile catfish experienced diminished growth when HFM was utilized as a complete substitute for other protein sources (Fornari *et al.*, 2023). In experimental trials involving gilthead seabream, a higher degree of fishmeal replacement with HFM adversely affected growth performance, suggesting that excessive substitution may impede nutrient assimilation (Psofakis *et al.*, 2020).

The amino acid composition of HFM may not completely satisfy the nutritional needs of all fish species, thereby necessitating the incorporation of certain essential amino acids to facilitate optimal growth (Fornari *et al.*, 2023; Psofakis *et al.*, 2020). The efficacy of HFM is also subject to modulation by the processing techniques employed, which can significantly impact the quality and digestibility of the resultant product (Anggraeni *et al.*, 2023). However, the complete replacement of fish meal with HFM led to decreased growth performance in some studies, highlighting the need for careful formulation (Psofakis *et al.*, 2020). The hydrolysis process improves the digestibility, which enhances the nutritional profile and supports fish growth. Moderate inclusion of HFM maintains liver health, while high levels may cause degradation, emphasizing the importance of amino acid supplementation at higher replacement rates (Psofakis *et al.*, 2020). While HFM presents a promising alternative to fish meal, its successful application depends on species-specific dietary formulations and the inclusion levels used. Notwithstanding these constraints, HFM continues to be a viable alternative when applied judiciously, especially when amalgamated with other protein sources to ensure a nutritionally balanced diet for aquatic organisms.

4. Conclusions

Hydrolyzed feather meal would be a nutrient-rich, cheaper feed ingredient that will support to the reduction in feed price. Hydrolysis process improved feed efficiency is critical in aquaculture, and directly impacts production costs and environmental sustainability. Market respondents had little knowledge about the unexplored value of poultry waste; however, its high protein content, beneficial amino acid profile, and cost-effectiveness make it a valuable alternative to traditional feed ingredients like fishmeal. As the aquaculture industry continues to grow in Bangladesh, the use of feather meal will likely increase, contributing to a more sustainable and profitable business. A significant quantity of poultry byproducts is generated, but merely a minor fraction of this byproduct is effectively employed. This phenomenon presents the dual benefit of moderating feed costs while concurrently contributing to environmental sustainability. The merits of waste recycling will thus become evident to these stakeholders which will uplift the socio-economic conditions of the poultry sellers.

Acknowledgments

This research was funded by the Ministry of Science and Technology (MoST), Government of Bangladesh, under the special allocation for science and technology in the year 2019-2020 (Ref. No. BS 16), which is gratefully acknowledged.

Animal ethics

No animals were harmed during the experiment. All animals were handled according to the Guidelines and policy are known as ethical conduct in the care and use of nonhuman animals in research.

Data availability

Data will be made available on request.

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

Conflict of interest

The authors declare that they have no conflicts of interest.

Authors' contribution

A. M. Shahabuddin: conceptualization, supervision, analysis and review; **S. M. Al-Munim:** data collection and draft manuscript; **Md. Foysul Hossain:** supervision, method development and review**;** **Sauda Afrin Anny:** monitoring and review of data; **Shahrear Hemal**, **Md. Abdur Rehan Rifat**, **Sawrup Sutrodhar:** manuscript editing. All the authors critically reviewed the manuscript and agreed to submit a final version of the article.

References

Abou-El-Atta ME, Abdel-Tawwab M, Abdel-Razek N and Abdelhakim TMN, 2019. Effects of dietary probiotic *Lactobacillus plantarum* and whey protein concentrate on the productive parameters, immunity response and susceptibility of Nile tilapia (*Oreochromis niloticus*) to *Aeromonas sobria* infection. Aquaculture Nutrition, 25(6): 1367–1377. https://doi.org/10.1111/anu.12957

Andriani Y, Pratama RI and Hanidah II, 2024. A review on chicken feather flour potential for fish feed. Torani Journal of Fisheries and Marine Science, 7(2): 171–180. https://doi.org/10.35911/torani.v7i2.34396

Anggraeni F, Haetami K, Andriani Y and Bachtiar E, 2023. Chemically treated chicken feather meal for fish feed. Asian Journal of Fisheries and Aquatic Research, 25(6): 1–8. https://doi.org/10.9734/ajfar/2023/v25i6711

AOAC. 2019. Official methods of analysis of AOAC International. In: Oxford University Press eBooks. https://doi.org/10.1093/9780197610138.001.0001

Berensen ML and Levine DM, 1992. Basic business statistics: Concepts and application. Pentin Hall, Inc., USA.

Boushy AE, Van Der Poel A and Walraven O, 1990. Feather meal—A biological waste: Its processing and utilization as a feedstuff for poultry. Biological Wastes, 32: 39–74. https://doi.org/10.1016/0269-7483(90)90071-y

Bureau D, Harris A and Cho C, 1999. Apparent digestibility of rendered animal protein ingredients for rainbow trout (*Oncorhynchus mykiss*). Aquaculture, 180(3–4): 345–358. https://doi.org/10.1016/s0044-8486(99)00210-0

Campos I, Matos E, Marques A and Valente LM, 2017. Hydrolyzed feather meal as a partial fishmeal replacement in diets for European seabass (*Dicentrarchus labrax*) juveniles. Aquaculture, 476: 152–159. https://doi.org/10.1016/j.aquaculture.2017.04.024

Dale N, 1992. True metabolizable energy of feather meal. The Journal of Applied Poultry Research, 1(3): 331–334. https://doi.org/10.1093/japr/1.3.331

Eugenio FA and Duperray J, 2020. Digestibility of extensively hydrolyzed poultry feather meal. BCF Life Sciences.

FAO, 2024. Global fisheries and aquaculture production reaches a new record high. Newsroom. Food and Agriculture Organization of the United Nations. Rome, Italy.

Fornari DC, Nazeer S, Weldon A and Davis DA, 2023. The efficacy of hydrolyzed feather meal as a protein source in diets for juvenile catfish (*Ictalurus punctatus*). Aquaculture, 576: 739823. https://doi.org/10.1016/j.aquaculture.2023.739823

Grisdale-Helland B, Helland S, Baeverfjord G and Berge G, 2002. Full-fat soybean meal in diets for Atlantic halibut: growth, metabolism and intestinal histology. Aquaculture Nutrition, 8(4): 265–270. https://doi.org/10.1046/j.1365-2095.2002.00216.x

Hua K, 2020. A meta-analysis of the effects of replacing fish meals with insect meals on growth performance of fish. Aquaculture, 530: 735732. https://doi.org/10.1016/j.aquaculture.2020.735732

Jasour MS, Wagner L, Sundekilde UK, Larsen BK, Greco I, Orlien V, Olsen K, Rasmussen HT, Hjermitslev NH, Hammershøj M, Dalsgaard AJT and Dalsgaard TK, 2017. A comprehensive approach to assess feather meal as an alternative protein source in Aquafeed. Journal of Agricultural and Food Chemistry, 65(48): 10673–10684. https://doi.org/10.1021/acs.jafc.7b04201

Khan MA, 2018. Histidine requirement of cultivable fish species: a review. Oceanography and Fisheries Open Access Journal, 8(5): 555746. https://doi.org/10.19080/ofoaj.2018.08.555746

Kim W and Patterson P, 2000. Nutritional value of enzyme- or sodium hydroxide-treated feathers from dead hens. Poultry Science, 79(4): 528–534. https://doi.org/10.1093/ps/79.4.528

Kumar J, 2021. Microbial hydrolysed feather protein as a source of amino acids and protein in the diets of animals including poultry. In: IntechOpen eBooks. https://doi.org/10.5772/intechopen.96925

Kumar V, Sinha AK, Makkar HPS, De Boeck G and Becker K, 2011. Phytate and phytase in fish nutrition. Journal of Animal Physiology and Animal Nutrition, 96(3): 335–364. https://doi.org/10.1111/j.1439-0396.2011.01169.x

Morel PCH, Melai J, Jame EAC, and Reynolds GW, 2003. Nutritive value of feather meal. Project report from New Zealand Pork. Institute of Food, Nutrition and Human Health: Massey University, Palmerston North.

Mpofu I and Ndlovu L, 1994. The potential of yeast and natural fungi for enhancing fibre digestibility of forages and roughages. Animal Feed Science and Technology, 48(1–2): 39–47. https://doi.org/10.1016/0377-8401(94)90110-4

Mugwanya M, Dawood MOA, Kimera F and Sewilam H, 2022. Replacement of fish meal with fermented plant proteins in the aquafeed industry: A systematic review and meta-analysis. Reviews in Aquaculture, 15: 62–88. https://doi.org/10.1111/raq.12701

Mustapha AK and Adeniyi WO, 2022. Replacement of fish meal with feather meal in the diet of *Clarias gariepinus*. Pan African Journal of Life Sciences, 6(3): 524–530. https://doi.org/10.36108/pajols/2202/60.0320

Novodworski J, Castilha LD and Silva AA, 2023. Insect meal in poultry feed: a potential protein source. Acta Scientiarum Animal Sciences, 45: e60317. https://doi.org/10.4025/actascianimsci.v45i1.60317

Nurnadia AA, Azrina A and Amin I, 2011. Proximate composition and energetic value of selected marine fish and shellfish from the West coast of Peninsular Malaysia. International Food Research Journal, 18: 137-148.

Pieterse E and Pretorius Q, 2014. Nutritional evaluation of dried larvae and pupae meal of the housefly (*Musca domestica*) using chemical- and broiler-based biological assays. Animal Production Science, 54(3): 347. https://doi.org/10.1071/an12370

Policy Insights, 2021. Feed feeds Bangladesh – Policy Insights. Retrieved December 12, 2021, from https://policyinsightsonline.com/2019/01/feed-feeds-bangladesh/

Prodhan ASU and Kaeser A, 2019. Municipal solid waste management in Dhaka city: Present status, problems, and probable solutions – A review. In: Environmental Thoughts, Part-I. Toyza Publications.

Psofakis P, Karapanagiotidis I, Malandrakis E, Golomazou E, Exadactylos A and Mente E, 2020. Effect of fishmeal replacement by hydrolyzed feather meal on growth performance, proximate composition, digestive enzyme activity, haematological parameters and growth-related gene expression of gilthead seabream (*Sparus aurata*). Aquaculture, 521: 735006. https://doi.org/10.1016/j.aquaculture.2020.735006

Sabeeh HT, Alshami IJJ and Al-Tameemi RA, 2021. Histochemical study of the intestine in the common carp *Cyprinus carpio* fingerlings to detect the impact of the replacement of dietary fish and soybean meals with shrimp wastes. Egyptian Journal of Aquatic Biology and Fisheries, 25(2): 721–734. https://doi.org/10.21608/ejabf.2021.169190

Santos RaD, Brisqueleal JCP, Piovesan MR, De Souza OJ, Boscolo WR and Bittencourt F, 2023. Attractiveness and palatability of feather protein hydrolysate for juvenile Nile tilapia (*Oreochromis niloticus*). Observatorio de La Economía Latinoamericana, 21(9): 11300–11317. https://doi.org/10.55905/oelv21n9-043

Sarmwatanakul A and Bamrongtum B, 2000. Aquarium fish nutrition. Extension paper, 1/2000. Ornament Fish Research and Public Aquarium. Bangkok.

Senina MA, Ledeneva OY and Shatokhina YP, 2024. The development of the export potential of aquaculture in the Novosibirsk region and the importance of preventive measures to prevent the spread of epizootics. Innovations and Food Safety, 2: 88–95. https://doi.org/10.31677/2311-0651-2024-44-2-88-95

Shahabuddin AM, Khan MND, Mikami K, Araki T and Yoshimatsu T, 2017. Dietary supplementation of red alga *Pyropia spheroplasts* on growth, feed utilization and body composition of sea cucumber, *Apostichopus japonicus* (Selenka). Aquaculture Research, 48(10): 5363–5372. https://doi.org/10.1111/are.13350

Sinhorini MR, Balbinot-Alfaro E, De Aguiar W and Da Trindade Alfaro A, 2020. Influence of process parameters and raw material on the characteristics of hydrolyzed feather meal. Waste and Biomass Valorization, 12(5): 2469–2476. https://doi.org/10.1007/s12649-020-01203-1

Tiutiunnyk H, 2023. Aquaculture innovation and multifunctional centers: enhancing aquaculture market development. ГРААЛЬ НАУКИ, 29: 32–34. https://doi.org/10.36074/grail-of-science.07.07.2023.002

Tursunova D and Maksumova O, 2024. Analysis of the amino acid and protein composition of feather keratin hydrolyzed using alkali and sodium hydrosulfite. Results in Chemistry, 9: 101621. https://doi.org/10.1016/j.rechem.2024.101621

Uushona T, Simasiku A and Petrus NP, 2019. Evaluation of *Musca domestica* (House fly) larvae production from organic waste. Welwitschia International Journal of Agricultural Sciences, 1: 35–40. https://doi.org/10.32642/wijas.v1i0.1361

Vorona N and Iegorov B, 2024. Fish farming is a promising branch of ensuring food security of the Earth's population. Grain Products and Mixed Fodder's, 23(2): 40–46. https://doi.org/10.15673/gpmf.v23i2.2712

Wang X and Parsons C, 1997. Effect of processing systems on protein quality of feather meals and hog hair meals. Poultry Science, 76(3): 491–496. https://doi.org/10.1093/ps/76.3.491

Yang Y, Xie S, Cui Y, Zhu X, Lei W and Yang Y, 2005. Partial and total replacement of fishmeal with poultry by-product meal in diets for gibel carp, *Carassius auratus gibelio* Bloch. Aquaculture Research, 37: 40–48. https://doi.org/10.1111/j.1365-2109.2005.01391.x

GENESIS PUBLISHING CONSORTIUM LIMITED

Publisher's note
Genesis Publishing Consortium Limited pledges to maintain a neutral stance on jurisdictional claims shown in published maps and institutional affiliations.