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Proximate Composition of Fishery By-Catch from a Small-Scale Anchovy Processing Facility in Papar, Sabah, Malaysia

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ABSTRACT

Fishery by-catch (FBC) generated from anchovy fisheries is an underutilized marine resource with potential for valorization into value-added products. This study evaluated the fish-group occurrence and temporal variation in the proximate composition of FBC from a small-scale anchovy processing plant in Sabah, Malaysia, over a six-month sampling period. Monthly by-catch sun-dried samples were sorted into fish, squid, shrimp, crab, and miscellaneous categories, and the fish fraction was processed into fishery by-catch meal (FBCM) for proximate analysis. Fish accounted for 94.16 ± 1.97% of the total by-catch, whereas squid, shrimp, and crab collectively contributed less than 1%. A total of 23 fish groups were successfully identified, with mackerels, ponyfishes, sardines, and terapons consistently occurring throughout the sampling period. The crude protein, lipid, and ash contents of FBCM varied among sampling months, ranging from 55.49–61.52%, 3.79–5.26%, and 31.58–37.86%, respectively, while moisture content showed only minor variation. The observed fluctuations are likely due to seasonal changes in by-catch species composition. Nevertheless, the consistently high crude protein content indicates that FBCM has potential for valorization into value-added protein ingredients. Further nutritional characterization, including amino acid, fatty acid, and mineral composition, is required to comprehensively evaluate its nutritional quality.

1. INTRODUCTION

The expansion of global fisheries has resulted in increasing challenges associated with the management and utilization of non-target catches. During fishing operations, non-target species are inevitably captured alongside the intended catch, generating what is collectively known as by-catch. A considerable proportion of these unintended catches is discarded or disposed of, representing a loss of potentially valuable marine biomass and contributing to environmental burdens associated with waste management [1]. The issue is particularly relevant to small-scale fisheries, where limited infrastructure, processing capacity, and market opportunities may constrain the effective utilization of by-catch [2, 3]. Consequently, developing practical approaches to recover and utilize by-catch biomass could contribute to more efficient use of marine resources and support circular-economy principles in fisheries.

In Sabah, Malaysia, anchovy fishing is conducted by local fishermen using the traditional '*bagang*' fishing method. Based on personal communication with local fishermen, substantial quantities of non-target fish are unintentionally caught during the fishing process. These by-catches are sun-dried together with the anchovy and subsequently sold in bulk to local fertilizer-processing companies. According to the operator of an anchovy-processing facility in Kimanis town, Papar district, Sabah, Malaysia, the monthly production of sun-dried fishery by-catch (FBC) from the facility could reach approximately 1,600–2,400 kg. Although by-catch cannot be completely avoided, its utilization should not necessarily be limited to low-value applications such as fertilizer production, particularly when the biomass contains potentially valuable nutrients. The availability of a continuous by-catch stream from a small-scale anchovy-processing operation therefore provides an opportunity to investigate whether this underutilized biomass could be further processed into a higher-value feed ingredient.

The potential utilization of FBC is also relevant to the increasing demand for protein ingredients in aquaculture. Fishmeal remains an important protein source in aquafeeds, particularly for carnivorous marine fish, but fluctuations in fishmeal availability and market prices have increased interest in alternative protein ingredients [4]. The continued expansion of aquaculture further strengthens the need to identify locally available and nutritionally suitable protein sources that can reduce dependence on conventional marine-derived ingredients. In this context, FBC represents a potentially useful source of animal protein because it can contain substantial amounts of protein and other nutrients while simultaneously providing a pathway for recovering biomass that might otherwise be underutilized.

Several studies have demonstrated the potential of fishery by-catch meal (FBCM) as a dietary protein ingredient for aquaculture species, including rainbow trout (*Oncorhynchus mykiss*) [5], Nile tilapia (*Oreochromis niloticus*) [6], and Indonesian river catfish (*Hemibagrus nemurus*) [7]. The relatively high crude protein content of FBCM, which generally exceeds 55%, also suggests its potential as an alternative protein ingredient for marine carnivorous fish such as groupers (*Epinephelus* spp.), which require high-protein diets [8]. However, the nutritional value and consistency of FBCM may be influenced by variation in the species composition of by-catch, which can fluctuate with season, fishing conditions, and local fish abundance. Such temporal variation may alter the proximate composition of the resulting meal and consequently affect its nutritional consistency and suitability for feed applications. Characterizing this variation is therefore an important preliminary step before assessing the broader utilization potential of locally sourced FBCM.

Despite the potential of FBC as a recoverable protein resource, information on the temporal variation in the proximate composition of anchovy-associated by-catch from small-scale fisheries in Sabah remains limited. In particular, there is a lack of information on whether monthly changes in by-catch composition are reflected in the proximate characteristics of the resulting FBCM. Therefore, the present study evaluated the proximate composition of anchovy-associated FBC over a six-month sampling period. The dominant by-catch fraction was identified, processed into fishmeal, and analyzed to determine monthly variation in its proximate composition. The findings provide baseline information on the nutritional consistency of this locally available by-catch biomass and its potential for further value-added utilization as a feed ingredient.

2. MATERIALS AND METHODS

2.1 Study area and sampling context

Sun-dried FBC was procured monthly from a small-scale, traditional anchovy-processing facility operated by local fishermen in Kimanis town, Papar district, on the west coast of Sabah, Malaysia (Figure 1), over a six-month period from March to August 2025. The anchovy and associated by-catch were harvested using '*bagang'* in the coastal waters of Kimanis and subsequently sun-dried at the processing facility. 30 kg of FBC was collected during each sampling month. The samples were specific to this facility and only represent facility-level by-catch rather than the broader by-catch composition of anchovy fisheries across Sabah.

Figure 1. Location of Kimanis town in Papar district of Sabah, Malaysia

2.2 Processing of fishery by-catch for meal production

The collected FBC samples were transported to the laboratory at the Borneo Marine Institute, Universiti Malaysia Sabah, for processing. Upon arrival, the FBC was first screened to remove foreign materials, including coral fragments, stones, seashells, and other debris. These materials were collectively classified as miscellaneous items, and their total weight was recorded. The remaining by-catch was subsequently sorted into four major categories: fish, squid, shrimp, and crab. The weight of each category was recorded.

Fish specimens were then visually examined based on external morphological characteristics, including body shape, mouth morphology, and caudal fin structure. Identification was aided using online taxonomic resources, including *FishBase* and *TalkAboutFish* websites, together with comparisons against reference photographs. As the by-catch had been sun-dried prior to collection, many specimens had undergone shrinkage and partial loss of diagnostic morphological features. Consequently, identification was limited to broad fish groups based on common names (e.g. boxfish, catfish, gobies, and mackerels), rather than to species level. Following identification, all fish specimens were collectively weighed and oven-dried at 45 °C for 16 h to remove excess moisture. The dried materials were then ground into a fine powder, sieved, and homogenized to produce FBCM, which was stored at −20 °C until further use. All processing procedures were conducted using clean equipment and work surfaces to minimize the introduction of external contaminants during sample handling. The full processing pathway for FBCM is shown in Figure 2.

2.3 Proximate composition of fishery by-catch meal

The proximate composition of the homogenized FBCM was determined according to the standard methods of the Association of Official Analytical Chemists (AOAC) [9], using AOAC Official Methods No. 930.15, 942.05, 984.13, and 920.39 for moisture, ash, crude protein, and crude lipid determination, respectively. The procedures used in the present study followed these AOAC methods with minor modifications based on the specifications and operating settings of the laboratory equipment used.

Moisture content was determined by oven-drying 2 g of FBCM at 105 °C for 24 h to a constant weight. The weight loss during drying (which refers to moisture content) was calculated and expressed as a percentage of the initial sample weight. A 0.5 g sample of dried FBCM was used for crude protein determination using the Kjeldahl method with a Kjeltec 2300 system (FOSS, Denmark). The measured nitrogen content was converted to crude protein using a nitrogen-to-protein conversion factor of 6.25. For crude lipid determination, a 0.5 g sample of dried FBCM was weighed and subjected to ether extraction using a Soxtec™ 2043 system (FOSS, Sweden). The Soxtec extraction programme consisted of boiling (submersion) for 30 min, rinsing (refluxing) for 60 min, evaporation (recovery) for 10 min, and oven-drying of the extracted lipid for 30 min at 101 °C. The lipid content was then calculated and expressed as a percentage of the initial sample weight. Ash content was determined by incinerating 2 g of dried FBCM in a muffle furnace at 550 °C for 5 h. The remaining ash was weighed and expressed as a percentage of the initial sample weight. All analyses were performed in triplicate using the same homogenized FBCM sample.

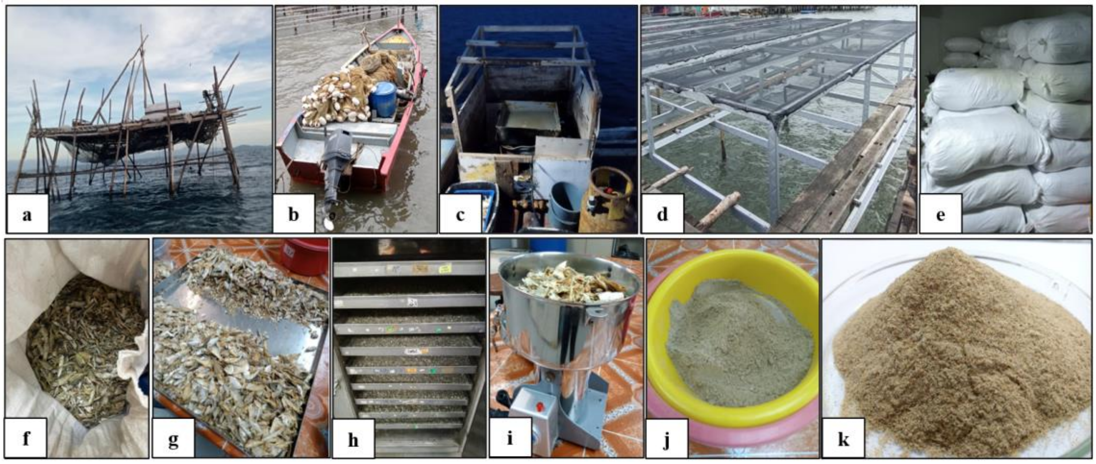


Figure 2. Processing pathway from anchovy harvesting to fishery by-catch meal (FBCM) production
Note: (a) The *'bagang'*. (b) Fishing boat used to transport harvested anchovy from the *bagang* to the processing facility. (c) All harvested fish were cooked in salted water (for approximately 2-3 min) in a large cooking pot. (d) Cooked fish were evenly spread on drying racks and repeatedly sun-dried for 2-3 days, depending on weather conditions. (e) The sun-dried fish were sorted into anchovy and associated by-catch before being packed into sacks (30 kg per sack) and stored in a dark room maintained at 18 °C. All harvested anchovy and associated by-catch will be sold within the month of collection. (f) A sack of by-catch was procured from the facility each month and brought back to the laboratory for examination. (g) The by-catch was screened and sorted into different categories. (h) All fish specimens were oven-dried at 45 °C for 16 h. (i) The oven-dried fish specimens were ground into fine powder using a grain mill grinder. (j) The meal powder was then sieved using a 500 µm sieve. (k) The end product, FBCM, was packed and stored at -20 °C until further use.

2.4 Derived proximate composition indices of fishery by-catch meal

The derived proximate composition indices of FBCM, including the protein-to-ash ratio, lipid-to-protein ratio, lipid-to-ash ratio, approximate organic fraction, variability range, and coefficient of variation (CV), were calculated from the monthly proximate composition data using the following formulas:

1. Protein-to-ash ratio = Crude protein (%) / Ash (%)
2. Lipid-to-protein ratio = Crude lipid (%) / Crude protein (%)
3. Lipid-to-ash ratio = Crude lipid (%) / Ash (%)
4. Approximate organic fraction (%) = 100 - Moisture (%) - Ash (%)
5. Variability range = Maximum value - Minimum value
6. CV (%) = [Standard deviation / Mean] × 100

3. RESULTS

3.1 Species composition of fishery by-catch

The FBC collected from anchovy landings was sorted into five categories: fish, squid, shrimp, crab, and miscellaneous items. The percentage composition of each category is presented in Table 1. Across the six-month sampling period, fish constituted the predominant component of the by-catch, accounting for an average of 94.16 ± 1.97% (28.25 ± 0.59 kg). In contrast, squid, shrimp, and crab were present only in small quantities, with mean proportions of 0.17 ± 0.11% (0.05 ± 0.03 kg), 0.08 ± 0.02% (0.02 ± 0.01 kg), and 0.12 ± 0.08% (0.04 ± 0.02 kg), respectively. Collectively, these three categories accounted for less than 1% of the total by-catch. The remaining 5.47 ± 1.98% (1.64 ± 0.59 kg) comprised miscellaneous items, including coral fragments, stones, seashells, and other debris.

Table A1 and Figure A1 present the FBC species identified from the monthly sampling batches. A total of 23 fish groups were identified. Among these, mackerels, ponyfishes, sardines, and terapons were consistently recorded throughout the six-month sampling period. In contrast, several fish groups, including leatherjacket, longfin trevallies, longtail seamoths, saddle grunts, sculpins, and spinefoots, were recorded only in a few samples from certain months. Other by-catch groups, including crabs, shrimps, and squids, were also recorded across all monthly sampling batches, although they occurred in very low quantities. Representative examples of the by-catch are shown in Figure A1.

Table 1. Monthly percentage composition and mass of fishery by-catch (FBC) categories

Category	March	April	May	June	July	August	Mean ± SD
	% (kg)	**% (kg)**	**% (kg)**	**% (kg)**	**% (kg)**	**% (kg)**	**% (kg)**
Fish	93.43 (28.03)	91.43 (27.43)	94.60 (28.38)	97.23 (29.17)	95.07 (28.52)	93.20 (27.96)	94.16 ± 1.97 (28.25 ± 0.59)
Squids	0.10 (0.03)	0.30 (0.09)	0.27 (0.08)	0.23 (0.07)	0.10 (0.03)	0.03 (0.01)	0.17 ± 0.11 (0.05 ± 0.03)
Shrimps	0.07 (0.02)	0.07 (0.02)	0.10 (0.03)	0.07 (0.02)	0.07 (0.02)	0.10 (0.03)	0.08 ± 0.02 (0.02 ± 0.01)
Crabs	0.03 (0.01)	0.17 (0.05)	0.23 (0.07)	0.13 (0.04)	0.10 (0.03)	0.03 (0.01)	0.12 ± 0.08 (0.04 ± 0.02)
Miscellaneous	6.37 (1.91)	8.03 (2.41)	4.80 (1.44)	2.34 (0.70)	4.66 (1.40)	6.64 (1.99)	5.47 ± 1.98 (1.64 ± 0.59)

Note: Miscellaneous items included coral fragments, stones, seashells, and other debris. Total sample weight = 30 kg each month. Mean ± SD indicates mean ± standard deviation. Values are expressed as percentage composition, with the corresponding mass in kg shown in parentheses.

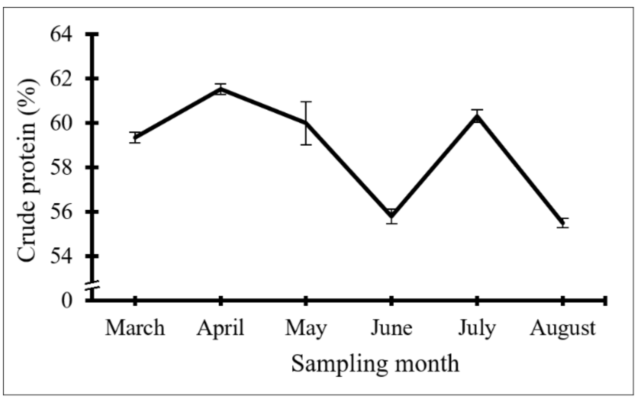
Table 2. Proximate composition of fishery by-catch meal (FBCM)

Proximate Component	March	April	May	June	July	August
Crude protein	59.34 ± 0.23	61.52 ± 0.24	59.98 ± 0.98	55.79 ± 0.34	60.30 ± 0.29	55.49 ± 0.21
Crude lipid	3.79 ± 0.03	4.11 ± 0.04	4.33 ± 0.11	5.26 ± 0.02	4.36 ± 0.03	5.17 ± 0.05
Ash	34.71 ± 0.25	31.58 ± 0.64	33.56 ± 0.03	37.81 ± 0.26	34.18 ± 0.14	37.86 ± 0.24
Moisture	6.36 ± 0.07	6.90 ± 0.06	6.24 ± 0.51	6.70 ± 0.54	5.31 ± 0.18	7.34 ± 0.07

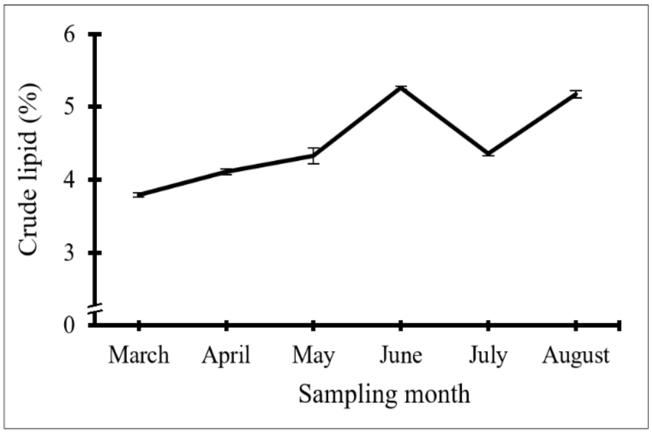
Note: Values of crude protein, crude lipid, and ash are presented as means ± standard deviation in % dry matter, whereas moisture is expressed as % wet basis.

3.2 Proximate composition of fishery by-catch meal

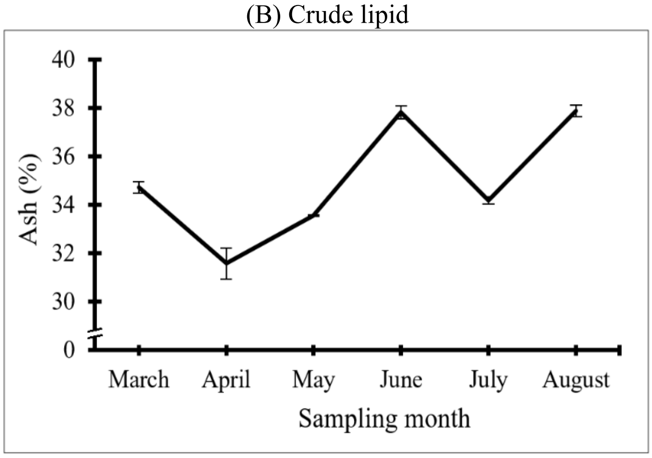
The proximate composition of FBCM from the monthly sampling batches is presented in Table 2. Crude protein content ranged from 55.49 ± 0.21% to 61.52 ± 0.24%, with the highest value recorded in April and the lowest in August. FBCM obtained in June had the highest crude lipid content (5.26 ± 0.02%), followed by August (5.17 ± 0.05%), July (4.36 ± 0.03%), May (4.33 ± 0.11%), April (4.11 ± 0.04%), and March (3.79 ± 0.03%). Moisture content ranged from 5.31 ± 0.18% to 7.34 ± 0.07%, with the lowest and highest values recorded in July and August, respectively. Ash content of the FBCM also varied among the sampling months. The lowest ash content was observed in FBCM collected in April (31.58 ± 0.64%), whereas the highest was recorded in August (37.86 ± 0.24%), followed by June (37.81 ± 0.26%), March (34.71 ± 0.25%), July (34.18 ± 0.14%), and May (33.56 ± 0.03%).



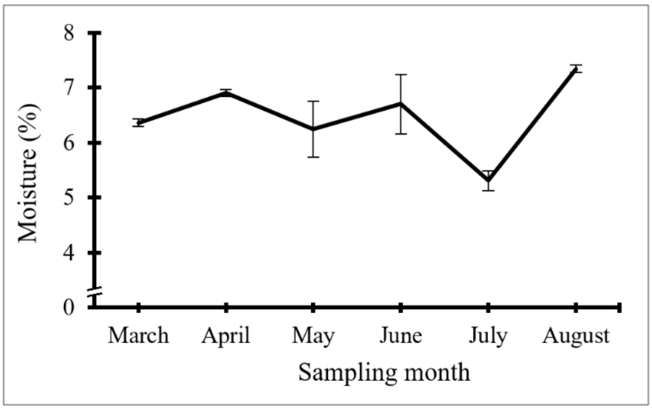
(A) Crude protein



(B) Crude lipid



(C) Ash



(D) Moisture

Figure 3. Monthly variation in the proximate composition of fishery by-catch meal (FBCM) from March to August 2025. (A) crude protein, (B) crude lipid, (C) ash, and (D) moisture
Note: Error bars represent standard deviation.

Figure 3(A–D) illustrates the monthly variation in the proximate composition of FBCM during the six-month sampling period. An apparent inverse relationship was observed between crude protein and ash contents, with higher protein levels generally coinciding with lower ash levels. This pattern was most evident in April, when crude protein was highest and ash was lowest, whereas the relatively low protein contents in June and August coincided with higher ash levels. A similar relationship was observed in July, where an increase in crude protein was accompanied by a decrease in ash content. In contrast, crude lipid content increased from March to June, decreased in July, and increased again in August, while moisture content fluctuated throughout the sampling period. Overall, crude lipid and moisture contents showed no consistent temporal pattern.

3.3 Derived proximate composition indices of fishery-by-catch meal

The derived proximate composition indices of FBCM are presented in Table 3. The protein-to-ash ratio ranged from 1.47 in August to 1.95 in April, while the lipid-to-protein ratio ranged from 0.06 in March to 0.09 in June and August. Similarly, the lipid-to-ash ratio ranged from 0.11 in March to 0.14 in June and August. The approximate organic fraction, expressed as the non-ash fraction, ranged from 62.14% in August to 68.42% in April. Overall, April exhibited the highest protein-to-ash ratio and approximate organic fraction, corresponding to its relatively high crude protein and low ash contents, whereas August showed the lowest values for both indices. Among the proximate components, crude protein showed a range of 6.03% and a CV of 4.26%, indicating relatively low variability across the sampling months. Ash showed a similar range of 6.28 percentage points, with a CV of 8.78%. In contrast, crude lipid and moisture exhibited higher relative variability, with CVs of 13.08% and 10.71%, respectively, despite their narrower absolute ranges of 1.47 and 2.03 percentage points.

Table 3. Derived proximate composition and variability indices of fishery by-catch meal (FBCM)

Parameter	March	April	May	June	July	August	Variability Range (%)	Coefficient of Variation (%)
Protein-to-ash ratio	1.71	1.95	1.79	1.48	1.76	1.47		
Lipid-to-protein ratio	0.06	0.07	0.07	0.09	0.07	0.09		
Lipid-to-ash ratio	0.11	0.13	0.13	0.14	0.13	0.14		
Approximate organic fraction (non-ash fraction) (%)	65.29	68.42	66.44	62.19	65.82	62.14		
Crude protein							6.03	4.26
Crude lipid							1.47	13.08
Ash							6.28	8.78
Moisture							2.03	10.71

Note: Variability range is expressed in percentage points for proximate composition parameters.

4. DISCUSSION

The composition of FBC varied among the monthly sampling batches, with no consistent temporal trend observed throughout the six-month sampling period. This variation may have been influenced by a combination of ecological, environmental, and fishing-related factors. In Sabah, Malaysia, anchovy fishing is traditionally conducted using '*bagang*', a lift-net fishing method operated at night from bamboo or wooden platforms installed in nearshore waters, where artificial light is used to attract fish. This fishing practice may influence by-catch composition by favoring the capture of species that are attracted to surface light sources and forage in the upper water column. For instance, several fish groups, including mackerels, ponyfishes, terapons, and sardines, were consistently recorded throughout all sampling months. Their frequent occurrence may be attributed to their feeding behavior, as these species commonly aggregate and feed near the water surface, making them more susceptible to capture by *bagang* operations [10-12]. In contrast, benthic fish groups such as seamoths, saddle grunts, and sculpins were recorded only occasionally, likely because their bottom-associated habitats reduce their probability of encountering surface-oriented lift nets [13-15]. Nevertheless, this study was conducted at a single anchovy landing site in Sabah, and the observed by-catch composition may not represent the diversity and abundance patterns across other landing locations. Differences in local environmental conditions, habitat characteristics, and fishing practices among sites may contribute to variations in by-catch species composition. Therefore, further investigations involving multiple anchovy landing sites and longer sampling periods are recommended to better understand the spatial and temporal dynamics of FBC composition in Sabah.

Based on the total by-catch mass, fish accounted for an average of 94.16 ± 1.97% of the by-catch across the six-month sampling period, whereas squid, shrimp, and crab collectively contributed less than 1%. The remaining proportion comprised miscellaneous materials, which were excluded from FBCM production. Owing to their low proportions, the squid, shrimp, and crab fractions were also excluded, and only the fish fraction was processed into meal. The exclusion of crustaceans may also have helped avoid an additional source of mineral matter, as their highly calcified exoskeletons are rich in minerals [16]. Nevertheless, the resulting FBCM still exhibited a relatively high ash content, ranging from 31.58% to 37.86%. This relatively high ash content may limit the potential applications of FBCM, as a substantial proportion of ash reduces the relative contribution of organic nutrients in the meal. Similarly, although meat and bone meal contains approximately 50% crude protein, its use as a fishmeal substitute has been limited largely because of its high ash content (approximately 29%) [17]. Excessive dietary ash has also been reported to reduce nutrient and protein digestibility in fish, thereby impairing feed utilization and growth performance [18, 19]. Therefore, pre-treatment approaches to reduce the ash content of FBCM should be explored to improve its nutritional value and potential application as a feed ingredient.

The relatively high ash content observed in the present study may be associated with the processing of whole fish, including their mineralized skeletal tissues. Although visible foreign materials, such as coral fragments, stones, seashells, and other debris, were carefully removed during sorting, acid-insoluble ash was not determined. Therefore, the relative contribution of fish-derived mineral matter and any residual inorganic materials to the total ash content cannot be confirmed. The 500 μm sieving step used in the present study was primarily intended to standardize meal particle size rather than to remove inorganic materials; consequently, fine mineral particles derived from fish bones may have remained in the final FBCM. Further studies should determine acid-insoluble ash and quantify mineral elements, particularly calcium, phosphorus, and sodium, to better characterize the mineral composition and potential sources of the high ash content. Appropriate pre-treatment strategies to reduce excessive mineral matter could also be investigated if subsequent studies demonstrate that the ash level limits particular applications of FBCM.

The crude protein and lipid contents of FBCM varied among the monthly sampling batches, ranging from 55.49% to 61.52% and from 3.79% to 5.26%, respectively. The observed variation may partly reflect differences in the composition of the by-catch. However, fish-group occurrence in the present study was recorded only as presence or absence rather than relative biomass; therefore, the contribution of individual fish groups to the observed nutritional variation cannot be directly established. Other biological and processing-related factors, including fish body size, viscera proportion, drying conditions, and storage duration, may also have contributed to the variation. Such variability in raw material characteristics is an important consideration in the utilization of FBC and processing by-products [20, 21]. Future studies could incorporate quantitative measurements of fish-group biomass together with relevant biological and processing parameters to better elucidate the factors contributing to temporal changes in FBCM composition. Sorting the by-catch into different fish groups before processing could also be investigated as a potential approach for improving the consistency of the resulting meal [6].

The derived proximate composition indices further illustrated differences in the relative composition of FBCM among sampling months. An apparent inverse pattern was observed between crude protein and ash contents, with higher ash contents generally coinciding with lower crude protein contents. This pattern was reflected in the protein-to-ash ratio, which was highest in April (1.95), when crude protein was highest and ash was lowest, and lowest in August (1.47), when crude protein was lowest and ash was highest. Similarly, the approximate organic fraction, expressed as the non-ash fraction, was highest in April (68.42%) and lowest in August (62.14%). These patterns may partly reflect differences in the relative contribution of protein-rich soft tissues and mineralized skeletal tissues among the monthly by-catch samples. However, because the relative biomass of individual fish groups and the contribution of bone-derived minerals were not directly determined, these relationships should be interpreted cautiously and do not establish a causal relationship between ash and protein contents.

In comparison, the lipid-to-protein and lipid-to-ash ratios showed relatively limited variation, ranging from 0.06 to 0.09 and from 0.11 to 0.14, respectively. The coefficients of variation indicated that crude protein was relatively consistent among the monthly sampling batches (CV = 4.26%), whereas crude lipid (CV = 13.08%) and moisture (CV = 10.71%) exhibited greater relative variability; ash showed intermediate variability (CV = 8.78%). These descriptive indices indicate that the magnitude of temporal variation differed among the proximate components. Nevertheless, proximate composition alone does not provide a complete assessment of the nutritional characteristics of FBCM. Given the observed monthly variation, temporal differences in other nutritional attributes cannot be excluded. Further studies should therefore evaluate essential amino acid and fatty acid profiles, mineral and vitamin composition, digestibility, and other relevant nutritional characteristics across sampling periods to better establish the nutritional consistency and potential applications of FBCM.

In addition to nutritional considerations, the occurrence of pufferfishes among the recorded fish groups warrants attention from a feed-safety perspective. Pufferfishes were not specifically removed before processing in the present study, and all fish material was ground together to produce FBCM. Consequently, the potential presence of naturally occurring toxins or other species-specific hazards in the resulting meal cannot be excluded. The present study also did not evaluate potential contaminants or safety indicators, such as heavy metals, natural toxins, or microbiological quality. Future processing strategies should therefore incorporate species-level screening and selective removal of potentially toxic fish before meal production, followed by appropriate safety assessments before the material is considered for feed applications.

A further limitation concerns the absence of mass measurements at the different processing stages. Although 30 kg of sun-dried FBC was procured for each monthly sampling batch, the masses of the separated fish fraction, material after oven drying, and final FBCM were not recorded. Consequently, material recovery and processing yield could not be determined. Sorting, additional drying, grinding, and sieving may result in material losses at different stages of processing. Future studies should therefore record the mass at each processing stage to establish the material balance, recovery rate, and processing efficiency of FBCM production.

5. CONCLUSION

FBC generated from the anchovy fishery of Kimanis town, Papar district, Sabah, Malaysia consisted predominantly of fish, particularly mackerels, sardines, ponyfishes, and terapons, providing a potential raw material for further processing into FBCM. However, the relatively high ash content of FBCM should be carefully considered, and further processing strategies may be required to reduce the ash level. Future studies should evaluate temporal variation in the amino acid, fatty acid, mineral, and other nutritional compositions of FBCM to better establish its nutritional consistency and potential applications. Overall, the findings of this study demonstrate the feasibility of processing anchovy FBC into FBCM and highlight this approach as a possible marine resource-recovery pathway for the utilization of an underutilized fishery by-product.

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APPENDIX

Table A1. Fish groups identified from monthly fishery by-catch (FBC) samples

No.	Fish Group (Family)	March	April	May	June	July	August
1	Boxfishes (Ostraciidae)	-	-	✓	✓	-	-
2	Breams (Sparidae)	✓	✓	-	✓	-	✓
3	Catfishes (Ariidae)	-	✓	-	-	-	-
4	Croakers (Sciaenidae)	-	✓	✓	-	✓	✓
5	Gobies (Gobiidae)	-	-	-	-	✓	✓
6	Filefishes (Monacanthidae)	-	-	✓	-	✓	✓
7	Flatheads (Platycephalidae)	-	-	-	✓	✓	✓
8	Hairtails (Trichiuridae)	-	-	-	-	✓	✓
9	Leatherjackets (Trachinotidae)	-	-	-	✓	-	-
10	Longfin trevallies (Carangidae)	-	-	-	-	✓	-
11	Longtail seamoths (Pegasidae)	-	-	-	-	✓	-
12	Mackerels (Carangidae)	✓	✓	✓	✓	✓	✓
13	Needlefishes (Belonidae)	✓	✓	-	-	-	-
14	Ponyfishes (Leiognathidae)	✓	✓	✓	✓	✓	✓
15	Pufferfishes (Tetraodontidae)	-	-	✓	-	✓	✓
16	Rabbitfishes (Siganidae)	-	-	-	-	✓	✓
17	Saddle grunts (Haemulidae)	-	-	✓	-	-	-
18	Sardines (Clupeidae)	✓	✓	✓	✓	✓	✓
19	Scads (Carangidae)	✓	✓	✓	-	-	-
20	Sculpins (Cottidae)	-	-	✓	-	-	-
21	Snappers (Lutjanidae)	-	-	✓	✓	-	-
22	Soles (Soleidae)	-	-	-	-	✓	✓
23	Terapons (Terapontidae)	✓	✓	✓	✓	✓	✓
24	Unidentified	✓	✓	✓	✓	✓	✓
No.	**Others**	**March**	**April**	**May**	**June**	**July**	**August**
1	Crabs	✓	✓	✓	✓	✓	✓
2	Mantis shrimp	✓	-	✓	-	✓	✓
3	Murex snail (shells）	-	-	✓	✓	-	✓
4	Sand dollar	✓	-	✓	✓	✓	✓
5	Shrimps	✓	✓	✓	✓	✓	✓
6	Squids	✓	✓	✓	✓	✓	✓

Note: (✓) indicates the presence of the fish group in the fishery by-catch (FBC) sample. (-) indicates the absence of the fish group.

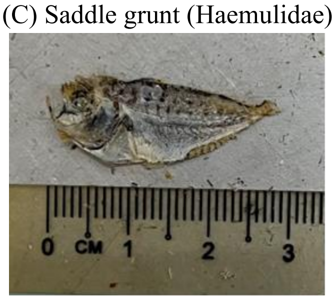

(A) Filefish (Monacanthidae)


(B) Boxfish (Ostraciidae)


(C) Saddle grunt (Haemulidae)


(D) Longtail seamoth (Pegasidae)


(E) Pufferfish (Tetraodontidae)


(F) Ponyfishes (Leiognathidae)

(G) Needlefish (Belonidae) (H) Sole (Soleidae) (I) Snapper (Lutjanidae)

(J) Mackerel (Carangidae) (K) Sardine (Clupeidae) (L) Terapon (Terapontidae)

(M) Murex snail (shell) (N) Sand dollar (O) Squids

(P) Shrimps (Q) Crabs (R) Mantis shrimp

Figure A1. Representative examples of the by-catch specimens identified in the present study