Nutritional composition and mineral analysis of the by-products from tropical marine fish, purple-spotted bigeye (*Priacanthus tayenus* Richardson, 1846) and barracuda (*Sphyraena obtusata* Cuvier, 1829)

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**Abstract.** The aim of this study is to evaluate the nutritional composition, macro- and micro-elements from purple-spotted bigeye (*Priacanthus tayenus*) and barracuda (*Sphyraena obtusata*) by product which are extensively used for surimi. The proximate composition showed significant differences (*p* < 0.05) for all parameters. The moisture, protein, fat, ash and carbohydrate contents of purple-spotted bigeye sample ranged from 56.22-79.26%, 12.46-31.14%, 0.24-1.29%, 1.27-22.86% and 0.42-0.98%, respectively. Meanwhile, barracuda recorded 55.76-79.86% moisture, 18.46-27.29% protein, fat 0.05-2.55% fat, 1.22-24.36% ash and 0.41-0.88% carbohydrate contents. For macro-elements analysis, both fish species contained high concentration of calcium, especially in fins, bone and skin. For other macro-elements, all samples recorded lower than 4.5 mg/g. Although the concentration of micro-element zinc and copper were dominant in all samples examined, their levels were still below the permissible limits recommended by the Food and Agriculture Organization/World Health Organization (FAO/WHO) and the Malaysian Food Regulations (MFR). More importantly, chromium, cadmium and lead were far below the toxic levels regulated by the FAO/WHO and the MFR. Thus, the by-products used may be applied for potential food ingredients and for baseline information in the further experimentation.

**Keywords:** barracuda; by-products; chemical composition; mineral; purple-spotted bigeye

1. Introduction
Purple-spotted bigeye (*Priacanthus tayenus* Richardson, 1846) is a species, belongs to the family of Priacanthidae and widely distributed in the Indo-West Pacific including Malaysia. This species is an important tropical marine fish due to its abundant, low cost and suitable as raw material for surimi production [1]. Purple-spotted bigeye surimi, or popularly known as *kintokidai*, is one of the high-grade surimi products in the seafood market [2]. Approximately 23,198 tons of purple-spotted bigeye was landed in 2019 [3]. Another tropical marine species, *Sphyraena obtusata* (Cuvier, 1829), commonly known as barracuda or *alu-alu* locally, is also a commercially important marine fish for surimi
processing and usually in combination with other species or commonly referred as mix surimi [4]. Surimi is made of minced fish flesh processed mechanically by adding cryoprotectants and it is an intermediate fish processing product [5]. During surimi processing, a large percentage of by-products (about 60-70%) was generated. The by-products contain substantial amount of organic and inorganic components derived from head, skin, bone, intestine, fins and scale [6]. In some cases, the fish by-products were reused as silage, fish meal, animal feed products, fertilizer and even biofuels [7]. All these are considered as low value-added products. Sometimes by-products are also dumped into the landfill or water bodies and led to harmful effects to environmental ecosystem [8].

In order to manage the by-products efficiently, among the most important information that is helpful in determination of the organic and inorganic components of by-products before transforming them into valuable goods. As widely known, fish by-products contain variety of nutritional components, including protein (amino acids), fat (fatty acids), ash (minerals), vitamins and pigments [9]. Nonetheless, the composition of nutrients varies between types of fish by-products. For instance, the head, fins, bone, gills and scale were greater in ash, calcium and phosphorous, while protein content is abundant in skin and flesh [6,9]. Studies have reported the successful extraction of fishbone-based powders and fortified in biscuit production and bakery [10,11] and fish skin-derived collagens and its use as functional food ingredients [12]. Although many reports related to nutritional content of fish by-products has been published to date, the information on the chemical composition and mineral elements harbored in the by-products of purple-spotted bigeye and barracuda are much less documented. Therefore, this study is carried out to determine the chemical compositions and mineral contents of purple-spotted bigeye and barracuda by-products.

2. Materials and methods
2.1. Materials
Marine fish used in this study were purple-spotted bigeye (P. tayenus) and barracuda (S. obtusata). Fish were purchased from a local fish market at Kota Kinabalu (Sabah, Malaysia). For chemical analysis, sulfuric acid (H$_2$SO$_4$), petroleum ether and ultrapure nitric acid were supplied from Merck, Germany. Kjeldahl catalyst selenium tablet (Fisher Chemical, USA). The certified reference materials (CRM) were obtained from the National Institute of Standard Technology (NIST) and subjected to the validation of ICP-MS method. Other chemicals used were of analytical grade.

2.2. Sample preparation
Three pieces of each fish sample were used in the experimentation. Fish samples were washed with running tap water and dried for 10 min at room temperature. The samples were weighed using a balance with two decimal places to obtain a fish-weighed mean. Afterwards, all samples were measured using a standard ruler (0-100 cm) to obtain total length of fish. Next, the prepared samples were separated into desired portions of flesh, skin, bone, fins and scale. All fish portions were then weighed and homogenized using a porcelain mortal. The homogenized samples were placed into a polyethylene container and kept in a freezer (-20 °C) until further analysis.

2.3. Determination of nutritional composition
Nutritional composition of by-products was determined based on the method of the Association of Official Analytical Chemist [13]. Moisture content determination was carried out using an air-oven (M720, Binder, Germany). Protein content was conducted by Kjeldahl method run with a Kjeltec 2300 Auto Distillation unit (FOSS Tecator, Sweden). For crude fat, soxtec method, using a Soxtec 2050 automated analyzer (FOSS Analytical, Denmark), was applied to determine crude fat content in the samples. Ash content of purple-spotted bigeye and barracuda by-products was performed using the gravimetric method. The carbohydrate component was obtained according to the method of Njinkoue et al. [14] through subtracting the sum of moisture, crude protein, fat and ash contents from 100.
2.4. Determination macro- and micro-elements
Macro- and micro-elements of fish by-products were performed according to the method of Jaziri et al. [6] using Inductively Couple Plasma Mass Spectrometry (ICP-MS) (Perkin Elmer Elan 9000, USA). Macro-elements of interest in this study, i.e., calcium, magnesium, potassium and sodium, whilst zinc, chromium, manganese, copper, iron, selenium, cadmium and lead were selected as micro-elements studies.

2.5. Statistical analysis
Values were presented as mean ± standard deviation (SD). Analysis of variance (ANOVA) was performed to assess different levels recorded in each sample. The significant differences were interpreted by Duncan’s multiple range tests using SPSS Statistics version 27.0 (IBM Corp., Armonk, New York).

3. Results and discussion
3.1. The detail information of the fish samples used
The average weight, total length and mean weight of by-products of purple-spotted bigeye and barracuda are depicted in figure 1. The mean weight and total length of purple-spotted bigeye were 152.92 ± 23.40 g and 23.27 ± 1.60 cm, respectively. For barracuda, average weight and length were about 226.27 ± 19.53 g and 36.73 ± 1.45 cm, respectively. These measurements were suitable for commercial surimi processing. The percentage of by-product parts obtained from the two marine fish varied remarkably. The percentages of skin, bone, fins and flesh derived from purple-spotted bigeye were around 5.09%, 5.98%, 4.64% and 30.74%, whilst from barracuda were 2.76%, 4.58%, 2.33% and 51.73% respectively. The results indicate meat portion comprises the highest quantity of fish material based on total weight, followed by bone, skin and fins.

Both marine fish samples used in this study yielded highest quantity of meat or muscle compared to bone, skin and fins. The results agreed with other studies using on the gilthead sea bream [9], Atlantic salmon and yellowtail kingfish [15]. The high amount of meat still available from the by-products because it is difficult to totally removed flesh from the crevices of the fish head, bones and skins particularly when the preparation and processing was being done by the machines. There will still be substantial amount of meat firmly attached to the bone and skin items. As a result, we obtained about 37.04% and 38.62% of the meat from purple-spotted bigeye and barracuda, respectively. Meanwhile,
other by-product yields reached around 19.69% and 19.73% for purple-spotted bigeye and barracuda, respectively.

3.2. Nutritional composition
The nutritional composition of the flesh and all by-products obtained from both purple-spotted bigeye and barracuda is illustrated in Table 1. There were significant differences ($p < 0.05$) in the moisture, crude protein fat and ash contents in the two fish species and no significant difference ($p > 0.05$) in the carbohydrate content. Moisture content represented the most abundant portion in muscle and other parts of purple-spotted bigeye and barracuda. High levels of protein were noted in the skin portion of purple-spotted bigeye and barracuda of 31.14% and 27.29% respectively, which was up to more than 27% of the proximate composition. On the other hand, the bone samples presented the lowest percentage of crude protein content (lower than 16%). The most dominant composition found in fins and bone of all treated samples was ash, representing greater than 16% of total chemical composition. The fat and carbohydrate contents in all purple-spotted bigeye and barracuda by-product parts were under 3%.

Due to the use of wet weigh basis samples, the moisture content found in all experimented samples was more dominant than other proximate compositions. Obviously, the meat from both fish species contained high moisture (around 79%) compared to skin, bone and fins. This result was in agreement with other literatures related to the nutritional value of fish species, such as lizardfish [6], threadfin bream [16], croaker fish [14], and grouper [17]. Protein was significantly higher ($p < 0.05$) in the skin portion of both purple-spotted bigeye and barracuda in comparison to other parts. The level of protein measured in purple-spotted bigeye’s skin was significantly higher (31.14%) than that of barracuda’s (27.29%). This might be due to the lower moisture content in the purple-spotted bigeye skin. Setijawati et al. [18] when the moisture content in the fish sample was high, resulting in the low level of protein, or vice versa. Previous works also reported high protein level in the fish skin of gilthead sea bream [9], sin croaker [19] and threadfin bream [16]. In addition to high protein content, fish skin which composed of fibrous proteins is also a good source collagen; t. Bone and fins had greater amount of ash as demonstrated in gilthead sea bream [9], croaker fish [14] and lizardfish [6]. However, the percentage of ash was significantly different ($p < 0.05$) in the fins with highest value compared to bone (nearly double). The high ash level suggested fins and bone might contain abundance of minerals, particularly calcium as highlighted by other researchers [14,20,21]. Interestingly, purple-spotted bigeye skin had a higher level of ash compared to barracuda. This could be due to the tightly attached scale of the skin. The by-products of both fish used in the present study had low quantity of fat and carbohydrate, ranging

| Table 1. Nutritional composition (%) of the fish by-products. |
|----------------------------------|
| Marine fish Type | Moisture | Protein | Fat | Ash | Carbohydrate |
|-------------------|---------|---------|-----|-----|--------------|
| Purple-spotted bigeye Meat | 79.26 ± 0.07f | 17.60 ± 0.21e | 1.18 ± 0.02b | 1.27 ± 0.01a | 0.69 ± 0.14a |
| Skin | 56.22 ± 0.77a | 31.14 ± 0.52f | 1.13 ± 0.05b | 10.52 ± 0.20b | 0.81 ± 0.00a |
| Bone | 71.31 ± 1.08e | 12.46 ± 0.15a | 1.29 ± 0.34b | 13.97 ± 0.70c | 0.98 ± 0.10a |
| Fin | 59.00 ± 0.41b | 17.49 ± 0.10e | 0.24 ± 0.07a | 22.85 ± 0.51d | 0.42 ± 0.08a |
| Barracuda Meat | 79.86 ± 0.20f | 18.46 ± 0.24d | 0.05 ± 0.01a | 1.22 ± 0.12e | 0.41 ± 0.30a |
| Skin | 69.30 ± 0.55d | 27.29 ± 0.29c | 1.44 ± 0.13b | 1.49 ± 0.21a | 0.48 ± 0.33a |
| Bone | 67.14 ± 0.12c | 15.39 ± 0.09b | 2.55 ± 0.30e | 14.04 ± 0.15c | 0.88 ± 0.13a |
| Fin | 55.76 ± 0.16b | 19.18 ± 0.06d | 0.08 ± 0.03a | 24.36 ± 0.16e | 0.62 ± 0.22d |

Means in the same column with different superscript letters indicate significant differences ($p < 0.05$).
from 0.05% to 2.55% and 0.41% to 0.98%, respectively. Even when compared to gilthead sea bream [9] and sin croaker [19]. Taken together, amount of chemical composition analyzed in this study varied depending on several factors, such as fish species, gender, age, feeding aspect, habitat (environment) and health status [9].

3.3. Macro-element evaluation

Table 2 shows the macro-elements detected in the flesh, skin, bone and fins of purple-spotted bigeye and barracuda. The results indicate the fins and bone from both fish had higher calcium levels compared to other macro elements. The skin of purple-spotted bigeye recorded highest amount of calcium about 43.38% more than barracuda studied. Magnesium was relatively low in all by-product samples, especially in the muscle (lower than 0.1 mg/g). Potassium was the most dominant macro-element found in the meat i.e., 1.40 mg/g in purple-spotted bigeye and 3.70 mg/g in barracuda. Sodium was higher in fins samples. Overall, calcium was the most abundance macro-element studied in the purple-spotted bigeye and barracuda, particularly in the fins and bone portions.

Macro-elements, including calcium, magnesium, potassium and sodium, are essential mineral compounds for fish or human being. Fish is considered as a good source of minerals and the quantity and composition of mineral are different depending on fish species, body parts (i.e., muscle, skin, bone, fins, scale, gill, and viscera, feeding diet, season, biology (sex, size and age) and environmental conditions (e.g., temperature, salinity and contaminations) [9,17]. As aforementioned, calcium was most abundant macro-element, in purple-spotted bigeye and barracuda especially in fins and bone. The higher content of calcium in the purple-spotted bigeye skin might be due to the presence of pieces of scale still attached to the skin that was unable to remove during fish preparation. Our readings were higher than calcium content reported from gilthead sea bream bone (16.18 mg/g) [9] and were lower compared to croaker bone (174.3-182.6 mg/g) [14], salmon mackerel and cod (135, 143 and 190 mg/g, respectively) [19]. For magnesium, the meat recorded amount in the range of 0.35-3.63 mg/g with the highest level detected in the fins. From these results, amount of calcium level found in the tested fish samples and their portions were in accordance with other fish species (salmon, mackerel, cod, croaker and lizardfish) [5, 14, 19]. Furthermore, the fins collected from barracuda had the greatest sodium value (4.44 mg/g) than other by-products and muscle samples, and even compared to other species with different portions explored from gilthead sea bream [9], croaker [14] and lizardfish [6]. However, other fish samples like salmon, cod and mackerel bone [20], and emperor, scad and grouper muscle [17] showed higher sodium level in comparison to the samples used in this study. Finally, the potassium content of purple-spotted bigeye and barracuda samples recorded more dominant in the muscle part, and these were accordance with other marine fish species investigated by Njinkoue et al. [14], Pateiro et al. [9], Jaziri et al. [6], but the proportion was different whereby the croaker muscle samples had most abundant potassium level.

| Marine fish surimi Type | Calcium (Ca) | Magnesium (Mg) | Potassium (K) | Sodium (Na) |
|------------------------|-------------|----------------|--------------|------------|
| Purple-spotted bigeye  |             |                |              |            |
| Meat                   | 0.37        | 0.35           | 1.40         | 1.54       |
| Skin                   | 43.38       | 1.30           | 0.14         | 1.14       |
| Bone                   | 60.77       | 1.68           | 0.61         | 1.67       |
| Fin                    | 61.60       | 1.86           | 0.25         | 1.77       |
| Barracuda              |             |                |              |            |
| Meat                   | 0.19        | 0.90           | 3.70         | 3.30       |
| Skin                   | 3.51        | 0.55           | 0.27         | 0.62       |
| Bone                   | 19.13       | 0.96           | 0.40         | 1.11       |
| Fin                    | 73.12       | 3.63           | 0.21         | 4.44       |
Overall, the level of macro-elements composition in the recent work and other previous studies was highly variable affected on the above-mentioned factors. For further exploration, through understanding of the macro-elements derived from both purple-spotted bigeye and barracuda samples, could be applied as a great source for enriching calcium content in the low-calcium products, such as bakery, biscuit and noodle. As reported by Nemati et al. [10] and Singh et al. [11], the bakery and biscuit fortified with bone powder from fish by-product increased the nutritional attributes, especially for calcium content, respectively. Meanwhile, although the content of magnesium was not much as found in the calcium of the tested samples, it offers several health benefits in human body, including regulation of important biological functions, being a cofactor for hundreds of enzymes, contributing on bone development, and related process [22].

### Table 3. Micro-element content (mg/kg) of the fish by-products.

| Marine fish     | Type    | Zinc (Zn) | Iron (Fe) | Manganese (Mn) | Copper (Cu) | Selenium (Se) | Chromium (Cr) | Cadmium (Cd) | Lead (Pb) |
|-----------------|---------|-----------|-----------|----------------|-------------|----------------|----------------|--------------|-----------|
| Purple-spotted  | Meat    | 20.46     | 5.84      | 0.24           | 4.99        | 0.81           | 0.07           | 0.01         | 0.05      |
| bigeye          | Skin    | 13.86     | 1.23      | 10.92          | 0.59        | 0.16           | 0.02           | 0.00         | 0.03      |
|                 | Bone    | 18.01     | 2.17      | 19.91          | 0.60        | 0.17           | 0.04           | 0.00         | 0.09      |
| Barracuda       | Fin     | 24.08     | 1.95      | 14.82          | 0.55        | 0.13           | 0.02           | 0.00         | 0.07      |
|                 | Meat    | 6.93      | 9.29      | 0.27           | 0.96        | 0.80           | 0.28           | 0.08         | 0.70      |
|                 | Skin    | 52.86     | 28.61     | 1.03           | 1.28        | 0.39           | 0.36           | 0.08         | 0.69      |
|                 | Bone    | 15.02     | 1.81      | 3.55           | 0.14        | 0.10           | 0.01           | 0.00         | 0.02      |
|                 | Fin     | 60.39     | 9.55      | 7.37           | 0.72        | 0.10           | 0.31           | 0.08         | 0.72      |
| MFR*            |         |           |           |                |             |                |                |              |           |
| FAO/WHO**       |         |           |           |                |             |                |                |              |           |

* Malaysian Food Regulation [29]  
** FAO/WHO [28]

(13 mg/g). Overall, the level of macro-elements composition in the recent work and other previous studies was highly variable affected on the above-mentioned factors. For further exploration, through understanding of the macro-elements derived from both purple-spotted bigeye and barracuda samples, could be applied as a great source for enriching calcium content in the low-calcium products, such as bakery, biscuit and noodle. As reported by Nemati et al. [10] and Singh et al. [11], the bakery and biscuit fortified with bone powder from fish by-product increased the nutritional attributes, especially for calcium content, respectively. Meanwhile, although the content of magnesium was not much as found in the calcium of the tested samples, it offers several health benefits in human body, including regulation of important biological functions, being a cofactor for hundreds of enzymes, contributing on bone development, and related process [22].

### 3.4. Micro-element profile

Micro-elements profile (zinc, selenium, iron, copper, manganese, chromium, cadmium and lead) from the muscle and other parts of the fish samples are presented in table 3. The level of zinc varied from 13.86 µg/g to 24.08 µg/g for the purple-spotted bigeye sample, while barracuda ranged between 6.93 µg/g and 60.39 µg/g with the highest level found in the fins part for both marine species used. In addition, both samples had the highest value of selenium obtained from the muscle part (about 0.8 µg/g). For purple-spotted bigeye, the most dominant iron and copper elements observed in the part of flesh, whilst barracuda samples found in the skin portion. The content of manganese element in the skin, bone and fins of purple-spotted bigeye was relatively higher compared to those found in barracuda, which the fins and bone portions had more dominance in both collected samples. Furthermore, the muscle and other by-products of purple-spotted bigeye and barracuda samples had a lower level of chromium, cadmium and lead elements, which ranged from 0 µg/g to 0.70 µg/g.

Micro-elements of purple-spotted bigeye and barracuda samples determined were zinc, selenium, iron, copper, manganese, chromium, cadmium and lead. Some of them are considered as vital elements involved in the metabolism process and some elements are considered as toxic with recommended safety limits, including lead, cadmium and chromium [23]. Both fish species recorded highest level of Zinc, particularly in the fins. However, the readings were lower than the acceptable limit recommended by the Malaysian Food and Regulations (MFR) and the Food and Agriculture Organization and World
Health Organization (FAO/WHO) which are at 100 mg/kg and 150 mg/kg, respectively. Other fish species and their portion samples experimented in lizardfish [6], croaker [14] and sea bream [9] were also recorded lower than 80 mg/kg, meaning that those samples are permissible limit for food application. As widely known, zinc is an essential element for metabolism process in living organisms especially for cell division, immune system, wound healing. On the contrary, the excess of zinc may pose negative effect to the organisms. For example, excessive zinc in the zebrafish (as an alternative vertebrate model) could cause malformations of the skeletal and serious defects in growth [24]. Another study reported that the excessive exposure could cause focal neuronal deficits, epigastric pain, respiratory disorder, and risk of prostate cancer in human [25].

In the context of iron, these levels were relatively lower compared to those found in lizardfish and croaker by-products [6,9], except exhibited in the barracuda skin. Other important micro-elements such as selenium and copper, ranging 0.10-0.81 mg/kg and 0.14-4.99 mg/kg, respectively. Selenium is an essential micro-mineral in blocking oxidative stress in human cell [26], and from our study the highest content observed in the muscle sample of both purple-spotted bigeye and barracuda, as well as found in the lizardfish flesh. For copper element, all samples used were below the safety limits from the FAO/WHO and the MFR, indicating that it should not lead an acute toxicological risk to human being, and it may contribute on beneficial effect due to its function as an essential element required for hemoglobin synthesis [27]. For chromium, cadmium, and lead contents, the tested samples were in accordance with those studied by Younis et al. [17], Jarapala et al. [26] and our previous study in lizardfish by-products. More importantly, all samples had lower level of elements than the toxic levels regulated by the FAO/WHO [28] and the MFR [29]. Thus, the by-product samples used in the present study may contribute on essential nutrient enrichment in food products.

4. Conclusion
Information on nutritional profiles of fish by products are important in order to decide proper strategy in converting them into valuable products. Both purple-spotted bigeye and barracuda had high protein content, especially in the skin portion. The content of ash which is a rich source of minerals, was more dominant in fins and bone for both species. Micro-element study confirmed the fins and bone of purple-spotted bigeye and barracuda were rich in the calcium value, as well as found in the skin of purple-spotted bigeye due to the presence of attached small scale, whilst other macro-elements were lower more than 4 mg/g. Moreover, zinc was most abundant micro-elements in all examined samples and interestingly all samples were far below safety limits of toxic elements recommended by the FAO/WHO and the Malaysian Food Regulations. Therefore, this study may be beneficial for further investigation on developing valuable products generated from surimi processing, as well as suitable used for food ingredients.

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