Byproducts of Tropical Marine Processing as a Candidate for Industrial Food Ingredients: An Appraisal on Macro and Micronutrients

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¶ Fisheries Research Institute, Batu Maung, Penang, Malaysia
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* Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, Sandakan, Malaysia

**Abstract**

Tropical marine fish is a main raw material for surimi processing plants, including golden threadfin bream (*Nemipterus virgatus* Houttuyn, 1782) and swallowtail dwarf monocle bream (*Parascolopsis eriomma* Jordan & Richardson, 1909). After processing, more than 60% of fish are considered as byproducts (i.e., head, viscera, skin, fins and scale), and tend to discard due to poor-utilization. Hence, this paper aims to evaluate macro- and micro-nutrients derived from golden threadfin bream (GTB) and swallowtail dwarf monocle bream (SDMB). The higher content of protein (25.31 ± 0.81%) was observed in the skin part of GTB, followed by the flesh (21.26 ± 0.83%) and the scale (21.32 ± 0.42%). For byproducts of SDMB, the scale and skin portions were dominant in protein, containing 26.81 ± 0.19% and 22.52 ± 0.20%, respectively. In terms of ash, the scales and fins from both fish species presented a higher composition compared to other byproducts. Furthermore, those tropical marine fish were rich in micronutrients, particularly calcium (Ca), magnesium (Mg) and sodium (Na) obtained from the bones, fins, and scales byproducts. Also, some microminerals were detected in the byproducts of GTB and SDMB. More importantly, the byproducts from those species were considered safe from toxic heavy metals. Taken together, the byproducts derived from GTB and SDMB may serve as a potential source for manufactured food ingredients.

**Keywords:** Marine fish, Byproducts, Chemical contents, Element compositions

**1. Introduction**

Globally, total production of fish increased from 166.13 million tonnes (MT) in 2016 to 178.5 MT in 2018 (FAO, 2022). Among these data, particularly collected in 2018, marine capture fisheries represented around 84.4 MT, with the most dominance found in the finfish group. Some finfish species are used as potential sources for industrial surimi production, including Alaska pollock (AP), blue whiting...
(BW), bigeye snapper (BS), golden threadfin bream (GTB) and swallowtail dwarf monacle bream (SDMB) due to abundance and their specific attributes such as strong gel forming capacity, high yield, and white colour (Huff-Lonergan & Lonergan, 2005). Surimi, an intermediate form of fish processing, is a well-known diversified fish product processed mechanically from minced fish flesh (Jaziri et al., 2021). During surimi processing, a large quantity of byproducts (ranging at around 60–75%) is produced, including skin, bone, head, viscera, fins and scale (Jaziri et al., 2021). Traditionally, the byproducts are reused as low-value commodities such as silage, fish meal, animal feed and fertilizer (Setijawati et al., 2020). Besides, underutilized or nonutilized seafood processing byproducts might be discarded as waste materials and subsequently could lead to a serious problem in the aquatic and terrestrial environments. On the other side, because of the high content of organic and inorganic compounds, fish by-products are often categorized as a certified waste, which are even more expensive to discard, and are getting an increasing cost burden for the fish industry (Torres et al., 2006).

To deal with this issue, understanding both organic and inorganic matters contained in each fish by-product is an essential strategy before converting underutilized and less added-value products into high-value products.

As aforementioned, byproducts of fish processing are rich in both macro and micronutrients e.g., protein, essential amino acids, lipids, polyunsaturated fatty acids, minerals, vitamins, and pigments (Shahidi et al., 2019). In general, byproducts derived from fish had moisture (45.11–76.26%), protein (10.11–29.63%), lipid (0.28–36.11%), ash (1.02–28.43%), calcium (0.25–6.88%), phosphorus (0.18–1.31%), potassium (0.01–0.09%), sodium (0.10–0.32), and magnesium (0.06–0.33%) (based on wet weight basis) (Jaziri et al., 2021; Pateiro et al., 2020). However, each portion of fish byproducts is different in the level of nutrients. For instance, the bone, fins, scale, gills, and head portions are more dominant in ash, calcium, and phosphorous than those found in the remnant flesh, viscera, and skin parts, while the content of protein within fish skin byproduct is higher compared to that of fish fins, scale, bone, gills and head parts. Interestingly, the byproducts generated from sea bream (Sparus aurata Linnaeus, 1758) possessed a high essential amino acids and polyunsaturated fatty acids (PUFA), which accounted for approximately 5.3% of 100g of tissue and 33% of total fatty acids, respectively (Pateiro et al., 2020). Referring to the nutritional profile that fish byproducts might be transformed into valuable products such as collagen (Jaziri et al., 2022a, 2022b, 2022c, 2022d, 2022e, 2023), fish protein hydrolysate (Nurdiani et al., 2016), and some utilization used for the development of functional food ingredients. Previous studies have reported that the use of fish bone powder derived from yellowfin tuna (Thunnus albacares Bonnaterre, 1788), fortified into bakery product could improve amount of calcium value and the customer acceptance score increased significantly (Nemati et al., 2017). The debittered fishbone hydrolysed from Atlantic salmon (Salmo salar Linnaeus, 1758) improved the nutritional value of biscuit (Singh et al., 2020). Also, the hydrolysate of seabass (Lates calcarifer Bloch, 1790) skin added into the soup enhanced the functional value, compared to the control (Benjakul et al., 2018). Another report showed the fortification of apple juice bigeye with red bigeye (Priacanthus macracanthus Cuvier, 1829) gelatine hydrolysate (around 0.3%) could remarkably enhance antioxidant activity (Phanturat et al., 2010).

Micronutrients in the form of mineral elements are important compounds to support health benefits in the human body. As known, mineral plays an essential role in maintaining body functions through controlling acid-base balance and supporting haemoglobin formation (Njinkoue et al., 2016). Additionally, some macro and microelements could help bone formation and teeth structure, as well as catalysing many metabolic reactions (Martiniakova et al., 2022). Those elements commonly composed of calcium, potassium, magnesium, iron, potassium, zinc, manganese, and copper. However, other mineral elements might be toxic and cause a serious damage in human health at a certain limit, including mercury, lead, arsenic, cadmium, and chromium (Jaishankar et al., 2014). Thus, study on micronutrient components derived from fish byproducts may give basic information to develop a proper utilization approach.

GTB (Nemipterus virgatus) and SDMB (Parascolopsis eriomma) are economically important marine fish species for surimi production. GTB surimi, more popularly known as itoyori, is one of the high-grade surimi products in the seafood market (Balange & Benjakul, 2009), while SDMB is usually used as a mixed surimi processing prepared with combination of other marine fish species (FAO, 2007). For GTB, around 42,696 tons collected in 2019 were landed in Malaysia, whilst the production of SDMB accounted for about 1370 tons (Department of Fisheries Malaysia, 2023). To date, although many studies on nutritional compositions from fish byproducts have been documented but very little information is available on the macro and micronutrients harbour in the byproducts of both GTB and SDMB. Hence, this research was conducted to determine the macro and micronutrients of the
byproducts derived from GTB and SDMB. The findings of the present study may give some baseline information on the macro and micronutrients potential for industrial food ingredients.

2. Methods

2.1. Materials

GTB and SDMB used in the present study were obtained from a central fish market at Kota Kinabalu, Sabah, Malaysia. For chemical analysis, sulfuric acid (H₂SO₄) (Merck, Germany) and Kjeldahl catalyst selenium tablet (Fisher Chemical, USA) was used to digest samples and measure the crude protein content in the samples, respectively. Petroleum ether (Merck, Germany) was employed in the crude fat extraction. In terms of macro- and microelements determination, ultrapure nitric acid (Merck, Germany) was used during samples digestion and ultrapure water (Millipore) was applied for sample preparation and dilution process. 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 and reagents used were of analytical grade.

2.2. Sample preparation

About five pieces of each marine fish species samples were used for experimentation. All fish samples were washed with the running tap water after arrival in the laboratory. The marine samples were authenticated for species determination. Then, all collected samples were weighed using a balance with two decimal places to obtain a fish-weighed mean (in gram) and subsequently measured using a standard ruler to get a total length of fish (in centimetre). Next, the prepared marine fish samples were separated by portions composed of flesh, skin, bone, fins, and scale. All selected portions were then weighed and recorded in percentage. Afterwards, the separated fish portions were homogenized using a porcelain mortal and placed into a polyethylene container. The packed samples were then kept in a freezer (−20°C) until use.

2.3. Determination of macronutrient content

Macronutrient composition of the by-products from GTB and SDMB was analysed according to the method of the Association of Official Analytical Chemist (AOAC, 2000). The detail procedure of each parameter was described below:

2.3.1. Moisture

Moisture content of each selected marine fish by-product was conducted using an air-oven (M720, Binder, Germany). About 3 g of each sample were placed into the prepared dish and placed in the oven for 3 h at 105°C. After drying, the dish containing sample was transferred into a desiccator and then calculated with the following equation:

\[ \text{Moisture} \left( \% \right) = \frac{w1 - w2}{w1} \times 100 \]

where \( w1 \) is weight (g) of sample before drying and \( w2 \) is weight (g) of sample after drying.

2.3.2. Crude protein

The content of crude protein in the selected by-products was carried out by the Kjeldahl method run with a Kjeltec 2300 Auto Distillation unit (FOSS Tecator, Sweden). Around 0.5–1.0 g of each sample was placed into digestion flask and subsequently added 5 g Kjeldahl catalyst and 200 mL of H₂SO₄. After digestion, the mixture was subjected to distillation, followed by titration. Protein content was measured based on the amount of nitrogen was present in the treated sample with a following equation:

\[ \text{Crude protein} \left( \% \right) = \frac{(mL \text{ HCl} - mL \text{ blank}) \times 14.007 \times \text{N HCl}}{w} \times 100 \]

where a nitrogen-to-sample conversion factor of 6.25 was used for the determination of crude protein contained in the sample.

2.3.3. Crude fat

Crude fat content of all prepared fish portions was performed using Soxtec method in a Soxtec 2050 automated analyser (FOSS Analytical, Denmark). Three gram of each sample was placed into an extraction thimble and then inserted into a bottle filled 250 mL of petroleum ether, which was previously weighed before use. Next, the prepared bottle containing sample was transferred into a Soxtec instrument and run for around 1 h. After completing, the bottle was transferred into a desiccator for around 5 min and then reweighed, followed by calculating the content of crude fat with a following formula:

\[ \text{Crude fat} \left( \% \right) = \frac{f2}{f1} \times 100 \]

where \( f1 \) indicates the weight (g) of the sample and \( f2 \) indicates the weight of the fat.
2.3.4. Ash
Ash content of GTB and SDMB by-products was determined using the gravimetric method. Approximately 2 g of homogenized sample was placed into a porcelain cup and then heated at 550 °C for overnight in a furnace (Furnace 62700, Dubuque, IA, USA). Afterwards, the heated sample was transferred into a desiccator and was then measured with the equation below:

\[
\text{Ash} \, (\%) = \frac{a2}{a1} \times 100
\]

where \(a1\) presents the weight (g) of the sample and \(a2\) presents the weight (g) of the dried ash sample.

2.3.5. Carbohydrate
The content of carbohydrate was determined according to the method of Njinkoue et al., (Njinkoue et al., 2016) with subtracting the sum of moisture, crude protein, fat and ash contents from 100.

2.4. Determination of micronutrients
Micronutrient composition of the by-products obtained from GTB and SDMB was carried out according to the method of Jarapala et al. (2014) with conveying an instrument of inductively couple plasma mass spectrometry (ICP-MS) (PerkinElmer Elan 9000, USA). All samples were prepared with a ceramic knife and homogenized with a porcelain mortar. After that, the prepared samples were immersed with ultrapure water to remove undesired components. Around 0.2–1.0 g of sample were digested by adding 1 mL of \(\text{H}_2\text{O}_2\) and 3 mL of \(\text{HNO}_3\). A blank digest was carried out using the same conditions as the calibration standards in 6% (v/v) \(\text{HNO}_3\). A blank digest was carried out using the same procedure. The ICP-MS was adjusted to nebulizer gas flow 0.96 L/min, radio frequency (RF) 1600 W, lens voltage 1.6 V, cool gas 13.0 L/min, and auxiliary gas 1.2 L/min. Macro elements of interest were selected in this study, i.e., Calcium, Magnesium, Potassium and Sodium, whilst Zinc, Chromium, Copper, Iron, Selenium, Cadmium and Lead were selected as micro-elements studies.

2.5. Statistical analysis
Data were presented in a mean ± standard deviation (SD), representing in a triplicate. Analysis of variance (ANOVA) was applied to determine different effects in each sample. The significant differences (\(p < 0.05\)) were interpreted by Duncan’s multiple range tests using a SPSS Statistics version 27.0 (IBM Corp., Armonk, New York).

3. Results and discussion
3.1. The weight and length from collected samples and their byproducts
This research used two tropical marine fish species, consists of GTB (\(N. \) virgatus) and SDMB (\(P. \) eriomma). As mentioned, these fish sources were widely utilised for raw materials of surimi processing. Before exploring their byproducts, we verified a basic information, including fish species, weight and total length of GTB and SDMB. The results show that GTB belonged to species of \(Nemipterus \) virgatus (Houttuyn, 1782) (Russell, 1990) and species of SDMB was \(Parascolopsis \) eriomma (Jordan & Richardson, 1909; Miyamoto et al., 2020). In terms of \(N. \) virgatus, its average weight and total length were \(127.66 ± 3.01 \) g and \(21.60 ± 0.22 \) cm, respectively, while \(P. \) eriomma had the weight of \(187.70 ± 22.27 \) g and its total length was \(23.90 ± 1.35 \) cm. Their measurements were in accordance with the common size of marine fish used for surimi production. For byproducts viewpoint, a variety of byproduct portions (in %) was observed both marine fish samples. For example, the portion of skin, bones, fins, and scales derived from GTB was 3.09%, 4.42%, 3.50%, and 3.67%, respectively, whilst the SDMB byproducts were respectively 2.27%, 3.54%, 4.37%, and 3.50% (Fig. 1). These findings were also comparable to the byproducts of other marine species, such as gilt-head sea bream (\(Sarus \) aurata Linnaeus, 1758) (Pateiro et al., 2020), purple-spotted bigeye (\(Priacanthus tayenus \) Richardson, 1846) and barracuda (\(Sphyraena obtusata \) Cuvier, 1829; Jaziri et al., 2022). On the other hand, the percentage of flesh from two marine fish species was most dominance compared to those byproducts, representing 42.58% and 41.82% respectively, as reported from other literatures (Jaziri et al., 2021; Pateiro et al., 2020).
3.2. Macronutrient profile

Macronutrients profile was composed of protein, fat, ash, carbohydrate and moisture. Table 1 presents the proximate analysis of each portion obtained from GTB (N. virgatus) and SDMB (P. eriomma). Almost all chemical parameters showed significant differences ($p < 0.05$) on the portions of both tropical marine fish species. The highest content was observed in the moisture because the samples used in this present study was based on wet weight basis fish (Jaziri et al., 2021). As referred in previous studies (Naqash & Nazeer, 2010; Njinkoue et al., 2016; Younis et al., 2011), the flesh and skin portions of each fish sample had a higher moisture content compared to the other parameters. More importantly, the protein content of skin and scale was significantly higher ($p < 0.05$) compared to the muscle, bones and fins of SDMB (P. eriomma), while a significantly greater ($p < 0.05$) protein in the GTB (N. virgatus) was obtained from the skin byproduct. The difference on protein content observed in the

![Fig. 1. Physical appearance of the tropical marine fish surimi and its by-products.](image-url)
Table 1. Nutritional content of the by-products obtained from surimi processing.

<table>
<thead>
<tr>
<th>Source</th>
<th>Portion</th>
<th>Moisture</th>
<th>Protein</th>
<th>Fat</th>
<th>Ash</th>
<th>Carbohydrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. virgatus</td>
<td>Flesh</td>
<td>76.55 ± 0.25&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.26 ± 0.83&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.17 ± 0.41&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.85 ± 0.39&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.57 ± 0.04&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Skin</td>
<td>79.11 ± 0.51&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.31 ± 0.81&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.43 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.68 ± 0.16&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.48 ± 0.11&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Bones</td>
<td>57.65 ± 0.45&lt;sup&gt;b&lt;/sup&gt;</td>
<td>17.11 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.70 ± 0.17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>17.29 ± 0.31&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.76 ± 0.11&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Fins</td>
<td>59.61 ± 0.20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19.39 ± 0.33&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.13 ± 0.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>24.76 ± 0.84&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.61 ± 0.11&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Scale</td>
<td>64.73 ± 0.30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.32 ± 0.42&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.07 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>24.32 ± 0.15&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.55 ± 0.15&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>P. eriomma</td>
<td>Flesh</td>
<td>83.06 ± 0.25&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.20 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.05 ± 0.01&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.85 ± 0.39&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.73 ± 0.24&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Skin</td>
<td>81.51 ± 0.04&lt;sup&gt;d&lt;/sup&gt;</td>
<td>22.52 ± 0.20&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.44 ± 0.13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.68 ± 0.16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.36 ± 0.06&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Bones</td>
<td>67.81 ± 0.22&lt;sup&gt;c&lt;/sup&gt;</td>
<td>14.25 ± 0.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.55 ± 0.30&lt;sup&gt;b&lt;/sup&gt;</td>
<td>16.78 ± 0.19&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.47 ± 0.41&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Fins</td>
<td>56.68 ± 0.31&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15.96 ± 0.18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.08 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>26.41 ± 0.49&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.82 ± 0.07&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Scale</td>
<td>49.34 ± 0.09&lt;sup&gt;a&lt;/sup&gt;</td>
<td>26.81 ± 0.19&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.24 ± 0.07&lt;sup&gt;a&lt;/sup&gt;</td>
<td>23.09 ± 0.08&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.69 ± 0.19&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Means in the same column with different superscript letters indicate significant differences (p < 0.05).

skin of both fish samples could be due to the lower moisture content in the SDMB (P. eriomma). Setijawati et al. (Setijawati et al., 2020) stated when the moisture level was higher in the fish sample, resulting in the low level of protein, or vice versa. This finding was also in line with other publications working in the threadfin bream (Nemipterus japonicus) (Naqash & Nazeer, 2010) and gilthead sea bream (S. aurata) (Pateiro et al., 2020). It could be assumed fish skins from those species contain number of fibrous proteins, which is great source of collagen. For ash content, the portions of scale, fins, and bones (13.97%−26.41%) derived from those marine fish species were more dominant than those of skin and meat parts (0.68%−10.52%). Among them, the percentage of ash found in the fins portion was significantly higher (p < 0.05) compared to scale and bone byproducts. In addition to this, sample with a high ash content might contain abundance of minerals, particularly calcium as demonstrated by other researchers (Jaziri et al., 2021; Njinkoue et al., 2016). Other parameters (fat and carbohydrate level), those portions were considered lower in comparison to the moisture, protein, and ash. Overall, a variety of chemical compositions observed in this work may be influenced by many factors, including fish species, gender, age, feeding aspect, habitat (environment) and health status (Pateiro et al., 2020).

3.3. Mineral profile

3.3.1. Macro-elements

The content of macro-elements of T. virgatus and P. eriomma by-products is presented in Table 2. The data showed that the bones, fins, and scale had a high level of calcium element (greater than 30 mg/g) in both selected tropical marine fish species, which the highest content (35.45−43.15 mg/g) was observed in the bones portion. Conversely, the skin and flesh byproducts exhibited a lower calcium content in the chosen marine fish samples, reaching values below 0.40 mg/g. Similar patterns were also found in the content of magnesium, in which the bone, fins and scale derived from two fish samples had more abundant compared to that of flesh and skin portions although the magnesium contents were not greater than 1.65 mg/g. The potassium content of all the byproducts from two different fish samples varied from 0.10 m/g to 1.94 mg/g with the highest obtained in the muscle portion, accounting for higher than 1.85 mg/g. Last macro-mineral detected in this study was sodium and the bone and fins performed the higher level, ranging between 1.29 mg/g and 1.88 mg/g. Pateiro et al. revealed that the number of minerals varied to other marine fish species, and might be affected by the fish species, feeding diet, season, age, sex, size, and environments (Pateiro et al., 2020).

Table 2. Macro-mineral contents (mg/g) of the byproducts derived from T. virgatus and P. eriomma.

<table>
<thead>
<tr>
<th>Marine fish species</th>
<th>Fish portion</th>
<th>Calcium (Ca)</th>
<th>Magnesium (Mg)</th>
<th>Potassium (K)</th>
<th>Sodium (Na)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. virgatus</td>
<td>Flesh</td>
<td>0.13</td>
<td>0.35</td>
<td>1.86</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>Skin</td>
<td>0.81</td>
<td>0.16</td>
<td>0.18</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>43.15</td>
<td>1.40</td>
<td>1.04</td>
<td>1.29</td>
</tr>
<tr>
<td></td>
<td>Fins</td>
<td>30.78</td>
<td>1.47</td>
<td>0.19</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>Scale</td>
<td>28.11</td>
<td>1.53</td>
<td>0.10</td>
<td>1.05</td>
</tr>
<tr>
<td>P. eriomma</td>
<td>Flesh</td>
<td>0.15</td>
<td>0.43</td>
<td>1.94</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>Skin</td>
<td>0.39</td>
<td>0.25</td>
<td>0.48</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>Bones</td>
<td>35.45</td>
<td>1.64</td>
<td>0.68</td>
<td>1.74</td>
</tr>
<tr>
<td></td>
<td>Fins</td>
<td>30.18</td>
<td>1.45</td>
<td>0.18</td>
<td>1.88</td>
</tr>
<tr>
<td></td>
<td>Scale</td>
<td>33.51</td>
<td>1.25</td>
<td>0.10</td>
<td>1.04</td>
</tr>
</tbody>
</table>
terms of calcium, it was considered as the highest macro-element content, particularly obtained in the bones, fins and scale of *T. virgatus* and *P. eriomma*. The calcium content of these marine fish was greater compared to that of gilthead sea bream bones (16.18 mg/g) (Pateiro et al., 2020), while when compared to other fish species such as croaker bone (174.3–182.6 mg/g) (Njinkoue et al., 2016), salmon mackerel and cod (135, 143 and 190 mg/g, respectively), our samples were lower in the level of calcium. Other macro-elements, like magnesium, potassium and sodium, our findings were comparable to previous research on various fish sources (e.g., gilthead sea bream, croaker and lizardfish) (Jaziri et al., 2021; Njinkoue et al., 2016; Pateiro et al., 2020). For further investigation, moreover, these byproducts derived from *T. virgatus* and *P. eriomma* might be used as a good source for fortification food. As reported by Nemati et al. (Nemati et al., 2017) and Singh et al. (Singh et al., 2020), the bakery and biscuit fortified with bone powder from fish by-product increased the nutritional attributes, especially for calcium content, respectively. While the levels of magnesium in the tested samples may not be as abundant as calcium, it still provides numerous health advantages for the human body. These include its role in regulating critical biological functions, acting as a cofactor for numerous enzymes, playing a part in bone development, and related processes (Kandyliari et al., 2020).

### 3.3.2. Microminerals

Table 3 shows the micromineral elements of the byproducts obtained from two selected marine fish species (i.e., *T. virgatus* and *P. eriomma*). The results performed that zinc element was dominant in all the fish byproduct samples and the more dominant levels was exhibited in the bone and fin portions, attaining values greater than 13.50 µg/g. The flesh portion of all fish samples was characterized by the lowest zinc level (lower than 3.11 µg/g). In line with this, the level of manganese in the byproduct samples showed that the bone and fins were characterized by the dominant content of manganese element, ranging from 7.88 µg/g to 18.19 µg/g. Next, the content of iron element varied in each byproduct from the chosen marine fish species, which the highest level of iron was detected in the skin portion, accounted for about 7.96 µg/g and 11.00 µg/g of *T. virgatus* and *P. eriomma*, respectively. For copper element, all the fish byproducts presented a lower value, which were detected below 0.35 µg/g. Also, the amount of selenium element for all selected fish by-products pointed lower levels, except flesh portion of *T. virgatus*, containing 0.60 µg/g of selenium element. Based on our understanding, those microminerals are important substances involved in the metabolism process. For instance, zinc is a vital mineral for living organisms that plays an important role in immune system, cell division, and wound healing acceleration. But a high level of zinc can pose adverse effects to the organisms. Salvaggio et al. (Salvaggio et al., 2016) reported an excess of zinc in zebrafish, used as an alternative vertebrate model, can lead to skeletal deformities and severe growth abnormalities. Another research investigation indicated that prolonged exposure could result in localized neuronal impairments, discomfort in the upper abdomen, respiratory issues, and an increased risk of prostate cancer in humans (Plum et al., 2010). Our findings show the fish fins and bones had more dominant level of zinc, but they were still below standard recommended by the Food and Agriculture Organization and World Health Organization (FAO/WHO) and the Malaysian Food and Regulations (MFR) which are at

<table>
<thead>
<tr>
<th>Marine species</th>
<th>Fish portion</th>
<th>Zinc (Zn)</th>
<th>Iron (Fe)</th>
<th>Copper (Cu)</th>
<th>Manganese (Mn)</th>
<th>Selenium (Se)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>T. virgatus</em></td>
<td>Flesh</td>
<td>3.10</td>
<td>3.53</td>
<td>0.33</td>
<td>0.16</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>Skin</td>
<td>6.18</td>
<td>7.96</td>
<td>0.34</td>
<td>1.08</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>13.67</td>
<td>7.79</td>
<td>0.23</td>
<td>18.19</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>Fins</td>
<td>19.27</td>
<td>1.54</td>
<td>0.13</td>
<td>16.92</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Scale</td>
<td>10.78</td>
<td>2.76</td>
<td>0.07</td>
<td>10.33</td>
<td>0.15</td>
</tr>
<tr>
<td><em>P. eriomma</em></td>
<td>Flesh</td>
<td>2.16</td>
<td>1.91</td>
<td>0.16</td>
<td>0.19</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>Skin</td>
<td>8.86</td>
<td>11.00</td>
<td>0.47</td>
<td>0.37</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>15.44</td>
<td>2.33</td>
<td>0.16</td>
<td>7.81</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Fins</td>
<td>14.65</td>
<td>1.59</td>
<td>0.09</td>
<td>7.58</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Scale</td>
<td>8.75</td>
<td>1.08</td>
<td>0.09</td>
<td>4.11</td>
<td>0.14</td>
</tr>
<tr>
<td>FAO/WHO&lt;sup&gt;a&lt;/sup&gt;</td>
<td>—</td>
<td>100</td>
<td>—</td>
<td>10</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>MFR&lt;sup&gt;b&lt;/sup&gt;</td>
<td>—</td>
<td>150</td>
<td>—</td>
<td>30</td>
<td>5.4</td>
<td>—</td>
</tr>
</tbody>
</table>

<sup>a</sup> FAO/WHO.

<sup>b</sup> Malaysian Food Regulation.
150 mg/kg and 100 mg/kg, respectively (FAO/WHO, 1984; Malaysian Food Act and Regulations, 1985). Other essential elements such as copper and selenium, each sample used had lower level of copper than the safety limits suggested from the FAO/WHO and the MFR, indicating that these fish samples are safe, and they may contribute to a positive outcome because of their role as a vital element necessary to produce hemoglobin (Sivaperumal et al., 2007). Moreover, selenium is a vital element in blocking oxidative stress in human cells (Jarapala et al., 2014), and according to our investigation the highest content was found in the flesh and skin portions of SDMB (P. eriomma), and GTB (N. virgatus).

3.3.3. Toxic heavy metals

As tabulated in Table 4, the toxic heavy metals studied in the present work consist of chromium, cadmium and lead. The results reported that the content of three heavy metal elements was lower than 0.23 μg/g. Despite that lower heavy metal, the skin byproduct derived from P. eriomma showed the highest level of heavy metal element, while the P. eriomma bone was characterized by the greater lead content. Our observations agreed with those observed by Jarapala et al. (2014), Younis et al. (2011), and our previous works on lizardfish (S. tumbil), purple-spotted bigeye (P. tayenus) and barracuda (S. obtusata) byproducts (Jaziri et al., 2022). Most important findings, all fish samples showed lower level of elements than the toxic levels regulated by the FAO/WHO (FAO/WHO, 1984) and the MFR (Malaysian Food Act and Regulations, 1985). Thus, the byproduct samples used in the present study may contribute to essential nutrient enrichment in food products.

### Table 4. Toxic heavy metal values (μg/g) of the by-products derived from T. virgatus and P. eriomma.

<table>
<thead>
<tr>
<th>Marine fish species</th>
<th>Fish portion</th>
<th>Chromium (Cr)</th>
<th>Cadmium (Cd)</th>
<th>Lead (Pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. virgatus</td>
<td>Meat</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Skin</td>
<td>0.03</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>0.02</td>
<td>0.00</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Fin</td>
<td>0.01</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Scale</td>
<td>0.01</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>P. eriomma</td>
<td>Meat</td>
<td>0.04</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Skin</td>
<td>0.12</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>0.01</td>
<td>0.01</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>Fin</td>
<td>0.02</td>
<td>0.00</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Scale</td>
<td>0.04</td>
<td>0.00</td>
<td>0.08</td>
</tr>
<tr>
<td>FAO/WHOa</td>
<td>—</td>
<td>2.00</td>
<td>2.00</td>
<td>—</td>
</tr>
<tr>
<td>MFRb</td>
<td>—</td>
<td>1.00</td>
<td>1.50</td>
<td>—</td>
</tr>
</tbody>
</table>

* a FAO/WHO.
  
* b Malaysian Food Regulation.

4. Conclusions

Macro and micronutrients derived from the flesh and byproduct portions of GTB (N. virgatus) and SDMB (P. eriomma) have been evaluated. Both fish sources contained a high protein content, particularly in the skin and scale portions. Moreover, the selected fish samples, particularly in the portion of fins and scale, showed a higher percentage of ash, which is a rich source of minerals. The analysis of trace elements confirmed that the bones, fins, and scale of fish samples were abundant in calcium. Other macro elements were generally less than 2 mg/g. Notably, zinc was the most abundant microelements in all examined samples, and it is worth mentioning that all samples were far below the safety limits for toxic elements recommended by the FAO/WHO and the Malaysian Food Regulations. As a result, this study holds potential for further research into the development of valuable products derived from tropical marine surimi processing and their suitability as industrial food ingredients.

Authors’ contributions

Nurul Huda created the concept of research. Abdul Aziz Jaziri and Hajariah Hasanuddin conducted the experiment and data collection. Abdul Aziz Jaziri did data analysis and wrote the drafted manuscript. Rossita Shapawi, Ruzaidi Azli Mohd Mokhtar, Wan Norhana Md. Noordin and Masmunira Ramli reviewed and edited the prepared manuscript. All authors did proofread the final manuscript.

Conflicts of interest

We declare that there is no conflict of interest in the publication of this article.

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References


Balange, A., & Benjakul, S. (2009). Enhancement of gel strength of bigeye snapper (Priacanthus tayenus) surimi using oxidised...
phenolic compounds. *Food Chemistry*, 113(1), 61–70. https://doi.org/10.1016/j.foodchem.2008.07.039


Malaysian Food Act and Regulations. (1985). In N. Hamid Ibra-}


