

## Physicochemical Properties and Sensory Acceptance of Noodles Incorporating Mixed Fish Bone Powder From Filleting Waste

Lee-Hoon Ho<sup>1\*</sup>, Nur Iffah Imanina Abd Kadir<sup>1</sup>, Thuan-Chew Tan<sup>2</sup>, Ishamri Ismail<sup>1</sup>

1. School of Food Industry, Faculty of Bioresources and Food Industry, Universiti Sultan Zainal Abidin, Besut Campus, 22200 Besut, Terengganu, Malaysia
  2. Food Technology Division, School of Industrial Technology, Universiti Sains Malaysia, Penang, Malaysia
- \*Corresponding author: holeehoon@unisza.edu.my

### ABSTRACT

This study investigated the effects of partially substituting wheat flour with fish bone powder, derived from mixed fish filleting waste, on the physicochemical and sensory attributes of noodles. The fish bones were sourced from filleting units, processed into powder, and incorporated into noodle production at 5–20% relative to wheat flour weight. Noodles with and without fish bone powder were evaluated. The substitution significantly enhanced the nutritional value of the noodles, with a 1.04–1.31-fold increase in crude protein, a 12–40-fold increase in ash, a 45–82-fold increase in calcium, and a 7–23-fold increase in phosphorus compared to the control. Conversely, cooking loss and yellow hue of the noodles increased with higher levels of fish bone powder, while the hardness, adhesiveness, pH, and cooking yield decreased. Noodles with 5% fish bone powder received the highest overall acceptability score. Fish bone powder shows potential as a nutrient-rich food ingredient for healthy noodles.

**Key words:** Fish bone, food waste, functional food ingredient, noodle, nutritional composition, sensory evaluation

### INTRODUCTION

In recent years, the fishing and aquaculture industries have experienced significant growth, with an annual consumption of approximately 91 million tons of fish and shellfish (Terzioğlu *et al.*, 2018). During the processing of fish into fillets, a substantial amount, up to 70%, of the total fish weight is discarded. This waste comprises heads (9–12%), viscera (12–18%), skin (1–3%), bones (9–15%), and scales (5%) (Boronat *et al.*, 2023). In Malaysia, particularly in the state of Terengganu, fish serves as a primary ingredient in the production of *keropok lekor*, a traditional Malaysian snack (Hatta, 2015). During the processing of *keropok lekor*, only the fish meat is utilised, while other parts, such as the head, bones, fins, and tail, are discarded, resulting in approximately 45% of waste (Essabiri *et al.*, 2022). In response to the growing awareness of ocean sustainability and the valorisation of existing resources, fish by-products are increasingly being incorporated as raw ingredients for human consumption (Boronat *et al.*, 2023).

Fish bone, a significant solid by-product generated from the fish processing industry after filleting, constitutes approximately 25–30% of the fish's weight (Terzioğlu *et al.*, 2018). Fish bone primarily comprises minerals (60–70%) and collagen (approximately 20%) (Yin *et al.*, 2016). The primary minerals in fish bone are sodium, phosphorus, and calcium (e.g., calcium carbonate & calcium phosphate), which are essential for the human body and collectively account for about 2% of the entire fish (Njoroge & Lokuruka, 2020). Notably, calcium compounds from fish bone are renowned for their high bioavailability (Yin *et al.*, 2016), making them a valuable natural source of calcium. Consequently, fish bone holds significant potential in addressing environmental pollution by effectively utilising these waste products rather than discarding them, aligning with SDG12 (Responsible Consumption & Production) of the United Nations.

Fish waste, a highly fermentable product, undergoes rapid degradation due to various factors. Spoilage can be attributed to endogenous enzymatic activity, chemical oxidation of lipids, and the metabolic activity of microorganisms (Essabiri *et al.*, 2022). The low acidity (pH>6) and the substantial presence of non-protein nitrogenous compounds in fish waste also create conducive conditions for the accelerated growth of degrading microorganisms (Coppola *et al.*, 2021). Specific spoilage organisms are microorganisms that produce compounds through their development and metabolic processes, altering the product's organoleptic characteristics. Consequently, drying is commonly employed to preserve the quality of fish bone, enabling its safe incorporation as an ingredient in food products.

Noodles are generally regarded as a secondary staple food in Asian countries (Niu & Hou, 2019). According to Shahsavani and Hosseinmardi (2018), plain noodles made solely from wheat flour are rich in carbohydrates but are deficient in essential nutrients, such as ash, dietary fibre, and essential amino acids (e.g., threonine & lysine). Fish bone flour has been employed in various studies to fortify culinary preparations. Supplementing plain noodles with fish bone powder could substantially enhance the nutritional profile by adding valuable protein and minerals. Uthai (2021) successfully incorporated salmon (*Salmo salar*) fish bone powder into noodles, thereby improving the nutritional content, particularly increasing the protein content in the final product.

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Similar studies have demonstrated that calcium and phosphorus contents increase in products fortified with fish bone flour (Abdel-Moemin, 2015). To our knowledge, there is no published data on the use of mixed fish bone powder from filleting waste in noodle processing. This study addresses this gap by utilising fish filleting by-products, specifically fish bones, transformed into powder as a value-added ingredient. The aim is to evaluate the nutritional content, physical properties, and sensory acceptance of noodles incorporating fish bone powder.

## MATERIALS AND METHODS

### Materials

Three species of mixed fish filleting waste, namely Atlantic horse mackerel (*Trachurus trachurus*), white sardinella (*Sardinella albella*), and torpedo scad (*Megalaspis cordyla*), collectively weighing approximately 2 kg, were procured from Seameq HQ, Setiu, Terengganu. The samples were refrigerated at -20°C before processing. The chemicals used for the analysis were of analytical grade, ensuring the reliability of the laboratory results.

### Fish bone powder preparation

Fish bone powder was prepared using a method adopted from Uthai (2021) with slight modifications. The process commenced by thawing frozen fish bones at room temperature for 1 hr. Subsequently, the bones were washed to eliminate dirt and blood. The fish bones were subsequently immersed in a 2% NaOH solution, with a NaOH-to-water ratio of 1:2, at 50°C for 30 min. The soaked bones were repeatedly rinsed with deionised water until neutralised. Approximately 200 g of fish bones were subjected to a mild heat treatment in 500 mL of deionised water at 70°C for 30 min to facilitate subsequent processing. The sample was subsequently dried in a hot air-drying oven at 60°C for 12 hr, then pulverised into fine particles using a grinder, and sieved to obtain a uniform particle size of 500 µm. The bone powder was subsequently stored in a tightly sealed container until utilisation.

### Noodle preparation

Noodles were prepared according to the method proposed by Uthai (2021). Fish bone powder was partially substituted for wheat flour at levels of 5, 10, 15, and 20% for the preparation of 5NFB, 10NFB, 15NFB, and 20NFB, respectively. Noodles formulated without fish bone powder were used as the control (0NFB). Substitution levels of fish bone powder were chosen based on preliminary trials, as levels above 20% produced noodles with a coarse and grainy texture, whereas lower levels maintained acceptable quality while enriching the nutrient content. The noodle formulation consisted of a total 100% of composite flour (wheat flour and fish bone powder), 46% water, 1.5% sodium chloride, and 1.5% sodium carbonate. The method began with mixing refined wheat flour with fish bone powder using a mixer (KitchenAid, Benton Harbor, USA) for 2 min. The pre-dissolved sodium chloride and sodium carbonate were subsequently added to the composite flour. The mixture was kneaded at room temperature until a smooth dough was obtained (~10 min). The dough was then allowed to rest for 30 min in the chiller before being sheeted to a thickness of 2 mm using a pasta maker (Nanjing Hope, HP-150, Jangsu, China). The kneaded dough was subsequently placed in a noodle maker to produce the noodles. The noodle strands were then cooked in boiling water for 80 to 120 s.

### Analysis of proximate composition

The proximate compositions of the samples were determined according to the official methods outlined by the American Association of Official Analytical Chemists (AOAC, 1995). Oven drying (AOAC Official Method 977.11), dry ashing (AOAC Official Method 923.03), Kjeldahl (AOAC Official Method 955.04), and Soxhlet (AOAC Official Method 960.39) methods were used to determine moisture, ash, crude protein, and crude fat contents, respectively.

### Computation of total carbohydrates

The percentage of total carbohydrates was calculated by subtracting the total percentages of moisture, ash, crude protein and crude fat from 100%. The formula used was: [% total carbohydrates = 100 – (moisture + ash + crude protein + crude fat)] (Giri & Sakhale, 2019).

### Determination of minerals

The mineral content, including calcium, iron, and zinc, was determined using inductively coupled plasma-optical emission spectrometry (ICP-OES) (Thermo Fisher Scientific, iCAP 7000 Plus Series, Massachusetts, USA), following the methodology outlined by Savlak *et al.* (2020). Approximately 1.5 g of the powder samples were added to concentrated nitric acid and subsequently digested in a microwave digestion system (Anton Paar Multiwave Go, Graz, Austria). The digested samples were then filtered and diluted to 100 mL with deionised water, at which point the mineral content was quantified using ICP-OES. Phosphorus content was determined via UV-VIS spectrophotometry using the ammonium phosphomolybdate method (Nemati *et al.*, 2017).

### Determination of cooking yield

The cooking yield was determined according to the methodology outlined by Nur Azura *et al.* (2020). Approximately 10 g of samples were weighed and subjected to cooking in 150 mL of boiling distilled water for 4 min. Subsequently, the cooked noodles were allowed to cool for 15 min before being weighed. The cooking water was retained for the purpose of calculating the cooking loss. The cooking yield (expressed in %, w/w) was calculated as the weight of the noodles after cooking divided by the weight of the noodles before cooking.

### Determination of cooking loss

The cooking loss was determined using the methodology described by Nur Azura *et al.* (2020). A 250-mL beaker was initially pre-dried and weighed. Subsequently, the cooking water collected from the cooked noodles was poured into the pre-dried beaker, which was then dried in an oven at 105°C until a constant weight was obtained. The beaker containing the dried matter was subsequently weighed. The results (expressed in %, w/w) were calculated as the weight of the dried matter divided by the weight of the noodles before cooking.

### Measurement of pH

The pH of noodle samples was determined using the methodology described by Yeoh *et al.* (2014) with minor modifications. Approximately 6 g of the sample was suspended in 30 mL of distilled water and vigorously mixed for 5 min. Subsequently, the mixture was allowed to rest for 30 min before being filtered to obtain the filtrate. The pH of the filtrate was subsequently measured using a pH meter, which had been pre-calibrated with buffer solutions of pH 4.0 and 10.0 before analysis.

### Analysis of colour

The colour of the samples was measured using a Chroma Meter (Konica Minolta CR-400/410, Tokyo, Japan). The colour of the noodle was measured in terms of lightness  $L^*$  (where  $L$ : 100 = white, 0 = black), chroma  $a^*$  (where negative values represent green chromaticity and positive values represent red), and  $b^*$  (where negative values represent blue chromaticity & positive values represent yellow). The Chroma Meter was calibrated with a Konica Minolta calibration plate before analysis.

### Measurement of texture profile

The texture of the samples was determined using a texture analyser (Stable Micro System, TA-XTPlus, Surrey, United Kingdom) equipped with a 5 kg load cell. The cooked noodle strands were measured using a firmness-stickiness rig (HDP-PFS) with the following settings: pre-test speed of 1.00 mm/s, test speed of 1.00 mm/s, post-test speed of 3.00 mm/s, strain of 75%, time of 2 sec, and trigger force of 0.05 N. Approximately 70 mm of noodle strand was placed straight and flat, adjacent to one another, on the centre of the heavy-duty platform for analysis. The data on hardness and adhesiveness were analysed using Texture Expert Version 1.05 Software (Stable Micro System Ltd, Surrey, UK).

### Sensory evaluation

The sensory evaluation of all the prepared noodles was conducted with 40 untrained panellists, comprising staff and students from the Faculty of Bioresources and Food Industry at the Universiti Sultan Zainal Abidin (UniSZA). Each sample (10 g) was presented to the panellists in a random order, labelled with three-digit random codes. The panellists were provided with five distinct types of noodles, each coded with a three-digit random number, a cup of plain water, a consent form, and a sensory evaluation form. They were instructed to rinse their mouths with the provided plain water before tasting the subsequent sample to cleanse their palates. The panellists were then requested to evaluate the attributes of appearance, colour, aroma, elasticity, hardness, and overall acceptability. These evaluations were scored on a 7-point hedonic scale (1 indicating dislike very much, 2 indicating dislike moderately, 3 indicating dislike slightly, 4 indicating neither like nor dislike, 5 indicating like slightly, 6 indicating like moderately & 7 indicating like very much) (Watts *et al.*, 1989).

### Statistical analysis

All data obtained in this research were analysed using Statistical Package for the Social Sciences (SPSS) Statistics version 20.0. All measurements conducted in the study were performed in triplicate ( $n=3$ ) to obtain mean values. One-way analysis of variance (ANOVA), followed by Duncan's test, was used to determine significant differences among the mean values of the samples, with a significance level set at  $p<0.05$ .

## RESULTS AND DISCUSSION

### Proximate compositions of noodles

The results of proximate compositions for noodles incorporating fish bone powder are presented in Table 1. The results indicate that the moisture content increased with increasing substitution levels of fish bone powder. Furthermore, samples containing 15 and 20% of fish bone powder (15NFB & 20NFB, respectively) exhibited significantly higher moisture content (34.08% & 34.37%, respectively) compared to the other noodle samples (i.e., 0NFB, 5NFB, & 10NFB). This may be attributed to the porous structure of fish bone and the presence of proteins, which enhance water-binding capacity by absorbing water from the environment (Asikin *et al.*, 2019).

The current results are comparable to those reported by Uthai (2021), who found that noodles incorporating salmon fish bones contain moisture content ranging from 35.54 to 38.26%. However, a contrasting trend in moisture content was observed in the findings reported by Uthai (2021), where the moisture content of noodles with added salmon fish bone powder decreased as the amount of salmon fish bone powder increased. According to Orisa and Udofia (2019), the moisture content influences the shelf life of noodles because it supports microbial growth, leading to deterioration. The shelf life of the product is shortened as the moisture content increases (Muhamad & Redzuan, 2019). Therefore, in the present study, a significant increase in the moisture content of noodles containing 15% or more fish bone powder suggests a shorter shelf life compared to the control noodle.

**Table 1.** Proximate composition of noodles.

| Parameter (%)       | Samples <sup>1</sup>    |                         |                         |                         |                         |
|---------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
|                     | 0NFB                    | 5NFB                    | 10NFB                   | 15NFB                   | 20NFB                   |
| Moisture            | 30.75±0.55 <sup>b</sup> | 31.10±0.43 <sup>b</sup> | 31.65±1.18 <sup>b</sup> | 34.08±0.93 <sup>a</sup> | 34.37±1.44 <sup>a</sup> |
| Ash                 | 0.36±0.13 <sup>e</sup>  | 4.43±0.09 <sup>d</sup>  | 6.30±0.12 <sup>c</sup>  | 10.30±0.17 <sup>b</sup> | 14.22±0.38 <sup>a</sup> |
| Crude Protein       | 10.73±0.06 <sup>d</sup> | 11.14±0.15 <sup>c</sup> | 12.89±0.10 <sup>b</sup> | 13.11±0.12 <sup>b</sup> | 14.04±0.34 <sup>a</sup> |
| Crude Fat           | 0.35±0.07 <sup>a</sup>  | 0.26±0.01 <sup>b</sup>  | 0.23±0.02 <sup>b</sup>  | 0.22±0.01 <sup>b</sup>  | 0.20±0.02 <sup>b</sup>  |
| Total carbohydrates | 57.81±1.60 <sup>a</sup> | 53.07±0.33 <sup>b</sup> | 48.93±1.17 <sup>c</sup> | 42.29±0.93 <sup>c</sup> | 37.17±1.12 <sup>d</sup> |

Data are expressed as mean± standard deviation. Mean values with different superscripts in the same row differ significantly at  $P<0.05$ .

<sup>1</sup>0NFB: noodle without fish bone powder (control); 5NFB: noodle with fish bone powder substituted for wheat flour at 5% level; 10NFB: noodle with fish bone powder substituted for wheat flour at 10% level; 15NFB: noodle with fish bone powder substituted for wheat flour at 15% level; 20NFB: noodle with fish bone powder substituted for wheat flour at 20% level.

The ash content of all the prepared noodle samples ranged from 0.36% in the control noodle to 14.22% in the 20NFB sample. The results indicated that noodles containing fish bone powder exhibited a significantly higher ash content compared to the control noodles. Furthermore, the ash content in the composite noodles (i.e., 5NFB, 10NFB, 15NFB, & 20NFB) increased proportionally to the amount of fish bone powder added. A study conducted by Uthai (2021) demonstrated a statistically significant improvement in the ash content of noodles with increasing levels of salmon fish bone powder, ranging from 3.98 to 8.04%. Noodles containing fish bone powder exhibited 1.7 times greater ash content compared to noodles made with salmon (*Salmo salar*) fish bone (Uthai, 2021). This difference was attributed to the varying ash content in the bones of different fish species (Frey, 2020). Additionally, Hemung (2013) reported that ash constitutes 75% of the total proximate compositions of fish bone powder. Furthermore, ash content serves as an indicator of the mineral content present in the food material (Sugumaran *et al.*, 2019). Consequently, the incorporation of fish bone powder may enhance the mineral content of the noodles.

Regarding crude protein, there was a significant increase in the crude protein content of noodle samples made with fish bone powder (i.e., 5NFB, 10NFB, 15NFB & 20NFB), ranging from 11.14 to 14.04%, compared to the control noodle, which had the lowest content at 10.73% (Table 1). Similarly, Uthai (2021) reported that the addition of salmon fish bone powder increased the protein content of noodles, from 7.96 to 10.13%, compared to the control noodle, which had a protein content of 7.00%. This enhancement may be attributed to the higher protein content of fish bone (ranging from 26–41 g/100 g, depending on the species) (Toppe *et al.*, 2007) compared to wheat flour (ranging from 9–13 g/100 g) (Stantiall & Serventi, 2018).

A significant decrease in the crude fat content of noodles produced with fish bone powder (ranging from 0.20–0.26%) was observed compared to noodles made with wheat flour (0.35%). This trend suggests a decreasing fat content in noodles incorporating fish bone powder. These results contrast with the results reported by Uthai (2021), which indicated an increase in crude fat concentration as salmon fish bone powder replacement level rose from 2.86 to 4.01 g/100 g. This discrepancy may be attributed to the fact that the crude fat content in fish is influenced by several factors, including species, diet, and environmental conditions (e.g., salinity, temperature, season, geographical location & weather) (Balami *et al.*, 2019). According to Toppe *et al.* (2007), unsaturated fatty acids are predominantly found in fish lipids, comprising over 80% of the fatty acid profile in fish bone powder. Unsaturated fatty acids are susceptible to oxidative degradation. Therefore, a low crude fat content may indicate a lower amount of unsaturated fatty acids, suggesting that noodles containing fish bone powder may have a reduced risk of oxidation. As a result, the shelf life of noodles containing fish bone powder could be extended due to the delayed oxidation process.

From Table 1, the percentage of total carbohydrates in the noodle samples prepared using fish bone powder (i.e., 5NFB, 10NFB, 15NFB & 20NFB) exhibited a significant decrease compared to those made with wheat flour (control). A similar trend was observed in the study conducted by Uthai (2021), which reported a lower total carbohydrate content in noodles formulated with salmon bone powder (ranging from 46.94 to 42.28%) in comparison to the control noodles (48.58%). The total carbohydrate content is inversely proportional to the total amounts of moisture, crude protein, crude fat, and ash. Therefore, the reduced carbohydrate content in noodles incorporating fish bone powder can be attributed to the elevated levels of crude protein, crude fat, and ash in comparison to noodles exclusively made from wheat flour. The diminished carbohydrate content in noodles containing fish bone powder presents several advantageous attributes, including facilitating digestion and mitigating constipation (Elleuch *et al.*, 2011). Therefore, noodles enriched with fish bone powder could potentially benefit individuals seeking low-carbohydrate dietary options for weight management and overall well-being.

### Mineral content of noodles

Table 2 presents the mineral content of noodles made with or without fish bone powder. Generally, noodles containing fish bone powder exhibited significantly higher mineral content (i.e., calcium, iron, zinc, and phosphorus) compared to the control noodle (0NFB). Calcium was the most abundant element in all the prepared noodles, with content ranging from 33.00 mg/100 g in the control noodles to 2,697 mg/100 g in the 20NFB sample. This indicates that consuming noodles with fish bone powder (which contains 1484.00–2,697.00 mg/100 g) can assist in meeting the daily intake levels of calcium (the recommended dietary allowance (RDA) for adults and children aged 4 years & above is 1,300 mg/day) (USA NIH, 2023). While most individuals consume milk and other dairy products for calcium, some may not tolerate milk due to lactose intolerance. Calcium is an essential micronutrient that plays a key role in various physiological functions, including bone health, enzyme function, nerve transmission, and fluid balance (Ali, 2023). Insufficient calcium intake can lead to osteoporosis (Orisa & Udofia, 2019). Consequently, fish bone powder may hold interest in the food industry for developing calcium-rich food products, providing an alternative source of calcium for humans.

**Table 2.** Mineral content of noodles.

| Sample <sup>1</sup> | Mineral composition (mg/ 100 g) |                         |                        |                           |
|---------------------|---------------------------------|-------------------------|------------------------|---------------------------|
|                     | Calcium                         | Iron                    | Zinc                   | Phosphorus                |
| 0NFB                | 33.00±0.01 <sup>d</sup>         | 8.00±0.00 <sup>c</sup>  | 1.00±0.00 <sup>e</sup> | 101.00±0.01 <sup>e</sup>  |
| 5NFB                | 1484.00±1.44 <sup>c</sup>       | 7.00±0.00 <sup>d</sup>  | 1.00±0.00 <sup>d</sup> | 714.00±0.62 <sup>d</sup>  |
| 10NFB               | 2248.00±1.32 <sup>b</sup>       | 10.00±0.00 <sup>a</sup> | 2.00±0.00 <sup>c</sup> | 1057.00±2.59 <sup>c</sup> |
| 15NFB               | 2595.00±0.35 <sup>a</sup>       | 9.00±0.00 <sup>b</sup>  | 3.00±0.00 <sup>b</sup> | 1791.00±0.66 <sup>b</sup> |
| 20NFB               | 2697.00±0.71 <sup>a</sup>       | 8.00±0.01 <sup>c</sup>  | 4.00±0.00 <sup>a</sup> | 2330.00±1.01 <sup>a</sup> |

Data are expressed as mean± standard deviation. Mean values with different superscripts in the same column differ significantly at  $P<0.05$ .

<sup>1</sup>0NFB: noodle without fish bone powder (control); 5NFB: noodle with fish bone powder substituted for wheat flour at 5% level; 10NFB: noodle with fish bone powder substituted for wheat flour at 10% level; 15NFB: noodle with fish bone powder substituted for wheat flour at 15% level; 20NFB: noodle with fish bone powder substituted for wheat flour at 20% level.

The iron content in the noodles varied from 8.00 mg/100 g in the control noodles to 10.00 mg/100 g in the 10NFB sample. This suggests that noodles made with fish bone powder (at a 10% substitution level) have the potential to be incorporated into food products that provide an adequate daily iron intake for children aged 1 through 3 years (the RDA of iron is 7 mg/day) (USA NIH, 2023). Iron is crucial for the formation of haemoglobin, which transports oxygen throughout the body (Orisa & Udofia, 2019). Additionally, zinc content increased from 1.00 to 4.00 mg/100 g with higher substitution levels (5% to 20%) of fish bone powder in noodle preparation. Zinc is essential for various functions in the human body, including gene expression, protein and DNA synthesis, and regulation of enzymatic reactions and the immune system, all of which support growth and development (Sangeetha *et al.*, 2022).

Regarding phosphorus content, noodles containing fish bone powder exhibited a significant increase (ranging from 714.0 to 2,330.0 mg/100 g) compared to the control noodle (101.0 mg/100 g). Furthermore, the phosphorus content in all prepared noodles with fish bone powder increased with higher levels of fish bone powder. Consuming 100 g of noodles with 15% or more fish bone powder provides an adequate daily phosphorus intake for adults and children aged 4 years or older (the RDA of phosphorus is 1,250 mg/day) (USA NIH, 2023).

### pH value, cooking yield, and cooking loss of noodles

Table 3 presents the pH values of noodles with or without fish bone powder. pH influences the dough's strength; an alkaline pH indicates a strong or tougher dough by enhancing bonding forces within starch granules, resulting in a harder texture of cooked noodles (Ho & Abdul Latif, 2016). The substitution of fish bone powder in noodle making affected the pH value of the end products. Noodles containing fish bone powder exhibited a significantly lower pH value (9.43 to 9.39) compared to the control noodle (9.81). Alkaline noodles typically have a high pH and appear yellow due to alkaline salts such as sodium carbonate (used in this study); the measured pH values align with the typical range for alkaline noodles (pH 9 to 11) (Chin *et al.*, 2012). Furthermore, the pH value decreased with increasing levels of fish bone powder substitution. The lower pH value in noodles with fish bone powder, compared to the control, was attributed to the dilution of gluten in wheat flour caused by the partial replacement with fish bone powder. This results in a weaker starch and protein network within the cooked noodles, impairing the network's ability to retain alkaline salts (Fan *et al.*, 2018).

**Table 3.** pH value, cooking yield, and cooking loss of noodles.

| Sample <sup>1</sup> | pH                     | Cooking quality (%)       |                         |
|---------------------|------------------------|---------------------------|-------------------------|
|                     |                        | Cooking yield             | Cooking loss            |
| 0NFB                | 9.81±0.06 <sup>a</sup> | 218.97±0.52 <sup>a</sup>  | 6.85±0.68 <sup>b</sup>  |
| 5NFB                | 9.43±0.04 <sup>b</sup> | 209.96±2.65 <sup>b</sup>  | 6.56±1.12 <sup>b</sup>  |
| 10NFB               | 9.41±0.04 <sup>b</sup> | 205.87±2.78 <sup>bc</sup> | 7.15±0.59 <sup>b</sup>  |
| 15NFB               | 9.43±0.01 <sup>b</sup> | 201.88±3.81 <sup>c</sup>  | 10.08±1.57 <sup>a</sup> |
| 20NFB               | 9.39±0.01 <sup>b</sup> | 201.13±4.24 <sup>c</sup>  | 11.37±0.22 <sup>a</sup> |

Data are expressed as mean± standard deviation. Mean values with different superscripts in the same column differ significantly at  $P<0.05$ .

<sup>1</sup>0NFB: noodle without fish bone powder (control); 5NFB: noodle with fish bone powder substituted for wheat flour at 5% level; 10NFB: noodle with fish bone powder substituted for wheat flour at 10% level; 15NFB: noodle with fish bone powder substituted for wheat flour at 15% level; 20NFB: noodle with fish bone powder substituted for wheat flour at 20% level.

Table 3 also presents the cooking yield and cooking loss of the noodles. The replacement of wheat flour with fish bone powder resulted in a significant decrease in cooking yield, with values of 209.96, 205.87, 201.88, and 201.13% for 5NFB, 10NFB, 15NFB, and 20NFB, respectively, compared to the control (218.97%). A lower cooking yield indicates reduced water absorption capacity and is inversely related to the protein content of the wheat flour (Ho & Abdul Latif, 2016). Conversely, a higher cooking yield reflects improved cooking quality due to enhanced water-holding ability, resulting in softer-textured noodles.

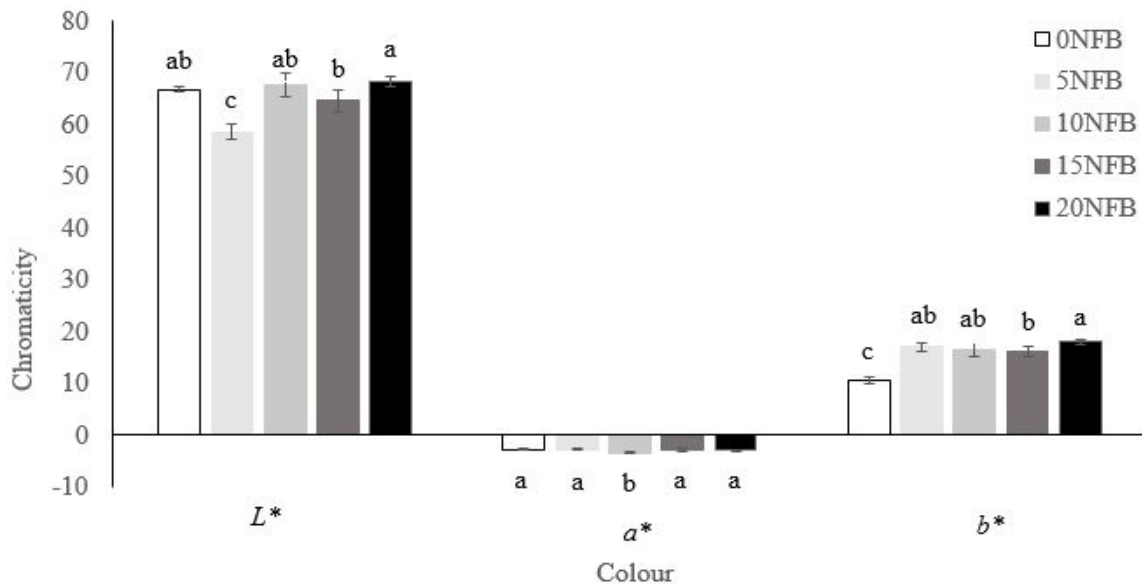
Cooking loss refers to the total solid content lost during cooking, such as the leaching of amylose and the solubilisation of water-soluble proteins in the cooking water (Fan *et al.*, 2018). This value also indicates the noodles' ability to maintain their structure during cooking. The replacement of wheat flour with fish bone powder at levels of 5 and 10% (5NFB & 10NFB, respectively) did not significantly influence cooking loss (6.56 and 7.15% for 5NFB & 10NFB, respectively) compared to the control noodles (6.85%). According to Kraithong and Rawdkuen (2021), low cooking loss is preferable as it indicates less turbid cooking water and reduced starch solubility. Furthermore, a cooking loss exceeding 10% (w/w) is considered undesirable (Ho & Abdul Latif, 2016). Therefore, the optimum substitution level of fish bone powder for wheat flour in noodle making was 10% level,

as cooking loss significantly increased for 15NFB and 20NFB samples (10.08 & 11.37%, respectively). This can be explained by the fact that the protein and starch networks become loose due to the activity of alkaline salts, increasing cooking loss (Li *et al.*, 2018).

**Colour characteristics of noodles**

Figure 1 presents the colour ( $L^*$ ,  $a^*$  &  $b^*$ ) characteristics of the noodles. The results indicated no significant difference in the lightness ( $L^*$ ) value of noodles made with fish bone powder at substitution levels of 10% and above (64.63–68.39) compared to the control noodle (66.84). This suggests that substituting fish bone powder for wheat flour at 10% or higher did not affect the  $L^*$  value of the noodles. Nammakuna *et al.* (2016) reported that the lightness of a food product is influenced by protein content, with higher levels of free amino acids reacting with reducing sugars under heat to produce a darker product through the Maillard reaction.

Results in Figure 1 indicate that all of the prepared noodles (-2.66 to -2.84), except for 10NFB (-3.36), exhibited no significant difference in the  $a^*$  value from each other. The  $a^*$  values of all the prepared noodles were negative, indicating that the colour of the noodles leaned more towards green and that red hues were absent. The slight greenish hue observed in the noodles may reflect subtle variations in pigment behaviour during processing, such as high pH. Additionally, minerals and starch in the flour, as well as environmental factors such as the wheat’s growing location and harvest conditions, may also contribute (Nasruddin *et al.*, 2018). However, the exact mechanism requires further investigation. These findings differ from the results reported by Uthai (2021), who observed a positive  $a^*$  value in noodles with added salmon fish bone powder, indicating the presence of red hues. Ho and Abdul Latif (2016) reported that a negative  $a^*$  value (green hues) is desirable and contributes to the overall external quality of noodles.



**Fig. 1.** Colour characteristics of noodles.

Mean value (triplicate value with ± error bar) of different letters recorded on the same clustered column is significantly different at ( $p < 0.05$ ).

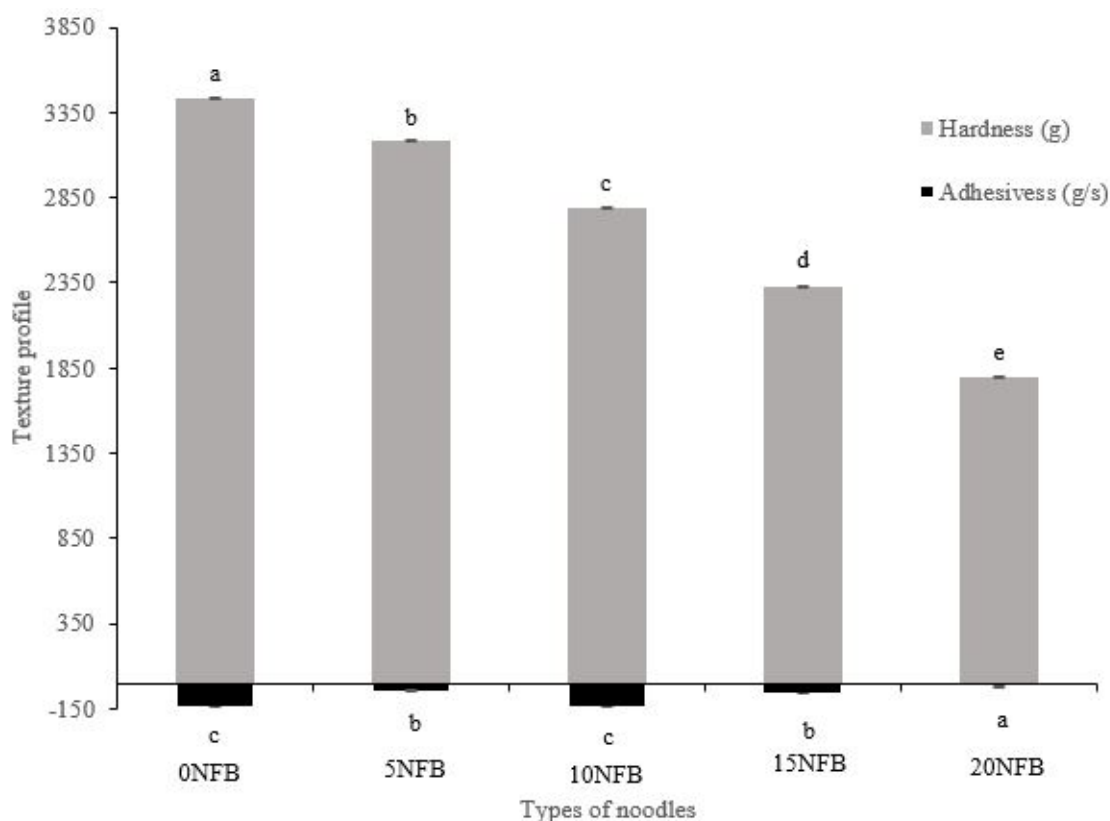
0NFB: noodle without fish bone powder (control); 5NFB: noodle with fish bone powder substituted for wheat flour at 5% level; 10NFB: noodle with fish bone powder substituted for wheat flour at 10% level; 15NFB: noodle with fish bone powder substituted for wheat flour at 15% level; 20NFB: noodle with fish bone powder substituted for wheat flour at 20% level.

Figure 1 demonstrates that all prepared noodles exhibited positive  $b^*$  values, indicating yellow colour. Notably, noodles prepared with fish bone powder (16.19–18.02) exhibited a significant increase in  $b^*$  values compared to the control noodles (10.73). As reported by Awuchi *et al.* (2022), fish contain carotenoid pigments in various forms, including astaxanthin (yellow), alpha- and beta-doradexthins (yellow), beta carotene (orange), canthaxanthin (orange-red), and lutein (yellow-green). These pigments may have contributed to the enhanced yellow colour observed in noodles containing fish bone powder. These findings align with the findings reported by Uthai (2021), which indicated that the addition of salmon fish bone powder resulted in an increase in  $b^*$  value in noodles.

**Texture profile of noodles**

Figure 2 presents the textural profile of the noodles. The results indicate a significant difference ( $p < 0.05$ ) in hardness among all the noodle samples, with values ranging from 1,799.18 to 3,434.57 g. A similar finding was reported by Uthai (2021), who observed that the inclusion of salmon fish bone decreased noodle hardness from 21.80 to 14.32 g. In the present study, the composite noodles exhibited a softer or more tender texture compared to the control noodles, likely due to a decrease in gluten content as the level of gluten-free flour (i.e., fish bone powder) increased, thereby weakening the protein-starch network (Ho & Abdul Latif, 2016). According to Kaur *et al.* (2015), the hardness of wheat-based products is also influenced by the amount of amylose in the flour; higher amylose content in wheat starch corresponds to higher hardness values. Thus, the amount of

starch (amylose) decreased proportionally with the increasing substitution level of fish bone powder for wheat flour in noodle preparation.



**Fig. 2.** Texture profile of noodles.

Mean value (triplicate value with  $\pm$  error bar) of different letters recorded on the same colour bar are significantly different at ( $p < 0.05$ ).

0NFB: noodle without fish bone powder (control); 5NFB: noodle with fish bone powder substituted for wheat flour at 5% level; 10NFB: noodle with fish bone powder substituted for wheat flour at 10% level; 15NFB: noodle with fish bone powder substituted for wheat flour at 15% level; 20NFB: noodle with fish bone powder substituted for wheat flour at 20% level.

The results for adhesiveness (Figure 2) indicate that noodles containing fish bone powder, except for the 10NFB sample, had significantly lower values (59.49–20.06 g/s) compared to noodles without fish bone powder (140.48 g/s). According to Ho and Abdul Latif (2016), the adhesiveness of noodles made with watermelon rind powder decreased significantly from -0.32 to -0.12 N/s as the amount of watermelon rind powder increased. Additionally, a low adhesiveness value is considered a desirable quality for cooked noodles as it can enhance the overall eating quality (Ho & Abdul Latif, 2016). Furthermore, future studies should consider evaluating additional textural parameters, such as springiness and elasticity, to provide a more comprehensive understanding of the effects of fish bone powder substitution on noodle quality.

### Sensory attributes of noodles

Table 4 presents a summary of the sensory evaluation scores for appearance, colour, aroma, elasticity, hardness, and overall acceptability of the noodles. The analysis of the ANOVA results revealed no significant difference in the appearance attribute between noodles incorporating fish bone powder at levels of 15% or below and the control noodles. Conversely, there was a significant reduction in sensory score for the 20NFB sample. This observation suggests that while the incorporation of fish bone powder in wheat flour did not adversely impact the visual appearance of the noodles at levels up to 15%, elevating the fish bone powder to 20% resulted in a rating of “neither like nor dislike” for 20NFB. This phenomenon can be attributed to the cooked 20NFB noodles exhibiting a looser strand configuration in comparison to the other noodles, as illustrated in Figure 2. A similar pattern was observed in the study by Uthai (2021), wherein the incorporation of salmon fish bone at a 20% level resulted in the lowest score for appearance.

Regarding the aroma attribute, there was no significant difference between the control noodle and those prepared using fish bone powder at levels of 15% or below (i.e., 5NFB, 10NFB & 15NFB). However, there was a significant decrease in the aroma score for the 20NFB sample in comparison to the control noodle. As elucidated by Olawoye and Gbadamosi (2020), the olfactory perception of food is influenced by the ingredients employed in its production. Consequently, the diminished aroma score for the 20NFB sample may be attributed to the fishy odour generated by the highest level (20%) of fish bone powder utilised in noodle making. A similar trend was observed in the research conducted by Uthai (2021), wherein the incorporation of fish bone powder at 20% level resulted in a reduction in the sensory score for aroma in the noodles.

In terms of the elasticity of noodles, there was no significant difference between the control noodle and those of 5NFB. Furthermore, the sensory score for elasticity exhibited a gradual decrease (4.60, 4.43 & 4.10 for 10NFB, 15NFB & 20NFB, respectively) as the level of fish bone powder substitution increased. As previously established by Ho and Abdul Latif (2016), gluten plays a crucial role in determining the elasticity of noodles. Consequently, the diminished sensory scores for elasticity

may be attributed to the substitution of a non-gluten ingredient (fish bone powder) for wheat flour, resulting in a dilution of gluten within the noodles.

**Table 4.** Sensory attributes of noodles.

| Attributes            | Samples <sup>1</sup>    |                        |                         |                         |                        |
|-----------------------|-------------------------|------------------------|-------------------------|-------------------------|------------------------|
|                       | 0NFB                    | 5NFB                   | 10NFB                   | 15NFB                   | 20NFB                  |
| Appearance            | 5.43±1.52 <sup>a</sup>  | 5.43±1.01 <sup>a</sup> | 4.97±1.52 <sup>a</sup>  | 5.00±1.34 <sup>a</sup>  | 4.10±1.45 <sup>b</sup> |
| Colour                | 5.37±1.54 <sup>ab</sup> | 5.87±0.82 <sup>a</sup> | 5.00±1.37 <sup>bc</sup> | 5.40±1.00 <sup>ab</sup> | 4.67±1.52 <sup>c</sup> |
| Aroma                 | 5.1±1.47 <sup>a</sup>   | 5.27±1.34 <sup>a</sup> | 4.47±1.68 <sup>ab</sup> | 4.43±1.31 <sup>ab</sup> | 4.10±1.69 <sup>b</sup> |
| Elasticity            | 5.43±1.41 <sup>a</sup>  | 5.67±0.76 <sup>a</sup> | 4.60±1.38 <sup>b</sup>  | 4.43±1.36 <sup>b</sup>  | 4.10±1.49 <sup>b</sup> |
| Hardness              | 5.27±1.66 <sup>a</sup>  | 5.53±1.20 <sup>a</sup> | 4.90±1.45 <sup>a</sup>  | 4.77±1.19 <sup>a</sup>  | 4.00±1.58 <sup>b</sup> |
| Overall acceptability | 5.43±1.59 <sup>a</sup>  | 5.47±0.90 <sup>a</sup> | 4.33±1.52 <sup>b</sup>  | 4.63±1.16 <sup>b</sup>  | 3.50±1.60 <sup>c</sup> |

Data are expressed as mean± standard deviation. Mean values with different superscripts in the same row differ significantly at  $P < 0.05$ .

<sup>1</sup>0NFB: noodle without fish bone powder (control); 5NFB: noodle with fish bone powder substituted for wheat flour at 5% level; 10NFB: noodle with fish bone powder substituted for wheat flour at 10% level; 15NFB: noodle with fish bone powder substituted for wheat flour at 15% level; 20NFB: noodle with fish bone powder substituted for wheat flour at 20% level.

Regarding the hardness attribute, there was no significant difference between the control noodle (5.27) and those containing fish bone powder, which ranged from 4.77 to 5.53. However, there was a significant decrease in the sensory score for the 20NFB sample. This decrease may be attributed to the excessively soft texture of 20NFB, which was deemed undesirable compared to the other noodle samples. This observation is corroborated by the hardness (g) values presented in Figure 2. These results suggest that panellists prefer noodles with a texture that falls within the acceptable range, neither excessively firm nor excessively soft.

The overall acceptability of noodles incorporating fish bone powder at a 5% level (5NFB) (5.47) was comparable to the control noodle (5.43), both indicating a “like slightly” rating. This similarity can be attributed to the insignificant discrepancies in all sensory attributes scores between the control noodle and the 5NFB. All prepared noodles, except for the 20NFB (“dislike slightly”), obtained scores exceeding 4.00, ranging from 4.33 to 5.47, which were deemed acceptable.

In conclusion, panellists demonstrated acceptance of noodles prepared with fish bone powder at a 5% substitution level, indicating the feasibility of producing nutrient-rich noodles using 5% (w/w, based on wheat flour) fish bone powder. Given the observed improvements in physicochemical properties of 10NFB, future research could explore 10% fish bone powder substitution in noodle production to further enhance taste and sensory attributes.

## CONCLUSION

The proximate composition results indicate that noodles incorporating fish bone powder significantly enhanced the crude protein, ash, and micronutrients such as calcium, iron, zinc, and phosphorus. Fish bone powder significantly increased the  $+b^*$  value, resulting in a yellowish hue in the composite noodles. All the produced noodles were classified as alkaline food products. However, the incorporation of fish bone powder in noodle preparation significantly compromised cooking quality by reducing the cooking yield and increasing cooking loss. Furthermore, noodles made with fish bone powder exhibited a softer or more tender texture and lower adhesiveness compared to the control noodles. In terms of sensory attributes, noodles with 5% fish bone powder received the highest score for overall acceptability, comparable to the control noodles. While fish bone powder enhances the nutritional profile of the noodles, it introduces challenges related to cooking performance, texture, and colour. These issues can impact consumer acceptance and necessitate addressing to optimise product formulation. This study provides a foundation for further exploration of the valorisation and food applications of functional ingredients derived from fish waste.

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## ETHICAL STATEMENT

This study was approved by the Universiti Sultan Zainal Abidin (UniSZA) Human Research Ethics Committee (UHREC), with approval number UniSZA/UHREC/2021/326.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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