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FULL PAPER

Nutritional, physical, and sensory properties of fish crackers produced from the head of catfish (*Clarias gariepinus*)

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Abstract

Catfish heads are a common byproduct of large-scale catfish processing, known for their rich nutritional content. However, despite their potential to be processed into food products such as crackers, catfish heads remain relatively underused. This study aimed to produce crackers made from catfish heads and evaluate the nutritional, physical, and sensory properties of the crackers. After the preparation of catfish head flour (CHF) and catfish head crackers (CHC), the crackers were analysed with various ratios of tapioca flour (TF) to CHF: CHC 0 (100: 0), CHC 1 (90:10), CHC 2 (80:20), CHC 3 (70:30), and CHC 4 (60:40). The examination of the nutritional, physical, and sensory properties showed that the CHF had high protein (30.89% db), calcium (21.83% db), and phosphorus (10.26% db) values, with the CHC 3 having higher protein, calcium, and phosphorus contents than the control group ($p<0.05$). The CHC 3 also exhibited good colours and textures, in addition to its superiority in all sensory attributes. In light of this analysis, the CHC 3 was indeed the best cracker processing. This study indicates that catfish heads as food ingredients can serve as nutritious crackers preferred by the panelists.

1. Introduction

Catfish is one of the leading freshwater fish commodities in Indonesia, with its production in 2017 reaching 1,125,526 tons and its target production in 2020 hitting 1,395,000 tons (Statistic Indonesia, 2018; Ministry of Maritime Affairs and Fisheries, 2020). As a favorite food item among the community, catfish is easy to obtain and cultivate and relatively cheap to be processed into food products. Catfish also has high nutritional values, containing high protein (66.31% db), calcium (304.82 mg/100 g db), and phosphorus (279.45 mg/100 g db). In addition, the essential amino acid content of catfish is high at 41.81 g/100 g of protein (Abdel-Mobdy *et al*., 2021). Given the benefits of catfish, the catfish consumption ranks first as the mostly consumed freshwater fish, with its consumption in Indonesia in 2020 reaching 0.037 kg per capita per week (Statistic Indonesia, 2020). However, catfish as a food ingredient is still limited to its meat, *pecel*, *mangut*, fish fillets, nuggets, fish balls, fish floss, shredded fish, biscuits, and cakes while the use of its byproducts (e.g., bones, skin, blood, scales, fins and head) is still widely overlooked. This is unfortunate as the catfish byproducts can constitute 55-65% of the total weight of the catfish, meaning that these byproducts can potentially be turned into economical food products (Bechtel *et al*., 2019). The potential utilization of fish byproducts has also been ascertained in a limited number of previous studies: protein hydrolysate from the skipjack tuna viscera byproduct (Klomklao and Benjalul, 2016), flavour formulation of the enzyme hydrolysates from the fish byproduct (Peinado *et al*., 2016), fish meal from fresh byproducts of cod and saithe (Ween *et al*., 2017), protein isolates from salmon, cod, and herring byproducts (Abdollahi and Undeland, 2018), crude oil from bluefin tuna (*Thunnus thynnus*) byproduct (Simat *et al*., 2020), gelatin from Barred mackerel byproduct (Mirzapour-Kouhdasht *et al*., 2020), and fish sauce from tilapia frames byproduct (Auttanak *et al*., 2022).

One nutritious byproduct of the catfish is the head, which makes up 24% of the total fish weight (Li *et al*., 2007). The head contains several nutritional contents,

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such as protein, lipid, ash, calcium salts, phosphate, and collagen. Nevertheless, catfish heads have not been used in food products—let alone being researched—in spite of the nutritional benefits of catfish heads when processed into flour or other food products. To illustrate, catfish head flour contains high protein (49.83±0.48% db), ash (21.13±0.32%), calcium (5.68%) and phosphorus (3.78%) (Ferazuma *et al*., 2011; Bechtel *et al*., 2017). Considering the contents, these catfish heads can be processed into a variety of food products, one of which is crackers.

Crackers have undeniably become a favorite choice, often consumed as a side dish or snacks. Being the second-largest miscellaneous food commodity consumed by Indonesians after instant noodles, the consumption of crackers in Indonesia has hit 0.173 ounces per capita a week (Statistic Indonesia, 2020). Crackers are traditionally produced by gelatinizing starch through a steaming process, whereby the dough is formed from a mixture of starch, mashed fish, salt, sugar, monosodium glutamate, and water (Neiva *et al*., 2011). The crackers commonly sold on the market are typically high in carbohydrates and low in protein, thereby providing fewer health benefits to the consumers. To add more protein to the crackers, fish meat is usually added into the mixture, hence called fish crackers. According to Indonesian national standards, fish crackers are processed fishery products with fish raw materials undergoing processing, boiling, and drying treatments (SNI, 2009). Given their possible advantages, this research aimed to produce fish crackers made from catfish heads and evaluate the nutritional, physical, and sensory properties. The crackers from catfish head flour are expected to reduce the wastage of fish byproducts, showing that the byproducts can serve as beneficial raw materials in food production.

2. Materials and methods

2.1 Materials

The catfish (*Clarias gariepinus*) were obtained from the Kebun Handil Market, Jambi City, Indonesia.

2.2 Preparation of catfish head flour

The catfish head flour was prepared following the method designed by Vignesh and Srinivasan (2012) with some modifications, divided into two main stages, the steaming and drying processes. First, the washed catfish heads were steamed at 121°C for 30 mins in a pressure cooker (Kirin, KPC-22S). The remaining meat in the catfish head was removed, and the clean catfish heads were then washed and dried at room temperature for 10 mins. The dry catfish heads were heated in a frying pan at 60°C for 10 mins and continuously turned over to evaporate the excess water in the catfish head. Afterwards, the catfish heads were dried twice: the first using a microwave oven (Hinano, MOV-628SB 850 W) at 120°C for 10 mins and the second a frying pan at 60°C for 2 mins. The catfish heads were eventually mashed using a mortar and pestle, with the obtained catfish head flour stored at -18°C until used.

2.3 Preparation of catfish head crackers

Catfish head crackers were prepared using the method described by Nor *et al*. (2014) with some modifications, which consisted of several stage including steaming, frying, chilling, and drying. The formula of catfish head crackers had five treatment ratios of tapioca flour (TF) to catfish head flour (CHF): CHC 0 (100: 0); CHC 1 (90:10); CHC 2 (80:20); CHC 3 (70:30) and CHC 4 (60:40). Other ingredients added into the crackers were 5% sugar, 4% salt and 1% seasoning. All the ingredients were mixed, then 50 mL of water were added slowly until the dough was not sticky to the hands. The dough was then moulded into an oval shape of 10 cm and a diameter of 2 cm. The dough was steamed using a steamer for 15 mins at a temperature of 80°C, followed by the cooling process at room temperature for 18 hrs. The cooled dough was sliced using a knife to form a thickness of around 2-4 mm. The sliced dough was dried in the sunlight for two to three days, and these dry crackers were fried on a frying pan at 170°C for 10–20 s until they expanded well.

2.4 Chemical analysis of catfish head flour and catfish head crackers

2.4.1 Moisture content

The moisture content was measured through the thermogravimetric method elaborated by the Association of Official Analytical Chemists (AOAC, 2005). The moisture content test was carried out by comparing the weight of the sample after and before drying. The sample (2 g) was weighed in a weighing bottle, and these samples were dried in an oven at 105°C for 3 hrs. The weighing bottles were then transferred to the desiccator for 15 mins and weighed until they reached a constant weight.

2.4.2 Ash content

The ash content was measured using the Gravimetry method described by AOAC (AOAC, 2005). First, empty *porcelain* crucibles were placed in a furnace at 550°C for 3 hrs, before being cooled and weighed in a desiccator for 30 mins. Ashing of the sample (2 g) was done in a furnace at 550°C for 3 hrs, with porcelain crucibles cooled in a desiccator for 30 mins and weighed until they reached a constant weight.

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2.4.3 Protein content

The protein content was measured using the Micro-Kjeldahl method outlined by AOAC (AOAC, 2005). A total of 0.1-0.5 g sample was mixed with 40 mg of HgO, 1.9 mg K_2SO_4, and 2 mL H_2SO_4, and this mixture was digested at 430°C for 90 mins. The digested mixture was cooled and had 20 mL of aquadest and 10 mL of NaOH-Na_2SO_3 solution added into it. After that, a total of 5 mL of HBO_3 and four drops of methylene red-methylene blue (MR-MB) indicator were poured into the Erlenmeyer flask for the distillation process, which was carried out until 15 mL of the distillate was collected. The distillate was then titrated with 0.02 N HCl, with the volume of HCl determined during the titration process. The resulting nitrogen value was multiplied by 6.25 to obtain the protein content.

2.4.4 Lipid content

The lipid content test was performed using the Soxhlet method based on AOAC (AOAC, 2005). A Soxhlet flask was dried at 105°C using an oven for 30 min and subsequently cooled in a desiccator for 15 min for weighing. A total of 5 g of the sample to be tested was wrapped using filter paper with hexane solved added therein and inserted into the thimble that was connected to the Soxhlet flask. Above the thimble was also the condenser. Then, the bottom of the Soxhlet flask was heated using a bath at a temperature of 80°C, with the extraction process running until reflux occurs for 5 hrs. The Soxhlet flask with lipid inside was redried in an oven at 10°C for 60 mins. The flask was finally transferred into a desiccator for 30 mins and weighed.

2.4.5 Carbohydrate content

The carbohydrate content test in samples was performed using a difference method based on AOAC (AOAC, 2005). The carbohydrate content was calculated by subtracting 100% with the moisture, ash, protein, and lipid content.

2.4.6 Total energy of catfish head flour and catfish head crackers

The total energy value of the samples was calculated using Atwater's conversion factors by multiplying the protein content by 4 kcal/g, carbohydrates by 4 kcal/g, and lipid by 9 kcal/g (Kassegn, 2018).

2.4.7 Calcium and phosphorus content of catfish head flour and catfish head crackers

Calcium and phosphorus content was measured using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) outlined by Visentin *et al.* (2016). The sample (2.5 g) was first added into the Teflon vessel with 2 mL 30% H_2O_2 and 7 mL 67% HNO_3. The Teflon vessel containing the sample was microwave heated at 200°C for 15 mins. These samples were kept at 200°C for 18 mins and immediately cooled to 35°C. The sample was mixed with demineralized water to reach the final volume of 25 mL. Using the ICP-OES, the ICP-OES wavelength was set at 317.933 nm for the calcium content and 178.287 nm for the phosphorus content. The standard calibrations for calcium and phosphorus were prepared using pure calcium and phosphorus with 0 and 100 mg/L concentrations in this test.

2.4.8 Amino acid profile of catfish head flour

Amino acid profile analysis was performed using the Ultra Performance Liquid Chromatography (UPLC) from Kıvrak *et al.* (2014), with some modifications in the concentration and ratio of solvent used. A total of 1 g of flour sample was mixed with 10 mL of 0.1% (v/v) formic acid, which had previously been dissolved in a mixture of distilled water and methanol in a ratio of 80:20 v/v. The flour and formic acid solvent mixture was vortexed for 5 min and centrifuged at 4000 rpm, 4°C for 15 mins. The supernatant was filtered using a polytetrafluoroethylene (PTFE) membrane. After that, 1 µL of the filtered sample was injected into the UPLC. Free amino acid calibration graphs were prepared with a concentration range of 0–50 ng/mL.

2.5 Physical analysis of catfish head crackers

2.5.1 Colour

Colour analysis was performed using the colorimeter app version 5.5.1 (Research Lab Tools, Sao Paulo, Brazil) from Google Play (Ravindranath *et al.*, 2018). The colorimeter application was installed on an android smartphone and could be used offline or online, with the images captured using a smartphone camera (48 MP). The parameters tested are L*, a*, b*. The value of L* denoted the lightness with the value from 0 (black)–100 (white), the value of a* denoted the degree of red (positive) and green (negative), and the value of b* denoted the level of yellow (positive) and blue (negative).

2.5.2 Linear expansion

The linear expansion analysis was carried out based on the method described by Pratama *et al.* (2018). In this test, the area of crackers before frying was compared with that of the crackers after frying. This test was performed by making two lines on the raw crackers which intersect one another using a marker. The horizontal lines represent the width of the crackers, while the vertical lines represent the length of the crackers. The area of the crackers was determined by multiplying the

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lengths of both horizontal and vertical lines. The linear expansion of the crackers produced was calculated using the equation (1):

$$\text{Linear expansion (\%)} = \frac{b-a}{a} \times 100\% \quad (1)$$

Where, a = area of crackers before frying (g), b = area of crackers after frying (g)

2.5.3 Texture

Texture analysis was performed using a texture analyzer with probes P/0.25 S. The parameter tested was the hardness of the crackers.

2.6 Sensory evaluation of catfish head crackers

The sensory evaluation was based on the acceptance test used by Meilgaard *et al*. (2016). The acceptance test involved fifty untrained men or women from Jambi city, aged between 17-70 years. Using catfish head crackers that have been fried as samples, the parameters tested in the acceptance test were comprised of colour, aroma, taste, texture, and overall liking. The evaluation follows the hedonic scale of 1-7: 1 = dislike very much, 2 = dislike moderately, 3 = dislike slightly, 4 = neither like nor dislike, 5 = like slightly, 6 = like moderately, 7 = like very much.

2.7 Statistical analysis

The data were collected using two replications. Initially, the normality test of the data was performed using the Kolmogorov-Smirnov test. If the data obtained were normally distributed, the data were analysed using the Analysis of Variance (ANOVA) test, followed by the Duncan test. If the data obtained were not normally distributed, then the data were analysed using the Kruskal-Wallis test, followed by a stepwise step-down test. The level of significance for each statistical test performed was set at $p<0.05$. All the statistical analyses were carried out using the IBM SPSS Statistics 26 program.

3. Results and discussion

3.1 The nutritional composition of catfish head flour

Table 1 shows the nutritional composition of catfish head flour. Catfish head flour had 5.97±1.00% wb moisture, 59.37±0.35% db ash, 30.87±0.11% db protein, 7.19±1.04% db lipid, and 2.55±1.13% db carbohydrate. The moisture content of the catfish heads was lower than that reported by Ogbe and Omada (2020) (56.48±0.68%) but higher than that reported by Bechtel *et al*. (2019) (4.01±0.02%). Regarding specific species, Kefas *et al*. (2014) reported that the moisture content of *Oreochromis noloticus* heads was 5.70±0.86% and that *Synodontis clarias* heads was 6.10±0.92%.

The ash content of catfish heads (59.37±0.35% db) was much higher than that of other species such as *Synodontis clarias* (42.20±0.92%) and *Oreochromis niloticus* (21.80±0.86%) (Kefas *et al*., 2014). Besides that, the ash content was also higher than that of rainbow trout (1.91±0.06%) or skipjack tuna (3.88±0.08%) (Li *et al*., 2019). The high ash content in catfish heads signified a large proportion of bone (Bechtel *et al*., 2019).

The protein content of the catfish heads (30.89±0.11% db) was higher than that found in the research of Ogbe and Omada (2020) (25.69±0.89%). The protein content was also higher than that of *Catla catla* (17.59±0.41%), tilapia (29.80±0.86%), Black Sea anchovies (13.39±0.17%), parrotfish (20.3±2.33%), rainbow trout (29±1%), skipjack tuna (18±3%), *Scomber scombrus* (29.44±0.47%), barracuda (14.32%) (Hussain *et al*., 2011; Kefas *et al*., 2014; Gencbay and Turhan, 2016; Li *et al*., 2019; Prihanto *et al*., 2019; Harianti, 2020; Ogbe and Omada, 2020). This study thus confirmed the high amount of protein in the catfish head, supporting its role as useful ingredient in food production.

The catfish head also had a higher lipid content (7.19±1.04% db) than that of *Synodontis clarias* (3.40±0.92%), *Oreochromis niloticus* (3.10±0.86%), rainbow trout (6.0±0.3%), skipjack tuna (4.8±0.5%),

Table 1. Nutritional quality of CHF and CHC

Component	CHF*	CHC 0	CHC 1	CHC 2	CHC 3	CHC 4
Moisture (% wb)	5.97±1.00	13.97±0.05^{c}	13.33±0.11^{a}	14.31±0.09^{d}	14.21±0.03^{cd}	13.62±0.07^{b}
Ash (% db)	59.37±0.35	3.97±0.01^{a}	8.52±0.03^{b}	15.84±0.05^{c}	19.59±0.01^{d}	24.76±0.47^{e}
Protein (% db)	30.89±0.11	1.08±0.01^{a}	3.18±0.05^{b}	5.38±0.02^{c}	8.26±0.11^{d}	11.67±0.04^{e}
Lipid (% db)	7.19±1.04	0.00±0.00^{a}	0.61±0.01^{b}	0.74±0.01^{c}	2.11±0.05^{d}	2.82±0.02^{e}
Carbohydrate (% db)	2.55±1.13	94.95±0.04^{e}	87.69±0.13^{d}	78.05±0.15^{c}	70.04±0.18^{b}	60.75±0.55^{a}
Total energy (kcal/100 g)	186.49±3.14	330.46±0.18^{e}	319.79±0.34^{d}	291.65±0.59^{c}	284.97±0.17^{b}	272.20±2.22^{a}
Calcium (% db)	21.83±1.18	0.03±0.00^{a}	1.65±0.01^{b}	5.28±0.07^{c}	6.99±0.02^{d}	9.45±0.01^{e}
Phosphorus (% db)	10.26±0.25	0.02±0.00^{a}	0.87±0.01^{b}	2.50±0.02^{c}	3.20±0.00^{d}	4.30±0.04^{e}

Values are presented as mean±SEM of duplicate testing. Values with different superscripts within the same row are significantly different ($p<0.05$). CHF: catfish head flour, CHC: catfish head crackers. Formula of catfish head crackers with ratio of tapioca flour (TF): catfish head flour (CHF) as follows: CHC 0 (100:0), CHC 1 (90:10), CHC 2 (80:20), CHC 3 (70:30), and CHC 4 (60:40). *no significant difference.

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parrotfish (3.92±0.38%), *Scomber scombrus* (1.48±0.67%) (Kefas *et al*., 2014; Li *et al*., 2019; Prihanto *et al*., 2019; Ogbe and Omada, 2020). The high lipid content signifies the potential of the fish head as a rich source of fish oil.

Based on the proximate analysis, catfish heads still contained carbohydrates, in contrast to the findings from Bechtel *et al*. (2019) and Ogbe and Omada (2020), who found no carbohydrates in the catfish heads. The difference in findings can be attributed to the characteristics of the catfish because, as suggested by Shim *et al*. (2017), the catfish heads' proximate content can be influenced by age, size, sex, maturity, environment, sexual feed cycle, and sampling location. The catfish head had an energy content of 186.49±3.14 kcal/100 g, which attested to benefit of catfish heads as a potential energy source.

The content of calcium (21.83±1.18% db) and phosphorus (10.26±0.25% db) in catfish heads was very high (Table 1). These figures were higher than those reported by Bechtel *et al*. (2019): 14.79±0.58% db calcium and 7.05±9.21% db phosphorus. In comparison to other species, the content of calcium and phosphorus in catfish heads was higher than that in sea bass heads (calcium: 2.51% db; phosphorus: 1.28% db) (Munekata *et al*., 2020). Similarly, the calcium content was higher than that in the heads of *Synodontis clarias* (4.57±0.71% db) and *Oreochromis niloticus* (3.54±0.55% db) (Kefas *et al*., 2014). These findings suggest that catfish heads can be used as a source of calcium and phosphorus in food products, which can benefit bones and teeth and can even prevent the risk of osteoporosis.

3.2 Amino acid profile of catfish head flour

As shown in Table 2, the analysis of the amino acid profile reveals that the CHF contained both essential and non-essential amino acids of 264.04 mg/g of protein, with the proportion of essential amino acids 66.32 mg/g and non-essential amino acids 197.72 mg/g. The dominant essential amino acids contained in the CHF were leucine (12.98±0.49 mg/g) and lysine (12.82±0.74 mg/g), while non-essential amino acid was glycine (56.75±1.87 mg/g). Compared to other fish species, the content of essential (lysine, leucine, valine, and threonine) and non-essential (proline, glycine, glutamic acid, arginine, serine, and alanine) amino acids in the CHF was higher than that in tilapia fish head flour (*Oreochromis mossambicus*) and sea bass (Vignesh and Srinivasan, 2012; Munekata *et al*., 2020).

The presence of amino acids in catfish heads can improve the overall nutritional quality of human diet, particularly when food processed with catfish heads (e.g., crackers) is consumed. Leucine plays a role in protein synthesis, regulates blood sugar levels, repairs

Table 2. Amino acid profile of CHF

Amino acids	Total (mg/g protein)	WHO/FAO/UNU (2007) (mg/g protein)	
		Child (3-10 y)	Adult (≥18 years)
Essential			
Leucine (Leu)	12.98±0.49	61	59
Lysine (Lys)	12.82±0.74	48	45
Threonine (Thr)	10.99±0.44	25	23
Valine (Val)	9.59±0.12	40	39
Phenylalanine + Tyrosine (Phe + Tyr)	13.44±0.55	41	38
Isoleucine (Ile)	6.61±0.04	31	30
Histidine (His)	4.42±0.09	16	15
Methionine + Cystine (Met + Cys)	n.d.	23	22
Tryptophan (Trp)	n.d.	6.6	6
Non-essential			
Glycine (Gly)	56.75±1.87	-	-
Glutamic acid + Glutamine (Glu + Gln)	30.02±1.49	-	-
Proline (Pro)	28.64±1.05	-	-
Arginin (Arg)	23.45±0.65	-	-
Alanine (Ala)	23.31±0.99	-	-
Aspartic acid + Asparagine (Asp + Asn)	17.48±1.09	-	-
Serine (Ser)	13.54±0.60	-	-
Total amino acid (TAA)	264.04		
Total essential amino acids (TEAA)	66.32		
Total non-essential amino acids (TNEAA)	197.72		

Values are presented as mean±SEM of duplicate testing. n.d.: not determined, CHF: catfish head flour

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muscles, and produces growth hormones (Zhang *et al*., 2017). Lysine is likewise helpful for calcium absorption, muscle protein formation, hormone production, and body antibodies (Singh *et al*., 2011). Glycine, a component of gelatin typically found in bones and scalp, is essential to bone and joint health because it can increase the growth of osteoblasts in bones by stimulating insulin secretion in the body (Liu *et al*., 2008; Yang *et al*., 2010). In addition, glycine plays a role in forming and synthesizing collagen (de Paz-Lugo *et al*., 2018). Other amino acids such as alanine, arginine, glutamic acid, leucine, lysine, and proline can help maintain bone mineral strength and density (BMD) (Jennings *et al*., 2016). The results demonstrate how catfish heads can be used for human consumption as nutritious and low-cost food, cutting the amount of wastage from fish byproducts that can negatively affect the environment.

Nevertheless, it is worth noting that the essential amino acids found in the CHF was lower than the standards set by WHO/FAO/UNU for both children and adults (WHO/ FAO/UNU, 2007). Some essential amino acids such as methionine, cysteine, tyrosine, and tryptophan were not measured in this research because these amino acids were unstable and easily degraded by acid treatment. Moreover, non-essential amino acid groups were more dominant, corresponding to the report from Munekata *et al*. (2020), who found that the content of non-essential amino acids in the head of sea Bass fish was higher than its essential amino acids. The proportion of both types of amino acids is important to consider because their content may determine the protein quality of any food, in addition the influence of the mutual proportions of specific essential amino acids and the digestibility of proteins (Boye *et al*., 2012).

3.3 The nutritional composition of catfish head crackers

As seen in Table 1, the moisture content of CHC was between 13.33±0.11 and 14.31±0.09% wb. The moisture content of crackers mixed with 10%, 20%, and 40% of CHF was significantly different from the that of the control group (without the addition of CHF) ($p<0.05$). However, the moisture content of control crackers was not significantly different from the moisture of those with the addition of CHF by 30% ($p>0.05$). Additionally, the moisture content of CHC 2 was not significantly different from CHC 3 ($p>0.05$). The moisture content of all cracker formulations accorded with the international standards of Codex Alimentarius CXS 222-2001 for all grades (I, II, and III) of fish crackers at 8% to 14% wb (Codex Alimentarius, 2018). The moisture content of crackers in this study was lower than that reported by Asikin *et al*. (2019), which ranged from 13.85% to 15.74% for seaweed crackers fortified with knife-fish bone powder. However, it was still higher than the moisture content of Bighead carp, Rohu, and Dory fish crackers—all of which ranges from 9.39% to 12.73% (Zzaman *et al*., 2017). Similarly, the moisture content was higher than that of commercial crackers which had around 9.37% to 13.83% of moisture content (Huda *et al*., 2010). In particular, the moisture content of the crackers with the CHF of 10% and 40% still fell within the commercial cracker range. According to the Indonesian national standard 8272:2016, the moisture content of fish crackers for all grades I, II, and III should not exceed the maximum value of 12% (SNI, 2016). All catfish head crackers' formulations still did not meet these standards because drying process relied on sunlight, which was further influenced by humidity, wind, temperature, and heating intensity (Taewee, 2011). As an implication, a noncontact infrared humidity sensor was needed to maintain the quality of the crackers produced.

The ash content of crackers added with CHF of around 10% to 40% was significantly different from the control crackers ($p<0.05$) (Table 1). The higher the addition of CHF, the higher the ash content and significant difference ($p<0.05$). Similar to the research of Asikin *et al*. (2019), the higher the addition of knife fish powder, the higher the ash content of the seaweed crackers. It is evident that the CHC had a high ash content owing to the high ash content in the CHF used to formulate crackers.

Table 1 also shows that the CHC had a protein content of 3.18±0.05 to 11.67±0.04% db. The protein content of CHC in all formulations mixed with CHF was significantly higher than the control crackers ($p<0.05$). The crackers with CHF 20%, 30%, and 40% had protein content that was in accordance with Codex Alimentarius grade II and III (minimum 5-8% wb) (Codex Alimentarius, 2018). Furthermore, all crackers with CHC (10%, 20%, 30%, and 40%) satisfied Indonesian national standards of grade I cracker protein content (minimum 8% and maximum 12%), II (minimum 5% and maximum 8%), III (minimum 2% and maximum 5%) (SNI, 2016). The protein content of crackers with CHF was higher than Belida fish flour bones (6.72–7.75%), milkfish bone flour (2.29–7.30%), seaweed crackers fortified with knife-fish bone powder (0.26–0.27%), Cork fish flour (5.90%) (Kusumaningrum and Asikin, 2016; Asikin *et al*., 2019; Imra *et al*., 2019; Alkhamdan and Husain, 2022). The study indicates the role of the CHF a rich protein source for food ingredients, attesting to the benefits of fish byproducts.

The higher the addition of CHF, the higher the lipid content of the crackers produced, and it was significantly different ($p<0.05$) (Table 1.). The lipid content of catfish head crackers still lay within the commercial cracker range of 0.85–3.38% (Huda *et al*., 2010). The CHC in the present study had lower lipid content than Rohu (3.06%) and Dory fish crackers (3.16%) (Zzaman *et al*. 2017), as well as bone belida flour (4.20–4.80%) (Imra *et al*., 2019). These findings suggest that fish species is likely to influence lipid content in fish crackers, in addition to the different cooking methods such as deep-frying and micro-oven baking (Neiva *et al*., 2011; Chudasama *et al*., 2019).

The carbohydrate content and total energy of CHC in all crackers formulations were significantly different ($p<0.05$) (Table 1), with the amounts lower due to the higher addition of CHF. The carbohydrate content and total energy of fish crackers were influenced by the raw materials used to prepare the crackers, such as tapioca flour and CHF. According to Ijioma *et al*. (2016), tapioca flour had 87.20–88.23% carbohydrate content, whereas the carbohydrate content of CHF was relatively low at 2.55%. The total energy content of CHC (272.20–319.79 kcal/100 g) was lower than that of the fish crackers in the research of Neiva *et al*. (2011) (518.07 kcal/100 g). The total energy value was influenced by the composition of protein, lipid and the ways to cook the crackers. It can be inferred that daily consumption of all CHC formulations per 100 g satisfy one-seventh or one-eighth of adults' energy needs, with the typical daily energy requirement at 2,100 kcal.

The CHC contained calcium (1.65±0.01–9.45±0.01% db) and phosphorus (0.87±0.01–4.30±0.04% db) (Table 1). The higher the addition of CHF, the higher the content of calcium and phosphorus in the crackers. The figures were significantly different from the control crackers ($p<0.05$) because of the high calcium and phosphorus in the head bones of catfish. In comparison, the calcium and phosphorus content in these crackers was higher than that of Belida fish bone crackers (4.19–6.57% calcium and 1.25–3.40% phosphorus), milkfish bones crackers (2.16–4.45% calcium and 0.002–0.007% phosphorus), fortified seaweed crackers knife-fish bone powder (0.41–3.70% phosphorus), crab crackers (0.12% calcium and 0.33% phosphorus), shrimp crackers (0.02% calcium and 0.05% phosphorus) (Kusumaningrum and Asikin, 2016; Asikin *et al*., 2019; Imra *et al*., 2019; Lawal-Are *et al*., 2022). The calcium content was likewise higher than that of commercial crackers (Huda *et al*., 2010). It has been suggested that the contents of calcium and phosphorus in fish crackers can be influenced by fish species, the concentration of flour used to prepare crackers, and the method of flour preparation (Kusumaningrum and Asikin, 2016). Adequate daily intake (AI) of calcium and phosphorus daily for adults (19–50 years) as stipulated in the regulation of the Ministry of Health of the Republic of Indonesia and the Institute of Medicine, should amount to 1,000 mg and 700 mg/day per day, respectively (Institute of Medicine, 1997; Bergman *et al*., 2009; Ministry of Health of the Republic of Indonesia, 2019). In light of this, consumption of crackers with the formula of CHC 2, CHC 3, and CHC 4 per 30 g can fulfil the daily calcium intake of 1,584–2,835 mg/day and phosphorus intake of 750–1,290 mg/day. Meanwhile, the consumption of CHC 1 crackers per 30 g cannot meet the necessary calcium (495 mg/day) and phosphorus (261 mg/day) intake. The findings have shown how the addition of CHF into crackers is an alternative to improving nutrition, increasing mineral bioavailability, and promoting health. The crackers with CHF have been found to be a nutritious food item which is rich in micronutrients needed by the body.

3.4 Physical properties of catfish head crackers

3.4.1 Colour

Table 3 presents the results of the CHC colour analysis. It is shown that the value of lightness (L*) of CHC for all formulations was significantly different ($p<0.05$), indicating that the higher the addition of CHF, the darker the colour of the crackers. This confirms the findings from Nurul *et al*. (2009) that the addition of higher fish meat can result in a decrease in the lightness of the crackers. The CHF particularly exhibited a grey colour with L* (63.45), a* (-0.58), b* (6.88) values, the colour of the CHF results from the melanin pigment normally found in catfish skin (Dong *et al*., 2011).

The value of a* showed red and green colors to denote a positive or negative value, respectively. All cracker formulations with the addition of CHF differed significantly ($p<0.05$), implying that more addition of CHF will likely produce crackers with a positive a* value. This is similar to the findings reported by Suryaningrum *et al*. (2016), who discovered that the higher the addition of fish meat, the higher the a* value of the crackers. The colors of the crackers were due to the higher amount of amino acid therein.

Meanwhile, the value of b* showed yellow for positive and blue for negative. It was observed in Table 3 that crackers with CHF of 10% were not significantly different from the control group ($p>0.05$), whereas those with CHF of 20%, 30%, and 40% exhibited significant differences ($p<0.05$). All of these crackers had a yellowish colour because of the Maillard reaction between the reducing sugar and the amine groups present in the protein, which could be due to the frying of the crackers at high temperatures. As pinpointed by Echavarria *et al*. (2012), the yellowish colour usually

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Table 3. Physical properties of CHC

Component	CHC 0	CHC 1	CHC 2	CHC 3	CHC 4
Colour					
L*	73.48±0.46[e]	63.63±0.38[d]	57.72±0.35[c]	50.88±0.41[b]	45.57±0.50[a]
a*	-1.48±0.24[a]	-0.38±0.05[b]	0.27±0.03[c]	1.37±0.24[d]	1.88±0.09[e]
b*	9.5±0.7[a]	9.83±0.37[a]	13.83±0.02[b]	14.87±0.59[b]	14.4±0.41[b]
Linear expansion (%)	265.95±10.33[c]	329.50±24.22[d]	128.88±13.14[b]	61.88±8.89[a]	23.71±2.58[a]
Texture (gf)	1355.64±41.83[a]	1506.40±71.21[a]	2873.66±85.03[b]	2885.47±154.31[b]	3095.55±77.83[c]

Values are presented as mean±SEM of duplicate testing. Values with different superscripts within the same row are significantly different (p<0.05). CHC: catfish head crackers. Formula of catfish head crackers with ratio of tapioca flour (TF): catfish head flour (CHF) as follows: CHC 0 (100:0), CHC 1 (90:10), CHC 2 (80:20), CHC 3 (70:30), and CHC 4 (60:40).

stems from melanoidin pigment resulting from the Maillard reaction. In addition, other factors contributing to the color include changes in pigment concentration caused by dehydration and cracker expansion (Wang *et al*., 2013).

3.4.2 Linear expansion

The linear expansion is an important parameter to assess the sensory quality of crackers. The linear expansion can occur due to a heating process which can further cause the air in the protein-starch matrix to expand, eventually resulting in the crackers expanding too (Kaewmanee *et al*., 2015). The results in Table 3 showed that the higher the addition of CHF to the cracker dough, the lower the linear expansion of the crackers, which was noticeable in the CHC with its significant difference (p<0.05) (Table 3). These finding conformed with what Nurul *et al*. (2009) observed: the ratio of adding fish flour was inversely proportional to the linear expansion of the crackers. The linear expansion of CHC was 23.71%–329.50%, higher than the value reported by Nurul *et al*. (2009) (37.18%–107.69%), Kaewmanee *et al*. (2015) (19%–41%), Zzaman *et al*. (2017) (57.46%–60.32%), Chudasama *et al*. (2019) (18.10%–83.03%). The figures were even higher than the linear expansion of commercial crackers, 37.55%–145.95% (Huda *et al*., 2010). The linear expansion of crackers with the addition of CHF of 10–20% was deemed ideal because it was higher than 77% (Siaw *et al*., 1985). The characteristics of the raw material can influence the linear expansion of crackers, alongside with the number and species of fish, the type and nature of starch, protein sources, protein and lipid content, seasoning, the process of preparing crackers, such as mixing, cooking, cooling, drying, and the method of frying crackers. High protein and lipid content can interact with starch granules, inhibiting linear expansion (Nurul *et al*., 2009). The ratio of starch and protein content will affect the formation and strength of the gel to reduce the linear expansion of crackers, which is likewise affected by the content of amylose and amylopectin in the crackers (Taewee, 2011).

3.4.3 Texture

Crackers with the addition of CHF by 10% and those in the control group did not exhibit any significant difference (p>0.05), unlike crackers with CHF by 20% to 40%, which were significantly different (p<0.05). In addition, the hardness of crackers with CHF 20% and 30% was significantly different from CHC 40% (p<0.05). It is noticeable that more addition of CHF may lead to harder textures of the crackers, which is similar to the earlier studies investigating the addition of fish meat (Nurul *et al*., 2009; Netto *et al*., 2014; Baishak *et al*., 2020) or fish bones (Putra *et al*., 2015) in crackers. There was a positive correlation between the addition of catfish head flour to the hardness of the crackers (r^2>0), indicating that the higher the addition of catfish head flour into the cracker dough, the higher the cracker hardness. The hardness was also subject to the linear expansion, whereby the hardness could increase just as the linear expansion decreased. The protein content can affect the hardness of crackers in the raw material for crackers because protein can inhibit starch from expanding (Zzaman *et al*., 2017).

3.5 Sensory evaluation of catfish head crackers

The sensory evaluation of the CHC is shown in Table 4. Based on the colour attribute, crackers with 10% and 20% CHF were not significantly different from the control (p>0.05), while those with CHF 30% to 40% were significantly different (p<0.05). However, those with 30% CHF were not significantly different from those with 20% (p>0.05). These findings mean that more addition of CHF is more likely to affect the colour of the crackers produced. When observing the crackers, the panelists preferred the colour attribute of the crackers with the addition of CHF by 10%–20%, which is similar to the report by Zzaman *et al*. (2017), where the panelists preferred brightly coloured fish crackers. In the aroma and texture attributes, the acceptance of the panelists for all cracker formulations was not significantly different from the control (p>0.05). The panelists did not smell any unpleasant aroma, namely the fishy aroma, and they also liked the hardness level of all the cracker formulas,

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Table 4. Sensory evaluation of CHC

Formula of CHC	Colour	Aroma	Taste	Texture	Overall liking
CHC 0	5.92±1.07[c]	5.48±1.27[a]	5.56±1.18[a]	5.50±1.50[a]	5.78±1.13[a]
CHC 1	5.78±1.04[c]	5.54±1.18[a]	6.06±0.89[b]	6.06±0.98[a]	6.02±0.94[a]
CHC 2	5.46±1.11[bc]	5.18±1.08[a]	5.70±0.99[ab]	5.94±0.91[a]	5.78±0.86[a]
CHC 3	5.26±1.27[ab]	5.26±1.12[a]	5.56±0.91[a]	5.76±1.12[a]	5.68±0.91[a]
CHC 4	4.92±1.43[a]	5.14±1.20[a]	5.36±1.16[a]	5.64±1.12[a]	5.52±0.99[a]

Values are presented as mean±SEM of duplicate testing. Values with different superscripts within the same column are significantly different ($p<0.05$). CHC: catfish head crackers. Formula of catfish head crackers with ratio of tapioca flour (TF): catfish head flour (CHF) as follows: CHC 0 (100:0), CHC 1 (90:10), CHC 2 (80:20), CHC 3 (70:30), and CHC 4 (60:40).

as shown in the sensory result.

The results examination of panelists' acceptance of the taste attribute revealed that crackers with the addition of CHF 10% were significantly different from those with CHF of 30%, 40%, and those in the control group ($p<0.05$) but not significantly different from those with CHF 20% ($p>0.05$). The addition of CHF affected the taste of crackers because CHF contained high contents of the amino acids, including leucine, lysine, phenylalanine, threonine, glycine, proline, alanine, serine, and glutamic acid. Specifically, the sweetness of crackers was attributed to several amino acids, such as histidine, phenylalanine, tryptophan, glycine, alanine, proline, serine, and threonine. Meanwhile, the umami taste in crackers, which can be obtained from garlic, sugar, salt, and flavouring, was caused by glutamic acid (Bachmanov *et al*., 2016; Astuti *et al*., 2022). Panelists noted that an increase in the perception of sweetness was in conjunction with more addition of CHF, as inferred from the fact that crackers with the addition of CHF by 40% had the sweetest taste perception. The perception of this sweet taste was due to the high amount of glycine, which is found to be the most abundant amino acid in CHF. The perceptions of sweetness in glycine is related to the interaction between glycine and the *Tas1r3* receptors on the tongue (Bachmanov *et al*., 2016).

The overall preference for all the cracker formulations did not show any significant difference ($p>0.05$). The addition of catfish head flour to the cracker formulations did not affect the overall assessment of the panelists. One group of panelists preferred crackers with white colours (i.e., CHC 1 and CHC 2), while the other panelists preferred those with a hard texture, dark colour, strong fish aroma, and taste (i.e., crackers CHC 3 and CHC 4). These findings have shown CHF can be used as an ingredient in food product formulations, potentially reducing the waste of fish byproducts.

4. Conclusion

The findings have demonstrated that fish head byproducts can successfully be processed into crackers with rich nutritional values. The CHC relatively have high amounts of protein, calcium, phosphorus, and essential amino acids such as leucine, lysine, threonine, valine, and phenylalanine. The addition of CHF can further enrich the nutritional value of CHC, such as carbohydrates, ash, lipid, protein, calcium, and phosphorus. The CHC has moisture and protein content that is in accordance with the International Codex Alimentarius standards and the Indonesian National Standards. The consumption of CHC per 30 g can cater for the recommended daily intake of calcium and phosphorus. Specifically, the CHC with a ratio of TF to CHF of 70:30 was the most nutritious because it had high protein, calcium, phosphorus contents, as well as good sensory and physical properties, such as the colour and texture. Overall, CHF can potentially serve as a nutritious food ingredient in food production.

Conflict of interest

The authors declare no conflict of interest.

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