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FOOD TECHNOLOGY

Preparation of Nile tilapia (*Oreochromis niloticus*) waste meal for human consumption

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ABSTRACT: This study aimed to prepare and characterize Nile tilapia (*Oreochromis niloticus*) waste meal. The experimental design consisted of three treatments (carcass meal, mechanically separated meat meal - MSM, and head meal) and five replications of each treatment. Yield, microbiological quality, pH, water activity, proximate composition, energy value, mineral composition, fatty acid profile, amino acid composition, color, and particle size fractions and the geometric mean particle diameter (GMD) analyses were performed. Data were subjected to ANOVA, and means were compared by Tukey's test at $P < 0.05$. Carcass, mechanically separated meat, and head meals had a protein content of 56.45%, 78.60%, and 50.33%, respectively, a lipid content of 7.16%, 13.15%, and 4.58%, respectively, and an ash content of 32.61%, 4.26%, and 38.41%, respectively. The mean yield of fish waste meals was 13%. Oleic, palmitic, and linoleic acids were the major fatty acids in the three fish waste meals, and glutamic acid, leucine, lysine, and glycine were the major amino acids. Color analysis showed that lightness (L^*) ranged from 55.32 to 77.19, redness (a^*) from 4.44 to 4.88, and yellowness (b^*) from 4.13 to 9.51. The GMD ranged from 0.37 to 0.99 mm. The results indicate that Nile tilapia waste meals have high nutritional value and adequate pH, water activity, and microbiological quality for use in human nutrition.

Key words: fish carcass, fish head, mechanically separated meat, microbiological quality, nutritional quality.

Preparação de farinha de resíduos de tilápia do Nilo (*Oreochromis niloticus*) para consumo humano

RESUMO: Este estudo teve como objetivo preparar e caracterizar farinha de resíduos de tilápia do Nilo (*Oreochromis niloticus*). O delineamento experimental consistiu em três tratamentos, farinha de carcaça, farinha de carne mecanicamente separada - CMS e farinha de cabeça, e cinco replicatas por tratamento. Foram realizadas análises de rendimento, qualidade microbiológica, pH, atividade de água, composição centesimal, valor energético, composição mineral, perfil de ácidos graxos, composição de aminoácidos, cor, frações granulométricas e o diâmetro médio geométrico das partículas (DMG). Os dados foram submetidos à ANOVA e as médias comparadas pelo teste de Tukey ($P < 0,05$). As farinhas de carcaça, de carne mecanicamente separada e de cabeça apresentaram teor de proteína de 56,45%, 78,60% e 50,33%, respectivamente, teor de lipídios de 7,16%, 13,15% e 4,58%, respectivamente, e teor de cinzas de 32,61%. 4,26% e 38,41%, respectivamente. O rendimento médio das farinhas de resíduos de peixe foi de 13%. Os ácidos oleico, palmítico e linoleico foram os principais ácidos graxos encontrados nas três farinhas de resíduos de peixe, e o ácido glutâmico, leucina, lisina e glicina foram os principais aminoácidos detectados nas farinhas. A análise de cor mostrou que a luminosidade (L^*) variou de 55,32 a 77,19, o vermelho (a^*) variou de 4,44 a 4,88 e o amarelo (b^*) variou de 4,13 a 9,51. O GMD variou de 0,37 a 0,99 mm. Os resultados indicam que as farinhas de resíduos de tilápia do Nilo apresentam alto valor nutricional e pH, atividade de água e qualidade microbiológica adequados para uso na alimentação humana.

Palavras-chave: carcaça de peixe, cabeça de peixe, carne mecanicamente separada, qualidade microbiológica, qualidade nutricional.

INTRODUCTION

The demand for healthy foods has increased in recent years as a result of population growth and changes in consumer preferences. Fish is an important source of proteins of high biological value, omega-3 and -6 fatty acids, calcium, phosphorus, iron, and vitamins A, D, and B, especially vitamin B12 (MAULU et al., 2021). Because of the growing demands for this highly nutritional food source, fisheries are expected to raise production by 104% by 2025 (Food and Agriculture Organization of the United Nations - FAO, 2016). Over the last 70 years, total fishing and aquaculture production has expanded significantly, from a production of 19 million tons in 1950 to approximately 179 million tons in 2018 (FAO, 2022). Nile tilapia (*Oreochromis niloticus*) is one of the most cultivated fish species, with more than 550,00 tons produced in 2022, in Brazil, Nile tilapia accounts for 63.93% of fish production (ANUÁRIO PEIXE, 2023).

This trend toward greater fish production implies an increase in waste generation. In general, two-thirds of raw fish is discarded as waste during processing (BOSCOLO & FEIDEN, 2007;

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COPPOLA et al., 2021). In tilapia filleting industries, for instance, only 35% of the fish material is exploited (VIDAL et al., 2011; LEIRA et al., 2019; SANTOS et al., 2021). Of the total amount of fish waste generated, 58% is used mainly to produce fish meal for animal feed, and the rest is disposed of in landfills (23%) or directly in the environment (9%) (BOSCOLO & FEIDEN, 2007).

Fish waste, however, may find application in the production of value-added by-products with nutritional benefits, promoting waste reduction and fish consumption. Mechanically separated meat (MSM) (COSTA et al., 2016; MAGALHÃES et al., 2020), fish head (STEVANATO et al., 2008; VIGNESH & SRINIVASAN, 2012; SOUZA et al., 2022), and whole carcass (PETENUCI et al., 2010; CORRÊA et al., 2023) can be processed into meal and added to food products including lasagna (KIMURA et al., 2017) and cookies (FUZINATTO et al., 2015; WIDYANINGRUM et al., 2022). Fish by-products can, therefore, be used as ingredients in foods of otherwise low nutritional value. This strategy may contribute greatly to the adoption of healthier eating habits by the population and the prevention of chronic malnutrition, overweight and obesity. This study aimed to prepare carcass, MSM, and head meals from Nile tilapia filleting waste and assess their nutritional, microbial, and physicochemical suitability for human consumption.

MATERIALS AND METHODS

Preparation of fish waste meals

Fish waste meals were prepared at the Laboratory of Fish Technology, of the Iguatemi Experimental Farm belonging to State University of Maringá, Paraná, Brazil. Nile tilapia waste was obtained from SmartFish Company, a fillet processing industry located in Rolândia, Paraná, Brazil. Carcasses (spine with ribs, meat left after filleting, heads and fins) were prepared by removing the head, fins, excess fat and visceral remains. Then they were disinfected by immersion in a peracetic acid-based disinfectant (0.1 mg/kg, Proxitane 1512 AL, Thech, São Paulo, Brazil) for 10 min. One part of the clean carcass material was processed into carcass meal (Treatment 1), and the other was deboned and processed into MSM meal (Treatment 2). The bone residue obtained after mechanical separation was calcined for 4 h in a muffle furnace at 600 °C to obtain bone ash, a by-product of MSM production. Fish heads were disinfected by the same procedure and processed into head meal (Treatment 3).

Meal's preparation

Raw materials were minced using a meat grinder (CAF-10, CAF Máquinas, Rio Claro, Brazil) and an 8 mm plate, mixed with equal volumes of water containing 200 mg/kg butylhydroxytoluene (BHT, 99.8%, Labsynth, Diadema, Brazil), and cooked at 100 °C for 60 min. After cooking, the mixture was dewatered using a 10-ton hydraulic press, ground using a meat grinder, and dried in a forced-air oven at 60 °C for 24 h. The resulting materials were processed with a knife mill to obtain carcass, MSM, and head meals (Figure 1). Triplicate samples were collected immediately after preparation and sent to the Laboratory of Food Microbiology and Microscopy of the State University of Maringá, Paraná, Brazil, for microbial analysis. Meals were stored at −18 ± 2 °C until physicochemical analyses.

Yield determination and microbiological analyses

Meal yield and production losses were calculated in relation to the amount of raw material used for each meal (carcass, MSM, and head).

Determination of total and fecal coliforms (most probable number, MPN), coagulase-positive Staphylococcus coagulase bacteria (colony-forming units, CFU/g), and Salmonella spp. (presence/absence) was performed according to American Public Health Association (APHA, 1992) and the Brazilian Health Regulatory Agency Resolution no. 12/2001 (ANVISA, 2001).

Chemical and physical analyses

Fish waste meals were subjected to chemical and physical analyses at the Laboratory of Animal Feed and Nutrition of the State University of Maringá. Moisture and ash contents were determined according to Association of Official Analytical Chemists (AOAC, 1995). Crude protein was assessed by the semi-micro Kjeldahl method (SILVA & QUEIROZ, 2002). Total lipid extraction and quantification followed the method of BLIGH & DYER (1959). Carbohydrate contents were calculated by subtracting the sum of moisture, crude protein, total lipids, and ash contents from 100. The energy value was estimated by the formula:

Energy value (*kcal/g*) = (Crude protein × 4) + (Total lipids × 9) + (Carbohydrates × 4) (SOUCI et al., 2000).

Fatty acids composition was analyzed by gas chromatography, performed by a private laboratory (CBO, Valinhos, São Paulo, Brazil). Identification and quantification were performed by comparison of spectra and retention times with those

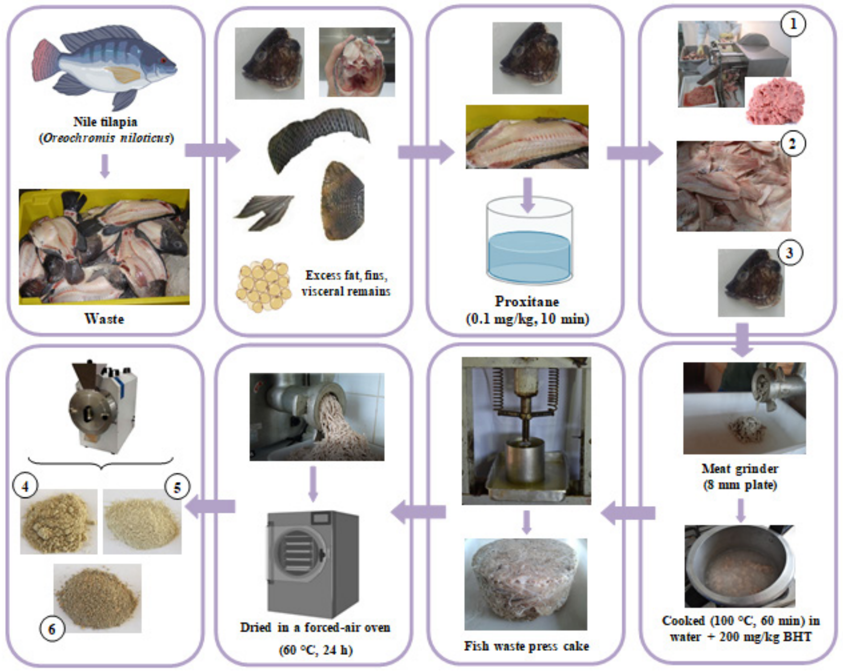

Figure 1 - Flowchart for the production of Nile tilapia (*Oreochromis niloticus*) waste meals from residues obtained from a filleting industry. Fish carcasses were trimmed of excess fat, visceral remains, and fins. Trimmed carcasses and heads were then disinfected by immersion in a 0.1 mg/kg solution of Proxitane® for 10 min. After disinfection, half of the carcasses were processed into mechanically separated meat (MSM) (1). The other half of the disinfected carcasses (2), fish heads (3). These raw materials (carcass, MSM and head) were passed through a meat grinder using an 8 mm plate, mixed at a ratio of 1:1 with water containing 200 mg/kg of butylhydroxytoluene, and cooked for 60 min at 100 °C. The resulting materials were pressed with a hydraulic press, ground in a meat grinder, dried in a forced-air oven at 60 °C for 24 h, and ground in a knife mill to obtain carcass (4), MSM (5), and head (6) meals. Created by Angélica de Souza Khatlab using the online BioRender software.

of authentic standards (Sigma–Aldrich, St. Louis, MO, USA). Fatty acid composition data were used to calculate three nutritional quality indicators: the atherogenicity index (AI, Equation 1) (ULBRICHT & SOUTHGATE, 1991) the thrombogenicity index (TI, Equation 2) (ULBRICHT & SOUTHGATE, 1991), and the hypocholesterolemic/hypercholesterolemic fatty acid (H/H) ratio (Equation 3) (PILARCZYK et al., 2015).

$$AI=[(C12{:}0)+(C14{:}0\times 4)+(C16{:}0)]/(\Sigma\text{Monounsaturated fatty acids}+\Sigma n\text{-}6+\Sigma n\text{-}3) \quad (1)$$

$$TI=(C14{:}0+C16{:}0+C18{:}0)/([(\Sigma\text{Monounsaturated fatty acids}\times 0.5)+(\Sigma n\text{-}6\times 0.5)+(\Sigma n\text{-}3\times 3)+(\Sigma n\text{-}3/\Sigma n\text{-}6)]) \quad (2)$$

$$H/H = (C18{:}1cis9 + \Sigma\text{Polyunsaturated fatty acids}) / (C14{:}0 + C16{:}0) \quad (3)$$

Amino acid and mineral composition analyses were performed by a private laboratory (CBO, Valinhos, São Paulo, Brazil) according to HAGEN et al. (1989) and AOAC (2005) methods, respectively.

The pH was measured in distilled water using a fish meal/water ratio of 1:10 (w/v). The pH was read with a pH meter (DM 22, Digimed, São Paulo, Brazil) during 5 min. Water activity (Aw) was measured using a water activity meter (Aw Sprint TH-500, Novasina, Lachen, Switzerland).

Particle size fractions and the geometric mean particle diameter (GMD) were determined according to standard methods. Briefly, 100 g of fish meal was sieved through a series of graded sieves (0.15, 0.3, 0.6, 1.2, 2.0, and 4.0 mm) for 10 min under agitation. The material retained in each sieved was weighed, and particle size fractions (GMD) were determined as: fine, GMD < 0.60 mm; intermediate, 0.60 ≤ GMD < 2.00 mm; and coarse, GMD ≥ 2.00 mm expressed as percentages. Particle size fractions are expressed as percentage and GMD as millimeter (mm).

Color analysis was performed using a portable colorimeter (CR-10, Konica Minolta, Osaka, Japan) at ambient temperature and a reading angle of 90°. Results are expressed as CIELAB coordinates: lightness (L^*), redness-greenness (a^*), and yellowness–blueness (b^*).

Statistical analysis

The experiment was conducted in a completely randomized design with three treatments (carcass, MSM, and head meals) and five replicates per treatment. Each batch of 5 kg of fish waste meal was considered an experimental unit.

Proximate composition, energy value, particle size, pH, water activity, and color data were subjected to analysis of variance (ANOVA) followed by Tukey's test at $P \leq 0.05$ using SAS version 9.00 (SAS Institute Inc., Cary, NC, USA). Fraction yields, fatty acid profile, amino acid composition, mineral composition, and microbiological results are only descriptive and were not analyzed statistically.

RESULTS AND DISCUSSION

Yield determination

Table 1 presents the results of meals yield and production loss in relation to the amount of raw material used in each meal (carcass, MSM and head). The yield of the meal production process in relation to the initial clean carcass weight was 13% for carcass and head meals and 9% for MSM meal. The production yield of MSM in relation to the initial clean carcass weight was 61%. The production of meal from MSM generated 20% of bone residue and 5% of bone ash. However, in meals made from tilapia carcasses and heads, these residues were not detected. Press cake was 33% for carcass meal 31% for MSM meal and 28% for head meal. During the MSM production process there was a loss of approximately 19%.

Fish waste meal production generated new wastes, albeit in low amounts. These residues composed of fins, excess fat, and visceral remains, were removed during carcass trimming. MSM meal production also afforded bone residue and resulted in a loss of 19% from meat retained in the deboning equipment. These residues can be further processed into meat and bone meal for use in animal feed. Bone residue can also be calcined to obtain bone ash, increasing waste use and process sustainability.

MSM meal was obtained at a lower yield and through a more laborious process than carcass and head meals. Nevertheless, other parameters need to be taken into account when determining the suitability of raw materials for the production of fish meal for human consumption, such as chemical, physical, and nutritional properties.

Microbiological analyses and chemical and physical analyses

The fish waste meals produced in this study met the microbiological standards established by the Brazilian Health Regulatory Agency (ANVISA, 2001). Total and fecal coliform levels were lower than 3 MPN/g, *Staphylococcus coagulase* concentrations were lower than 1×10^2 CFU/g, and Salmonella was not detected in 25 g samples. Therefore, carcass, MSM, and head meals were fit for human consumption.

Table 2 shows the proximate composition, physical parameters (pH and Aw) and mineral composition of fish waste meals. Proximate

Table 1 - Yield of fractions obtained during the preparation of carcass, mechanically separated meat (MSM), and head meals from Nile tilapia (*Oreochromis niloticus*) waste.

Fraction	--------------Carcass meal-------------		-----------MSM meal-----------		------------Head meal------------	
	g	%	g	%	g	%
Clean carcass	5000 ± 86	100	5000 ± 98	100	5000 ± 122	100
MSM	-	-	3067 ± 53	61	-	-
Bone residue	-	-	1004 ± 33	20	-	-
Press cake	1675 ± 45	33	951 ± 39	31	1394 ± 42	28
Bone ash	-	-	265 ± 12	5	-	-
Meal	670 ± 19	13	427 ± 13	9	649 ± 15	13
Process loss (discard)[1]	-	-	929 ± 27	19	-	-

[1] Material lost due to retention or contamination in the equipment during MSM production or during processes.

Table 2 - Proximate composition, energy value, physical parameters (pH and Aw) and mineral composition of carcass, mechanically separated meat (MSM), and head meals prepared from Nile tilapia (*Oreochromis niloticus*) waste.

	Carcass meal	MSM meal	Head meal
Proximate composition (%)^{1}			
Moisture	3.43 ± 0.06^{b}	3.63 ± 0.09^{b}	5.93 ± 0.07^{a}
Crude protein	56.45 ± 0.20^{b}	78.60 ± 0.23^{a}	50.33 ± 0.27^{c}
Total lipids	7.16 ± 0.09^{b}	13.15 ± 0.12^{a}	4.58 ± 0.08^{c}
Ash	32.61 ± 0.31^{b}	4.26 ± 0.16^{c}	38.41 ± 0.13^{a}
Carbohydrates	0.32 ± 0.20^{b}	0.35 ± 0.12^{b}	0.74 ± 0.12^{a}
Energy value (kcal/100 g)	291.63 ± 1.31^{b}	434.17 ± 0.50^{a}	245.51 ± 0.82^{c}
Physical parameters			
pH	7.33 ± 0.06^{a}	7.13 ± 0.03^{b}	7.15 ± 0.04^{b}
Water activity (Aw)	0.29 ± 0.02^{c}	0.31 ± 0.02^{b}	0.36 ± 0.05^{a}
Mineral composition (mg/100 g)^{2}			
Calcium	54.80	48.20	57.00
Iron	0.60	0.70	0.40
Phosphorus	213.30	272.90	229.00
Potassium	39.90	39.90	39.90
Magnesium	21.40	21.20	23.20
Zinc	0.50	4.30	0.50

[1] Results are expressed as mean ± standard deviation. $^{a-b-c}$Means within rows followed by different letters differ significantly by Tukey's test ($P \leq 0.05$).

[2] The results of the mineral composition of the fish meals are purely descriptive and cannot be used for comparisons between fish meals.

composition was significantly influenced by the type of fish waste ($P \leq 0.05$). Head meal had higher moisture content (5.93%) than carcass (3.43%) and MSM meals (3.63%). All meals, however, had moisture contents well below the regulatory limit for whole dry fish (12% moisture) (BRASIL, 1952; 2017; 2020). This is a beneficial result as the low moisture value of the products can be useful in maintaining the shelf life of these products. This is because the lower moisture content increases the resistance of products against microbial attacks and reduces enzymatic reactions (SABINO et al., 2017).

MSM meal had the highest protein (78.60%) and lipid (13.15%) contents, whereas head meal had the highest ash content (38%). MSM meal is composed of meat waste (skeletal muscle and fat) and some bone and cartilage residues resulting from the deboning process. Carcass meal, composed mainly of muscle and bone, had 28% and 45% lower protein and fat contents than MSM meal, respectively, but a 15% higher ash content. Head meal, because of its higher proportion of bone tissue, had 35% and 65% lower protein and fat contents, respectively, than MSM meal. This may be related to the higher moisture content observed in this meal since increasing the moisture content reduces the concentration of other nutrients (STEVANATO et al., 2008). The ash content of head meal, on the other hand, was 90% higher than that of MSM meal.

Nile tilapia bone meal prepared by PETENUCI et al. (2010) had higher moisture (14.2%) and total lipids (25.3%) contents but lower protein (40.8%) and ash (18.3%) contents than meals produced in the current study (Table 2). VIGNESH & SRINIVASAN (2012) and STEVANATO et al. (2008) determined the proximate composition of tilapia head meal; the moisture content was similar to that found in the present study, but protein and ash contents were lower. Lipid content varied greatly between studies: VIGNESH & SRINIVASAN (2012) reported a much lower total lipids content (0.20%) than that found in the current study, whereas STEVANATO et al. (2008) found a much higher total lipids content (35.46%). REBOUÇAS et al. (2012) analyzed Nile tilapia protein concentrate (MSM meal) and found similar moisture (4.85%), protein (85.16%), ash (2.45%) and lipid (8.20%) contents to those observed in the present study for MSM meal (Table 2). MSM meal prepared by VIDAL et al. (2011) had a similar proximate composition but a higher fat content (mean 32.63%) than the MSM meal obtained in the current study. EL-SHERIF et al. (2021) demonstrated that meal from crayfish by-products had 7.35 moisture, 61.75 crude protein, 6.02 fat, 23.66 ash and 1.22 carbohydrates. Thus, we found that the composition and nutritional value of fish meals may vary in approximate composition depending on the species, age, weight, type of residue and farming system of the fish. However, ours and these other studies show that the approximate composition of fish meals and their high nutritional value are within the values stipulated by the organizations that govern human nutrition, and can therefore be used in human and animal nutrition.

Head meal had a higher carbohydrate content (0.74%) than MSM (0.35%) and carcass meals (0.32%) ($P \leq 0.05$) (Table 2). Carbohydrates, however, accounted for less than 1% of meal composition (Table 2), as also observed by VIGNESH & SRINIVASAN (2012). MSM meal had 33% and 44% higher energy value than carcass and head meals, respectively, mainly because of its high lipid content (Table 2). According to MINOZZO (2011), the energy value of fish depends mostly on fat content. The energy values of carcass and head meals were lower than those of maize, wheat, and rice meals (330-370 kcal/100 g). MSM meal, in contrast, had a higher energy value than instant cereal (415 kcal/100 g) (SYAHIDA et al., 2023) and the energy value of instant cereal is derived mostly from carbohydrates (POUTANEN et al., 2022). Therefore, replacing cereal flours with fish waste flours is beneficial and attractive as it has the potential to increase the protein and lipid content of foods, while reducing the carbohydrate content and energy value.

All meals had low acidity. Carcass meal had a higher pH (7.33) than MSM (7.13) and head (7.15) meals ($P < 0.05$) (Table 2). The pH values of fish meals were similar to those of fresh shrimp (6.8-7.0), fish (6.6-6.8), and crustaceans (6.8-7.0) (International Association of Milk, Food and Environmental Sanitarians, IAMFES, 1995). Overall, the water activity of fish meals was low (< 0.60); the highest value ($P < 0.05$) was observed in head meal (0.36) (Table 2). These results suggest good microbial and enzymatic stability. Microbiological quality, moisture content, water activity, and pH are important indicators of food quality. High pH combined with high water activity may favor the proliferation of pathogenic microorganisms, such as Salmonella, Campylobacter, Yersinia, Escherichia coli, Shigella, Clostridium, and Staphylococcus spp. (IAMFES, 1995). The moisture content, water activity, and pH of fish meals were within the ideal range for good microbial, sensorial, and nutritional characteristics.

The results of the mineral composition of the fish meals presented in table 2 are purely descriptive and cannot be used for comparisons between fish meals. However, the results show that fish waste meals prepared in the present study are good sources of minerals and may be used to meet the daily protein, vitamin, and mineral needs of children and adults (ANVISA, 2005).

Table 3 presents the fatty acid profile of fish waste meals, trans fat was not detected in any meal. Unsaturated fats (65%-66%), particularly monounsaturated fats (34%-43%), were the major fatty acids in carcass, MSM, and head meals. Thirteen fatty acids were identified, and the most predominant were oleic (C18:1n−9), palmitic (C16:0), and linoleic (C18:2n−6) acids. Oleic acid exerts important hypolipidemic effects in the human body; it can reduce serum levels of cholesterol and triacylglycerols (MARTIN et al., 2006; NOGOY et al., 2020). Palmitic acid (C16:0), in contrast, is one of the most hypercholesterolemic and atherogenic fatty acids; consumption in large quantities is considered a risk factor for cardiovascular diseases (RAYMOD & COUCH, 2012; SILVA et al., 2020).

Although omega-3 fatty acids were detected in fish meals, they accounted for less than 1% of total lipids. Omega-6 fatty acid content ranged from 2.10 to 7.60 g/100 g. Omega-9 fatty acids was detected at the highest concentrations, reaching 15.90 g/100 g in MSM meal. Important omega-3 and -6 fatty acids were observed, such as docosahexaenoic (DHA), α-linolenic, and γ-linolenic. Many polyunsaturated fatty acids (omega-3, -6, and -9) are essential to humans. These compounds play important roles in the control and prevention of cardiovascular disease, arthritis, cancer, and other chronic conditions (GODOY et al., 2013; KHAN et al., 2021; MUKHAMETOV et al., 2022). The omega-6/omega-3 ratios of fish waste meals (7.00-7.80, Table 4) were within the range recommended by the FAO/WHO (1994) (5:1 to 10:1) (MUKHAMETOV et al., 2022). The ratios are lower than those obtained in a traditional Brazilian diet (10:1 to 25:1) but higher than that recommended by the Japan Society of Lipid Nutrition (4 to 5:1 for healthy adults and 2:1 for the prevention of chronic diseases in the elderly) (MARTIN et al., 2006). Because Nile tilapia is a freshwater fish, it has a low concentration of omega-3 and a high proportion of omega-6 and -9. A low dietary omega-6/omega-3 ratio is essential to maintain a healthy diet and reduce the risks of developing diseases. These groups of fatty acids may compete with each other for enzymes; therefore, the consumption of high amounts of one type of fatty acid may affect the metabolism of the other (GODOY et al., 2013).

Table 3 - Fatty acid profiles (g/100 g) of carcass, mechanically separated meat (MSM), and head meals prepared from Nile tilapia (Oreochromis niloticus) waste.

	Carcass meal	MSM meal	Head meal
----------Fatty acids----------			
Myristic (C14:0)	0.40	0.90	0.20
Palmitic (C16:0)	2.80	10.10	2.00
Palmitoleic (C16:1)	0.30	0.40	0.40
Stearic (C18:0)	0.90	2.20	0.60
Oleic (C18:1n−9)	4.40	14.60	2.30
Linoleic (C18:2n−6)	2.40	6.70	1.40
γ-Linolenic acid (C18:3n−6)	0.10	0.30	0.10
α-Linolenic (C18:3n−3)	0.10	0.60	0.10
cis-11-Eicosenoic (C20:1n−9)	0.20	0.90	0.10
cis-8,11,14-Eicosatrienoic (C20:3n−6)	0.00	0.00	0.20
Arachidonic (C20:4n−6)	0.60	0.60	0.50
Nervonic (C24:1n−9)	0.00	0.40	0.00
Docosahexaenoic (C22:6n−3)	0.30	0.30	0.20
ΣMonounsaturated fatty acids	4.90	16.40	2.90
ΣPolyunsaturated fatty acids	3.50	8.60	2.50
ΣUnsaturated fatty	8.40	25.00	5.40
ΣSaturated fatty acids	4.30	13.20	2.90
ΣTrans fatty acids	0.00	0.00	0.00
ΣOmega-3 fatty acids	0.40	1.00	0.30
ΣOmega-6 fatty acids	3.10	7.60	2.10
ΣOmega-9 fatty acids	4.60	15.90	2.50
Omega-6/omega-3 ratio	7.80	7.60	7.00
----------Lipid nutritional quality indicators[1]----------			
AI	0.52	0.55	0.53
TI	0.32	0.58	0.27
H/H	2.47	2.11	2.18

[1] AI: atherogenicity index; IT: thrombogenicity index; H/H: hypocholesterolemic/hypercholesterolemic fatty acid ratio.

To better understand the health implications of the fatty acid profile of fish waste meals, we determined atherogenicity and thrombogenicity indices (AI and TI, respectively). These indices are used to estimate the potential of a food to stimulate platelet aggregation (TONIAL et al., 2010; JAVARDI et al., 2020). Low atherogenicity and thrombogenicity values indicate high amounts of antiatherogenic fatty acids, which contribute to reducing the risk of coronary diseases (TONIAL et al., 2010). Carcass, MSM, and head meals had atherogenicity indices of 0.52, 0.55 and 0.53 and thrombogenicity indices of 0.32, 0.58 and 0.27, respectively. The ratio of hypocholesterolemic to hypercholesterolemic fatty acids (H/H) was 2.47, 2.11 and 2.18 in carcass, MSM, and head meals, respectively. These results are similar to those of TESTI et al. (2016) for fish fillet of three different species. According to BENTES et al. (2009), high H/H ratios indicate high nutritional quality. The ratio is directly proportional to the content of polyunsaturated fatty acids, compounds considered beneficial to human health (MATOS et al., 2019). Thus, the AI, IT and H/H values evaluated in this study, suggest that the three meals (carcass, MSM and head) may have beneficial effects on human health, preventing the occurrence of coronary diseases.

GODOY et al. (2013) detected 23 fatty acids in Nile tilapia carcass meal, including the omega-3 fatty acids eicosapentaenoic and docosahexaenoic. In a study by COSTA et al. (2016), Nile tilapia MSM meal was found to contain 23 fatty acids, with a predominance of monounsaturated fatty acids (8.06 to 24.56 g/100 g), as also observed in the current study, but with lower values (4.90 to 16.40g/100g).

SOUZA et al. (2022) evaluated carcass meal with Nile tilapia head and reported that this meal

Table 4 - Amino acid profiles (g/100 g) of carcass, mechanically separated meat (MSM), and head meals prepared from Nile tilapia (*Oreochromis niloticus*) waste.

	Carcass meal	MSM meal	Head meal
--Amino acids--			
Aspartic acid	3.71	3.80	2.30
Glutamic acid	6.10	8.20	4.00
Serine	2.40	2.70	2.00
Glycine	3.90	4.20	3.80
Histidine[1]	1.30	1.20	1.30
Taurine	0.00	0.00	0.00
Arginine	3.60	3.40	3.30
Threonine[1]	2.60	2.60	2.20
Alanine	2.50	2.10	3.20
Proline	2.90	3.20	2.80
Tyrosine	2.10	2.80	1.90
Valine[1]	2.70	2.90	2.40
Methionine[1]	1.50	1.80	1.20
Cystine	0.50	0.90	0.40
Isoleucine[1]	2.70	2.80	2.30
Leucine[1]	4.20	6.40	3.70
Phenylalanine[1]	2.30	2.70	2.10
Lysine[1]	4.90	5.20	4.00
Tryptophan[1]	0.40	0.40	0.40
ΣAmino acids	51.30	57.30	42.90
ΣEssential amino acids	22.60	26.10	19.40

[1] Essential amino acids.

had 33 major fatty acids, but of these, only three fatty acids in greater proportions, being palmitic (24.0 g/kg), oleic (35.5 g/kg) and linoleic (19.0 g/kg), while the other fatty acids found in percentages below 5.55 g/kg. However, the methodology used by SOUZA et al. (2022) was different from that used in this work, in which the meal was produced from the separate parts, head and spine (carcass) and this may be the cause of this difference, being associated with the type of raw material used. However, SOUZA et al. (2017) prepared meals with residues from different fish species, including tilapia.

In this work, the authors analyzed the meal made from tilapia carcasses, but without the head, using the same methodology as that applied in this experiment, for one of the treatments. The authors reported that 29 fatty acids were found, of which three were the majority, palmitic, oleic and linoleic, whose values were 21.05 g/kg, 25.66 g/kg and 11.24 g/kg, respectively. Even using the same methodology and cut (spine), these values reported by SOUZA et al. (2017) were much higher than those obtained in this work with the three types of tilapia waste meal.

This difference observed in the fatty acid profile, these differences are probably associated with the origin of the fish, body weight of the fish at slaughter, type of filleting residue (head or carcass with head) of the fish used, methodology applied in the production of meal, among other factors that may have influenced.

Fish waste meals had amino acid contents of 42.90 to 57.30 g/100 g, about 45% of which were essential amino acids (Table 4). The highest amino acid contents were found in MSM meal, although no statistical comparisons were made. Glutamic acid (4.0 to 8.2g/100g), leucine (3.7 to 6.4 g/100g), lysine (4.0 to 5.2 g/100g), and glycine (3.8 to 4.2 g/100g) were the major amino acids (Table 4). Our results corroborate those of COSTA et al. (2016), VIDOTTI & GONÇALVES (2006), CHO & KIM, 2011 and CORREA et al. (2023).

However, CORREA et al. (2023) observed more major amino acids, considering values above 4 g/100, they reported eight in tilapia backbone meal, the same four being observed in the meals of this experiment (glutamic acid, 8.5 g/100g, leucine 4.76

g/100g, glycine 4.91 g/100g and lysine 5.31 g/100g) and leucine (4.76 g/100g), alanine (4.10 g/100g), arginine (4.16 g/100g) and aspartic acid (4.52 g/100g). However, the values observed by the authors were higher than those obtained in this experiment.

COSTA et al. (2016), however, observed a decrease of 50% in amino acid content after oven-drying at 40, 50, and 60 °C. MSM meal meets almost all essential amino acid requirements of children aged 2 to 5 years (FAO/WHO, 1991): phenylalanine + tyrosine (6.3 g/100 g), histidine (1.9 g/100 g), isoleucine (2.8 g/100 g), leucine (6.6 g/100 g), lysine (5.8 g/100 g), methionine + cystine (2.5 g/100 g), threonine (3.4 g/100 g), tryptophan (1.1 g/100 g), and valine (3.5 g/100 g). Tryptophan is the limiting amino acid in MSM meal (11% of daily nutritional requirements). The other fish waste meals partially meet amino acid requirements of children. The protein quality of foods can be determined by the content of essential amino acids and non-essential nitrogen (VIDOTTI & GONÇALVES, 2006; ADHIKARI et al., 2022). Nile tilapia waste meals had good levels of the essential amino acids arginine, lysine, methionine, and threonine.

Color parameters differed significantly between meals ($P \leq 0.05$, Table 5). L^{*} was highest in carcass meal (77.19) and lowest in MSM meal (55.32). The high lipid content of MSM meal probably contributed to making it visibly darker (opaquer) than other meals. MSM meal had the lowest a^{*} value (4.44, slightly red), but the difference was not sufficient to produce visible changes in color and b^{*} values showed that meals were slightly yellowish (4.13 9.51), particularly MSM meal (Table 5). Our results differed from those of COSTA et al. (2016) for MSM meal. The authors reported lower values of L^{*} ranging from 50.57 to 59.16, a^{*} from 0.80 to 3.39 and higher values of b^{*} (12.03 to 14.24). CORREA et al. (2023) also observed a lower luminosity, intensity of yellow color (b^{*}) and greater intensity of red (a^{*}) in spine and head meal compared to the results obtained in this work. The authors observed 66.88 and 56.56 for luminosity in spine and head meal, values of 1.46 and 1.82 for a^{*} and 10.59 and 8.80 for b^{*}, respectively. FUZINATTO et al. (2015) also reported that tilapia spine meal had lower luminosity, therefore they obtained a darker meal (L = 41.73-42.79), with similar intensity of red (a^{*} = 1.47-1.80) and more yellowish meals (b^{*} = 19.42-20.11). The aforementioned works showed that the meals obtained were darker and with a greater intensity of red (b^{*}) in relation to the same parameters analyzed in this work for spine meal. Differences between studies are likely due to differences in raw materials and meal preparation techniques.

Particle size fractions differed significantly between fish meals ($P \leq 0.05$) (Table 5). MSM meal had the lowest percentage of fine particles (0.47%) and the highest percentage of intermediate particles (98.64%) (Table 5). The GMD diameter of meals ranged from 0.37 mm (carcass meal) to 0.99 mm (MSM meal). The MSM meal had a more homogeneous particle size distribution than carcass and head meals. The difficulty in grinding bone residues explains the higher heterogeneity of particle size in carcass and head meals. However, the fat content of MSM meal may have impaired the dispersion of fine particles, leading to a greater concentration of particles in intermediate sieves and increasing the geometric mean diameter of

Table 5 - Color coordinates, geometric mean particle diameter (GMD) and particle size fractions of carcass, mechanically separated meat (MSM), and head meals prepared from Nile tilapia (Oreochromis niloticus) waste.

	Carcass meal	MSM meal	Head meal
--------------Color coordinate--------------			
Lightness (L^{*})	77.19 ± 0.43^{a}	55.32 ± 0.46^{c}	62.49 ± 0.93^{b}
Redness (a^{*})	4.82 ± 0.061^{a}	4.44 ± 0.13^{b}	4.88 ± 0.10^{a}
Yellowness (b^{*})	5.29 ± 0.20^{b}	9.51 ± 0.08^{a}	4.13 ± 0.27^{c}
--------------Parameter--------------			
GMD (mm)	0.37 ± 0.05^{c}	0.99 ± 0.05^{a}	0.45 ± 0.015^{b}
Fine fraction (%)	91.66 ± 0.06^{a}	0.47 ± 0.12^{c}	85.32 ± 0.92^{b}
Intermediate fraction (%)	7.40 ± 0.12^{c}	98.64 ± 0.24^{a}	14.00 ± 0.88^{b}
Coarse fraction (%)	0.96 ± 0.15^{a}	0.88 ± 0.14^{a}	0.64 ± 0.11^{b}

Results are expressed as mean ± standard deviation. $^{a-b-c}$Means within rows followed by different letters differ significantly by Tukey's test ($P \leq 0.05$).

MSM meal. Particle size distribution may influence the texture, digestibility, and availability of nutrients in fish waste meals. This parameter depends on many factors, such as raw fish material, type of milling equipment, milling time, and meal moisture content.

There are limited data on the color, particle size, pH, oxidative stability, purchase intention, and consumer acceptability of fish waste meals. Because of the lack of standardized preparation methods, the composition of this by-product may vary greatly. Further studies should be carried out to support the elaboration of high nutritional value food products formulated with Nile tilapia waste meals.

CONCLUSION

In conclusion, the method used in this study to prepare carcass, MSM, and head meals afforded products with good physicochemical properties, microbial quality, and nutritional value. Meals had high contents of proteins (50-79%), minerals (30%), unsaturated fatty acids, glutamic acid, leucine, lysine, and glycine. Fish waste meals, particularly MSM meal, had a low thrombogenicity index and a high atherogenicity index because of the high concentrations of monounsaturated fats and palmitic acid. MSM meal had the highest protein and essential amino acid contents. Its high lipid concentration, however, may have affected color and particle size distribution. Nile tilapia carcass, MSM, and head meals show great physicochemical and nutritional, to be used as ingredients for enrichment in foods consumed daily by the population, but with low protein content, mineral and quality fatty acids, in addition, these meals provide a reduction in carbohydrate content.

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DECLARATION OF CONFLICT OF INTEREST

The authors have no competing interests to declare.

AUTHORS' CONTRIBUTIONS

All authors contributed equally to the design and writing of the manuscript. All authors reviewed the manuscript and approved the final version.

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