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COMPARATIVE ANALYSIS OF GENETIC GROUPS OF GREY AND RED TILAPIA: ELLIPTICITY, CARCASS YIELDS, PHYSICOCHEMICAL PROPERTIES AND LIPID NUTRITIONAL QUALITY

ANÁLISE COMPARATIVA DE GRUPOS GENÉTICOS DE TILÁPIA CINZA E VERMELHA: ELIPTICIDADE, RENDIMENTO DE CARCAÇA, PROPRIEDADES FÍSICO-QUÍMICAS E QUALIDADE NUTRICIONAL LIPÍDICA

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Diana Carla Fernandes Oliveira[1]

Francielly Corrêa Albergaria[2]

Ana Luiza de Souza Miranda[3]

Renan Rosa Paulino[4]

Priscila Vieira Rosa[5]

Maria Emília de Sousa Gomes[6]

Rilke Tadeu Fonseca de Freitas[7]

ABSTRACT

The study evaluated carcass yield, fillet quality, and lipid profile of different tilapia strains. Ten specimens from each genetic group (UFLA Red, UFLA, Genetic Group I, and Genetic Group II) were analyzed for morphometric traits, carcass yields, proximate composition, and lipid profile. Morphometric differences were observed only between UFLA and Group II. UFLA showed higher fillet yield and greater visceral fat deposition. Fillet color did not differ among groups; however, Group II presented higher pH values, while UFLA showed higher water activity. Group II had higher protein and ash contents, whereas UFLA Red exhibited the lowest values. Monounsaturated fatty acids predominated in all groups. Although PUFA/SFA ratios were similar, UFLA showed lower atherogenicity and thrombogenicity indices and a higher hypocholesterolemic/hypercholesterolemic ratio. Red and gray tilapia are valuable sources of high-quality protein and lipids.

Keywords: fish farming; morphometry.*Oreochromis* sp.

RESUMO

O estudo avaliou o rendimento de carcaça, a qualidade do filé e o perfil lipídico de diferentes linhagens de tilápia. Dez espécimes de cada grupo genético (UFLA Red, UFLA, Grupo Genético I e Grupo Genético II) foram analisados quanto às características morfométricas, rendimentos de carcaça, composição centesimal e perfil lipídico. Diferenças morfométricas foram observadas apenas entre a UFLA e o Grupo II. A UFLA apresentou maior rendimento de filé e maior deposição de gordura visceral. A cor dos filés não diferiu entre os grupos; entretanto, o Grupo II apresentou valores mais elevados de pH, enquanto a UFLA apresentou maior atividade de água. O Grupo II apresentou maiores teores de proteína e cinzas, enquanto a UFLA Red exibiu os menores valores. Os ácidos graxos

monoinsaturados predominaram em todos os grupos. Embora as razões AGPI/AGS tenham sido semelhantes, a UFLA apresentou menores índices de aterogenicidade e trombogenicidade e maior razão hipocolesterolêmico/hipercolesterolêmico. As tilápias vermelha e cinza são fontes valiosas de proteínas e lipídios de alta qualidade.
Palavras-chave: piscicultura; morfometria.*Oreochromis* sp.

1. INTRODUCTION

The Nile tilapia (*Oreochromis niloticus*) is the most common fish species in aquaculture due to its favorable production traits, meat quality, and strong acceptance in the consumer market (Prabu *et al.*, 2019; Grígio *et al.*, 2020). Historically, research in tilapia genetics has supported the evaluation of species and strains under various farming systems (Araújo et al., 2020), improvement in growth performance (Oliveira *et al.*, 2015; Morais *et al.*, 2017; Rodrigues *et al.*, 2018; Yoshida *et al.*, 2021), fillet yield (Rutten *et al.*, 2005; Turra *et al.*, 2012) and the production of all-male populations (Suresh, 1999; Dan Little, 2000; Hulata, 2001; Pechsiri; Yakupitiyage, 2005; Piferrer *et al.*, 2009).

Advancements in tilapia production have increased the demand for strains with improved performance and adaptability to agricultural environments, in order to meet the expectations of consumer markets and industrial processing (Wagner *et al.*, 2004). Over the years, several tilapia strains have emerged through selective breeding programs (Medina *et al.*, 2022), with particular emphasis on grey- and red-colored strains. Most tilapia exhibit a grey coloration and are genetically based on *Oreochromis niloticus*.

The red tilapia (*Oreochromis* sp.) is a hybrid strain that exhibits good performance (Brol *et al.*, 2017) particularly when farmed in brackish water. Due to its attractive coloration (Hamzah *et al.*, 2008), it is considered a viable alternative to Nile tilapia, as it is well accepted by consumers (Hilsdorf, 1995; Kubitza, 2006) and often commands higher market prices compared to grey tilapia (Clark *et al.*, 1990). However, consumers frequently question whether there are differences in meat quality between grey and red strains.

Although previous studies have evaluated the performance and fillet yield of farmed varieties, there is a lack of comparative research involving the more recently developed selectively bred strains in Brazil (Nunes *et al.*, 2023), particularly regarding carcass yield, fillet quality, and lipid profile. Therefore, the objective of the present study is to evaluate carcass yield, fillet quality, and lipid profile of different tilapia strains.

2. MATERIAL AND METHODS

This study was conducted at the Fish Laboratory, Federal University of Lavras (UFLA), Minas Gerais, Brazil, and was approved by the Ethics Committee on Animal Use (CEUA) under protocol No. 69/19. Ten specimens from four genetic groups were selected. The fish were reared under identical farming conditions and were fed twice daily (at 08:00 and 14:00 hours) with a commercial diet containing 32% crude protein (Table 1), offered to apparent satiation over a period of six months. Water quality parameters were maintained within the optimal range recommended for the species: temperature between 26–30°C; pH between 6.0 and 8.5; and dissolved oxygen levels above 4.0 $mg \cdot L^{-1}$ (Zimmermann; Fitzsimmons, 2004).

Table 1. Proximate composition and lipid profile of the commercial diet provided to different genetic groups of Tilapia spp.

Commercial feed with 32% crude protein	
Moisture (g/kg)	120
Crude protein (g/kg)	320
Ether extract (g/kg)	60
Crud fiber (g/kg)	45
Mineral Matter (g/kg)	120
Calcium (g/kg)	20
Phosphorus (g/kg)	6
Fatty Acids	
Saturated (SFA)	
Lauric (C12:0)	0.85
Myristic (C14:0)	1.73
Pentadecanoic (C15:0)	0.53
Palmitic (C16:0)	0.02
Heptadecanoic (C17:0)	1.50
Stearic (C18:0)	ND
Behenic (C22:0)	ND
ΣSFA 4.63	
Monounsaturated (MUFA)	
Palmitoleic (C16:1)	21.75
Oleic (C18:1 n9c)	8.30

Erucic (C22:1n9)	0.24
Nervonic (C24:1n9)	ND
ΣMUFA	30.29
Polyunsaturated (PUFA)	
γ - Linolenic (C18:2n6)	30.18
α - Linolenic (C18:3n3)	0.49
Eicosapentaenoic (C20:5n3)	0.50
Docosahexaenoic (C22:6n3)	ND
ΣPUFA 31.17	
Σ total fatty acids	
Omega 6	30.18
Omega 3	0.99
n6/n3	30.48
n3/n6	0.03

*ND- Not detected

Basic composition: corn grain; sprouted corn; corn gluten meal; ground whole corn; soybean meal; degummed soybean oil; wheat bran; meat and bone meal; blood meal; hydrolyzed feather meal; sodium chloride (common salt) (min) 2.800mg/kg; calcium propionate; iron sulfate (min) 30mg/kg; copper sulfate (min) 5mg/kg; manganese monoxide (min) 30mg/kg; zinc oxide (min) 60mg/kg; calcium iodate (min) 1mg/kg; cobalt sulfate (min) 0.10mg/kg; sodium selenite (min) 0.30mg/kg; vitamin A (min) 15,600mg/kg; vitamin D3 (min) 3,120 IU/kg; vitamin E (min) 65 IU/kg; vitamin K3 (min)

6.5mg/kg; vitamin B1 (min) 13mg/kg; vitamin B2 (min) 26mg/kg; niacin (min) 130mg/kg; pantothenic acid (min) 65mg/kg; vitamin B6 (min) 13mg/kg; folic acid (min) 5.2mg/kg; biotin (min) 0.30mg/kg; vitamin B12 (min) 52mg/kg; vitamin C (min) 350mg/kg; choline chloride (min) 480mg/kg; methionine (min) 6.5mg/kg; lysine (min) 17g/kg.

2.1. Experimental Sampling

To collect the 10 specimens from each genetic group, the fish were fasted for 24 hours. Initially, the selected specimens were sedated to obtain morphometric measurements and weighing: the specimens of UFLA Vermelha 448.604 ± 172.927 g; Genetic Group I 422.903 ± 217.423 g; UFLA 348.50 ± 135.452 g and Genetic Group II 448.601 ± 172.925 g. Subsequently, the fish were taken to deep anesthesia and euthanized with benzocaine (300 $mg.L^{-1}$). Once fully insensible, with no opercular movement or muscle activity, the spinal cord was severed according to McFarland (1959), as cited by Ross and Ross (2008). The internal organs (liver, gonads, and visceral fat) and skin (with scales) were collected and weighed. The fish were then filleted, and the head was removed (cut from the body at the junction with the vertebral column, including gills), as well as the fins (pectoral, dorsal, caudal, and anal) using a band saw. All parts were weighed to calculate the yield. Muscle samples and fillets were frozen at -80°C for further analysis.

2.2. Morphometric Measurements And Shape Calculation

The morphometric measurements were performed as described by Merigot *et al.*, (2007): standard length (SL), measured from the anterior end of the head to the narrowest perimeter of the peduncle

(insertion of the caudal fin); body height (BH), measured in front of the first dorsal fin ray; and body width (BW), taken at the region of the first dorsal fin ray. The standard length was measured using an ichthyometer, and the other measurements were taken with a caliper graduated in millimeters (mm). These measurements were used to calculate ellipticity, since the contours of the transverse planes approximate an ellipse (with all fins removed) (Trong *et al.*, 2013). The ellipticity calculation was performed using the body length (L), body height (H), and body width (T) measurements, as demonstrated in Trong et al., (2013). The equations used were: (1) Mid-saggital plane (E_{L-H}) = (Length - Height) / (Length + Height); (2) Traversal plane (E_{L-T}) = (Length - Thickness) / (Length + Thickness), and (3) Frontal plane (E_{H-T}) = (Height - Thickness) / (Height + Thickness). Higher values (maximum = 1) reflect more elongated shapes, while lower values represent more circular shapes. In a perfect circle, the ellipticity is zero.

2.3. Carcass Yields

To obtain the carcass characteristics, the following equations were used: live weight, carcass weight (live weight – fins, skin, internal organs, head, fillet), carcass yield (vertebral column and ribs), and other yields (%), including: head, fins, skin, liver, gonads, visceral fat, hepatosomatic index (%) = (liver weight ÷ fish weight) × 100, and gonadosomatic index (%) = (gonad weight ÷ fish weight) × 100. The fillet yield percentage was calculated relative to the whole fish, following the methodology adapted from Frascá-Scorvo *et al.* (2008).

2.4. Physicochemical Characterization Of The Fillet

Fillet color was measured using the Nix Color Sensor Pro (NPRO; Nix Sensor Ltd, Burlington, Ontario, Canada), employing the CIELab color system, defining the chromatic space in rectangular coordinates (L*, a*, b*), where: I) L* measures lightness, ranging from 100 for perfectly white surfaces to 0 for black; II) a* measures the intensity of red (+) and green (-); and III) b* measures the intensity of yellow (+) and blue (-) (Oliveira et al., 2019).

Water activity was determined using a 10 g sample at a standardized temperature of 25°C ± 1°C, and analyzed with the Aqualab® device (model 4 TE, Barueri, SP, Brazil). The pH values of the fillets were measured using a penetration electrode connected to a digital pH meter (model HI 99163, Hanna Instruments, Barueri, SP, Brazil).

For the chemical composition of the fillets, analyses were conducted for moisture (method No. 967.08), lipids (method No. 2003.06), ash (method No. 942.05), and protein (method No. 988.05), according to the methodologies outlined by the Association of Official Analytical Chemists (AOAC, 2012). Moisture and ash contents were determined by gravimetric methods of drying in an oven at 105°C and incineration of the sample, previously charred in a muffle furnace at 550°C, respectively. The lipid content was determined by extraction with ether using a Soxhlet apparatus. Protein content was estimated using the Kjeldahl method, with a nitrogen conversion factor of 6.25. All analyses were performed in triplicate.

2.5. Fatty Acid Profile And Nutritional Quality Indices

Fatty acids were extracted from a 1 g sample of the white muscle from the left fillet of the animals, following the methodology described by Folch, Lees, and Sloaney (1957) and methylated

according to Metcalfe, Schmitz, and Pelka (1966). The resulting methyl esters from the esterification process were subjected to gas chromatography (GC) analysis (GC-2010 model, Shimadzu, Barueri, SP, Brazil), with a flame ionization detector (FID), using a Carbowax capillary column (30 m × 0.25 mm) with a stationary phase: nitroterephthalic, modified with polyethylene glycol.

The nutritional quality of the lipid portion was determined through the fatty acid composition. The ratio of polyunsaturated fatty acids to saturated fatty acids was calculated by dividing the sum of these fatty acids, according to Equation 1. The atherogenicity index (AI) was calculated using Equation 2 (Ulbricht; Southgate, 1991).

$$(PUFA/SFA) = \Sigma PUFA/\Sigma SFA \text{ (equation 1)}$$

$$(IA)= C12:0 + [(4 \times C14:0) + C16:0] / (n\text{-}3\ PUFA + n\text{-}6\ PUFA + MUFA) \text{ (equation 2)}$$

The thrombogenicity index (TI) was calculated according to Equation 3, with C14:0, C16:0, and C18:0 representing myristic, palmitic, and stearic acids, respectively.

$$(TI)= (C14:0 + C16:0 + C18:0) /[(0.5 \times \Sigma MUFA) + (0.5 \times \Sigma n\text{-}6\ PUFA) + (3 \times \Sigma n\text{-}3\ PUFA) + (n\text{-}3/n\text{-}6)] \text{ (equation 3)}$$

The ratio of hypocholesterolemic to hypercholesterolemic fatty acids (HH) was calculated using Equation 4 (Santos-Silva et al., 2002). C12:0, C14:0, and C16:0 represent lauric, myristic, and palmitic acids, respectively; MUFA represents the sum of all monounsaturated fatty acids; and PUFA represents the sum of polyunsaturated fatty acids, ∫n-6, ∫n-3, which are the sums of the omega-6 and omega-3 fatty acids, respectively.

(H/H) = (C18:1n9 + C18:2n6 + C20:4n6 + C22:6n3 + C18:3n3 + C20:5n3 + C22:5n3) / (C14:0 + C16:0) (equation 4).

2.6. Statistical Analysis

The results are presented as mean ± combined standard error of the mean. Statistical analyses were performed using the SAS statistical software (Statistical Analyses System, 2004). The data were checked for normality and homogeneity of variances and analyzed using unidirectional or bidirectional analysis of variance (ANOVA). Significant differences between means were determined by the Tukey test. A probability level of 0.05 was used to reject the null hypothesis.

3. RESULTS AND DISCUSSION

Table 2 presents the values for the sagittal, transverse and frontal planes. A significant difference was observed between the UFLA genetic groups and Genetic Group II regarding the transverse plane.

Table 2. Ellipticity indices in the mid-sagittal plane (E_{L-H}), transverse plane (E_{L-T}), frontal plane (E_{H-T}) of different genetic groups of Tilapia ssp.

	Genetic Groups				
	UFLA Red	Genetic Group I	UFLA	Genetic Group II	*p*-val
Mid-sagittal plane	0.460 ± 0.180	0.456 ± 0.163	0.459 ± 0.148	0.462 ± 0.178	0.85

Transversal	0.678 ±	0.679 ±	0.606 ±	0.691 ±	0.034

⚠ Esta tabela possui muitas colunas e foi cortada para impressão. Para visualizá-la completa, acesse o artigo original em: https://revistatopicos.com.br/artigos/comparative-analysis-of-genetic-groups-of-grey-and-red-tilapia-ellipticity-carcass-yields-physicochemical-properties-and-lipid-nutritional-quality?noblockage

Values refer to the average of 10 fish (mean ± SD). Means with different letters in the same line are significantly different by the Tukey test at 5% significance.

The body shape of fish is becoming a focus of interest for both consumers (Freitas *et al.*, 2023) and producers, who are willing to pay higher prices for well-shaped fish (Trong *et al.*, 2013; Oliveira *et al.*, 2016). Ellipticality measurements provide a direct method to assess the body shape of fish. In the present study, a difference was observed in the transverse plane between UFLA and Genetic Group II. In addition, the values observed for the median sagittal plane (4.6) indicate a rounded body shape. Fish body shape is correlated with fillet weight and quality, where round fish tend to have higher yields than lean or long-bodied fish (Haffray *et al.*, 2013, Whatmore *et al.*, 2013).

Table 3 presents the body yields, gonadosomatic and hepatosomatic indices, as well as physical, physicochemical, and chemical parameters. It was observed that the UFLA genetic group showed a higher fillet yield and visceral fat content compared to the other groups. Additionally, while carcass and head composition did not differ between genetic groups, the UFLA Red variety showed a lower percentage of skin.

Table 3. Physical, physicochemical, and chemical characteristics of different genetic groups of Tilapia ssp.

	Genetic Groups				
	UFLA Red	Genetic Group I	UFLA	Genetic Group II	*p*-val
RF (%)	30.433 ± 1.865 ^{ab}	30.308 ± 1.717 ^{ab}	32.726± 2.163 ^{a}	29.849 ± 2.992 ^{b}	0.03(
Carcass (%)	15.029 ± 2.024	16.578 ±2.497	15.600 ± 1.410	14.647 ± 0.822	0.10(
Head (%)	30.288 ±	29.089 ±	27.835 ±	30.989 ±	0.06

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Values refer to the mean of 10 fish (mean ± SD). Means with different letters in the same row are significantly different by Tukey's test at 5% significance.

Regarding the physical, physicochemical, and chemical characteristics of the fillets, the genetic groups did not differ in the color parameters (L*, a*, and b*). However, the highest pH was observed in animals from genetic group II, while water activity was higher in the UFLA group. As for the chemical composition of the fillet, genetic group II exhibited the highest levels of protein and ash, while UFLA Red had the lowest levels of protein and ash, not differing from group II in terms of protein content. No differences

were observed between the groups regarding moisture content and ether extract.

The fillet is considered the prime cut of the fish and is the most accepted by consumers (Fernandes *et al.*, 2010). The average filleting yield of 30.82% observed in this study falls within the expected range, between 27% and 36% (Souza *et al.*, 2007). The result of this study is slightly higher than the 29.06% observed by Nunes *et al.* (2023) for males of the Aqua América variety and the 30.1% observed by Thodesen *et al.* (2012) for males of the first generation of selectively bred GIFT. The UFLA genetic group showed the highest fillet yield. This result highlights the significant genetic potential of this group. Considering that the current Nile tilapia market is mainly focused on fillet commercialization, this is an important trait to improve through selective breeding programs. Variations in fillet yield may be attributed to genetics (Geri *et al.*, 1995).

It is known that the percentage of waste is inversely related to the percentage of edible parts. The main fish waste components are the head, scales, skin, viscera, and carcass (skeleton with attached meat), which can represent between 50% (Feltes *et al.*, 2010) and depends on the species of fish being processed. In the present study, no differences were observed between genetic groups regarding the percentages of head, carcass, and fin yields. Nunes *et al.* (2023) found no differences in head yield when evaluating different genetic groups, Tilamax and Aqua América. Additionally, the average waste value of 57,43% observed in this study is lower than the values reported in the literature, around 60% (Chalamaiah *et al.*, 2012, Tahergoabi *et al.*, 2013), indicating that the genetic groups under study exhibit good utilization of edible parts.

It was observed that the UFLA Red showed lower skin yield; however, this lower yield did not result in higher fillet yield. Silva *et al.* (2009) found no differences in Nile tilapia skin percentages across different weight ranges.

The liver weight, gonad weight, gonadosomatic index, and hepatosomatic index did not differ between the varieties. However, UFLA showed a higher percentage of visceral fat (2.36).

The genetic groups did not differ regarding the parameters L*, a*, and b*. The similarity in fillet color between the fish indicates that these variables are not influenced by the genetic group, with no difference between the fillets of gray and red genetic groups. Similar results were observed in previous publications among gray genetic groups (Nunes *et al.*, 2023, Lima *et al.*, 2015, Rebouças *et al.*, 2017).

The trend in the preference of the national consumer market for red tilapia has been observed, providing better prices in the market when compared to gray tilapia, which makes red tilapia a variety with great potential to be explored. However, in the present study, no difference was observed between the color characteristics of the fillets.

The pH values of the fillets differed between genetic groups I and II. Muscle pH has a great influence on the quality of the fish, as it affects the water retention and texture properties of the products, due to its action on the solubility and functionality of the proteins (Zhang, 2017). The pH of the fish is generally between 5.4 and 6.2, insufficient to inhibit the growth of microorganisms, however, ideal for the activation of proteolytic enzymes in the muscle (Veiga Filho; Mesquita, 2018). Genetic group I presented a more acidic pH,

however within the pH range of the fish, not being sufficient to inhibit bacterial growth.

Water activity (Aw) values were close to 1.0. The UFLA variety showed the highest water activity, 0,97. According to Franco *et al.* (2013), microorganisms have varying levels of tolerance to water activity, but in general, the lowest Aw limit for most bacterial growth is 0.90. The value observed for the genetic groups is above 0.90. According to Girard (1991), meat products with water activity above 0.95 need to be stored at temperatures below -5°C, as they are considered susceptible to spoilage.

According to Yarnpakdee *et al.* (2014), the main chemical components of fish meat are water (50 to 85%), protein (12 to 24%), and lipids (0.1 to 22%), with 2% consisting of minerals (0.08 to 2%), carbohydrates (0.1 to 3%), and vitamins. Fillet quality is a key attribute when aiming to increase fish consumption (Nunes et al., 2023), which remains low in countries such as Brazil, where per capita fish consumption in 2018 was approximately 9 kg/year (FAO, 2018).

The genetic groups did not differ in moisture and ether extract content; however, significant differences were observed in protein and ash levels. Genetic Group I showed higher protein and ash content, while the UFLA Red group exhibited lower levels of both. Different results were reported by Olopade *et al.* (2016), who observed higher crude protein content in the fillet of hybrid (red) tilapia compared to *O. niloticus*. Oetterer, Siqueira, and Gryschek (2004), evaluating the proximate composition of fillets from two tilapia species, reported crude protein, lipid, ash, and moisture values of 16.62%, 1.68%, 1.07%, and 79.20%, respectively, for red tilapia, and 17.08%, 1.99%, 1.09%, and 78.43% for Nile tilapia.

Regarding the presence of fatty acids in the fillets of the varieties (Table 4), a higher content of monounsaturated fatty acids (MUFA) was observed (39.690 ± 4.962%). The most abundant polyunsaturated fatty acids were linoleic acid (C18:2 n6), eicosatrienoic acid (C20:3n3), linolenic acid (C18:3 n3) and eicosapentaenoic acid (EPA, C20:5n3).

Table 4. Fillets fatty acid profile of different genetic groups of Tilapia ssp.

Fatty acids	Genetic Groups				
	UFLA Red (10)	Genetic Group I (8)	UFLA (8)	Genetic Groups II (8)	*p*-val
Saturated (SFA)					
Lauric (C12:0)	1.047 ±1.983	ND	0.612 ± 0.544	0.351 ± 0.678	0.32
Myristic (C14:0)	2.683 ± 0.422a	1.779 ± 0.863b	1.608 ± 0.572b	2.129 ± 0.940ab	0.016

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Values refer to the mean of 10 fish (mean ± SD). Means with different letters in the same row are significantly different by Tukey's test at 5% significance.

Regarding the presence of fatty acids in the fillet, the highest concentration was of palmitoleic acid. Divergent results were

reported by Bonafé *et al.* (2013) in tilapia fillets fed with tung oil and by Higuchi *et al.* (2013), who evaluated different vegetable oils in the diet of tilapia fingerlings. In those studies, the predominant fatty acids were oleic acid (C18:1 n9), followed by palmitic acid (C16:0) and linoleic acid (C18:2 n6), as well as stearic acid (C18:0) in smaller proportions. Rodrigues *et al.* (2017), evaluating the nutritional quality of five Brazilian freshwater fish species—matrinxã (*Brycon cephalus*), tucunaré (*Cichla ocellaris*), curimbatá (*Prochilodus lineatus*), piau (*Leporinus friderici*), and pintado (*Pseudoplatystoma corruscans*)—found similar results, with palmitic, oleic, linoleic, and docosahexaenoic acids predominating.

The lipid nutritional quality values are presented in Table 5. The PUFA/SFA ratios were 1.627 ± 0.111, 1.690 ± 0.078, 1.692 ± 0.100 and 1.660 ± 0.158 for UFLA Red, Genetic Group I, UFLA and Genetic Group II, respectively. The observed AI and TI values were 0.229 ± 0.047 and 0.109 ± 0.070 for UFLA Red, 0.183 ± 0.034 and 0.052 ± 0.010 for Genetic Group I, 0.141 ± 0.046 and 0.059 ± 0.017 for UFLA, and 0.190 ± 0.033 and 0.073 ± 0.022 for Genetic Group II. The observed H/H values were 14.027 ± 2.708, 17.215 ± 7.499, 25.343 ± 9.485 and 16.371 ± 4.531 for UFLA Red, Genetic Group I, UFLA and Genetic Group II, respectively.

Table 5. Nutritional quality of the lipid portion in fillets different genetic groups of Tilapia ssp.

			Genetic Groups		
	UFLA Red	Genetic Group I	UFLA	Genetic Group II	*p*-val
PUFA/SFA	1.627 ± 0.111^{b}	1.690 ± 0.078^{a}	1.692 ± 0.100^{a}	1.660 ± 0.158^{ab}	0.04

AI	0.229 ± 0.047^{a}	0.183 ± 0.034^{ab}	0.141 ± 0.046^{b}	0.190 ± 0.033^{a}	0.00

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Values refer to the mean of 10 fish (mean ± SD). PUFA/SFA- Polyunsaturated fatty acid/Saturated fatty acid ratio; AI- Atherogenic Index; TI – Thrombogenic Index; H/H- Hypocholesterolemic/Hypercholesterolemic fatty acids ratio. Means with different letters in the same row are significantly different by Tukey's test at 5% significance.

Among the free fatty acids (FFA), the predominant fatty acid was heptadecanoic acid (C17:0), which can induce hypercholesterolemia in humans (Fernandes *et al.*, 2014), representing a potentially negative aspect of the result. Genetic Group I and Red UFLA presented higher percentages than UFLA and Genetic Group II. From a nutritional point of view, fish consumption is widely recommended by several health authorities, foundations and associations as a beneficial source of omega-3 fatty acids. The PUFA/SFA and n6/n3 ratios are considered useful indicators of nutritional quality (Memon *et al.*, 2011; Mert *et al.*, 2015). According to FAO/WHO (2010), a minimum PUFA/SFA ratio of 0,45 is recommended to achieve a balanced intake of fatty acids. The PUFA/SFA ratios of the fillets of all varieties in this study were above the minimum recommended value, indicating a favorable consumption. Higher PUFA/SFA ratios were observed by Mert *et al.* (2015) in Esox lucius (2.46), and in Lates niloticus (3.15) by Ugoala *et al.*

(2009), as well as by Rodrigues *et al.* (2020) for Brazilian freshwater species, with PUFA/SFA values ranging from 2.67 to 3.93.

The Atherogenicity Index (AI) indicates the relationship between the sum of major saturated fatty acids and the main types of unsaturated fatty acids (Ulbricht; Southgate, 1991). The Thrombogenicity Index (TI) reflects the tendency to form clots in blood vessels. Therefore, lower values are desirable for both indices, as they are associated with better nutritional fat quality and a reduced risk of cardiovascular diseases. Ouraji *et al.* (2009) and Stancheva *et al.* (2014) reported that AI and TI values greater than 1,0 are harmful to human health. The values observed in the present study are below 1, thus the Nile tilapia varieties analyzed in this study can be considered beneficial for human health.

Fernandes *et al.* (2014) reported higher AI values for tilapia raised in net cages (0.42) and values close to the TI observed in sardine fillets (0.20). Rodrigues *et al.* (2020), evaluating the lipid profile of four species — pacu (*Piaractus mesopotamicus*), tambaqui (*Colossoma macropomum*), tambacu (*Piaractus mesopotamicus* × *Colossoma macropomum*), and pirapitinga (*Piaractus brachypomus*) — found AI and TI values ranging from 0,18 to 0,25 and from 0.04 to 0.12, respectively.

The hypocholesterolemic/hypercholesterolemic fatty acid index (H/H) is based on the functional effects of fatty acids on cholesterol metabolism (Santos *et al.*, 2002; Fernandes *et al.*, 2014). Thus, in contrast to AI and TI, high H/H values are recommended to provide health benefits. Matos *et al.* (2017) reported H/H values of 2.94 for Hungarian carp, 2.21 for tilapia fillets raised in net cages, and 2.15 for grass carp. The values observed for the varieties exceed those

reported by Fernandes *et al.* (2014) for marine fish (0.87 ± 2.46). Therefore, the Nile tilapia varieties in this study provide health benefits to consumers.

4. CONCLUSION

Red and gray tilapia varieties show similarities in body shape and chemical composition. The Nile tilapia varieties evaluated in this study proved to be excellent sources of protein, fatty acids, and favorable nutritional quality indices of the lipid fraction, suggesting that the consumption of any tilapia variety can be considered beneficial to human health.

Data availability

The data used in this study are publicly available in the institutional repository of the Federal University of Lavras (UFLA), ensuring transparency and access to information for verification, replication, and use in future research.

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[1] Pesquisadora na Empresa Brasileira de Pesquisa Agropecuária (Embrapa) – Unidade Embrapa Caprinos e Ovinos. E-mail: acesse o artigo original para visualizar o e-mail

[2] Doutora em Ciência dos Alimentos, Universidade Federal de Lavras. E-mail: acesse o artigo original para visualizar o e-mail

[3] Doutora em Ciência dos Alimentos, Universidade Federal de Lavras. E-mail: acesse o artigo original para visualizar o e-mail

[4] Doutor em Zootecnia, Universidade Federal de Lavras. E-mail: acesse o artigo original para visualizar o e-mail

[5] Doutora em Zootecnia, Universidade Federal de Lavras. E-mail: acesse o artigo original para visualizar o e-mail

[6] Doutora em Zootecnia, Universidade Federal de Lavras. E-mail: acesse o artigo original para visualizar o e-mail

[7] Doutor em Zootecnia, Universidade Federal de Lavras. E-mail:
acesse o artigo original para visualizar o e-mail