NUTRIVISA

ORIGINAL ARTICLE

https://doi.org/10.52521/nutrivisa.v12i1.15710

Development, proximate composition, and oxidative stability of mechanically separated tilapia meatballs added with garlic extract

Elaboração, composição centesimal e estabilidade oxidativa de almôndegas de carne de tilápia separada mecanicamente adicionada de extrato de alho

Alynne Rodrigues da SILVA[1] Jéssica Frota COSTA[1] Janevane Silva de CASTRO[1]
Luiz Alves BITU[1] Marcelo Levi Almeida de MENEZES[1] José Ariévilo Gurgel RODRIGUES[1]
Larissa Morais Ribeiro da SILVA[1] Alessandra Cristina da Silva FARIAS[1]
Ana Paula Colares de ANDRADE[1] Ianna Wivianne Fernandes de ARAÚJO[1]*

[1]Universidade Federal do Ceará - UFC, Fortaleza, Ceará, Brasil

*Corresponding author: iwfaraujo@gmail.com

ABSTRACT

Fish meatballs are a value-added product that is widely accepted, but their perishability requires the use of additives that are safe for human consumption. This study evaluated the incorporation of garlic clove extract into tilapia meatballs containing mechanically separated meat (MSM). Tilapia MSM meatballs were shaped by hand, and four formulations were developed: negative control: no additive, positive control: 0.1% butylhydroxytoluene (BHT), F3%: 3% garlic extract, and F6%: 6% garlic extract. The formulations were analyzed for nutritional quality, water-holding capacity (WHC), weight loss (WL), pH, and thiobarbituric acid reactive substances (TBARS) after 28 days of refrigeration. The chemical composition differed from MSM, but the addition of preservatives (garlic extract and BHT) did not affect the nutritional quality of the tilapia meatballs. Although there was no change in WHC or WL, garlic extract delayed pH and TBARS parameters, especially in F6% at 21-28 days, making this product more stable than BHT, used as a reference. Therefore, tilapia meatballs formulated with garlic extract are a convenient option that meets the quality standards set by Brazilian legislation.

Keywords: minced fish; fish technology; co-product; natural preservative; stability.

RESUMO

Almôndega de peixe é um produto de valor agregado com alta aceitabilidade, mas sua perecibilidade requer o uso de aditivo sem causar danos à saúde humana. Este estudo avaliou a incorporação de extrato de dente de alho em almôndegas de tilápia desenvolvidas a partir de carne mecanicamente separada (CMS). Almôndegas de CMS de tilápia foram produzidas manualmente e quatro formulações (controle negativo: sem aditivo; controle positivo: butil-hidroxitolueno-BHT a 0,1%; F3%: extrato de alho a 3%; F6%: extrato de alho a 6%) foram caracterizadas em termos de qualidade nutricional, capacidade de retenção de água (CRA), perda de peso (PP), pH e substâncias reativas ao ácido tiobarbitúrico (SRAT) após 28 dias de refrigeração. Os resultados mostraram que a composição química diferiu da CMS, mas a aplicação dos conservantes (extrato de alho e BHT) não teve efeito na qualidade nutricional das almôndegas de tilápia. Embora não tenha ocorrido variação na CRA e PP, o extrato de alho retardou os parâmetros de pH e SRAT, especialmente em F6% aos 21-28 dias, sendo a estabilidade deste produto mais eficaz do que o BHT utilizado como referência. Portanto, a almôndega de tilápia formulada com extrato de dente de alho revela-se uma opção de conveniência com os atributos de qualidade estabelecidos pela legislação brasileira.

Palavras-chave: peixe moído; tecnologia do pescado; coproduto; conservante natural; estabilidade.

Cite this article as

SILVA, A. R. da; COSTA, J. F.; CASTRO, J. S. de; BITU, L. A.; MENEZES, M. L. A. de; RODRIGUES, J. A. G.; SILVA, L. M. R. da; FARIAS, A. C. da S.; ANDRADE, A. P. C. de; FERNANDES, I. Elaboração, composição centesimal e estabilidade oxidativa de almôndegas de carne de tilápia separada mecanicamente adicionada de extrato de alho. Nutrivisa Revista de Nutrição e Vigilância em Saúde, Fortaleza, v. 12, n. 1, p. e15710, 2025. DOI: 10.52521/nutrivisa.v12i1.15710. Disponível em: https://revistas.uece.br/index.php/nutrivisa/article/view/15710.

INTRODUCTION

The Nile tilapia (Oreochromis niloticus Linnaeus 1758) is one of the most widely marketed aquaculture species in Brazil, with a production of 534,000 tons in 2022 (FAO, 2022). Its nutritional value (e.g., essential amino acids, unsaturated fatty acids, vitamins, and minerals) makes this freshwater fish suitable for human consumption. The process of producing mechanically separated meat (MSM) allows one to mince carcasses of different sizes and weights while still providing edible parts with beneficial characteristics for the development of versatile technological options with desirable attributes (Biscalchingryschek *et al.*, 2003; Kirschnik; Macedo-Viegas, 2009; Angelini *et al.*, 2013; Ribeiro *et al.*, 2014; Fogaça *et al.*, 2015; Lustosa-Neto *et al.*, 2018; Leite *et al.*, 2024).

Meatballs are ground meat rolled into balls and can be ready-made products mixed with other ingredients and seasonings. They are a practical technological alternative to the current demand for healthier meat products with optimal acceptability in consumers' daily diets as popular snacks (Lustosa-Neto *et al.*, 2018; Aviles *et al.*, 2020; Akkaya *et al.*, 2024). However, processing and storage can alter meat quality due to diverse physiological and biochemical events (e.g., oxidation and microbiological contamination), which discourages consumers from purchasing meat products (Aviles *et al.*, 2020). Incorporating synthetic or natural antioxidants into fresh meat products or coatings is a key strategy for neutralizing or reducing these issues and extending shelf life (Mei; Ma; Xie, 2019). Studies have revealed that seaweed (Ribeiro *et al.*, 2014), plant (Chen *et al.*, 2024), and animal (Wang *et al.*, 2025) extracts are safe alternatives to synthetics (Mei; Ma; Xie, 2019), which can cause toxic reactions in consumers when consumed frequently (Cenci-Goga *et al.*, 2020).

Garlic (Allium sativum L.) is well-known for its antimicrobial (Fadare *et al.*, 2022) and antioxidant (Maney *et al.*, 2014) properties. It is often added to animal products to minimize chemical or microbial changes (Paglarini *et al.*, 2018; Zhang *et al.*, 2024).

Given the susceptibility of fish meat to physical, chemical, and microbiological changes, MSM from tilapia (Oreochromis niloticus) is a promising alternative. This raw material can be used to formulate various value-added products that offer technological and nutritional benefits. Thus, this study aimed to develop meatballs containing MSM from tilapia and added garlic extract, determine their proximate composition, and evaluate the product's oxidative stability during 28 days of refrigerated storage.

MATERIALS AND METHODS

Nile tilapia for MSM production and microbiological quality

Forty monosex specimens of O. niloticus (34.746 kg) were purchased from local stores in Fortaleza, state of Ceará, Brazil, in July 2024. The fish had an average weight of 849 g and an average length of 33 cm. The fish were transported in polystyrene boxes (2:1 ice--to-fish ratio) to the National Department of Works Against Droughts (DNOCS) in Pentecoste, Brazil, for MSM production. Before this, the fish were washed to remove mucus and impurities resulting from handling. Then, they were scaled, eviscerated, and stored in a sealed box with ice. The fish were registered with the National System for the Management of Genetic Heritage and Associated Traditional Knowledge (SISGEN CODE ADA3181). Upon arrival at the DNOCS, the fish were filleted in a processing unit. This involved making a cut with a knife behind the head or at the base of the pectoral fins that reached the dorsal spine; the meat was then separated from the central spine by cutting along the spine toward the tail. The MSM was separated from the spine using a deboning machine (HT 250) (BISCALCHINGRYSCHEK *et al.*, 2003; KIRSCHNIK; MACEDO-VIEGAS, 2009). Finally, the MSM was washed with filtered water according to Angelini *et al.* (2013) and Ribeiro *et al.* (2014). The MSM samples from Nile tilapia were packaged in ~1 kg portions using polyethylene bags, which were sealed and frozen at -22°C for further transport to the Meat and Fish Processing Laboratory at the Department of Food Engineering at the Federal University of Ceará. The microbiological quality of the MSM was checked for the presence of Salmonella, Escherichia coli, coagulase-positive Staphylococcus, and mesophilic aerobes, and was compared with the standards established by Collegiate Board Resolution No. 724

https://doi.org/10.52521/nutrivisa.v12i1.15710

through Normative Instruction No. 161 of July 1, 2022 (BRAZIL, 2022).

Preparation of garlic clove extract

A. sativum samples (500 g) of garlic cloves that had been washed and peeled were added to 250 mL of distilled water at a ratio of 1:2 (m/v), as described by Fadare *et al.* (2022), who properly crushed the cloves before aqueous extraction. The mixture was then ground in a blender for 5 min until homogeneous. Then, the mixture was filtered through filter paper with 125-mm porosity to obtain liquid garlic clove extract. Two solutions were prepared (3% and 6%) and stored at temperatures between -14°C and -25°C until use.

Elaboration of the MSM meatball

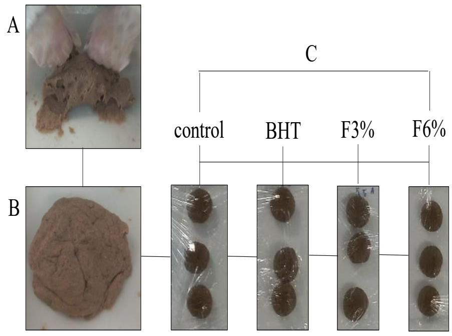
Tilapia MSM meatballs were prepared using the methodology described by Castro *et al.* (2019). The MSM dough was mixed with the predetermined ingredients and homogenized. The synthetic antioxidant BHT and garlic extract were then incorporated at concentrations of 3% (F3%) and 6% (F6%) (Table 1 and Figure 1). Each 50 g meatball was shaped by hand and refrigerated at 4 ± 1 °C for subsequent stability assessment analyses. The amount of BHT added to the co-product followed the Brazilian legislation (BRASIL, 2006).

Table 1 - Formulations of Nile tilapia MSM meatballs.

Ingredients	NC	PC	F3%	F6%
MSM	80.1% 400.5g	80% 400g	77.1% 385.5g	74.1%, 370.5g
soy protein	6.6% 33g	6.6% 33g	6.6% 33g	6.6% 33g
moisture	5% 25mL	5% 25mL	5% 25mL	5% 25mL
salt	2% 10g	2% 10g	2% 10g	2% 10g
onion	5% 25g	5% 25g	5% 25g	5% 25g
pepper	1% 10g	1% 10g	1% 10g	1% 10g
glutamate	0.3% 3g	0.3% 3g	0.3% 3g	0.3% 3g
BHT	0%	0.1% 1g	0%	0%
garlic extract	-	-	3% 15mL	6% 30mL
unit	50g	50g	50g	50g

negative control (NC): without BHT; positive control (PC): added BHT; F3%: added 3% garlic extract; F6%: added 6% garlic extract with chitosan as an edible coating.

Figure 1 - Tilapia meatball development stages. Fresh MSM was homogenized with the ingredients (A) prior to product modeling (B), which was formulated with four treatments (control: no additive, BHT, F3%, and F6%) (C) and kept frozen for 28 days.



Proximate composition

The moisture (%), protein (%), lipid (%), and ash (%) determination was performed according to AOAC (2005), while the carbohydrate level (%) was calculated by subtracting the sum of the percentages of the other constituents from 100%. The assays were performed in triplicate. The caloric value was obtained using Equation 1 according to Atwater's factors (1910).

$$\text{Caloric value} = (\text{g/100g proteins} \times 4) + (\text{g/100g carbohydrates} \times 4) + (\text{g/100g lipids} \times 9) \quad (1)$$

Water holding capacity and weight loss

The water holding capacity of the meatballs was measured using the modified Barbut (1997) method. This method calculates the difference between the initial and final masses after discarding the supernatant and dividing it by the initial mass, then multiplying by 100. This calculation is represented by Equation 2.

$$WHC (\%) = ((mi - mf)/mi) \times 100 \quad (2)$$

Where: mi = initial mass; mf = final mass

Weight loss and shrinkage of the meatballs due to cooking were determined according to Liu *et al.* (2004). The weight loss and size reduction (area) were expressed as percentage reductions. The weights were considered before (m1) and after (m2) cooking, as described by Chen *et al.* (2024) and calculated using Equation 3.

$$\text{Cooking loss (\%)} = (m1 - m2) / m1 \times 100\% \quad (3)$$

Measurement of pH

The pH analysis was conducted in triplicate using a digital potentiometer (PG3000), which was measured with 10 g of ground sample homogenised manually for 1 min in 10 mL of distilled water (PREGNOLATO; PREGNOLATO, 1985).

Oxidative evaluation

Lipid oxidation was evaluated using the thiobarbituric acid reactive substances (TBARS) method according to Vynche (1970). Tetramethoxypropane was used to obtain the straight-line equation, which was used to calculate the TBARS values. Aldehydes were extracted from a homogenized aqueous acid extract prepared with 5 g of the sample and 25 mL of trichloroacetic acid diluted in propyl gallate and a chelating agent (sodium EDTA) to avoid the erroneous formation of malonaldehyde or other thiobarbituric acid-reactive substances during mixing and filtration of the sample. The filtered extract then reacted with the TBARS solution in a water bath at 95 °C for 40 min to form a colored complex. This complex was measured using a spectrophotometer at a wavelength of 532 nm. The results are expressed as a TBARS value, defined as mg of malonaldehyde per kg of sample.

Statistical analysis

Data analysis was based on the study by Chen *et al.* (2024), in which the determinations were repeated three times, considering four treatments × three batches × four stockpiles, with three parallel sets each time. Values were expressed as mean ± standard deviation. The data obtained were statistically analyzed using the GraphPad Prism® 5.01 software (GraphPad Software, 1992–2007, San Diego, CA; www.graphpad.com). The data were subjected to a two-way ANOVA analysis where treatment and storage time were considered fixed variables and repetition was considered a random effect. A level of significance of $P < 0.05$ was considered statistically significant using Duncan's multiple range test.

RESULTS AND DISCUSSION

Chemical characterization of the tilapia meatball

The meatballs had a high moisture content (70.6 to 76.56%), with the highest value found in the formulation that did not add an antioxidant, possibly due to the hydration of the myofibrillar proteins of the washed fresh MSM (Kirschnik; Macedo-Viegas, 2009). Meanwhile, the presence of organosulfur compounds in the garlic extract would retain water that would be available for microbial action (Fadare *et al.*, 2022). The ash content ranged from 0.81 to 3.62%, with the highest results found in the BHT, F3%, and F6% formulations. The F0 formulation had a lipid content of 7.53%, while the BHT control, F3%, and F6% formulations had lower values (1.28–1.30%). Protein values ranged from 14.94 to 19.41% and the carbohydrate content was very low (0.14 to 4.61%) (Table 2).

The composition values of fresh tilapia MSM differed from the values reported by Lustosa-Neto *et al.* (2018) for protein (21%) and lipids (2.3%). However, the average values for proteins (8.93–15.87%), lipids (1.63–7.62%), ashes (0.46–0.96%), and carbohydrates (0.64%) in fresh tilapia MSM were similar to those in other studies (Biscalchingryschek *et al.*, 2003; Kirschnik & Macedo-Viegas, 2009; Ribeiro *et al.*, 2014; Fogaça *et al.*, 2015; Leite *et al.*, 2024). Therefore, these parameters may also depend on the raw first-matter used.

As can be seen (Table 2), the use of garlic extract and BHT did not modify the chemical composition of these formulations ($p > 0.05$). The compositional levels were also similar to those of tilapia MSM with seaweed (Ribeiro *et al.*, 2014) and other co-products, such as surimi (Angelini *et al.*, 2013; Fogaça *et al.*, 2015), in terms of proteins (14.4–14.81%) and lipids (7.75–8.3%), except for ash content (0.48–2.5%), which depended on the elaborated product.

The different values found for fresh tilapia MSM, in terms of protein, ash, carbohydrate, and moisture, compared to those found in formulated products, were the result of the addition of ingredients (Lustosa-Neto *et al.*, 2018). However, when considering the respective parameters of tilapia meatballs, the addition of garlic clove extract did not significantly influence the nutritional quality or caloric value (Ribeiro *et al.*, 2014; Fogaça *et al.*, 2015), but the values were significantly different from those of washed MSM based

Table 2 - Proximate composition of *in natura* MSM and chilled Nile tilapia meatballs.

parameter (%)	chemical composition (g 100 g^{-1})			
	MSM	BHT control	F3%	F6%
moisture	76.55 ± 0.09^{a}	70.61 ± 0.03^{a}	70.87 ± 0.34^{a}	71.52 ± 0.20^{a}
proteins	14.94 ± 0.12^{b}	18.61 ± 0.69^{a}	19.40 ± 0.29^{a}	18.95 ± 0.04^{a}
lipids	7.53 ± 0.00^{b}	1.29 ± 0.07^{a}	1.30 ± 0.00^{a}	1.28 ± 0.00^{a}
ashes	0.81 ± 0.00^{b}	3.60 ± 0.04^{a}	3.56 ± 0.02^{a}	3.61 ± 0.02^{a}
carbohydrates	0.143^{b}	5.87^{a}	4.83^{a}	4.61^{a}
caloric value, Kcal g^{-1}	128.16^{b}	109.59^{a}	108.75^{a}	105.87^{a}

Control: added BHT; F3%: added 3% garlic clove extract; F6%: added 6% garlic clove extract. Similar letters among the formulations indicate absence of statistical difference ($p > 0.05$).

on its origin, processing, and/or fat adhesion when handling was used (Biscalchingryschek *et al.*, 2003; Leite *et al.*, 2024).

The stability of the tilapia meatballs in terms of moisture and reduction of liquid was not affected by changes to the flesh during refrigeration (Table 3). Greater weight loss during cooking (27.4%) was attributed to the structural disintegration and fragmentation of the fish's musculature in mechanically deboned fresh meat (Biscalchingryschek *et al.*, 2003). Paglarini *et al.* (2018) observed a reduction in water content with the addition of inulin, a natural carbohydrate found in garlic. This strengthened the protein network structure in emulsion gels for meat products. There is little evidence regarding the interaction between garlic and the moisture content of animal meat; however, specific interactions could develop between garlic and myofibrillar proteins (Wang *et al.*, 2025).

Meatball pH

The pH values ranged from 5.92 ± 0.00 (day 0) to 6.54 ± 0.01 (day 28) among the formulations and were in accordance with the RIISPOA Brazilian legislation (Brasil, 2017). An increase in pH values was observed throughout the 28 days of storage, which can be attributed to possible chemical and microbial changes during shelf life. Notably, the 6% garlic clove extract formulation delayed the pH values at the end of the experiment, whereas the 3% formulation presented increases in pH, similar to the BHT control (Table 4). The values suggested that there was less formation of nitrogenous bases during the MSM extraction and in the storage time of meatballs in other studies (Kirschnik; Macedo-Viegas, 2009; Fang *et al.*, 2018; Lustosa-Neto *et al.*, 2018).

Although the values were within the range established by national legislation (Brasil, 2001), the pH of the F6% tilapia meatballs had a more significant

Table 3 - Water loss of *in nature* MSM and chilled Nile tilapia meatballs.

Formulations	water holding capacity (%)	weight loss due to cooking (%)
negative control	61.16 ± 1.01^{b}	7.62 ± 0.07^{a}
positive control	53.22 ± 1.24^{a}	7.60 ± 0.09^{a}
F3%	52.59 ± 1.12^{a}	7.48 ± 0.12^{a}
F6%	52.56 ± 1.15^{a}	7.57 ± 0.16^{a}
MSM	89.88 ± 1.19^{c}	27.44 ± 0.16^{b}

Control: added BHT; F3%: added 3% garlic clove extract with chitosan coating; F6%: added 6% garlic clove extract. Similar letters among the formulations indicate absence of statistical difference ($p > 0.05$).

values for traditional products, but positively affecting this paramater in the final F6% (Paglarini *et al.*, 2018), which may result in a good acceptability after 28 days of storage (Cenci-Goga *et al.*, 2020). The organosulfur compounds found in garlic clove extract create a stabilizing environment that delays deterioration in meatballs (Mnayer *et al.*, 2014; Fadare *et al.*, 2022). The behavior of pH in each treatment group increased during refrigeration (Table 4), which aligns with refrigerated beef meatballs (Chen *et al.*, 2024). The authors discussed the pH profile during refrigeration, which is explained by the presence of microorganisms that degrade proteins and other meat compounds to produce ammonia and amines, thereby raising the pH.

effectively delays lipid oxidation in the meat product (Zhang *et al.*, 2024).

In fact, this major antioxidant response from the addition of garlic extract could also be associated with the reduced values in pH, as observed in Table 4, whose inhibitory effect generated an environment favorable to the oxidative stability of the product. Therefore, the additional use of garlic clove extract may provide a greater stabilizing effect (Gim *et al.*, 2017) and prevent approximately 1.58 times more oxidation than meatballs treated only with BHT during refrigeration, as well as a greater inhibitory effect than F3%, according to Chen *et al.* (2024), who analyzed pork stored in a modified atmosphere at 4 °C.

Table 4 - pH values of the refrigerated tilapia meatball formulations.

formulation	day 0	day 7	day 14	day 21	day 28
control	5.92 ± 0.00^{a}	6.10 ± 0.01^{a}	6.05 ± 0.00^{a}	6.20 ± 0.01^{a}	6.54 ± 0.01^{a}
F3%	5.92 ± 0.00^{a}	6.09 ± 0.01^{a}	6.01 ± 0.01^{a}	6.13 ± 0.00^{a}	6.48 ± 0.01^{a}
F6%	5.93 ± 0.01^{a}	6.03 ± 0.01^{a}	5.95 ± 0.04^{a}	6.08 ± 0.00^{b}	6.29 ± 0.00^{b}

Control: added BHT; F3%: added 3% garlic clove extract; F6%: added 6% garlic clove extract. Different letters among the formulations indicate statistical difference ($p < 0.05$).

Oxidative stability

The measurement of lipid oxidation, where epoxides formed from unsaturated fatty acids present in meat products produce malondialdehyde (Vynche, 1970), revealed that the TBARS values for MSM samples of Nile tilapia were 1.58 ± 0.02 mg kg-1 malondialdehyde (Table 5). This contrasts with the values reported by Biscalchingryschek *et al.* (2003), Kirschnik and Macedo-Viegas (2009), Fogaça *et al.* (2015), and Angelini *et al.* (2013) for fresh MSM from Nile tilapia, which were related to the origin of the MSM: 0.14, 0.25–0.49, 1.03 ± 0.01, and 1.12 mg kg-1, respectively.

Regarding tilapia meatball (Table 5), there was a continuous increase in TBARS values in tilapia meatballs from all formulations throughout the 28 days of refrigerated storage, as expected for washed MSM (Kirschnik; Macedo-Viegas, 2009). However, significant differences were observed over time, particularly in F6%, which had significantly lower TBARS values than F3%, the BHT control, and the MSM. This finding supports the idea that the natural additive more

Fluctuations in TBARS values were observed for quenelles (Angelini *et al.*, 2013) and surimi fish burgers (Fogaça *et al.*, 2015) over 28 days of storage. These fluctuations were attributed to the biological composition of the ground fish meat, the antioxidant ingredients used, the reduction of lipid oxidation, and the storage time. In this study, chilled tilapia meatballs were stable foods with regard to toxic compounds and had TBARS levels acceptable to consumers for up to 28 days, since Brazil does not establish a limit for fishery products regarding TBARS (Angelini *et al.*, 2013). According to Kirschnik and Macedo-Viegas (2009), reference values of less than 3 mg kg-1 of malonaldehyde were reported as acceptable for consumption. These authors discussed the stability of Nile tilapia MSM in terms of TBARS values over 180 days at 18 °C. Results showed that garlic clove extract drastically impacted TBARS values more rapidly than other treatments until the last day of storage, indicating that this approach can prevent lipid oxidation earlier (Table 5). Similar behavior was found in TBARS values in pork

Table 5 - TBARS values (mg kg^{-1}) in the tilapia meatball during 28 days of storage.

formulation	day 0	day 7	day 14	day 21	day 28
MSM	1.589 ± 0.02^{b}	-	-	-	-
control	1.304 ± 0.01^{a}	2.138 ± 0.02^{a}	3.053 ± 0.01^{a}	3.816 ± 0.03^{a}	4.894 ± 0.02^{a}
F3%	1.446 ± 0.01^{a}	2.00 ± 0.01^{b}	2.149 ± 0.02^{b}	2.253 ± 0.07^{b}	3.243 ± 0.01^{b}
F6%	1.307 ± 0.00^{a}	1.68 ± 0.00^{c}	1.996 ± 0.01^{c}	2.152 ± 0.01^{c}	3.101 ± 0.03^{c}

Control: added BHT; F3%: added 3% garlic clove extract with chitosan coating; F6%: added 6% garlic clove extract. Different letters among the formulations indicate statistical difference ($p < 0.05$).

application during storage in a modified atmosphere at 4 °C (Fang *et al.*, 2018).

The study promoted the eco-friendly use of MSM from O. niloticus to develop meatballs enriched with garlic clove extract. These refrigerated products have desirable physicochemical, nutritional, and oxidative stability attributes. The practical technological use of a food matrix containing garlic clove extract can validate the development of biotic formulations that benefit the gastrointestinal system (Fadare *et al.*, 2022). This represents a low-cost option for meeting the current demand for healthier meat in daily diets (Lustosa-Neto *et al.*, 2018; Aviles *et al.*, 2020; Akkaya *et al.*, 2024).

CONCLUSION

Mechanically separated tilapia (Oreochromis niloticus) meat from processing waste, allowed to make meatballs composed of natural ingredients and garlic extract at concentrations of 3% and 6%. This generated an important technological option with practical applications, providing nutritional quality in terms of protein, lipid, ash, and carbohydrate content, as well as a reduced caloric value. There was no difference in cooking loss, and the pH and lipid oxidation were delayed over the storage time under refrigeration, especially between 21 and 28 days. Thus, it is a natural alternative to commercially available butylhydroxytoluene.

The tilapia meatballs formulated with garlic extract and stored in the refrigerator showed uniform behavior for 28 days. They had good added value in terms of stability, quality, and practicality as popular, health-promoting foods.

REFERENCES

AKKAYA, E.; BINGOL, E.B.; MURATOGLU, K.; HAMPIKYAN, H.; CETIN, O.; COLAK, H. Impact of microwave heating on product safety and quality in meatballs. Innovative Food Science & Emerging Technologies, v.93, p.103643, 2024. doi: https://doi.org/10.1016/j.ifset.2024.103643

ANGELINI, M.F.C.; GALVÃO, J.A.; VIEIRA, A.F.; SILVA, L.K.S.; SHIRAHIQUE, L.D.; CABRAL, I.S. R.; MODESTA, R.C.D.; GALLO, C.R.; OETTERER, M. Shelf life and sensory assessment of tilapia quenelle during frozen storage. Pesquisa Agropecuária Brasileira, v.48, p.1080-1087, 2013. doi: https://doi.org/10.1590/S0100-204X2013000800038

AOAC. Official methods of analysis. 18 th ed. Washington, DC, USA: Association of Official Analytical Chemists, 2005.

ATWATER, W. O. Principles of nutrition and nutritive value of food, Farmers' Bulletin, 142, Washington: Government Printing Office, US Department of Agriculture, (1910).

AVILES, M.V.; NAEF, E.F.; ABALOS, R.A.; LOUND, L.H.; OLIVERA, D.F.; GARCÍA-SEGOVIA, P. Effect of familiarity of ready-to-eat animal-based meals on consumers' perception and consumption motivation. International Journal of Gastronomy and Food Science, v.21, 100225, 2020. doi: https://doi.org/10.1016/j.ijgfs.2020.100225

BARBUT, S. Problem of pale soft exudative meat in broiler chickens. British Poultry Science, v.38, n.4, p.355-358, 1997. doi: https://doi.org/10.1080/00071669708418002

BISCALCHINGRYSCHEK, S.F.; OETTERER, M.; GALLO, C.R. Characterization and frozen storage stability of minced Nile tilapia (Oreochromis niloticus) and red tilapia (Oreochromis spp.). Journal of Aquatic Food Product Technology, v.12, p.57-69, 2003. doi: https://doi.org/10.1300/J030v12n03_06

BRASIL. Agência Nacional de Vigilância Sanitária (ANVISA). Resolução da Diretoria Colegiada – RDC nº 724, de 1º de julho de 2022. Brasília, DF, n. 126, p. 205, 2022. Disponível em: https://in.gov.br/en/web/dou/-/resolucao-rdc-n-724-de-1-de-julho-de-2022-413364812 Access in 18 mar. 2023.

BRASIL. Instrução normativa nº 161 de 1º julho de 2022. Estabelece os padrões microbiológicos dos alimentos. [Brasília, DF]: ANVISA, 2022. Disponívelem:https://antigo.anvisa.gov.br/documents/10181/2718376/IN_161_2022_.pdf/b08d70cb-add6-47e3-a5d3-fa317c2d54b2. Acesso em: 18 set. 2024.

BRASIL. Ministério da Agricultura e do Abastecimento. Secretaria de Defesa Agropecuária. Instrução Normativa n° 20, de 31 de julho de 2000. Regulamentos Técnicos de Identidade e Qualidade de Almôndega, de Apresuntado, de Fiambre, de Hambúrguer, de Kibe, de Presunto Cozido e de Presunto. Disponível em: https://www.gov.br/agricultura/pt-br/assuntos/defesa-agropecuaria/suasa/regulamentos-tecnicos-de-identidade-e-qualidade-de-produtos-de-origem-animal-1/rtiq-carneos-e-seus-derivados-1 Access in 18 mar. 2024.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. Instrução Normativa nº 51, de 29 de dezembro de 2006. Regulamento técnico para atribuição de aditivos e seus limites para as seguintes categorias de alimentos: carnes e produtos cárneos. Diário Oficial da União, Brasília, DF, 29 dez. 2006. Disponível em https://www.normasbrasil.com.br/norma/instrucao-normativa-51-2006_76049.htmlxxxxx Acesso em :20 de mar.2024

BRASIL. Decreto nº 9.013, de 29 de março de 2017. Regulamento da inspeção industrial e sanitária de produtos de origem animal (RISPOA). Pescado e derivados, C7, seção 1. Brasília: Ministério da Agricultura, Pecuária e Abastecimento. Disponível em: https://intranet.cati.sp.gov.br/wp-content/uploads/2021/08/DECRETO-9013_2017-Inspecao-Industrial-e-Sanitaria-POA.pdf Acesso: em 20 de mar.2024

CENCI-GOGA, B.T.; KARAMA, M.; HADJICHRALAMBOUS, C.; SECHI, P.; GRISPOLDI, L. Is EU regulation on the use of antioxidants in meat preparation and in meat products still cutting edge. European Food Research and Technology, v.246, n.4, p.661-668, 2020. doi: https://doi.org/10.1007/s00217-020-03433-y

CHEN, Y.; ZHA, E.; ZHANG, Z.; ZHANG, J.; WANG, R.; LI, J.; SUN, J. Effect of combined treatment of curcumin and sodium bicarbonate on quality characteristics of refrigerated beef meatballs. LWT - Food Science and Technology, v.204, 116483, 2024. doi: https://doi.org/10.1016/j.lwt.2024.116483 agric

FAO. The state of world fisheries and aquaculture 2022: towards blue transformation. Rome: FAO, 2022. Disponível em: https://openknowledge.fao.org/items/11a4abd8-4e09-4bef-9c12-900fb4605a02 Acesso em: 20 de mar.2024

FARARE, O.S.; SINGH, V.; ENABULELE, O.I.; SHITTU, O.H.; PRADHAN, D. In vitro evaluation of the synbiotic effect of probiotic Lactobacillus strains and garlic extract against Salmonella species. LWT - Food Science and Technology, v.153, 112439, 2022. doi: https://doi.org/10.1016/j.lwt.2021.112439

FOGAÇA, F.H.S.; OTANI, F.S.; PORTELLA, C.G.; SANTOS-FILHO, L.G.A.; SANT'ANA, L.S. Characterization of surimi from mechanically separated tilapia meat and fishburger preparation.

Semina: Ciências Agrárias, v.36, p.765-775, 2015. doi: https://doi.org/10.5433/1679-0359.2015v36n2p765

KIRSCHNIK, P.G.; MACEDO-VIEGAS, E.M. Efeito da lavagem e da adição de aditivos sobre a estabilidade de carne mecanicamente separada de tilápia do Nilo (Oreochromis niloticus) durante estocagem a –18 °C. Ciência e Tecnologia de Alimentos, v.29, n.1. p.200-206, 2009. doi: https://doi.org/10.1590/S0101-20612009000100031

LEITE, L.O.; NOGUEIRA, S.M.S.; SILVA, A.I.M.; VALE, D.A.; CERQUEIRA, D.A.; SILVA, A.L.C.; FILHO, M.S.S.; SOUZA, B.W.S. Development and characterization of myofibrillar protein film obtained from Nile tilapia mechanically separated meat (MSM). Revista Ciência Agronômica, v.55, e20238808, 2024. doi: https://doi.org/10.5935/1806-6690.20240036

LIU, Y.; LYON, B.G.; WINDHAM, W.R.; LYON, C.E.; SAVAGE, E.M. Principal component analysis of physical, color, and sensory characteristics of chicken breasts deboned at two, four, six, and twenty-four hours postmortem. Poultry Science, v.83, n.1, p.101-108, 2004. doi: https://doi.org/10.1093/ps/83.1.101

LUSTOSA-NETO, A.D.; NUNES, M.L.; MAIA, L.P.; BARBOSA, J.M.; LIRA, P.P.; FURTADO-NETO, M.A.A. Meatballs of pirarucu and Nile tilapia: characterization and application in school meals. Acta of Fisheries and Aquatic Resources, v.6, n.2, p.1-12, 2018. doi: https://doi.org/10.2312/Actafish.2018.6.2.1-12

MEI, J.; MA, X.; XIE, J. Review on natural preservatives for extending fish shelf life. Foods, v.8, p.1-23, 2019. doi: https://doi.org/10.3390/foods8100490

MNAYER, D.; FABIANO-TIXIER, A.S.; PETITCOLAS, E.; HAMIEH, T.; NEHME, N.; FERRANT, C.; FERNANDES, X.; CHEMAT, F. Chemical composition, antibacterial and antioxidant activities of six essentials oils from the Alliaceae Family. Molecules, v.19, p.20034-20053, 2014. doi: https://10.3390/molecules191220034

PAGLARINI, C.S.; FURTADO, G.F.; BIACHI, J.P.; VIDAL, V.A.S.; MARTINI, S.; FORTE, M.B.S.; CUNHA, R.L; POLLONIO, M.A.R. Functional emulsion gels with potential application in meat products. Journal of Food Engineering, v.222, p.29-37, 2018. doi: https://doi.org/10.1016/j.jfoodeng.2017.10.026

PREGNOLATO, W.; PREGNOLATO, N.P. (Coords). Métodos químicos e físicos para análise de alimentos. In: PREGNOLATO. Normas analíticas do Instituto Adolfo Lutz 3.ed. São Paulo: Instituto Adolfo Lutz, v.1, p.533, 1985.

RIBEIRO, I.S.; SHIRAHIGUE, L.D.; SUCASAS, L.F.A.; ANBE, L.; CRUZ, P.G.; GALLO, C.R.; CARPES, S.T.; MARQUES, M.J.; OETTERER, M. Shelf life and quality study of minced tilapaia with nori and hijiki seaweeds as natural additives. The Scientific World Journal, v.2014, 485287, 2014. doi: https://doi.org/10.1155/2014/485287

VYNCKE W. Direct determination of the thiobarbituric acid value in trichloroacetic extracts of fish as a measure of oxidative rancidity. Fette, Seifen, Anstrichmittel, v.72, n.12, p.1084-1087, 1970.

RECEBIDO: 13/6/2025
ACEITO: 19/9/2025
PUBLICADO: 22/9/2025