Effect of grilling and baking on physicochemical and textural properties of tilapia (*Oreochromis niloticus*) fish burger

Eduarda Molardi Bainy · Larissa Canhadas Bertan ·
Marcos Lucio Corazza · Marcelo Kaminski Lenzi

Revised: 7 September 2014 / Accepted: 9 October 2014 / Published online: 19 October 2014
© Association of Food Scientists & Technologists (India) 2014

Abstract The influence of two common cooking methods, grilling and baking, on chemical composition, water retention, fat retention, cooking yield, diameter reduction, expressible water, color and mechanical texture of tilapia (*Oreochromis niloticus*) fish burgers was investigated. Texture analyses were performed using a Warner-Bratzler test. The fish burger had a softer texture with a lower shear force than other meat products reported in the literature. There were no significant differences in proximate composition, diameter reduction, fat retention and expressible water between the grilled and oven-baked fish burgers. Cooking methods did not affect the cooking times and cooking rates. Warner-Bratzler parameters and color were significantly influenced by the cooking method. Grilling contributed to a shear force and work of shearing increase due to the lower cooking yield and water retention. Raw burgers had the highest L^* (69.13 ± 0.96) and lowest b^* (17.50 ± 0.75) values. Results indicated that baking yielded a product with better cooking characteristics, such as a desired softer texture with lower shear values (4.01 ± 0.54) and increased water retention (95.82 ± 0.77). Additionally, the baked fish burgers were lighter (higher L^*) and less red (lower a^*) than the grilled ones.

Keywords Fish · Cooking methods · Texture · Color

Introduction

About 81 % of the global production of fish are destined for human consumption, and it was estimated that the world demand for fish will increase in all continents, reaching 17.9 kg per capita by the year 2020 (OECD/FAO 2011). This growing demand is a result of a positive consumer perception that fish and its products are healthy and nutritious foods with beneficial effects on human health (OECD/FAO 2011).

The world's largest producer of tilapia is China with 1.5 million tons in 2012, followed by Egypt, Indonesia, Philippines, Thailand and Brazil (FAO GLOBEFISH 2014). Tilapia is the most commonly farmed species in Brazil, whose production exceeded 253 thousand tons in 2011, representing 47 % of the national production of fish in continental waters (MPA 2011) and growing approximately 17 % per year (MPA 2013). Despite the known nutritional value of fish, the fish meat represents only 5 % of the meat consumed in Brazil (FIESP 2009). This low consumption is due to lack of habit of Brazilian consumers and a limited availability of convenience food products, such as fish burger, fish fingers, sausage, and others.

There are few studies in the literature regarding fish-based products, such as fish burger, and not enough information about the potential use of meat from tilapia (*Oreochromis niloticus*) to produce these products. Tokur et al. (2004) monitored the chemical and sensory changes in tilapia fish burger during frozen storage. Other studies have evaluated the quality and stability during chilled and frozen storage of fish burgers from catla (*Catla catla*), Arabian sea meagre (*Argyrosomus heinii*) and rainbow trout (*Oncorhynchus mykiss*) (Vanitha et al. 2013; Al-Bulushi et al. 2005; Taskaya et al. 2003).

Different cooking methods reduced moisture and increased the protein contents of catfish (*Rhamdia quelen*) fillets (Weber et al. 2008). Cooking methods also

E. M. Bainy (✉) · L. C. Bertan
Department of Food Engineering, Federal University of Southern
Border, P.O. Box 106, 85.301-970 Laranjeiras do Sul, PR, Brazil
e-mail: ebainy@gmail.com

M. L. Corazza · M. K. Lenzi
Department of Chemical Engineering, Federal University of Paraná,
81531-990 Curitiba, PR, Brazil

affected the proximate composition of sardine (*Sardina pilchardus*) fillets (García-Arias et al. 2003). Bochi et al. (2008) reported that fish burgers produced from silver catfish (*Rhamdia quelen*) fillets and filleting wastes had similar fat and moisture retention after cooking. Additionally, the cooking process also affected the color parameters of silver catfish burgers, mainly due to a yellow color development and lightness decrease in all formulations tested. However, to the best of our knowledge, no studies were found on the effect of cooking methods such as grilling and baking, which are commonly used to prepare this type of product on the texture properties, color and cooking characteristics of tilapia fish burger.

Considering the importance of diversification of fish-based products due to its high nutritional value, as well as the lack of studies in this area, the objective of this study was to investigate the effect of different cooking methods - grilling and baking - on the chemical composition, cooking characteristics, color and texture of tilapia (*Oreochromis niloticus*) fish burger.

Material and methods

Fish burger manufacture

Tilapia fillets (*Oreochromis niloticus*) were obtained from a local market in the city of Curitiba (Paraná, Brazil). The fillets were maintained chilled at 4 °C for up to 2 days of storage. The fillets were washed in cold water at 4 °C containing 5 ppm of chlorine for 15 min. The formulation of fish burger was based on the study of Bochi et al. (2008) with modifications. Six independent batches were produced. For each batch of 1,000g, 880g minced tilapia and 120g hydrated textured soy protein (TSP) (1:2 w/v TSP/water) were used. The following ingredients were incorporated into the mixture: salt (1.5 %), onion powder (0.1 %), garlic (0.1 %), coriander powder (0.2 %), white pepper powder (0.1 %), sodium glutamate (0.2 %), and the binding agents: wheat flour (5 %), cold water (10 %) and sunflower oil (5 %). The formulation consists of 72 % minced tilapia, 3 % TSP, 2 % condiments, and 23 % binding agents. The mass of fish was kept at low temperature (ice water bath) for partial formation of protein gel, and mixed manually until obtaining a homogeneous mass. The mass was weighed and shaped in a manual hamburger mold with 11 cm in diameter to obtain burgers with 80g each. Fish burgers were individually packaged in high-density polyethylene bags packed into PVC-lined hermetic boxes and stored at 4 °C.

All analyses were made immediately after preparation (raw samples) and after cooking (cooked samples).

Microbiological analysis

Procedures described in the Compendium of Methods for the Microbiological Examination of Foods (APHA 2001) were followed for *Escherichia coli*, *Staphylococcus aureus* and *Salmonella* sp. analyses. *E. coli* was enumerated by the Most Probable Number (MPN) technique using Lauryl Sulfate Tryptose broth, incubated at 35(±)2 °C for 48 h, and confirmed with a long-wave ultraviolet lamp to check the tubes for fluorescence. *S. aureus* was determined by spread plate method using Baird Parker Agar and plates were incubated at 35(±)2 °C for 48 h. *Salmonella* detection used lactose broth and incubated at 35(±)2 °C for 24 h. Culture media were from Oxoid (Oxoid, Cambridge, UK).

Cooking methods

Two common ways of cooking were used. Six fish burgers per treatment were submitted to: (1) Electric grill (Grill Light 3, Britania, Sao Paulo, Brazil) with 980 W of power, pre-heated to a temperature around 150 °C, without thermostat and cooked with the grill cover closed; (2) Forced air convection oven (Forno Vipinho mod 0448, Curitiba, Brazil) with 10 kW of power, pre-heated and set at an average temperature of 150°C with the thermostat device. The average air velocity of the oven was 1.3 m/s, measured by a thermal anemometer. The temperature was monitored at the geometric center of the product until the final temperature of 76 °C, using T-type thermocouples. After cooking, the burgers were cooled at room temperature for 1 h and blotted before weighing for subsequent analysis.

Cooking curves

A thermocouple (Type T) was inserted into the geometric center of the fish burger. A second thermocouple was used to measure air temperature in the oven or the grill surface temperature, located approximately 2 cm from the sample. All thermocouples were connected to a data acquisition system (FieldLogger, Novus, Porto Alegre, Brazil) connected to a computer. Temperature data were recorded every 10 s during testing. Prior to the experiments, the grill and the oven were pre-heated to 150 °C. The time required for fish burger to cook from room temperature to 76 °C was determined for baking and grilling. All experiments were conducted in triplicate.

Cooking rate

The time for the centre temperature of the fish burger to increase from room temperature to the final temperature of 76 °C was recorded. The cooking rate was determined as:

$$\text{Cooking rate} = \frac{\text{half thickness of sample(mm)}}{\text{cooking time(min)}}$$

The mean cooking rate was calculated from the cooking time of the individual samples.

Proximate composition

The chemical composition was performed for the raw tilapia fillets, raw tilapia burgers, and cooked burgers by both cooking methods. The moisture, protein and ash contents were determined according to AOAC methods (AOAC 2000). The lipid content was determined according to Bligh and Dyer (1959). All analyses were performed in triplicate.

pH and water activity

The *pH* was measured on a suspension resulting from blending a 10g sample with 100 mL distilled water for 2 min with a pH meter (Tecnopon mod. mPA210, Piracicaba, Brazil). Water activity (*aw*) was measured at 25°C using an Aqualab system (mod. series 3TE, Pullman, United States) with direct readings. All determinations were performed in triplicate.

$$\% \text{fat retention} = \frac{(\text{cooked weight(g)} \times \% \text{average fat in cooked samples})}{(\text{raw weight(g)} \times \% \text{average fat in raw samples})} \times 100$$

$$\% \text{moisture retention} = \frac{(\text{cooked weight(g)} \times \% \text{moisture in cooked samples})}{(\text{raw weight(g)} \times \% \text{moisture in raw samples})} \times 100$$

Cooking characteristics

The fish burgers were weighed in a semi-analytical balance before and after each cooking method, as described by Berry (1992), for six replicates per treatment. The cooking yield was obtained using the following equation:

$$\% \text{Cooking yield} = \frac{\text{cooked weight(g)}}{\text{raw weight(g)}} \times 100$$

The diameters were measured in both raw and cooked burgers, using digital caliper 150 mm with accuracy of 0.01 mm. Two measures were obtained for each sample (6 burgers) for each treatment using fixed locations, according to Berry (1992). The diameter reduction percent was calculated as follows:

$$\% \text{Diameter reduction} = \frac{(\text{raw diameter} - \text{cooked diameter})}{\text{raw diameter}} \times 100$$

Lipids and moisture contents were determined in the raw samples and cooked samples by both cooking methods in order to estimate the remaining contents after each cooking method, according to Aleson-Carbonell et al. (2005). The following equations were used to estimate the fat and moisture retention values, respectively.

Expressible water

The amount of expressible water in baked and grilled fish burger was determined as described by Ramirez et al. (2002). The expressible water (EW) is inversely proportional to the water holding capacity (WHC), thus the lowest percentage of water extracted means the highest WHC. For the analysis, 2.4g (±0.3g) of cooked samples were weighed and placed on a layer of Whatman No. 1 filter paper for ten replicates per treatment. The samples were placed in the bottom of 50 mL centrifuge tubes and centrifuged at 1,500×g for 5 min, 25°C. After

centrifugation, the samples were weighed again, and the amount of expressible water was estimated as following:

$$\text{Expressible water} = \frac{\text{Initial weight(g)} - \text{Final weight(g)}}{\text{Initial weight(g)}} \times 100$$

Shear force

Two cylindrical samples (2.5 cm diameter) were taken for each fish burger, totaling 12 replicates per cooking method. The samples were subjected to a shear force test with a

Warner-Bratzler blade attached to a Texture Analyzer Brookfield (model CT3, Middleboro, United States), as described by Das et al. (2008). The crosshead speed was 2 mm/s. The maximum force required to cut the sample (shear force) and the work required to move the blade through the samples (work of shearing) were obtained.

Color measurements

The color of the raw, baked and grilled fish burgers was measured by L^* , a^* , b^* system, using a spectrophotometer HunterLab MiniScan (model XE Plus-45/0-L, Reston, United States) calibrated with white and black ceramic plates. The measurements were performed with D65 illuminant at observer angle 10° . In this color system, L^* represents lightness ($L^*=0$ is black and $L^*=100$ is white) and a^* and b^* are the color coordinates representing chromaticity: $+a^*$ is red and $-a^*$ is green; $+b^*$ is yellow and $-b^*$ is blue (Hunterlab 1996). The parameters chroma ($C^*=(a^{*2}+b^{*2})^{0.5}$) and hue angle [$h^\circ=\arctg(b^*/a^*)$] were calculated using the a^* and b^* values. Chroma is expressed as intensity and clarity of the color. Hue angle (H^*) is the observable color and is defined as starting at the $+a$ axis and is expressed in degrees: 0° would be red, 90° would be yellow, 180° would be green and 270° would be blue. Color measurements were performed on the surface of three cooked burgers per treatment at four randomly selected locations at room temperature ($\sim 22^\circ\text{C}$).

Statistical analysis

Analysis of variance (ANOVA) was used to determine significant difference ($p<0.05$) between cooking methods and between samples state (raw and cooked). Post hoc analysis was carried out using Tukey's test. Differences were considered to be significant when $p<0.05$. Data were analyzed using the *Statistica* for Windows (Statsoft Inc., Tulsa, USA).

Results and discussion

Microbiological quality

For the determination of the initial freshness quality of fish burgers before cooking, *E. coli*, *S. aureus* and *Salmonella* sp. were analyzed. *E. coli* and *S. aureus* were found to be <3 MPN/g and $<10^2$ CFU/g, respectively. The International Commission on Microbiological Specifications for Food (ICMSF) recommends that *E. coli* and *S. aureus* should not exceed 500/g and 10^4 /g, respectively. *Salmonella* sp. could not be found, as required by ICMSF. These recommendations were met by our results. These data indicate that the

processing of fish burger until cooking was conducted under good hygienic-sanitary conditions.

Cooking curves

Temperature-time curves of the center of fish burger samples during baking and grilling processes are shown in Fig. 1. Both methods apply dry heat to the sample. The sample subjected to baking took a longer time, about 20 s, to increase the temperature. This happened due to the opening of the oven door when the sample was placed in the oven which decreased the temperature causing this delay. On the other hand, grilling uses a pre-heated surface which is the heat source and the temperature increases more quickly reaching 30°C in 20 s of process, as observed in Fig. 1. However, baking increased the central temperature of the sample more quickly after 40 s (Fig. 1) when the oven temperature reached again the pre-set temperature (150°C). During baking, heat transfer occurs mainly by convection of heated air around the sample which cooks the sample more uniformly. On the contrary, grilling heat is applied to the top of the surface of the food and heat is transferred by conduction taking a longer time for the central temperature to reach higher temperatures. Table 1 shows the fish burger thickness, cooking time to reach the final temperature of 76°C and cooking rate for baking and grilling methods. Cooking times for baking and grilling were 4.0 and 4.4 min, respectively, and were not significantly different ($p>0.05$). Cooking rates ranged from 0.95 to 1.01 cm/min and did not differ statistically between the two methods studied.

Characterization of raw materials and processed products

The proximate composition (on wet and dry basis), water activity (a_w) and pH of the raw material and tilapia fish burgers (raw, baked and grilled) are presented in Table 2.

The proximate composition of tilapia fillet was similar to the values reported by Filho (2009) who obtained values of 78 %, 3 %, 18 %, 1 % for moisture, lipid, protein, and ash contents, respectively. Carbohydrates, mainly glycogen, consist of a minor percentage of the chemical composition of the fish muscle which is used for energy in fish (Babalola et al. 2011). Nurnadia et al. (2011) determined the proximate composition for 20 species of fish and found that *Fringescale sardinella* had 3 % of carbohydrate content. Babalola et al. (2011) reported carbohydrate content ranging from 1.5 to 4.5 % for 5 fish species (*T. trachurus*, *S. aurita*, *M. furnieri*, *S. scombrus* and *C. gariepinus*) in Nigeria. According to the authors, this value is insignificant because it was derived and estimated from the difference of other compounds and it is known that fish has low carbohydrate content.

The proximate composition of the raw fish burger was similar to that found by Dos S Fogaça and Sant'Ana (2007),

Fig. 1 Cooking curves of fish burger samples during baking and grilling processes

who reported moisture (76.1 %), lipids (0.63 %), protein (20.7 %), and ash (2.33 %) for tilapia burgers containing 98.8 % tilapia fillet and 1.2 % condiments. The formulation of the present study exhibited higher lipid content (5.21 %) due to the addition of sunflower oil. The lower protein content (13.98 %) is probably due to the lower level of protein source (72 % tilapia fillet and 3 % TSP) in the formulation compared to 98.8 % tilapia fillet used in the Dos S Fogaça and Sant'Ana (2007) formulation. The proximate composition for the cooked fish burgers was similar to that reported by Bochi et al. (2008) who studied grilled fish burgers from catfish fillets and found 68.3 % moisture, 6.1 % fat, 18.9 % protein, 2.6 % ash, and 4.2 % carbohydrate content.

In this study, the sum of moisture, lipid, protein and ash contents was approximately 92 % for both baked and grilled fish burgers. The remaining percentage, approximately 6 % is due to the addition of wheat flour in the formulation as a binding agent, as also reported by Bochi et al. (2008). Vanitha et al. (2013) and Taskaya et al. (2003) found 12.5 % and 14.5 % carbohydrate contents for fish burger from *Catla catla* and rainbow trout, respectively, due to the addition of carbohydrate rich ingredients such as corn flour, potatoes and breadcrumbs. The increase in ash content of fish burger (2.17 %) when compared to tilapia fillet (0.79 %) was due to the addition of ingredients during processing.

Table 1 Thickness, cooking time and cooking rate for fish burger baking and grilling

Cooking method	Thickness (mm)	Cooking time (min)	Cooking rate (mm min ⁻¹)
Baking	8.0±0.4	4.0±0.2 ^a	1.01±0.05 ^a
Grilling	8.3±0.5	4.4±0.8 ^a	0.95±0.22 ^a

Results are means ± standard deviation ($n=3$). Different letters in the same column represent different results by Tukey's test ($p<0.05$)

Table 2 also shows the changes in chemical composition after cooking. The moisture content of the raw fish burger reduced from approximately 72 to 68 % for both cooking processes. The same water content (68 %) found for the baked and grilled burgers may be related to the cooking time (~4 min) which was not significantly different (Table 1). Bochi et al. (2008) also observed a decrease in the moisture content of catfish burgers after grilling, which decreased from 73.6 to 63.3 %. The highest moisture content of fish burgers obtained in the present study may be due to the lower final temperature (76°C) and cooking times (~4 min, Table 1) used. There was no significant difference ($p>0.05$) between the moisture content of the burgers subjected to the 2 cooking methods. Dreeling et al. (2000) also found that the cooking methods (baking and grilling) did not affect the moisture content of low fat beef burger.

The lipid, protein and ash contents (on wet basis) increased after cooking. When analyzing the chemical composition on dry basis (g/100g dry matter) for a better comparison, the cooking process did not affect ($p>0.05$) the lipids content. However there was an increase in the protein content after cooking. This result is consistent with that reported by Bochi et al. (2008), who also observed an increase in protein content after cooking. Similar results were found by García-Arias et al. (2003), who observed an increase in protein content for sardine fillets after baking in a conventional oven. In addition, the authors found that the lipid content of the fillets decreased after baking, which did not occur with the fish burgers of this study.

There was no significant difference ($p>0.05$) in the proximate composition of baked and grilled burgers, evidencing that the 2 cooking methods studied did not affect the chemical composition of the final products. Similar results were found for baked and grilled catfish fillets (Weber et al. 2008), sardine fillets (García-Arias et al. 2003) and beef burgers (Dreeling et al. 2000).

Table 2 Proximate composition [% w/w], water activity (aw) and pH of tilapia fillet and fish burgers

	Moisture (%)	Lipid (%)	Protein (%)	Ash (%)	aw	pH
Raw tilapia fillet	78.36±0.04	2.56±0.15	15.08±0.17	0.79±0.04	0.99±0.00	6.50±0.10
Cooking effect (wet base)						
Raw fish burger	71.96±0.33 ^a	5.21±0.25 ^b	13.98±0.17 ^b	2.17±0.04 ^b	0.98±0.00 ^a	6.10±0.05 ^a
Baked fish burger	68.28±0.33 ^b	6.57±0.41 ^a	16.55±0.12 ^a	2.69±0.09 ^a	0.98±0.00 ^a	6.30±0.05 ^a
Grilled fish burger	68.40±0.46 ^b	6.62±0.23 ^a	16.63±0.19 ^a	2.60±0.05 ^a	0.98±0.00 ^a	6.30±0.05 ^a
Cooking effect (dry base)						
Raw fish burger		18.57±0.90 ^a	49.86±0.62 ^b	7.72±0.14 ^b		
Baked fish burger		20.71±1.28 ^a	52.17±0.37 ^a	8.48±0.30 ^a		
Grilled fish burger		20.94±0.72 ^a	52.62±0.59 ^a	8.22±0.17 ^{ab}		

Results are means ± standard deviation ($n=3$). Different letters in the same column represent different results by Tukey's test ($p<0.05$)

No differences were observed in pH and water activity (aw) among raw and cooked products. The pH of the raw burger reduced to 6.1 as compared to the pH 6.5 found for the tilapia fillet. Vanitha et al. (2013) obtained pH values ranging from 6.8 to 6.1 for fish burger from *Catla catla*. Taskaya et al. (2003) found pH values between 5.6 and 7.0 for fish burger from rainbow trout during 21 days of refrigerated storage.

The aw value found for the minced tilapia fillet was 0.99, which is close to the value of 0.98 found for the raw, baked and grilled products. Similar results were found by Sánchez-Zapata et al. (2010) who reported a water activity between 0.99 and 0.98 for raw and cooked pork burgers. Moisture contents of cooked samples (68 %) were high. Additionally, the high water activity and water retention found for the cooked products, shows that the formulation employed in this study has good gelling properties entrapping moisture and fat. Even though tilapia is a fresh water fish, it was evidenced that 1.5 % salt concentration used in the present formulation was sufficient to form a gel-like emulsion.

Cooking characteristics and texture properties

The cooking characteristics such as cooking yield, diameter reduction, fat retention, moisture retention, expressible water and texture properties of fish burger submitted to baking and grilling are presented in Table 3.

The cooking yields for the baking and grilling methods were 88.56 and 85.30 %, respectively. The baking method had the highest yield, and the values were higher than other studies with catfish burger and beef burger. Bochi et al. (2008) evaluated the yield of grilled catfish burgers and obtained values from 66 to 75 %. Aleson-Carbonell et al. (2005) found values around 73 % for beef burger baked in an oven. Regarding the moisture retention, the baked burgers showed higher moisture retention (95.82 %) than the grilled burgers (92.51 %). Consequently, the greater yield found for the baking method was probably due to the higher moisture retention of baked

fish burgers (88.56 %) as compared to those obtained by the grilling method (85.30 %). Bochi et al. (2008) investigated catfish burger and found moisture retention values between 58 and 64 % for different formulations. The higher moisture retention with consequent higher yield for the baked and grilled fish burgers of this study may be due to lower final cooking temperature (76 °C) chosen as the end point of cooking, compared to 80 °C used by Bochi et al. (2008). Similar results have been reported by Berry (1992) who reported that burgers cooked up to higher internal temperatures around 80 °C presented lower cooking yield. Besides this, the use of binding agents, as wheat flour, and the low temperature employed during the homogenization step to form a gel protein, may have also contributed to the highest yield found in this study.

The diameter reduction of baked and grilled burgers showed no significant difference ($p>0.05$). Berry (1992) found values ranging from 13 to 18 % for beef burgers. The reduction in diameter found in this study was lower (~6 %)

Table 3 Cooking characteristics and texture properties of baked and grilled fish burger

	Baked	Grilled
Cooking characteristics		
Cooking yield (%) ($n=6$)	88.56±0.69 ^a	85.30±1.04 ^b
Diameter reduction (%) ($n=12$)	6.29±1.24 ^a	6.08±1.22 ^a
Fat retention (%) ($n=3$)	133.73±3.20 ^a	137.62±0.37 ^a
Moisture retention (%) ($n=3$)	95.82±0.77 ^a	92.51±0.12 ^b
Expressible water (%) ($n=8$)	11.74±1.08 ^a	12.09±0.98 ^a
Texture properties ($n=12$)		
Shear force (N)	4.01±0.54 ^b	5.52±0.64 ^a
Work of shearing (J)	0.077±0.013 ^b	0.106±0.009 ^a

Results are means ± standard deviation. Different letters in the same row represent different results by Tukey's test ($p<0.05$)

than that found by other authors, which is consistent with the greater yield. Dreeling et al. (2000) also concluded that the grilling and baking methods did not influence the diameter reduction of beef burgers.

The fat retention did not differ ($p>0.05$) between the cooking methods. Fat retention had positive values. Khalil (2000) also found positive fat retention ranging from 130 to 138 % in low-fat beef burgers. Tornberg et al. (1989) concluded that fat is more easily removed from high-fat burgers due to the expansion of lipid droplets that are greater in number and melt during cooking. Consequently, low-fat burgers, as the formulation of this study (5.21 %, Table 2) and the one investigated by Khalil (2000) with lipid content of around 3.5 %, have dense protein matrix with low fat content, which prevents the lipids migration during the cooking process. Bochi et al. (2008) found values between 76 and 90 % fat retention for catfish fish burgers, and the highest value was found for the control formulation using the highest concentration of catfish fillet, i.e., with the highest protein content which formed a dense protein matrix and prevented the fat loss during cooking. The positive fat retention may also be due to the greater lipid extraction after cooking, since the extraction of this study was performed by a cold extraction method (Bligh and Dyer), and the cooking process itself may have released fatty acids which were previously bonded to other components of the food matrix.

The parameter “expressible water” (EW) represents the inverse of the water holding capacity (WHC), that is, the lowest percentage of water extracted by centrifugation means the highest WHC (Das et al. 2008; Ramirez et al. 2002). The cooking methods showed no significant difference for this property ($p>0.05$), with values around 12 %. Therefore, the baking and grilling methods did not affect the water retention capacity of the products. The expressible water ranged from 7.6 to 28 % for restructured fish products similar to hams (Ramirez et al. 2002), whose values are within this study. The results agree with those obtained by Das et al. (2008) who found EW values ranging from 10 to 13 % for goat meat nuggets. According to Das et al. (2008), the higher the protein content, the higher the content of water absorbed by the mass. Ramirez et al. (2002) also reported that the WHC in meat products is influenced by protein-protein and protein-water interactions. The high cooking yield values and water retention obtained in this study may be related to these interactions.

The texture properties, shear force and work of shearing showed significant differences ($p<0.05$) for the two methods evaluated. The grilled fish burger showed values of 5.52 N and 0.106 J for shear force and work of shearing, respectively, while the baked fish burger had lower values of 4.01 N and 0.077 J, respectively. This increase in the texture properties for grilled burgers may be due to the dryness of the burger surfaces in contact with the upper and lower grids of the grilling equipment used in this study. These results are in

disagreement with HassabAlla et al (2009) who concluded that there was no significant difference in texture scores between baked and grilled catfish burgers conducted by sensory evaluation.

To the extent of our knowledge, there are no studies on the instrumental texture of fish burgers. Das et al. (2008) reported values ranging from 7 N to 11 N for shear force of goat meat nuggets. Troy et al. (1999) found values ranging from 15 to 27 N for shear force and from 0.14 to 0.27 J for work of shearing for low-fat beef burgers. The shear force found for the cooked fish burgers were lower than the values found in the literature for other types of meat products, as previously mentioned. This is probably due to the high water content of the cooked fish burgers; therefore they are less resistant to shear force. Besides this, the fish burgers had positive lipid retention, as well as, high yield and water retention values which may also contribute to the softer texture found in this study. Lower texture values found for the baked fish burger can be evidenced by the increased water retention of baked fish burgers (95.82 %) as compared to the grilled fish burgers (92.51 %).

Color measurement

Table 4 shows the color measurements for raw, baked and grilled fish burgers. Similar L^* , a^* and b^* values were obtained by Bochi et al. (2008) for fish burgers containing catfish filleting residues. Al-Bulushi et al. (2005) evaluated the color of raw fish burgers and obtained L^* and b^* values ranging from 69.8 to 77.8 and from 17.6 to 18.9, respectively, which are similar to those found in the present study for the raw fish burgers.

The cooking processes changed the color of fish burgers. The cooking process develops flavor and aroma due to browning and formation of colored compounds from the Maillard reaction on the surface of the burgers. The raw hamburger was lighter (higher L^* value), had a less intense yellow color (lower b^* and lower chroma) and closer to the red axis (lower value of hue angle) than cooked fish burgers. The high L^* values for the raw fish burger are in accordance with the

Table 4 Color measurements for raw, baked and grilled fish burgers

	Raw	Baked	Grilled
L^*	69.13±0.96 ^a	65.50±1.40 ^b	63.89±1.40 ^c
a^*	4.05±0.34 ^a	2.60±0.53 ^c	4.11±0.79 ^a
b^*	17.50±0.75 ^b	21.50±0.96 ^a	21.62±1.41 ^a
Chroma	17.96±0.74 ^b	21.66±0.98 ^a	22.01±1.51 ^a
Hue angle	76.96±1.11 ^c	83.12±1.30 ^a	79.30±1.50 ^b

Results are means ± standard deviation. Different letters in the same row represent different results by Tukey test ($p<0.05$)

results found by Al-Bulushi et al. (2005) who developed bright fish burgers with L^* values around 70. Even after the cooking process, the fish burgers exhibited a bright color with L^* values between 63.89 and 65.50, with no dark color that is set at a L^* value of 58 (Ochiai et al. 1988). The yellowness (b^*) parameter had a significant increase after the cooking processes, as also observed by HassabAlla et al (2009). Additionally, the color of cooked fish burgers neared the yellow axis (higher value of hue angle, nearer 90°) after cooking.

The cooking method had a significant effect on the color of baked and grilled fish burgers. The baked sample had yellow coloration nearest the yellow axis (higher value of hue angle) than the grilled burger. The grilled fish burgers were darker (lower L^* value), and had a more reddish color (higher a^* value) than the baked sample. Grilled burgers exhibited a darker, reddish color as a result of the burger's surface contact with the grids of the grilling equipment which also contributed to increase Warner-Bratzler values and decrease cooking yield, as well as, moisture retention. Moreover, the cooking method did not affect the color intensity (chroma was not significant). HassabAlla et al (2009) found that color parameters for oven-baked fish burger produced from catfish had a higher sensory acceptance than grilled burgers.

Conclusion

The cooking method did not affect the chemical composition, but influenced the texture and color parameters of the tilapia fish burgers. The fish burgers produced from tilapia meat had a softer texture than other meat products, such as goat and beef. The baking method produced softer and lighter burgers, with less reddish color than the burgers produced by the grilling method.

Acknowledgments The authors thank the CNPq and CAPES (Brazilian Agencies) for financial support and scholarships.

References

- Al-Bulushi IM, Kasapis S, Al-Oufi H, Al-Mamari S (2005) Evaluating the quality and storage stability of fish burgers during frozen storage. *Fish Sci* 71:648–654
- Aleson-Carbonell L, Fernandez-Lopez J, Perez-Alvarez JA, Kuri V (2005) Characteristics of beef burger as influenced by various types of lemon albedo. *Innovat Food Sci Emerg Technol* 6:247–255
- AOAC (2000) Official Methods of Analysis of Association of Analytical Chemists International, 17th edn. Washington, USA
- APHA (2001) In: Downes FP, ITO K (eds) Compendium of methods for the microbiological examination of foods. APHA Publication, 4th Edition, Washington, USA
- Babalola AF, Adeyemi RS, Olusola AO, Salaudeen MM, Olajuyigbe OO, Akande GR (2011) Proximate and Mineral Composition in the Flesh of Five Commercial Fish Species in Nigeria. *Internet J Food Saf* 13: 208–213
- Berry BW (1992) Low fat level effects on sensory, shear, cooking, and chemical properties of ground beef patties. *J Food Sci* 57(3): 537–540
- Bligh EG, Dyer WJ (1959) A rapid method of total lipid extraction and purification. *Can J Biochem Physiol* 37:911–917
- Bochi VC, Weber J, Ribeiro CP, Victório AM, Emanuelli T (2008) Fish burgers with silver catfish (*Rhamdia quelen*) filleting residue. *Bioresour Technol* 99:8844–8849
- Das AK, Anjaneyulu AS, Gadekar YP, Singh RP, Pragati H (2008) Effect of full-fat soy paste and textured soy granules on quality and shelf-life of goat meat nuggets in frozen storage. *Meat Sci* 80(3):607–14
- Dos S Fogaça FH, Sant'Ana LS (2007) Tocopherol in the lipid stability of tilapia (*Oreochromis niloticus*) hamburgers. *Food Chem* 105: 1214–1218
- Dreeling N, Allen P, Butler F (2000) Effect of Cooking Method on Sensory and Instrumental Texture Attributes of Low-fat Beefburgers. *LWT - Food Sci Technol* 33:234–238. doi:10.1006/fstl.2000.0649
- FAO GLOBEFISH (2014) Tilapia - January 2014. www.globefish.org/tilapia-january-2014.html/. Accessed 27 May 2014
- FIESP (2009) A sector study on fish production. www.abtilapia.com.br/. Accessed 27 August 2013
- Filho DUC (2009) Quality evaluation of tilapia fish burger (*Oreochromis sp*) using different concentrations of wheat flour. Master's dissertation. Piauí Federal University, Graduate Program of Animal Science, p 25
- García-Arias MT, Alvarez-Pontes E, García-Linares MC, García-Fernández MC, Sánchez-Muniz FJ (2003) Cooking–freezing–reheating (CFR) of sardine (*Sardina pilchardus*) fillets. Effect of different cooking and reheating procedures on the proximate and fatty acid compositions. *Food Chem* 83:349–356
- HassabAlla AZ, Mohamed GF, Ibrahim HM, Abdelmageed MA (2009) Frozen cooked catfish burger: Effect of different cooking methods and storage on its quality. *Glob Vet* 3:216–219
- Hunterlab (1996) CIE $L^*a^*b^*$ color scale. Applications Note. <http://www.hunterlab.com/application-notes.html>. Accessed 20 November 2013
- Khalil AH (2000) Quality characteristics of low-fat beef patties formulated with modified corn starch and water. *Food Chem* 68:61–68
- MPA (2011) Ministry of Fisheries and Aquaculture (MPA) - Boletim da pesca e aquicultura 2011. www.mpa.gov.br/. Accessed 27 May 2014
- MPA (2013) Ministry of Fisheries and Aquaculture (MPA) - Balanço 2013. www.mpa.gov.br/. Accessed 27 May 2014
- Nurnadia AA, Azrina A, Amin I (2011) Proximate composition and energetic value of selected marine fish and shellfish from the West coast of Peninsular Malaysia. *Int Food Res J* 18:137–148
- Ochiai Y, Chow C, Watabe S, Hashimoto K (1988) Evaluation of tuna meat discoloration by Hunter Color Difference Scale. *Nippon Suisan Gakkaishi* 54:649–653
- OECD/FAO (2011) OECD-FAO Agricultural Outlook 2011–2020. <http://www.oecd.org/>. Accessed 21 November 2013
- Ramirez J, Uresti R, Téllez S, Vásquez M (2002) Using Salt and Microbial Transglutaminase as Binding Agents in Restructured Fish Products Resembling Hams. *J Food Sci* 67(5):1778–1784. doi:10.1111/j.1365-2621.2002.tb08722.x
- Sánchez-Zapata E, Muñoz CM, Fuentes E, Fernández-López J, Sendra E, Sayas E, Navarro C, Pérez-Alvarez JA (2010) Effect of tiger nut fibre on quality characteristics of pork burger. *Meat Sci* 85:70–76

- Taskaya L, Cakli S, Kisla D, Kilinc B (2003) Quality changes of fish burger from rainbow trout during refrigerated storage. *EU J Fish Aquat Sci* 20(1–2):147–154
- Tokur B, Polat A, Beklevik G, Ozkutuk S (2004) Changes in the quality of fishburger produced from Tilapia (*Oreochromis niloticus*) during frozen storage (-18°C). *Eur Food Res Technol* 218:420–423
- Tornberg E, Olsson A, Persson K (1989) A comparison in fat holding between hamburgers and emulsion sausages. *Proc Int Congr Meat Sci Technol* 35:753–757
- Troy DJ, Desmond EM, Buckley DJ (1999) Eating quality of low-fat beef burgers containing fat-replacing functional blends. *J Sci Food Agric* 79:507–516
- Vanitha M, Dhanapal K, Reddy GVS (2013) Quality changes in fish burger from *Catla* (*Catla Catla*) during refrigerated storage. *J Food Sci Technol*. doi:10.1007/s13197-013-1161-1
- Weber J, Bochi VC, Ribeiro CP, Victorio AM, Emanuelli T (2008) Effect of different cooking methods on the oxidation, proximate and fatty acid composition of silver catfish (*Rhamdia quelen*) fillets. *Food Chem* 106:140–146