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Effect of galactomannan (*Caesalpinea pulcherrima)* on different fish restructuring methods[1]

Efeito da galactomanana (*Caesalpinea pulcherrima*) em distintos métodos de reestruturação de pescado

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ABSTRACT - Restructuring consists of aggregating small food parts with the addition of binding agents which, after mold pressing will undergo a gel configuration stage using hot or cold methods. This work aims to evaluate the effect of galactomannan from *Caesalpinea pulcherrima* as a binding agent, in a restructured fish product obtained from the meat of tibiro - Maracaibo leatherjacket (*Oligoplites palometa)* by hot and cold restructuring methods, comparing it with a restructured control made with transglutaminase, regarding the physicochemical and mechanical characteristics. The restructured product elaborated with galactomannan using the cold method denoted better water retention capacity, also registering the smallest weight loss values of cooking in the two restructuring methods. The results obtained from the mechanical properties of texture such as hardness and cohesiveness of the product restructured with galactomannan using the cold method were similar to those of the control sample. Furthermore, the addition of galactomannan by the hot method provided closer similarity with the control sample, resulting in better softness, lower adhesiveness, and elasticity. The restructured product elaborated by the cold method with galactomannan from *C. pulcherrima* revealed better physicochemical characteristics; the mechanical properties exhibited an analogy with the restructured product using transglutaminase; hence, it can be indicated as a binding agent in the elaboration of this type of product.

Key words: Restructured. Gum. *Oligoplites palometa*.

RESUMO - A reestruturação consiste na união de partes menores de um alimento com adição de agentes ligantes que após a prensagem em moldes passarão por uma etapa de configuração do gel pelos métodos a quente ou a frio. Este trabalho tem como objetivo avaliar o efeito da galactomanana de *Caesalpinea pulcherrima* como agente ligante, em um produto reestruturado de peixe obtido da carne de tibiro (*Oligoplites palometa)* por variados métodos de reestruturação (a quente e a frio) comparando-o com a de um reestruturado controle, elaborado com transglutaminase, quanto as características físico-químicas e mecânicas. O reestruturado elaborado com galactomanana no método a frio denotou maior capacidade de retenção de água, registrando-se também os menores valores de perda de peso por cocção nos dois métodos de reestruturação. Os resultados obtidos das propriedades mecânicas de textura como dureza e coesividade dos reestruturados com galactomanana pelo método a frio foram semelhantes aos da amostra-controle. Ademais, pelo método a quente, a adição de galactomanana proporcionou maior similaridade com a amostra-controle obtendo-se maior maciez, menor adesividade e elasticidade. O reestruturado elaborado com galactomanana de *C. pulcherrima* demonstrou melhores características físico-químicas pelo método a frio e nas propriedades mecânicas exibiu analogia com o reestruturado de transglutaminase podendo ser indicado como agente ligante na elaboração desse tipo de produto.

Palavras-chaves: Reestruturado. Goma. *Oligoplites palometa*.

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INTRODUCTION

Product restructuring consists of aggregating small pieces of a given food to which binding agents are added, and pressed into molds of different shapes, acquiring a diverse appearance and texture from its original form (KUNNATH *et al*., 2015; RAMÍREZ *et al*., 2011). This common process in the meat industry has been used in the fishing industry to meet growing demand for fish-like products. As a result, new products were made available on the market, with texture, color, odor, and appearance that were more attractive to consumers.

The restructuring of pieces or shredded muscle to be consolidated, requires the solubilization of myofibrillar proteins and the use of binding agents that will help binding important molecules for the gelling process. The transglutaminase of microbial origin is effectively used in industry, as it promotes cross covalent bonds between proteins, expressing excellent structural results and good sensory acceptance. Galactomannan is a new binding agent researched, which appears as an innovative option in fish restructuring, due to its availability and low cost.

The traditional restructuring process uses heat to form the gel and is divided into three stages: solubilization, configuration, and heating. In the solubilization step, salt is added to change the ionic strength, inducing the salting-in phenomenon, which allows greater interaction between the proteins and the salt, while reducing protein-protein interactions, thus favoring solubilization (BANERJEE; BHATTACHARYA, 2012; MARTÍN-SANCHEZ *et al.*, 2009). In the shaping step, viscous slurry containing disorganized actomyosin complexes is formed. This paste is heated below 50 °C, to stabilize the intra- and intermolecular bonds and promote the formation of a translucent gel called suwari. In the heating step, the paste is subjected to temperatures from 80 to 90 °C, for irreversible gel formation (MARTÍN-SANCHEZ *et al.*, 2009).

Another way of restructuring the product is to carry out the gel configuration phase at low temperatures. In this case, the binding agent is added to the raw material, molded, and kept under refrigeration, at 4 or 5 °C for 24 h, the time needed for the essential interactions of gel formation to occur (ANDRÉS-BELLO *et al.*, 2011; KUNNATH *et al.*, 2015; MORENO; CARBALLO; BORDERÍAS, 2011). The advantage of using the cold configuration is the fresh product aspect, since fish whose restructuring is induced by heat appear cooked and, according to Moreno, Carballo, and Borderías (2013), the preference for fresh products is greater than by those cooked. Furthermore, there are countless possibilities of using this product, such as in sushi, marinated, carpaccio, or as fish fillets, which can be consumed raw or cooked (MORENO; CARBALLO; BORDERÍAS, 2008). This experiment aimed to evaluate the effect of the hot and cold restructuring methods, regarding the physicochemical and mechanical properties of restructured tibiro - Maracaibo leatherjacket (*Oligoplites palometa*), prepared with galactomannan, using the restructured products made with transglutaminase as a control.

MATERIAL AND METHODS

Material

Tibiro - Maracaibo leatherjacket fillets (*Oligoplites palometa)* and refined salt were obtained from the retail trade in Fortaleza – Ceará. Galactomannan in powder from *Caesalpinea pulcherrima* was supplied by the Department of Pharmacy of the University of Fortaleza (UNIFOR), Ceará. Microbial transglutaminase (ACTIVA GS), containing in its composition: sodium chloride, gelatin, trisodium phosphate, maltodextrin, transglutaminase, and safflower oil, was obtained from Ajinomoto Co., Tokyo, Japan, with activity from about 47 to 82 Ug^{-1}.

Preparation of the restructured product

An aqueous dispersion of galactomannan from *Caesalpinea pulcherrima* at 1.84% (w/v) concentration was prepared with water at 80 °C, being homogenized for 60 seconds with a mixer, and allowed to cool to room temperature. The fish was ground in a meat grinder (Skymsen, PS-22), using a 7 mm plate; refined salt at 1.8% and 10:90 (w/w) galactomannan gel were added to it, to obtain a final concentration of 0.2%; and then homogenized for a further 120 seconds. The tibiro - Maracaibo leatherjacket processed products were molded in aluminum rings measuring 7 cm in diameter and 16 mm in height, and then wrapped in PVC film, to undergo hot and cold restructuring processes.

The hot restructuring followed the methodology of Cardoso, Ribeiro, and Mendes (2012). The prepared samples were cooked in two stages in a water bath, initially at 35 °C for 60 minutes, and subsequently at 90 °C for another 60 minutes. Then, the samples were cooled in an ice bath, and kept at 4 °C. The cold restructuring consisted of keeping the ready samples under refrigeration at 4 °C for 24 hours, following the methodology proposed by Moreno, Carballo, and Borderías (2008).

The restructured tibiro - Maracaibo leatherjacket, prepared with transglutaminase (ACTIVA GS), was applied at a concentration of 0.5% about the restructured product, and in a 1:4 solution ratio with water, was used as control (MONTEIRO *et al*., 2015). The restructured products were molded in aluminum rings measuring 7 cm in diameter and 16 mm in height and then wrapped in PVC film. After preparation, the same procedures were followed for the hot and cold restructuring described above. The various formulations were coded as shown in Table 1.

Table 1 - Composition of restructured products from tibiro - Maracaibo leatherjacket, with galactomannan (GM) and with transglutaminase (TG), obtained by the hot (H) and cold (C) methods

Product	Muscle (%)	Salt (%)	GM (%)	TG (%)
GM C	98.0	1.8	0.2	0.0
TG C	99.5	0.0	0.0	0.5
GM H	98.0	1.8	0.2	0.0
TG H	99.5	0.0	0.0	0.5

Restructured with galactomannan by the hot method (GM H), restructured with galactomannan by the cold method (GM C), restructured with transglutaminase by the hot method (TG H), and restructured with transglutaminase by the cold method (TG C)

Methods

The gravimetric method was used to determine moisture, from the loss of weight of the sample subjected to oven heating at 105 °C; method 925.09 (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 2005). The total protein content was determined by the micro Kjeldahl method, using the 6.25 conversion factor. The lipid determination was carried out by the Soxhlet method (945.38), the ash content by incineration at 550 °C (923.03), following the norms of the Association of Official Analytical Chemists (2005). The carbohydrate content was calculated by subtracting 100 from the sum of the percentages of the four compounds described.

Five grams of the sample were weighed for the pH analysis, and 50 mL of distilled water was added, homogenized, and then read in a pH-meter model R-TEC7MP (Tecnal, Brazil). The water activity was performed according to the manufacturer's instructions, using an AQUALaB 4TEV meter at 25 °C, calibrated with distilled water. The measurements were carried out in triplicate; the products were cut into small pieces and placed in capsules which were taken to the measuring compartment of the device.

The expressible water content followed the methodology of Martelo-Vidal, Mesas, and Vázquez (2012). The samples were weighed (2 ± 0.2 g) and placed on two layers of filter paper; then, they were inserted in 50 mL centrifuge tubes and subjected to centrifugation at 1000 g for 15 min at 4 °C. Immediately after centrifugation, the wet filter papers were removed and the samples were weighed again, and five samples were analyzed for each treatment. The percentage of expressible water was calculated according to equation (1), where W_E is the expressible water (%), P_0 is the initial weight and P is the final weight.

$$W_E(\%) = \left(\frac{P_0 - P}{P_0}\right)100 \quad (1)$$

To determine the weight loss by cooking, the restructured fish samples were cut into rectangular segments and placed in properly labeled plastic bags, and subsequently cooked in a water bath at 85 °C for 25 minutes. After cooking, the samples were removed from the bags, cooled in running water and the surface gently dried with a paper towel (LIU *et al*., 2004). The analysis was performed in quintuplicate and calculated by the difference between the initial and final weights, corresponding to the weight loss by cooking, according to Equation (2).

$$WLC(\%) = \frac{(Weight\ before\ cooking - Weight\ after\ cooking)}{(Weight\ before\ cooking)}100 \quad (2)$$

The color analysis was performed in a spectrophotometer (CM-3700ª, Konica Minolta, Japan), where samples were placed in a glass cuvette, and color readings were recorded by a coupled software, following the CIE L* a* b* colorimetric system; readings were taken in quintuplicate. Instrumental analyzes of the textural profile (TPA) were carried out after the products were stabilized at room temperature for 30 minutes. Ten measurements were registered for each treatment, following the methodology described by Kunnath *et al.* (2015). The analysis was carried out in a texture analyzer (TA-XT2i, Stable Micro System, UK) equipped with a 30 kg load cell and a 50 mm diameter cylindrical probe (P50). The specimens were axially compressed to 75% of their original height, with a pre-test speed of 2 mm/s, a test speed of 1 mm/s, and a post-test speed of 5 mm/s. The probe penetration distance was maintained at 30 mm and the duration between the first and the second compression was adjusted to 2.5 s. The samples were placed on the baseplate and, subsequently, were compressed and decompressed twice by the cylindrical probe, so that typical curves were generated. The attributes thus measured are hardness, which is the peak force required for the first compression (g); cohesiveness – the ratio of the active work performed under the first compression curve (dimensionless); elasticity – the length that the sample recovers after the first compression; adhesiveness – the area of the negative force of the first compression bite. The results were statistically treated. The analysis of variance (one-way ANOVA) and Tukey's test at 5% significance level were applied, using the Statistica program, version 7.0 (STATSOFT, 2008).

RESULTS AND DISCUSSION

The centesimal composition of the tibiro - Maracaibo leatherjacket restructured products is shown in Table 2. The highest moisture values were obtained in the restructured products prepared by the cold method, which did not differ significantly, while the lowest moisture values were obtained in the restructured products prepared by the hot method, which were significantly different, although having similar values. The reduction of moisture in products prepared by the hot method can be explained by the evaporation of water during heating, which increased the concentration of proteins and lipids, in both restructured products prepared by the hot method. The mean moisture values of the restructured products obtained by the cold method in this study were similar to those of the tilapia surimi hamburgers developed with galactomannan by Maia *et al.* (2015), who reported moisture values ranging from 79.86 to 82.05%, and protein content ranging from 12.65 to 13.38%.

Regardless of the restructuring method applied, the highest protein contents were found in the TG samples, and the highest carbohydrate values were observed in the GM samples. This is due to the nature of the polymers used since transglutaminase (TG) is an enzyme; therefore, it is a protein, while galactomannan (GM) is a polysaccharide. Note that, due to the loss of water during cooking, there was a higher concentration of lipids in the restructured GM H, which was not observed in the samples with transglutaminase, which did not show a significant difference in the hot and cold methods. There was a higher loss of minerals as a result of the heat treatment in the sample with galactomannan (GM H), while in the TG samples there was no significant difference between the mineral content of hot and cold restructured products.

The pH values of the restructured products of the tibiro - Maracaibo leatherjacket are shown in Table 3. It can be seen that the pH of the products prepared by the cold method did not vary between them, but differed between the hot treated samples. The pH of the sample with transglutaminase obtained by the hot method (TG H) showed the highest value pH=6.76, differing significantly from the restructured tibiro - Maracaibo leatherjacket, with galactomannan (GM H), with a pH=6.56. In the work of Cardoso *et al*. (2010), pH changes are the indirect effects of the hydrocolloids used and, as a result of changes in conformations of substances, exposing protein groups more or less acidic, a fact that is enhanced by the heat treatment. In the specific case of transglutaminase (TG), this enzyme may have catalyzed reactions that release ammonia, which explains the higher pH value in the TG H sample.

The water activity of tibiro - Maracaibo leatherjacket restructured products prepared by the cold and the hot methods did not differ significantly (Table 3), that is, the free water content of the products was not affected by the restructuring method used, as it was not affected by the binding agents. According to Huang and Clarke (2017), dissolved substances tend to reduce water activity. However, this reduction was not observed, both in galactomannan (GM) and transglutaminase (TG) samples. The values obtained in the current work were higher than those found by Andrés-Bello *et al*. (2013), who reported water activity in restructured goldfish prepared with salt and transglutaminase by the cold method, ranging from 0.973 to 0.978. In a similar study, Martelo-Vidal *et al*. (2016a) also reported water activity values ranging from 0.970 to 0.980 in restructured white tuna obtained by the hot method. According to Bainy *et al*. (2015), high values of water activity and water retention demonstrate that the formulations used have gelling properties of moisture and fat retention, important properties in acceptance, as well as in product yield.

Expressible water (W_E) is an indirect measurement of water holding capacity (WHC), being inversely proportional to this parameter. A low W_E means a high WHC, which is important to ensure moisture and juiciness during the products' cooking processes (MARTELO-VIDAL *et al.*, 2016b). The restructured products with galactomannan (GM) prepared by the cold method had

Table 2 - Centesimal composition of tibiro - Maracaibo leatherjacket restructured products prepared with galactomannan (GM), and transglutaminase (TG), obtained by the hot (H) and cold (C) methods

Products	Moisture (%)	Proteins (%)	Lipids (%)	Carbohydrates (%)	Ashes (%)
GM C	81.67 aA ± 0.20	14.72 bD ± 0.08	0.45 bC ± 0.04	1.32 aA ± 0.20	1.84 aA ±0.04
TG C	81.63 aA ± 0.05	16.35 aC ± 0.02	0.67 aBC ± 0.05	0.79 bB ± 0.03	0.56 bBC ± 0.00
GM H	76.29 aB ± 0.04	20.70 bB ± 0.02	1.34 aA ± 0.07	1.21 aA ± 0.05	0.46 bC ± 0.05
TG H	72.40 bC ± 0.04	25.94 aA ± 0.07	0.85 bB ± 0.11	0.15 bC ± 0.20	0.66 aB ± 0.03

Results are expressed as means ± standard deviation. Different small letters in the same column indicate significant differences to the same treatment ($p < 0.05$). Different capital letters in the same column indicate significant differences for different treatments ($p < 0.05$)

Table 3 - Results of pH, water activity (A_w), expressible water (W_E), and weight loss due to cooking (WLC) of tibiro - Maracaibo leatherjacket restructured products prepared with galactomannan (GM) and transglutaminase (TG) by the hot (H) and cold (C) methods

Products	pH	Aw	W_E (%)	WLC (%)
GM C	6.27 aC ± 0.00	0.991 aA ± 0.00	24.59 bB ± 1.14	6.42 bB ± 0.13
TG C	6.27 aC ± 0.03	0.997 aA ± 0.00	32.44 aA ± 0.55	26.17 aA ± 0.51
GM H	6.56 bB ± 0.01	0.995 aA ± 0.00	32.34 aA ± 0.19	4.09 aC ± 0.42
TG H	6.76 aA ± 0.02	0.997 aA ± 0.00	22.86 bB ± 0.54	1.79 bD ± 0.47

Results are expressed as means ± standard deviation. Different small letters in the same column indicate significant differences to the same treatment ($p < 0.05$). Different capital letters in the same column indicate significant differences for different treatments ($p < 0.05$)

lower W_E = 24.59%, that is, they had higher water retention capacity (WHC), while GM achieved via the hot method showed greater W_E = 32.34%, hence, lower WHC due to the weakening of the water-galactomannan interactions after the use of heat in the restructuring process (Table 3).

The tibiro - Maracaibo leatherjacket restructured with transglutaminase (TG) exhibited the opposite behavior to the samples with galactomannan (GM), regarding W_E. The TG sample from the cold process showed higher W_E = 32.44%, in comparison to the TG sample obtained by the hot method, W_E = 22.86%, a value reflecting greater capacity to retain water. These results were similar to those found by Kunnath *et al*. (2015), who reported better water retention capacity in restructured panga fish (*Pangasius* sp.), prepared hot, compared to the cold processed restructured products of the same origin. These data suggest that the cross-links formed by TG kept water trapped inside the network during the heat treatment.

The transglutaminase enzyme causes intra- and intermolecular covalent bonds, with protein-protein interactions prevailing, but for the formation of a good gel in restructured products with good water retention capacity, it is necessary to have a balance with the protein-water interactions induced by the NaCl (ANDRÉS-BELLO *et al*., 2011; BANERJEE; BHATTACHARYA, 2012; MARTÍN-SANCHEZ *et al*., 2009), which explains the lower water retention capacity in the restructured TG C, since there was no addition of salt in this formulation. Téllez-Luis, Ramírez, and Vázquez (2004) reported a minimal effect of transglutaminase in WHC and, according to Ramírez *et al*. (2011), the use of hydrocolloids is more efficient to maintain high WHC. The current results suggest that galactomannan binds to water more effectively than transglutaminase in cold preparations; however, transglutaminase shows better water retention capacity in records taken by the hot method.

Regarding the weight loss by cooking (WLC) of the restructured tibiro - Maracaibo leatherjacket, it can be observed that all formulations differed significantly among them. The products restructured with TG exhibited WLC values compatible with those of the expressible water analysis (W_E), as the TG C sample produced higher W_E and higher WLC, while the TG H sample showed the lowest WLC = 1.79%, and the lowest W_E = 22.86%. Higher expressible water values (W_E) correspond to lower WHC values and, as a consequence, increasing water loss during cooking (FONTAN *et al*., 2011).

In the restructured tibiro - Maracaibo leatherjacket prepared with galactomannan, the referred compatibility with W_E was not observed, because, in the GM C sample, there was a higher WLC = 6.42%, and in the GM H sample, a lower value of WLC = 4.09%. The values obtained in this research are close to fish restructuring studies with konjac gum, whose WLC values ranged from 6.3% to 9.0% obtained by the cold method (SOLO-DE-ZALDÍVAR *et al*., 2014). The hot restructured samples had lower WLC because most of the water was eliminated during the preparation. As the heat treatment caused muscle tissue retraction, less water was eliminated during the analysis, explaining the low WLC values, both in the GM H and in the TG H samples. In general, cold preparations with galactomannan showed greater water retention capacity and lower weight loss from cooking, whereas, in the hot method, products restructured with TG showed the best characteristics.

The coordinates (L*, a*, b*) were analyzed to verify whether the addition of the gelling agent and/or restructuring method influenced the color. The corresponding results are shown in Table 4. The L* values of the cold restructured products (55.28 and 58.49) placed these samples within the grayscale range for most consumers. The L* values of the hot restructured products were higher and did not differ significantly between TG H and GM H. Moreno, Carballo, and Borderías (2013) reported similar results in restructured hake, prepared with sodium alginate and transglutaminase (TG), attributing the increase in L* to protein denaturation, as a result of the heat treatment.

The a* coordinate differed significantly among all tibiro - Maracaibo leatherjacket restructured products. The samples obtained by the cold method denoted the highest values of a*, indicating a more reddish color in these products, closer to the color of the tibiro - Maracaibo leatherjacket muscle. Among the heat prepared samples, the one restructured with galactomannan (GM H) had the highest a* value. According to Bainy *et al*. (2015), cooking processes, in addition to developing flavors and aromas, change the superficial color of the prepared products. The highest values of the b* coordinate were found in samples obtained by the hot method, which did not differ significantly from each other, whereas, the intensity of yellow was lower in samples prepared by the cold method. Therefore, the heat had a significant effect on color. The restructured products obtained by the hot method were more yellow and lighter (higher values of b* and L*), while samples obtained by the cold method were darker and redder (lower values of L* and higher values of a*), respectively.

The texture profile test consists of pressing the sample placed on a base plate. The sample is compressed and decompressed twice by a compression plunger, with a waiting time between the two actions; teeth chewing are simulated in two bites. Table 5 shows the hardness values of restructured tibiro - Maracaibo leatherjacket with TG and GM, prepared by the hot and cold methods. The hardness values of the tibiro - Maracaibo leatherjacket restructured by the cold method did not differ significantly from each other, indicating that galactomannan behaved like transglutaminase for this parameter. Andrés-Bello *et al*. (2013) also reported that no effect on hardness was found in cold restructured goldfish prepared with konjac gum, carboxymethylcellulose, and transglutaminase. There was a significant increase in compressive strength, with an increase in hardness values in the TG hot prepared sample, about three times greater than in the GM hot prepared one. The restructured TG H revealed a higher hardness value, within the range for this parameter reported in the hot restructured white tuna, which ranged from 11485 to 20981 g (MARTELO-VIDAL *et al*., 2016a). According to Herrero *et al*. (2008), the hardness increase in hot prepared samples is due to heat-induced protein denaturation, resulting in water displacement, making the restructured product harder. The restructured GM H showed a hardness value higher than that stated by Huang and Clarke (2017) in hot restructured fish prepared with carrageenan (3226 g) and corn starch (1859 g).

Monteiro *et al*. (2015) evaluated sensory acceptance in a consumer test, obtaining means above seven, in terms of texture. Hardness values of restructured tilapia steaks ranged from 1307 to 1734 g in raw products, and from 1724 to 1795 g in cooked samples. The results obtained in the restructured tibiro - Maracaibo leatherjacket were higher than those reported by Monteiro *et al*. (2015), particularly in the hot prepared samples (Table 5). Although the methods of preparation, fish used, and salt and transglutaminase concentrations were different, it is noted that the restructuring process may have been very intense for the hardness parameter, which could generate future problems of texture acceptance for these products.

Table 4 - Color coordinates (L*, a*, and b*) of tibiro - Maracaibo leatherjacket restructured meat with galactomannan (GM) and transglutaminase (TG), obtained by the hot (H) and cold (C) methods

Products	L*	a*	b*
GM C	55.28 bC ± 0.39	1.65 bB ± 0.08	13.60 bC ± 0.43
TG C	58.49 bB ± 0.59	2.49 aA ± 0.26	14.99 bB ± 0.10
GM H	67.27 aA ± 0.72	1.08 aC ± 0.02	17.02 aA ± 0.25
TG H	67.74 aA ± 0.33	0.70 bD ± 0.04	16.37 aA ± 0.47

Results are expressed as means ± standard deviation. Different small letters in the same column indicate significant differences to the same treatment ($p < 0.05$). Different capital letters in the same column indicate significant differences for different treatments ($p < 0.05$)

Table 5 - Hardness (g) and cohesiveness (g.s) parameters of tibiro - Maracaibo leatherjacket restructured products, prepared with galactomannan (GM) and transglutaminase (TG) following the hot (H) and cold (C) methods

Products	Hardness (g)	Cohesiveness (g.s)
GM C	2010.64 aC ± 21.90	0.13 aC ± 0.00
TG C	2088.53 aC ± 35.30	0.13 aC ± 0.00
GM H	4494.05 bB ± 131.38	0.17 bB ± 0.00
TG H	13277.22 aA ± 40.18	0.33 aA ± 0.00

Results are expressed as means ± standard deviation. Different small letters in the same column indicate significant differences to the same treatment ($p < 0.05$). Different capital letters in the same column indicate significant differences for different treatments ($p < 0.05$)

Table 6 - Adhesiveness, elasticity, and chewiness parameters of restructured tibiro - Maracaibo leatherjacket with galactomannan (GM) and transglutaminase (TG) prepared by the hot (H) and cold (C) methods

Products	Adhesiveness	Elasticity (mm)	Chewiness
GM C	-1751.96 bD ± 12.58	0.14 bC ± 0.01	34.98 bD ± 6.89
TG C	-408.57 aC ± 22.63	0.38 bB ± 0.02	188.41 aC ± 11.64
GM H	-211.64 bB ± 1.49	0.64 aA ± 0.00	775.14 bB ± 6.30
TG H	-42.55 aA ± 1.17	0.65 aA ± 0.00	2500.80 aA ± 26.66

Results are expressed as means ± standard deviation. Different small letters in the same column indicate significant differences to the same treatment ($p < 0.05$). Different capital letters in the same column indicate significant differences for different treatments ($p < 0.05$)

Cohesiveness varied among the preparation methods. There was no significant difference between the restructured products obtained by the cold method, but there was a significant difference at the 5% level between the heat-treated samples. Cohesion is related to the union between the smaller parts of the fish muscle and is numerically measured with the texturometer. After two compressions and decompressions, two peaks are registered; the ratio between the areas of positive force under the first and the second compressions is defined as cohesion (BOURNE, 1978). The cohesiveness of the restructured TG H showed a value similar to that of cooked fillets of pacu, tambacu, and tambaqui, whose values ranged from 0.33 to 0.35 (BORGES *et al*., 2013); these are lower than the cohesiveness of restructured hake prepared with various concentrations of carrageenan, which ranged from 0.48 to 0.54 (CARDOSO; MENDES; NUNES, 2007).

The values adhesiveness, elasticity, and chewiness of the restructured products of the tibiro -Maracaibo leatherjacket are shown in Table 6. The area of negative force after the first compression, or the first bite, represents the work required to pull the compression plunger from the sample and is defined as adhesiveness. This parameter is expressed by negative values and, the closer to zero, the less adhesiveness the product has. The samples prepared with galactomannan (GM) had the lowest adhesiveness values, due to the nature of the material and its thickening properties in the mixture, which will naturally occur in these restructured products. The heat reduced this attribute in the GM H sample, but it remained below the adhesiveness of the TG H sample. The adhesiveness values in the samples prepared with TG are overall higher, which is expected. According to Andrés-Bello *et al*. (2011), the TG enzyme increases protein-protein interactions, building a three-dimensional structure responsible for the capture of water and lower stickiness.

The height that foods regain during the time elapsed between the end of the first compression and the beginning of the second one, is defined as elasticity. The product tested recovers its original shape after the force is removed (BOURNE, 1978). The hot-treated samples presented the highest elasticity and did not differ significantly from each other, whereas in the samples obtained by the cold method, the restructured TG C had greater elasticity than GM C. Low elasticity values may mean that the product experienced internal fractures that do not allow the sample returning to its original size, which is consistent with the low cohesion values of the cold-treated samples (ANDRÉS-BELLO *et al*., 2011). The increase of this parameter in the samples prepared by the hot method is caused by the heat-induced gelling process. According to Kunnath *et al.* (2015), water molecules are kept in the protein network, making the product more elastic by nature, unlike samples obtained by the cold method, which have a higher content of free water that will be released during cooking, as well as lower cohesion.

Chewing is defined as the energy required to disintegrate a solid food product, reducing it to a state of readiness to be swallowed; numerically, it is calculated as the product of hardness, cohesiveness, and elasticity (BOURNE, 1978). The chewiness of the TG restructured samples was higher than GM restructured ones, in both preparation methods. In cold-treated samples, the elasticity of TG C was the only parameter that differed significantly from GM C, implying greater chewiness. Between the heat restructured products, TG H expressed the highest chewiness value, as it carries the highest values of hardness, cohesiveness, and elasticity of all the restructured products. Santos *et al*. (2018) found lower hardness and chewiness in cooked pirarucu fillets, in comparison to fresh samples. This is the opposite of what was obtained in the present study, which suggests that the gelling agents contributed to raising the values of the texture parameters in the samples obtained by the hot method.

CONCLUSION

1. The use of galactomannan proved to be an efficient binding agent in fish restructuring prepared by hot and cold methods. In the hot method, lower moisture values were obtained, which explains the higher content of proteins and lipids, whereas, in the cold method, greater water retention

capacity and lower weight loss from cooking were observed in the products restructured with galactomannan;

2. Regarding the mechanical properties, cold prepared samples with galactomannan developed hardness and cohesiveness characteristics, similar to those restructured with transglutaminase, whereas samples with galactomannan that were obtained by the hot method had a higher softness and lower adhesiveness.

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