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Article

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Abstract: Surimi consists in a technique for concentrating myofibrillar proteins with gelling ability, which aims to make use of by-products from fish slaughter, such as bullfrog back, which can be basis for the manufacture of emulsified products. Due to the strategic need to develop clean label foods, products such as collagen have been reported as potential natural additives with bioactive properties. The objective was to elaborate a surimi from the mechanically separated bullfrog back and to develop an emulsion, replacing the soy lecithin used by hydrolyzed collagen, evaluating its emulsifying and antioxidant potential during 120 days of storage under freezing. Three meat emulsions were prepared: EC0 (100% soy lecithin), EC50 (50% soy lecithin + 50% collagen), and EC100 (100% collagen), which were subjected to analysis of chemical composition, emulsion stability, water holding capacity, luminosity, whiteness, texture profile, TBARS and antioxidant activity. Insertion of collagen increased whiteness, lightness, hardness, and chewiness values compared to the EC0, but showed greater fluid loss. All treatments showed stable WHC values (88 – 91%) over time. Replacement with collagen was satisfactory as an emulsifier and as an antioxidant, and the EC50 and EC100 treatments were not negatively affected in the investigated parameters.

Keywords: emulsifier; Antioxidants; bioactive compunds

1. Introduction

Collagen is the most abundant animal protein, composing the structure of skin, tendons, cartilage, bones, in addition to being present in the lining of organs and mucous membranes [1,2], with 29 different types distributed in nature already recognized. The literature reports that collagen can be obtained from by-products from the slaughter of mammals [3–5], poultry [6,7] and fish [8–10], increasing the biological value of proteins that often are discarded or underutilized, which has been driving researchers to extract and market this protein. Currently, the global collagen market was valued at US$ 4.6 billion in 2022, with an estimate of US$ 8.2 billion by 2032 [11].

Different methods of obtaining collagen can be applied, from the use of acids and alkalis [12,13], at low and high temperatures [14,15], enzymatic and thermal separation methods [16,17], which will imply in different ways of obtaining collagen: in the form of native, hydrolyzed, gelatinized collagen or collagen peptides, with several applications, the main ones being in the cosmetic, pharmaceutical and food industries [2].

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Obtaining collagen at temperatures that cause its denaturation transforms it into gelatin, which presents technological properties of interest to the industry, such as viscosity, transparency and structure [18]. The same properties can be achieved when hydrolyzed collagen is used in foods that are manufactured by cooking [19]. Currently, with the need to offer products with practicality and healthiness, the clean label concept arises, with the least possible inclusion of chemical additives. In this way, collagen can be used as an additive of natural origin that can give foods foaming, texturizing, antioxidant and emulsifying properties [8,20,21].

Surimi is a japanese term that refers to the concentrate of myofibrillar proteins obtained from fish that can form a gel when added with sodium chloride and subjected to heat treatment. It is made from fish of low commercial value or low-yield cuts discarded at slaughter, such as bullfrog back [22,23]. Surimi is considered an intermediate product for the development of other foods, such as kani, kamaboko and other meat emulsions, reported in some studies [24].

In the formation of a meat emulsion, since there is a mixture of immiscible ingredients, emulsifying agents must be used that bind simultaneously to water and fat. Several natural compounds can be used as emulsifying agents, such as sodium tripolyphosphate, gums and soy lecithin [25,26]. Hydrolyzed collagen, due to its hydrophilic and hydrophobic terminals, can replace commercial chemical additives, also conferring other properties, expanding the offer of foods in the clean label segment.

2. Materials and Methods

2.1. Raw Material, Supplies and Location of the Research

Mechanically deboned meat (MDM) from bullfrog back was used, acquired at the Laboratory of Frogculture and Aquaculture Products, at the Federal University of Paraíba. The other inputs and packaging were purchased from local market. The hydrolyzed collagen used (Germina®, Brazil) in the research also was obtained from the local market, as it presented satisfactory results in previous studies on inclusion in meat products by Sousa et al. [19] and Araújo et al. [21].

2.2. Obtaining Surimi from Bullfrog MDM

For the elaboration of surimi, the mechanically separated meat was weighed, after which the washing steps were carried out, in a ratio of 1:5 MDM to 0.2 M NaCl solution in distilled water (10 ºC), respectively, in five cycles with stirring for 8 minutes. At the end of each wash, the MDM was drained before the next wash step. After the manual pressing step, 4% sorbitol (cryoprotectant) was added to the mass obtained. The mass was homogenized in a cutter (Skymsen, Brazil) for 5 minutes (4 °C) to obtain a homogeneous mixture. The finished surimi was vacuum-packed in high-density polyethylene (HDPE) plastic bags and kept frozen (-18 ºC) until the surimi gel emulsions were produced.

2.3. Production of Surimi Gel Emulsions

To prepare the surimi gel emulsions, the bullfrog surimi was thawed and cut into smaller pieces. Three formulations were developed, varying the levels of use of the commercial emulsifier soy lecithin and collagen hydrolyzed as its substitute: EC0 (100% soy lecithin), EC50 (50% soy lecithin + 50% collagen hydrolyzed), and EC100 (100% collagen hydrolyzed). All treatments were added with 2% sodium chloride, 0.3% sodium triplophosphate, 4% ice and 9% backfat and were based on the methodology of Zhou et al. [28] and Yan et al. [29].

The ingredients of each treatment were added to the surimi and homogenized in a cutter (Skymsen, Brazil) for 4 minutes at 4 ºC. The obtained emulsions were packed in high-density polyethylene packages for sousvide, under vacuum, and kept under refrigeration (4 ºC) for 12 hours for better incorporation of the ingredients into the batter. After this period, the treatments were submitted to cooking in a water bath at 90 ºC for 20 minutes, in their packages. The cooked emulsions were cooled, stored under freezing (-18 ºC) and analyzed at intervals of 20 days, for 120 days.

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2.4. Proximate Composition of Surimi Gel Emulsions

Chemical analyzes on the surimi gel emulsions of moisture and ash were carried out, by gravimetry, and proteins by the Kjeldahl method [30]. Lipids were measured by cold extraction, following the proposal by Folch, Lees and Stanley [31].

2.5. Physical and Technological Quality Parameters of Surimi Gel Emulsions

In the formation of surimi gel emulsions stage, the emulsion stability was determined according to Horita's methodology [32], which quantified the total loss of fluid from the formed meat mass, once subjected to cooking at 90 °C.

The pH was determined by dissolving the sample in distilled water and reading it in a pH meter (Quimis, Brazil) [30]. The emulsions were submitted to color determinations at CIELab system, of the parameters L*, a* and b* using a Minolta CR-400 colorimeter (Konica Minolta INC., Japan). The measured parameters were used to determine the whiteness (W), according to Equation 1 [33]:

$$W = 100 - [(100 - L^*)^2 + (a^*)^2 + (b^*)^2]^{1/2} \quad (1)$$

To evaluate the formation and stability of the gel, water holding capacity (WHC) was determined by the sample compression method, according to the methodology adapted from Huff Lonergan and Lonergan [34]. The instrumental parameters of color and CRA were evaluated at all storage intervals.

2.6. Texture Profile Analysis of Surimi Gel Emulsions

The surimi gel emulsions were analyzed on days 0, 60 and 120 of storage, prepared according to the method by Seighalani, Jamilah and Saari [35], cut in a 2 cm diameter cylindrical cutter. Texture properties were analyzed using a texturometer (Brookfield Texture analyzer, USA with Texture Pro CT software), equipped with a cylindrical-type probe (25.4 mm in diameter). The probe moved perpendicular to the sample at a speed of 1.0 mm/s with a trigger force point of 0.5 g. Two cycles of compression analysis with a compression level of 50% were applied to the samples. Hardness, gumminess, resilience, cohesiveness, elasticity and chewiness parameters were determined.

2.7. Evaluation of Lipid Oxidation of Surimi Gel Emulsions and Determination of Antioxidant Activity

For the determination of reactive substances to 2-thiobarbituric acid (TBARS), the spectrophotometric methodology described by Rosmini et al. [36], with modifications. Samples were analyzed every 20 days for a period of 120 days of storage at -18ºC. Absorbance was read at 532 nm in a UV-Vis spectrophotometer (QUIMIS, Q898U2M5, Brazil). Results were expressed as mg of malondialdehyde (MDA)/kg of sample.

The antioxidant activity in surimi gel emulsions was evaluated by applying the ABTS and FRAP free radical scavenging methods and by iron chelating ability. To carry out the analyzes, the extracts were prepared following the methodology proposed by Fernandes et al. [37], with modifications. The $ABTS^{\circ+}$ (2,2'-azino-bis (3-ethylbenzothiazolin) 6-sulfuric acid) method was performed according to the methodology of Ruffino et al. [38]. The values found for oxidant activity were expressed in trolox equivalent in μmol/100 g of sample.

Antioxidant activity evaluated in terms of iron reduction power was measured by the FRAP method, according to Benzie et al. [39], with adaptations. The standard curve was performed with trolox and the results expressed in μmol of trolox/100 g of sample. In determining the antioxidant activity by the iron chelating ability method methodology of Stookey [40] was followed. The samples were prepared and the initial absorbances read in a UV-Vis spectrophotometer (QUIMIS, Q898U2M5) at a wavelength of 562 nm. After chemical reactions and rest for 10 minutes, the absorbance was read at the same wavelength to obtain the value of. The chelating ability was calculated as the percentage of absorbance reduction between the readings performed.

2.8. Statistical Treatment of Data

The averages of the analyzed parameters were submitted to ANOVA two-way, for the effects of treatment and storage time, at a 5% significance level. When there were significant differences, the means obtained were submitted to the Tukey test ($p<0.05$) using the statistical software IBM® SPSS® Statistics, version 21.0.

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3. Results

3.1. Proximate Chemical Composition

The averages and standard deviations obtained for the parameters of the chemical composition of meat emulsions based on surimi from bullfrog MDM are listed in Table 1.

Table 1. Means and standard deviations of chemical composition parameters of surimi gel emulsions with bullfrog MDM.

Paramaters (g/100g)	Treatments		
	EC0	EC50	EC100
Moisture	61.39±0,62a	59.66± 0.80ab	57.64±2.21b
Ash	4.45±0,29a	4.02± 0.39a	4.01±0.14a
Protein	18.71±0,60b	21.03± 0.78a	20.82±1.16a
Lipids	9.28±0,45a	8.85± 0.20ab	8.15±0.20b[1]

[1]EC0: 100% soy lecithin; EC50: 50% soy lecithin + 50% collagen hydrolyzed; EC100: 100% collagen hydrolyzed. Different letters indicate statistical difference in treatments ($p<0.05$).

It was observed that the treatment containing only soy lecithin as an emulsifier (EC0) had a higher moisture content (61.39%), differing significantly ($p<0.05$) when compared to the treatment containing only hydrolyzed collagen (57.64%), which could have contributed to this difference.

3.2. Physical and Technological Quality Parameters of Surimi Gel Emulsions

Table 2 presents the results obtained for the emulsion stability analysis.

Table 2. Means and deviations obtained for the emulsion stability parameters of surimi gels in their formation.

Parameters	Treatments		
	EC0	EC50	EC100
ES (%)	75.45±0.41[a]	71.51±0.54[b]	71.20±1.26[b]
Total fluid released (%)	24.55±0.41[b]	28.49±0.54[b]	28.80±1.26[a2]

[2]EC0: 100% soy lecithin; EC50: 50% soy lecithin + 50% collagen hydrolyzed; EC100: 100% collagen hydrolyzed. Different lower-case letters in row indicate statistical difference in treatments ($p<0.05$).

Regarding the emulsion stability, all treatments showed a significant difference between them for the two analyzed parameters ($p<0.05$. The stability of the emulsion of the treatment containing only the soy lecithin as emulsifier showed a higher value and consequent lower total fluid loss, when compared to the treatments containing hydrolyzed collagen.

The pH of ttreatments is listed in Table 3. The values showed a significant difference ($p<0.05$) between the treatments only at times 0, 20, 40 and 100 days of storage, with the EC0 treatment standing out over the others (EC50 and EC100) which did not differ significantly.

Table 3. Means and deviations obtained for the pH of surimi gel emulsions with bullfrog MDM in 120 days of storage.

pH	
Days of storage	**Treaments**

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	EC0	EC50	EC100
0	7.55±0.03aB	7.41±0.02bB	7.40±0.01bB
20	7.88±0.01aA	7.83±0.01bA	7.83±0.01bA
40	6.98±0.02aCD	6.94±0.02bCD	6.91±0.01bCD
60	6.85±0.03aE	6.87±0.06aD	6.82±0.02aE
80	7.01±0.05aC	7.04±0.09aC	6.93±0.02aC
100	7.01±0.03aCD	6.98±0.03abCD	6.91±0.03bCD
120	6.92±0.05aDE	6.96±0.05aCD	6.87±0.01aD[3]

[3]EC0: 100% soy lecithin; EC50: 50% soy lecithin + 50% collagen hydrolyzed; EC100: 100% collagen hydrolyzed. Different capital letters indicate difference in column and different lower-case letters indicate difference in row ($p<0.05$).

The pH does not only influence the proliferation of microorganisms, it can interfere with the quality of food in the face of heat treatments, composition and during storage, it is also responsible for deterioration in food, especially when talking about fish, where the main attribute is the freshness. A fresh fish has a pH that varies between 6.6-6.8 [40]. The pH values showed a significant difference ($p<0.05$) between treatments only at times 0, 20, 40 and 100 days of storage, with EC0 standing out over the others (EC50 and EC100) which did not differ significantly.

Figure 1 contains the results found by for the water holding capacity analysis over the 120 days of storage.

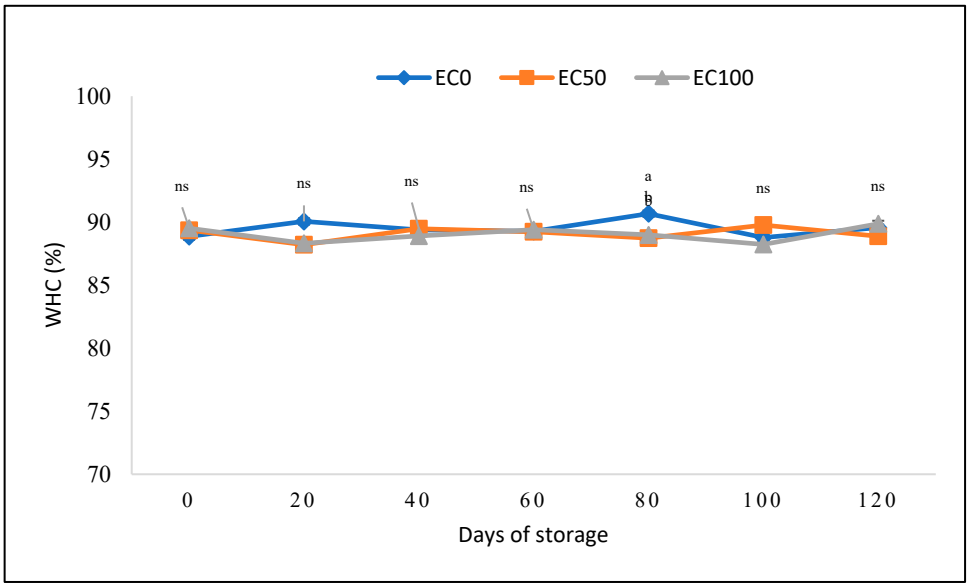

Figure 1. Behavior of the water retention capacity of bullfrog surimi gel emulsions over the 120 days. EC0: 100% soy lecithin; EC50: 50% soy lecithin + 50% collagen hydrolyzed; EC100: 100% collagen hydrolyzed. Different lower-case letters indicate statistical difference in treatments($p<0.05$). ns: no significative ($p>0.05$).

Regarding the water holding capacity, similar values were observed when comparing the different treatments ($p>0.05$), except for 80 days of storage, however with little disparity, implying that the use of hydrolyzed collagen behaved in a similar way to soy lecithin emulsifier. For storage time, a stabilization in the water holding capacity was observed, as there was no significant difference throughout the investigated period.

The average values for the parameters of color, luminosity (L*) and whiteness (W) of the surimi gel emulsions over the 120 days of storage are contained in Figure 2. The average values for the

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parameters of color, luminosity (L*) and whiteness (W) of the surimi gel emulsions over the 120 days of storage are contained in Figure 2.

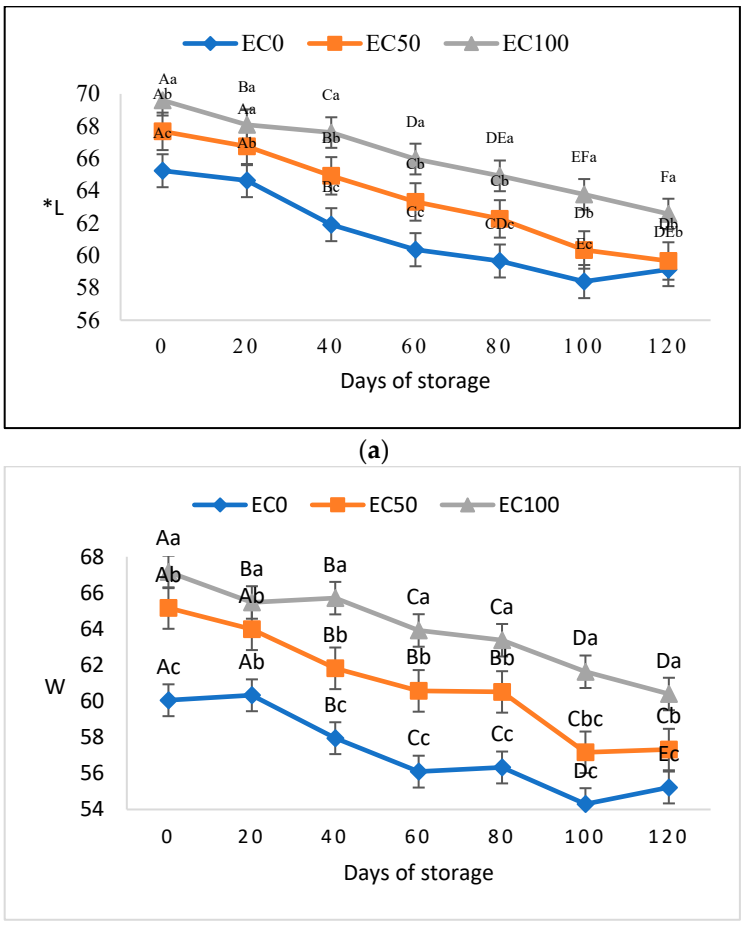

Figure 2. Color parameters related to the luminosity (a) and whiteness (b) of bullfrog surimi gel emulsions over the 120 days. EC50: 50% soy lecithin + 50% collagen hydrolyzed; EC100: 100% collagen hydrolyzed. Different uppercase letters indicate difference in time and different lowercase letters indicate difference between treatments ($p<0.05$).

According to luminosity throughout the storage period, a linear trend of reduction of the average values was noticed. It was observed that the whiteness (W) of surimi gel emulsions was affected by both treatment and storage time. A gradual loss of whiteness was noted throughout storage, indicating that there was no color stability. As with luminosity, the highest whiteness loss rates were observed in the EC50 treatment (12.0%), followed by EC100 (10.0%) and EC0 (8.0%).

3.3. Texture Profile Analysis of Surimi Gel Emulsions

Table 4 contains the values obtained for the analysis of the texture profile of the bullfrog surimi gel emulsions for the parameters of hardness, cohesiveness, resilience, elasticity, gumminess and chewiness.

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Table 4. Means and deviations for texture parameters of bullfrog surimi gel emulsions.

Parameters	Treatments	Storage (days)		
		0	60	120
Hardness (N)	EC0	8.58 ± 0.19^{cB}	9.05 ± 0.38^{bAB}	9,46 ± 0,23^{bA}
	EC50	10.29 ± 0.88^{bB}	12.09 ± 0.22^{aB}	16,84 ± 1,13^{aA}
	EC100	17.56 ± 0.13^{aA}	12.52 ± 1.35^{aB}	16,84 ± 0,58^{aA}
Gumminess (N)	EC0	1.67 ± 0.34^{aA}	1.59 ± 0.01^{bA}	1.61 ± 0.44^{bA}
	EC50	2.19 ± 0.29^{aA}	2.48 ± 0.38^{aA}	3.14 ± 0.57^{aA}
	EC100	2.17 ± 0.22^{aAB}	1.98 ± 0.26^{abB}	2.76 ± 0.29^{aA}
Resilience	EC0	0.07 ± 0.02^{aA}	0.07 ± 0.01^{bA}	0.07 ± 0.01^{bA}
	EC50	0.09 ± 0.03^{aA}	0.11 ± 0.01^{aA}	0.11 ± 0.02^{aA}
	EC100	0.07 ± 0.01^{aB}	0.11 ± 0.01^{aA}	0.11 ± 0.01^{aA}
Cohesiviness	EC0	0.19 ± 0.03^{aA}	0.19 ± 0.02^{aA}	0.16 ± 0.03^{bA}
	EC50	0.23 ± 0.06^{aA}	0.19 ± 0.01^{aA}	0.21 ± 0.01^{aA}
	EC100	0.15 ± 0.02^{aA}	0.16 ± 0.01^{aA}	0.17 ± 0.02^{bA}
Elasticity (mm)	EC0	4.46 ± 0.76^{aA}	4.61 ± 0.42^{bA}	5.11 ± 0.36^{bA}
	EC50	5.35 ±0.77^{aB}	6.90 ± 0.30^{aA}	6.21 ± 0.66^{aAB}
	EC100	5.50 ± 0.14^{aB}	6.16 ± 0.52^{aAB}	6.80 ± 0.11^{aA}
Chewiness (mJ)	EC0	6.35 ± 0.75^{cB}	6.95 ± 0.35^{cAB}	9.24 ± 1.70^{bA}
	EC50	11.63 ± 0.55^{bC}	14.65 ± 0.15^{aB}	23.23 ± 1.33^{aA}
	EC100	13.40 ± 0.20^{aB}	12.64 ± 1.30^{bB}	20.60 ± 0.87^{aA4}

[4]EC0: 100% soy lecithin; EC50: 50% soy lecithin + 50% collagen hydrolyzed; EC100: 100% collagen hydrolyzed. Different capital letters indicate difference in column and different lower-case letters indicate difference in row ($p<0.05$).

In hardness analysis of surimi gel emulsions, there were significant differences between treatments ($p<0.05$). Emulsions containing hydrolyzed collagen showed the highest values. In treatments, there was a trend towards an increase in hardness, proportionally to the percentage of fluid loss at time 0, in which EC50 and EC100 had greater losses, reflecting a greater perception of hardness (Table 2). About gumminess and resilience, it was observed that after 60 days the treatments showed differences among themselves, but with the same trend observed in the hardness and chewiness parameters.

In the cohesiveness parameter, it was observed that there was no difference between treatments at least until day 60, as well as there were no significant oscillations during storage, demonstrating that both the use of collagen and lecithin did not negatively affect the internal bonds of the emulsions, promoting greater stability. According to elasticity, variations were observed between treatments after 60 days, where treatments containing collagen had higher averages, therefore showing a greater

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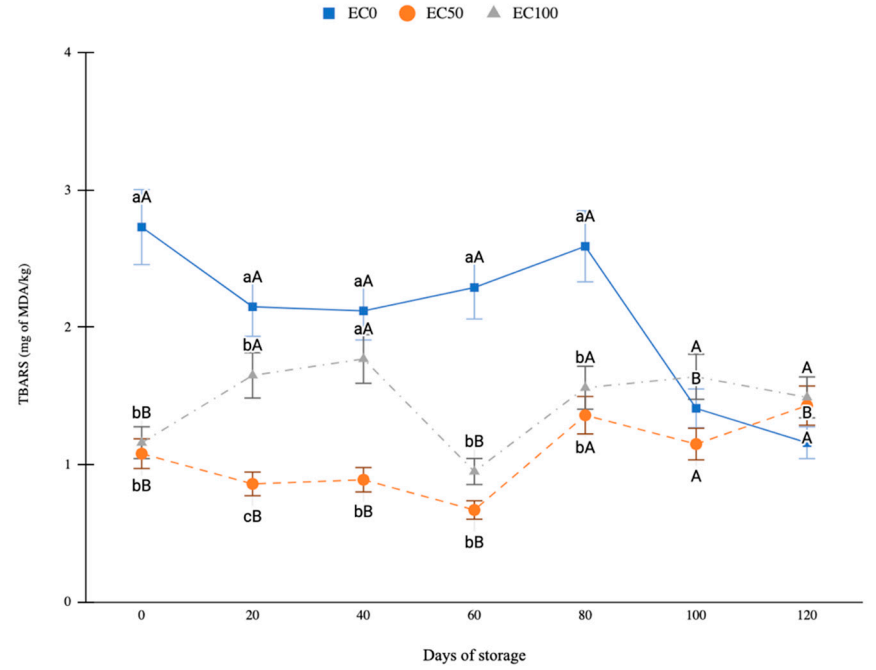
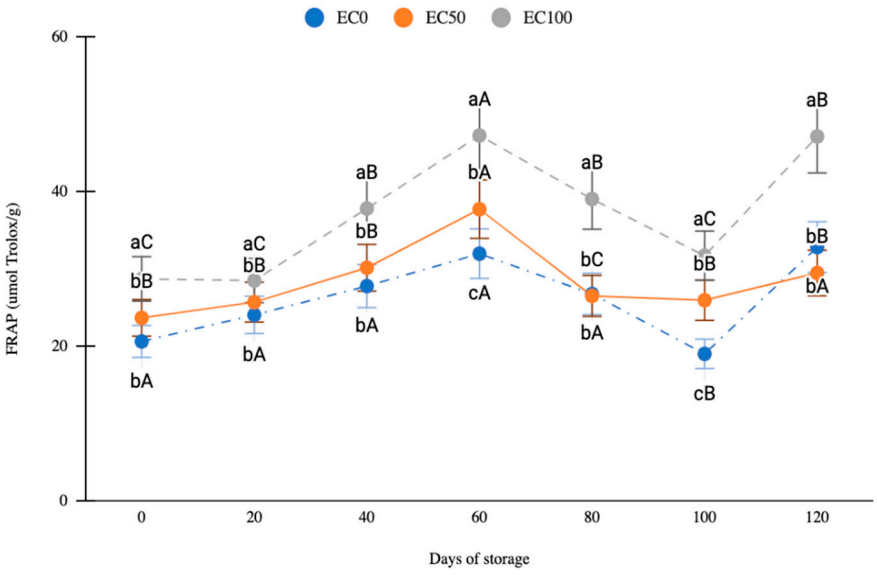
tendency to recover their original shape. It was also observed that the results indicate that the use of hydrolyzed collagen increases the hardness of the emulsions, as well as parameters related to it, such as gumminess, cohesiveness and chewiness.

3.4. Evaluation of Lipid Oxidation of Surimi Gel Emulsions and Determination of Antioxidant Activity

The values obtained for the number of thiobarbituric acid reactive substances (TBARS), as well as the antioxidant activity indicators in surimi gel emulsions during storage are distributed in Figure 3.



(**a**)



(**b**)

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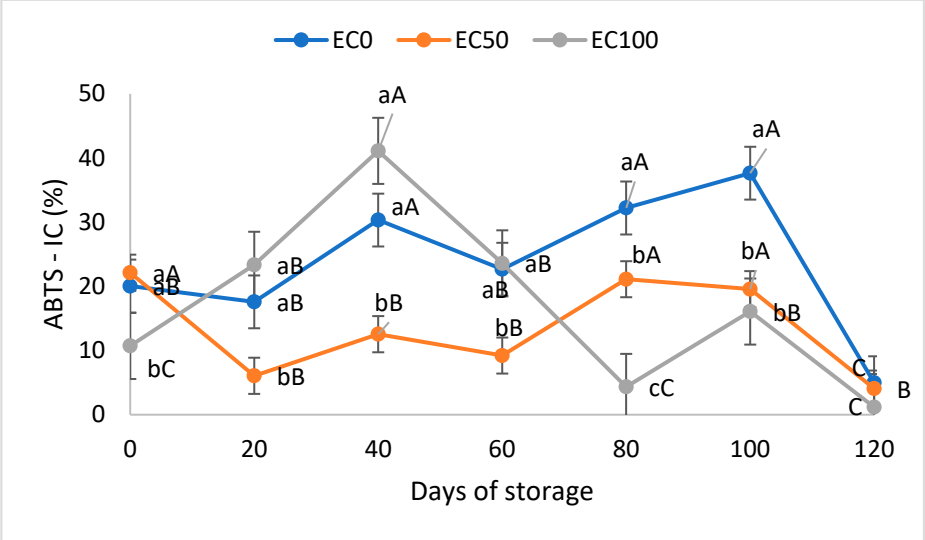
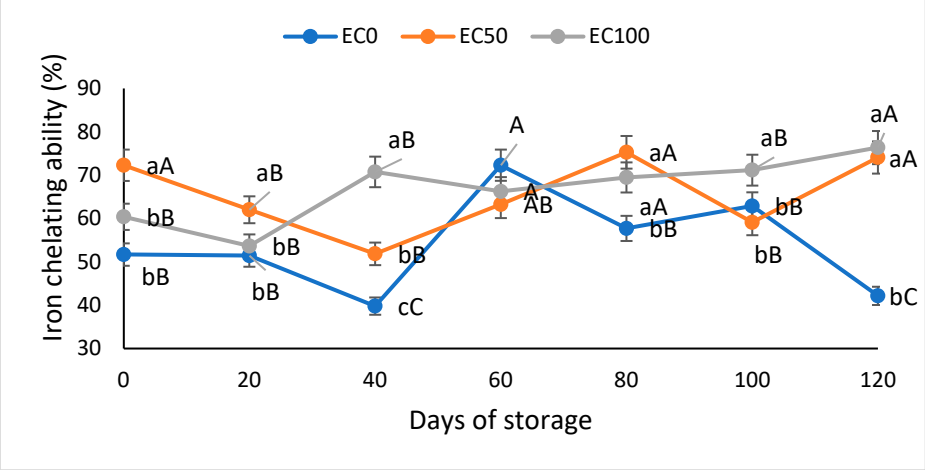


(c)



(d)

Figure 3. Parameters of lipid oxidation (a) and antioxidant activity by the FRAP method (b), ABTS (c) and iron chelating ability (d) analyzed in bullfrog surimi gel emulsions. EC0: 100% soy lecithin; EC50: 50% soy lecithin + 50% hydrolyzed collagen; EC100: 100% hydrolyzed collagen. Different uppercase letters indicate difference in time and different lowercase letters indicate difference between treatments ($p<0.05$).

Initially, regarding the number of TBARS, it was observed that the treatments using hydrolyzed collagen (EC50 and EC100) had lower values compared to EC0, using soy lecithin as an emulsifier. Regarding the effect of storage, the treatments with collagen inclusion showed an increase in the production of malondialdehyde over the 120 days, however with values below 2 mg of MDA/kg, considered a limit value by the literature for the detection of undesirable aromas [41].

As for the values obtained in the analyzes related to antioxidant activity, it was observed that for the three parameters (FRAP, ABTS and iron chelating ability) the EC100 treatment stood out compared to the other treatments, indicating that hydrolyzed collagen is probably playing a protective role in the control of lipid oxidation, in addition to the emulsifying function, being a potential additive for clean label foods. As for the effect of storage time, it was found that in the first 40 days hydrolyzed collagen had better protective activity in lipid oxidation.

4. Discussion

In proximate composition of the surimi gel emulsions (Table 1), the values obtained for moisture, protein and lipids were close to those found by Zhou et al. [28], who found higher values (above 70%) of moisture and 11% of proteins when studying the properties of white croaker surimi gel improved with camellia tea oil, however they used a greater amount of water in their formulation.

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The differences obtained for lipids may be associated with the soy lecithin used in emulsification, which contains refined soy oil and vegetable fatty acid in its composition, which may have contributed to the higher lipid content found in EC0. For ash, the value obtained was higher than that found by Fragoso et al. [23], probably due to the incorporation of minerals in the formulation of emulsions.

Regarding the emulsion stability of surimi gel, in their formation phase (Table 2), the behavior observed in which EC0 was more stable, with less fluid loss, can be explained by the chemical nature of lecithin, which is a molecule amphipathic (has hydrophilic and hydrophobic poles in the same molecule), unlike collagen powder, which has a more hydrophobic character [18].

The water retention capacity of the bullfrog surimi gel emulsions, in general, remained stable in all treatments, which probably indicates that the hydrolyzed collagen behaved similarly to the soy lecithin emulsifier in this investigated parameter. (Figure 1). The values found are close to those found by Zhou et al. [28], for its treatment of higher concentration of oil. The same stabilization can also be verified regarding storage. Fragoso et al. [23] obtained lower values and observed the loss of water retention capacity over 60 days of storage in surimi gels containing starch in their formulation. In this study, meat emulsions had fat, a constituent that contributes to high WHC values, in addition, sodium tripolyphosphate was used, which, according to the literature, also has the function of increasing the capacity to retain water. Vasconcelos et al. [42] obtained similar values when they evaluated the effects of adding cryoprotectants to matrinxã surimi during its storage under freezing.

According to color parameters, related to luminosity (Figure 2a) and whiteness (Figure 2b), it was observed changes between treatments, because when using collagen in the formulation, the luminosity value increased significantly ($p<0.05$) , probably due to the fact that the liquid commercial emulsifier of soy lecithin has a darker color, unlike powdered collagen, which has a lighter color. Despite this, EC0 showed the lowest rate of decrease in luminosity (9.37%) at the end of the 120 days, while EC50 showed the greatest decrease (11.86%) in relation to its initial value. The actual storage effect may be related to browning reactions in foods such as the Maillard reaction, in the heat treatment of surimi gels, and to lipid oxidation which can also affect color [43]. A gradual loss of whiteness was also noted during storage, indicating that there was no color stability. The highest whiteness loss rates were observed in the EC50 treatment (12.0%), followed by EC100 (10.0%) and EC0 (8.0%). This behavior corroborates what was observed for luminosity in this study. Sousa et al. [44] found results above 70 in surimi gels containing *Spondias mombin* residue extract, however its processing took place differently from that used in this study, as well as the formulation, which may explain these higher values.

In the evaluation of lipid oxidation of bullfrog surimi gel emulsions, related to the number of TBARS (Figure 3a), the highest values obtained in EC0 are probably due to the composition of the commercial emulsifier soy lecithin, which contains oils in its composition, increasing the lipid content (Table 1) and making the treatment more susceptible to oxidation. This behavior can also be attributed to the available terminals of hydrolyzed collagen chains, which may have controlled the progress of oxidation [18]. The values obtained are close to those found by Sousa et al. [44], in cambucu hake surimis with *Spondias mombin* extract as a natural antioxidant.

For the FRAP and ABTS data (Figure 3b,c), the same behavior obtained was observed by Marín-Peñalver et al. [45], in surimis with addition of carrageenan gum obtained by spray-dryer. In storage, treatments with collagen were superior, especially between days 40 and 60 of storage. Hydrolyzed collagen is reported in the literature as a potential antioxidant, due to possible interactions of the molecule in the food matrix, with a protective effect in meat products [20].

For texture profile analysis (TPA) (Table 4), a similar behavior was observed between hardness and fluid loss, which occurred in greater proportion in EC100. Emulsions containing collagen had the highest hardness values, suggesting that the insertion of this protein made the product harder. A similar behavior was observed for the chewability parameter, where the treatment containing only soy lecithin showed the lowest values. These values are close to those investigated by Zhu et al. [24], in cod surimi gel emulsions using perilla and soybean seed oils as lipid source. For gumminess and resilience, Sousa et al. [44] found similar results for the resilience parameter and lower results for gumminess. The values obtained in this study demonstrate that there is a need for greater force to disintegrate treatments containing collagen until it is ready for swallowing, as well as greater resilience. Cohesiveness showed values close to Buda et al. [45] when studying the effects of apple

pectin and konjac glucomannan on quality characteristics of silver carp surimi. Regarding elasticity, which means the ability of a product to recover after being deformed in the first compression, it was observed that higher values were reported by Laksono et al (2019) in the texture profile of kamaboko from fish conger pike tooth of Daggertooth.

The use of hydrolyzed collagen increased the hardness of the emulsions, as well as related parameters such as gumminess, cohesiveness and chewiness. During storage, an increase was observed, mainly between 60 and 120 days, in hardness, gumminess, elasticity and chewiness. Such changes may be related to possible changes in the surimi gel network, as on day 0 a greater loss of fluid was observed in EC50 and EC100 treatments (Table 2), as well as lower WHC values at time 80 (Figure 1). In general, a slight strengthening of the gel network of the emulsions was observed over time with the increase in hardness values of all treatments, as well as in chewiness, which may be linked to the stability of the water retention capacity observed in this research. .

5. Conclusions

The utilization of hydrolyzed collagen as a substitute for commercial emulsifier based on soy lecithin in surimi emulsion brought positive results, especially for water holding, whiteness and texture of the gels, with similar values obtained between 50% and 100% of substitution. To improve the parameters of fluid loss and hardness, more research is needed to optimize formulations with ingredients that minimize such losses. In addition to acting as a potential emulsifier in emulsions made with surimi, collagen also played an important role in protecting the matrix against lipid oxidation agents. Best results were achieved after 40 days of frozen storage.

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