Desenvolvimento de requeijão com extrato aquoso de semente de *Moringa oleifera*

Development of processed cheese with aqueous extract of *Moringa oleifera* seed

Elaboración de queso procesado con extracto acuoso de semilla de *Moringa oleifera*

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Resumo
Neste estudo o queijo fundido foi produzido com substituição total e parcial da goma xantana pelo extrato da semente de Moringa e armazenado a 4ºC. Foram estudados a composição química pH, acidez, cor, textura e reologia. A composição química diferiu significativamente (p <0,05) entre as amostras. O teor de proteína foi maior para a amostra contendo apenas extrato de Moringa. A acidez diferiu significativamente (p <0,05) apenas no último dia de armazenamento. Os valores de pH permaneceram dentro dos limites de qualidade estabelecidos (pH ≥ 6,0) para todas as amostras durante os 21 dias de armazenamento. A adição do extrato afetou a cor e a microestrutura das amostras; Queijos processados com extrato adicionado apresentaram partículas de menor tamanho de glóbulos de gordura e distribuídos sem uniformidade. O extrato de Moringa interferiu na textura do produto, revelando-se um grande substituto parcial e / ou total dos conservantes químicos. A amostra com maior substituição de goma pelo extrato de Moringa teve dureza igual à amostra controle. Além disso, esta amostra (T4 - 0,15% goma e 0,35% extrato de Moringa) apresentou maior índice de consistência (K). As amostras não apresentaram diferenças significativas durante o período de armazenamento para coesividade. O perfil reológico mostrou que todas as amostras apresentaram um perfil não newtoniano (pseudoplástico). Dessa forma, acredita-se que a semente da Moringa tenha potencial para uso como substituto de espessante.
Palavras-chave: Queijo; Proteína; Emulsificante; Aditivo.

Abstract
In this study, processed cheese was produced with a total and partial substitution of xanthan gum by Moringa seed extract and stored at 4ºC. Chemical composition pH, acidity, color, texture, and rheology were studied. The chemical composition differed significantly (p <0.05) between the samples. Protein content was higher for the sample containing only Moringa extract. The acidity differed significantly (p <0.05) only on the last day of storage. The pH values remained within the established quality limits (pH≥6.0) for all samples during the 21 days of storage. The addition of extract affected the color and microstructure of the samples; processed cheese with added extract showed smaller particle size fat globules and distributed without uniformity. The Moringa extract interfered in the texture of the product, proving to be a great partial and/or total substitute of chemical preservatives. The sample with greater gum substitution by the Moringa extract had hardness equal to the control sample. Also, this sample (T4 - 0.15% gum and 0.35% Moringa extract) presented higher consistency index (K). Samples did not show significant differences during storage period for cohesiveness. The rheological profile showed that all samples presented a non-Newtonian (pseudoplastic) profile. Thus, it is believed that the Moringa seed has a potential for use as a thickener substitute.
Keywords: Cheese; Protein; Emulsifier; Additive.

Resumen
En este estudio, se produjo queso procesado con sustitución total y parcial de goma xantana por extracto de semilla de Moringa y se almacenó a 4ºC. Se estudió la composición química pH, acidez, color, textura y reología. La composición química difirió significativamente (p <0.05) entre las muestras. El contenido de proteína fue mayor para

la muestra que solo contenía extracto de Moringa. La acidez difirió significativamente (p <0.05) solo en el último día de almacenamiento. Los valores de pH se mantuvieron dentro de los límites de calidad establecidos (pH ≥6.0) para todas las muestras durante los 21 días de almacenamiento. La adición de extracto afectó el color y la microestructura de las muestras; El queso procesado con extracto agregado mostró glóbulos de grasa de menor tamaño de partícula y se distribuyó sin uniformidad. El extracto de Moringa interfirió en la textura del producto, demostrando ser un gran sustituto parcial y / o total de los conservantes químicos. La muestra con mayor sustitución de goma por el extracto de Moringa tuvo una dureza igual a la muestra de control. Asimismo, esta muestra (T4 - 0.15% goma y 0.35% extracto de Moringa) presentó mayor índice de consistencia (K). Las muestras no mostraron diferencias significativas durante el período de almacenamiento para la cohesión. El perfil reológico mostró que todas las muestras presentaron un índice no newtoniano (pseudoplástico) perfil. Por lo tanto, se cree que la semilla de Moringa tiene potencial para usarse como un sustituto espesante.
Palabras clave: Queso; Proteína; Emulsionante; Aditivo.

1. Introdução

We note an increase in consumption per food product with functional properties, as in addition to being a source of essential nutrients and energy, they can be enriched with additives that are essential to improve human health (Colín-Cruz et al., 2019).

In the dairy products area, we can observe an increase in the versatility of products, mainly for yogurt and cheeses. Due to its versatility, cream cheese and creamy melted cheese has become one of the focuses in research in the production of functional and differentiated products (Vieira et al., 2014). Felix et al. (2016) clarifies that According to the Technical Regulation for the Identification and Quality of Curd, Curd is defined as the product obtained from the coagulation of milk, which may be acidic or enzymatic followed by the melting of curd, removal of whey and washing, and the addition of cream of milk, butter or butter oil in its composition according to the Brazilian Legislation.

Due to cost reduction in production, nowadays there is a series of similar products using the same process (Torres et al., 2015). Even though the modified processed cheese has non-dairy ingredients, they have similar sensorial characteristics to the traditional ones. In addition to reducing costs, ingredients substitution can result in other benefits such as improving the nutritional and functional characteristics of the product (Belsito et al., 2017)

In this context, studies of protein sources have increased in order to apply their technological properties in food processing (Mao et al., 2018).

Moringa (*Moringa oleifera*) is a tropical plant known for its high nutritional value (Gopalakrishnan et al., 2016). Moringa seeds are recognized for having antimicrobial, antioxidant, and nutritional properties, and a significant amount of lipids and proteins (Gupta et al., 2017). According to Baptista et al. (2015), moringa seeds contain high levels of proteins, approximately 45% of their constitution. Some of these proteins able to interact with sugars through hydrogen bonding, hydrophobic interactions and Van der Waals forces promoting agglutination (Yeh et al., 2014). Moreover, chemical composition studies of this plant have identified several bioactive substances that can be used in various industrial applications (Gupta et al., 2017).

Ultrafiltration is an effective alternative for concentrating/purifying numerous proteins based on their molar mass. However, despite its extensive use, the protein fractionation potential has not yet been explored in the industry (Baptista et al., 2017).

Understanding the functional properties and behavior of proteins is important to the technological development of the food industries, once these compounds become alternative sources of protein and chemical compounds substitutes resulting in cost reductions (Mao et al., 2018).

Therefore, based on the importance of proteins for the industry, the objective of this study was to evaluate the total and partial substitution of xanthan gum, a thickener agent, by the Moringa extract ultrafiltrate in processed cheese. The product composition, physical, texture, rheological and microstructural properties of processed cheese were evaluated.

2. Metodologia

2.1 Material

Moringa seeds were obtained in Aracaju - SE, located between 10°55'56 "south of the geographical coordinate latitude and 37°04'23" west longitude. Xanthan gum (Rhodigel 80) was donated by Danisco®, and nisin and fondant salt (R9) donated by Simionato Leite Vida Ativa®. Milk and cream were purchased on the supermarket in Maringa. All reagents used were of analytical grade.

2.2 Moringa extract

Peeled seeds (1 g) were mixed with 10 mL of sodium chloride 1.0 M and triturated in a blender for 30 seconds, followed by 30 min of magnetic stirring. Right after, the extract was filtered on a vacuum filter with 0.45 μm cellulose ester membrane. Finally, the extract was purified in Millipore® pellicon2mini ultrafiltration system (flow 1 bar, 5 kDa polyurea membrane and 0.056 m2 filter area). The concentrate was used in the elaboration of the processed cheese.

2.3 Processing of processed cheese

The curd mass was obtained by heating pasteurized whole milk at 80 °C and subsequent coagulation with 85% lactic acid (0.28% v/v). The milk was maintained under slow and continuous stirring until complete mixing of the acid. Then, the curds were drained and washed with filtered water until reach pH 5.2.

Five formulations were prepared (formulation in table 1): Con, T1, T2, T3, and T4. The curd mass, fondant salt, sodium chlorate, xanthan gum, and some water were mixed and heated on Thermomix Vorwerk (75 °C/ 4 min). Thereafter, the cream, remaining water and the extract were added under constant stirring until the temperature reached 90 °C. The treatments were defined as follows: control with 0.5% of xanthan gum (Con); 0.25% gum and 0.25% Moringa extract (T1); 0.5% Moringa extract (T2); 0.35% gum and 0.15 % Moringa extract (T3) 0.15% gum and 0.35% Moringa extract (T4). Each sample was individually packed in sterile plastic containers and stored at 4 °C. Samples were randomly taken at 1, 7, 14 and 21 days of storage for analysis.

Table 1. Processed cheese formulation.

Ingredients (%)	**Processed Cheese**				
	Con (0.5% gum)	**T1 (0.25% gum, 0.25% Moringa)**	**T2 (0.5 % Moringa)**	**T3 (0.35% gum, 0.15 % Moringa)**	**T4 (0.15% gum, 0.35% Moringa)**
Curd Mass	40	40	40	40	40
Cream	37	37	37	37	37
Filtered water	21.3	21.3	21.3	21.3	21.3
Fondant salt	0.6	0.6	0.6	0.6	0.6
Sodium chloride	0.6	0.6	0.6	0.6	0.6
Nisin	0.003	0.003	0.003	0.003	0.003
Xanthan gum	0.5	0.25	-	0.35	0.15
Moringa Extract	-	0.25	0.5	0.15	0.35

Source: Author.

2.4 Chemical composition

The moisture and ash content were determined according to the Association of Official Analytical Chemists. The protein content was obtained by the micro Kjeldahl method Total lipids were extracted using the method of Gerber. Total carbohydrate was calculated by difference. (AOAC, 2019).

2.5 Color

Color was evaluated using a portable colorimeter (Minolta CR400) witha 10° view angle and a D65 illuminant. Color was determined at nine points, recording lightness (L*), redness (a*) and yellowness (b*).

2.6 Titratable Acidity and pH

Titratable acidity was obtained by titration with 0.1 NaOH. The pH was measured using a pH meter (pHmeter Thermo – Scientific VSTAR 92 Orion Versastar) (AOAC, 2019).

2.7 Texture

The parameters of hardness, adhesiveness, elasticity and cohesiveness were determined using a CT3 texture analyzer (Brookfield Engineering laboratories, Inc., Middleboro, USA), equipped with a cylindrical acrylic probe (35 mm). The texturometer was adjusted with a 5 kg load cell and pre-test speeds, test and post-test: 2.0 mm/s, 10 mm distance, with 5 seconds of contact time and contact force of 100 g (Dender et al., 2012).

2.8 Rheology

The rheological measurements were carried out according Felix et al., (2017), which was performed at 10 °C using a MARS II controlled stress rheometer (Hacke Thermo Fisher Scientific Inc., Newington, Germany), equipped with a 35 mm diameter cone plate with a 0.052 mm gap. The analysis was performed in triplicate for each formulation at 10 °C. The shear rate ranged from 0 to 100 s^{-1}. Data from flow curves were fitted to the Herschel-Bulkley model (Eq. 1) by non-linear regression analysis using Origin Pro 9.1 (Origin Lab Corporation, Northampton, MA, USA).

$$\sigma = \sigma_0 . K . \gamma^n$$

where σ represents the shear stress (Pa), k is the consistency index (Pa.s^n), $\dot{\gamma}$ is the shear rate (s^{-1}), and n represents the consistency index (dimensionless).

2.9 Scanning electron microscopy

The surface morphology of the processed cheese was observed through a scanning electron microscope (Quanta 250, FEI, Germany) at 20 kV. The samples were fixed on a double-sided carbon tape and coated with a gold layer, with a thickness of approximately 30 nm (Ahuja, 2017).

2.10 Statistical analysis

All experiments were performed with four treatments in triplicate. The processed cheese characteristics were assessed by analysis of variance using the general linear model (GLM) with SPSS (v.15.0) (IBM SPSS Statistics, SPSS Inc., Chicago, EUA) for Windows. Means and standard deviation were calculated for each variable. Differences between means were evaluated by Tuckey test ($p < 0.05$).

3. Resultados e Discussão

3.1 Chemical composition

Processed cheese chemical composition is shown in Table 2, where protein, fat, moisture, ash and carbohydrates were analyzed.

Table 2. Chemical composition of all processed cheese formulations.

Analysis	**Con**	**T1**	**T2**	**T3**	**T4**
Protein	5.51^{c}±0.005	5.41^{d}±0.005	5.82^{a}±0.005	5.71^{b}±0.005	5.59^{c}±0.005
Fat	19.88^{b}±0.080	19.16^{c}±0.065	18.56^{d}±0.060	18.49^{d}±0.090	21.07^{a}±0.075
Moisture	67.59^{b}±0.005	69.59^{a}±0.348	71.37^{a}±0.444	71.31^{a}±0.178	68.51^{b}±0.684
Ash	1.58^{b}±0.002	1.54^{b}±0.023	1.60^{b}±0.023	1.74^{a}±0.021	1.73^{a}±0.040
Carbohydrate	5.43±0.066	4.60±0.079	2.78±0.710	2.79±0.339	2.60±1.092

*Means with different letters on the same line are significantly different ($p<0.05$). Results are expressed as mean and standard deviation. Source: Authors.

For all treatments, proteins presented a significant difference ($p<0.05$), the formulation T2, with 0.5% Moringa, showed the highest value, followed by formulation T3, T4, Con, and T1. As expected, adding Moringa resulted in an increase of protein, since the seeds have good nutritional quality, with high protein concentrations, approximately 38 g/100 g, and the extract was purified by ultrafiltration process (Baptista et al., 2015; Gopalakrishnan et al., 2016).

Mahami, Ocloo and Odonkor (2012) reported a significant increase in protein content on cottage cheese by adding Moringa seeds extract (0.5, 1, 1.5 and 2%). Considering the high protein content of Moringa seeds, its use on dairy products is justified by the increase on the yield on the final product because processed cheese is formed by the coagulation of proteins in milk, thus the higher protein content on the extract may increase the final yield (Ogunsina et al., 2011).

Regarding the fat content, a significant difference was observed between the samples. The T4 sample had the highest fat content (21.07), followed by Con, T1, T2 and T3 samples with fat contents of 19.88, 19.16, 18.56 and 18.49 respectively. In addition, the formulation containing only extract (T2) and the formulation containing 0.35% of gum and 0.15% of Moringa (T3) did not show a significant difference between them. This result was expected, since the ultrafiltration membrane retains components of high molecular mass, such as fat (Cunha et al., 2010).

Felix et al. (2016) studied the effect of adding konjac gum on cheese, and conclude that formulations with lower fat cheese showed an increase in moisture. A similar fact was observed in this study, where fat and moisture contents were inversely correlated, T2 was the sample with the highest fat content followed by T3, T1, T4, and Con, respectively. Higher moisture content contributes to the reduction of the defatted dry extract (DDE). The high casein content contained in the DDE promotes the strengthening of the protein-protein interactions, causing the protein matrix to stiffen and, thus, to reduce the creaminess of the processed cheese (Silva, 2012).

The mineral content of the samples differed significantly ($p <0.05$), where the T1, Con and T2 formulations had the lowest values of 1.58, 1.54 and 1.60 respectively. The values found on this study were lower than the ones reported by Dender et al., (2012), who found values ranging from 2.52 to 2.57% in their processed cheese without fat addition and reduced sodium content. Regarding the carbohydrate content, there was no difference between the formulations. However, all formulations presented a high carbohydrate content when compared to a typical processed cheese, which the carbohydrate content is about 1.2% (Dender et al., 2012).

3.2 Color

The results of the color analysis are presented in Table 3. The samples presented high L values and low values for the parameter a *, indicating a trend of the samples for green color, while the parameter b * the values were positive, indicating a trend towards a yellow color. There were significant differences (p> 0.05) between the samples in relation to the parameters. The addition of the Moringa had a significant effect on luminosity, yellowness (b *) and redness values (a *).

Table 3. Instrumental color of processed cheese.

Parameter	**Con**	**T1**	**T2**	**T3**	**T4**	**P<0,05**
L	101.11^{a}±0.413	88.13^{c}±0.989	90.35^{c}±0.502	98.56^{ab}±0.046	96.74^{b}±0.837	0.000
a*	0.27^{a}±0.015	0.14^{b}±0.036	0.13^{c}±0.019	0.19^{ab}±0.008	0.12^{b}±0.018	0.000
b*	11.36^{c}±0.032	13.31^{ab}±0.184	13.43^{a}±0.147	13.22^{ab}±0.022	12.63^{b}±0.104	0.000

* Means with different letters on the same line are significantly different (p<0.05). Results are expressed as mean and standard deviation. Source: Authors.

The differences among the samples may be explained by the use of the gum and extract since the differences tend to increase with the increase of the use of the gum substitute. Cunha et al (2010) observed a similar behavio in his study when worked with cheese analogue produced with vegetable fat, and the color variation was directly correlated with the addition of the vegetable fat.

3.3 Titratable Acidity and pH

Milk is considered a buffer system with a low concentration of free hydrogen ion, thus its total amount of acid can be obtained only by the titratable acidity measure (Dender et al 2012). Titrable acidity and pH values are shown in table 4. Titratable acidity significantly differed (p> 0.05) only at 21 days of storage, where T3 showed the highest acidity (0.094), followed by samples T4, T1, Con, and T2 with 0.088, 0.084, 0.080 and 0.059 respectively.

The treatment added only with Moringa, T2, presented the lowest acidity values throughout storage. Moringa seeds extract may have inhibited the growth of lactic acid microorganisms resulting in the reduction of the amount of acid produced, due to its antimicrobial properties (Mahami; Ocloo; Odonkor., 2012).

Table 4. Titratable acidity and pH of all processed cheese during storage period.

	Days	Con	T1	T2	T3	T4	SEM	p < 0.05
Titratable Acidity								
	1	0.027	0.031	0.020	0.027^{B}	0.027	0.001	0.101
	7	0.080	0.066	0.062	0.065^{B}	0.061	0.003	0.543
	14	0.088	0.080	0.066	0.071^{B}	0.075	0.003	0.480
	21	0.080^{b}	0.084^{ab}	0.059^{c}	0.094^{aA}	0.088^{ab}	0.004	0.002
SEM		0.003	0.003	0.002	0.004	0.004		
p < 0.05		0.811	0.392	0.536	0.005	0.075		
pH								
	1	6.365^{A}	6.395^{A}	6.415^{A}	6.400^{A}	6.370^{A}	0.007	0.113
	7	6.350^{bcA}	6.385^{aA}	6.380^{abA}	6.350^{bcB}	6.335^{cB}	0.006	0.031
	14	6.365^{A}	6.390^{A}	6.390^{A}	6.355^{B}	6.370^{A}	0.005	0.103
	21	6.235^{abB}	6.240^{aB}	6.240^{aB}	6.195^{bC}	6.155^{cC}	0.011	0.012
SEM		0.021	0.024	0.026	0.029	0.033		
p < 0.05		0.000	0.000	0.001	0.001	0.000		

*Means in the same line with the same lower case overwritten are not significantly different (p<0.05). Means in the same column with the same upper case letter overwritten are not significantly different (p<0.05). Source: Authors.

The pH is an important parameter of cheese identity and quality, once it directly affects the cheese structure and rheological properties (Belsito et al., 2017). pH values below 5.4 may indicate damage to the structure of the melted cheeses since they tend to form a very firm and granular texture, as well as to promote flavor changes. On the other hand, pH between 5.5 and 5.7 results in cheese with a creamy and firm consistency. Processed cheese showed pH higher than 6.0, as a result of the decrease in the protein-protein interaction and the increase of the protein hydration, causing less firm curd and thus altering the consistency of the product (Dender et al., 2012). The pH values remained within the established quality limits (pH≥6.0) for all samples during the 21 days of storage. The variation of pH and titratable acidity of cream cheese is related to the composition of the products (Felix et al., 2017).

3.4. Texture

Texture results are shown in Table 5. It was observed statistical differences (p<0.05) for hardness during all days. Cohesiveness showed differences at day 1 and 14, adhesiveness at days 7, 14, and 21, and elasticity at day 7 and 14.

Table 5. Evaluation of texture parameter during storage period.

	Days	Con	T1	T2	T3	T4	SEM	p<0.05
Hardness								
	1	227.500^{a}	92.500^{cBC}	32.500^{d}	142.500^{b}	212.500^{a}	24.42	0.001
	7	222.500^{a}	85.000^{cC}	32.500^{d}	137.500^{b}	222.500^{a}	25.07	0.001
	14	265.000^{a}	90.000^{cAB}	32.500^{d}	157.500^{c}	215.000^{b}	28.29	0.001
	21	243.000^{b}	105.000^{dA}	30.500^{e}	155.000^{c}	243.500^{a}	25.82	0.001
SEM		7.043	2.978	0.886	3.651	3.659		
p<0.05		0.076	0.028	0.884	0.108	0.847		
Cohesiveness								
	1	0.850^{a}	0.860^{a}	0.515^{b}	0.720^{b}	0.770^{a}	0.043	0.006
	7	0.770	0.815	0.845	0.830	0.720	0.018	0.126
	14	0.920^{a}	0.955^{a}	0.555^{b}	0.835^{ab}	0.760^{ab}	0.051	0.029
	21	0.860	0.860	0.850	0.885	0.740	0.045	0.931
SEM		0.034	0.032	0.070	0.036	0.013		
p<0.05		0.612	0.592	0.149	0.537	0.692		
Adhesiveness								
	1	3.500	1.950^{C}	0.001^{B}	3.000	5.250	0.670	0.094
	7	5.250^{a}	2.800^{bBC}	0.299^{cA}	4.100^{ab}	3.150^{b}	0.556	0.000
	14	9.550^{a}	2.350^{bcB}	0.350^{cA}	3.500^{b}	2.950^{bc}	1.044	0.000
	21	5.200^{a}	4.290^{abA}	0.300^{cA}	4.400^{ab}	2.700^{ab}	0.595	0.002
SEM		0.885	0.338	0.053	0.233	0.577		
p<0.05		0.014	0.000	0.002	0.095	0.461		
Elasticity								
	1	6.045	6.210^{C}	8.645	6.285 ^{C}	6.790	0.427	0.313
	7	6.305^{ab}	6.195^{abC}	5.360^{b}	6.485^{abBC}	6.690^{a}	0.165	0.033
	14	6.415^{ab}	6.685^{abB}	5.770^{b}	7.230^{aA}	6.400^{ab}	0.595	0.036
	21	6.370	7.110^{A}	5.790	6.715^{B}	6.745	0.177	0.138
SEM		0.093	0.143	0.596	0.135	0.218		
p<0.05		0.612	0.000	0.160	0.001	0.956		

*Means in the same line with the same lower case overwritten are not significantly different (p<0.05). Means in the same column with the same upper case letter overwritten are not significantly different (p<0.05). SEM – mean standard deviation. Source: Authors.

The results obtained in the evaluation of the texture of the creamy curd are shown in Table 5. Statistical differences (p <0.05) can be observed for the firmness parameter in all the days analyzed. The other parameters showed differences on days 1 and 14 for cohesiveness, days 7.14 and 21 for adhesiveness and on days 7 and 14 for elasticity. Throughout the storage period, only the T1 sample differed between storage days for firmness. Adhesiveness differed for samples Con, T1 and T2 and elasticity for samples T1 and T3 during storage days. The samples showed no significant differences during storage for cohesiveness.

Changes in the texture profile can happen during storage due to activities such as proteolysis, glycolysis, lipolysis and pH changes. Proteolysis can occur during cheese storage due to changes in the texture of this product, as there is a break in its protein matrix, destabilizing the texture, firmness, adhesiveness and elasticity (Mattanna et al., 2012).

Regarding firmness, the control cheese and the T4 sample were firmer than the others. The T2 sample showed less firmness compared to the others on days 1,7 and 14 of storage. Moisture plays an important role in the technological processing of curd, since it influences the firmness of the final product (Silva, 2012). High humidity values weaken the protein's stiffness contributing to the softness of the curd (Cunha et al., 2010). In addition, complexes formed from proteins with polysaccharides can improve emulsifying properties, as they contribute to texture improvement (Felix et al., 2017). According to Mattanna et al. (2012) a number of factors can influence the texture of processed cheeses, including composition, pH, type and concentration of emulsifying salt, in addition to the parameters used in processing, such as agitation and temperature.

3.5 Rheology

The samples showed a non-Newtonian behavior and the shear rate curves were mathematically modeled using the Herschel-Bulkley model, with the parameters presented in Table 6. We can observe that the data fit the model, since for all treatments, R^2 was superior than 0.95.

Table 6. Herschel-Bulkley Model Parameters.

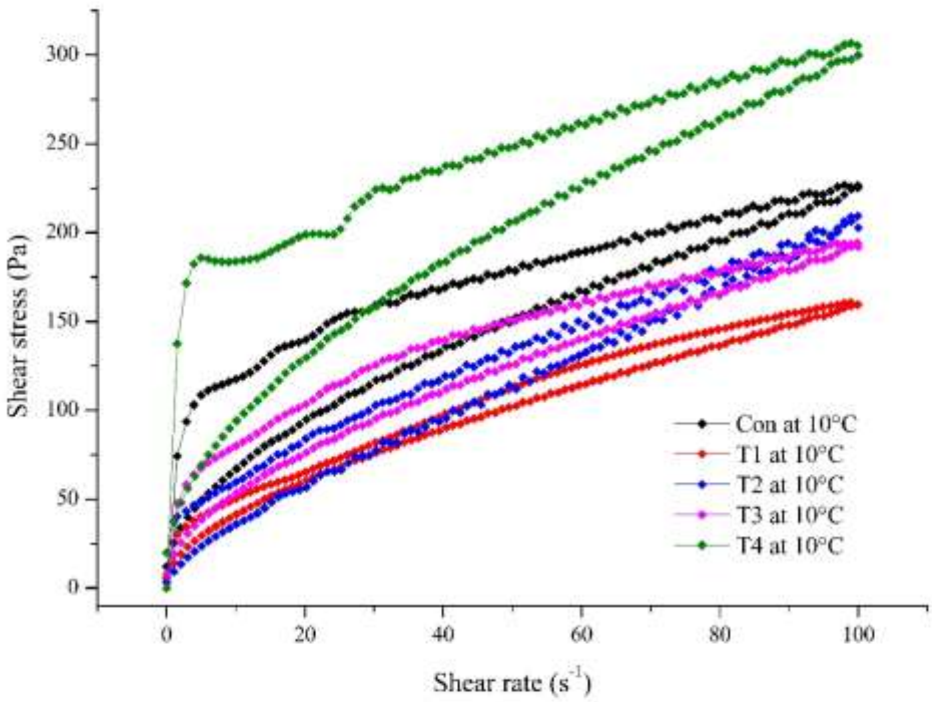
Treatment	σ_0	**K (Pa.s^n)**	***n***	**R^2**
Con	10.53	52.59	0.303	0.991
T1	4.393	10.55	0.578	0.996
T2	28.66	5.70	0.746	0.998
T3	7.33	29.83	0.399	0.996
T4	13.56	94.42	0.239	0.966

Source: Authors.

Observing flow behavior index (*n*), all are smaller than one ($n<1$), in accordance with literature data, corroborating to classify the fluid as non-Newtonian and shear-thinning (pseudoplastic) behavior. The highest consistency index (K) was calculated for sample T4, followed by samples Con, T3, T1, and T2, respectively. Sample T2 presented the highest value for the yield stress (σ_0), which was quite high in relation to the others, and this high value could be associated to a concomitant increase in protein hydration, viscosity, and consistency (Kelimu et al., 2017).

Rheological differences may be explained by the composition of the formulations and the interactions of the particles, due to the partial or total substitution of the thickener by the Moringa extract that acts on the viscosity of the product (Belsito et al., 2017). Low fat content may be responsible for changes in texture. Once there is a fat reduction, there is an increase in protein-protein interaction, causing the stiffening of the protein matrix and, thus, a decrease in the creaminess of processed cheese (Silva, 2012). The flow curves of the samples at 10 ° C are shown in Figure 1.

Figure 1. Rheological behavior of processed cheese formulations.



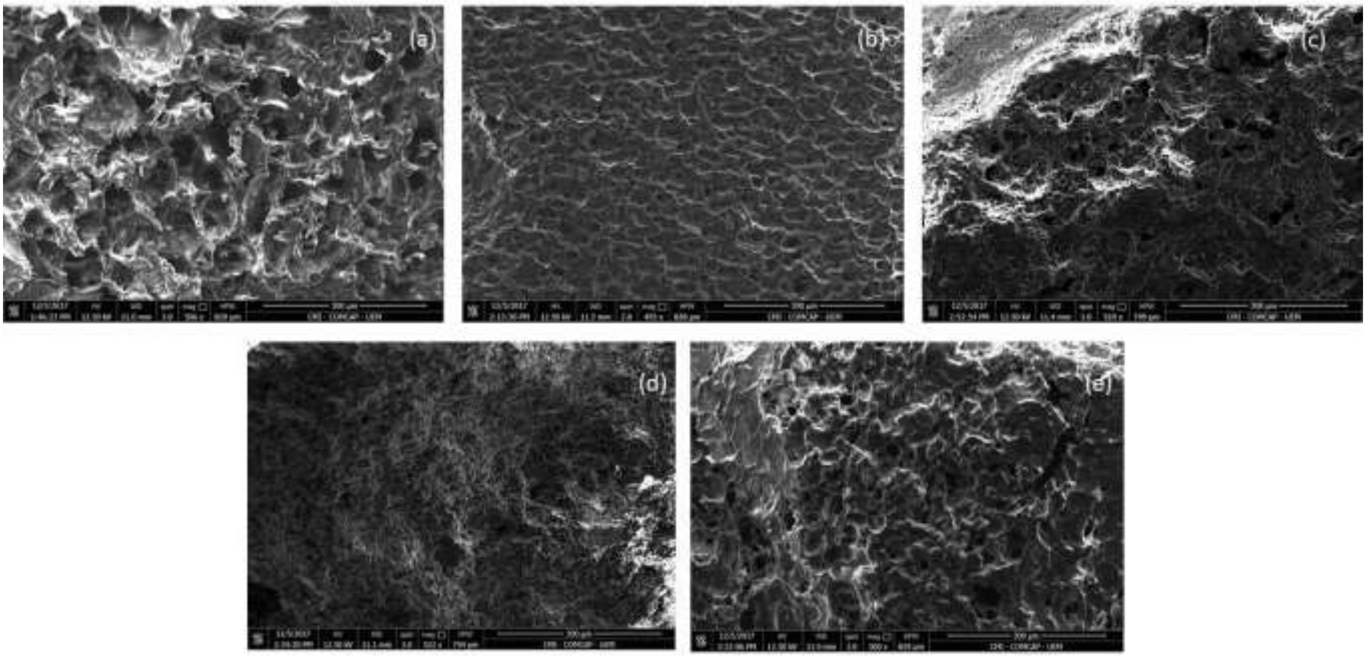
Source: Authors.

When analyzing Figure 1 we can observe that all the samples had thixotropic characteristics, as a function of the difference of tension and viscosity shown in the ascending and descending curves. This phenomenon can be explained by the change of viscosity when a shear force is applied to gel network. Initially, the gel tends to resist the shear force, thus only the deformation occurs (Felix et al., 2017).

3.6. Scanning electron microscopy

Figure 2 shows the micrographs of the microstructure of the processed cheese, with magnitudes of approximately 500X.

Figure 2. Micrographs of the microstructure of the processed cheese.



Source: Authors.

The same type of structure in all samples was observed. The control sample (Figure 2 (a)) showed dispersed fat particles in a uniform protein network, where the fat globules are predominantly spherical and evenly distributed throughout the protein matrix. On the other hand, in the groups with the addition of the extract, the fat globules presented particle size with smaller diameters. In addition, they were distributed less uniformly in the protein matrix. Comparing the microstructure of the processed cheese with the addition of Moringa extract (Figure 2 (a), (b), (c) and (d)) with control, there was an increase in the number of fat globules and a decrease in their diameters.

The size of the particles is directly related to the rate of rupture, which depends on the shear force applied during processing, as well as the composition of fatty acids and the structure of the fat network (Cunha et al., 2010). This decrease in size/diameter of the fat globules may indicate that the emulsion process occurred and thereby the breakage and dispersion of the extract/gum in the mass. Considering that during processing, stirring and heating favored the rupture of those fat globules, the smaller particles formed could be more easily emulsified by casein (Felix et al., 2016).

4. Conclusão

The main conclusions are related to the rheological aspects and texture parameters of the processed cheese. The Moringa extract interfered in the texture of the product, proving to be a great partial and/or total substitute of chemical preservatives. The sample with greater gum substitution by the Moringa extract had hardness equal to the control sample. Also, this sample (T4- 0.15% gum and 0.35% Moringa extract) presented higher consistency index (K). Samples did not show significant differences during storage period for cohesiveness. Thus, it is believed that the Moringa seed has a potential for use as a gum substitute, its application in other types of cheeses, yoghurts and dairy desserts can be explored.

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