COBEM 2023 27TH INTERNATIONAL CONGRESS OF MECHANICAL ENGINEERING

ABCM Brazilian Society of Mechanical Sciences and Engineering
27th ABCM International Congress of Mechanical Engineering
December 04-08, 2023, Florianópolis-SC, Brazil

COB-2023-1889
OBTAINING AND MECHANICAL CHARACTERIZATION OF FILMS BASED ON STARCH BLENDS, CHITOSAN AND SODIUM ALGINATE

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Abstract. *The objective of this study was to obtain and characterize biodegradable films composed of ternary blends of biopolymers. The films produced were composed of chitosan, starch and sodium alginate, based on an experimental design using a ternary mixing plan. The solutions filmogenic were obtained by casting technique, with dry matter fixed at 2%. O plasticizer used was glycerol and its percentage was fixed at 20%, about dry mass of the biopolymer. After producing the biofilms, they were cut into specimens, to carry out the mechanical characterization. An analysis of variance (ANOVA) was performed to obtain the models and the F Test to verify their statistical significance. After this check, response surface graphs were generated. From the surfaces and models obtained, it was possible to evaluate the effect of the composition of the biopolymer blends on the parameters of tensile strength limit, modulus of elasticity, and elongation at break. The results showed that the polymeric blend from test 13 (80% starch and 20% sodium alginate) has the highest tensile strength (67,97Mpa), around 90% greater than isolated starch, 71% greater than isolated alginate and 79% higher than chitosan alone. About the Young's modulus, it was observed that the blend from test 11 (80% starch and 20% chitosan) presented the highest modulus (297,56Mpa), with around 90% greater than the isolated starch, 85% greater than the isolated chitosan and 69% higher than alginate. The elongation at break was greater (76,44Mpa) with the blend from test 12 (80% chitosan and 20% alginate) around 86% greater than starch, 55% greater than chitosan and 82.8% greater than alginate. Biofilms made up of the combination of two or more biopolymers showed satisfactory properties when compared to biofilms formulated with a single component.*

Keywords: *biopolymers; biopolymer blends; mix planning; mechanical properties.*

1. INTRODUCTION

Biofilms appear as an alternative to plastic films of synthetic origin. Biofilms are materials of biodegradable origin that, when exposed to external agents, do not cause damage to the environment in which they degrade (Talón et al., 2016). The main objective of using biofilms is to replace products derived from synthetic polymers. Biofilms can be applied in various industrial sectors, including packaging in general, supporters, coating for produce, etc. (Kowalczyk et al., 2015). Biodegradability and biocompatibility are two essential requirements for the composition and application of the biofilm. In addition to these factors, an ideal film or coating should have great adhesion capacity, provide effective microbial protection, have adequate gas and moisture transfer properties, have a good aesthetic appearance, be tasteless, and be reasonably priced (Saha et al., 2016).

Several materials can be used for the production of biofilms, and polysaccharides stand out among these, such as starches, because they have non-toxic, biodegradable characteristics, come from low-cost natural sources and have the capacity and stability for the formation of biofilms (Colivet and Carvalho, 2017; Narkchamnan and Sakdaronnarong, 2013). Although polysaccharide films show good barrier properties against gases and lipids, they form a poor barrier to water vapor (Leceta et al., 2014; Edhirej et al., 2017). Like starches, chitosan is a cationic polysaccharide of a non-toxic and biodegradable nature. It comes mainly from the reaction of partial alkaline deacetylation of chitin, which is abundant

in nature and found in crustacean exoskeletons such as crab, shrimp, and lobster, as well as other sources such as insects, mollusks, fungi and algae (Zhang et al., 2017). Chitosan films have exhibited a high antimicrobial effect (Baldwin et al., 2011).

Another promising polysaccharide is sodium alginate, which is a natural anionic polysaccharide existing in the cell wall of brown algae, that can represent 40% of the dry weight of algal biomass. Its excellent viscosity and gelling properties draw the interest of industries. Its biodegradability, biocompatibility, and lack of toxicity make sodium alginate an interesting material for numerous applications, such as packaging production, cross-linked coverage for drug delivery systems, covering and protecting foods, medicines, etc. The feasibility of extracting sodium alginate from brown seaweed depends on the region and the focus of the extractive industry, in addition to the quantities used to manufacture the final product to be offered. It is worth mentioning that the abundance of this material is predominant in coastal areas (Mei et al., 2020).

Generally, biofilms synthesized from natural raw materials have fragile characteristics and a brittle appearance, so it is necessary to use plasticizing agents, to reduce the frictional forces between the polymer chains (Narkchamnan and Sakdaronnarong, 2013).

Polymeric blends are mechanical mixtures of different polymers, in most cases, there is no chemical reaction between them. They are prepared to obtain materials with a better balance of properties in cases where pure polymers used alone do not meet the requirements. The most common example is the use of rigid and mechanically resistant materials, that have high impact resistance at the same time. In addition, the mixture between two or more polymers is considered an economical alternative for developing new materials when compared to the synthesis of new polymers or copolymers (Oliveira et al., 2018).

Thus, this study aimed to obtain biopolymeric films based on starch, chitosan, and sodium alginate using the casting technique and characterize them in terms of their mechanical properties. The selection of components was carried out based on their abundance in the semi-arid region, in addition to the possible production from technologies adjusted to its reality. This evaluation was done through a ternary mixing plan and representative models of the response surfaces were obtained by correlating the properties to the composition of the films.

2. MATERIALS AND METHODS

2.1 Materials

The following were used in the composition of the biofilms: starch, obtained from the company *Kouzina Alimentos Saudáveis* (Brazil); chitosan, acquired from the company *Polymar* (Brazil), with a degree of deacetylation of 97%; glacial acetic acid (PA – 99.7%), obtained from the company IMPEX - *Labimpex Indústria e Comércio de Produtos Para Laboratório LTDA.*; sodium alginate P.A. and bidistilled glycerin P.A. (glycerol), of analytical grade, obtained from *Dinâmica Química Contemporânea*, São Paulo, Brazil.

2.2 Methods for obtaining the biofilms

Experimental Planning

The experimental design with real values can be seen in Table 1.

Table 1. Matrix of the ternary mixing plane with real values.

Formulation	Formulation Components (%)		
	Starch (FB)	Chitosan (QT)	Alginate (ALG)
1*	100	0	0
2*	0	100	0
3*	0	0	100
4*	0	50	50
5*	50	0	50
6*	50	50	0
7*	33.33	33.33	33.33
8*	33.33	33.33	33.33
9*	33.33	33.33	33.33
10*	33.33	33.33	33.33
11**	80	20	0
12**	0	80	20
13**	80	0	20
14**	20	0	80
15**	20	80	0
16**	0	20	80
17**	66.66	16.66	16.66
18**	16.66	66.66	16.66
19**	16.66	16.66	66.66

* Adjustment points; ** Validation points.

A ternary mixing plan was used, with 4 repetitions at the central point, making 19 tests, sufficient to obtain quadratic models. The independent variables used were the percentages of chitosan (QT), sodium alginate (AG), and starch (FB). In contrast, the dependent variables evaluated were tensile strength limit (LRT), modulus of elasticity (ME), elongation at rupture (AL). For the color and opacity variables, an ANOVA was performed. Glycerol was used as a plasticizer at a constant concentration of 20% about the total dry matter. Tests 1 to 10 were used to obtain the fit of the quadratic models, and tests 11 to 19 were used to validate this model.

The total concentration of biopolymer in the film-forming mixtures remained constant and equal to 2%. However, the composition of this total varied according to the percentages of biopolymers (potato starch, chitosan, and alginate) shown in Table 1. A graphical scheme of the ternary mixing plane can be seen in Figure 1.

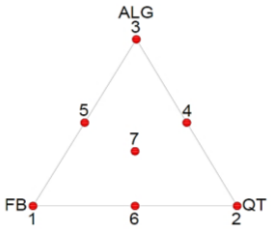


Figure 1. Graphical scheme of the ternary mixing plane.

It is necessary to point out that the adjustment points are the values that will be used to obtain the mathematical models; the validation points, on the other hand, carry with them the effectiveness of the mathematical model in describing or predicting the proposition of new points, in short, the validity of the model.

Preparation of filmogenic solutions

Chitosan solutions were prepared according to a methodology adapted from Genskowsky et al. (2015) and Bonilla and Sobral (2016). Chitosan powder was solubilized in a 2% (v/v) acetic acid solution, and left for 24 hours under mechanical agitation at room temperature of 27 °C, resulting in a homogeneous, viscous, yellowish solution.

Starch solutions were prepared according to the methodology adapted from Chiumarelli and Hubinger (2014). The mixture of water and starch was heated, in a water bath at 75 °C, under constant mechanical agitation, until it was possible to observe the complete gelatinization of the starch.

Alginate solutions were prepared according to methodology adapted from Bagheri et al. (2019). The alginate mixture was heated to 70 °C, under constant mechanical agitation, until complete dissolution and gelatinization of the alginate.

Finally, the chitosan, starch, and alginate solutions were mixed in such proportions that the final concentrations of these compounds corresponded to the values contained in Table 1. The final mixtures were heated to 50 °C for 10 minutes under constant mechanical agitation, followed by 10 minutes in an ultrasonic bath.

Preparation of biofilms using the solvent evaporation technique (casting)

After preparation and due homogenization of all components, 60 g of each solution was deposited on an acrylic plate 150 mm long, 150 mm wide, and 10 mm high, stored in an oven with air circulation at 50 °C for 5 hours. After forming a homogeneous and cohesive matrix film on the plates, it was removed and analyzed. The amount of deposited solution was determined experimentally so that, after drying in an oven, the films presented thickness values similar to those described in the literature that used the casting technique to obtain biopolymeric films: Jost et al. (2014); Luchese et al. (2017); Guerrero et al. (2015); Hromis et al. (2015); Gutiérrez et al. (2015); Oliveira et al. (2018).

2.3 Characterization methods

Thickness

The determination of the thickness of the biodegradable films was carried out according to the methodology proposed by Luchese et al. (2017), in which 5 randomly chosen points of the film were measured with a Syntek digital micrometer with a scale of 0.001 mm.

Mechanical Tests

Biofilm specimens, with dimensions of 60 mm in length and 5 mm in width, were tested to obtain the mechanical properties studied in accordance with the ASTM 882-83 in a universal testing machine (DL 10000 from EMIC), with a load cell of 5.0 kN at a temperature of 23 °C and relative humidity of 75% (kept in a desiccator with a saturated NaCl solution and measured through a thermo-hygrometer) with a test speed of 5 mm/min. Five specimens were tested for each test in the experimental design.

Statistical Analysis

The data obtained with the experimental planning were analyzed using the Statistica® 12.5 software (StatSoft, Inc., USA). An analysis of variance (ANOVA) and the F test were performed to verify whether the models were statistically significant with $p < 0.05$. For models in which the calculated F was greater than the tabulated F and $R^2 \geq 0.75$, response surfaces were generated.

3. RESULTS AND DISCUSSIONS

3.1 Average values of the obtained results

In Table 2 it is possible to observe the mean values of the evaluated dependent variables: tensile strength limit (LRT), modulus of elasticity (ME), and elongation at break (AL).

Table 2: Mean values of tensile strength limit (LRT), modulus of elasticity (ME), elongation at break (AL) and thickness (TH).

Test	X_1	X_2	X_3	LRT (MPa)	ME (MPa)	AL (%)	TH (mm)
1*	1	0	0	6.93 ± 0.15	51.56 ± 0.13	10.49 ± 0.10	0.042 ± 0.0006
2*	0	1	0	14.89 ± 0.14	44.17 ± 0.20	34.10 ± 0.13	0.069 ± 0.0004
3*	0	0	1	19.68 ± 0.13	93.08 ± 0.12	13.13 ± 0.15	0.042 ± 0.0006
4*	0	0.5	0.5	7.22 ± 0.17	23.69 ± 0.14	33.17 ± 0.12	0.088 ± 0.0007
5*	0.5	0	0.5	50.83 ± 0.11	82.47 ± 0.15	7.27 ± 0.11	0.077 ± 0.0008
6*	0.5	0.5	0	22.17 ± 0.20	121.37 ± 0.11	11.90 ± 0.23	0.056 ± 0.0005
7*	0.3333	0.3333	0.3333	42.37 ± 0.16	82.87 ± 0.21	29.64 ± 0.18	0.098 ± 0.0007
8*	0.3333	0.3333	0.3333	42.18 ± 0.17	82.41 ± 0.20	29.39 ± 0.19	0.085 ± 0.0006
9*	0.3333	0.3333	0.3333	42.65 ± 0.14	83.45 ± 0.22	28.93 ± 0.15	0.082 ± 0.0008
10*	0.3333	0.3333	0.3333	42.52 ± 0.13	82.93 ± 0.11	29.42 ± 0.13	0.089 ± 0.0009
11**	0.8	0.2	0	36.32 ± 0.19	297.56 ± 0.13	5.52 ± 0.14	0.060 ± 0.0006
12**	0	0.8	0.2	15.81 ± 0.20	20.60 ± 0.14	76.44 ± 0.19	0.053 ± 0.0007
13**	0.8	0	0.2	67.97 ± 0.11	131.4 ± 0.15	5.15 ± 0.23	0.049 ± 0.0008
14**	0.2	0	0.8	20.62 ± 0.13	123.60 ± 0.17	12.36 ± 0.14	0.057 ± 0.0009
15**	0.2	0.8	0	51.26 ± 0.16	139.28 ± 0.13	44.16 ± 0.25	0.059 ± 0.0006
16**	0	0.2	0.8	12.04 ± 0.19	231.97 ± 0.12	5.39 ± 0.18	0.052 ± 0.0005
17**	0.6666	0.1666	0.1666	20.32 ± 0.20	130.07 ± 0.18	15.62 ± 0.25	0.054 ± 0.0007
18**	0.1666	0.6666	0.1666	27.39 ± 0.11	103.75 ± 0.12	26.42 ± 0.14	0.047 ± 0.0009
19**	0.1666	0.1666	0.6666	30.69 ± 0.10	212.39 ± 0.11	4.99 ± 0.17	0.052 ± 0.0006

* Adjustment points; ** Validation points.

The thicknesses of the produced biofilms are between 0.042 mm to 0.098 mm. The thickness was controlled during the deposition of the films on the acrylic tray, 60 g of each mixture. This difference in thickness is possibly associated with the density of the films. Several studies claim that the type of biopolymer influences the thickness of each film; its concentration about dry mass also causes changes in thickness (Oliveira et al., 2018; Jost et al., 2014; Luchese et al., 2017; Guerrero et al., 2015; Hromis et al., 2015; Gutiérrez et al., 2015).

The lowest thickness value is associated with the biofilm consisting of only one type of biopolymer. In this case, potato starch, with the highest average thickness value is related to the biofilm that has the highest concentration of different biopolymers (33.33% potato starch, 33.33% chitosan, 33.33 % alginate, and glycerol). According to Abdullah and Talip (2014), the thickness value can affect different properties, such as water vapor permeability, and mechanical and transparency properties of the films. Oliveira et al. (2018) produced films of corn starch, cassava starch, and bovine gelatin, with the addition of beeswax, for application as a coating in the post-harvest conservation of guavas, and the biofilms had thicknesses between 0.049 and 0.205 mm. On the other hand, Siracusa and Ingrao (2017) analyzed already available industrial films for coverage, which were 0.015 to 0.04 mm thick.

Regarding the LRT, it can be observed that the highest average value was 67.97 MPa, relative to the biofilm consisting of 80% potato starch and 20% sodium alginate. At the same time, the lowest average value observed was 6.94 MPa, of the biofilm consisting only of potato starch.

The highest average value was obtained for the polymeric blend consisting of potato starch and sodium alginate, due to the molecular interaction between the polymeric chains, making this composition a miscible blend with the predominance of secondary bonds of the hydrogen bond type. This fact is directly related to the lowest average value obtained, the biofilm consisting only of potato starch and glycerol, since alginate appears as an additive that gives the biofilm better mechanical properties. However, up to a certain concentration, when exceeding this value, the alginate

becomes increasingly fragile, due to the loss of interaction of the secondary bonds between the biopolymers (Oliveira et al., 2018; Xiao et al., 2017).

Nandi and Guha (2018) produced films of potato starch and guar gum and obtained the LRT value for the control film formed only by potato starch of 5.82 MPa, a value very close to that found in this study. Shah, Fernandes and Suares (2019) produced films with starch and sodium alginate for the production of adhesives for dressings. The authors observed that the introduction of alginate to the starch matrix resulted in better mechanical properties, in addition to less moisture retention at the application site, what corroborates the information of this analysis.

Among starches, the higher the amylose content, the higher the LRT value, that is, the greater the resistance of the films (Domene-López et al., 2019). Compared to films formed by chitosan and sodium alginate, this one has the lowest average value of the analysis, but the value is still expressive among the class of starches, since these are contained in intervals of 0.004 and 3.75 MPa (Oliveira et al., 2018; Domene-López et al., 2019; Nandi and Guha, 2018).

As for Young's modulus (ME) , it can be seen that the highest average value was 297.56 MPa, relative to the biofilm consisting of 80% potato starch and 20% chitosan, while the lowest average value observed was 20.68 MPa for the biofilm consisting of 80% chitosan and 20% sodium alginate.

Ren et al. (2017) analyzed films composed of starch with different concentrations of chitosan for application in packaging, and obtained a value of 39 MPa for the Young's modulus, assuming that the addition of chitosan to the starch matrix increased the rigidity of the biofilm, as observed in this study.

The highest average ME value is given to the polymeric blend formed by chitosan and starch. This is due to the hydrogen bonds formed between the NH_3^+ groups of the protonated chitosan and the OH^- groups of the starch/starch, which provide greater stability to the polymeric matrix in relation to the matrix composed only of starch (Mujtaba et al. 2019; Ren et al., 2017).

The lowest mean ME value was obtained from the blend consisting of chitosan and sodium alginate. This occurs because the alginate allows the formation of a gel when exposed to a pH lower than its ionotropic gelling point. The electrostatic interactions between polyanionic/polycationic sodium alginate (crosslinking process) and chitosan make them highly biocompatible for the production of stable polymeric films. This electrostatic interaction is derived from the bond between the NH_3^+ groups of chitosan and the COO^- groups of sodium alginate, originating an insoluble polymer (Nair et al., 2020; Varaprasad et al., 2020).

Nair et al. (2020) state that the presence of alginate in the chitosan matrix makes the films more flexible, improving the functional properties of application in fruits and vegetables, as observed in this study. Al obtained its highest mean value of 76.44% for the biofilm consisting of 80% chitosan and 20% sodium alginate, while the lowest mean value observed was 4.99% for the biofilm consisting of 66.66 % sodium alginate, 16.66% chitosan, 16.66% potato starch and glycerol.

The lowest average value obtained in Al from the polymeric blend consisting of potato starch, chitosan and sodium alginate is due to the anti-plasticizing effect. This effect comes from the high concentration of sodium alginate (Varaprasad et al., 2020; Abou-Okeil et al., 2018).

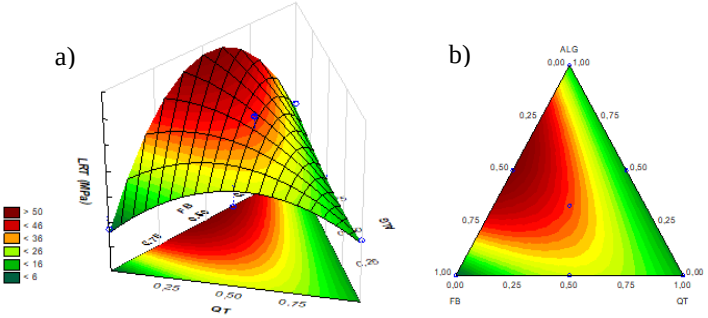
The highest mean value of AL is directly related to the lowest mean value of ME. This is due to the formation of a biofilm with low rigidity and, consequently, high flexibility. Nair et al. (2020) and Ren et al. (2017) observed that the elongation at film rupture increased with increasing chitosan concentration, which corroborates this study.

3.2 Tensile Strength Limit (LRT)

The coded model proposed to describe the Tensile Strength Limit (LRT) of the analyzed biofilms included in the established concentration limits is described by Eq. (1):

$$LRT = 1.721 + 5.499X_1 + 13.453X_2 + 18.244X_3 + 73.787X_1X_2 + 178.850X_1X_3 - 11.514X_2X_3 \quad (1)$$

In Figure 3a and 3b, it is possible to observe the behavior of the response variables about the composition of each biofilm.



Figures 3a and 3b. Response surfaces for the Tensile Strength Limit (TSL) as a function of the concentration of starch (FB), chitosan (QT), and sodium alginate (ALG) in biofilms.

Analyzing Figures 3a and 3b, it is possible to verify that both the potato starch content, as well as sodium alginate and chitosan content, influence the resistance of biofilms, based on the model obtained by Eq. (1).

Potato starch concentration plays an increasing linear effect. This is possibly due to the hydrophilic nature that potato starch has, resulting in a film with a fragile characteristic due to the presence of hydroxyl groups, which is indicative of stronger interactions between the starch and the plasticizer, developing a good transfer of tension by the biofilm, which has a high resistance as previously seen in Table 2. According to Kowalczyk et al. (2015), films based on starch with a high amylose content generally have a higher mechanical performance due to the formation of mechanically resistant films, which corroborates the result found here.

According to Ramírez et al. (2014) and Bonilla and Sobral (2016), there is a correlation between relative crystallinity and mechanical properties due to the presence of amylopectin, which, although linear, forms a helix, making it difficult to regularly associate with other chains. There is usually an increase in tensile strength and modulus of elasticity, as well as a reduction in elongation at break. This behavior was also observed in the present work.

In films in which potato starch interacts with another polysaccharide, in high concentrations, the biofilm matrix has high fragility as a result of water absorption processes, where amylose molecules in solution tend to orient themselves in parallel due to their linearity; when they get close enough, they form hydrogen bonds between the hydroxyls of adjacent polymers. Thus, the affinity of the polymer with water is highly reduced, favoring the formation of more resistant films, as also seen by Piñeros-Hernandez et al. (2017), Ren et al. (2017) and Talón et al. (2017).

Chitosan has a positive linear effect on LRT. Bourtoom and Chinna (2008) point out that the increase in LRT is achieved due to a high formation of intermolecular hydrogen bonds between the NH_3^+ groups of chitosan and the OH^- groups of potato starch. The amine groups (NH_2) of chitosan were protonated to NH_3^+ in the acetic acid solution and, on the other hand, the ordered crystalline structures of the starch molecules were disrupted due to the gelatinization process, deriving the OH^- groups, available to immediately form bonds of hydrogen with the NH_3^+ group of chitosan, thus increasing the LRT of the films.

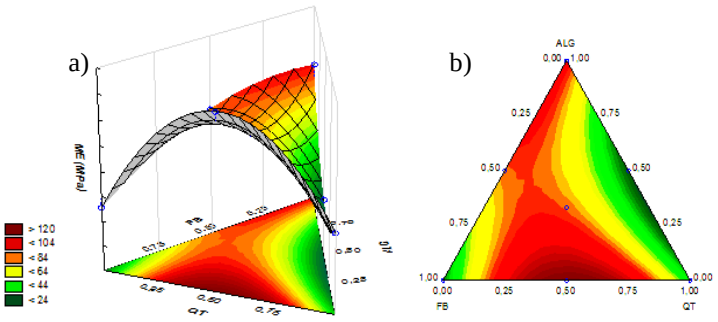
Films produced from sodium alginate also have a positive linear parameter. Films prepared from alginate aim to form strong films, as seen in Table 3, but due to their hydrophilic nature, they exhibit low resistance to water due to the hydroxyl groups present in their structure, as observed by Mei et al. (2020).

3.3 Modulus of Elasticity (ME)

The proposed coded model to describe the modulus for elasticity (ME) of the analyzed biofilms included in the established concentration limits is described by Eq. (2):

$$ME = 0.008 + 31.493X_1 + 44.107X_2 + 93.011X_3 + 335.417X_1X_2 + 81.987X_1X_3 - 178.369X_2X_3 \quad (2)$$

In Figures 5a and 5b it is possible to observe the behavior of the response variables about the composition of each biofilm.



Figures 5a and 5b. Response surface for the Modulus of Elasticity (ME), as a function of the the concentration of potato starch (FB), chitosan (QT), and sodium alginate (ALG) in the biofilms.

According to Figures 5a and 5b and the model obtained by Eq. (2) for the Modulus of Elasticity (ME), it is possible to observe that all the polymers used in the study have a significant influence on the ME. In addition to stability and mechanical rigidity, other factors must be considered, such as the natural elasticity values of each polysaccharide, which is a relevant property.

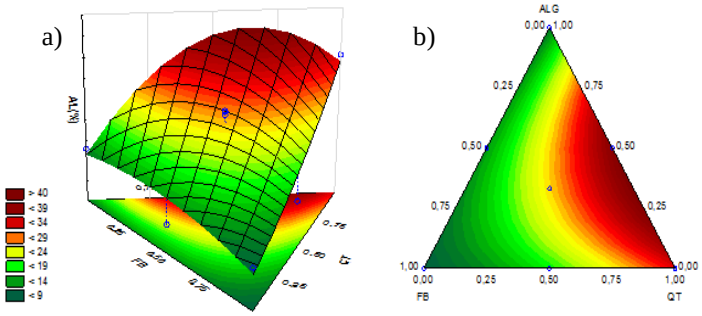
Ahmed and Ikram (2016) confirmed that the effect of the plasticizer interferes with polymer chain interactions, decreasing intermolecular forces, softening film stiffness, and increasing polymer mobility. The mixture of chitosan and alginate decreased the mechanical stability, forming films with less rigidity, which can be confirmed by the response surface shown in Figure 6a. Nandi and Guha (2018) demonstrate that the mixture of potato starch and chitosan exhibits high elasticity values and that the low mobility of the chain of components increases the value of the Modulus of Elasticity, as observed in this study.

3.4 Elongation at Break (Al)

The coded model proposed to describe the elongation at break (AL) of the analyzed biofilms included in the established concentration limits is described by Eq. (3):

$$AL = 3.363 + 58.017X_1 + 17.777X_2 + 87.927X_3 + 1.011X_1X_2 - 71.168X_1X_3 - 123.928X_2X_3 \quad (3)$$

In Figures 7a and 7b, it is possible to observe the behavior of the response variables about the composition of each biofilm.



Figures 7a and 7b. Response surface for Elongation at Break (AL), as a function of the the concentration of potato starch (PS), chitosan (CH), and sodium alginate (ALG) in biofilms.

Based on Eq. (3) and analyzing Figures 9a and 9b, Elongation at Break (Al), the three components influence the elongation of the films. Chitosan exerts a positive linear effect. This occurs due to the influence of its high flexibility, as previously mentioned.

Elongation at break of chitosan and sodium alginate films increased with increasing chitosan concentration but decreased at the highest alginate concentration analyzed. The rate of flexibility of the films is due to the concentration of chitosan and the interaction of the plasticizing and polymeric chains that facilitate the sliding of the chain and thus contribute to improving the general flexibility and mobility of the chain.

As for the films that have the presence of starch, it is verified that they satisfy the increasing linear parameter. Liu et al. (2013) suggest that this is possibly due to its hydrophilicity, which weakens the sample and compromises the plasticity of the films.

Suderman et al. (2018) state that the plasticity of a film can be achieved by mixing the polymer with a low molecular weight compound or with another polymer that reduces crystallinity and increases chain flexibility and that the plasticizer reduces the molecular interaction, thus increasing the molecular spaces, causing greater elongation of the films.

Thus, the response surface for elongation at break (Figures 7a and 7b) shows that the interaction between sodium alginate and chitosan increased the values of this property. Sodium alginate appears as a low-weight polymer with plasticizing characteristics, which contributes to the increase in the properties under analysis, in addition to the 20% plasticizer addition, such as the glycerol used in this study, also contributes to the increase of stretching (Santana; 2010).

4. CONCLUSION

The filmogenic solutions of potato starch, chitosan, and sodium alginate showed appropriate characteristics for obtaining biopolymeric films.

The biofilm that presented the smallest thickness value was the one composed of the starch, while the biofilm with the greatest thickness was the one composed of the three polysaccharides.

The biofilms that showed the best mechanical properties were: trial 13 (80% potato starch and 20% sodium alginate), with higher LRT (67.97 MPa); trial 11 (80% potato starch and 20% chitosan) with higher ME (297.56 MPa); and trial 12 (80% chitosan and 20% sodium alginate) with higher AL (76.44 MPa).

Based on this study, it was possible to observe that the blends made up of two polysaccharides showed better mechanical properties than those made up of just one polysaccharide or three combinations thereof.

5. ACKNOWLEDGEMENTS

We thank the Mechanical Engineering Laboratory of the Federal University of Rural Semi-Arid (UFERSA) for performing the mechanical tests, and the Federal University of Paraíba and FAPESQ for granting the costs to participate in this congress and financing the project.

6. REFERENCES

Abdullah, K., Talip, K., 2014, Characterization of a new biodegradable edible film made from salep glucomannan, Carbohydrate Polymers, Vol. 104, pp. 50-58.

Abou-Okeil, A., Fahmy, H. M., Aly, A. A., 2018, A non-woven fabric wound dressing containing layer–by–layer deposited hyaluronic acid and chitosan, International Journal of Biological Macromolecules, Vol. 114, pp. 929-934.

Ahmed, S., Ikram, S., 2016, Chitosan and gelatin-based biodegradable packaging films with UV-light protection, Journal of Photochemistry and Photobiology B: Biology, Vol. 163, pp. 115-124.

ASTM, 2014, *ASTM D3039/D3039M – 14: Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*, American Society for Testing Materials ASTM. In: Annual Book of ASTM. West Conshohocken, Pennsylvania, United States of America.

Baldwin, E.A., Hagenmaier, R. and Bai, J., 2011. Edible coatings and films to improve food quality, Second Edition. CRC Press, Boca Raton.

Bonilla, J., Sobral, P. J. A., 2016, Investigation of the physicochemical, antimicrobial, and antioxidant properties of gelatin-chitosan edible film mixed with plant ethanolic extracts, Food Bioscience, Vol. 16, pp. 17-25.

Bourtoom, T., Chinna, M. S., 2008, Preparation and properties of rice starch-chitosan blend biodegradable film. LWT - Food Science and Technology, Vol. 41, pp. 1633-1641.

Chiumarelli, M., Hubinger, M. D., 2014, Evaluation of edible films and coatings formulated with cassava starch, glycerol, carnauba wax and stearic acid, Food hydrocolloids, Vol. 38, pp. 20-27.

Colivet, J., Carvalho, R. A., 2017, Hydrophilicity and physicochemical properties of chemically modified cassava starch films, Industrial Crops and Products, Vol. 95, pp. 599-607.

Domene-López, D., Delgado-Marín, J. J., Martin-Gullon, I., García-Quesada, J. C., Montalbán, M. G., 2019, Comparative study on properties of starch films obtained from potato, corn and wheat using 1-ethyl-3-methylimidazolium acetate as a plasticizer, International Journal of Biological Macromolecules, Vol. 135, pp. 845-854.

Edhirej, A., Sapuan, S. M., Jawaid, M., Zahari, N.I., 2017, Cassava/sugar palm fiber reinforced cassava starch hybrid composites: Physical, thermal and structural properties, International Journal of Biological Macromolecules, Vol. 101, pp. 75-83.

Genskowsky, E., Puente, L. A., Pérez-Álvarez, J. A., Fernandez-Lopez, J., Muñoz, L. A., Viuda-Martos, M., 2015, Assessment of antibacterial and antioxidant properties of chitosan edible films incorporated with maqui berry (*Aristotelia chilensis*), LWT - Food Science and Technology, Vol. 64, pp. 1057-1062.

Guerrero, P., Garrido, T., Leceta, I., De La Caba, K., 2015, Films based on proteins and polysaccharides: preparation and physical-chemical characterization. European Polymer Journal, Vol. 49, pp. 3713-3721.

Gutiérrez, T. J., Tapia, M. S., Pérez, E., Famá, L., 2015, Structural and mechanical properties of edible films made from native and modified cush-cush yam and cassava starch, Food Hydrocolloids, Vol. 45, pp. 211-217.

Hromis, N. M., Suput, D., Lazic, V. L., Popovic, S. Z., 2015. Edible films and coatings - sources, properties and application, Food and Feed Research, Vol. 42, pp. 11-22.

Jost, V., Kobsik, K., Schmid, M., Noller, K., 2014, Influence of plasticiser on the barrier, mechanical and grease resistance properties of alginate cast films, Carbohydrate Polymers, Vol. 110, pp. 309-319.

Kowalczyk, D., Kordowska-Wiater, M., Nowak, J., Baraniak, B., 2015, Characterization of films based on chitosan lactate and its blends with oxidized starch and gelatin, International Journal of Biological Macromolecules, Vol. 77, pp .350-359.

Leceta, I., Etxabide, A., Cabezudo, S., De La Caba, K., Guerrero, P., 2014, Bio-based films prepared with by-products and wastes: environmental assessment. Journal of Cleaner Production, Vol. 64, pp. 218-227.

Liu, J., Chi, G., Jia, C., Zhang, C., Xu, B., Jin, Z., 2013, Function of a citrate synthase gene (MaGCS) during postharvest banana fruit ripening, Postharvest Biology and Technology, Vol. 84, pp. 43-50.

Luchese, C. L., Sperotto, N., Spada, J. C., Tessaro, I.C., 2017, Effect of blueberry agro-industrial waste addition to corn starch-based films for the production of a pH-indicator film, International Journal of Biological Macromolecules, Vol. 104, pp. 11-18.

Mei, J., Yuan, Y., Guo, Q., Wu, Y., Li, Y., Yu, H., 2020, Characterization of edible starch–chitosan film and its application in the storage of Mongolian cheese, International Journal of Biological Macromolecules, Vol. 57, pp. 17-21.

Mujtaba, M., Morsi, R. E., Kerch, G., Elsabee, M. Z., Kaya, M., Labidi, J., Khawar, K. M., 2019, Current advancements in chitosan-based film production for food technology; A review, International Journal of Biological Macromolecules, Vol. 121, pp. 889-904.

Nair, M. S., Tomar, M. Punia, S., Kukula-Koch, W., Kumar, M., 2020, Enhancing the functionality of chitosan- and alginate-based active edible coatings/films for the preservation of fruits and vegetables: A review, International Journal of Biological Macromolecules, Vol. 164, 1 pp. 304-320.

Nandi, S., Guha, P., 2018, Modelling the effect of guar gum on physical, optical, barrier and mechanical properties of potato starch based composite film, Carbohydrate Polymers, Vol. 200, pp. 498-507.

Narkchamnan, S., Sakdaronnarong, C., 2013, Thermo-molded biocomposite from cassava starch, natural fibers and lignin associated by laccase-mediator system, Carbohydrate Polymers, Vol. 96, pp. 109-117.

Oliveira, M., Abadias, M., Usall, J., Torres, R., Viñas, I., 2017, Application of modified atmosphere packaging as a safety approach to fresh-cut fruits and vegetables – A review, Trends in Food Science & Technology, Vol. 46, pp. 13-26.

Oliveira, V. R. L., Monteiro, M. K. S., Santos, F. K. G., Leite, R. H. L., Aroucha, E. M. M., 2018, Effect of Drying Temperature in Biopolymeric Films of Cassava Starch and its Effect on Wettability, Water Vapor Barrier and Mechanical Properties, Materials Science Forum, Vol. 930, pp. 270-275.

Piñeros-Hernandez, D., Medina-Jaramillo, C., López-Córdoba, A., Goyanes, S., 2017, Edible cassava starch films carrying rosemary antioxidant extracts for potential use as active food packaging, Food Hydrocolloids, Vol. 63, pp. 488-495.

Ramírez, M. G. L., Kestur, S. G., González, R. M., Iwakiri, S., Muniz, G. B., Sahagun, T. S. F., 2014, Bio-composites of cassava starch-green coconut fiber: Part II – Structure and properties, Carbohydrate Polymers, Vol. 102, pp. 576-583.

Ren, L., Yan, X., Zhou, X., Tong, J., Su, X., 2017, Influence of chitosan concentration on mechanical and barrier properties of corn starch/chitosan films, International Journal of Biological Macromolecules, Vol. 105, pp. 1636-1643.

Saha, N. R., Sarkar, G., Roy, I., Rana, D., Bhattacharyya, A., Adhikari, A., Mukhopadhyay, A., Chattopadhyay, D., 2016, Studies on methylcellulose/ pectin/ montmorillonite nanocomposite films and their application possibilities, Carbohydrate Polymers, Vol. 136, pp. 1218-1227.

Shah, Z., Fernandes, C., Suares, D., 2019, Investigation of effect of anti-angiogenic green tea extract on the mechanical, physical and wound healing property of 2D wheat starch- 59 sodium alginate biocomposite film, Journal of Drug Delivery Science and Technology, Vol. 52, pp. 255–262.

Santana, A.A., 2010. *Influence of physical and chemical characteristics of plasticizers on the manufacture and structural and hygroscopic behavior of calcium alginate films (in Portuguese)*. Master's thesis, Graduate Program in Chemical Engineering, State University of Campinas, Campinas, São Paulo, Brazil.

Siracusa, V., Ingrao, C., 2017, Correlation amongst gas barrier behaviour, temperature and thickness in BOPP films for food packaging usage: A lab-scale testing experience, Polymer Testing, Vol. 59, pp. 277-289.

Suderman, N., Isa, M. I. N., Sarbon, N. M., 2018, The effect of plasticizers on the functional properties of biodegradable gelatin-based film: A review, Food Bioscience, Vol. 24, pp. 111-119.

Talón, E., Trifkovic, K. T., Nedovic, V. A., Bugarski, B. M., Vargas, M., Tavassoli-Kafrani, E., Shekarchizadeh, H., Masoudpour-Behabadi, M., 2016, Development of edible films and coatings from alginates and carrageenans. Carbohydrate Polymers, Vol. 137, pp. 360-374.

Varaprasad, K., Jayaramudu, T., Kanikireddy, V., Toro, C., Sadiku, E. R., 2020, Alginate-based composite materials for wound dressing application:A mini-review, Carbohydrate Polymers, Vol. 236, pp. 116025.

Xiao, X., He, Q., Li, Z., Antoce, A. O., Zhang, X., 2017, Improving traceability and transparency of table grapes cold chain logistics by integrating WSN and correlation analysis, Food Control, Vol. 73, pp. 1556-1563.

Zavareze, E. R., Halal, S., Pereira, J. M., Radunz, A., Elias, M. C., Dias, A. R. G., 2009, Chemical characterization and extraction yield of rice starch with different amylose contents (in Portuguese), Brazilian Journal of Food Technology, Vol. 5, pp. 24-30.

Zhang, B., Mei, J., Chen, B., Chen, H., 2017, Digestibility, physicochemical and structural properties of octenyl succinic anhydride-modified cassava starches with different degrees of substitution, Food Chemistry, Vol. 229, pp. 136-141.

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