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Rheological parameters of mixed Brazilian Cerrado fruits sugar-free preserves: the effect of body agents

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Abstract: The aim of this study was to evaluate the effect of the bodying agents (erythritol, sorbitol, xylitol, and polydextrose) and their mixtures on the preparation of mixed Brazilian Cerrado fruit preserves (marolo, soursop, and sweet passion fruit). Mixture design was used for product optimization and the preserves were evaluated by texture profile, stress relaxation test, and uniaxial compression test. The research data were analyzed using regression equations on SAS software. The results indicated that the rheological parameters were affected by the body agents. Erythritol should not be used as an isolated component because it provoked changes in the properties of the final product (harder and brittle preserves); xylitol and sorbitol made preserves more elastic, cohesive, and more fragile; and polydextrose showed a synergistic effect with erythritol for rupture deformation and lesser effects for hardness, adhesiveness, and gumminess.

Key words: Mixture design, polydextrose, polyols, sugar-free.

INTRODUCTION

Brazil has one of the largest fruit biodiversities in the world (Souza et al. 2012a) and the use of fruit pulp in the manufacture of preserves, jams, juices and jellies has been addressed by several authors (Costa et al. 2020, Farias et al. 2019, Schiassi et al. 2020, 2018, 2019, Souza et al. 2014). However, the fruits of the Brazilian Cerrado are still little known and have unique sensory characteristics and high concentrations of nutrients (Bailão et al. 2015), so they are promising in the elaboration of products and able to acquire a great space in the consumer market (Georgiev et al. 2014). Among the countless fruit trees in the Cerrado, soursop (*Annona muricata*), marolo (*Annona crassiflora* Mart) and sweet passion fruit (*Passiflora alata* Dryand) stands out and the mixture of two or more of these fruits to produce products, can contribute to improve the sensory and nutritional aspects of the final product (Nascimento et al. 2020, Schiassi et al. 2018, Sobhana et al. 2015).

Consumer awareness of food has led to the growth of the healthy-food industry and the reduction of sugar content by replacing all or part of that carbohydrate (Basu et al. 2011). However, the development of sugar-free products requires the inclusion of many additives, such as sweeteners, body agents, gelling agents and preservatives, in order to compensate for their withdrawal (Hracek et al. 2010). Among the body agents, erythritol, xylitol and sorbitol are the most used since they have greater thermal and acid stability (Chen et al. 2017, Mäkinen 2016). In addition to these polyols there are also polymeric substitutes, such as polydextrose, which is a polysaccharide that provides body and texture to products and has reduced caloric value (Aidoo et al. 2016). Additives can be used in all foods, as long as they are used under good manufacturing practices and adequate handling conditions, and there is no maximum limit for the use of polyols and polydextrose, which allows the manufacturer to use the amount he deems sufficient to get the desired effect (FAO/WHO 2018).

The introduction of the additives mentioned above, with the purpose of bringing low-calorie products closer to traditional products (made with sucrose) can have a negative effect on some food properties, especially on rheological parameters. A previous study was conducted to evaluate the influence of these bodying agents on the physicochemical and sensorial properties of mixed Brazilian Cerrado fruit sugar-free preserves (Farias et al. 2019). With this research, has realized the need to explore the influence of bodying agents on the rheological parameters of final product. Several instrumental methods have been developed to determine the rheological properties of semi-solid foods, including texture profile analysis, tension relaxation test and the uniaxial compression test, which are widely used by several authors (Pereira et al. 2013a, Souza et al. 2014).

Thus, in the development of products in which there is total or partial replacement of sugar, it is important to study rheology (Pereira et al. 2013a) to control the quality of the final product (Basu et al. 2011). Based on this context, the objective of this work was to evaluate the effect of body agents (erythritol, sorbitol, xylitol, and polydextrose) and their mixtures, as sucrose substitutes, on the texture profile, tension relaxation test and uniaxial compression test of mixed Brazilian Cerrado fruit sugar-free preserves.

MATERIALS AND METHODS

Materials

Soursop (*Annona muricata*), marolo (*Annona crassiflora* Mart.) and sweet passion fruit (*Passiflora alata Dryand*) were acquired from the Minas Gerais Supply Centers (CEASA, Belo Horizonte, MG, Brazil). The ingredients used were: erythritol, sorbitol, xylitol, polidextrose, blend of sucralose/acesulfame-K (3:1) (Nutramax, Catanduva, SP, Brazil), locust bean gum (LBG), carrageenan gum, low-methoxyl pectin LA210 (Danisco, Jundiaí, SP, Brazil), citric acid (Gemacom Tech, Juiz de Fora, MG, Brazil) and potassium sorbate (Vetec, Duque de Caxias, RJ, Brazil).

Preparation of fruit pulps

All fruits were washed with neutral detergent and sanitized with 200 $mg \cdot L^{-1}$ sodium hypochlorite for 15 min, and then they were separated into seed, husk and pulp. The soursop and marolo pulps were manually extracted with the aid of a knife, and homogenized separately in a blender (Metvisa-LQ.10, Brusque, SC, Brazil). The sweet passion fruit pulp was homogenized in a blender, the seeds separated by sieving. Lastly, all pulps were stored in polypropylene containers, sealed and frozen at –18 °C.

Preserves processing

The methodology proposed by Souza et al. (2013, 2012b) was followed to elaborate the mixed Brazilian Cerrado fruit sugar-free preserves. For the elaboration of preserves, sucralose and acesulfame-K sweeteners were used (3:1) and combined presented sweetness potency of 847.45 in relation to sucrose (Souza et al. 2013). The sweetener mix used (percentage) was defined based on the polyols and polydextrose (bodying agent) proportion added in each formulation, and their respective sweetening powers. Sucrose was considered to be 100%, erythritol 75% (Hu et al. 2012); sorbitol 50–60%; xylitol 90–100% (Ghosh & Sudha 2012); and polydextrose 0% (Nopianti et al. 2013). The proportions of the fixed ingredients used in the elaboration of the preserves are presented in Table I.

For the preserves formulation, 40% of the mixture of the bodying agents (Table II) and 60% of the fixed ingredients (Table I) were used. Processing of preserves occurred in an open pan (Macanudo, SC, Brazil), and pulp mixtures (in equal proportions of fruit) were added firstly and, later, bodying agents (polydextrose and polyols). When the mixture reached 45 °Brix, gums (LBG and carrageenan) and pectin (LMP), previously dissolved in water at 80 °C, were added. At the end of the cooking process, when the preserves reached 65 °Brix the sweeteners (acesulfame-K and sucralose), acidulant (citric acid) and preservative (potassium sorbate) were added. Using a portable refractometer (RT-82, Higmed, Tatuapé, SP, Brazil), soluble solids were determined at a temperature of ±25 °C. After the process finished, the preserves were then hot-poured into sterile polypropylene bottles, closed with lids, and then stored in refrigerators at ±7 °C.

Experimental design

In this work the sucrose substitution by bodying agents in the elaboration of preserves was studied and the effects of the factors (erythritol, sorbitol, xylitol and polydextrose) were evaluated considering the simplex mixture design (Cornell 2012). The simplex mixture design was elaborated with a mixture of four components, totaling 11 trials. The coded and actual values of the simplex mixture design factors are presented in Table II. The polynomial considered in the fit of the model (Equation 1) was:

$$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{14} x_1 x_4 + \beta_{23} x_2 x_3 + \beta_{34} x_3 x_4 \quad (1)$$

β_1, β_2, β_3 , β_4, β_{12}, β_{13}, β_{23} , β_{34} are regression coefficients for linear and non-linear terms (interaction); x_1, x_2, x_3 and x_4 are the coded independent variables (mass fractions of erythritol, sorbitol, xylitol and polydextrose in the mixture of bodying agents, respectively), and y is the evaluated response (texture profile, relaxation test and uniaxial compression test).

Table I. Fixed ingredients used in the preparation of mixed Brazilian Cerrado fruit sugar-free preserves.

Fixed ingredients	Concentration
Fruit pulp marolo/soursop/sweet passion fruit	56.97%
Low-methoxyl pectin (LMP)	1.50%
Carrageenan gum	0.64%
Locust bean gum	0.64%
Citric acid	0.20%
Potassium sorbate	0.05%

Table II. Experimental design of the mixtures, showing the coded and uncoded levels of the variables used in the simplex mixture design.

Treatments	Coded variables				Real variables			
	x_1	x_2	x_3	x_4	X_1 (%)	X_2 (%)	X_3 (%)	X_4 (%)
T1	1	0	0	0	100	0	0	0
T2	0	1	0	0	0	100	0	0
T3	0	0	1	0	0	0	100	0
T4	0	0	0	1	0	0	0	100
T5	0.50	0.50	0	0	50	50	0	0
T6	0.50	0	0.50	0	50	0	50	0
T7	0.50	0	0	0.50	50	0	0	50
T8	0	0.50	0.50	0	0	50	50	0
T9	0	0.50	0	0.50	0	50	0	50
T10	0	0	0.50	0.50	0	0	50	50
T11	0.25	0.25	0.25	0.25	25	25	25	25

X_1 - erythritol, X_2 - sorbitol, X_3 - xylitol, X_4 – polydextrose.

Rheological parameters

Preserve of fruits are viscoelastic foods (Pereira et al. 2017), that is, depending on the applied tension and the time scale, they can present properties of the liquid phase or of a solid body (Guillet 2010), being necessary your study at low and high deformations (Ishihara et al. 2011). Thus, three types of analysis were performed to find out the rheological behavior of mixed Brazilian Cerrado fruit sugar-free preserves: stress relaxation test (low strain), texture profile (medium strain), and uniaxial compression test (high strain). These analyses were carried out at about room temperature (25 °C). For that, the samples were cut into a cylindrical shape using a stainless-steel cylindrical mold (22 mm height × 22 mm diameter), and kept at room temperature for 2 h, enough time to stabilize the temperature of each sample. The test was performed in triplicate with six measurements in each repetition.

Texture profile

The evaluation of the texture profile analysis was performed according Souza et al. (2014), using a texture analyzer (TAXT2i, Stable Micro Systems, Goldaming, England) with a 5 kg load cell. The measurement conditions for the texture profile were standardized in: (1) pretest, test, and post-test speed of 1.0 mm/s; (2) compression distance of 40.0 mm; (3) time interval between the first and second compressions of 5 s; and (4) cylindrical aluminum probe (6.0 mm diameter). The samples were axially compressed by approximately 30%. The parameters analyzed were hardness, adhesiveness, springiness, cohesiveness, and gumminess.

Stress relaxation test

The simplified Maxwel model was chosen to describe the rheological behavior of preserves (Equation 2), as it presented a better coefficient of variation (R^2) than the generalized Maxwel model. The simple Maxwell model involves two simple elements combined in series to represent different behaviors. These two elements are the ideal elastic element, which can be represented as a spring and has a behavior defined by an elastic constant "*E*", and the viscous ideal element, which is represented by a shock absorber and has a behavior defined by its viscosity "*η*" (Campus et al. 2010). In Maxwell's model with a constant deformation (ε_0), σ describes the voltage applied from σ_0 per $\sigma(t)$ after time *t* (Del Nobile et al. 2007), represented by Equation 2:

$$\sigma(t) = \varepsilon_0\left(E \cdot exp\left(^{-t}/_{\lambda}\right) + E_0\right) \tag{2}$$

where *E* is the modulus of elasticity of the material, E_0 is the modulus of equilibrium elasticity, λ is the relaxation time given by η/E. The viscosity of element *i* can be calculated according to Equation 3:

$$\eta_i = E_i\lambda_i \tag{3}$$

The relaxation test was performed on a texturometer (TAXT2i, Stable Micro Systems, Goldaming, England) with a 5 kg load cell and compressed to 5% deformation with a speed of 1.0 mm/s if this deformation was kept constant for 10 min, which allowed the tension to reach equilibrium. During that time, tension relaxation was recorded at a rate of 1.0 measured per second. The 7.0 cm diameter probe was lubricated with silicone oil to reduce the friction between the sample and the equipment, without influencing the results obtained. The adjustment of the experimental data for Maxwell's model was performed by non-linear regression using the statistical program Statistical Analysis System (SAS Institute 2016).

Uniaxial compression test

The uniaxial compression test was performed on a texturometer (TAXT2i, Stable Micro Systems, Goldaming, England) with a 5 kg load cell using a 7.0 cm diameter cylindrical probe. These were compressed to 80% strain with a speed of 1.0 mm/s. The rupture stress (σ) and rupture strain (ε) were calculated using Equations 4 and 5 (Bayarri et al. 2003, 2007, Pereira et al. 2013a, b).

$$\sigma = F\left(\frac{h_0 - \Delta h}{A_0 h_0}\right) \tag{4}$$

$$\varepsilon = ln\left(\frac{h_0}{h_0 - \Delta h}\right) \tag{5}$$

Where *F* is the force applied to the sample, A_0 is the initial height, and *Δh* the change in height during compression. From the stress-strain curves obtained, the rupture tension was determined (σ_{rup}), rupture deformation (deformation of Hencky – ε_{rup}) and the rupture work (W_{rup}). The modulus of elasticity (*E*) was obtained by the angular coefficient of the initial linear part of the stress-strain curve at 2% strain and the rupture work (W_{rup}) was determined by the area of the force versus distance curve to the breaking point.

Statistical analysis

The statistical program Statistical Analysis System (SAS Institute 2016) was used for data analysis (analysis of variance and regression coefficients calculations), with a significance level of 5%.

RESULTS AND DISCUSSION

Texture profile analysis

Table III presents the results of the texture profile analysis for mixed fruit sugar-free preserves. In Table IV the adjustments of the complete models for the response variables can be verified by the coefficients of determination (R^2), which explain values higher than 0.7, significant regressions (p <0.05), and non-significant non-adjustments (p >0.05).

The hardness of the preserves ranged from 2.50 N (T9) to 26.86 N (T1) (Table III). According to the predicted model (Table IV), erythritol contributed to increase the hardness of the preserves, since it had the greatest effect when compared to the other polyols, however when mixed with xylitol and polydextrose it caused a negative effect, decreasing the value this parameter. In general, as described by Costa et al. (2020), the bodying agents are responsible for binding water and providing structure to products having good texture, which influences consumer choice and acceptance.

The greater hardness of preserves caused by erythritol can be explained by the fact that this polyol has an open chain, with hydroxyl groups in a favorable position for hydrogen bonds and also for complexation with calcium ions (Tyapkova et al. 2014), originating from the fruits used (Souza et al. 2012a), since in this experiment they were no added salts (calcium and potassium ions). Second Tyapkova et al. (2014) the hardness resulting from the use of erythritol is lower compared to sucrose in gels made with LMP pectin and calcium citrate, since erythritol can compete with pectin for calcium, in addition these authors associate this fact with the lower molecular weight of erythritol (122.12 g/mol) compared to sucrose (342.30 g/mol). According to Pereira et al. (2019) the increase in hardness in guava preserves decreases its acceptability because, according to Rogers et al. (2009), an increase in firmness of a product allows a lower degree of decomposition during mastication, thereby reducing its acceptance.

Regarding the adhesiveness parameter, this ranged from −0.03 N·s (T6) to −1.53 N·s (T1) (Table III). Preserves were significantly influenced only by erythritol, where it stood out in relation to the others, generating more adhesive preserves (Table IV). According to the predicted model (Table IV), it was verified, by the linear coefficient, that only erythritol caused an effect on adhesiveness.

The elasticity ranged from 0.44 mm (T1) to 0.91 mm (T3 and T11) (Table III). According Huang et al. (2007) and Rensis et al. (2009) high elasticity observed in samples T3 and T11 show that the gel structure is broken into a few large pieces during the first compression, showing a greater tendency for the material to recover, but low elasticity observed in sample T1 results in a brittle gel in many small pieces. Body agents positively affected elasticity with xylitol and sorbitol having the greatest effects (more elastic preserves) and erythritol the least effect (less elastic and more brittle preserves). According to the predicted model, in relation to the interactions, it was observed that the mixture of erythritol-xylitol and erythritol-polydextrose (significant effect) was significant.

The cohesiveness of the preserves ranged from 0.17 (T1) to 0.70 (T3 and T11). Formulations T3 and T11 were the samples that showed the highest cohesiveness, which means that in these treatments there will be a greater disintegration of the material in the first compression cycle (Pereira et al. 2013a). According to the predicted model, the cohesiveness of the preserves was positively influenced by the linear coefficients of the body agents, obeying the following decreasing order: xylitol, sorbitol, polydextrose, and erythritol, and by the erythritol-xylitol and erythritol-polydextrose interactions. As

Table III. Texture profile analysis (TPA) of mixed Brazilian Cerrado fruit sugar-free preserves.

Treatments	Hardness (N)	Adhesiveness (N·s)	Springiness (mm)	Cohesiveness (dimensionless)	Gumminess (N·mm)
T1	26.86±1.62	-1.53±0.92	0.44±0.05	0.17±0.02	4.50±0.52
T2	5.25±1.39	-0.85±0.11	0.90±0.02	0.59±0.11	2.75±0.35
T3	5.94±0.77	-0.80±0.34	0.91±0.03	0.70±0.03	4.15±0.41
T4	2.71±0.94	-0.17±0.10	0.81±0.16	0.55±0.13	1.85±0.45
T5	19.90±2.11	-1.06±0.60	0.69±0.05	0.41±0.03	8.06±0.40
T6	6.98±2.17	-0.03±0.01	0.80±0.06	0.58±0.05	4.05±1.37
T7	10.54±2.15	-0.26±0.17	0.79±0.03	0.55±0.03	5.87±1.35
T8	4.16±1.09	-0.82±0.15	0.88±0.03	0.67±0.06	2.80±0.80
T9	2.50±0.57	-0.35±0.07	0.90±0.02	0.69±0.03	1.71±0.35
T10	4.94±0.94	-0.56±0.29	0.89±0.07	0.57±0.13	3.08±0.46
T11	4.33±0.67	-0.63±0.07	0.91±0.02	0.70±0.01	3.03±0.43

Notes: N = 3. Mean value±standard deviation. (T1) erythritol, (T2) sorbitol, (T3) xylitol, (T4) polydextrose, (T5) 50% erythritol and 50% sorbitol, (T6) 50% erythritol and 50% xylitol, (T7) 50% erythritol and 50% polydextrose, (T8) 50% sorbitol and 50% xylitol, (T9) 50% sorbitol and 50% polydextrose, (T10) 50% xylitol and 50% polydextrose and (T11) 25% erythritol, 25% sorbitol, 25% xylitol and 25% polydextrose.

Table IV. Predicted models for texture profile analysis (TPA) of mixed Brazilian Cerrado fruit sugar-free preserves.

Variable	Predicted model	R^2	$P > F$
Hardness (N)	$y = 27.01X_1^{*} + 5.40X_2^{*} + 6.09X_3^{*} + 2.86X_4 + 13.58X_1X_2 - 39.48X_1X_3^{*} - 18.79X_1X_4^{**} - 7.55X_2X_3 - 7.72X_2X_4 + 0.64X_3X_4$	0.99	0.0005
Adhesiveness (N·s)	$y = 1.44X_1^{*} + 0.77X_2 + 0.72X_3 + 0.09X_4 + 0.49X_1X_2 - 3.54X_1X_3 - 1.35X_1X_4 + 0.95X_2X_3 + 0.36X_2X_4 + 1.27X_3X_4$	0.80	< 0.0001
Springiness (mm)	$y = 0.44X_1^{*} + 0.89X_2^{*} + 0.90X_3^{*} + 0.80X_4^{*} - 0.13X_1X_2 + 0.54X_1X_3^{*} + 0.73X_1X_4^{*} - 0.03X_2X_3 + 0.26X_2X_4 + 0.20X_3X_4$	0.98	< 0.0001
Cohesiveness (dimensionless)	$y = 0.16X_1^{*} + 0.58X_2^{*} + 0.69X_3^{*} + 0.54X_4^{*} + 0.23X_1X_2 + 0.68X_1X_3^{*} + 0.89X_1X_4^{*} + 0.23X_2X_3 + 0.58X_2X_4^{**} - 0.11X_3X_4$	0.97	0.0005
Gumminess (N·mm)	$y = 4.60X_1^{*} + 2.84X_2^{**} + 4.24X_3^{*} + 1.94X_4 + 16.61X_1X_2^{*} - 2.24X_1X_3 + 9.64X_1X_4 - 3.70X_2X_3 - 3.49X_2X_4 - 0.81X_3X_4$	0.93	0.0005

Notes: **X_1: mass fraction of erythritol, X_2: mass fraction of sorbitol, X_3: mass fraction of xylitol, X_4: mass fraction of polydextrose, used in the mixing rule. *,**significant at 0.05 and 0.10 levels, respectively.**

with elasticity, xylitol was responsible for making preserves more cohesive, and according to Menezes et al. (2009) gels with greater cohesiveness are massive and easily breakable when tasted, while gels with lower cohesiveness values are generally smoother and more difficult to break up in the mouth. According to Thrimawithana et al. (2010) more cohesive gels expel water from the system and according to Alirezalu et al. (2019) this syneresis makes the product less accepted.

Gumminess is a characteristic of semi-solid foods (Teng et al. 2013) and in the samples, this parameter ranged from 1.71 N·mm (T9) to 8.06 N·mm (T5). For formulation T5 the consumer will need greater strength to chew the preserve until it is swallowed, since it presented the highest gumminess value among the samples (Oliveira et al. 2009). The results indicated a significant positive influence of erythritol, sorbitol, xylitol and of the erythritol-sorbitol interaction, and the increasing order of effects were sorbitol, xylitol, erythritol and the erythritol-sorbitol mixture (Table IV), confirming the results obtained for the hardness parameter.

Stress relaxation test

Table V presents the results of viscoelastic parameters of Maxwell model of mixed Brazilian Cerrado fruit sugar-free preserves. In Table VI the adjustments of the complete models for the response variables can be verified by the coefficients of determination (R^2), which explain values greater than 0.7, significant regressions (p <0.05), and non-significant non-adjustments (p >0.05).

The modulus of elasticity E_e ranged from 3.60 Pa (T9) to 37.05 Pa (T1), and E_1 ranged from 2.96 Pa (T9) to 70.83 Pa (T1). Erythritol, provided it is not used in combination with another polyol, provided greater modulus of elasticity (E_e and E_1) (Table V), that is, the preserves became more rigid. These data are in accordance with the hardness parameter described in the analysis item of the texture profile, since due to possible complexation with calcium ions this polyol also provided higher hardness values. For formulations that showed lower modulus of elasticity, as is the case with T9, this preserve can be less elastic and therefore more plastic. Regarding these modules (E_e and E_1), a significant positive effect of erythritol and a significant negative effect of mixtures of erythritol with the other body agents were observed, where the interaction with sorbitol showed the greatest effect (Table VI).

Relaxation time (λ) of samples ranged from 47.97 s (T1) to 117.10 s (T2) (Table V) and according to Campus et al. (2010) high values of λ, observed in T2 indicates that the product is firmer and more elastic. Through mathematical models, a significant effect was observed only for the linear coefficients, all of which had positive effects, with sorbitol being responsible for the greatest effect and erythritol for the lowest. However, these results are inconsistent, since, in parameters mentioned above (hardness and elasticity modules), erythritol was responsible for firmer gels.

The viscosity (η) ranged from 284.02 Pa.s (T8) to 3428.49 Pa.s (T1) (Table V), the linear coefficients being significant (Table VI). Xylitol had the least effect, followed by sorbitol, polydextrose and erythritol, and with interactions (with negative effect) erythritol-xylitol < erythritol-polydextrose < erythritol-sorbitol. As with the elasticity modules, this parameter was mainly influenced by erythritol, as it presented higher values. Therefore, we can say that samples made with erythritol are harder, because the greater the resistance to deformation, the less the softness of the product (Rensis et al. 2009).

As reported by several studies (Costell et al. 2000, Rogers et al. 2009, Thrimawithana et al. 2010) more rigid gels are difficult to dissolve in the mouth, making the product less accepted.

Uniaxial compression test

Table VII presents the results of the uniaxial compression test analyses of mixed Brazilian Cerrado fruit sugar-free preserves. The predicted models are in Table VIII. Bodying agents influenced (p < 0.05) the parameters of the uniaxial compression test in relation to the new product for all evaluated attributes.

The **rupture tension** (σ_{rup}) ranged from 13.95 kPa (T8) to 55.62 kPa (T1) and this parameter is related to the hardness of the product (Robin et al. 2012), since it can be interpreted as the tension necessary to break the food matrix (Pereira et al. 2013b). Higher values of σ_{rup} were found in preserves preferably made with erythritol (Table VII), indicating that the use of this polyol increased the hardness and rigidity of the preserves. These results are consistent with the values of the hardness parameter of the TPA and with the elastic modules of Maxwell's Model. Regarding the predicted model, it was noted that the least positive linear effect was in the presence of sorbitol. Regarding the interactions, the results indicated a significant negative influence of the erythritol-sorbitol, erythritol-xylitol, erythritol-polydextrose and sorbitol-xylitol interactions.

Regarding rupture deformation (ε_{rup}) the samples showed variation ranging from 0.28 (T1) to 0.69 (T9) and although erythritol caused higher rupture stress values, this polyol led to lower deformation values (Table VII). Samples with high rupture stress and rupture deformation values are more rigid and strong, while samples with high rupture stress, but with low values of rupture strain are hard and brittle (Pereira et al. 2013a). Therefore, it can be said that the preserves made with erythritol became rigid and brittle. Regarding the predicted model, a significant effect was observed in its linear

Table V. Viscoelastic parameters of Maxwell's model of mixed Brazilian Cerrado fruit sugar-free preserves.

Treatments	E_e (Pa)	E_1 (Pa)	λ (s)	η (Pa·s)
T1	37.05±6.02	70.83±25.37	47.97±4.29	3428.49±0.93
T2	4.54±0.17	3.49±0.32	117.10±5.47	405.19±0.06
T3	5.87±0.25	4.15±0.63	97.41±6.35	402.97±0.06
T4	6.46±0.27	4.33±0.71	100.66±11.56	437.56±0.09
T5	9.07±1.17	12.19±2.08	84.88±4.22	1044.20±0.22
T6	6.52±1.31	5.23±0.71	90.89±6.75	483.43±0.07
T7	7.56±1.40	6.70±0.76	98.71±3.71	667.74±0.07
T8	3.79±1.46	3.48±0.79	82.79±9.36	284.02±0.04
T9	3.60±0.79	2.96±0.30	100.34±14.39	295.62±0.04
T10	6.60±1.02	4.11±0.51	108.27±5.39	445.91±0.06
T11	5.28±0.79	3.99±0.58	110.73±13.20	438.98±0.06

Notes: N = 3. Mean value±standard deviation. (T1) erythritol, (T2) sorbitol, (T3) xylitol, (T4) polydextrose, (T5) 50% erythritol and 50% sorbitol, (T6) 50% erythritol and 50% xylitol, (T7) 50% erythritol and 50% polydextrose, (T8) 50% sorbitol and 50% xylitol, (T9) 50% sorbitol and 50% polydextrose, (T10) 50% xylitol and 50% polydextrose and (T11) 25% erythritol, 25% sorbitol, 25% xylitol and 25% polydextrose.

Table VI. Predicted models for viscoelastic parameters of Maxwell's model of mixed Brazilian Cerrado fruit sugar-free preserves.

Variable	Predicted model	R²	*P > F*
E_e (Pa)	$y = 36.57X_1^{*} + 4.06X_2 + 5.40X_3 + 5.98X_4 - 41.21X_1X_2^{*} - 54.07X_1X_3^{*} - 51.10X_1X_4^{*} + 0.03X_2X_3 - 1.88X_2X_4 + 7.45X_3X_4$	0.99	< 0.0001
E_1 (Pa)	$y = 68.91X_1^{*} + 2.56X_2 + 3.22X_3 + 3.41X_4 - 88.74X_1X_2^{*} - 117.91X_1X_3^{*} - 112.39X_1X_4^{*} + 9.80X_2X_3 + 7.31X_2X_4 + 10.63X_3X_4$	0.99	< 0.0001
λ (s)	$y = 47.42X_1^{*} + 116.55X_2^{*} + 98.85X_3^{*} + 100.11X_4^{*} + 16.01X_1X_2 + 79.44X_1X_3 + 104.22X_1X_4 - 91.23X_2X_3 - 27.55X_2X_4 + 43.57X_3X_4$	0.93	< 0.0001
η (Pa·s)	$y = 3399.30X_1^{*} + 376.00X_2^{**} + 373.78X_3^{**} + 408.37X_4^{*} - 3140.27X_1X_2^{*} - 5378.89X_1X_3^{*} - 4710.86X_1X_4^{*} - 129.93X_2X_3 - 152.74X_2X_4 + 452.87X_3X_4$	0.99	0.0005

Notes: X_1**: mass fraction of erythritol,** X_2**: mass fraction of sorbitol,** X_3**: mass fraction of xylitol,** X_4**: mass fraction of polydextrose, used in the mixing rule.** *,****significant at 0.05 and 0.10 levels, respectively.**

coefficients and in the erythritol-polydextrose interaction, in addition to the significant effect, there was also synergistic interaction (Table VIII).

For the modulus of elasticity (E) the samples ranged from 4.98 kPa (T9) to 84.29 kPa (T1). Among the polyols, the effect of erythritol was greater. As previously mentioned, erythritol has an open chain, favoring hydrogen bonds and complexing with calcium ions, thus making the gel more rigid (Tyapkova et al. 2014). Regarding the predicted model, the samples showed a significant positive effect for erythritol and a significant negative effect for erythritol-sorbitol and erythritol-xylitol interactions.

In the samples the rupture work (W_{rup}), ranged from 2.60 kJ/m^2 (T8) to 9.06 kJ/m^2 (T1). Regarding the predicted model, the body agents affected this parameter, and the linear coefficients were significant (positive effects), as well as the erythritol-xylitol interaction (negative effect). According to Foo et al. (2013), the rupture work is the energy needed to decompose the sample and the higher the value of the W_{rup}, the harder it will be to break the food matrix and the greater the energy spent. As with other evaluated parameters, erythritol was responsible for the most effect, this result is in line with the data on the rupture stress, since products with high stress values require more energy to be broken.

CONCLUSION

The results indicated that the rheological parameters were affected by the body agents. The effect of erythritol was greater for hardness, adhesiveness, gumminess, elastic modules (E_e and E_1), viscosity, rupture tension (σ_{rup}), modulus of elasticity (E) and rupture work (W_{rup}). Therefore, the use of erythritol enabled the production of harder and brittle preserves, and its use in mixed Brazilian Cerrado fruits sugar-free preserves can make the product less accepted by consumers. The xylitol and sorbitol made preserves more elastic, cohesive and more fragile (higher values of breakage deformation). Polydextrose showed a synergistic effect with erythritol for rupture deformation (ε_{rup}) and less effect

Table VII. Parameters of the uniaxial compression test of mixed Brazilian Cerrado fruit sugar-free preserves.

Treatments	σ_{rup} (kPa)	ε_{rup} (kPa)	E (kPa)	W_{rup} (kJ·m^{-2})
T1	55.62±4.01	0.28±0.02	84.29±16.79	9.06±0.57
T2	16.00±1.93	0.55±0.09	7.61±1.94	4.36±1.24
T3	24.50±3.07	0.61±0.01	7.72±1.96	7.21±1.45
T4	23.98±5.27	0.50±0.10	9.60±2.50	3.72±1.62
T5	26.74±3.93	0.44±0.06	12.38±2.52	5.90±1.28
T6	24.24±2.09	0.45±0.04	13.48±1.76	4.75±0.62
T7	32.99±6.11	0.47±0.05	16.01±3.37	8.68±1.61
T8	13.95±2.17	0.46±0.02	7.85±2.40	2.60±0.60
T9	21.53±1.22	0.69±0.06	4.98±1.23	6.15±0.89
T10	22.94±0.74	0.50±0.09	9.67±0.68	4.95±2.60
T11	19.83±6.92	0.61±0.07	6.54±1.33	5.14±2.25

Notes: N = 3. Mean value±standard deviation. (T1) erythritol, (T2) sorbitol, (T3) xylitol, (T4) polydextrose, (T5) 50% erythritol and 50% sorbitol, (T6) 50% erythritol and 50% xylitol, (T7) 50% erythritol and 50% polydextrose, (T8) 50% sorbitol and 50% xylitol, (T9) 50% sorbitol and 50% polydextrose, (T10) 50% xylitol and 50% polydextrose and (T11) 25% erythritol, 25% sorbitol, 25% xylitol and 25% polydextrose.

Table VIII. Predicted models for the uniaxial compression test parameters of mixed Brazilian Cerrado fruit preserves sugar-free.

Variable	Predicted model	R^2	*P > F*
σ_{rup} (kPa)	$y = 55.88X_1^* + 16.26X_2^* + 24.76X_3^* + 24.23X_4^* - 39.43X_1X_2^* - 66.42X_1X_3^* - 30.38X_1X_4^* - 28.35X_2X_3 + 3.02X_2X_4 - 8.33X_3X_4$	0.99	< 0.0001
ε_{rup}	$y = 0.28X_1^* + 0.55X_2^* + 0.61X_3^* + 0.50X_4^* + 0.07X_1X_2 + 0.01X_1X_3 + 0.30X_1X_4^* - 0.51X_2X_3 + 0.63X_2X_4 - 0.23X_3X_4$	0.83	< 0.0001
E (kPa)	$y = 83.27X_1^* + 6.59X_2 + 6.70X_3 + 8.58X_4 - 122.05X_1X_2^* - 117.85X_1X_3^* - 111.49X_1X_4^* + 12.97X_2X_3 - 2.57X_2X_4 + 16.28X_3X_4$	0.99	< 0.0001
W_{rup} (kJ·m^{-2})	$y = 9.91X_1^* + 4.49X_2^* + 7.34X_3^* + 3.85X_4^* - 4.80X_1X_2 - 15.13X_1X_3^* + 7.57X_1X_4 - 14.31X_2X_3^* + 6.86X_2X_4 - 3.61X_3X_4$	0.96	< 0.0001

Notes: X_1**: mass fraction of erythritol,** X_2**: mass fraction of sorbitol,** X_3**: mass fraction of xylitol,** X_4**: mass fraction of polydextrose, used in the mixing rule.** * **significant at 0.05 level.**

for hardness, adhesiveness and gumminess. Therefore, it is concluded that for the preparation of mixed Brazilian Cerrado fruits sugar-free preserves it is necessary to use erythritol in combination with polydextrose or to use xylitol or sorbitol in isolation.

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