

Rheological properties of fermented rice extract with probiotic bacteria and different concentrations of waxy maize starch



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ABSTRACT

Fermented rice extracts (FRE) obtained from bran and broken grains in a proportion of 8:92, and probiotic bacteria with different concentrations of waxy maize starch (WMS) were elaborated. Pearson correlations and multivariate analysis by Principal Component Analysis (PCA) were applied to evaluate the rheological behaviour of FRE. A completely randomized design was used, with five treatments from FRE1 to FRE5 (0, 4, 8, 12 and 16 g 100 g⁻¹ of WMS, respectively), in four original repetitions. The multivariate analysis using PCA found that the shear stress and the WMS percentage showed a higher contribution in the first component (CP1 47.5%), and the viscosity in the second component (CP2 29.0%). The FRE5 presented the highest hysteresis, 128.12 Pa s⁻¹. The Ostwald-de Waele model showed the best fit for the flow curves with R² > 0.99 and a relative approximate error of 3.14%. All FRE presented non-newtonian behaviour, with n < 1. The FRE with different concentrations of WMS presented rheological behaviour similar to yogurts and lactic beverages described in the literature, indicating that such products can be comparable to traditional yogurts in relation to viscosity and to the flow characteristics. The results also suggest an improvement in the sensory properties of FRE.

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1. Introduction

Rice (*Oryza sativa* L.) is one of the main foods consumed by humans. The world production in 2014 was 475,500 tons (USDA, 2015). During the processing of this cereal, the rice bran stands out as an important byproduct, due to its high nutritional value. Although little explored, many studies have been conducted in order to evaluate its potential as a food source (Chaud, Arruda, & Felipe, 2009; Garcia, Lobato, Benassi, & Soares Júnior, 2012). In addition, these studies were focused on how to utilize and how to add value to the product. Broken grains are another important byproduct and have the same chemical composition of whole grains, but for the rice industry, it is an economical problem (Amato & Elias, 2005). From the broken grains, only 4% is destined to the beer industry, and the rest is used for animal feeding (Limberger, Silva, Emanuelli, Comarela, & Patias, 2008).

The combination of rice bran and broken grain, when properly manipulated, allows the reconstitution of whole grain rice

(proportion of bran and endosperm, 8:92), with nutritional advantages in relation to the separated byproducts.

Thus, the development of extracts and fermented beverages starting from rice brain and broken grains can provide a low cost product with nutritional and functional quality.

Yogurt is a fermented lactic product with important texture and rheological properties for consumers' acceptance. The texture of this product is influenced by many factors, such as the quality and composition of milk, the fat content and total solids, the heat treatment of the milk, the lactic bacteria used, the acidification rate of the milk and the storage time (Purwandari, Shah, & Vasiljevic, 2007).

Probiotics are live microorganisms that confer a beneficial effect when administered to individuals in appropriate amounts (Fao/Who, 2001). Among the foods with added probiotics, yogurt and fermented milk are the main types (Cruz et al., 2013; Granato, White, Cross, Faria, & Shan, 2010). However, due to a large amount of people who are lactose intolerant, allergic to milk proteins or opt for vegetarianism, the plant-based beverage market has been growing. In the case of fermented plant extracts, the texture and rheological characteristics are also dictated by factors similar to animal-based products, taking into consideration, however, the differences between the raw materials.

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The product viscosity and the propensity to syneresis (serum extraction) are essential characteristics that will define the yogurt quality (Lee & Lucey, 2010). Different polymeric materials used as thickeners are composed of plant or microbial origin. Among the polysaccharides thickeners there are starches, pectins, carrageenans, the alginates, and the xanthan, gellan and Arabic gums. There are also proteinaceous thickening materials, such as the caseinate and the gelatin (Walstra, Wouters, & Geurts, 2006). The waxy maize starch (WMS) has been used for texture improvement, mainly in refrigerated products, due to its low propensity to syneresis (Lamsal, 2012), and a low cost compared to other thickeners. However, irrespective of the thickener type, the temperature of the heat treatment and the fermentation, and the pressure used for homogenization, among other factors, can influence the rheological properties of the products (Paseephol, Small, & Sherkat, 2008).

Rheology is defined as the science that studies the solid deformation and the flow (fluidity) of liquids, influenced by applied mechanical forces (Corrêa, Camargo Júnior, Ignácio, & Leonardi, 2005). There are fluids denominated Newtonians, where the viscosity of the system is independent of the deformation rate, but is dependent or not from shear time. However, the non-Newtonian nutritional fluids, independent of time, can be 1. the pseudoplastic type, where the material viscosity decreases with an increase in the deformation rate; 2. the Herschel-Bulkley type, whose behavior is similar to the pseudoplastic, but with initial stress (Sato & Cunha, 2007). If the value of the behavioral index (n) is equal to 1, then the fluid is characterized as newtonian; lower than 1 is pseudoplastic; and higher than 1 is called dilatant (Bueno & Garcia-Cruz, 2001).

The goal of rheological studies is to verify the structural behavior of foods and their processing capabilities, allowing the correct dimensioning of bombs, pipes, heat exchangers, agitation and packaging operations, preventing any damage to the quality of the final product (Oliveira, Souza, & Monteiro, 2008). In addition, it is possible to obtain parameters such as the consistency index (K), and the behavior index. Thus, these properties are not only good parameters for comparison among different products, but, in addition, they can lead to a refinement of the parameters for one kind of food material (Agrahar-Murugras, Kotwaliwalt, Kumar, & Gupta, 2013). Therefore, due to the inexistence of rheological parameters for the products studied here, this paper aimed to evaluate the rheological behavior of fermented rice extracts (FRE), obtained from bran and broken grains in a proportion of 8:92, with different WMS concentrations.

2. Material and methods

2.1. Raw materials

Rice byproducts (bran and broken grains) were donated by a company called 'Arroz Cristal', located in Aparecida de Goiânia – GO, Brazil. The WMS was donated by "Febela – Fecularia Bela Vista", located in Bela Vista de Goiás – GO, Brazil. The lactic fermentation Rich[®], constituted by cultures of *Streptococcus thermophilus*, *Bifidobacterias* sp. and *Lactobacillus acidophilus*, and the crystalline saccharose (Cristal[®]) were purchased in the local commerce of Goiânia – GO, Brazil.

2.2. Fermented rice extracts

Rice bran was kept for 3 min in a microwave oven (Panasonic, NN-ST652W, Manaus, Brazil), for enzymatic inactivation and for acidification prevention (Abdul-Hamid, Sulaiman, Osman, & Saari, 2007). Next, it was roasted in batches of 500 g in stainless steel recipient (40 cm diameter and 20 cm height), on direct flame, at a

temperature of 110 ± 5 °C for 10min. Manual homogenization was carried out with a stainless steel spoon. In the next step, the product went through 0.595 mm sieve, packaged in laminated bag (polyethylene/nylon/polyethylene) under vacuum, and stored at a temperature of -18 °C until its processing. For processing, extracts of the roasted rice bran (80 g) and broken grains (920 g) were mixed in the proportion of the whole rice composition. The mixture was placed in a 10 L container, previously sanitized with sodium hypochlorite solution (200 mg L^{-1}). The active chlorine evaporates after drying. Water was added to the mixture (1:3) in order to obtain a cooked product with an approximate yield of 300% ($3\times$). Industrial stove was used to cook the mixture. Next, the drained cooked mixture was disintegrated with water (750:750 v/v in each batch) for 3min using an industrial blender (Siemsen, LSB 25, Brusque, Brazil), until obtaining a homogeneous mixture. The homogenized product was immediately sifted in cotton fabric, previously sterilized using an autoclave at 121 °C for 30min, and through a fine mesh strainer (2 mm), previously sanitized with sodium hypochlorite solution (200 mg L^{-1}). The permeated product, an opaque and whitish liquid, is called water-soluble extract.

The extract of rice byproducts was heated on a water bath (Tecnal, TE-054-MAG, Piracicaba, Brazil) to 60 ± 2 °C. WMS concentrations of 0, 4, 8, 12 or $16 \text{ g } 100 \text{ g}^{-1}$ of WMS (FRE1 to FRE5, respectively) was used, and after that, sugar was added (100 g L^{-1}), and the temperature was increased to 85 °C, for 5 min. It was cooled to 45 °C, then lactic culture was added (400 mg L^{-1}), packaged in plastic pots (50 mL) with screw cap, previously sanitized with sodium hypochlorite solution (200 mg L^{-1}) for 15min. The mixture was incubated (Tecnal, TE-4013, Piracicaba, Brazil) in controlled temperature of 45 °C until pH 4.5, measured with a potentiometer (Tecnal, TEC-51, Piracicaba, Brazil). At the end, the mixture was stored (5 ± 1 °C) for the analysis.

2.3. Rheological properties

The rheological analysis was performed in a rotational rheometer (Physica, MCR 101, Ostfildern, Germany), equipped with a temperature controller Peltier Thermostated Temperature Device, whose value was adjusted to 8 °C. The rheometer contains a plate/plate geometry, with 50 mm of diameter and a gap between the plates of 1 mm, with a sample volume of 1 mL, as indicated by the equipment software (Sodini, John, & Tong, 2005). First, the sample was agitated (Marconi, MA 039, Piracicaba, Brazil), for 1 min, at the speed rotation of 2.5 Hz, and then, remained under refrigeration (10 °C) for 10 min (Paseephol et al., 2008). The flow curves and viscosity were obtained by the shear stress determination and the viscosity through the deformation rate, respectively. The rate varied between 0.02 and 100 s^{-1} (upward curve) and between 100 and 0.02 s^{-1} (downward curve), and again between 0.02 and 100 s^{-1} (upward curve). The total analysis time (upward, downward and upward curves) was 20 min, where 80 points were collected in this interval. The rheometer was coupled to the software Rheo plus 32 V3.40 to obtain the curves. The analysis was done in two replicates.

2.4. Statistical analysis

A randomized design was used, with five treatments and four original repetitions. The rheological analysis was performed, and the results were adjusted to the models of Newton, Bingham, Casson, Herschel-Bulkley and Ostwald-de Waele (Steffe, 2006) to obtain the flow curves (Table 1) and the viscosity curves.

The adjustment of the models was performed using the OriginPro 8 Program. After the experimental data was adjusted to the models, the relative approximate error between the experimental and the theoretical data for the shear stress was calculated. The

Table 1
Rheological models used for the experimental data adjustment.

Model	Stress	Equation	Reference
Newton	$\tau = A \dot{\gamma}$	(Equation 1)	Newton (1687)
Bingham	$\tau = \tau_0 + \eta_p \dot{\gamma}$	(Equation 2)	Bingham (1922)
Ostwald de Waele	$\tau = K \dot{\gamma}^n$	(Equation 3)	Reiner (1949)
Herschel-Bulkley	$\tau = \tau_0 + K \dot{\gamma}^n$	(Equation 4)	Herschel; Bulkley; Koll (1926)
Casson	$\tau^{0.5} = \tau_0^{0.5} + K(\dot{\gamma})^{0.5}$	(Equation 5)	Casson (1959)

In which: τ = shear stress (Pa); A = rheological parameter; $\dot{\gamma}$ = deformation rate (s^{-1}); τ_0 = initial shear stress (Pa); η_p = plastic viscosity; K = consistency index ($Pa s^n$); n = behavior index.

theoretical data was obtained through equations (1)–(5) (Table 1), based on the experimental values.

The relative errors were calculated through equation (6), considering the differences among the theoretical and experimental values of shear stress:

$$ER = \frac{100}{80} \sum \left| \frac{VE - VT}{VE} \right| \quad (6)$$

where: ER = relative approximate error (%); VE = experimental value; and VT = theoretical value.

The hysteresis was calculated using the OriginPro 8 Program, and the graphs plotted through the software Rheo plus 32V340, using the “integral” function, in mathematical analysis, for the area calculated below the curves. The results were evaluated through univariate analysis of variance (ANOVA) and Tukey was used as a post hoc test (Statsoft, Statistic 7.0, Tulsa, EUA). In addition, it was performed the Pearson correlation test applying the t-Student test and the qualitative multivariate analysis through the Principal Component Analysis (PCA) with the R application (R Development Core Team, 2015).

Data were analyzed using Principal Component Analysis (PCA), which is a well-known pattern-recognition technique commonly used to display and analyze the structure of multivariate data by projecting them into a reduced hyperspace (Ballabio, Consonni, & Costa, 2012; Grassi, Alamprese, Bono, Casiraghi, & Amigo, 2014).

3. Results and discussion

The rheological behaviour of each sample of FRE with different concentration of WMS can be observed through the rheogram, which relates the shear stress with the deformation rate (Fig. 1). Fig. 1 shows the upward curves, followed by the downward and

upward curves of each treatment, where it can be seen the hysteresis between the upward and the downward curves.

According to Pearson correlation coefficient for the variables related to the rheological behaviour, a positive correlation of 0.774 ($p < 0.01$) between the WMS and the shear stress was obtained. The viscosity decreased with the elevation of the deformation rate, with a Pearson correlation of -0.130 ($p < 0.01$). The extracts of bran and broken grains of rice obtained showed flowability characteristics, independent of the WMS content added to the formulation.

WMS addition to the rice extract resulted in fermented products with higher values of approximate viscosity, with a correlation of 0.09 ($p < 0.01$). The FRE presented higher viscosity value in the entire shear range analyzed, as it follows in decreasing order: FRE5, FRE4, FRE3, FRE2, FRE1 (Fig. 2).

Only two principal components (PC), PC1 (47.5%) and PC2 (29.0%), explained the total variation (77%). The multivariate analysis by principal components explained the correlations between the WMS and the shear stress in the PC1 and between the deformation rate and viscosity in the PC2 (Fig. 3). The WMS concentration was the most important factor for differentiating the rheological characteristics in the FRE formulations, demonstrating the increase of viscosity in the extracts.

The loads dispersion coefficients associated to the first two principal components, showed the contribution of each variable for differentiation between the fermented extracts in relation to the rheological profile (Fig. 3). The higher the coefficient of a variable, the higher is its influence on the degree of score dispersion.

This happens because each of them represents a linear combination of the original variables, and the loads of the variables represent the coefficients from this linear combination (Ballabio et al., 2012; Grassi et al., 2014). The shear stress and WMS content showed a large contribution for the first component (CP1 47.5%). This confirms the obtained results in the univariate level

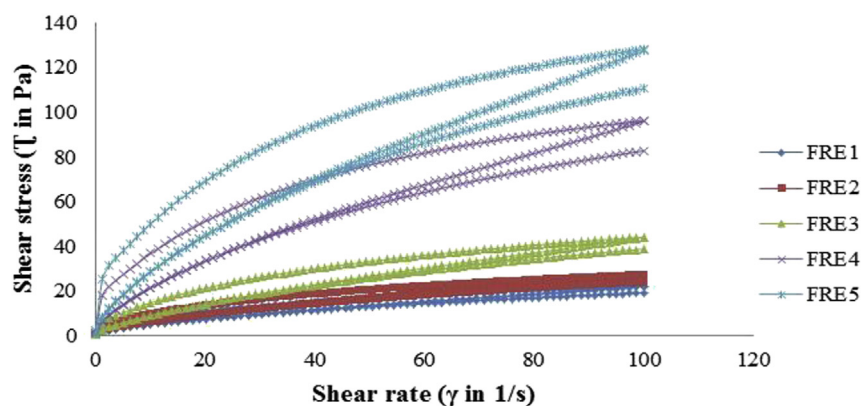


Fig. 1. Flow curves (upward, downward and upward) of the samples from fermented extracts of bran and broken grains of rice in the proportion 8:92 (FRE) with different concentration of waxy maize starch (WMS): FRE1: without WMS; FRE2: with 4 g 100 g⁻¹ of WMS; FRE3: with 8 g 100 g⁻¹ of WMS; FRE4: with 12 g 100 g⁻¹ of WMS and FRE5: with 16 g 100 g⁻¹ of WMS.

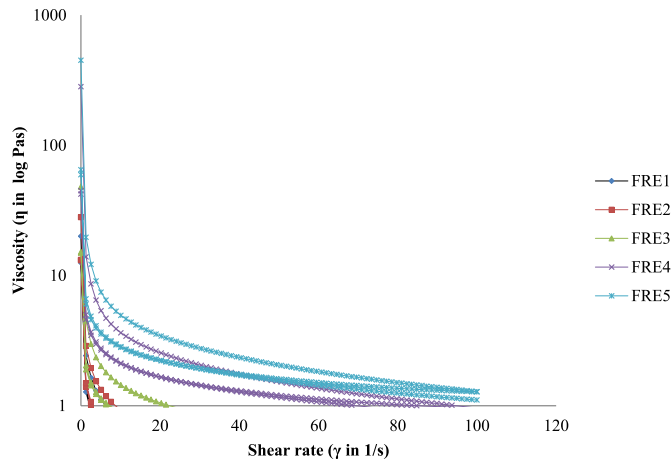


Fig. 2. Viscosity curves from the three running of fermented extract samples of bran and broken grains of rice in the proportion 8:92 (FRE) with different concentration of waxy maize starch (WMS): FRE1: without WMS; FRE2: with 4 g 100 g⁻¹ of WMS; FRE3: with 8 g 100 g⁻¹ of WMS; FRE4: with 12 g 100 g⁻¹ of WMS and FRE5: with 16 g 100 g⁻¹ of WMS.

(ANOVA). The viscosity showed a low correlation with the first axis, however it was the coefficient (load) with the highest value in the second component (CP2 29.0%), which allowed the differentiation of the extracts in relation to their values of viscosity. Fig. 3 showed the rising trend in the viscosity values with increasing WMS values. FRE1 and FRE2 exhibited similar behavior, probably because FRE1 had rice starch, and the added amount of WMS in FRE2 was not enough to modify the rheological behavior of FRE1.

All the FRE also presented thixotropic characteristics, due to

differences of stress and viscosity between the upward and downward rate curves (Figs. 1 and 2). This phenomenon, known as hysteresis, represents the gel brake up, and can be quantified by calculating the area among the flow curves. The largest the area in the curves, the largest is the thixotropic effect (Holdsworth, 1993). The FRE1, FRE3, FRE4 and FRE5 hysteresis differed significantly among them at the 5% of probability, while the FRE2 was similar to FRE1 and to FRE3 (Table 2).

The FRE5 fermented extract with the highest WMS concentration and highest values of viscosity, was the one that presented a clear thixotropic characteristic, represented by a higher hysteresis. The others presented hysteresis values in ascending order in relation to WMS. These results can be explained by the highest values of viscosity obtained with a gradual increase of WMS content on the FRE, causing a higher hysteresis during the shear, because of the gel breakup during the product processing, and it was not possible to verify the protecting effect of the starch, that was observed in the FRE with low concentrations of WMS.

Mathias, Andrade, Rosa, and Silva (2013) analyzed three types of commercial yogurt formulated with different types and combinations of thickening agents (locust bean gum; xanthan gum and guar gum; carboxymethyl cellulose, carrageenan and xanthan gum). The hysteresis values obtained were 112 Pa s⁻¹, 27.2 Pa s⁻¹ and 16 Pa s⁻¹, respectively, close to the values in this work. The highest hysteresis value obtained in this study (128.12 Pa s⁻¹) was 8 times higher than that the value found for yogurt with carrageenan and xanthan gum. However, it was not reported the quantity of carrageenan and xanthan gum used, so it is not possible to confirm that the WMS has the highest rheology protective character.

The lowest hysteresis value that these authors found was for the carrageenan gum and xanthan gum (16 Pa s⁻¹), lower than the one found in this study for the FRE (22.04 Pa s⁻¹), which indicates that

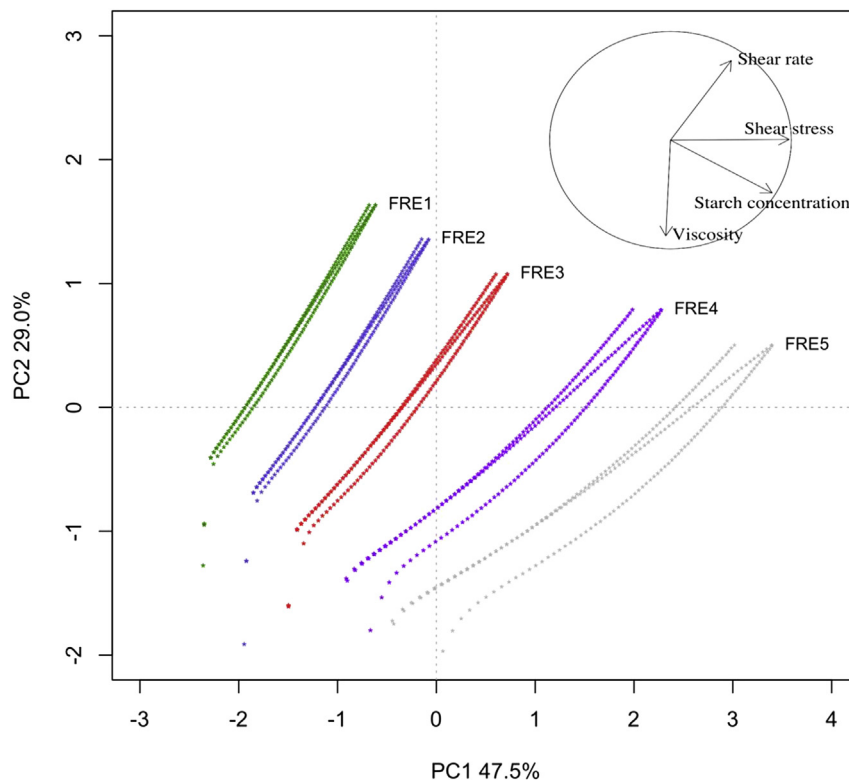


Fig. 3. Graphic representation of fermented extracts of bran and broken grains of rice in the proportion 8:92 (FRE) with different concentration of waxy corn starch (WMS): FRE1: without WMS; FRE2: with 4 g 100 g⁻¹ of WMS; FRE3: with 8 g 100 g⁻¹ of WMS; FRE4: with 12 g 100 g⁻¹ of WMS and FRE5: with 16 g 100 g⁻¹ of WMS, in relation to the two first principal components (PC), and in relation to the four variables related to the rheological profile.

Table 2

Hysteresis of the fermented extracts of bran and broken grains of rice in the proportion 8:92 (FRE), with different concentration of waxy maize starch (WMS).

Tratamento	Histerese (Pa s ⁻¹) ²
FRE1	22.04 ± 1.08 ^d
FRE2	27.01 ± 0.45 ^{cd}
FRE3	44.06 ± 11.11 ^c
FRE4	96.14 ± 5.16 ^b
FRE5	128.12 ± 12.47 ^a

FRE1: without WMS; FRE2: with 4 g 100 g⁻¹ of WMS; FRE3: with 8 g 100 g⁻¹ of WMS; FRE4: with 12 g 100 g⁻¹ of WMS and FRE5: with 16 g 100 g⁻¹ of WMS; ² Means followed the standard deviation with different letters in the same column differ by Tukey test at 5% significance level.

the extract of bran and broken grains of rice (8:92) adds to the product a thixotropic aspect. To characterize FRE rheologically and to obtain the values of rheological parameters, five rheological models were tested: Newton, Bingham, Ostwald-de Waele, Herschel-Bulkley and Casson. They were adjusted to the upward, downward and upward curves of the sample flow from the fermented extract (Table 3).

The Ostwald-de Waele model (Power Law) was the one that adjusted better to the flow curves, with a determination coefficient higher than 0.99, and the relative approximate error inferior to 10%. According to Leite, Park, Ramalho, and Furlan (2004), these values indicate a good adjustment. Thus, this model was chosen for the rheological characterization and to obtain both the consistency and the behaviour index of the FRE.

Table 3

Determination coefficients (R²) and the approximate error (ER) from the models of Newton, Bingham, Ostwald-de Waele, Herschel-Bulkley and Casson adjusted to upward, downward and upward flow curve for the extracts of bran, broken grains of rice in the proportion 8:92 fermented (FRE) with different concentration of waxy maize starch (WMS).

Extract Parameters		Model				
		Newton	Bingham	Ostwald de Waele	Hershel-Bulkley	Casson
Upward flow curve						
FRE 1	R ²	0.4548	0.9222	0.9988	0.9992	0.9222
	ER(%)	29.3677	31.9989	1.8530	2.7925	18.5613
FRE 2	R ²	0.5009	0.9267	0.9987	0.9990	0.9267
	ER(%)	28.9508	29.5002	1.6121	2.8867	17.3927
FRE 3	R ²	0.5540	0.9284	0.9978	0.9983	0.9284
	ER(%)	28.4634	30.1565	1.8844	3.9554	16.6192
FRE 4	R ²	0.2983	0.9013	0.9958	0.9962	0.9013
	ER(%)	30.8385	29.2622	2.1571	3.9134	18.7021
FRE 5	R ²	0.2461	0.8970	0.9956	0.9959	0.8970
	ER(%)	31.1788	33.7093	2.3507	4.0376	20.3611
Downward flow curve						
FRE 1	R ²	0.9045	0.9884	0.9987	0.9994	0.9884
	ER(%)	20.2151	20.6958	3.1423	3.8724	10.9977
FRE 2	R ²	0.9101	0.9874	0.9994	0.9997	0.9874
	ER(%)	19.9012	23.9208	2.4706	3.0139	10.7092
FRE 3	R ²	0.9308	0.9889	0.9997	0.9998	0.9889
	ER(%)	18.5804	29.4195	1.9250	2.4831	10.0779
FRE 4	R ²	0.8962	0.9826	0.9998	0.9999	0.9993
	ER(%)	20.5733	28.8283	1.2880	0.8771	11.0433
FRE 5	R ²	0.8918	0.9812	0.9999	0.9999	0.9812
	ER(%)	31.1788	28.4464	1.1390	0.6250	10.9649
Upward flow curve						
FRE 1	R ²	0.8102	0.9694	0.9998	0.9998	0.9694
	ER(%)	23.7773	26.8203	1.2793	1.0793	12.8656
FRE 2	R ²	0.8305	0.9697	0.9997	0.9997	0.9697
	ER(%)	23.1624	30.1414	1.3781	2.2150	12.5381
FRE 3	R ²	0.8630	0.9717	0.9993	0.9994	0.9717
	ER(%)	22.0047	36.8548	1.7898	4.4269	12.2352
FRE 4	R ²	0.7922	0.9571	0.9983	0.9987	0.9571
	ER(%)	24.3215	34.5763	2.5048	5.6867	13.4009
FRE 5	R ²	0.9243	0.9797	0.9976	0.9987	0.9797
	ER(%)	24.0791	24.8249	8.8264	16.6090	16.8430

FRE1: without WMS; FRE2: with 4 g 100 g⁻¹ of WMS; FRE3: with 8 g 100 g⁻¹ of WMS; FRE4: with 12 g 100 g⁻¹ of WMS and FRE5: with 16 g 100 g⁻¹ of WMS.

These results showed that FRE have flowability characteristics, in other words, the higher the applied deformation rate, the lower will be the viscosity of the fluid (Fig. 2). The Ostwald-de Waele model was also used to describe the pseudoplastic behaviour of products such as yogurts (Aportela-Palacios, Sosa-Morales, & Vélez-Ruiz, 2005; Damian, 2013; Donkor, Henriksson, Vasiljevic, & Shah, 2007; Espírito-Santo et al., 2013; Fischer, Pollard, Erni, Marti, & Padar, 2009), chocolate beverages with soy and whey base (Moreira, Madrona, Branco, Bergamasco, & Pereira, 2010), lactic desserts (González-Tomás, Bayarri, Taylor, & Costell, 2008) and icecreams (Oliveira et al., 2008).

The FRE pseudoplastic behaviour similar to yogurts present an alternative way to produce FRE by the industry without great changes during FRE processing.

The consistency index of FRE increased with an increase of the WMS concentration in all flow curves (upward: 2.98 a 21.48 Pa s⁻¹; downward: 0.99 a 6.32 Pa s⁻¹; upward: 1.33 a 4.92 Pa s⁻¹) (Table 4).

Espírito-Santo et al. (2013) observed a similar increase of the consistency index in the upward curves of yogurt with probiotic culture with no passion fruit fiber addition (control) compared to the one containing passion fruit fiber. The values found for the control (12 Pa s⁻¹) was 4 times higher than the values of FRE1, while the yogurt with passion fruit fiber (15.8 Pa s⁻¹) was similar to FRE4.

In relation to the behaviour index, it was observed a decrease from 0.15 (control) to 0.08 (yogurt with passion fruit fiber). In general, the same behaviour was observed for this study, between the FRE and WMS in relation to the FRE1, because the behaviour index decreases in the FRE5 in relation to FRE1.

Table 4

Ostwald-de Waele parameters adjusted to flow curves for the fermented extracts of bran and broken grains of rice in the proportion 8:92 (FRE) with different concentration of waxy maize starch (WMS).

Treatment	Upward flow curve	
	K (Pa s ⁿ) ⁶	n ⁷
FRE1	2.9828	0.43711
FRE2	3.4569	0.49942
FRE3	5.27266	0.46538
FRE4	15.40734	0.40377
FRE5	21.47838	0.39395
	Downward flow curve	
	K (Pa s ⁿ)	n
FRE1	0.9987	0.6661
FRE2	1.1948	0.6728
FRE3	1.7066	0.7023
FRE4	4.6328	0.6554
FRE5	6.3174	0.6505
	Upward flow curve	
	K (Pa s ⁿ)	n
FRE1	1.3308	0.5801
FRE2	1.5537	0.5951
FRE3	2.2325	0.6228
FRE4	6.1389	0.5697
FRE5	4.9257	0.7070

FRE1: without WMS; FRE2: with 4 g 100 g⁻¹ of WMS; FRE3: with 8 g 100 g⁻¹ of WMS; FRE4: with 12 g 100 g⁻¹ of WMS and FRE5: with 16 g 100 g⁻¹ of WMS.

Connecting both studies, it was observed a similar change of the WMS with passion fruit fiber addition, changing the rheological characteristics of the products, increasing the consistency index and decreasing the behaviour index with the addition of polymers.

The consistency index value indicates the degree of resistance of the fluid in relation to the flow. The higher the K value, more consistent will be the fluid. The use of WMS increases the consistency of the fluid so as the fibers. Thus, it is possible to replace the fibers for WMS.

The behaviour index of the flow is related to the removal of the fluid from the newtonian model. Thus, it can be observed that the rheological behaviour of the FRE is pseudoplastic, because the values of the behaviour index were all inferior to 1 (Table 4), as found by Tamime and Robinson (2007) for yogurt, and by Espirito-Santo et al. (2013) for probiotic yogurt enriched with fiber.

The viscosity curves were adjusted by the Ostwald-de Waele model, and it was obtained the parameters of consistency index, behaviour index, and the regression coefficient (R²) for each FRE. As it was expected, the model gave a good fit, with a coefficient of correlation greater or equal to 0.99 for all treatments and all curves. The consistency index increased according to the WMS elevation in all curves, varying from 2.5757 to 20.6036 Pa s⁻¹ (upward), from 1.7180 to 9.0302 Pa s⁻¹ (downward), and from 1.7017 to 9.2901 Pa s⁻¹ (upward) (Table 5).

In relation to the behaviour index, the values decreased up to 12 g 100 g⁻¹ of WMS only in the first curve (upward), and for the other curves, the behaviour was different, increasing up to 8 g 100 g⁻¹ of WMS. For all viscosity curves, the FRE4 and the FRE5 showed a different behaviour in relation to the adjusted parameters for the viscosity curves. In spite of the model adjustment, the high concentration of WMS in the formulations, due to the gel break up during the processing, could be irreversible, changing its rheological characteristics. Therefore, it was not possible to verify the protective effect that the starch could cause in FRE with lower concentrations of WMS (Table 5).

High concentration of starch in the presence of acid (produced by the inoculated microorganisms for the fermentation) is

Table 5

Ostwald-de Waele parameters and determination coefficients (R²) adjusted to the viscosity curves for the fermented extracts of bran and broken grains of rice in the proportion 8:92 (FRE) with different concentration of waxy maize starch (WMS).

Treatment	Upward viscosity curve		
	K (Pa s ⁿ) ^a	n ^b	R ²
FRE 1	2.5757	0.4860	0.9999
FRE 2	3.2514	0.4640	0.9999
FRE 3	5.2060	0.4573	0.9999
FRE 4	15.1745	0.4054	0.9999
FRE 5	20.6036	0.4120	0.9999
	Downward viscosity curve		
	K (Pa s ⁿ)	n	R ²
FRE 1	1.7180	0.4857	0.9985
FRE 2	1.9401	0.5093	0.9978
FRE 3	2.6440	0.5574	0.9963
FRE 4	6.6332	0.5269	0.9971
FRE 5	9.0302	0.5180	0.9968
	Upward viscosity curve		
	K (Pa s ⁿ)	n	R ²
FRE 1	1.7017	0.4898	0.9994
FRE 2	1.9306	0.5115	0.9989
FRE 3	2.6487	0.5550	0.9981
FRE 4	6.7517	0.5178	0.9985
FRE 5	9.2901	0.5058	0.9983

FRE1: without WMS; FRE2: with 4 g 100 g⁻¹ of WMS; FRE3: with 8 g 100 g⁻¹ of WMS; FRE4: with 12 g 100 g⁻¹ of WMS and FRE5: with 16 g 100 g⁻¹ of WMS; ^a consistency index and ^b behaviour index.

hydrolyzed to smaller molecules (Wang & Wang, 2001). The viscosity change can be induced by a change in the starch granule size, and by the number of chains of free amylopectin, elevated in the presence of acids (Hirashima, Takahashi, & Nishinari, 2005).

González-Tomás et al. (2008) studied the influence of two types of thickeners, modified manioc starch and k-carrageenan, in the rheological properties of lactic desserts with low fat. He found that the addition of the k-carrageenan and the increase of starch concentration, elevated the consistency index and viscoelastic parameters, and diminished the value of the behaviour index to the flow, also observed in this study.

Aportela-Palacios et al. (2005) studied fiber and calcium fortified yogurts, and they observed that all yogurt systems analyzed exhibited pseudoplastic behaviour. The presence of wheat bran as fiber source favored a measurable resistance to the flux, thus, the apparent viscosity and consistency of the enriched systems increased due to the fiber percentage, showing a decreased viscosity with an increase of shear rate. The significant increase of viscosity was observed with an increase in the concentration of wheat bran, which also occurred in this study, relating a viscosity increase with an increase of WMS concentration. From a nutritional and physiological perspective, the starch is generally classified in three main fractions, depending on the rate of digestion *in vitro*: 1. fast digestible starch (ARD), which is the portion of starch digested in the first 20 min of incubation; 2. slow digestible starch (ALD), the portion of starch digested between 20 and 120min, and 3. resistant starch (AR), the remaining part that cannot be digested (Englyst, Kingman, & Cummings, 1992).

For this reason, it confers to WMSa similarity with fibers, because it has 29 g 100 g⁻¹ of fast digestible starch, 66.7 g 100 g⁻¹ of slow digestible starch and 4.3 g 100 g⁻¹ of resistant starch (Cai, Shi, Rong, & Hsiao, 2010).

Donkor et al. (2007), studied the soy yogurt with probiotic supplemented with inulin, glucose and raffinose, and found high values of K 12.87 Pa s⁻¹ (upward) and 8.54 Pa s⁻¹ (downward), and low values of n, 0.18 (upward) and 0.26 (downward). In other

words, $n < 1$, for all soy yogurts, indicating that the products were more viscous, and showed pseudoplastic properties, with values close (difference of 15% - upward and 22% - downward) to the ones found on FRE4. Therefore, soy yogurt supplemented with inulin, glucose and raffinose have similar characteristics to FRE4, both for viscosity and for pseudoplastic properties.

4. Conclusions

The increase of WMS content caused an increase in viscosity and hysteresis. The results of PCA identified the shear stress and the WMS content as determinant factors in the first component. On the other hand, the viscosity was the coefficient with the highest value for the second component, and the viscosity differentiated the beverages in relation to their viscosity values. The Ostwald-de Waele model was the one that best described the rheological behavior of the FRE. All fermented rice extracts presented a non-Newtonian behavior with $n < 1$. The FRE with different concentrations of WMS presented rheological behaviour similar to yogurts and lactic beverages described in the literature, indicating that such products can be compared to the traditional yogurts in relation to viscosity and flow characteristics. Therefore, the results suggest an improvement in the sensory properties of FRE.

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