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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 $R^2 > 0.99$ 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.

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×). 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 g 100 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