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Rheological and thermal properties of dough and textural and microstructural features of bread obtained from nixtamalized corn/wheat flour blends

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ABSTRACT

Bread made with corn flour has a rich tradition in several countries. On the other hand, nixtamalization is a process conferring malleability and functionality to corn flour via calcium incorporation. The aim of this work was to study the rheological and thermal properties of dough, and the textural and microstructural features of bread obtained from nixtamalized corn (NCF)/wheat flour (WF) blends. Thermal analysis indicated that NCF promoted the interaction between starch molecules and lipids. The incorporation of NCF improved the viscoelasticity of dough, indicative that the participation of lower amounts of gluten (protein) due to WF substitution by NCF might be compensated by the cross-linking capacity of calcium ions. Morphological analysis via SEM showed that as NCF was incorporated, a more compact and porous microstructure arose that caused breads to exhibit increasing hardness, but a decrease in the rest of the textural characteristics. Increasing amounts of NCF led to more homogeneous bread crust color, characterized by a more subdued lightness and yellow hue. Overall, NCF offers a mean to improve dough viscoelasticity and granular microstructure of wheat-based bread.

1. Introduction

Bread made with wheat flour accounts for about 50% of dietary energy requirements in many countries. Although flours from other botanical sources offer also high carbohydrate contents, the widespread usage of wheat flour for bread making can be attributed to its relatively high gluten content. Wheat proteins have the ability of developing a viscoelastic network when the flour is mechanically blended with water. In turn, the viscoelastic network allows an easy manipulation of dough for fabrication of a wide diversity of specialties. Besides, the viscoelastic matrix enables the retention of the gas produced during fermentation, leading to aerated crumb bread morphology.

It has been recognized that high costs of wheat importation in regions where climatic conditions do not favor its cultivation (e.g., tropical and sub-tropical Africa) limits its utilization as a source of dietary energy (Goodall et al., 2012). This problem has been addressed by the use of flours from non-wheat botanical sources, including rice (Torbica et al., 2010; Torres et al., 2014), chestnut (Demirkesen et al., 2010; Torres et al., 2014), soybean (Ribotta et al., 2004) among others. Results obtained with non-wheat flours are motivating, although some problems related to dough viscoelasticity and bread texture require further research (Berta et al., 2015). On the other hand, the bread production in underdeveloped economic and impoverished regions has been addressed by using inexpensive flour from local botanical sources, like cassava (Onyango et al., 2011), and sorghum (Schober et al., 2005).

Corn flour has been also considered for bread production (Brites et al., 2010; Falade et al., 2014). Besides its low-gluten content, corn is cultivated in many countries with large climate diversity. The use of corn flour for bread preparation has an ethnic tradition in some countries. *Pan de Elote* in Mexico and *Broa* in Portugal are examples of traditional bread recipes incorporating corn flour. Given the reduced protein content (about 2% w/w) of corn flours, the bread production is confronted with some challenges, including weak viscoelastic networks and poor gas retention capacity. In this

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regard, an accurate understanding of bread making processes involving corn flours is a requisite for developing reduced- and free-gluten bread formulations, and for designing bread specialties with tailored textural properties.

Nixtamalization is a lime-based alkaline corn grain treatment used since pre-Columbian Mesoamerican cultures, which results in an increased nutritional value, enhanced flavor and aroma, and reduced mycotoxins contents (Sefa-Dedeh et al., 2004; Estrada-Girón et al., 2015). Some corn oil fractions are broken down into monoglycerides and diglycerides, while bonding of proteins is facilitated. Besides, the divalent calcium provided by lime acts as a cross-linking agent for starch chains, improving gel viscoelastic properties and network stability (Lobato-Calleros et al., 2015). Besides the functional availability of calcium, nixtamalization via calcium cross-linking effects can partially compensate the poor functionality of corn flour proteins (i.e. mainly zein). Unlike wheat flour, corn flour, when hydrated, does not form a viscoelastic dough, due in part from the marked hydrophobicity of corn proteins. Also, corn proteins have different structures than wheat proteins, which impart them with different reactivities (Lawton, 1992). It has been shown that nixtamalization is able to increase the protein and resistant starch levels (Rendon-Villalobos et al., 2002). Besides, nixtamalization leads only to slight degradation of antioxidant content of colored corn grains (Mora-Rochin et al., 2010). Commercially available nixtamalized flour is worldwide available, inexpensive (about 0.5 $/kg as compared with about 0.6 $/Kg for standard wheat flour) and enriched with Zn, niacin, vitamin B1, B2 and B3. These features make nixtamalized corn flour an attractive ingredient for enhancing the nutraceutical content of bread and the malleability of dough variations.

The aim of this work was to evaluate the rheological and thermal properties of dough, and the textural and microstructural characteristics of bread obtained made from commercial nixtamalized corn/wheat flour blends.

2. Materials and methods

2.1. Materials

Wheat flour (WF; moisture content 13.10 g/100 g, protein 7.39 g/100 g, dietary fibre 0.5 g/100 g, lipids 0.39 g/100 g, ash 0.8 g/100 g) obtained from Cia. Harinera del Parayas S.A. de C.V. (Guadalajara, Mexico), nixtamalized corn flour (NCF; moisture content 11.10 g/100 g, protein 2.63 g/100 g, dietary fiber 0.65 g/100 g, lipids 0.37 g/100 g, ash 1.1 g/100 g) manufactured by Maseca S.A. de C.V. (Monterrey, Mexico). According to manufacturer, the nixtamalized maize flour does not contain additives (e.g., hydrocolloids). Butter, fresh egg, sugar, baking powder, ultrapasteurized low fat content milk (3.12% of protein, and 2.8% of total fat) were obtained in a local supermarket (Walmart, Mexico City). Deionized water was used for all experimental runs.

2.2. Preparation of the dough variations

The dough variations were made according to traditional recipes for sponge cake fabrication (see, for instance, www.bbc.co.uk/food/recipes). Dough variations were prepared in two stages. In the first stage, a liquid blend was prepared by mixing milk (22.5 g), fresh whole egg (75 g, previously homogenized for 1 min before weighing) and deionized water (3 g). In the second stage, a powder blend was obtained by combining flour (75 g), sugar (75 g) and baking powder (1.9 g). The batter, a solid water-in-oil emulsion, was obtained by adding 87.4 g of butter in a bowl and mixing with a spiral mixer (Taurus, Mexico City) at high velocity (10,000 rpm) for 10 min until total fusion of the fat was achieved. This step induced best distribution of the fatty acids enhancing their textural and spreadable properties. Subsequently, half of liquid blend was added and mixed at high velocity (3 min). Then the powder blend was incorporated and mixed (3 min), and finally the other half of liquid blend was mixed (3 min). Five dough variations were obtained by blending NCF:WF in the following proportions: 0:100, 25:75, 50:50, 75:25 and 100:0. The dough variations were coded as D_0, D_{25}, D_{50}, D_{75} and D_{100}, where the sub-index refers to NCF proportion in the blend. Dough variations were sealed and stored at 20 °C for 30 min to allow stabilization of components. Three samples were made for each dough variation.

2.3. Thermal characterization of dough variations

Thermal properties were analyzed by differential scanning calorimetry (DSC) (TA Instruments, Q1000, New Castle, DE, USA) previously calibrated with indium. To this end, dough variation samples (15.0 ± 1 mg) were hermetically closed in aluminum pans and heated in a calorimeter from 25 to 100 °C at constant rate 10 °C/min. Empty aluminum pan was used as reference. Temperatures (T_o - onset, T_p - peak, T_m - middle point, T_e - endset) and enthalpy of thermal transitions (ΔH) were determined with the use of instrument's software Universal Analysis 2000 (New Castle, DE, USA). Enthalpy values were expressed as J/g starch. Three measurements were carried out for each sample.

2.4. Rheological properties of the dough variations

Dynamic oscillatory measurements were carried out using a Physica MCR 300 rheometer (Physica Meβtechnik GmbH, Stuttgart, Germany), with a cone-plate geometry, in which the rotating cone was 50 mm in diameter, and cone angle of 2° with a gap of 0.05 mm. About 1.25 mL of sample was carefully placed in the measuring system, and left to rest for 5 min at 25 °C for structure recovery. Amplitude sweeps were carried out in the range of 0.001–1000% at 1 rad/s. Temperature maintenance was achieved with Physica TEK 150P temperature control and measuring system. The storage modulus (G') and the loss modulus (G'') were obtained from the equipment software (US200/32 V2.50) in all cases. Flow curves were obtained by varying the shear rate from 0.00001 to 1000 s^{-1} and the corresponding shear stress and apparent viscosity values measured. Creep and recovery tests were performed at a fixed stress of $\sigma_0 = 1$ Pa in the range of proportionality of strain to stress. The experiments were performed under controlled stress mode. Creep phase lasted 150 s, and recovery phase 300 s. As a result of these measurements, strain values were obtained as a function of time. Analysis was performed by triplicate. The experimental creep-compliance data were fitted by Burger's model, which can be described as follows:

$$J(t) = J_0 + \frac{t}{\eta_0} + J_1\left(1 - \exp^{-t/\lambda_{ret}}\right), \text{ for } t < t_1$$

$$J(t) = \frac{t_1}{\eta_0} - J_1\left(1 - \exp^{-t/\lambda_{ret}}\right), \text{ for } t > t_1$$

where J is the compliance, J_0 ($=1/E_0$) is the instantaneous compliance, J_1 is the retardation compliance, η_0 is the (Newtonian) zero shear stress viscosity, λ_{ret} is the retardation time-constant and t_1 is the time at which the shear stress is removed. E_0 is the instantaneous elastic modulus.

2.5. Bread variations

100 g of each dough variation were put into metallic containers