Journal of Food Engineering 122 (2014) 72–77

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Effect of steeping time and calcium hydroxide concentration on the water absorption and pasting profile of corn grits

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ARTICLE INFO

Article history:
Received 15 March 2013
Received in revised form 30 August 2013
Accepted 2 September 2013
Available online 8 September 2013

Keywords:
Diffusion coefficient
Steeping time
Relative viscosity
Water absorption

ABSTRACT

Water diffusion in corn is important in both dry and wet milling because it is one of the factors that determine the functionality and quality of any final product for which this cereal is intended. The diffusion of water into the starch granule will be affected by the type of solvent used, the temperature, and the size and shape of the starch granule. Therefore, the aim of this investigation was to assess the effect of steeping corn grits at room temperature in a solution with and without the addition of calcium hydroxide on the hydration and pasting properties. We evaluated the moisture gain, pH change, viscosity profile, and the microstructure of the endosperm relative to the steeping time of corn grits with and without calcium hydroxide. Corn grits steeped in water without calcium hydroxide showed lower water absorption (35 g/100 g) than those steeped with 1 g $Ca(OH)2$/100 g (38 g/100 g) and 2 g $Ca(OH)2$/100 g (40 g/100 g). Electron micrographs show that the starch granule size in corn grits increases due to water absorption. Viscosity increases with steeping time and the calcium hydroxide concentration shows a correlation ($r = 0.7$) with water absorption. We calculated effective diffusion coefficient of corn grits with and without calcium hydroxide concentration, solving Fick's equation for a sphere. Water diffusion into the starch granule is an important step that significantly influences the pasting properties of the corn grits.

1. Introduction

Water diffusion in corn is important in both dry and wet milling because it is one of the factors that determine the functionality and quality of any final product for which this cereal is intended. Thermo-alkaline treatment in relation to wet milling has been widely studied. Several authors have proposed mathematical models that attempt to explain water diffusion and lime into corn (Fernández-Muñoz et al., 2002; Valderrama-Bravo et al., 2010; Pineda-Gómez et al., 2011; Pineda-Gómez et al., 2012). The thermo-alkaline process has two major stages: corn cooking and steeping. The hydration of the corn during the thermo-alkaline process is directly related to the time and temperature of cooking, as well as concentration of calcium hydroxide, and the variety of corn used. Fernández-Muñoz et al. (2011a) reported that the range of corn grain hydration is approximately 36% regardless of the concentration of calcium hydroxide used. They attributed this to the fact that the pericarp acts as a barrier to the entry of water into the inner layers of the corn kernels. Narváez-González et al. (2007) reported that the thickness of the pericarp significantly influences the diffusion of water. Fernández-Muñoz et al. (2004) indicated that during the heating process, the alkaline solution degrades and solubilizes the pericarp, produces the softening of the structure of the endosperm and the diffusion of calcium ions and water into the starch granules, which swell, partially gelatinize, and lose their crystalline structure. Laria et al. (2005) studied water diffusion in two corn varieties at room temperature using water with and without the addition of lime. They reported that the efficiency of water diffusion and calcium ions within the grain are dependent on the percentage of the calcium ions, which affect the diffusion rate and pathways. The aforementioned authors wrote that this phenomenon begins at the tip cap, through which the water moves by capillary action through the open spaces of the innermost layers of the pericarp, as well as through the transverse tube cells and cross cells; subsequently the water diffuses through the testa and the aleurone cell layer into the endosperm and the germ. Thus, the process is slower because the pericarp hinders diffusion. However,

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http://dx.doi.org/10.1016/j.jfoodeng.2013.09.005

Laria et al. (2007) did not assess whether there is any change in the pasting properties of the grain due to the diffusion of water and Ca^{++} ions into the corn.

Pasting properties have been used to determine starch types, starch sources, the starch granule size, the degree of starch gelatinization or modification, changes due to chemical or thermal effects as well as the functionality of the products, among many others (Okechukwu and Rao, 1995; Becker et al., 2001; Narváez-González et al., 2007; Quintanar-Guzmán et al., 2009; Fernández-Muñoz et al., 2011b).

However, it has not been reported in the literature whether or not during the steeping process at room temperature in solutions with and without added calcium hydroxide, any change in the pasting properties is produced. Therefore, the aim of this investigation was to assess the effect of steeping corn grits at room temperature in a solution with and without the addition of calcium hydroxide, on the hydration and pasting properties.

2. Experimental procedure

2.1. Raw materials

Commercially available yellow dent corn was obtained from the local market in Querétaro, Querétaro, México. The physical and chemical properties of the corn were: flotation index: 10 floating grains; weight of 1000 grains: 390 g; length: 11.3 mm; width: 8.4 mm; thickness: 2.7 mm; protein 7.5 g/100 g; fat: 5 g/100 g; ash: 1.3 g/100 g. The calcium hydroxide ($Ca(OH)_2$) was food grade. Yellow dent corn is widely known and used for production of masa and tortillas.

2.2. Preparation of samples

Clean corn was grounded using a Nixtamatic grinder to obtain corn grits. 200 g portions of corn grits were placed in plastic containers and suspended in 600 mL of water with 0 g $Ca(OH)_2$/100 g corn, 1 g $Ca(OH)_2$/100 g corn and 2 g $Ca(OH)_2$/100 g corn (dry basis), according to the experimental design. The samples were mixed for 5 min in order to obtain homogeneity. The capped containers were maintained at room temperature (30 ± 2 °C) throughout the steeping time. The corn grits were steeped for 0.16, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 h. After steeping, the excess water was removed using a blanket in order to prevent loss of material. At each steeping time interval, 50 g were taken in order to measure moisture and pH. The remaining material was dried in a drying and heating chamber with forced convection at a temperature of 45 ± 2 °C. The dry steeped corn was ground with a coffee grinder in order to obtain an approximate particle size of 250 μm (60 mesh). Each treatment was performed in triplicate.

2.3. Moisture content determination

Moisture content of steeped maize grits samples was determined by drying in a forced-air oven (Binder Modelo FD 53 Tuttlingen, Germany) at 110 °C (method 44-15A, AACC, 2000). The moisture gain was calculated by subtraction of the initial corn moisture.

2.4. Water diffusion coefficients

The analytical solution of one dimensional second Fick's law with constant diffusion coefficient without chemical reaction for a sphere is given by Crank (1975) as:

$$MR = \frac{M_t}{M_\infty} = 1 - \sum_{n=1}^{\infty} \frac{6}{\pi^2 n^2} \exp\left[\frac{D_{eff} n^2 \pi^2 t}{a^2}\right] \quad (1)$$

where MR is the moisture ratio, $M(t)$ is the moisture at time t, M_∞ is the saturation moisture (after 10 h), n is the number of terms in the summation ($n = 10$ for these calculations), D_{eff} is the effective water diffusion coefficient and a is the radius of the corn grits (2 mm). From experimental water absorption data together with Eq. (1) the D_{eff} coefficients were calculated by using Mathematical 9 software (Wolfran Research Company).

We assumed that the corn grit has a spherical shape with an equivalent diameter. It was proposed that equivalent diameter of the sphere is the mean value of the corn grit sides defined as [length + width + height]/3. For this experiment the equivalent diameter calculated was 4.1 ± 0.6 mm. Thus, to compute the coefficient of diffusion, it was estimated a radius of 2 mm for the sphere.

2.5. Sample pH values

The pH values were determined using a pH meter (pHmeter Orion, Model 310, Thermo Fisher Scientific, Waltham, MA, USA) according to approved Method 44-19 (AACC, 2000). Readings were taken on three replicate samples and averaged.

2.6. Pasting profiles

The method used to determine the pasting profile was AACC (Approved Method 61-02; AACC, 2000) with modification proposed by Ménera-López et al. (2013) using a rheometer (Anton Paar model MCR-101, Graz, Austria) and an accessory for starch viscosity C-ETD 160 S/T with peltier heating. Aliquots of 3 g were taken from each sample and distilled water was added in such an amount to keep a constant total mass of 21 g. The rotating paddles (160 rpm) were held at 50 °C for 2 min to stabilize the temperature and ensure uniform dispersion, then heated to 92 °C at a rate of 5.6 °C/min and held constant at that temperature for 5 min. The samples were then cooled to 50 °C at 5.6 °C/min. The relative viscosity was measured in cP. Each treatment was performed in duplicate.

2.7. Scanning electron microscopy (SEM)

The changes in the morphology of the starch at different steeping times in water and alkaline solution, were studied with an environmental scanning electron microscope (ESEM; Philips model XL30) with a beam of 20 kV (50 μA) and BSE (Back scatter electron) detector was used. Corn grit pieces of approximately 4 mm thickness were selected and mounted on aluminum holders for observation. The images were taken at 1000×, 0.9 torr, with a spot size of 4.6, to observe the packed cell and starch granule size in the maize endosperm matrix.

2.8. Experimental design and data analysis

The experimental design used was a full factorial with two factors: steeping time (0.16, 0.5, 2, 3, 4, 5, 6, 7, 8, 9, 10 h) and $Ca(OH)_2$ concentration (0, 1, 2 g $Ca(OH)_2$/100 g corn dry basis). The data corresponding to relative viscosity profile, moisture, and pH were analyzed using MINITAB (2010) version 16.1.0 (State College, PA). Tukey's test ($p < 0.05$) was used for comparisons.

3. Results and discussion

3.1. Moisture gain and pH changes in corn grits steeped at room temperature in water with and without the addition of $Ca(OH)_2$

Fig. 1 shows the moisture gain behavior of corn steeped in water with and without the addition of $Ca(OH)_2$, relative to