FOOD AND BIOPRODUCTS PROCESSING 100 (2016) 477–486

Contents lists available at ScienceDirect

Food and Bioproducts Processing

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

The mass transport phenomenon through pericarp during the nixtamalization process

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ARTICLE INFO

Article history:
Received 27 May 2015
Received in revised form 8 August 2016
Accepted 27 September 2016
Available online 4 October 2016

Keywords:
Diffusion
Calcium
Mass transfer
Nixtamalization
Pericarp
Photoacoustic cell

ABSTRACT

The aim of this study was to correlate the apparent diffusion coefficients with the morphological changes that take place in pericarp through the evaluation of cooking stage of corn grains, in order to set the process conditions, where the diffusion rate is faster to reduce time in nixtamalization process.

In order to set the process conditions where the diffusion rate is greater to reduce the nixtamalización process time. The diffusion of calcium was studied at three temperatures (70, 80 and 90 °C). The cooking of the corn was conducted in a differential photoacoustic cell (DPC). Additionally, diffusion process was simulated in a modulated temperature differential scanning calorimeter (MDSC). After cooking, the residual calcium content in the pericarp was determined by atomic absorption spectroscopy (AAS). These data were used to solve the mathematical modeling. The diffusion model employed was developed using Fick's law in order to explain the transport of mass into the corn. The diffusion phenomenon was related to the morphological changes experienced by pericarp using the low-vacuum scanning electron microscopy technique (LV-SEM). The final apparent diffusion coefficients were 0.9265, 1.2101 and 1.4533 $m^2/s \times 10^{-8}$ at 70, 80 and 90 °C respectively; then, the best process conditions recommended for cooking stage of QPM corn grains are 90 °C during 50 min.

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http://dx.doi.org/10.1016/j.fbp.2016.09.008

1. Introduction

Nixtamalization consists in subjecting corn to an alkaline; it comprises two stages. The first stage involves cooking the corn and the second stage consists in letting the corn rest in the cooking liquid. Both stages involve a combination of transport phenomena: transference of heat, momentum and mass (Gutiérrez-Cortez et al., 2010). The nixtamalization process serves to make dough for tortillas, which are a staple in the diet of the Mexican population (Cornejo-Villegas et al., 2010). Fernández-Muñoz et al. (2004) reported that during the nixtamalization of corn, calcium diffusion is higher in the pericarp with short steeping times, while with rest times longer than five hours. Calcium diffusion occurs simultaneously in the endosperm and the germ, which are the most internal structures of corn. Welti-Chanes et al. (2005) reported that the transport of momentum, heat and mass are the main phenomena governing unit operations in the transformation processes of food engineering. The analysis of mass transfer processes is a challenge for the field of food processing, and it is useful for the design of new equipment and processes. Generally, transfer models can be applied to add efficiency to operational processes such as corn nixtamalization. Laria et al. (2007) determined that the physicochemical and structural changes that occur in the pericarp of corn kernels are a function of temperature. These changes are reflected in the nutritional properties of nixtamalized products (Rojas-Molina et al., 2007, 2008, and 2009). Gutiérrez et al. (2007) reported that the pericarp must be partially removed to allow the entry of calcium into the internal structures of the kernel. Rodríguez et al. (2007) used a differential photoacoustic cell (DPC) to demonstrate that the pericarp fixes the greatest quantity of calcium during the cooking stage of the nixtamalization process of corn. Gutiérrez-Cortez et al. (2010) studied the morphological and microstructural changes in the pericarp of nixtamalized corn and concluded that this structure governs the diffusion of water and calcium into the corn. In the nixtamalization process, the main mechanism of mass transport is calcium diffusion, which takes place mainly through the pericarp into the corn (Valderrama-Bravo et al., 2010). Fernández-Muñoz et al. (2011) developed a mathematical model of the kinetics of diffusion of the alkaline solution during the nixtamalization process at different temperatures and calcium concentrations using whole grains. In addition, these authors observed that the moisture content and the calcium concentration in the corn increased with the cooking temperature. Pineda-Gómez et al. (2012) described the diffusion of calcium in the corn endosperm during the nixtamalization process and determined that the influx of calcium into this structure is limited by starch due to the gelatinization phenomenon. Currently, there are no reported studies on mass transport (calcium) through the pericarp of the corn, a mechanism of great interest due to the importance of this structure in determining the cooking time in the nixtamalization process (Gutiérrez et al., 2007). This point is important because of the diversity of corn grains and the need thereby to determine a cooking time for each of the corn varieties through quantitative methods that provide data in situ. On the other hand, in the last decades there has been an increasing interest in studying the physicochemical changes of organic materials such as biopolymers in food systems; specifically, studies on the kinetics of transformation processes. The apparent diffusion coefficients during nixtamalization process provide the calcium transfer rate through the pericarp. This fact allows identifying process conditions where a greater amount of calcium is set in the pericarp in less time, due to this structure governs calcium diffusion into the corn grains.

For these reasons, the purpose of this study was to obtain a mathematical model of the cooking stage of nixtamalization that describes mass transport (calcium) in the pericarp of corn at three temperatures (70, 80 and 90 °C) corresponding to different temperature conditions used in Latin America, and that allows us to identify the optimal conditions of the cooking stage of the nixtamalization process, those which provide the highest residual calcium content in the grain, which implies a higher contribution of calcium in the finished products. The modeling of the diffusion of calcium was done assuming a Fickian behavior, considering the variation in the concentration of calcium in the pericarp of corn with respect to the time of the cooking stage. We also used unconventional methodologies. This allowed us to make evident the physicochemical changes that take place in the pericarp during the cooking of corn and correlate them with the diffusion of calcium into corn.

2. Materials and methods

2.1. *Dimensions of the kernels of Quality Protein Maize*

Quality Protein Maize (H-368C) is a white dent corn hybrid; it was provided by the National Institute of Agricultural and Livestock Research (INIFAP) and by the Research Center for the Improvement of Corn and Wheat (CIMMYT). Crop management was done according to INIFAP recommendations. The ears were hand harvested in March 2013 and the grain was stored at 4 °C until use. The dimensions of the corn (length, width and thickness) were measured with a digital vernier (Steren, Mul-100) for seeds (Moreno, 1984; Serna-Saldívar et al., 1992). These measurements were used to determine the initial conditions for the mathematical model.

2.2. *Thickness and morphology of the pericarp samples*

Pericarp thickness was measured in 25 different regions using 10 samples. Each sample was rotated to move the focus position of the microscope. Further, surface views of isolated pericarps were taken to obtain the micrographs. The morphology of the native pericarp and the thickness of each sample were analyzed using a LV-SEM, JSM 5600LV, with a resolution of 5 nm in low vacuum and fitted with an energy dispersive X-ray spectrometer (Noran instrument, Voyager 4.2.3). Prior to the analysis, the corn samples were mounted on an aluminum specimen holder with carbon tape. The analysis was performed using an electron acceleration voltage of 20 kV and a pressure of 12–20 Pa in the specimen chamber, obtaining images of the fracture surfaces with the backscattering electron signal. The thickness of pericarp is a determining factor to set up the depth of laser beam in photoacoustic tests.

2.3. *Cooking stage of samples with a differential photoacoustic cell (DPC)*

The cooking stage of the corn was carried out according to the methodology described by Gutiérrez-Cortez et al. (2010), with modifications. In the lower chamber of the photoacoustic cell, we placed 40 g of corn, 80 mL of water and 0.4 g of $Ca(OH)_2$ to flood the corn, including the corn in the upper chamber. The cell was installed on the differential photoacoustic system. The mirrors were aligned to direct the light beam to the photoacoustic cell. At the start of the experimental run, the cooking chamber was heated by a temperature controller Watlow-96i/116D/N. The temperatures were monitored by two thermocouples (Type 6302986). The excitation source was a 532 nm laser (Coherent Compass 415 M) was brought to focus on the two upper plates of the quartz windows. The laser radiation was modulated from 5 Hz to 5 kHz by an opto-acoustic modulator (ISOMET 232A-2).

In this test, corn grains were used with the purpose to notice changes in the pericarp, due to the depth of the laser beam that was set up to penetrate pericarp exclusively. The signals obtained were amplified in a lock-in amplifier (OPAM-TL084) connected to an SRS 830 interface (Rodríguez et al., 2007). The cell was isolated with a thermal jacket to prevent