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Steeping time and cooking temperature dependence of calcium ion diffusion during microwave nixtamalization of corn

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Abstract

We report the calcium ion diffusion through the different parts of the maize kernel during microwave nixtamalization, as a function of steeping time, and for two cooked processes, one for 100 min at 72 °C and the other for 45 min at 92 °C. In each case, we carried out several nixtamalization processes, with different steeped time, from 0 to 24 h. By means of atomic absorption spectroscopy we measured calcium content in pericarp, germ and endosperm obtained from maize kernel after each nixtamalization process. We obtained a notable difference of calcium content in those different parts of the maize kernel, being a bigger quantity in the pericarp and smaller in the endosperm. Calcium ion diffusion in the pericarp and endosperm show a no linear dependence with the steeping time and a notable increasing with the cooked temperature. This behavior, for higher temperatures, is due to faster pericarp degradation. In the other hand, calcium ion diffusion in the germ shows an irregular linear dependence with the steeping time, as well as, an increase of calcium ion diffusion with the cooked temperature for steeping time smaller than 12 h and a decrease of calcium diffusion with the cooked temperature for steeping time bigger than 12 h. This last, is due to the lost of part of the germ surface, which is rich in calcium content, during the rinsed process, which it has a bigger damage for highest cooked temperature.

Keywords: Corn tortillas; Calcium diffusion; Microwave; Nixtamalized

1. Introduction

During the traditional nixtamalization process, corn kernels are cooked in an aqueous solution of hydroxide calcium, allowed to steep for 1 to 24 h and then washed two or three times to remove the remains of organic components (pericarp, germ, and endosperm fractions) and excess calcium. After nixtamalization, the wet maize kernels are stone milled to produce masa or, alternatively, they are hammer milled and dried to obtain instant flour (Fernández-Muñoz et al., 2002; Serna Saldivar, Gomez, Almeida Domínguez, Islas Rubio, & Rooney, 1993). In the period of steeping and cooking time exists calcium diffusion inside of the maize kernels that determined the physicochemical and sensory characteristics of the instant corn flours. The steeping time causes partial starch gelatinization, limited granule swelling and disruption of the crystalline structure. For the period of steeping added ordered starch structures are formed due crystallization or annealing.

Maize tortilla has been a basic food for the Mexican population for centuries, and recently tortilla consumption has also been adopted in USA, mainly in areas with an important contingent of Mexican immigrants. In Mexico, the average daily consumption of this product is 325 g per person (Paredes-López &

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Saharopulos-Paredes, 1983). The tortilla market is now important for a growing number of families in Mexico and in USA, where tortilla consumption has grown with the increase in scientific knowledge and technology for the industry of this nixtamalized product.

Nixtamalization is a traditional Mexican process, which consists of two successive steps. First, maize kernels are cooked in an alkaline aqueous suspension of calcium hydroxide and, second, the cooked maize remains steeped in the same solution for several hours after cooking. In the traditional process, the kernels are then rinsed to remove excess calcium hydroxide.

Market acceptability of nixtamalized corn products is directly related to the cooking and steeping stages of their preparation. The amount of calcium incorporated into each one of the different components of the maize kernels affects the final properties of the product (Fernández-Muñoz et al., 2004; San Martín-Martínez, Jaime-Fonseca, Martínez-Bustos, & Martínez-Montes, 2003).

Rodríguez et al. (1995, 1996) have shown that variations in calcium content affect some physical, thermal, rheological, structural, and optical properties of corn tortillas. They have also shown non-linear variations in calcium content for instant flours as steeping time increases. The entry of calcium ion into the maize kernels has been visualized with the aid of a calcium radioisotope, showing a significant intake after several hours of steeping time (Zazueta et al., 2002).

Fernández-Muñoz et al. (2004) have also shown that, for traditional nixtamalization, calcium ion diffusion depends on the integrity and particular characteristics of each of the main parts of the maize kernels.

Traditionally, electrical or butane heaters are used for the cooking stage. In remote areas burning wood is still a common practice. Microwave ovens have also been used for corn nixtamalization, as in the work of Martínez-Bustos, García, Chang, Sánchez-Sinencio, and Figueroa (2000), who conclude that nixtamal obtained by microwave cooking has characteristics similar to those obtained with other heating methods.

In this work we report a study on calcium diffusion into the different parts of corn grains cooked at two different temperatures in a domestic microwave oven. Variations in steeping time are reflected in the calcium content of pericarp, germ, and endosperm.

2. Experimental

2.1. Sample preparation

The maize variety used was a white dent corn available from the local market in the city of Querétaro. The water/maize input ratio was 2:1 (v/w). The calcium content of the suspension was 20 g of calcium hydroxide per kg of maize. Cooking temperatures were 72 and 92 °C, for cooking times of 100 and 45 min, respectively. Steeping times of 0, 2, 5, 7, 8, 9, 12, 15, 19, and 24 h were used.

For each temperature, 1 kg of corn was nixtamalized. The maize was cooked in a microwave-resistant plastic container with 20 g of calcium hydroxide suspended in 2 l of water. The cooking stage was carried out in a domestic commercial microwave oven (Daewoo, 1000 W maximum power), with an average cooking power of 30% during 100 min for the samples cooked at around 72 °C. For samples cooked at around 92 °C, the cooking time was 45 min, with an average microwave power of 70%. Figs. 1 and 2 show the time profile of microwave power used and the sample temperature during the cooking stage, for cooking temperatures around 72 and 92 °C, respectively.

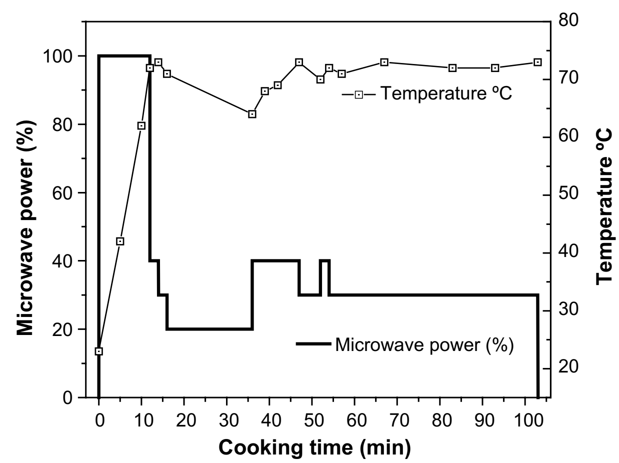

Fig. 1. Time profile of the sample temperature and microwave oven power used for the alkaline cooking stage of corn nixtamalization at 72 °C.

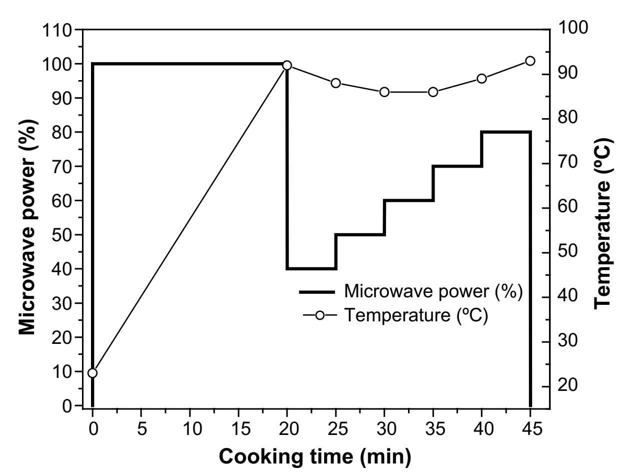

Fig. 2. Time profile of the sample temperature and microwave oven power used for the alkaline cooking stage of corn nixtamalization at 92 °C.

After cooking, samples were taken from the container at preselected steep times to measure the calcium content in the different parts of the kernels. Each sample was twice rinsed in water, before proceeding to the separation of pericarp, germ, and endosperm, which was carried out manually, kernel by kernel. Finally, all samples were dried in an air oven at 45 °C after which the calcium content was assayed.

2.2. Atomic absorption spectroscopy

The calcium content of the main parts (pericarp, germ, and endosperm) of the nixtamalized maize kernels was obtained by mineralizing the sample using the dry-ashing method 968.08 (AOAC, 1998), followed by calcium ion determination with a double-beam atomic absorption spectrometer (Analyst 300, Perkin Elmer), equipped with a deuterium lamp, background corrector, and a hollow cathode lamp, operated with 12 psi of dry air, 70 psi acetylene, 422.7-nm flame, 10-mA lamp current, and 0.7-mm slit width.

3. Results and discussion

Variations in the calcium content of the endosperm as the steeping time is increased are shown in Fig. 3 for samples cooked at around 72 and 92 °C. Each data point corresponds to the average of three measurements. It can be seen that calcium diffusion into the endosperm of the kernels is a non-linear process, whose progress in detail depends on the cooking temperature, as previously suggested by Fernández-Muñoz et al. (2004).

Samples cooked at 92 °C show a high degree of diffusion into the endosperm, reaching a maximum of 0.186% of calcium content at 5 h of steeping time. In contrast, the samples cooked at 72 °C show a much lower maximum: 0.119% for a steeping time of 7 h. These results demonstrate the importance of the cooking temperature for calcium ion incorporation in nixtamalized corn.

In general, the trends shown by the curves in Figs. 3–5 are in agreement with results formerly reported by Gomez, McDonough, Rooney, and Waniska (1989) and Fernández-Muñoz et al. (2004) for calcium diffusion in the different components of nixtamalized maize kernels. A more severe degradation of the pericarp due to higher cooking temperature and greater concentration of $Ca(OH)_2$ allows a more extensive calcium diffusion into pericarp and endosperm (Fernández-Muñoz et al., 2002, 2004; Morad, Iskander, Rooney, & Earp, 1986; Zazueta et al., 2002). This effect is confirmed in Fig. 4 for short steeping times (<7 h), where samples cooked at 92 °C have higher calcium concentration in pericarp and endosperm.

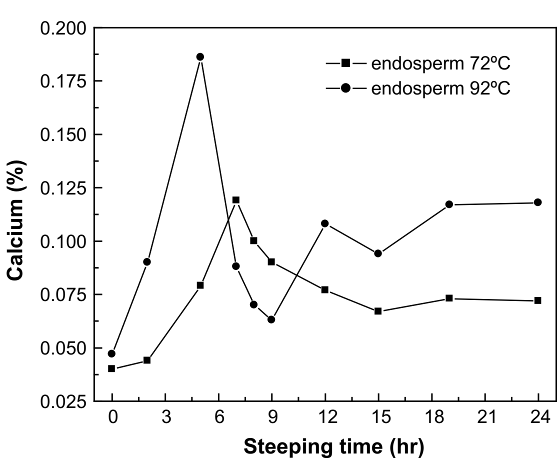

Fig. 3. Calcium content in the endosperm of maize kernels, microwave-nixtamalized at 72 and 92 °C, as a function of steeping time.

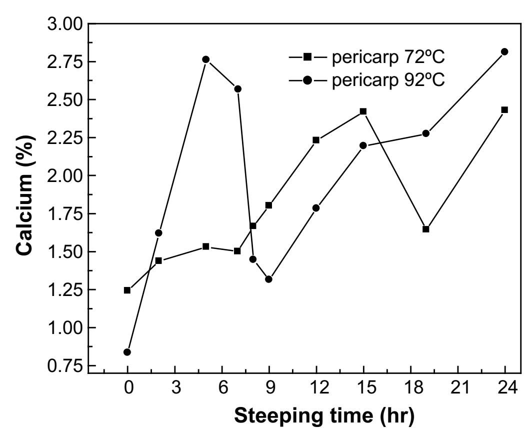

Fig. 4. Calcium content in the pericarp of corn, microwave-nixtamalized at 72 and 92 °C, as a function of the steeping time.

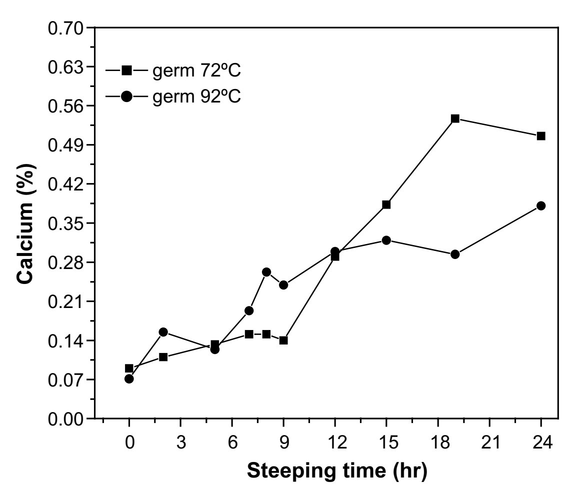

Fig. 5. Calcium content in the germ of corn, microwave-nixtamalized at 72 and 92 °C, as a function of steeping time.

The drop in calcium content observed for intermediate steeping times in the endosperm (>7 h for 72 °C and >5 h for 92 °C) for both cooking temperatures tested, corresponds to the matter lost during the washing process. Calcium-rich zones in external areas of the endosperm (Fernández-Muñoz et al., 2002, 2004; Zazueta et al., 2002) are removed in the rinsing stage. An important difference between samples cooked at 92 °C and those cooked at 72 °C can be seen after 5 h of steeping time, where for the first case the calcium content drops to a minimum value, to later reassume an upward trend, while for the second case, the calcium content remains low for long steeping times (for >7 h). Disregarding the effect of the rinsing stage, it is clear that calcium diffusion continues into the inner regions of the maize kernels in samples cooked at 92 °C, while for samples cooked at 72 °C the calcium diffusion into the endosperm is halted.

Fig. 4 shows the calcium diffusion into the pericarp for kernels cooked at 72 and 92 °C as a function of steeping time. Calcium diffusion through the pericarp is greater because it is the first component of the kernel to come into direct contact with the alkaline suspension. Depending on the cooking temperature, the pericarp undergoes hydrolysis, losing components such as the hemicelluloses and other carbohydrates contained in the pericarp to leach out into the cooking solution, which can temporarily lead to marked decreases in the calcium content of the pericarp. Such temporary minima can be observed at 19.0 h of steeping time for the experiments using a cooking temperature of 72 °C, and at 9 h of steeping for the case of 92 °C cooking temperatures (Fig. 4). We can also observe that pericarp cooked at 72 °C allows the incorporation of more calcium without significant degradation at long steeping times, while pericarp cooked at 92 °C is degraded faster (after about 7 h), resulting in a lower ability to incorporate calcium at longer steeping times. A comparison of the results of Fig. 3 with those of Fig. 4 shows that the permeability of the pericarp to calcium ions, which is strongly determined by the cooking temperature, has a similar influence on the calcium content in the pericarp and in the endosperm. As a consequence of the physicochemical changes in the pericarp during the cooking stage, calcium diffusion into germ and endosperm is altered (González, Reguera, Mendoza, Figueroa, & Sánchez-Sinencio, 2004; Martínez-Bustos et al., 2001).

Fig. 5 shows the calcium content of the germ of microwave-nixtamalized corn, as a function of steeping time. The results obtained for corn cooked at around 72 °C agree with the observations of Fernández-Muñoz et al. (2004), showing that after pericarp degradation calcium diffusion into the germ increases. Due to the high content of lipids and proteins in the germ, calcium hydroxide can diffuse inside of this structure (Fig. 5), saponifying the triglycerides, thus liberating the fatty acids. This reaction proceeds throughout the steeping process, leading to a gradual increase in calcium content in the germ. Also, the alkaline character of the solution and the high temperature favor denaturation of the proteins, leading to increased binding of calcium ions to the newly exposed groups in the proteins. These processes explain the steady increase of calcium content in the germ during steeping.

Comparing the time course of calcium diffusion into germ and endosperm for corn cooked at 72 °C, we note the similar behavior shown by both curves over the entire steeping time interval, reinforcing the idea of calcium entrance via the tip cap for short steeping times (0–7 h), and via the pericarp thereafter. For steeping times longer than 12 h, the incorporation of calcium ions into the germ is higher for the sample cooked at around 72 °C than for the corn cooked at around 92 °C. This result is due to the lost of part of the germ surface during the rinsed process, which it has a bigger damage for highest cooked temperature.

4. Conclusions

(a) This results show that calcium diffusion into germ, endosperm, and pericarp during microwave nixtamalization of corn is a non-linear process strongly influenced by the cooking temperature and steeping time.
(b) Samples cooked around 92 °C show stronger calcium diffusion into the endosperm, due to higher degradation of the pericarp, in comparison to samples cooked around 72 °C, for which the pericarp acts as a barrier to the penetration of calcium ions into the inner parts of the maize kernels.
(c) Microwave cooking changes the physicochemical characteristics of the pericarp, affecting the calcium diffusion process through it and into the rest of the maize kernel.

Acknowledgments

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