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Ultrasound technology enhances the hydration of corn kernels without affecting their starch properties

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ABSTRACT

This work studied the effects of ultrasound treatment on the process of hydration of corn kernels, evaluating both the water uptake and its starch properties. For that, an ultrasound bath at a frequency of 25 kHz and volumetric power of 41 W/L was used. Furthermore, different treatments were applied in order to determine the mechanisms of enhancement of the hydration process (direct or indirect effects), by studying the hydration kinetics and the microstructure of the kernels. Finally, the rheological, thermal and structural properties of the starch extracted from the corn kernels (hydrated with and without ultrasound) were evaluated. Due to the particular behavior of the corn kernels during hydration, a two terms semi-empirical equation was proposed to explain the process, which contains two simultaneous ways related to the different mechanisms of water influx. Ultrasound significantly improved the hydration process, increasing water uptake and decreasing the process time by ~35%. In contrast to other grains, it was demonstrated that the enhancement of the process was only due to the direct effects (inertial flow and sponge effect) and not the indirect effects (micro-channels formation). Finally, it was demonstrated that the ultrasound treatment did not alter the properties of the starch. As a conclusion, it was shown that the corn kernels can be quickly hydrated using ultrasound treatment without modifying any of the properties of the starch, this being highly desirable for the starch industry.

1. Introduction

Corn is one of the most important crops in the world, being widely used in the food, chemical, pharmaceutical and agricultural industries, due to its high starch content. Cornstarch, native, modified or cleaved, is used in food preparation, drug production, paper making, the textile industry, petroleum refining, among others uses (Bertolini, 2010). Moreover, it is used as a substrate for ethanol production. The first unit operation during the corn processing is the hydration of the corn kernels, which is carried out by immersion in water, as it is necessary for wet milling of the grain. The hydration of corn kernels is a lengthy batch process that may take up to 36 h (Singh and Eckhoff, 1996). Therefore, optimization of the hydration process is very desirable for the starch industry. The ultrasound technology seems to be a promising option to improve the hydration process.

Ultrasound technology has been widely studied as an alternative for improving food processing, in such operations as on defoaming, freezing, extraction, emulsification, hydration, drying (Awad et al., 2012) and germination (Miano et al., 2015a). The application of ultrasound showed good results in the hydration process of chickpeas (Yildirim et al., 2013), navy beans (Ghafoor et al., 2014), sorghum grains (Patero and Augusto, 2015) and common beans (Ulloa et al., 2015), reducing the process time and increasing the equilibrium moisture. However, the hydration process of a grain with high economic importance, such as corn, has yet to be studied, likewise the impact of this process on the starch properties. It should be a very important evaluation from an industrial point of view.

Furthermore, from a scientific point of view, much more than proving the effect of the ultrasound treatment, it should be important to identify the mechanisms that allow improvements in the process. As described by Miano et al. (2016), most of the published works only mention all the possible effects of the ultrasound

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treatment on the mass transfer processes, although each specific process and condition has its own mechanisms (direct and indirect effects). This then highlights the importance of evaluating the precise mechanisms that take place during corn hydration.

Finally, it is highly desirable to enhance the hydration process of grain without impairing its quality, especially its starch properties. In consequence, this work studied and described the effect of ultrasound treatment on the hydration process of corn kernels, verifying the possible effects on the starch properties by comparing the pasting properties, thermal properties and microstructure.

2. Materials and methods

2.1. Raw material and hydration process

During the experiments, an ultrasonic bath with a frequency of 25 kHz and a volumetric power of 41 W/L (Q13/25, Ultronique Brazil; determined following the method described by Tiwari et al. (2008)) was used. This bath has its piezoelectric elements arranged below the tub. It generates mechanical waves that are transmitted through the water to the product. The ultrasonic waves distribution in the water bath was determined by the method of the aluminum foil (Mason, 1991; Vinatoru, 2015). Further, the other good practices described by Mason (1991) and Vinatoru (2015) were also verified. Thus, the samples were placed in the parts where the waves had the highest and more homogeneous intensity.

Corn kernels (*Zea mays* var. amylacea; 12.68 ± 0.82 mm length, 8.45 ± 0.46 mm width and 4.27 ± 0.46 mm thick; kindly provided by Ingredion Brazil) with a moisture content of 12.55 ± 0.55% d.b. (g water/100 g of dry matter) were used. For the hydration process, 15 g of pre-selected (only intact grains were used) kernels were soaked in 4 L of distilled water at 25 °C with and without using ultrasound. During the hydration process, the samples were periodically drained, superficially dried and their moisture content was obtained by mass balance. The sampling was carried out every 20 min for the first hour and every 30 min from then on, until constant mass was reached. The hydration process was performed at constant temperature and in triplicate.

2.2. Hydration mechanisms and effect of the ultrasound treatment

Ultrasound enhances the mass transfer due to two possible mechanisms: direct and indirect effects produced by the alternate expansion and rarefaction of the sound wave. Therefore, experiments were carried out in order to evaluate the mechanisms that take place during the hydration of corn kernels with the ultrasound treatment.

To verify whether the micro-channels were formed during the process (the so-called indirect effects), the kernels were pretreated with ultrasound, then hydrated conventionally. One layer of corn kernels was vacuum packed in order to treat the kernels with ultrasound without hydration. This pack was placed at the bottom of the water bath to receive the ultrasound waves better. After 180 min and 300 min of pretreatment (the conditions were determined after pretests and taking into account the amount of time to hydrate the grains), the kernels were unpacked and conventionally hydrated without ultrasound application at 25 °C. Corn kernels with a high moisture content (40 g water/100 g d.b; water activity of 0.988 ± 0.005) were also evaluated, since Miano et al. (2016) demonstrated that grain with higher moisture content (higher water activity) may be necessary for cavitation to take place. To obtain grains with the higher moisture content, the corn kernels were previously hydrated for 360 min and stored for one week at 5 °C in order ensure that the moisture in the tissue was uniformly distributed.

To verify if the direct effects ("sponge effect" and inertial flow) took place during the process, the kernels were hydrated with different treatments with or without the ultrasound treatment. The first treatment (US + N) consisted of hydrating the kernels using ultrasound for the three hours, then hydrating them without ultrasound. The second treatment (N + US + N) consisted of hydrating the kernels without ultrasound for the first three hours. Over next three hours, they were hydrated with ultrasound, and finally they were hydrated without ultrasound (the conditions were determined after pretests and taking into account the time magnitudes to hydrate the grains). In addition, as described by Ramos et al. (2004), a varnish (nail polish; Risqué – Cosmed Industry Brazil) was used as a sealant to cover the pericarp or the tip cap in order to determine the effect of ultrasound on the hydration rate of these structures.

Finally, the microstructure of the corn kernels was analyzed by SEM analysis and X-ray diffraction. For SEM, the samples were cut in order to see the different tissues (pericarp, endosperm and tip cap) and dehydrated using silica gel for 3 days. Then, they were sputtered with a 30 nm gold layer. Finally, the samples were observed in a scanning electronic microscope operating at an acceleration voltage of 15 kV (LEO 435 VP, Leo Electron Microscopy Ltd., Cambridge, England). SEM analysis was performed for corn kernels hydrated with and without ultrasound. For the X-ray analysis, the kernels were X-rayed using a model MX-20 DC-12 digital Faxitron X-ray, exposing them to the radiation at 20 kV for 10 s. The grains were subjected to X-ray at different positions in order to evaluate their internal structure.

2.3. Modeling of the hydration process

The corn kernels hydration kinetics were fitted using different equations, which describe a downward concave shape (DCS) behavior: the Peleg equation (Peleg, 1988), the Page equation (Page, 1949), the First order kinetics equation (Lewis, 1921), the Ibarz-González-Barbosa-Cánovas equation (Ibarz et al., 2004) and the equation proposed in this work (Table 1). The proposed model is an equation with two terms, similarly to that used to explain the drying process (Verma et al., 1985).

For that, the kernels moisture content at dry basis (M; g water/100 g of dry matter) versus time (min) of the hydration process was evaluated for each initial moisture. The data were fitted to the equations with a confidence level of 95% using the Levenberg-Marquardt algorithm in Statistica 12.0 (StatSoft, USA) software. The goodness of the fit of the models was evaluated by the coefficient of determination (R^2) of the regression value, the root-mean-square deviation values (RMSD, Eq. (1)), and the normalized RMSD (NRMSD, Eq. (2)).

$$RMSD = \sqrt{\frac{\sum_{i=1}^{n}\left(M_{experimental} - M_{model}\right)^2}{n}} \quad (1)$$

$$NRMSD = 100\cdot\frac{RMSD}{\left(M_{experimental}\right)_{maximun} - \left(M_{experimental}\right)_{minimun}} \quad (2)$$

2.4. Starch properties

The starch from the corn kernels (hydrated with and without ultrasound) was extracted as follow (Ji et al., 2004): The kernels were soaked in a sodium methabisulfite solution (0.1% w/v) for