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Roxana Yglesias

University of Nebraska-Lincoln

Anne M. Parkhurst

University of Nebraska-Lincoln, aparkhurst@unl.edu

David S. Jackson

University of Nebraska-Lincoln, djackson1@unl.edu

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Development of Laboratory Techniques to Mimic Industrial-Scale Nixtamalization¹

Roxana Yglesias,² Anne M. Parkhurst,³ and David S. Jackson^{2,4}

ABSTRACT

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A laboratory nixtamalization process was developed to imitate larger scale cooking/steeping conditions. Corn (45 kg) was cooked in a pilot plant gas-fired cook/steep tank and temperature was monitored every 30 sec. Cooling and heating rates were mimicked in the laboratory using a digital temperature programmable hot plate that adjusted grain-water-lime temperature changes at a specified rate. A Response Surface Central Composite Design was used to model pasting and thermal properties of nixtamal and masa as a function of cooking temperature (86–96°C), cooking time (20–40 min), and steeping time (3–11.77 hr). Nixtamal and

masa moisture, dry matter loss, nixtamal and masa RVA peak temperature, shear thinning, nixtamal peak viscosity, masa final viscosity, nixtamal and masa DSC enthalpy peak and end temperatures, and nixtamal onset temperature were explained by the same regression terms for results obtained using both processes conditions. The intercept and slopes of the fitted models for the pilot plant and laboratory responses were not significantly different ($P < 0.05$). The laboratory method can be used to mimic larger scale processing over a wide range of nixtamalization conditions.

Nixtamalization is an ancient alkali-cooking process developed by the Aztecs that is still used in the production of tortillas and related food products. Whole-kernel corn is cooked in large tanks with water and lime, followed by a steeping period. Establishing the optimum conditions for an acceptable masa consistency is still considered an art based on experience and scientific insight. Processors incur high costs if their assessment of process conditions for a given corn lot are inaccurate, resulting in loss of substantial amounts of cooked corn and generation of excess waste stream solids. Because corn characteristics and starch properties are important contributors to quality, there is a need for processors, suppliers, and corn breeders to evaluate these attributes using a small-scale method that would allow them to test minor processing changes and different hybrids without the need for capital investments in pilot plant equipment or to tie up production facilities.

During nixtamalization, starch undergoes functional and structural changes that depend not only on corn characteristics but also on processing conditions. Analytical methods that evaluate pasting and thermal properties have been used to investigate changes in starch during nixtamalization (Robles et al 1988; Gomez et al 1991; Almeida-Dominguez et al 1997). Sahai and coworkers (1999) concluded that RVA and DSC are valuable techniques for assessing degree of cook as well as evaluating impact of process conditions on nixtamalized products.

The objective of this study was to develop a laboratory technique that would imitate a wide range of industrial scale cooking/steeping conditions so that the laboratory process can be used to evaluate small amounts of grain and test the impact of altering process conditions.

Nixtamal and masa produced using the laboratory technique were compared with the same materials produced in a near-commercial-size pilot plant.

MATERIALS AND METHODS

Samples

Bags (22.5 kg) of yellow corn (Pioneer 34K77-2002 crop year; O'Malley, Fremont, NE) were stored in a freezer (−18°C) and equilibrated to room temperature before nixtamalization and

analysis. Samples (≈200 g) from each bag were collected to form a composite sample used for grain characterization. In addition, samples (≈100 g) were collected from each of the two bags used for every nixtamalization trial, combined, and ground using a cyclone sample mill (model 3010-030, Udy Corp., Fort Collins, CO) for moisture, RVA, and DSC measurements. Samples of nixtamal and masa were also collected, frozen with liquid nitrogen, freeze-dried using an 8L benchtop freeze-drier (The VirTis Co., Gardiner, New York, NY) and ground using a sample mill as described above for further analysis.

Corn Characterization

A tangential abrasive dehulling device (TADD) was used to evaluate corn hardness (model 4E-220, Venables Machine Works, Saskatoon, SK, Canada). TADD losses were calculated as a percent of loose material after abrading 40 g of raw corn for 10 min while suctioning off abraded material (Reichert et al 1986).

Corn was also evaluated using the Stenvert hardness test. Maize (20 g) was ground using a micro-hammermill fitted with a 2-mm mesh screen at 360 rpm (model V, Glen Mills, Maywood, NJ). The height of soft endosperm and total ground material collected, time to grind, lowest rpm at maximum grinding power, and weight of material recovered over a 425-μm sieve was measured as described by Pomeranz et al (1986).

Apparent corn density was determined by the floaters test; the percentage of buoyant kernels immersed in a 31.3° Baume solution of sodium nitrate maintained at 60°C, corresponding to a specific gravity of 1.275, was calculated as described by Peplinski et al (1989). Thousand-kernel weight was calculated by hand-

Fig. 1. Hardness index classes as a function of % moisture and % buoyant kernels. (Data from research concluded by the Quaker Oats Co. in 1952.)

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² Former graduate research assistant and professor, respectively, Department of Food Science and Technology, University of Nebraska, Lincoln, NE 68583-0919.

³ Professor, Department of Statistics, University of Nebraska, Lincoln, NE.

⁴ Corresponding author. Fax: 402-472-1693. E-mail: djackson@unlnotes.unl.edu

counting 100 whole kernels and multiplying their weight by ten. Hardness index class was determined combining the information from the floaters test and the moisture content of the sample as shown in Fig. 1 (Wichser 1961).

Experimental Design

To nixtamalize corn using the wide range of process conditions used commercially, a Response Surface Central Composite Design (CCD) with three quantitative factors (cook temperature, cook time, and steep time) was generated using Design Expert software (v. 6.0.9, Stat-Ease, Minneapolis, MN). Based on preliminary research, a total of 20 trials (6 central + 8 factorial + 6 axial points) were run under both pilot plant and laboratory conditions, as explained in Table I.

Pilot Plant Nixtamalization

A 1:3 corn-to-water weight ratio was used to cook 45 kg of corn. Water (135 kg) was placed in a gas-fired horizontal cook-steep tank (model OCT002-01, Lawrence Equipment, South El Monte, CA) with 450 g of food-grade lime Ca(OH)_2 (Mississippi Lime Co., Alton, IL) and mixed until dispersed. The tank was covered with a lid and the lime solution was heated to 90°C. Next, corn was added to the tank and stirred every 10 min with a wooden

paddle. Due to the addition of raw corn to the already heated water-lime mixture, the temperature of the cooking tank decreased by ≈ 5 –10°C. Heating was continued until the temperature recovered to the temperature specified in the experimental design (Table I). A temperature logger (HiTemp102, ERTCO, West Patterson, NJ) was used to record temperatures every 30 sec. Once the cooking time for each sample was reached, the lid was removed and steeping started. Steeping ended by draining the nejayote (cook-steep liquor). Nixtamal (cooked corn) was rinsed twice using 65L of water per wash and then drained. Masa was obtained by grinding nixtamal with a stone-grinder (stones 30 cm in diameter, model OCG2000-01, Lawrence Equipment, South El Monte, CA). Samples of nixtamal and masa were collected (≈ 300 g) and placed in 600-mL wide-mouth freeze-drying flasks (VirTis) with ≈ 300 mL of liquid nitrogen until completely frozen. Flasks were connected to a 8L benchtop freeze-drier (VirTis) at -50°C for 24 hr. Samples were then ground using a cyclone sample mill with a 1-mm mesh screen (model 3010-030, Udy) for further analysis.

Laboratory Nixtamalization

Clean corn (500 g) was weighed and cooked in a 2,000-mL glass beaker with 1,500 mL of water and 5 g of food-grade lime Ca(OH)_2 (Mississippi Lime). A wire mesh was constructed and fixed into the beaker so that the kernels stayed ≈ 3 cm above the hot plate. A stirring bar was placed in this space, allowing uniform solution mixing and adequate temperature control. Temperatures were monitored by a probe inserted into the solution connected to a digital hot plate/stirrer (model HS30, Torrey Pines Scientific, Solana Beach, CA). To efficiently maintain the programmed cooling rate during the steeping step, eight polystyrene rings were constructed (2 cm thickness, 18 cm external diameter, and 14 cm internal diameter), wrapped with electric tape, and placed around the beaker for insulation. Once cooking was complete, the steeping phase was started and ended by draining the nejayote. Nixtamal was rinsed twice using 700 mL of water per wash, drained, and ground into masa dough with a small-scale stone grinder (stones 17.5 cm in diameter). Samples of nixtamal and masa were collected (≈ 100 g) and placed in 600-mL wide-mouth freeze-drying flasks (VirTis) with ≈ 300 mL of liquid nitrogen until completely frozen. Samples were freeze-dried and ground as described above for further analysis.

Compositional Analysis

Protein (N $\times 6.25$), crude fiber, fat, ash, and total starch of raw corn, freeze-dried nixtamal, and freeze-dried masa were determined by Servi-Tech Laboratories (Dodge City, KS) using methods described in Approved Methods (AACC 2000). Moisture contents of composite samples of raw corn, nixtamal blotted with paper towel, and fresh masa were determined using a two-stage method for samples containing $>13\%$ moisture content, as described by Approved Method 44-15A (AACC 2000). Nejayote pH was measured with a pH meter (model 801, Orion Research, Cambridge, MA). Data was collected in duplicate and averages reported.

Process Waste Analysis

Nixtamal pericarp removal was estimated by staining kernels with May-Greenwald solution as generally described by Serna-Saldivar et al (1991). Effluent dry matter loss (DML) was calculated by determining solids in nejayote and wash water. Total weight of nejayote and wash water was measured; representative samples of nejayote and wash water were collected, dried, and calculated back to represent total losses as described by Sahai et al (2000).

RVA Analysis

Pasting properties of uncooked corn, freeze-dried nixtamal, and freeze-dried masa were determined using a Rapid Viscosity Analyser (RVA-4, Newport Scientific Pty. Ltd., of Warriewood, Australia).

TABLE I
Levels of Factors Used in Response Surface
Central Composite Design for Corn Nixtamalization

Factors	Levels ^a	
	$-\alpha$	α
Cooking temperature ($^\circ\text{C}$)	86.43	96
Cooking time (min)	20	40
Steeping time (hr)	3	11.77

^a Each numeric factor is varied over five levels: $\pm\alpha$ (axial points), ± 1 (factorial points), and center point. Coding the middle levels as 0, then $\alpha = 1.68$ and 1 = distance one unit apart from the coded centers.

TABLE II
Proximate Composition and Physical Characteristics of Yellow Corn
(Pioneer 34K77 Crop Year 2002) Used in Nixtamalization Trials

Constituents ^a	
Whole corn moisture (%)	11.0
Protein (N $\times 6.25$) (%)	8.8
Crude fiber (%)	4.0
Fat (%)	4.0
Ash (%)	1.3
Physical characteristics ^b	
TADD hardness test (%) ^c	57.25 $\pm$ 0.19
Stenvert hardness test (%) ^d	73.35 $\pm$ 4.40
Floaters (%)	49.33 $\pm$ 3.06
Thousand-kernel weight (g)	335.68 $\pm$ 1.34
Hardness index	Hard

^a Results based on a 100% db sample weight.

^b Mean and standard deviation of results collected in triplicate.

^c TADD hardness test data correspond to % of material removed (yield of bran).

^d Stenvert hardness test % corresponds to weight of material recovered over a 425- μm sieve divided by the total weight of the sample; other Stenvert data not shown.

TABLE III
Mean and Standard Deviation of Variables with Nonsignificant Models
Measured Under Pilot Plant and Laboratory Nixtamalization Conditions

Variable	Pilot Plant	Laboratory
Nixtamal pericarp removal (%)	24.33 $\pm$ 6.15	23.99 $\pm$ 5.23
Nejayote pH	11.35 $\pm$ 0.16	10.49 $\pm$ 0.72
Nixtamal total starch (%) ^a	73.6 $\pm$ 1.5	74.8 $\pm$ 1.8
Masa total starch (%) ^a	74.8 $\pm$ 1.1	74.4 $\pm$ 2.0

^a Results based on a 100% db sample weight.

Slurries were prepared by combining the samples and 25 mL of distilled water in an aluminum cup containing a plastic paddle. Sample weight and added water were corrected to a 4 g, 14% moisture basis. Suspensions were equilibrated at 50°C for 2 min, heated to 95°C in 5 min, held at 95°C for 3 min, and finally cooled to 50°C within 5 min (Whalen 1999). The RVA paddle was programmed to turn at 160 rpm, except for the first 30 sec when it was set at 500 rpm to help mix the sample. Data were collected and analyzed using Thermocline software (v. 2.3, Newport Scientific). RVA parameters obtained included peak viscosity (RVU), peak temperature (°C), shear thinning viscosity (RVU), setback viscosity (RVU), final viscosity (RVU), and pasting temperature (°C).

DSC Analysis

Thermal properties of ground raw corn, freeze-dried nixtamal, and freeze-dried masa were investigated using differential scanning calorimetry (Pyris 1, Perkin Elmer Co., Norwalk, CT). Samples (≈ 10 mg) were accurately weighed into stainless steel pans and hydrated with 55 μ L of distilled water to $\approx 80\%$ moisture content. Pans were sealed and stored at room temperature ($23 \pm 2^\circ\text{C}$) for ≈ 12 hr. Endotherms were obtained after heating the aluminum pans from 30 to 110°C at a rate of 5°C/min. Onset temperature (°C), peak temperature (°C), end temperature (°C), and enthalpies (J/g) were calculated by endotherm peak analysis as generally described by Sahai et al (1999).

Statistical Analysis

Central Composite Design Response Surfaces were analyzed with SAS Proc Mixed (v. 8. SAS Institute, Cary, NC). A second-order model including the predictors' linear interaction was fit. Nonsignificant terms ($P > 0.05$) were dropped from the regression equation and a test for lack-of-fit was included to evaluate model adequacy. Bonferroni confidence intervals were built about the parameter estimates whenever a response variable was modeled by the same regression terms under the two experimental situations (pilot plant and laboratory). The α level was adjusted according to the number of parameter estimates in the equation so that a 95% confidence interval was always obtained (Draper and Smith 1998). Overlapping intervals meant that the estimates for those terms were not significantly different. Whenever pilot plant and laboratory environments had different models, a regression was run for the difference of the laboratory minus the pilot plant value (Δ), using the same predictors as those considered in the CCD analysis. The reduced model for the difference and its adequacy were tested following the guidelines described above. Surface plots were built using the Design Expert Software. If the response variable could not be significantly explained by any predictor or there was significant lack-of-fit, the mean response was considered to be the best estimate.

RESULTS AND DISCUSSION

Corn Characterization

The corn used in this study had the chemical-physical characteristics shown in Table II.

Pericarp Removal, pH, and Total Starch

Table III summarizes the results obtained for nixtamal pericarp removal, nejayote pH, and nixtamal and masa total starch. Nixtamalization factors such as cooking temperature (°C), cooking time (min), and steeping time (hr) within the ranges tested did not significantly ($P < 0.05$) affect these parameters. Masa and nixtamal total starch were not critical factors affecting RVA pasting or DSC thermal properties of the samples analyzed. Sahai et al (1999) found similar results and indicated that the extent of starch leaching from the kernels was independent of nixtamalization cooking conditions. Serna-Saldivar (1991) previously concluded that pericarp removal was significantly affected by corn hybrid/cultivar. Sahai

et al (2001) determined that nejayote pH of five different samples of corn, all processed using varying conditions, was more influenced by corn physical characteristics than by alkaline cooking settings. The same corn and water-lime ratios were used for all the nixtamalization trials; thus, changes in pericarp removal and nejayote pH were not expected.

Nixtamalization Time-Temperature Profile

During pilot plant nixtamalization, a data logger was used to measure and record changes in the temperature of the grain-water-lime mixture every 30 sec. This procedure was done with two purposes: 1) to assess how close the temperature-time profile of each trial was to the experimental design, and 2) to provide the data necessary to imitate the pilot plant temperature profile with the laboratory technique. As an example, for the central points of the Response Surface Design (90° cooking temperature for 30 min and 8.5 hr of steeping), four thermal phases were clearly identified: 1) a linear drop in temperature once grain was added to the preheated water-lime solution ($-3.7 \pm 0.5^\circ\text{C}/\text{min}$), a linear increase in the grain-water-lime mixture to recover the cooking temperature ($+0.95 \pm 0.05^\circ\text{C}/\text{min}$), a near-thermal steady-state during cooking ($\pm 3^\circ\text{C}$), and a power temperature decline during steeping ($-0.095 \pm 0.005^\circ\text{C}/\text{min}$). Figure 2 shows the temperature-time profile for a nixtamalization trial corresponding to a central point in the CCD under pilot plant and laboratory nixtamalization conditions.

The laboratory technique was successful in recreating the thermal profile found in the pilot plant nixtamalization process. Most of the response variable equations were modeled by the same regression terms in both pilot plant and laboratory conditions.

Nixtamal and Masa Moisture

Nixtamal and masa moisture are important variables for obtaining optimum texture characteristics in table tortillas and tortilla chips. Some authors recommend specific percentages of nixtamal moisture for certain types of nixtamalized corn products (Gomez et al 1991; Serna-Saldivar et al 1993). Pilot plant and laboratory nixtamal moisture were significantly affected by the linear terms of cooking temperature, cooking time, and steeping time as described by the equation

$$\hat{Y} = \beta_0 + \beta_1 (\text{cooking temperature}) + \beta_2 (\text{cooking time}) + \beta_3 (\text{steeping time}) \quad (1)$$

where β_0 is the intercept and β_1 , β_2 , β_3 are the linear slopes for each of the factors. No significant differences were found when pilot plant and laboratory slopes were compared (data not shown).

Given a steeping time of 8.5 hr, nixtamal moisture increased as temperature and cooking time increased. Cooking temperature had the greatest single effect on nixtamal moisture (Fig. 3).

Fig. 2. Representative temperature-time profile for pilot plant and laboratory nixtamalization treatment (cooking temperature 90°C, cooking time 30 min, and steeping time 8.5 hr) as measured with a temperature logger every 30 sec.

Sahai and coworkers (2001) noted that nixtamal moisture followed a trend dependent on cooking time and temperature, and also on steeping time (among other factors). Suhendro et al (1998) found similar results for sorghum nixtamal.

Masa moisture was also best explained by cooking temperature, cooking time, and steeping time with an equation of the same form as Equation 1 above. Likewise, no difference was found between the pilot plant and laboratory slopes (data not shown). As for nixtamal, cooking temperature had the greatest effect on masa moisture (Fig. 4).

Dry Matter Loss (DML)

The quadratic effect of corn cooking temperature and lime concentration were more critical factors influencing corn solids loss than were cooking or steeping times (Sahai et al 2000). Plufugelder and coworkers (1988), however, reported that it was overnight steeping time that accounted for most of the solids lost during nixtamalization. In the processing ranges used in the present study, the pilot plant and laboratory DML increased (Fig. 5) solely

due to the effect of temperature as described by the equation

$$\hat{Y} = \beta_0 + \beta_1 (\text{cooking temperature}) + \beta_2 (\text{cooking temperature})^2 \quad (2)$$

where β_0 is the intercept, and β_1 and β_2 , are the linear and quadratic slopes for cooking temperature, respectively. No slope differences were observed for pilot plant and laboratory processing. Pilot plant nixtamal and masa moisture, as well as DML, can be properly estimated using the laboratory nixtamalization technique.

RVA Peak Temperature

RVA peak temperature of nixtamal samples was affected by cooking time and temperature. As cooking temperature increased, so did the peak temperature with quadratic behavior (Fig. 6). Likewise, the cooking time effect followed a second-order trend

$$\hat{Y} = \beta_0 + \beta_1 (\text{cooking temperature}) + \beta_2 (\text{cooking time}) + \beta_3 (\text{cooking temperature})^2 + \beta_4 (\text{cooking time})^2 \quad (3)$$

Fig. 3. Pilot plant (A) and laboratory (B) predicted values for nixtamal moisture (%) as a function of cooking time (min) and temperature (°C), holding steeping time constant at 8.5 hr.

Fig. 4. Pilot plant (A) and laboratory (B) predicted values for masa moisture (%) as a function of cooking time (min) and temperature (°C), holding steeping time constant at 8.5 hr.

($P < 0.0001$, P Value LOF = 0.8059, $R^2 = 0.74$)

($P < 0.0001$, P Value LOF = 0.9173, $R^2 = 0.77$)

Fig. 5. Pilot plant (A) and laboratory (B) predicted values for dry matter loss (%) as a function of cooking temperature (°C).

where β_0 is the intercept, and β_1 , β_2 , β_3 , and β_4 are the slopes for each factor. No significant differences were found when pilot plant and laboratory slopes were compared (data not shown).

Masa RVA peak temperature had a similar cooking time dependency but linearly increased with cooking temperature (Fig. 7). This behavior is described in equation

$$\hat{Y} = \beta_0 + \beta_1 (\text{cooking temperature}) + \beta_2 (\text{cooking time}) + \beta_3 (\text{cooking time})^2 \quad (4)$$

where β_0 is the intercept and β_1 , β_2 , and β_3 are the slopes. No significant slope differences were found between pilot plant and laboratory conditions (data not shown).

Sahai et al (1999) were not able to find a significant model for masa peak temperature as a function of the evaluated nixtamalization process parameters. They observed, however, that other RVA factors such as peak viscosity, setback, and final viscosity were affected mostly by steeping time. In our study, steeping time did not appear to be as important as cooking temperature and cooking time except for nixtamal pasting temperature.

RVA responses such as nixtamal and masa pasting temperature, shear thinning, nixtamal peak viscosity, and masa final viscosity had similar slopes when pilot plant and laboratory equations were compared (data not shown).

Whalen (1999) considered RVA data to be indicators of starch transformation. He stated that, in general, changes in degree of cooking would directly affect peak temperature and final viscosity. In our study, these important variables were not significantly different, indicating a similar degree of cooking of starch when pilot plant and laboratory nixtamalization conditions were compared.

Masa peak viscosity, nixtamal final viscosity, and nixtamal and masa setback had different slopes when pilot plant and laboratory conditions were compared. Differences in these variables are perhaps the result of not being able to maintain the target cooking temperature constant throughout the established cooking time, especially under pilot plant conditions. The combination of extreme cooking temperatures (88 and 96°C) with the extreme cooking times (20 and 40 min) resulted in greater temperature variation than the temperature variation during the center point cooking process (90°C and 30 min). Perhaps, in these cases, the experimental error outweighed the effect of the target nixtamalization treatment. These differences were modeled to be able to predict a pilot plant result from a laboratory outcome. The equations are presented in Table IV.

($P < 0.0001$, P Value LOF = 0.1381, $R^2 = 0.85$)

($P < 0.0001$, P Value LOF = 0.3946, $R^2 = 0.87$)

Fig. 6. Pilot plant (A) and laboratory (B) predicted values for RVA nixtamal peak temperature (°C) as a function of cooking time (min) and cooking temperature (°C), holding steeping time constant at 8.5 hr.

DSC Enthalpy

Nixtamal DSC enthalpy was affected mostly by steeping time (Fig. 8) and the behavior was described in the equation

$$\hat{Y} = \beta_0 + \beta_1 (\text{cooking temperature}) + \beta_2 (\text{steeping time}) + \beta_3 (\text{cooking temperature} \times \text{steeping time}) \quad (5)$$

where β_0 is the intercept, and β_1 , β_2 , and β_3 are the slopes of the factors in parentheses. When the pilot plant process was compared to the laboratory technique, no differences were found between slopes (data not shown).

Endotherm peak temperatures and enthalpy values were greatly influenced by steeping time due to the annealing phenomenon that takes place around gelatinization temperatures (Krueger et al 1987; Robles et al 1988; Sahai and Jackson 1999).

Masa enthalpy, however, was affected exclusively by cooking temperature as described in the equation

$$\hat{Y} = \beta_0 + \beta_1 (\text{cooking temperature}) + \beta_2 (\text{cooking temperature})^2 \quad (6)$$

where β_0 is the intercept, and β_1 and β_2 are the linear and quadratic slopes for cooking temperature, respectively. Again, no slope differences were observed for pilot plant and laboratory processing.

Starch gelatinization and loss of crystallinity occurred to a greater extent at higher cooking temperatures (Fig. 9), in accordance with the results reported by Sahai and coworkers (1999).

Other DSC parameters such as nixtamal onset temperature, nixtamal, and masa peak and end temperatures were not significantly different when the slopes describing their behavior in pilot plant and laboratory were compared (data not shown).

Masa onset temperature, however, presented a significantly different trend between pilot plant and laboratory nixtamalization and the difference was explained exclusively by the steeping time as observed by the equation with an $R^2 = 0.81$

$$\hat{Y} = -6.6991 + 1.0569 (\text{steeping time}) \quad (7)$$

where $\hat{Y}$ = laboratory masa onset temperature – pilot plant masa onset temperature.

CONCLUSIONS

The trends observed in chemical-physical properties of nixtamalized end products as a function of process conditions were in accordance with previous studies reported in the literature.

Fig. 7. Pilot plant (A) and laboratory (B) predicted values for RVA masa peak temperature (°C) as a function of cooking time (min) and cooking temperature (°C), holding steeping time constant at 8.5 hr.

Fig. 8. Pilot plant (A) and laboratory (B) predicted values for DSC nixtamal enthalpy (J/g) as a function of cooking temperature (°C) and steeping time (hr), holding cooking time constant at 30 min.

TABLE IV
Regression Equations and Coefficient of Determination (R^2) for Difference in Laboratory and Pilot Plant RVA Response Variables

RVA Variable (RVU)	Equation ^a	R^2
Masa peak viscosity	$\hat{Y} = +1084.69 - 8.63 (\text{cooking temperature}) - 3.2082 (\text{cooking time})$	0.88
Nixtamal setback	$\hat{Y} = +1111.31 - 12.3664 (\text{cooking temperature})$	0.60
Masa setback	$\hat{Y} = -19.9564 - 2.1397 (\text{cooking temperature}) + 5.1154 (\text{cooking time}) + 15.2373 (\text{steeping time}) - 1.0770 (\text{steeping time})^2$	0.83
Nixtamal final viscosity	$\hat{Y} = -703.38 + 3.8749 (\text{cooking temperature}) + 19.6895 (\text{cooking time}) + 133.34 (\text{steeping time}) - 0.2789 (\text{cooking time})^2 - 1.2072 (\text{steep time})^2 - 0.6926 (\text{cooking time} \times \text{steeping time}) - 1.0831 (\text{cooking temperature} \times \text{steeping time})$	0.89

^a $\hat{Y}$ = Laboratory – pilot plant.

($P < 0.0001$, P Value LOF = 0.4280, $R^2 = 0.83$)

($P < 0.0001$, P Value LOF = 0.2305, $R^2 = 0.83$)

Fig. 9. Pilot plant (A) and laboratory (B) predicted values for masa enthalpy (J/g) as a function of cooking temperature (°C).

Similar results were obtained in products produced from pilot plant and laboratory nixtamalization processes for several variables that indicate quality, yield, pasting, and endothermic properties of nixtamal and masa. Whenever different results were observed, it was possible to develop a significant equation to predict the pilot plant outcome from a value obtained in the laboratory. This study demonstrates that the laboratory technique can be used to mimic larger-scale processing over a wide range of nixtaalization conditions, serving as an important tool for researchers and processors.

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