Assessing Degree of Cook During Corn Nixtamalization: Impact of Processing Variables[1]

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ABSTRACT

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Nixtamalization involves cooking and steeping corn in a lime solution, washing the corn (nixtamal), and stone grinding nixtamal to form a corn dough or masa. Masa is used to produce nixtamalized products (corn tortillas, tortilla chips, corn chips, taco shells, etc.) by forming and baking or deep-fat frying. The degree of corn kernel cook determines the quality and texture of masa. Response surface methodology (RSM) was used as an experimental design to study the impact of process variables (cook temperature, cook time, initial steep temperature, and steep time) on the degree of cook measured using a Rapid Visco Analyser (RVA) and differential scanning calorimetry (DSC). RSM data exhibited significant ($P < 0.005$), although not predictive, linear models for RVA peak viscosity ($r^2 = 0.63$), setback ($r^2 = 0.61$), final viscosity ($r^2 = 0.61$), and peak time ($r^2 = 0.57$), indicating a dependence of these parameters on nixtamalization conditions. Peak viscosity, setback, and final viscosity increased linearly with steep time. DSC enthalpy ($r^2 = 0.83$) and peak temperature ($r^2 = 0.89$) of freeze-dried masa also exhibited significant ($P < 0.0001$) linear regression models with processing variables. DSC enthalpy increased with an increase in steep time, suggesting that starch is annealed during steeping. This study demonstrated that fundamental starch properties were altered on extended steeping during nixtamalization.

Nixtamalization or cooking and steeping of corn with lime (calcium hydroxide), is the first step in the manufacture of alkaline corn products such as corn chips, tortilla chips, corn tortillas, and taco shells. The steeped corn or *nixtamal* is washed to remove loose pieces of pericarp and stone ground to produce *masa* or corn dough. Masa is used to produce tortillas, taco shells, tostadas, tamales, and snacks such as corn and tortilla chips. For a given corn hybrid, the extent of cooking and steeping primarily govern masa textural characteristics. However, establishing nixtamalization conditions to achieve the required degree of cook and masa texture is still considered an art, learned through experience.

Analytical techniques such as differential thermal analysis and viscoamylography that quantify changes in starch have been used to investigate changes in product characteristics during nixtamalization (Robles et al 1988, Gomez et al 1991). Differential scanning calorimetry (DSC) used to measure starch crystallinity, might effectively be used to assess changes in starch thermal profiles and quantify degree of cook during nixtamalization. The Rapid Visco Analyser (RVA) (Newport Scientific Pty Ltd. Warriewood, Australia) is extensively used to quantify changes in starch pasting characteristics during food processing (Walker et al 1988). During nixtamalization, there is partial gelatinization and retrogradation of starch, which alters its pasting profiles (Gomez et al 1991). It appears possible to correlate RVA characteristics to assess degree of cook during nixtamalization.

The effect of grain quality and processing conditions, expressed as changes in nixtamal and masa texture, influence the final textural attributes of nixtamalized products (E. L. Suhendro, H. D. Almeida-Dominguez, L. W. Rooney, and R. D. Waniska *unpublished*). Commercial nixtamalization demands optimum cooking and steeping of corn to produce masa of proper consistency and repeatable quality (I. Bosiger, H. D. Almeida-Dominguez, and L. W. Rooney, *unpublished*). The extent or degree to which corn is cooked during nixtamalization is an important prerequisite for controlling product characteristics and quality. Degree of cook affects pericarp softening and removal, dry matter loss, water uptake, starch gelatinization, vitamin availability, and protein quality (Bressani et al 1958). Extent of cooking also plays a vital role in masa texture, flavor, and color. Degree of cook may also influence how processing parameters such as the gap between the grinding stones and the amount of water added during grinding are adjusted to obtain a high quality product. Besides the intrinsic characteristics of corn, degree of cook during nixtamalization may depend on processing factors such as cook temperature, cook time, initial steep temperature, and steep time. Our research focused on determining whether an RVA or DSC can be used to evaluate the degree of cook as well as determine the impact of nixtamalization processing variables on degree of cook. Response surface methodology (RSM) using a Box-Bahnken design with four factors (nixtamalization cook temperature, cook time, initial steep temperature, and steep time [with 27 experimental trials]) was employed to study the impact of process variables on degree of cook and masa pasting properties.

MATERIALS AND METHODS

Corn Sample

Pioneer 3162 (Pioneer Hi-Bred International) a yellow corn (*Zea mays* L.) hybrid from the 1997 crop grown in central Nebraska was used for the nixtamalization experiments. The corn was field-dried and commercially cleaned and bagged (22.5 kg/bag) at FlatWater Mills (Hastings, NE). The cleaned corn was stored in a freezer (maintained at –18°C) until just before equilibration to room temperature and subsequent nixtamalization. The corn sample had a test weight of 74.82 kg/hL.

Corn Characterization

A composite corn sample was collected for characterization using tests outlined by Shandera et al (1997). Corn (≈200 g ± 10) was removed from each bag used for the nixtamalization experiments and combined to form the composite sample. Corn hardness was evaluated using a tangential abrasive dehulling device (TADD) and a Stenvert hardness tester. Breakage susceptibility was evaluated using a Wisconsin breakage tester. Thousand kernel weight, percent floaters, and proximate analysis (fat, protein, crude fiber, and ash) of the corn sample were also determined.

TADD loses were calculated as the percent loss of kernel material after abrading 40 g of maize (model 4E-220, Venables Machine Works, Saskatoon, SK) for 10 min while suctioning off abraded material as described by Reichert et al (1986).

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The Stenvert hardness test involved grinding 20 g of maize using a micro-hammermill (GlenMills model V fitted with a 2-mm screen) at 360 rpm. The heights of soft endosperm and total ground material collected in the recovery tube, time to grind, reduced hammermill rpm at maximum grinding power, and quantity of hard endosperm recovered over a 425-µm sieve was measured (Pomeranz et al 1985). The breakage susceptibility of the corn sample was determined by using a Wisconsin breakage tester (model 9/84, 1,800 rpm) as described by Watson and Herum (1986) and Pomeranz et al (1986).

Thousand-kernel weight was determined by hand-counting 100 whole kernels of each sample and multiplying their weight by 10. Floaters were determined as percent of buoyant kernels immersed in a 31.3 Baume' sodium nitrate solution maintained at 60°C corresponding to a specific gravity of 1.275 (Peplinski et al 1989).

For the proximate analysis of the composite corn sample, the corn sample was ground first in a Buhler mill (Buhler, Minneapolis, MN) and subsequently finely ground using a sample mill (Udy Corp., Boulder, CO). Corn moisture (ground sample) was determined by Approved Method 44-15A (AACC 1995). Corn protein content (N × 6.25) was calculated using the Kjeltec procedure (Tecator, Herndon, VA) based on AACC Method 46-12. Fat content was determined by the Soxtec AOAC 960.39 procedure (Soxtec extraction unit model HT 1043 and model HT 1046 service unit, Tecator). Ash content was calculated by Approved Method 08-01 (AACC 1995), while crude fiber content was determined by AOAC method 962.09 using a FiberTec system (model M 1020 hot extractor and model 1021 cold extractor, Tecator).

All the above analyses were conducted in triplicate; means with standard deviations are reported. The data was statistically analyzed using statistical software (NCSS-97, Visual Statistical Systems, Kaysville, UT).

Experimental Design

A Box-Behnken model RSM experimental design was used. Cook time, cook temperature, initial steep temperature, and steep time were selected as the four factors studied. A total of 27 trials with three central points were generated by Design Expert (Ver 5.08, 1997, Stat-Ease Inc, Minneapolis, MN) statistical software. The process variables were varied (Table I). These ranges were

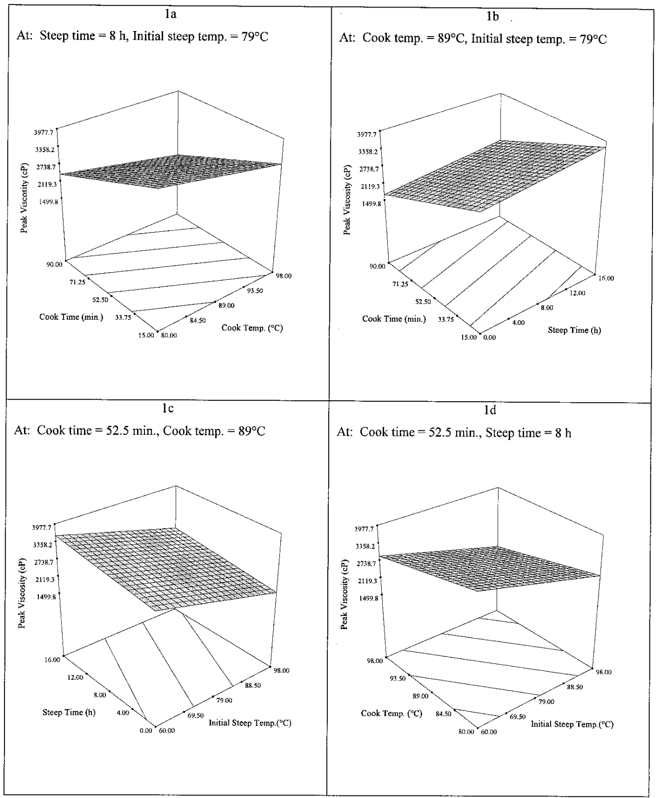
TABLE I
Levels of the Four Nixtamalization Factors Used in the Box-Benkhen Design

Factor	Units	Levels		
Cook temperature	°C	80	89	98
Cook time	min	15	52.5	90
Initial steep temperature	°C	60	79	98
Steep time	hr	0	8	16

TABLE II
Physical Characteristics and Composition of Pioneer 3162 Corn Used in Nixtamalization

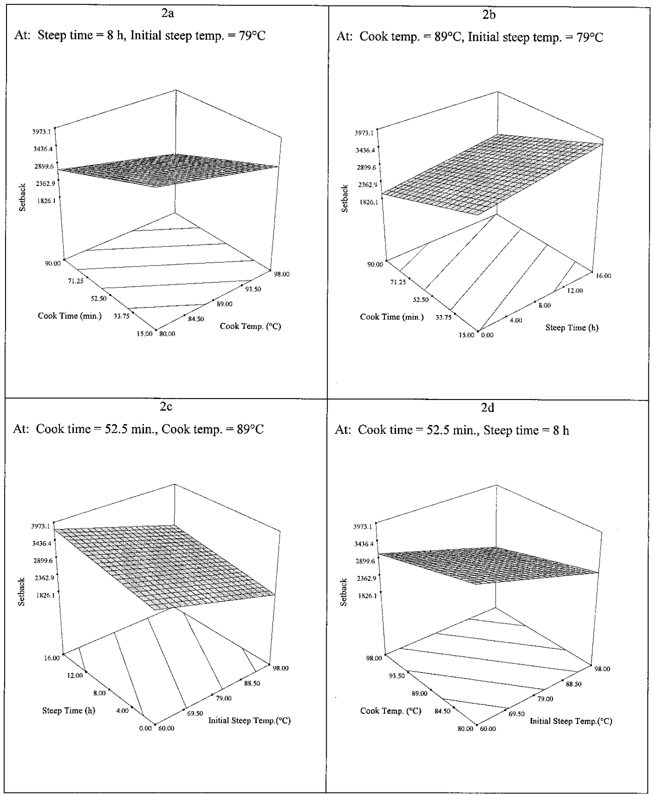
Characteristic/Component	Value (%)	Standard Deviation
Wisconsin breakage[a]	58.19	1.01
TADD index[b]	59.30	3.42
Stenvert hardness[c]	67.13	0.93
Floater percent[d]	90.00	3.46
1,000 kernel weight	332.0	1.04
Ground corn moisture	9.76	0.073
Fat	4.23	0.44
Protein	8.44	0.015
Crude fiber	2.23	1.17
Ash	1.31	0.043

[a] Higher Wisconsin breakage values indicate extensive internal cracks in the corn kernels.
[b] Higher tangential abrasive dehulling device (TADD) values indicate higher percent loss and a softer pericarp.
[c] Higher Stenvert hardness values indicate harder corn.
[d] Higher floater percent indicates less apparent corn density.



*Significant linear regression model, P < 0.0005, r²=0.629, Lack of fit P = 0.3653

Fig. 1. Response surface graphs describing changes in peak viscosity of fresh masa with processing variables.



*Significant linear regression model, P < 0.0003, r²=0.615, Lack of fit P = 0.3301

Fig. 2. Response surface graphs describing changes in Rapid Visco Analyser (RVA) setback of fresh masa with processing variables.

selected based on preliminary nixtamalization trials and literature data. The various responses (RVA peak viscosity, setback, final viscosity, peak time, DSC peak temperature, and enthalpy) were plotted against process variables to generate response surface graphs. RSM model significance ($P < 0.05$), degree of model fit (lack-of-fit test $P > 0.05$), and the degree to which the model helps explain the measured response (r^2 values) were obtained.

Nixtamalization Procedure

For nixtamalization, 120 kg of water was accurately weighed and pumped into a gas-fired horizontal cook-steep tank (model OCT002-01, Lawrence Equipment, South El Monte, CA). Lime (200 g as pure $Ca(OH)_2$) was added to the cooking tank and mixed until dispersed. The tank was covered with a lid and the lime solution heated to the desired temperature according to the experimental design. Corn (20 kg) was added to the tank and gently stirred to ensure a uniform temperature in the vessel. Due to addition of corn to preheated water, the temperature of the cooking tank decreased by ≈5–10°C. Heating was continued until the temperature of the corn-water-lime mixture recovered to the specified cooking temperature; cook time countdown was then started. Corn was cooked for the time required by the experimental design. Tank temperature was maintained thermostatically during cooking.

Nixtamalizations were conducted using 20 kg of corn and 120 kg of water, a corn-to-water ratio of 1:6. Use of excess water assured that water was not a limiting factor during cooking and steeping. Corn was cooked with the tank covered with a lid. Covering the tank during cooking allowed water to be conserved as vapor loss was reduced. The water temperature also reached the desired cooking temperature more rapidly after addition of corn, and temperatures could be maintained with less fluctuation.

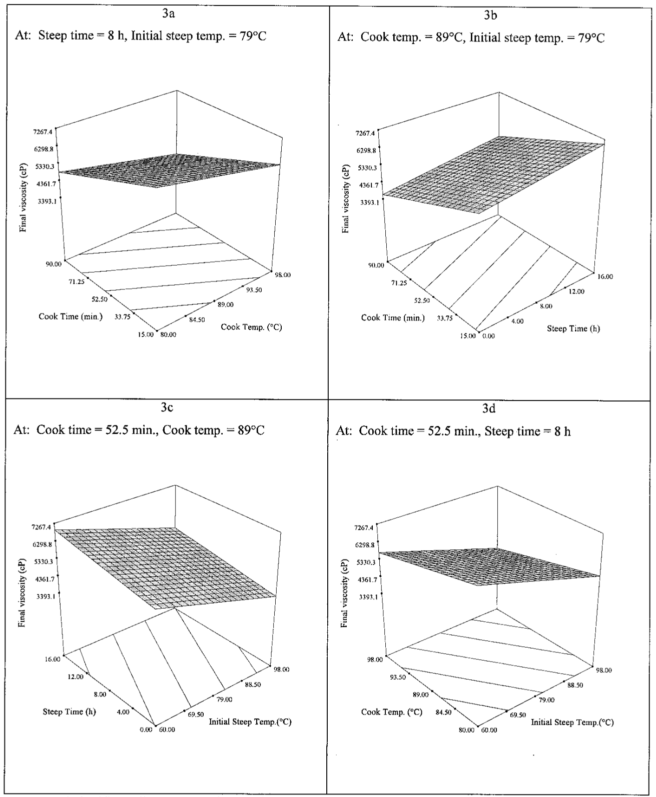
At the end of cooking, addition of either boiling or cold water adjusted the initial steep temperature to the desired value for the experimental design. The lid of the cooking tank was removed and steeping started for the required time. Steeping was terminated by draining *nejayote* (the alkaline cook-steep liquid). Nixtamal was washed twice using 50 L of water per wash. Nixtamal was vigorously stirred in the wash water for ≈5 min before draining. At the end of the two washings, the corn was drained for ≈20 min before it was ground into masa using a hand meat grinder. The grinder setting was maintained at a constant gap for all the experimental trials. While masa produced from this grinder did not experience the high temperature and shear sometimes associated with large commercial stone grinders, our treatment effects were not confounded by grinder variability, and the masa produced in all cases was suitable for tortilla production.

Masa RVA Analysis

The pasting characteristics of fresh masa were evaluated using an RVA. Masa moisture content was rapidly determined using an Ohaus moisture balance (model 6010PC, Ohaus Scale Corp. Florhan Park, NJ). The amount of sample weighed in the RVA pan was calculated on a 4 g, 14% moisture basis. The temperature profile was set such that the suspension was first equilibrated to 50°C for 1 min, heated in 4 min 32 sec to 95°C, held at 95°C for 3 min 30 sec, and finally cooled to 50°C within 3 min 48 sec. RVA pasting parameters such as peak viscosity, final viscosity, setback, peak time, and peak temperatures were recorded.

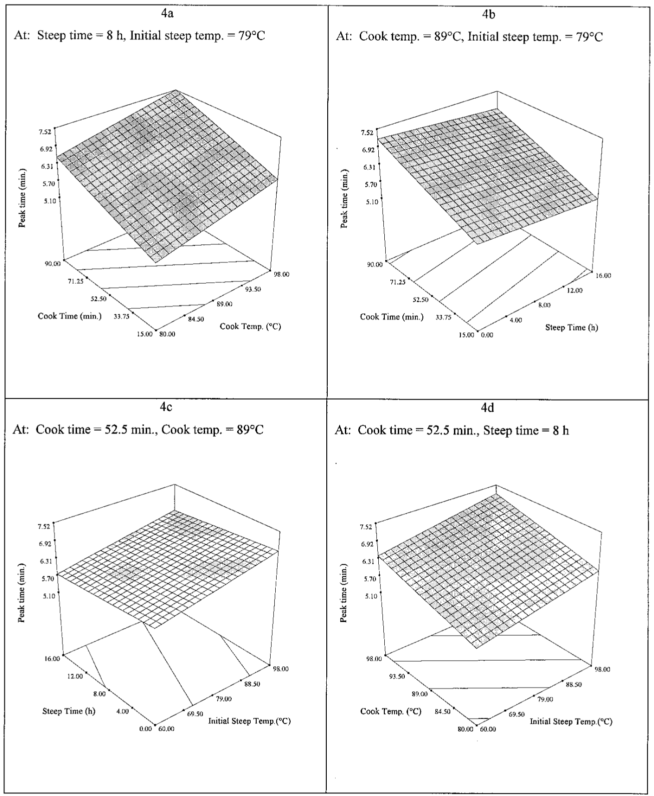
DSC Analysis of Masa

DSC analysis of masa was conducted using a Du Pont 2000 DSC (910 DSC cell, TA Instruments Inc., New Castle, DE). Fresh, finely ground masa was immediately frozen to –18°C in a deep freezer. The frozen samples were freeze-dried in an 8-L freeze drier (VirTis Co., Gardiner, New York, NY). The freeze-dried samples were finely ground in a micro-hammer mill (GlenMills model V fitted with a 1.5-mm screen). Sample (≈0.015 mg) was accurately weighed into aluminum DSC pans. The samples were hydrated to ≈80% moisture content and the aluminum pans were firmly sealed. The pans were stored at room temperature (25°C) for ≈12 hr



*Significant linear regression model, P < 0.0002, r²=0.611, Lack of fit P = 0.4494

Fig. 3. Response surface graphs describing changes in Rapid Visco Analyser (RVA) final viscosity of fresh masa with processing variables.



*Significant linear regression model, P < 0.0006, r²=0.575, Lack of fit P = 0.2481

Fig. 4. Response surface graphs describing changes in Rapid Visco Analyser (RVA) peak time of fresh masa with processing variables.

to obtain uniform sample hydration. The pans were heated in the DSC (from 30 to 120°C at the rate of 10°C/min) to obtain the endotherms. DSC analysis of each sample was conducted in duplicate; mean values are reported. Peak melt temperature and enthalpy of melt was calculated by endotherm peak analysis.

Masa Total Starch Analysis

Total starch content in freeze-dried masa was determined by Approved Method 76-13 (AACC 1995) using the Megazyme (Warriewood Australia) amyloglucosidase/α-amylase total starch kit.

RESULTS AND DISCUSSION

Pioneer 3162 corn has a history of being used commercially for nixtamalization. The results of various hardness and characterization tests are listed in Table II. The corn sample was graded as medium hard corn using the Stenvert hardness test.

Masa total starch content did not generate a significant regression model with process variables ($P = 0.0604$, $r^2 = 0.325$), indicating the extent of starch leaching from corn kernels during nixtamalization was apparently independent of cooking and steeping conditions. This observation also implies that the concentration of masa starch was not a critical factor influencing RVA pasting and DSC characteristics. Observations registered by the RVA and DSC analysis of masa reflected differences in the thermal history of the samples due to variations in cooking and steeping and were not due to variations in starch concentration.

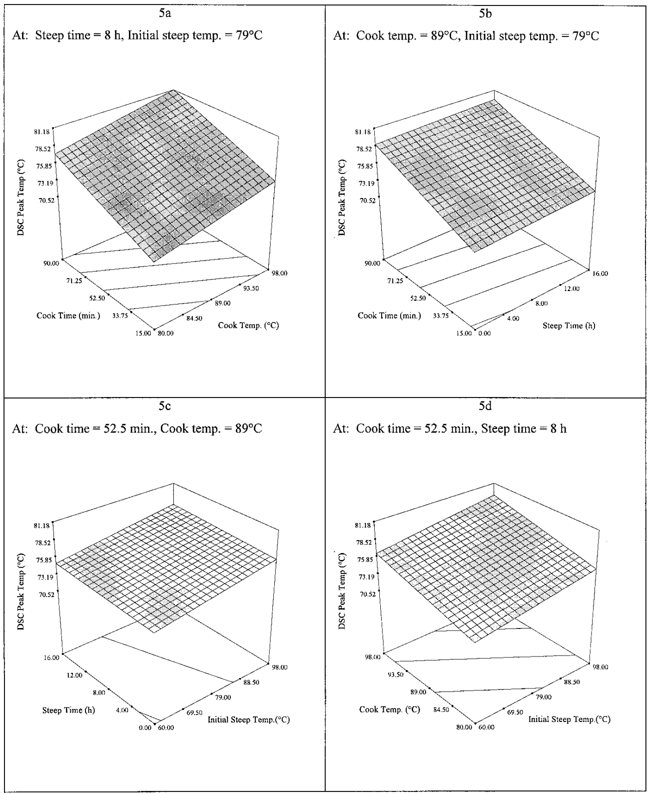
RVA Analysis

RVA pasting characteristics (peak viscosity, setback, final viscosity, and peak time) of fresh masa exhibited significant ($P < 0.005$, $r^2 = 0.63$) RSM linear regression models, indicating relationships between pasting characteristics and nixtamalization conditions. RVA peak temperature, however, did not generate a significant model ($P = 0.2025$, mean model), suggesting that masa peak temperature was independent of processing parameters.

When RVA parameters (peak viscosity, setback, and final viscosity) were graphed (Figs. 1–3), it was evident by observing the surface slope that steep time was probably the most critical factor influencing masa paste peak viscosity, setback, and final viscosity (Figs. 1b, 1c, 2b, 2c, 3b, and 3c). A linear increase in peak viscosity, setback, and final viscosity was observed with an increase in steep time. Other factors such as cook temperature, cook time, and initial steep temperature were of secondary importance. Peak viscosity, setback and final paste viscosity linearly decreased with increasing cook temperature, cook time, and initial steep temperature.

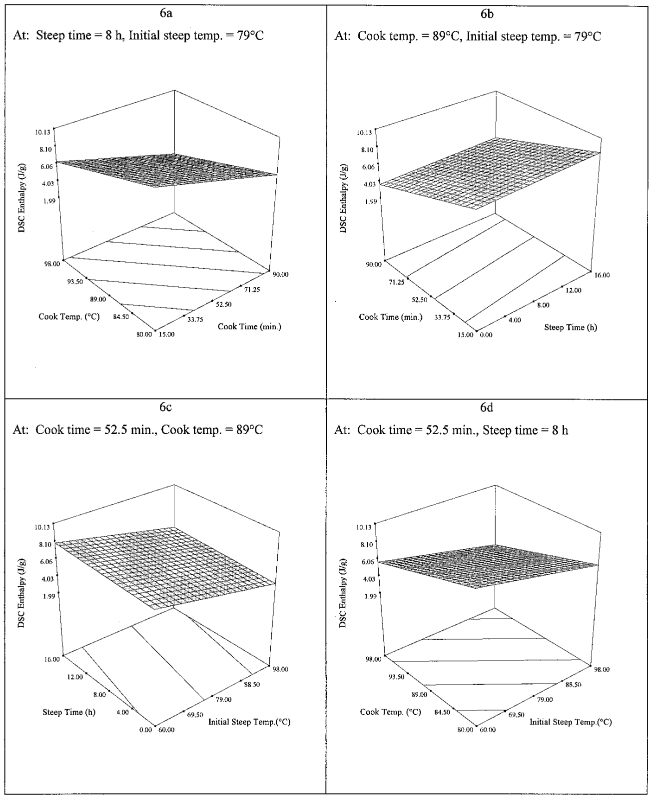
RVA peak time also exhibited a significant linear regression model ($P < 0.0006$, $r^2 = 0.57$, lack-of-fit $P = 0.2481$) with processing variables. It was observed from the response surface graphs (Fig. 4) that cook time, cook temperature, and initial steep temperature were critical variables influencing peak time, while steep time was of secondary importance.

Changes in RVA masa peak viscosity, setback, and final paste viscosity with increasing steep times suggests the importance of alkaline steeping for the development of optimum masa texture. In modern masa production facilities, where efforts are often focused on expediting the process, corn is usually overcooked and quenched to reduce or eliminate steeping (Khan et al 1982, Gomez et al 1987, Pflugfelder et al 1988a). Our results suggest that pasting characteristics of masa produced without steeping will differ significantly from that produced after extended steeping for 16 hr. Robles et al (1988) investigated the physicochemical changes in maize starch during nixtamalization and observed that the Brabender peak viscosity of masa increased during the first 35 min of cooking and then gradually decreased on further cooking to 60 min. These researchers concluded that besides cook time and temperature, steep time was critical for the development of optimum masa texture. In our response surface study, RVA peak viscosity linearly decreased



*Significant linear regression model, P < 0.0001, r^2=0.898, Lack of fit P = 0.2175

Fig. 5. Response surface graphs describing changes in differential scanning calorimetry (DSC) gelatinization peak temperature of freeze-dried masa with processing variables.



*Significant linear regression model, P < 0.0001, r^2=0.829, Lack of fit P = 0.2468

Fig. 6. Response surface graphs describing changes in differential scanning calorimetry (DSC) gelatinization enthalpy of freeze-dried masa with processing variables.

with increasing cook time; the profound effect of steeping on masa peak viscosity, setback and final viscosity was also evident. Changes in masa pasting viscosity reflect differences in organization of starch molecules and degree of granule swelling. Physicochemical interactions of starch, nonstarch polymers, and lime during alkaline cooking may also affect masa pasting properties (Robles et al 1988).

DSC Analysis

DSC endotherm peak temperature and enthalpy values of freeze-dried and ground masa exhibited significant ($P < 0.005$, $r^2 > 0.82$) linear regression models. Previous experimentation in our laboratory has shown that when masa is freeze-dried, DSC profiles show the appearance of retrogradation endotherms (data not shown); however, freeze-drying fresh masa into a flour results in minimal thermal damage to masa starch and makes DSC analysis of masa more practical. Response surface graphs showing how DSC endotherm peak temperatures change with processing variables (Fig. 5) suggest that cook temperature, cook time, and initial steep temperature were more critical factors than steep time. The overall gelatinization peak temperature, however, increased during steeping. On the other hand, DSC enthalpy was primarily influenced by steep time (Fig. 6). Higher cook temperature, longer cook time, and higher initial steep temperature decreased enthalpy values, indicating more starch gelatinization and an increased loss of crystalline order. DSC enthalpy, however, increased with increases in steeping time.

Increased endotherm peak temperatures and enthalpy values are typically associated with the starch annealing process, much of which takes place in the critical temperatures around gelatinization (Krueger et al 1987, Robles et al 1988, Sahai and Jackson 1999). It appears that as higher cook temperatures, longer cook times, and higher initial steep temperatures decrease starch crystallinity, the impact of longer steep times (increased annealing) is to create a more crystalline starch, particularly in those granules not fully gelatinized during nixtamalization.

CONCLUSIONS

Masa is a unique dough system composed of alkaline cooked, steeped, and ground corn, where changes in starch during processing determine the mechanical properties of masa (Gomez et al 1990). Most of the functional changes in starch during nixtamalization have been attributed to corn cooking conditions. From a physicostructural perspective, masa is a network of solubilized starch polymers supporting dispersed, ungelatinized, swollen, or partly gelatinized starch granules along with cell fragments and lipids (Gomez et al 1992).

Robles et al (1988) concluded that extensive starch gelatinization does not take place during nixtamalization. These researchers attributed this to the hydrothermal treatment and stabilization of the starch granules due to calcium ions. Gomez et al (1989) showed that only 15–25% of starch crystallinity is lost during nixtamalization. Pflugfelder et al (1988b) fractionated commercial corn masa and suggested that only 5% of corn dry matter was solubilized during commercial nixtamalization, and masa consisted of large numbers of ungelatinized or partly gelatinized starch granules. In our response surface experiment, within the ranges tested, RVA peak viscosity, setback, and final viscosity were more influenced by steep time than by other processing parameters (cook temperature, cook time, and initial steep temperature). Masa consists of ≈75–85% undamaged and ungelatinized starch granules that undergo changes such as annealing during steeping. Such changes appear to be important and possibly contribute significantly to masa functionality. This study demonstrates that extended steeping during nixtamalization alters fundamental starch properties in masa detectable by RVA and DSC analysis.

DSC endotherm peak temperature exhibited a linear regression model ($r^2 = 0.89$) with processing parameters and can be used as an indicator of degree of cook during nixtamalization. RVA peak time models, though significant, were less predictive ($r^2 = 0.57$) of processing performance. DSC enthalpy values, which exhibited a pronounced increase due to starch annealing ($r^2 = 0.83$), can be a useful indicator for determining the extent of steeping during nixtamalization.

LITERATURE CITED

American Association of Cereal Chemists. 1995. Approved Methods of the AACC, 9th ed. Method 08-01; Method 44-15A; Method 46-12. The Association: St. Paul, MN.

AOAC. 1984. Official Methods of Analysis of the Association of Official Analytical Chemists. Methods 960.39 and 962.09. The Association: Arlington, VA.

Bressani, R., Paz, R. P., and Scrimshaw, N. S. 1958. Chemical changes in corn during preparation of tortillas. Agric. Food Chem. 6:770-773.

Gomez, M. H., Lee, J. K., McDonough, C. M., Waniska, R. D., and Rooney, L. W. 1992. Corn starch changes during tortilla and tortilla chip processing. Cereal Chem. 69:275-279

Gomez, M. H., Waniska, R. D., and Rooney, L. W. 1991. Starch characterization of nixtamalized corn flour. Cereal Chem. 68:578-582.

Gomez, M. H., McDonough, C. M., Rooney, L. W., and Waniska, R. D. 1989. Changes in corn and sorghum during nixtamalization and tortilla baking. J. Food Sci. 54:330-336.

Gomez, M. H., Rooney, L. W., and Waniska, R. D. 1987. Dry corn masa flours for tortilla and snack foods. Cereal Foods World 32:372-377.

Gomez, M. H., Waniska, R. D., and Rooney, L. W. 1990. Effects of nixtamalization and grinding conditions on the starch in masa. Starch/Staerke 42:475-482.

Khan, M. N., Desrosiers, M. C., Rooney, L. W., Morgan, R. G., and Sweat, V. E. 1982. Corn tortillas: Evaluation of corn cooking procedures. Cereal Chem. 59:279-284.

Krueger, B. R., Knutson, C. A., Inglett, G. E., and Walker, C. E. 1987. A differential scanning calorimetry study on the effect of annealing on gelatinization behavior of corn starch. J. Food Sci. 52:715-718.

Peplinski, A. J., Paulsen, M. R., Anderson, R. A., and Kwolek, W. F. 1989. Physical, chemical, and dry milling characteristics of corn hybrids from various genotypes. Cereal Chem. 66:117-120.

Pflugfelder, R. L., Rooney, L. W., and Waniska, R. D. 1988a. Dry matter losses in commercial corn masa production. Cereal Chem. 65:127-132.

Pflugfelder, R. L., Rooney, L. W., and Waniska, R. D. 1988b. Fractionation and composition of commercial corn masa. Cereal Chem. 65:262-266.

Pomeranz, Y., Czuchajowska, Z., and Lai, F. S. 1986. Comparison of methods for determination of hardness and breakage susceptibility of commercially dried corn. Cereal Chem. 63:39.

Pomeranz, Y., Czuchajowska, Z., Martin, C. R., and Lai, F. S. 1985. Determination of maize hardness by Stenvert Hardness Tester. Cereal Chem. 62:108.

Reichert, R. D., Tyler, R. T., York, A. E., Schwab, D. J., Tatarynovich, J. E., and Mwasaru, M. A. 1986. Description of a production model of the tangential abrasive dehulling device and its application to breeders' samples. Cereal Chem. 63:201-207.

Robles, R. R., Murray, E. D., and Paredes-López, O. 1988. Physicochemical changes of maize starch during the lime-heat treatment for tortilla making. Int. J. Food Sci. Technol. 23:91-98.

Sahai, D., and Jackson, D. S. 1999. Enthalpic transitions in native starch granules. Cereal Chem. 76:444-448

Shandera, D. L., Jackson, D. S., and Johnson, B. E. 1997. Quality factors impacting processing of maize dent hybrids. Maydica 42:281-289

Walker, C. E., Ross, A. S., Wrigley, C. W., and McMaster, G. J. 1988. Accelerated starch-paste characterization with the rapid visco-analyzer. Cereal Foods World 33:491-493.

Watson, S. A., and Herum, F. L. 1986. Comparison of eight devices for measuring breakage susceptibility of shelled corn. Cereal Chem. 63:139-142

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