Perspectives on Nixtamalization (Alkaline Cooking) of Maize for Tortillas and Snacks

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Our laboratory has been conducting research on alkaline cooking for the past 23 years. We have seen tortillas, tortilla chips, and corn chips go from being an almost exclusively Hispanic food to being a highly accepted food across America with increasing importance worldwide. Researchers from our laboratory have conducted cooking trials in commercial tortillerias in Mexico, Central America, and the United States. We have developed procedures requiring from a few grams of grain to 25 kg to evaluate alkaline cooking properties. The purpose of this article is to summarize some of our findings and present perspectives on the state of this increasingly important process and its products. We have not attempted to review all of the publications on this subject.

The nixtamalization of maize into tortillas and related products has existed for centuries. The Aztecs cooked maize in alkali (lime or leachate of wood ashes) to produce tortillas, which were their major bread (1,2). Nixtamalization of maize in Mesoamerica led to improved health in the population for two reasons. It eliminated pellagra by making the niacin in maize available and improved protein quality because some of the least nutritional proteins were rendered indigestible by the process (2).

Today, nixtamalized maize is used to produce tortilla chips, corn chips, tamales, taco shells, atoles, pinoles, and tortillas of various kinds. Over $4.3 billion worth of tortilla and corn chips and $1.0 billion worth of tortillas are produced each year in the United States. Sales increase 8-10% each year. Moreover, tortilla chips and related products are becoming familiar to Asians and Europeans as Tex-Mex cuisine spreads. There is a real demand for maize-based products now, and it will expand worldwide in the 21st century.

Nixtamalization is the process of cooking and soaking maize in water containing 1% lime (based on corn), which softens the pericarp and endosperm; the starch and protein matrix is hydrated and a small amount of starch is gelatinized. Washing removes part of the pericarp, the leached solubles, and the excess lime. The cooked, steeped product, called nixtamal, is then ground, using stone attrition mills, into masa, which is sheeted, cut into pieces, and baked using a triple-pass oven. The tortillas are cooled and eaten immediately or within the day. In Mesoamerica, leftover tortillas are fried in the morning and consumed as tostados or refried tortillas.

In the United States, alkaline cooking processes are carefully designed to produce specific kinds of masa for different products: table tortillas, tortillas for further processing, taco shells, tortilla chips, and corn chips (1). Each process is optimized for the particular product desired. Thus, tortilla chips have a significantly more fragile texture than Mexican tostadas and refried tortillas. In Mexico, several companies produce snacks from nixtamalized maize using these same specific procedures. However, the majority of tortillas in Mexico are still produced from fresh masa and consumed fresh. The tortilla industry in Mexico is changing rapidly because subsidies for tortillas have been removed. Dry masa use is increasing along with consolidation of the industry.

Methods of Evaluating Alkaline Cooking Properties

We have utilized an array of cooking procedures ranging from laboratory tests on grams of grain using a small hand grinder and sheeter to processing 12-25 kg of grain into tortillas and chips, using a pilot-scale process with a 20-hp 12-in. lava stone grinder (3-10). The masa is sheeted in a commercial sheeter and baked using a slotted, three-tier, gas-fired commercial tortilla oven with a conveyor and cooling facilities. Tortilla chips are batch fried.

Nylon bags are used to cook corn to determine optimum cooking time, water uptake, pericarp removal, and dry matter losses of different corn and sorghum samples. We routinely evaluate the quality of dry masa flours (DMFs) from various experimental procedures using the pilot-plant equipment. These laboratory procedures are effective for exploratory testing to optimize processes and evaluate potential ingredients for tortillas and snacks before subsequent evaluation in commercial plants. Significant time and costs can be saved using these laboratory procedures.

Alkaline Corn Cooking Quality Selection and Prediction

The quality of maize hybrids for use in alkaline cooking and dry milling has improved dramatically in the past 10-15
years (11–15). Hybrid seed companies have spent significant time and money to improve corn hybrids for use in alkaline cooking and dry milling, where harder corns produce greater yields of large grits, which command a premium price. Thus, excellent quality white and yellow food corn hybrids are available in most areas of the United States. The cost differential between white and yellow corn has been reduced by these advances, and a greater proportion of white maize products are used now.

Suppliers and processors use several methods, ranging from simple to sophisticated, to monitor food corn properties (15). Bulk density, floaters, true density, and hull removal are quite effective when used appropriately in the correct settings. Most food corn suppliers specify the hybrids that they will accept for production. The key parameters measured at harvest are the federal grade, broken kernels, stress cracks, bulk density, density, and possibly kernels that float in nitrate solutions of various specific gravities. Maize with a clean, bright yellow or white color is preferred by alkaline processors. For dry milling, test weight, stress cracks, and broken kernels are important parameters; test weight is used to pay premiums to farmers who produce low stress-cracked corn of the accepted hybrids. The ease of determination makes test weight very effective when it is applied to clearly identified hybrids with similar kernel properties. Many other tests are too slow to be used during harvest to evaluate quality. The development of more effective near-infrared methods shows promise for future selections.

Corn cooking time is significantly affected by hybrid, by environmental conditions during production, and by storage and handling procedures (11,15,16,17). Stored corn requires additional cooking time. The industry in general prefers corn in which the pericarp is removed during cooking. For table tortillas, the alkaline-treated pericarp forms gums that improve rollability and quality of tortillas. Thus, some processors want to retain pericarp while others want to remove it. Also, some processors want to have softer corn, which requires shorter cooking times that usually do not remove the pericarp. Thus, corn breeders developing food corn hybrids are confused as to what the industry wants in terms of corn quality. Flint corn is undesirable for alkaline cooking. However, breeding of corns with high endosperm texture and good pericarp removal with intermediate cooking times is needed. Environmental conditions during production often cause hard corns to be softer, and we hope that plant breeders do not abandon the goal of producing hard food corns. There are plenty of soft feed corn hybrids available for processors who desire them.

Genetically modified corn hybrids containing *Bt* genes have positively affected quality because of the reduced numbers of insect-damaged kernels, which usually results in reduced levels of mycotoxins. However, the controversy about the use of genetically modified organisms (GMOs) internationally and the alleged potential lethal effects of *Bt* corn pollen on monarch butterfly larvae is a major concern for the continued use of the *Bt* gene. It is clear that future improvements in corn and other crops will require the use of biotechnology techniques as part of plant breeding programs to ensure world food supplies. However, some consumers may have strong prejudices against GMO crops. This will likely be a continuing debate and will create problems for international marketing of crops containing GMOs.

**Nixtamalization Procedures**

The production of high-quality nixtama­lized corn products is most effectively done by cooking whole corn in lime, steeping, grinding, and further processing (16–18). Various short-cut procedures have been attempted over the years with undesirable results. Continuous cooking and extrusion procedures usually overcook the corn and produce masa with poor quality. Numerous procedures have been proposed to produce fresh masa by cooking ground corn.
corn with lime and shortening the process to enhance efficiency and reduce effluent. None of them have been particularly successful when compared to authentic nixtamalized masa. In some areas, ground corn has been cooked and used to produce "chips" that have been successful because consumers do not know the properties of properly cooked masa products.

Methods to nixtamalize corn with reduced production of effluent are urgently required. Choosing the proper corn significantly reduces wastewater (19). Incomplete washing also reduces wastewater and sewage charges. Significant progress has been made to reduce the biological oxygen demand (BOD) that goes to city sewage plants. However, one of the major disadvantages of cooking corn is the effluent generated. In some areas, corn processing plants cannot use city waste facilities, or the cost is prohibitive.

Chemistry of Nixtamalization

Progress has been made in understanding alkaline cooking (20-25). Lime quantity and quality affect the cooking time and extent of cooking of corn. The lime acts on the components of cell walls and converts the hemicellulose into soluble gums. Nixtamal is sticky and slippery before washing. Microscopy has shown that the fluorescence of cell walls is lost during alkaline cooking, while it is not lost during cooking in water. The alkali gelatinizes the starch, causes part of the lipid to saponify, releases the niacin from the niacytin complex, and solubilizes part of the proteins that surround the starch granules. At high pH, the starch chains are charged, which helps to slow retrogradation and retain the freshness of the tortillas. Relatively small amounts of starch are gelatinized during cooking and steeping. Most gelatinization occurs during attrition grinding, which disperses partially swollen granules into the "glue" that holds the masa particles together. Too much gelatinized starch causes major handling problems related to stickiness, while undercooking produces noncohesive masa. Thus, optimum cooking and grinding work together to produce excellent masa. The grinder cannot be used to gelatinize the starch in a severely undercooked masa because downstream difficulties occur.

DMF particles are quite different from those of fresh masa (20,24,26). Fresh masa particles include significant quantities of free starch granules containing low protein content, while DMF has particles that contain starch and protein at levels similar to those of the original corn endosperm. This difference is related to the different methods of processing. The highly hydrated nature of nixtamal for fresh masa means that, during grinding, the starch granules are freed from the protein matrix and therefore function differently in subsequent processing. For dry masa, the particles are obtained by hammer milling lower-moisture nixtamal, which does not allow separation of starch from the other components. The differences in processing corn into fresh masa and DMF are very marked. For example, during steeping of cooked nixtamal, the starch granules actually undergo annealing. This affects the properties of the masa; therefore, DMF products cannot be the same as those from fresh masa. DMF products are not necessarily inferior. It depends upon the type of product desired. The future is bright for both fresh and dry masa products.

Dry Masa Flour

DMF production has increased significantly during the past 10 years along with consolidation of the industry. The two largest companies are based in Mexico with significant operations in the United States. Both produce 20-30 different types of flour of DMFs that vary in color, particle-size distribution, protein, content of preservatives, level of carboxymethyl cellulose (CMC), and expected end use. DMFs have improved very significantly in quality, consistency and availability (27-29). The largest DMF company has nearly 20 dry masa plants in Mexico, the United States, and Central America. Dry masa producers using whole corn spend considerable time selecting the best corn hybrids for their process and work closely with hybrid seed company personnel. Certain hybrids are tested, accepted, and put on lists. Producers grow the hybrids knowing that the companies will purchase them provided they meet specifications.

Several methods are used to produce DMF. The most common method is to cook the corn, intact whole kernels in lime by injecting steam into a continuous screw conveyor for a relatively short time (30-60 min). The cooked corn is allowed to equilibrate for a short time, it is rinsed to remove some of the pericarp and ground using a modified, specially designed hammer mill. The ground particles are flash dried and sieved; coarse particles are reground and sieved, and then the particles are reformulated into the correct particle size distribution needed for specific DMFs. Drying is critically important since additional cooking and some expansion occur in the particles. Other methods include batch cooking, steeping, and stone grinding to produce flours of different qualities (27).

The advantage of DMF is that a chip or tortilla maker can produce products by simply rehydrating the masa with water, then sheething, molding, and baking or frying it, depending on the product. This greatly reduces labor, capital outlay for processing equipment, problems of corn acquisition and cooking, and wastewater treatment. It also provides considerable flexibility. Sometimes dry masa is used in conjunction with fresh cooked masa. For example, in Mexico, dry masa is often used to overcome problems when fresh masa is too sticky. This happens because poor quality corn for processing is often the only maize available.

The disadvantages are that the price of dry masa is high, the number of manufacturers has been reduced by consolidation, and there are important differences in flavor and texture between fresh and dry masa products. For producers who are used to cooking corn, the profitability is optimized along with improved quality.

Dry masa quality is more consistent now than ever before but there is still variation that significantly affects product quality. The particle size distribution, which is evaluated by sieving, is critically important. The pH, water absorption, and viscosity of the masa are important. Subjective evaluation of water absorption is an effective way to evaluate the flour. Viscosity methods include use of the Bostwick consistometer, the Rapid Viscosity Analyzer (RVA), the viscosygraph, the penetrometer, and various proprietary tests. The use of mixograph and farinograph may be helpful for certain applications (29).

DMFs can be produced using dry-milled fractions that are treated with lime, partially cooked, and formulated to produce particles of the proper size and water uptake. They are used mainly in tortilla chips, taco shells, and other fried products. Some of these DMF products produce excellent tortilla chips and taco shells. The flavor, color, and texture may be slightly different but quite acceptable. Sometimes the color is brighter than those of traditional whole-corn DMFs. In general, these products are not effective for tortillas. Table tortillas require subtle properties that are difficult to produce using milling fractions. Significantly more research is required to overcome this hurdle.

The future is bright because Tex-Mex types of cuisine penetrate Asia and other areas, DMF will be extremely useful. Improved quality control and new products will likely fuel the expansion of corn snacks and other foods. Both fresh and DMF will be used.

Tortilla Quality and Staling

Maize tortillas have excellent properties when consumed immediately after production, but they stale rapidly, become brittle, and cannot be wrapped around food. They can be freshened by proper reheating but must be used quickly. Most non-Hispanics in the United States have never enjoyed a fresh corn tortilla. Maize tortillas have low fat, high calcium, and high dietary fiber levels, so they are nutritionally desirable. The biggest problem with corn tortillas is that preservatives are used to produce a shelf life of a month or more in supermarkets. The strong smell of propionates and other preservatives and the firmer texture of corn tortillas significantly reduce acceptability.
DMFs used to make table tortillas have CMC added to ensure sufficient flexibility for use as a wrap. During DMF production, the starch is gelatinized and retrogrades during subsequent drying. Thus, some of the starch can not be rehydrated, and CMC must be used to hold water and improve flexibility. CMC is the usual hydrocolloid used because of its functionality and cost. Other gums have been considered, but they are relatively inefficient (30).

We have developed several objective methods for measuring the texture of corn masa and tortillas (31-35). Staling occurs rapidly after baking; amylase retrogrades rapidly and cannot be reversed. The retrograded amylase molecules can be redispersed during warming to give a flexible tortilla for a short time. Once the freshened tortilla cools, the rigid structure resets; the tortilla is brittle and difficult to freshen again. A procedure that stabilizes fresh tortillas by methanol extraction followed by drying and uses the residue for analysis with an RVA is effective to determine changes during staling (36). This method shows that nixtamalized corn, sorghum, and DMF tortillas change rapidly after production. The RVA curves are related to changes observed in the objective and subjective texture measurements of the tortillas.

High-pH tortillas are softer than lower-pH tortillas; waxy corn and sorghum grains substituted for 10-15% normal maize significantly improve flexibility of fresh and rewarmed tortillas. Waxy corn starches added to DMF significantly improve tenderness and friability of baked tortilla and corn chips.

The use of 1% wheat gluten and 5% native soy flour in DMF tortillas improves their texture and acceptability significantly. Above those levels, the flavor of the tortillas is no longer that of corn tortillas. A combination of CMC and amylose enzymes appears to improve the flexibility of corn tortillas, while use of emulsifiers alone makes tortilla texture deteriorate. Various emulsifiers in corn tortillas do not produce much response unless relatively high levels are utilized. The cost and functionality does not warrant their use at this time.

Several methods have been tested for evaluating the texture of maize tortillas (32-34). The extensibility test, which measures the force needed to extend a tortilla until it breaks, is highly correlated with other objective methods and with subjective tests of rollability and flexibility. Subjective evaluation of rollability and pliability are effective; the objective methods are helpful to study effects of ingredients and their interactions.

Special Products
Blue corn tortillas and tortilla chips are often served in specialty restaurants and are available as organic and regular products. Blue corn has a pigmented aleurone layer with very soft, floury endosperm. It is difficult to cook; the aleurone and pericarp are retained, giving an intense blue or black product. The pH affects the color significantly, along with the type of cultivar. Blue corns are open-pollinated, late-maturing, tall plants that have significantly reduced grain yields. Blue corn hybrids are being developed, but the color is often not intense enough. Blue corns likely have very high levels of flavonoids and other phenolics that may have nutraceutical properties. Red corn, sweet corns, and soft, floury large kernel types are used in snacks. Certain companies also have one or more proprietary hybrids that are used for their products.

Tortilla Chips
Special processes to produce baked, low-fat tortilla chips have been developed that combine air impingement, infrared, and microwaves. Special ingredients are sometimes used to improve the texture and to attach flavors to baked chips. FritoLay, Inc. has a product line fried in olestra, which is indigestible. In general, these products are very similar to their counterpart oil-fried products. Subjective differences in texture that relate to the higher melting point of olestra are evident as a coating in the mouth. The role of these products remains to be determined. The extra cost, problems related to waste disposal, digestive upset in some consumers, and consumer perception of low-fat products may affect their success.

White corn tortilla chips have increased in popularity with consumers in non-Hispanic areas of the country. The sweeter, more intense maize flavor and taste of white corn tortilla chips has caught on with consumers. The strong flavor of the β-lactone and related compounds in yellow tortilla chips masks the corn flavor. The availability of significantly improved white corn hybrids enables their use in these products.

Sorghum Nixtamalization and Use
Sorghum is utilized for tortillas in Central America by hillside farmers who interplant maize and sorghum. The sorghum is nixtamalized and used in tortillas, usually as a mixture with maize (35). Sorghum tortillas have a bland flavor and darker color than white maize tortillas (7,17). Breeding programs to improve sorghum quality for tortillas continue to be effective; new sorghum cultivars with vastly improved tortilla-making properties are being grown and utilized (39). The cooking and steeping time of sorghum is significantly reduced from that of maize. Sorghum is not preferred for tortillas, but it is used in significant quantities in some areas of Central America.

Alkaline Cooking and Maize Future
The availability, storability, and low cost of corn-based snack foods will fuel significant expansion worldwide in the 21st century. In many countries, corn products will become an important part of the cuisine. Alkali cooking in some form or other is likely to be used to expedite preparation of an array of foods from snacks to breads. Biotechnology will produce maize plants that will have unique properties for these foods.

Acknowledgments
We thank legions of former graduate students and technical support personnel who have been involved in our long-term efforts to understand maize processing and all its ramifications. We are grateful for continued partial support over many years from the Snack Foods Association, the Tortilla Industry Association, the food industry, the Texas Agricultural Experiment Station, the Agency for International Development Title XII CRSP on Sorghum and Millet Improvement, and the Lawrence Equipment Co.

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