# Influence of Kernel Damage on Corn Nutrient Composition, Dry Matter Losses, and Processability During Alkaline Cooking

H. D. Almeida-Domínguez,[1] G. G. Ordoñez-Durán,[2] and N. G. Almeida[3]

## ABSTRACT

Cereal Chem. 75(1):124–128

The nutrient losses of corn containing 0–30% damaged kernels that occurred during alkaline cooking into tortillas were examined. Samples from different stages during processing were tested for chemical composition and protein fractionation. The most prevalent type of kernel damage was mechanical, followed in decreasing order by molds, insects, heat, and rodent damage. Corn with higher content of damaged kernels was susceptible to overcooking, resulting in cracked or fully open nixtamal kernels and sticky masa that were difficult to handle during processing. Nutrient losses increased with increasing levels of kernel damage. Most nutrient losses from sound corn kernels occurred during washing as the pericarp and attached solids were removed. During simmering, damaged corn kernels were fully cooked into physically opened kernels with more nutrients being extracted into the water. About 15% of total solids and 50% of both crude fiber and fat were lost during cooking of corn with 30% kernel damage. The greatest losses were consistently observed for albumins and globulins from both sound and damaged kernels at all stages of cooking. Appropriate control of kernel damage level is required to improve yield of product with consistent quality. The susceptibility to overcooking of excessively damaged corn increases the complexity to consistently meet product quality specifications. Excess dry matter losses in the cooking liquor can significantly increase the risk of environmental contamination and cost of sewage water treatment.

Corn tortillas have been a staple food in Mexico and Central America for many centuries and have rapidly moving into other countries during the last decade. The 1994 tortilla and tortilla chips sales in the United States were $5 billion (Barret 1996). Presently, tortillas and tortilla chips manufacturing plants are in operation, and others in construction, in several countries in Europe and Asia. The increased presence of alkaline-cooked corn products in the food industry emphasizes the importance of maintaining high, consistent product quality standards as related to sensory characteristics and nutritional value to secure its participation in the market.

During alkaline cooking, corn kernels are simmered in excess water in the presence of lime ($CaOH_2$), steeped, ground to produce masa, sheeted and cut, and baked to produce tortillas. Tortilla chips require an additional frying step. Masa is also used for other snacks and dishes. Control of the grain quality is fundamental to assure consistent cooking level required for masa texture and quality of the product. Kernel characteristics, including kernel size, density, and endosperm hardness have been reported to significantly affect the alkaline cooking performance of corn (Martinez-Herrera and Lachance 1979, Bedolla and Rooney 1982, Herrera et al 1986, Serna-Saldivar 1993).

Corn kernel characteristics are defined by environment and genetics, and then further affected during harvesting, drying, storage and handling (Thompson and Foster 1963, Peplinski et al 1975, Pierce and Hanna 1985, Bauer and Carter 1986, Vyn and Moes 1988). The combined effects of harvesting of corn with high moisture, rapid drying at high temperature, and mechanized harvesting and handling promote development of tension, compression, and shearing stress in kernels that can result in formation of fissures and cracks. Fissured kernels are highly susceptible to breakage during storage and handling. Some of these conditions occur during normal commercial grain production operation. Broken kernels are easily detectable and used as grading criteria. However, accurate assessment of stress cracks and fissured or chipped kernels is not as easy to achieve in large bulk corn loads. Unexpected increases in kernel damage levels can result in inappropriate and often excessive alkaline cooking.

Excess cooking increases dry matter losses (Bressani et al 1958, Pflugfelder et al 1988) that results in lower product yield and loss of nutrients into the sewage water. Achieving minimum dry matter losses is important to maintain low production costs and maximum nutrient content in the product. The nutritional contribution of tortillas consumed as staple foods or tortilla chips as snacks is a direct benefit to consumers and high nutritional quality must be maintained. Attempts to improve the nutritional quality of tortillas and chips are numerous, including addition of legumes, leaf proteins, and utilization of high lysine and tryptophan corn (Parades-Lopez and Saharopulos-Parades 1983, Ortega et al 1986, Bressani et al 1990, Barron and Espinoza 1993). However, in any case, appropriate assesment and monitoring of the kernel quality is fundamental to control the corn alkaline-cooking process and achieve maximum retention of nutrients in a product with consistently high quality.

The purpose of this study was to determine the type and extent of the effect of kernel damage on the performance and nutrient losses of corn during alkaline cooking to make tortillas.

## MATERIALS AND METHODS

### Raw Materials

Commercial food-grade corn (10.8 ± 1.1% moisture content) was obtained from a storehouse in Mérida, Yucatán, México, and was manually examined, separating damaged from sound kernels. A blend of kernels damaged by mold, insects, and rodents, as well as mechanically damaged kernels was put together maintaining the same proportion of damaged kernels found in commercial corn. All foreign material was removed and discarded. Subsequently, corn blends containing 0, 15, and 30% (w/w) damaged kernels were formulated by adding calculated amounts of damaged kernels blend to sound kernels.

### Alkaline Cooking Process

Corn (3.5 kg) was simmered in a fired-heated 50-L aluminum pot containing 11 L of water and 35 g of lime for 30 min at 95–98°C and steeped overnight (12 hr) to produce nixtamal (alkaline-cooked corn kernels). Nixtamal was hand-washed in running water and stone ground into masa. Masa was shaped into tortilla pieces (30 g per piece, 3 mm thick) with a hand-press and then baked on a griddle at 240–280°C surface temperature for 30 sec each of the first, second, and first side (again) to produce tortillas.

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[1] Cereal Quality Lab., Soil & Crop Sciences Dept., Texas A&M University, College Station, TX 77843-2474. Corresponding author. E-mail: H-almeida@tamu.edu Phone: 409/845-2967. Fax: 409/845-0456.

[2] Div. de Estudios de Graduados e Investigación, Instituto Tecnológico de Mérida, Km. 5 Carretera Mérida-Progreso. Mérida, Yucatán 97118. México.

[3] Centro de Investigación en Alimentación y Desarrollo, A.C., Km. 0.6 Carretera A La Victoria. Apdo. Postal 1735. Hermosillo, Sonora 83000. México.

Publication no. C-1998-0107-07R.

All corn blends were processed in the same manner. Weights of nixtamal and tortillas were recorded to calculate product conversion ratios expressed as kilogram of product per kilogram of raw corn. Samples of raw grain, unwashed nixtamal, cooking liquor (containing a blend of both cooking and washing waters), and tortillas were collected and dried in a forced-air oven at 55°C for testing. Dry samples were stored in the freezer in low density polyethylene bags until testing.

### Physical Analyses

Grain samples (100 g) were manually examined for foreign material and damaged kernels. Contents (%) of damage from blue-eye mold, insect boring, rodent bites (mostly at the germ), and heat (caused by external heat, drying), as well as mechanically damaged kernels were recorded (USDA 1993). Husk pieces, stones, dirt, dust, and kernels other than corn were considered foreign material. Mechanical damage included broken, cracked, chipped, and fissured kernels.

### Chemical Analyses

Moisture, ash, crude fat, crude protein (N × 6.25) and crude fiber content of corn, nixtamal, solids from cooking liquor, and tortillas was determined (AACC 1995). Samples were cyclone milled (model 3010-030, Udy Corp., Fort Collins, CO) milled through a 1-mm screen before analysis.

### Protein Fractionation

Protein fractions were sequentially extracted from cyclone-milled samples of corn, nixtamal, and tortillas (Jambunathan and Mertz 1973). Albumins were extracted from a 1-g sample with 20 mL of deionized water with horizontal shaking at 150 cycles/min for 15 min at 25°C. Subsequently, samples were centrifuged at 3,200 × *g* for 10 min, and the supernatant decanted into an Erlenmeyer flask. The extraction was repeated with the supernatant recovered into the same flask. The precipitate from albumin extraction was extracted with 20 mL of 0.5*M* NaCl with shaking and then centrifuged to obtain the globulin fraction. The extraction process was conducted three times for 60, 30, and 15 min, respectively, collecting the supernatant into the same flask. The precipitate from globulin extraction was extracted with 20 mL of a 70% (v/v) isopropanol, 0.6% (v/v) 2-mercaptoethanol, and water solution with shaking for 30 min, and then centrifuged for 10 min to obtain prolamins. Extraction was repeated collecting the supernatant into same flask. The precipitate from prolamin extraction was extracted with 20 mL of a solution of 25% (v/v) buffer (1.2% boric acid and 2.9% NaCl in water), 22% (v/v) 0.2*N* NaOH, 0.6% (v/v) 2-mercaptoethanol, and 0.5% (v/v) sodium lauryl sulfate with shaking, followed by 10 min of centrifugation to obtain glutelins. Extraction was conducted three times for 60, 30, and 15 min, respectively, collecting the supernatant into same flask. Supernatants from all four extractions were analyzed for nitrogen (AACC 1995). Protein fraction percentages were calculated based on initial sample protein content. The residue was calculated by difference after subtraction of the four protein extracts from the total protein content.

### Mass Balance

Mass balance using product yield, chemical composition, and protein fractionation data was conducted on a dry basis to determine the trajectory of solids and nutrients during processing. The content of solids, nutrients, and protein fractions were calculated as percent relative to raw corn.

### Experimental Design and Statistics

The effect of kernel damage level on alkaline cooking characteristics of corn was evaluated using one-way analysis of variance in a completely randomized design with three replicates. All analyses were conducted in triplicates. Protected Fisher's least significant differences were used for mean comparison.

## RESULTS AND DISCUSSION

Mechanical damage was the major cause of kernel deterioration, followed in decreasing order by mold, insects, heat, and rodents (Table I). Kernel maturity level at harvest, harvesting practices, and handling and storage conditions directly affect grain quality (Thompson and Foster 1963, De Dios 1973, Peplinski et al 1975, Vyn and Moes 1988). Immature kernels tend to be soft with high moisture content that require additional drying before storage. Inadequate control of the drying process in which kernels are exposed to extreme temperatures and air humidity levels are potential conditions to create gradients of moisture content inside kernels that result in fissuring and cracking. A 77% content of stress-cracked corn kernels has been reported by Pierce and Hanna (1985) for on-farm handling of mechanically harvested corn with 19% moisture (at harvest). Most of the cracking occured during drying, while the mechanical seed coat damage occured during harvesting. Breakage susceptibility becomes of major importance when handling fissured kernels. Mechanical harvest and handling (moving, lifting, dropping, and unloading grain) involve high-impact and shearing conditions that can promote breakage of kernels. Fissures are weak areas where kernels fail following tension, compression, or shear forces resulting in breakage. The exposure of kernel contents caused by mechanical damage, insect boring, and rodent bites combined with an increased permeability of the outer layers caused by heat (wrinkled, fractured pericarp) and mold (partially digested germ) are potential conditions that affect the alkaline cooking performance of corn. The effect of kernel damage was magnified by manually formulating corn blends with up to a total of 30% damaged kernels (the distribution of the various types of damage was kept as in the original commercial sample).

The level of kernel damage affected the conversion ratio of products obtained during alkaline cooking of corn (Table II). Increased kernel damage level increased the conversion ratio of nixtamal before and after washing due to the increased water uptake. However, no practical differences were found in the conversion ratio of tortillas (average = 1.52 kg of tortilla/kg of corn). Resulting values represent the combined effects of weight increase due to water uptake during boiling and steeping, and weight decrease due to dry matter losses during boiling, steeping and washing, and dehydration during baking.

**TABLE I**
**Grain Inspection Characteristics (%) of Commercial Corn and Formulated Corn Blends[a]**

| | | Type of Damage[b] | | | | |
|---|---|---|---|---|---|---|
| Corn | Foreign Material | Insect | Rodent | Mold | Mechanical | Heat |
| Commercial | 5.5 | 0.7 | 0.01 | 1.0 | 6.7 | 0.5 |
| Formulated experimental blends (% kernel damage level) | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0 | 1.0 | 0.01 | 1.5 | 9.6 | 0.6 |
| 30 | 0 | 2.0 | 0.03 | 3.0 | 19.2 | 1.2 |
| LSD[c] | · · · | 0.2* | 0.01* | 0.5* | 1.0* | 0.2* |

[a] Values are means of three replicates.
[b] Manually examined fractions.
[c] * = Least significant difference ($P < 0.05$).

Dry matter losses into the cooking liquor during cooking of commercial corn and corn with 0% damage kernels ranged from 8.0 to 8.6%. These losses increased by 5% when kernel damage level increased from 0 to 30%. Extraction of solids into the cooking liquor increased as the contents of damaged kernels were more exposed. Broken kernels significantly increase dry matter losses during cooking (Jackson et al 1988). Nixtamal from highly damaged corn was overcooked, resulting in kernels that were manifestly open and masa that was significantly stickier than that from corn with lower damage level. Furthermore, tortillas from damaged corn became rigid and brittle faster than those from sound corn. Total corn dry matter losses ranged from 8.5 to 12.5% in commercial operations that use the traditional batch alkaline cooking (simmering) followed by overnight steeping (Pflugfelder et al 1988). Potential causes of increased dry matter losses include utilization of damaged or soft endosperm kernels, excess cooking or simmering and steeping, and mechanical abuse during mixing, pumping, and washing.

**TABLE II**
**Conversion Ratios (product weight/corn weight) of Products Obtained During Alkaline Cooking of 3.5 kg of Corn to Produce Tortillas[a]**

| | Nixtamal | | | |
|---|---|---|---|---|
| **Corn** | **Before Washing** | **After Washing** | **Tortillas** | **Dry Matter Losses (%)[b]** |
| Commercial | 2.44 | 2.10 | 1.52 | 8.0 |
| Formulated experimental blends (% kernel damage level) | | | | |
| 0 | 2.39 | 2.06 | 1.49 | 8.6 |
| 15 | 2.53 | 2.14 | 1.54 | 11.8 |
| 30 | 2.54 | 2.22 | 1.54 | 13.9 |
| LSD[c] | 0.06* | 0.05* | 0.05 | 1.5* |

[a] Values are means of three replicates based on the initial as-is corn weight.
[b] Solids from cooking and washing waters based on initial corn dry weight.
[c] * = Least significant difference ($P < 0.05$).

**TABLE III**
**Proximate Composition (%) of Products Obtained During Alkaline Cooking of 3.5 kg of Corn to Produce Tortillas[a]**

| **Property** | **Corn** | **Nixtamal Before Washing** | **Tortillas** | **LSD[b]** |
|---|---|---|---|---|
| Commercial corn | | | | |
| Moisture | 11.6 | 66.1 | 48.7 | 1.5* |
| Protein (N ×6 .25) | 9.6 | 9.4 | 9.7 | 0.5* |
| Fat | 3.4 | 2.8 | 2.0 | 0.4* |
| Starch | 79.7 | 79.1 | 81.1 | 0.5* |
| Ash | 1.6 | 1.9 | 1.6 | 0.2* |
| Crude fiber | 2.6 | 2.4 | 1.6 | 0.2* |
| Formulated corn (0% damage) | | | | |
| Moisture | 11.6 | 63.7 | 46.1 | 1.6* |
| Protein (N × 6.25) | 8.1 | 7.9 | 8.4 | 0.5 |
| Fat | 3.2 | 3.1 | 2.3 | 0.4* |
| Starch | 79.9 | 79.5 | 81.0 | 0.7* |
| Ash | 1.5 | 2.0 | 1.6 | 0.3* |
| Crude fiber | 2.5 | 2.4 | 1.8 | 0.1* |
| Formulated corn (15% damage) | | | | |
| Moisture | 11.8 | 67.4 | 49.4 | 1.6* |
| Protein (N × 6.25) | 7.9 | 8.1 | 8.2 | 0.3 |
| Fat | 3.4 | 3.0 | 1.9 | 0.3* |
| Starch | 79.4 | 79.2 | 81.2 | 0.5* |
| Ash | 1.5 | 2.0 | 1.7 | 0.1* |
| Crude fiber | 2.7 | 2.7 | 1.5 | 0.2* |
| Formulated corn (30% damage) | | | | |
| Moisture | 11.4 | 70.2 | 51.2 | 1.4* |
| Protein (N × 6.25) | 7.8 | 8.1 | 8.0 | 0.4 |
| Fat | 3.6 | 2.8 | 1.8 | 0.3* |
| Starch | 79.5 | 81.7 | 81.9 | 0.6* |
| Ash | 1.6 | 1.8 | 1.7 | 0.1* |
| Crude fiber | 2.6 | 2.2 | 1.5 | 0.2* |

[a] Values are means of three replicates (db). Moisture content is as-is basis.
[b] * = Least significant difference ($P < 0.05$).

The increased water uptake (Table III) of corn with a high level of kernel damage resulted in an increased weight of wet nixtamal in spite of the increased losses of dry matter (Fig. 1). However, the yield-increasing effect of the higher moisture content of nixtamal was reduced in magnitude by the dehydration that occured during baking, resulting in practically similar tortilla conversion ratios. The increased dry matter losses caused by increased kernel damage level was evenly counteracted by the increase of moisture content of tortillas.

It is important to note that even though the effect of kernel damage level on tortilla conversion ratio was not statistically significant, the machinability characteristics and quality of tortillas from highly damaged corn were undesirable. Damaged corn can be easily overcooked, producing high levels of dry matter losses and sticky masa. Bedolla and Rooney (1982) reported that corn with >4% cracked kernels is very susceptible to produce sticky masa unless the cooking extent is significantly reduced as compared to sound kernels. Sticky masa is difficult to sheet. Final tortillas dehydrate rapidly becoming rubbery and then rigid upon cooling.

The rate of water uptake during the cooking process is regulated by the ability of water to penetrate the pericarp into the kernel and the cell walls to hydrate starch, fiber, and protein. When cooking sound kernels, the combined effects of lime and heat degradates the waxy pericarp cover, softens the pericarp, and promotes penetration of water into the kernel. High rates of water uptake can be attributed to increased surface area of small kernels, air spaces from floury endosperm, weakly bound cell contents from soft endosperm, and the presence of fissures, cracks, and chips in kernels.

Most of the solids losses from sound kernels occured during the washing step due to removal of the kernel outer layers (Fig. 1). As the level of kernel damage increased, the losses of dry matter during boiling and steeping increased significantly. In commercial operations, the stirring, pumping, and washing are responsible for most dry matter losses that occur after cooking (Pflugfelder et al 1988). Damaged kernels generally have increased dry matter losses during steeping. Similar trends were observed for individual nutrients.

A small increase in the protein and starch concentrations of corn during processing into nixtamal and tortillas was observed due to the concentration effect caused by the losses of fat and fiber at all kernel damage levels (Table III). The concentrations of fat and crude fiber decreased significantly during processing. The losses of fat and fiber were due to the removal of germ and pericarp during processing. Similar protein and fat concentration values and loss trends were observed by Bressani et al (1990) during alkaline cooking of corn.

The mass balance indicated that ≈40% of each of the fat and crude fiber contents of the original sound grain was lost during processing. When the content of damaged kernels increased to 30%, the losses of fat and crude fiber increased to >50%. Protein losses during corn tortilla production increased from 6 to 12% when kernel damage level increased from 0 to 30%, whereas starch losses increased from 8 to 13%. Lower losses of fat (ether extract, 17.5%), starch (4.6%), and protein (1.8%) have been reported for a commercial alkaline-cooking operation (Pflugfelder et al 1988). Possible reasons are the use of better quality corn (intermediate-hard endosperm, less kernel damage) and application of minimum cooking during commercial processing to achieve high product yield.

The kernel and cell contents from damaged corn were overexposed during cooking. The presence of kernel fissures favors susceptibility to overcooking (Bedolla and Rooney 1982). Exposed nutrients are dissolved and particles dispersed in the cooking-steeping water. Additional dry matter losses can be expected when opened cooked kernels are mechanically washed and pumped (conveyed) during processing. Soft, open, and highly hydrated cooked kernels are extremely sensitive to breakage by compression and shearing forces applied during machine handling. The overall solids lost during processing, carried into the cooking liquor, are responsible for increased plant sewage costs.

The fractionation of proteins showed that albumins and globulins were the main groups of proteins lost during alkaline cooking (Table IV). The final tortillas contained 56, 47, 79, and 74% of the albumins, globulins, prolamins, and glutelins, respectively, of the raw sound grain. The amount of proteins gone into the extraction residue increased five- to sevenfold as a result of processing into tortillas. Alkaline-cooking treatment reduced the ability of corn proteins to solubilize in any of the solvent systems used for extraction. All protein fractions were mostly lost during the cooking and steeping stages into the water liquor. This effect was observed in both sound and damaged corns. Significant reductions of albumin and globulin fractions during alkaline cooking of corn have been reported elsewhere (Ortega et al 1986, Vivas et al 1987). A reduction of protein solubility measured as an increased amount of protein residue obtained after extractions was also reported.

Damaged corn had a lower content of prolamins than sound corn. This was possibly due to the loss of endosperm fractions that occurs in mechanically damaged, broken, and insect-bored kernels. All prolamins are contained in the endosperm tissues.

The recovery (content relative to raw grain) of all the individual protein fractions in tortillas were decreased with increased kernel damage level. Recovery of albumins and globulins in tortillas from sound kernels (56.8 and 47.4%) was greater than that from damaged kernels (51.3 and 46.4%). Tortillas from damaged kernels had higher albumin and globulin contents when compared to those from sound kernels. This effect was likely due to the greater albumin and globulin content of the raw damaged corn used for processing and a concentration effect that occured at expense of the prolamin and glutelin losses during cooking. Protein losses were caused by the combined effect of the losses of dry matter and losses of specific protein fractions into the cooking liquor.

Processing of damaged corn through a standardized alkaline cooking operation will result in overcooking with excess dry matter and nutrient losses into the cooking liquor. The resulting masa and tortillas will have inferior quality. Our study showed that masa will tend to be sticky with low machinability, and tor-

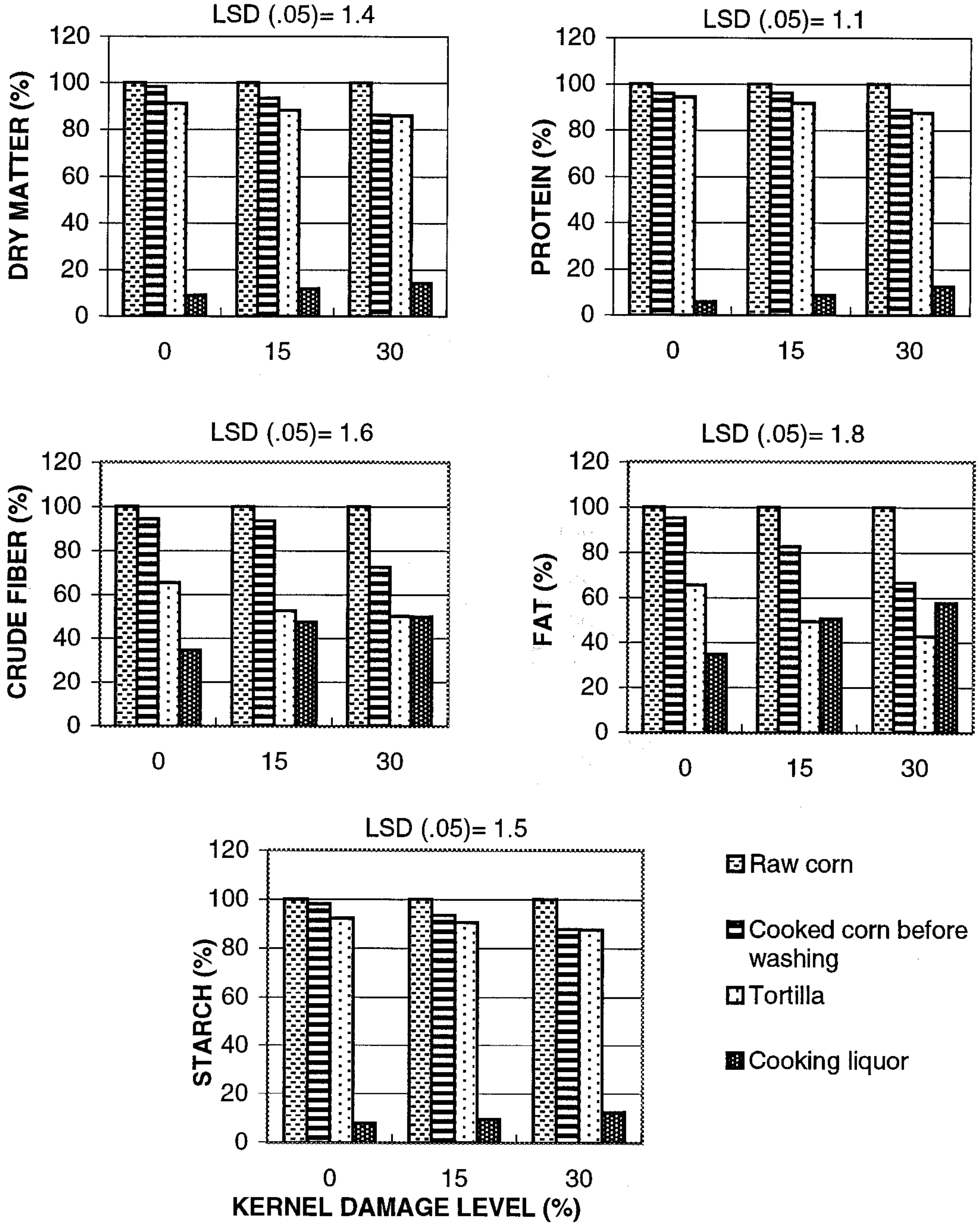

**Fig. 1.** Contents of dry matter, protein, crude fiber, fat, and starch of products obtained during alkaline cooking relative to the total initial content of 3.5 kg of of raw corn containing different kernel damage levels.

**TABLE IV**
**Protein Fractionation (g/100 g of protein) and Relative Content (% based on raw grain content) of Products Obtained During Alkaline Cooking of 3.5 kg of Corn Containing Different Kernel Damage Levels[a]**

| | Corn | | Nixtamal[b] | | Tortillas | | |
|---|---|---|---|---|---|---|---|
| **Protein Fraction** | **g/100 g of protein** | **%** | **g/100 g of protein** | **%** | **g/100 g of protein** | **%** | **LSD[c]** |
| Formulated corn (0% damage) | | | | | | | |
| Albumins | 15.1 | 100 | 9.5 | 60.2 | 9.1 | 56.8 | 3.1* |
| Globulins | 17.3 | 100 | 7.4 | 40.2 | 8.7 | 47.4 | 4.9* |
| Prolamins | 24.0 | 100 | 15.4 | 61.3 | 20.2 | 79.3 | 2.8* |
| Glutelins | 37.4 | 100 | 22.9 | 58.6 | 29.6 | 74.5 | 3.8* |
| Residue[d] | 5.9 | 100 | 44.7 | 737.7 | 32.4 | 526.1 | 5.0* |
| Formulated corn (30% damage) | | | | | | | |
| Albumins | 16.8 | 100 | 8.6 | 45.4 | 9.9 | 51.3 | 4.6* |
| Globulins | 18.3 | 100 | 7.0 | 33.9 | 9.7 | 46.4 | 3.8* |
| Prolamins | 22.0 | 100 | 16.3 | 65.7 | 19.5 | 77.1 | 5.6* |
| Glutelins | 38.0 | 100 | 27.5 | 63.8 | 30.1 | 68.8 | 5.9* |
| Residue[d] | 4.9 | 100 | 40.6 | 735.0 | 30.7 | 544.9 | 3.2* |

[a] Values are means of three replicates.
[b] Before washing.
[c] * = Least significant difference ($P < 0.05$).
[d] Values calculated by difference after subtraction of the four protein fractions.

tillas will stale rapidly, becoming excessively rigid upon cooling. The cooking process must be adjusted or tailored specifically, as well as very closely monitored, to practically overcome the undesirable effects of corn damage. Controlling the cooking extent by means of lower temperatures and controlled times can be an option to avoid overcooking while achieving partial hydration of kernels. The stone grinder must be adjusted to a fine grinding with addition of regulated amounts of water to produce masa with adequate cohesiveness and softness. Hopefully, the minimum cooking applied at low temperature will restrict the losses of nutrients and improve the tortilla yield and quality. Tortilla processors are aware that there are times when corn with certain damage level is the only raw material available for processing that the margin of profit permits them to use. They have to learn how to modify their processes for optimum machinability and product composition and quality.

## CONCLUSIONS

The presence of damaged kernels increased the losses of total solids and nutrients during alkaline cooking of corn to produce tortillas. Damaged corn kernels were highly susceptible to overcooking, producing sticky masa and tortillas that rapidly became excessively rigid, where sound kernels produced acceptable masa and tortillas. Broken and cracked kernels were open during simmering and steeping, resulting in exposure of endosperm and cell contents that favored nutrient extraction into the cooking liquor.

Crude fiber and fat were the components with the largest losses into the steeping liquor, followed by carbohydrate and protein in decreasing order. The losses of tortilla protein fractions increased with increased kernel damage level.

Appropriate modification of the alkaline-cooking conditions is fundamental when processing damaged corn to avoid excessive solids losses while maintaining acceptable quality of masa and tortillas. Quantitative measurements of the relationship between corn kernel damage level and optimum cooking conditions (time, temperature, etc.) is still needed by the corn alkaline-cooking industry for process control purposes and optimization of product quality.

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