Alkaline Processing Properties of Stress-Cracked and Broken Corn (*Zea mays* L.)[1]

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ABSTRACT

Samples of three food-grade corn hybrids (Dekalb Pfizer T1100, Pioneer 3780, and Asgrow 405W) with different levels of stress-cracked kernels were alkaline cooked using mild and harsh laboratory procedures. Stress-cracked grains, in general, did not significantly increase the levels of dry matter and chemical oxygen demand of the cook-steep water. However, stress-cracked grains can easily break when handled, and broken kernels greatly increased dry matter loss and chemical oxygen demand. The pericarp of the Asgrow 405W hybrid was easily and completely removed during processing, whereas those of Dekalb Pfizer T1100 and Pioneer 3780 were only partially removed. Samples cooked using the harsh procedure had greater dry matter losses and chemical oxygen demand than those cooked under the mild procedure. Methods of determining stress-cracked and broken kernels were compared. Percent breakage, as determined with the Wisconsin breakage tester, was significantly correlated with visual identification of multiple and total numbers of stress-cracked kernels. The Wisconsin breakage tester can be used to screen corn for potential breakage. The level of broken kernels and the ease of pericarp removal were the major factors influencing chemical oxygen demand and dry matter loss. Any protocol for assessing corn quality for alkaline cooking should include measures of broken kernels, potential for breakage, and ease of pericarp removal.

Alkaline-processed corn (*Zea mays* L.) products are prepared by cooking and steeping whole kernels in a calcium hydroxide solution. Then the cooked corn (nixtamal) is removed from the cook-steep water (*nejayote*), washed, and ground into a dough (masa). Masa is shaped and further processed into tortillas, tacos, tortilla chips, corn chips, or related products. The solids and solubles in the *nejayote* and wash water must be discarded.

Alkaline cooking-steeping times and product yields are different depending upon the corn variety used in processing. Corn with a "hard" or corneous endosperm texture requires longer cooking (Rooney and Serna-Saldivar 1987) but cooks in a more predictable fashion than "soft" corn (Ellis et al 1983). Optimum nixtamal moisture for tortilla production is around 52% (Bedolla and Rooney 1982).

Corn mechanically shelled, artificially dried, and transported by commercial conveyors frequently has small internal fissures (stress cracks) and broken kernels. Although the cause of this damage is usually undocumented, the damage can lower the U.S. grain grade and result in food processing losses. The use of stress-cracked and broken kernels results in large dry milling losses (Brekke 1968, Manoharkumar et al 1978, Paulsen and Hill 1985), but few data have been published on the effects of using fissured or broken kernels during alkaline processing. However, Bedolla and Rooney (1982) reported that damaged kernels resulted in sticky masa.

The purpose of this study was to evaluate the cooking and steeping losses associated with the alkaline processing of corn with different levels of stress-cracked and broken kernels.

MATERIALS AND METHODS

Grain Samples

Three food-grade corn hybrids were obtained for this study (Table I). One, Asgrow 405W (405W), is a white cob, hard white kernel hybrid grown in south Texas. Two softer yellow kernel, red cob corn hybrids, Dekalb Pfizer T1100 (T1100) and Pioneer 3780 (3780), were grown and obtained from a food corn supplier in Wisconsin.

Three samples of T1100 corn from the same lot were prepared by the food corn supplier. The first sample was elevator dried with heated air at 60° C, tempered in a bin for 6 hr, and then cooled with ambient temperature air. The second sample was batch dried in a bin dryer at 43–49° C, then cooled with ambient temperature air. The third sample was allowed to dry in the field.

Two samples of 3780 from the same lot were also prepared by the food corn supplier. The first sample was elevator dried with heated air at 46° C, tempered in a bin for 6 hr, and then cooled with ambient temperature air. The second 3780 sample was bin (batch) dried at 43–49° C. All grain samples were mechanically shelled before drying, but the exact relative humidities and specific drying histories of the commercially prepared samples are not known.

The Texas grown 405W was dried in the field, mechanically shelled, and stored at −10° C until it was separated into three samples for this study. The first sample remained untreated. The second and third samples were submerged in 22° C water for 1 hr, drained and blotted dry, and then allowed to equilibrate at room temperature (24° C, 33% rh) for 72 hr. The third sample, after equilibration, was subsequently treated to induce broken kernels by placing the corn in a commercial Hobart mixer (model A-200, 1/3 HP) for 10 min on low speed. Fines were removed by passing the corn through a 4.76-mm mesh sieve. All grain samples, after preparation, were stored at −10° C until used.

Stress-Cracked and Broken Kernels

Three replicates of 100 kernels per sample were observed under a bright light. Grains from each sample were visually classified as undamaged, single stress cracked, multiple stress cracked, or checked/crazed (Thompson and Foster 1963). Kernels with exposed endosperm were classified as broken kernels.

The surface area of exposed endosperm was quantified by using the fast-green colorimetric test described by Chowdhury and Buchele (1976). The test was repeated three times for each grain sample; absorbance of dye solutions at 610 nm was determined using a Bausch & Lomb Spectronic 21 spectrophotometer.

Breakage Susceptibility

Breakage susceptibility was determined using a Wisconsin breakage tester (model 9/84, serial no. C0220, 1,800 rpm) as described by Watson and Herum (1986) and Pomeranz et al (1986). A 220-g sample of corn, precleaned over a 4.76-mm mesh sieve for 90 sec on a modified Strand shaker (serial no. SS-102), was fed into the Wisconsin breakage tester. After breakage, the sample was sieved again for 90 sec, and the overs were weighed. The percent breakage (four replicates) was calculated by dividing the difference between the initial and final sample weight by the initial sample weight, then multiplying the result by 100.

Tangential Abrasive Dehulling Device (TADD) Hardness Index

The TADD was used to determine an index of hardness (Reichert et al 1986). Samples (40 g) of corn were placed in each of eight sample cups and abraded for 10 min. The percentage of

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sample removed during abrasion was calculated as the TADD index. Sample measurements were replicated five times.

Density Related Measures

Bulk density was measured with a Winchester bushel meter. Thousand-kernel weight was determined by hand counting 100 whole kernels of each sample and multiplying their weight by 10. Density was determined using a Beckman air-comparison pycnometer (model 930); two readings were performed on each replicate. The percentage of floaters (Wichser 1961) was determined using a sodium nitrate solution maintained at 15.6°C with a specific gravity of 1.250. Three replicates were performed for all tests.

Ease of Pericarp Removal

The ease of pericarp removal was determined subjectively by the method described by Goldstein (1983). Five kernels were soaked in 2*N* NaOH solution. The extent of pericarp peeling/removal was evaluated and scored from one to five. If all five kernels had no pericarp attached after 3 hr, the sample received a score of one; if no pericarp was removed from at least 3 kernels after 3.5 hr, the sample received a score of five. The test was repeated three times.

Alkaline Cooking

Two alkaline cooking methods were used. For the first method, 2 kg of corn, 5 L of water, and 1% lime ($Ca[OH]_2$) on a corn weight basis (0.4% on a water basis) were added to a steam kettle (Dover Corp. model TDC/2-20). The top of the kettle was partially covered with a Plexiglass cover; the cover had a center hole to allow a Hobart mixer (A-200, 1/3 HP), operating at speed "1," to stir the mixture. The mixer was started, and steam heating began as soon as both the preweighed corn and lime were added to the water. The mixture was heated to a boil in an average of 3.25 min, and a steady boil with continuous stirring was maintained for 20 min. After cooking was completed, 2 L of quench water was added to the steam kettle. This dropped the nixtamal-*nejayote* temperature to approximately 62–66°C. Then the corn was allowed to steep 16 hr.

The second cooking method was designed to partially simulate a more vigorous commercial processing environment. The corn was cooked as described in the preceding paragraph, but after boiling, the cooked, hot corn and *nejayote* were removed from the cooking tank. The tank was rinsed with 1 L of water to remove any adhering solids, and the rinse water was mixed with the *nejayote* and placed in a Hobart cutter/mixer (model VCM 25) with an attached blunt S-shaped blade knead/mix attachment. The chopper was operated for two 5-sec pulses (10 sec total). This process was used to simulate the level of broken and damaged kernels seen in large commercial operations that pump nixtamal to steeping tanks after cooking. Also, to simulate commercial conditions in which relatively high steep water temperatures are found, the nixtamal and *nejayote* were then allowed to steep in an insulated chest. The initial steep water temperature was between 62 and 66°C for all trials, and fell to between 40 and 43°C after 16 hr.

After the nixtamal was steeped for 16 hr, the corn was washed (procedure applies to both cooking methods) with two 2-L aliquots of water (4 L total). Then the nixtamal and *nejayote* were separated over a 4.76-mm mesh sieve. The total recovered volume of *nejayote* was brought to a volume of 10 L with additional water, and representative samples of nixtamal and *nejayote* were collected for analysis. Masa and tortillas were made to assure that they could be produced from all nixtamal samples. Three replicates of all corn samples were cooked, each on separate days in a random sequence, for both cooking methods.

Product Loss Parameters

The sewage waste strength from the cooking process was quantified by determining the chemical oxygen demand (methods 33.034–33.038, AOAC 1984) of three homogenized *nejayote* and wash water replicates from each cook. The percent dry matter loss of the corn was determined by drying 10 ml aliquots of *nejayote*-wash water for 7 hr at 80°C. Dry matter loss was expressed as a percentage of the dry weight of grain and lime before cooking.

Moisture and Crude Protein

Raw corn and nixtamal moisture were determined according to ASAE standard S352.1 (1986). Protein (N $\times$ 6.25, db) was determined by AACC method 46-09 (1983) in raw corn and nixtamal. Three replicates of corn from each individual cook or raw sample were analyzed.

Statistical Design and Analysis

Raw corn moisture, pericarp removal, 1,000-kernel weight, kernel density, breakage susceptibility, bulk density, floaters, dye grain damage, and TADD hardness index values were statistically analyzed using a randomized complete block design, whereas stress cracks, broken kernels, protein, nixtamal moisture, chemical oxygen demand, and dry matter loss were analyzed using a completely randomized design. Analysis of variance was performed using the Statistical Analysis System (SAS) versions 5.0 and 5.1 (SAS Institute 1985). The raw data was used to calculate means, and the SAS-Duncan procedure was used for mean separation. The SAS Pearson Correlation procedure was used to determine correlation coefficients between all measured variables (Freund and Littell 1981).

RESULTS AND DISCUSSION

Physical Properties

The stress crack data (Table II) support the observations by Thompson and Foster (1963) that the formation and kinds of stress cracks reflect the severity of treatment stresses. Single cracks, caused by drying (for example), appear with mild stress; multiple cracks and checked/crazed kernels developed from more severe stresses. Single cracks were observed in an larger number of grains as stress was increased, but multiple cracks and checked/crazed grains began to develop before all kernels had a single crack. This observation was similar for all the hybrids. Therefore, it is more meaningful to judge the extent of stress-cracked kernel damage by examining the distribution of stress crack types within a sample, especially the numbers of both multiple and checked/crazed stress-cracked kernels.

The two artificially dried T1100 samples originally had the same levels of single stress cracks, but these levels were significantly higher than those of the T1100 sample that was allowed to dry in the field (Table II). Total stress cracks and combined multiple and

TABLE I
Corn Hybrids and Sample Preparation

Corn Hybrid	Treatment	Stress Crack Level	Abbreviation
Dekalb Prizer T1100	Dried at 60°C	High	T1100 High
	Dried at 43–49°C	Medium	T1100 Medium
	Dried in field	Low	T1100 Low
Pioneer 3780	Dried at 60°C	High	3780 High
	Dried at 43–49°C	Medium	3780 Medium
Asgrow 405W	Broken and stress cracked	High	405W Broken
	Stress cracked	High	405W High
	Untreated	Low	405W Low

checked/crazed kernels were significantly different among all three samples.

The 405W samples that were treated with water to induce cracking were significantly different from the untreated sample in both numbers of multiple cracked and checked/crazed kernels (Table II). The sample that was treated to induce broken kernels was significantly higher in the level of visually observed broken kernels than either of the other 405W samples.

The relative amount of exposed endosperm, as measured by the fast-green colorimetric test (Table II), showed clear differences between the water stress cracked 405W sample and the 405W sample that was treated to induce broken kernels. Both water-treated samples had the same stress crack levels, only a difference in the number of broken kernels. While it is apparent that the fast-green colorimetric test highlights the presence of exposed endosperm, an insufficient range of broken grain samples was used to judge its sensitivity.

Breakage susceptibility, as measured by the Wisconsin breakage tester (Table III), increased with greater numbers of stress cracks; significant differences were found between hybrid samples. Breakage susceptibility correlated with multiple and checked/crazed kernel counts ($r = 0.89$, $P < 0.01$; $r = 0.95$, $P < 0.001$, respectively) and with total stress crack counts ($r = 0.85$, $P < 0.01$). The Wisconsin breakage tester is a more rapid procedure to assess the presence of multiple cracked and checked/crazed appearing kernels than is visual classification. It would be especially useful for measuring stress cracks within given corn hybrids where kernel size and shape are similar.

The TADD hardness index indicated significant differences (Table III) within variety samples in their ability to resist tangential abrasive forces. The TADD index values indicated that the Asgrow hybrid is more abrasion resistant than the northern corns tested.

The air-comparison pycnometer density measurements of the northern corn samples (T1100 and 3780) were significantly lower than the 405W densities (Table III). The 1,000-kernel weights were not statistically different (Table III) within any hybrid. Thousand-kernel weight and density were positively correlated ($r = 0.98$, $P < 0.001$). Percent crude protein (Table III), for the corn hybrids examined, was correlated with both density ($r = 0.79$, $P < 0.05$) and 1,000-kernel weight ($r = 0.85$, $P < 0.05$).

The floaters test (Table III) indicated that the northern hybrids were softer than the 405W hybrid. Floaters were correlated with the TADD hardness index, density, and moisture ($r = 0.90$, $P < 0.01$; $r = -0.87$, $P < 0.01$; $r = 0.90$, $P < 0.01$, respectively).

The percent floaters shows a trend to increase with increasing stress damage within a variety. However, the broken 405W sample, the one anomaly, has a lower percentage floaters than its stressed only counterpart. It is likely that the less dense 405W kernels were those that broke during treatment; floaters values are obtained using intact kernels, and so only the most dense kernels remained unbroken in the Asgrow 405W broken sample.

Bulk density (Table III) was significantly correlated with those hardness indexes less susceptible to kernel packing: the TADD index ($r = -0.81$, $P < 0.05$) and floaters ($r = -0.76$, $P < 0.05$). Probably, because of different kernel sizes, bulk density was not well correlated with density ($r = 0.45$, $P < 0.26$).

Alkaline Cooking

When cooked under mild conditions (Table IV), the field-dried T1100 sample had lower chemical oxygen demand and dry matter loss values than the artificially dried T1100 samples. The field-dried T1100 was, by far, lower in stress-cracked kernels. Within-hybrid cooking properties were not significantly different between the two artificially dried T1100 samples or between the two 3780 samples.

The 405W samples showed no significant differences between the untreated and the stress-cracked (unbroken) sample in dry matter loss, chemical oxygen demand, or protein. The stress-cracked 405W had a higher nixtamal moisture than the untreated

TABLE II
Measurements of Stress Cracked and Broken Corn Kernels

Samples[a]	Single Stress Cracks (%)	Multiple Stress Cracks (%)	Checked Crazed Kernels (%)	Total Stress Cracks (%)	Multiple and Checked/Crazed (%)	Broken Kernels (%)	Fast-Green Grain Damage (A_{610})
T1100 High	20.7 a[b]	25.7 c	11.7 b	58.0 c	37.3 c	3.7 bc	0.075 bc
T1100 Medium	17.7 ab	11.7 d	3.0 c	32.3 d	14.7 d	2.7 c	0.058 bcd
T1100 Low	1.7 c	0.0 e	0.0 c	1.7 g	0.0 e	4.3 bc	0.025 d
3780 High	18.7 ab	46.0 b	10.3 b	75.0 b	56.3 b	4.0 bc	0.077 b
3780 Medium	13.7 b	12.0 d	2.0 c	27.7 e	14.0 d	2.3 c	0.051 bcd
405W Broken	2.7 c	74.7 a	22.7 a	100.0 a	97.3 a	33.3 a	0.152 a
405W High	1.0 c	74.0 a	25.0 a	100.0 a	99.0 a	6.7 b	0.042 cd
405W Low	6.0 c	0.7 e	0.0 c	6.7 f	0.7 e	5.3 bc	0.046 bcd

[a]Corn sample codes as in Table I.
[b]Means in each column with the same letter are not significantly different ($\alpha = 0.05$).

TABLE III
Physical Properties of Uncooked Corn Samples

Samples[a]	Floaters 1.250 SG (%)	TADD[b] Index (% removed)	WBT[c] (% breakage)	Bulk Density (kg/m^3)	Density (g/cm^3)	1,000-Kernel Weight (g)	Pericarp Removal (1=easy removal 5=no removal)	Grain Moisture (%)	Crude Protein[d] (%)
T1100 High	88.7 a[e]	61.0 a	11.7 c	752.5 f	1.292 cd	290.0 c	2.0 b	10.65 b	9.3 b
T1100 Medium	72.0 c	58.9 b	7.7 d	766.2 e	1.285 d	290.0 c	2.0 b	10.74 b	9.3 b
T110 Low	56.7 d	58.1 b	4.4 e	789.8 b	1.294 cd	289.4 c	2.0 b	10.48 c	9.4 b
3780 High	80.7 b	58.6 b	8.7 d	770.9 d	1.297 c	305.8 b	3.5 a	10.79 a	10.1 a
3780 Medium	66.7 c	55.2 c	3.7 e	777.7 d	1.294 cd	305.0 b	3.5 a	10.83 a	10.2 a
405W Broken	16.0 f	53.9 d	20.5 b	774.8 d	1.356 a	N/A	1.0 c	10.29 d	10.5 a
405W High	30.7 e	54.5 cd	22.1 a	783.8 b	1.349 a	355.4 a	1.0 c	10.12 e	10.3 a
405W Low	2.0 g	47.2 e	8.8 d	802.7 a	1.336 b	351.0 a	1.0 c	10.06 e	10.4 a

[a]Corn sample codes as in Table I.
[b]Tangential Abrasive Dehulling Device.
[c]Wisconsin breakage tester.
[d]Nitrogen × 6.25.
[e]Means in each column with the same letters are not significantly different ($\alpha = 0.05$).

405W. When the pericarp is rapidly removed the fissured endosperm is more quickly exposed to direct water contact. Stress cracks likely provide a water channel into the interior of the endosperm, thus providing an opportunity for increased rate water uptake during cooking.

Directly exposed endosperm, as in the broken 405W sample, absorbed more water than the other 405W samples. Nixtamal moisture, water uptake, chemical oxygen demand, and dry matter loss values were much greater for the broken 405W sample than for the stress-cracked (unbroken) 405W sample. Chung et al (1972) showed that broken kernels rapidly absorb more water than their undamaged counterparts; alkaline-cooked corn should behave no differently. In addition, the exposed endosperm on a broken kernel is more quickly solubilized than the pericarp-covered endosperm of an undamaged kernel, resulting in a higher chemical oxygen demand and dry matter loss.

Chemical oxygen demand and dry matter loss values for each hybrid were highly correlated ($r = 0.99$, $P < 0.001$), as was expected. The dry matter from alkaline processing is almost all organic material, which is easily oxidized by the strong reducing agent used in the chemical oxygen demand test. Nixtamal moisture was not significantly correlated with *nejayote* chemical oxygen demand or dry matter loss. The primary source of dry matter loss is probably the pericarp, whereas the extent of water uptake is more closely linked with endosperm texture.

The *nejayote* chemical oxygen demand and dry matter loss differences between hybrids were related to several factors. First, the differences in permeability of kernels to warm water and alkaline solution may allow faster water transport and increased solubility of materials into the kernel, and second, the extent of pericarp removal differs for the three hybrids. Observations during washing confirmed the results of the alkaline pericarp test; 405W pericarp was completely removed during processing. Pericarp of T1100 and 3780 varieties, however, was only partially removed. The higher overall dry matter loss and chemical oxygen demand for the 405W samples was due in large part to the greater ease of pericarp removal into the *nejayote* and wash water. When cooking time was increased to allow complete removal of 3780 pericarp, the effects of overcooking resulted in excessive (59%) nixtamal moisture (*unpublished data*).

The more severe cooking-steeping method produced higher dry matter loss, chemical oxygen demand, nixtamal moisture, and water uptake (Table IV) but only slightly higher percent crude protein than the less severe cooking treatment. Any cooking method that exposes kernels to increased steeping temperatures and/or increased kernel damage from pumping would probably result in increased product losses. Percentage crude protein increased during the cooking process because the material lost was predominantly starch and crude fiber.

Because none of the corn cooked for these trials was overcooked, the dry matter and chemical oxygen demand of the cooking-steeping water came mostly from pericarp. So it is not surprising that sometimes there was little difference in chemical oxygen demand and dry matter loss within the same hybrid. Nixtamal moisture and water uptake, as mentioned previously, are more affected by the ease of water movement into the kernel. The presence of stress cracks probably facilitates water uptake by providing easier access into the endosperm of the grain.

Predicting alkaline cooking properties from corn quality tests is difficult. Values obtained for nixtamal moisture, dry matter loss, and chemical oxygen demand are influenced by multiple grain quality factors. Breakage susceptibility, as measured with the Wisconsin breakage tester, was correlated ($P < 0.05$) with both dry matter loss and chemical oxygen demand ($r = 0.77, r = 0.70$—mild cook; $r = 0.73$, $r = 0.70$—harsh cook). Broken kernels were also correlated ($P < 0.01$) with both dry matter loss and chemical oxygen demand ($r = 0.91$, $r = 0.92$—mild cook; $r = 0.98$, $r = 0.98$—harsh cook). The fast-green test also correlated ($P < 0.05$) with chemical oxygen demand and dry matter loss. The ease of pericarp removal was correlated ($P < 0.05$) with dry matter loss and chemical oxygen demand of the mild cooking process ($r = -0.70, r = -0.70$) but was not significantly correlated with the harsh cooking process. The harsher cooking process increased the relative contribution of broken kernels to both dry matter loss and chemical oxygen demand. Density was correlated ($P < 0.05$) with dry matter loss and chemical oxygen demand ($r = 0.72, r = 0.73$—mild cook; $r = 0.70$, $r = 0.73$—harsh cook). The 405W pericarp was easily removed; not all hard food corns will have an easily removed pericarp and thus high dry matter losses.

CONCLUSIONS AND SUMMARY

The presence of broken kernels in corn increased dry matter losses and sewage waste strength (chemical oxygen demand), which resulted in excessive nixtamal moisture. These factors reduce profitability. The effect of stress-cracked grains on alkaline cooking was minimal. In a commercial environment, however, stress-cracked kernels may become broken when handled before and during cooking and steeping. Increased impact forces are associated with conveyance of raw corn, storage and other handling systems, agitation during cooking, and pumping corn into steeping tanks. Any additional breakage would increase losses associated both with decreased yield and increased chemical oxygen demand, and interject uncertainties into the determination of appropriate processing times.

Although effective tests to rapidly and quantitatively predict all the alkaline cooking properties of corn are not available, this study does suggest possible techniques that are effective in assessing some aspects of this process. The most accurate method to quantify the presence of stress-cracked and broken kernels is by counting. Accurate counting, however, is labor intensive and unsuitable for use as a routine quality control check. Breakage susceptibility, measured with the Wisconsin breakage tester, correlates well with numbers of multiple stress cracked grains; commercial processors could use the Wisconsin breakage tester effectively in quality control programs. In addition, the fast-green colorimetric test can be used to quantify the surface area of exposed endosperm and thus completely eliminate manual counting of kernels.

TABLE IV
Alkaline Cooking and Product Loss Parameters for Mild and Harsh Procedures

	Dry Matter Loss (%)		Chemical Oxygen Demand (g/L)		Nixtamal Moisture (%)		Nixtamal Protein[b] (%)	
Samples[a]	Mild	Harsh	Mild	Harsh	Mild	Harsh	Mild	Harsh
T1100 High	7.8 b[c]	8.6 bc	13.0 b	15.0 bc	50.6 b	53.0 bc	9.6 c	10.1 c
T1100 Medium	7.8 b	8.3 cd	13.6 b	13.8 de	51.2 b	52.3 c	9.5 c	10.0 c
T1100 Low	6.8 c	8.1 cd	11.7 c	14.1 cd	50.4 b	50.3 d	9.4 c	10.0 c
3780 High	6.7 c	8.5 bc	11.1 d	14.7 bcd	53.2 a	56.0 a	11.1 a	11.4 a
3780 Medium	6.3 c	7.7 d	10.2 d	12.9 e	52.6 a	53.6 bc	11.4 a	11.6 a
405W Broken	10.8 a	12.1 a	20.0 a	22.2 a	51.1 b	54.4 b	10.4 b	10.5 b
405W High	8.1 b	8.9 b	13.4 b	15.6 b	48.7 c	50.2 d	10.5 b	10.4 b
405W Low	7.8 b	8.6 bc	13.7 b	14.9 bc	46.1 d	47.0 e	10.4 b	10.4 b

[a] Corn sample codes as in Table I.
[b] Nitrogen × 6.25.
[c] Means in each column with the same letter are not significantly different ($\alpha = 0.05$).

Because complete pericarp removal is important to many processors, the ease of pericarp removal is an effective preliminary measure of this variable. Actual cooking, however, would be necessary to measure the extent of pericarp removal in a commercial setting. Complete removal of pericarp from softer endosperm kernels would result in overcooked nixtamal and higher *nejayote* chemical oxygen demand and dry matter loss levels. In many commercial operations the pericarp must be removed; if soft corn is used, some degree of overcooking is unavoidable.

The harder corn hybrids, in general, are less affected by inconsistency in processing and handling than the softer corns. The unbroken Asgrow 405W hybrid can be easily cooked with complete pericarp removal, within the recommended moisture range of nixtamal and without substantially higher chemical oxygen demand and dry matter loss than other hybrids. Generally, the pericarp of softer corn is not fully dissolved until the nixtamal is well past the optimum moisture level. Some softer corns, however, are used successfully to produce alkaline-cooked products; cooking times are generally shorter, and the pericarp is not completely removed. A commercial processor must optimize his process for a particular kind of corn. A consistent uniform supply of corn is essential; corn lots that vary greatly from the norm will probably result in unexpected cooking results and increased product losses.

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