Dry Matter Losses in Commercial Corn Masa Production[1]

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ABSTRACT

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Production of corn masa was studied in two commercial plants that manufacture tortilla chips, corn chips, and table tortillas. The magnitude and composition of corn dry matter (CDM) lost in the wastewater from each process were determined. Total losses of CDM were 8.5–12.5% for the four processes using overnight (normal) steeping. Abbreviated steeping (5 hr) at a higher temperature reduced CDM loss to 4.4%. About 50% of the wastewater solids were suspended solids that could be easily removed. The average composition of the suspended solids was 64% nonstarch polysaccharides (primarily pericarp fiber), 20% starch, and 1.4% protein. Total starch, protein, and lipid losses during processing were less than 5, 2, and 20%, respectively. Losses of starch, protein, and lipid appeared to be greater when damaged corn and softer corn hybrids were processed. Other important factors were long steeping times, shear stresses during processing, and high cooking temperatures.

Modern commercial processes for production of corn masa evolved from the traditional method of nixtamalization, or alkaline cooking, used by the Aztecs. The basic process begins by cooking whole corn in water containing lime and steeping the cooked corn 12–24 hr. The steeped corn is termed nixtamal and the liquid, which is rich in solids, is called *nejayote*. After washing to remove loose pericarp, the nixtamal is stone ground into masa. Masa, or corn dough, is used to produce tortillas, taco shells, tostadas, tamales, and snack foods, such as corn and tortilla chips.

The loss of corn dry matter (CDM) during cooking, steeping, and washing operations is economically important to commercial masa producers. The costs of effluent processing and yield loss are considerable. Commercial CDM losses have been estimated to be from 5 to 14%, based upon data for traditional nixtamalization (Katz et al 1974, Khan et al 1982). Laboratory cooking (70 min) and steeping (15 hr) were reported to cause losses of 13.3% of total CDM, 6.5% of corn protein, and 10.6% of corn starch (Gonzalez de Palacios 1980). Khan et al (1982) found that CDM losses increased with cooking time, but steeping accounted for much of the loss. Pericarp, starch, protein, and germ solubles composed the major portion of dry matter in wastewater.

Alkaline cooking and steeping of corn and the subsequent stone grinding of the nixtamal cause a partitioning of CDM between the masa and wastewater. Each is composed of particulate and dissolved fractions. This study reports CDM losses, composition, and distribution in wastewater from commercial masa production. Five contrasting commercial processes for masa production were characterized by analysis of samples and data collected during normal production.

MATERIALS AND METHODS

Plant Samples and Data

Corn was processed into tortilla chips (Ch) and extruded corn chips (F) at plant X and tortilla chips and tortillas (Tl) in plant Z. Plants X and Z were each visited several times over eight months to collect samples and data. Plant X processed many small batches of corn per day, from which two sets of samples were taken during each visit. Plant Z cooked a single large batch of each product per day. Samples of raw corn, cooked corn, cooking water, nixtamal, and *nejayote* were obtained. Plant data included corn variety; amounts of corn, water, and lime used per batch; temperature and duration of cooking, quenching, and steeping operations; and equipment design and specifications.

Where possible, composited samples of both corn and wastewater were collected during pumping operations following cooking and steeping. When tank sampling was necessary, the tank contents were thoroughly agitated to ensure uniform dispersion of suspended solids. All wet samples were stored on ice until analyzed. Wastewater samples were stabilized by the addition of 75 ppm of sodium azide.

Wastewater Sample Preparation

Wastewater samples included cooking water, *nejayote*, and wash water (from laboratory washing of nixtamal). Unlike cooking and steeping samples, nixtamal washing did not take place in a closed system; washing losses of dry matter were determined by the following procedure. Drained nixtamal samples (300 g) were quantitatively rinsed with 300 ml of water in small aliquots, and the liquid was collected. The extent of pericarp removal was equivalent to that achieved by commercial washing. Six replicates were measured.

Total solids samples of wastewater were prepared by adjusting the pH to 5–6 with 2*N* HCl to dissolve all residual lime, and then blending at high speed. Another portion was passed through a U.S. standard sieve no. 230 and centrifuged at 4,000 × *g*. The supernatant, containing the dissolved solids fraction, was adjusted to pH 5–6. Suspended solids were determined by difference. Washwater solids were treated as suspended.

Preparation of Samples and Moisture Determination

Raw corn, cooked corn, and nixtamal samples were prepared for chemical analysis by drying to 5–10% moisture content at 50–60° C and hammer milling through a 1-mm mesh screen. Another portion of each sample was frozen in airtight bags.

The moisture content of corn samples and solids content of wastewater samples were determined by drying in a forced-air oven at 140 and 105° C, respectively (AACC 1983). Percent loss of raw corn dry weight during processing was compared to dry matter loss calculated from wastewater solids content.

Mass Balance Calculations

A mass balance was calculated on each batch to quantify the movement of moisture and CDM in the corn-water-lime system. The data required included the initial weight of each component, corn moisture content, and wastewater solids content at each stage, and a preliminary estimate of CDM losses in cooking and steeping. Data from chemical analysis was used to partition the weight of total CDM in cooking water, *nejayote*, and wash water from each batch into its starch, nonstarch polysaccharides (NSP), protein, and calcium components. Percentage losses of total CDM, starch, NSP, and protein were calculated. Calcium data was used to calculate the lime content of each sample, which was subtracted from total solids to give CDM losses.

Chemical and Physical Analyses

Because alkaline cooking causes partial hydrolysis of corn fiber,

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the difference between total carbohydrates and total α-glucans was used as an index of fiber and fiber hydrolysates. Total carbohydrate was determined by a modified method (Dubois et al 1956). Corn and masa samples were gelatinized in 4*N* NaOH prior to dilution. Wastewater samples were diluted to contain 10–70 μg carbohydrate per milliliter. Total α-glucans were measured after amyloglucosidase hydrolysis (Technicon 1978).

Crude protein (N × 6.25) in corn samples was measured by the micro-Kjeldahl method (Technicon 1976, AACC 1983). Wastewater samples containing azide nitrogen were digested with pronase for 4 hr at 40° C and total α-amino nitrogen determined (Hahn et al 1982).

Total ether extracts of raw corn and masa were determined using a Goldfisch extraction apparatus (AACC 1983). Total corn lipid losses during processing were calculated from the difference.

Atomic absorption spectrophotometry was used to determine the calcium content of corn and wastewater. For corn samples, calcium was determined on Kjeldahl digests.

Test weight of the corn was determined (AACC 1983) using a calibrated 150-ml container. Thousand-kernel weights were taken on randomly selected subsamples of 150 kernels. Losses after milling 5 min on the Tangential Abrasive Dehulling Device (TADD; Reichert et al 1986) were calculated as an index of corn hardness. The proportion of kernels exhibiting endosperm stress cracks extending at least 50% of the kernel width was evaluated visually in 200-kernel subsamples.

TABLE I
Materials and Conditions for Cooking and Steeping of Corn at Commercial Plants X and Z to Process Corn into Nixtamal

Process Variables	Plant X X-Ch	 X-F	Plant Z Z-Ch	 Z-ChS	 Z-Tl
Product	Tortilla chips	Corn chips	Tortilla chips	Tortilla chips	Tortillas
Yellow corn, %	100%	67	80	80	100
White corn, %	0	33	20	20	0
Water added, %	278	278	240–365	170–185	170–185
Lime added (% of corn)	1.0	1.0	0.80–1.25	0.80–1.25	5.0–6.25
Cooking time, min[a]	18	37	47	60	50
Max. temp., °C	100	100	85	86	83
Time at max. temp., min	3–5	21–24	0	0	0
Type of agitation	Mech.[b]	Mech.[b]	Air	Air	Air
Corn quenched?	Yes	Yes	Yes	No	No
Steeping time, hr	16–20	16–20	20–24	5	20–24

[a] Total time above 67° C.
[b] Mech. = mechanical.

RESULTS AND DISCUSSION

Plant Data and Observations

Materials and processing conditions for the five processes are summarized in Table I and Figure 1. At plant X, corn was heated to boiling in a steam-jacketed kettle with vigorous agitation. After cooking and quenching with cold water, the corn was pumped to small tanks where it was steeped overnight. Physical stresses on the nixtamal were high at plant X, especially during pumping operations through small-diameter pipes after cooking and after steeping. Visual examination of nixtamal revealed considerable shear damage, especially in the softer yellow corn hybrids Pioneer 3186 and Conlee 202.

Alkaline cooking of corn at plant Z was done in larger batches and under less severe conditions. The cooking water was heated directly by steam injection and recirculated through the corn. Cooking temperatures never exceeded 87° C. Compressed air agitation was used in place of mechanical stirrers. Steeping was done in the same tank, and a large diameter hose was used for the pumping operation following steeping. In general, shear stresses on the nixtamal during processing appeared to be much lower than at plant X.

Corn Hybrid Characteristics

Asgrow 405W and 404 corn hybrids are considered the best quality corn for alkaline processing. They have hard kernels with pericarps that are easily removed during alkaline cooking. Properties of the kernels (Table II), in general, show that Asgrow 404 was harder than Conlee 202 and Pioneer 3186. Protein

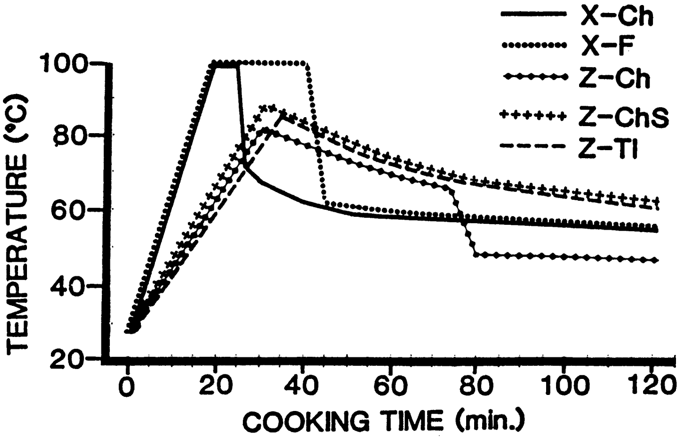

Fig. 1. Corn temperature profiles used during the first 2 hr of nixtamalization at plants X and Z.

TABLE II
Characteristics of Corn Used at Commercial Plants X and Z[a]

Process Code	Corn Type	Corn Hybrid	Test Weight (kg/hl)	1,000-Kernel Weight (g)	TADD Milling Loss[b] (%)	Stress-Cracked Kernels[c] (%)	Protein (N × 6.25) (%, db)
X-Ch	Yellow	Conlee 202	77.3	303.5	57.7	2.8	9.7
X-Ch	Yellow	Asgrow 404	78.1	331.6	49.8	2.2	10.0
X-F	Yellow	Pioneer 3186	76.9	302.1	61.0	6.8	9.6
X-F	White	Asgrow 405W	76.8	345.0	52.3	10.5	10.1
Z-Ch	Yellow	Asgrow 404	77.9	331.1	49.9	4.0	9.9
Z-ChS							
Z-Tl	White	Asgrow 405W	77.4	360.3	51.3	3.2	10.4
Z-Ch							
Z-ChS							
SEM[d]			0.2	2.3	0.3	1.3	0.3

[a] These corn hybrids were selected for alkaline processing quality, i.e., hard endosperm texture and easy pericarp removal.
[b] Loss on milling with a tangential abrasive dehulling device (TADD).
[c] Percent of kernels showing cracks extending >50% of kernel width.
[d] Standard error of the mean ($n = 6$).

compositions, however, were similar. Asgrow 404 yellow corn from the two plants was nearly identical in physical properties. Asgrow 405W white corn, by contrast, had a lower test weight and a higher incidence of stress cracks at plant X than plant Z. Conlee 202 and Pioneer 3186 corn kernels are harder than most commercial corns even though they are softer than Asgrow hybrids.

Corn Dry Matter Losses

Total CDM losses were 8.5–12.5% for the four normal steeping processes and 4.4% for the abbreviated steeping process Z-ChS (Table III and Fig. 2A). This compares favorably with results of Bressani and co-workers (1958), Katz and co-workers (1974), and Khan and co-workers (1982). Plant Z showed higher dissolved solids and total losses after steeping, although losses during cooking were generally lower than at plant X. Total losses were clearly not proportional to cooking losses. Normal steeping accounted for about 2.9% CDM losses at plant X and 5.3–8.0% at plant Z. Increased losses of CDM from damaged kernels that occurred during bulk corn handling is the most likely explanation for the high steeping losses at plant Z, since steeping temperatures were similar. The low CDM loss for process Z-ChS indicates that very little of the steeping loss occurred during the first 5 hr. Losses during washing were near 2% for all processes.

Dry matter losses were affected by corn hybrid and processing conditions (Figs. 3A and 4A). Corn with a prominent soft crown and floury endosperm (Conlee 202) was more vulnerable to shearing losses than corn with a harder crown and endosperm. Increased amounts of suspended solids were lost from Conlee 202 in the Z-Ch process. Hotter steeping temperature (>60° C vs. >40° C) also increased CDM losses especially in dissolved solids in the X-Ch process. Lower CDM was also reported by Khan and co-workers (1982) and Bedolla and co-workers (1983) when lower steeping temperatures and shorter steeping times were evaluated. Hence, corn hybrid and processing conditions significantly affected how much CDM was lost.

Shearing of the nixtamal during agitation and pumping in plant X was most likely responsible for the increased suspended solids after cooking. Shearing of the kernel crown at the dent, especially in soft yellow hybrids such as Pioneer 3186, is exhibited in Figure 5A. Nixtamal is shown on the top left and raw corn on the top right. The smooth curved shape of nixtamal indicates that friction from the pipe surfaces during pumping abraded the crown of the kernel. Shearing of the tip cap and adjacent floury endosperm was also apparent in the nixtamal from processes X-F and X-Ch (Fig. 5B), and it resulted in the loss of the germ and tip cap from many kernels.

Wastewater Composition

The average composition of total wastewater solids for the five

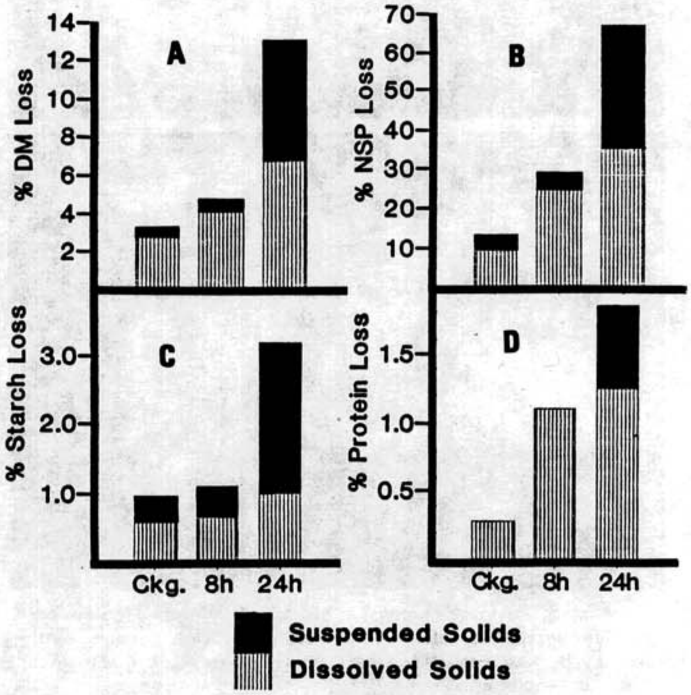

Fig. 2. Effects of steeping time on losses of: **A**, corn dry matter (DM); **B**, nonstarch polysaccharides (NSP); **C**, starch; and **D**, protein in process Z-Ch. **Ckg** = Cooking loss; **8h** = total loss after 8 hr of steeping; **24h** = total loss after 24 hr of steeping.

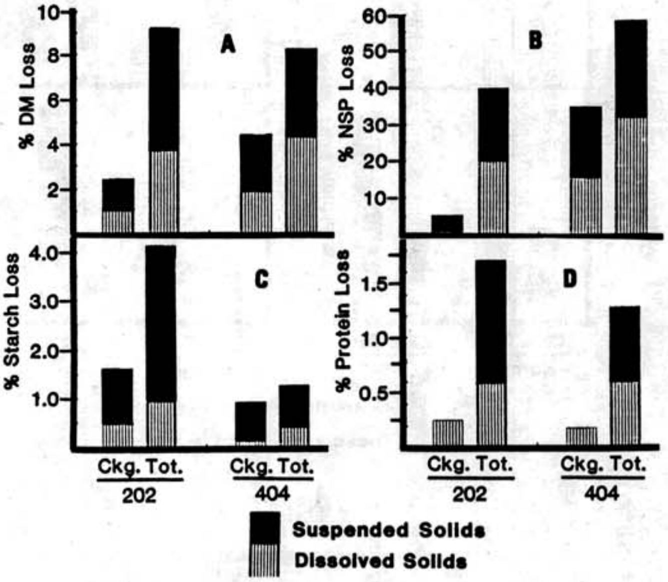

Fig. 3. Effects of corn hybrid on losses of: **A**, corn dry matter (DM); **B**, nonstarch polysaccharides (NSP); **C**, starch; and **D**, protein in process X-Ch. **Ckg** = Cooking loss; **Tot** = total loss; **202** = Conlee 202 yellow corn; **404** = Asgrow 404 yellow corn.

TABLE III
Distribution of Corn Dry Matter Losses (%) During Cooking, Steeping, and Nixtamal Washing Operations[a]

		Commercial Process					
Operation	**Solids Fraction**	**X-Ch**	**X-F**	**Z-Ch**	**Z-ChS**	**Z-Tl**	**SEM**[b]
Cooking	Total	3.70	6.30	2.66	1.26	2.19	0.50
	Dissolved	1.58	3.01	2.34	1.16	1.62	0.28
	Suspended	2.12	3.29	0.32	0.10	0.57	
Cooking plus steeping	Total	6.60	9.22	10.67	2.79	7.48	0.47
	Dissolved	4.08	4.90	6.00	2.22	6.29	0.45
	Suspended	2.52	4.32	4.67	0.57	1.20	
Washing	Total	1.93	1.90	1.87	1.63	1.98	0.08
Total losses	Total	8.53	11.12	12.53	4.42	9.46	0.55

[a] Expressed as percent corn dry matter.

[b] Standard error of the mean ($n = 4$).

processes was 75.6% NSP, 11.6% starch, and 1.4% protein (Table IV). Khan and co-workers (1982) reported that protein accounted for 24 to 35% of the total wastewater solids. Suspended solids, which were easily recoverable by screening and centrifugation, contained on a dry basis, 61.4–77.9% NSP, 9.6–27.6% starch, and 1.4% protein. Ether extract probably constituted much of the remaining 12–16% that was not directly determined.

Losses of Major Corn Components

Losses of corn pericarp during alkaline cooking were expected and are generally considered desirable. Corn pericarp, accordingly, was the major component of CDM losses and was determined as NSP. Cooking accounted for losses of from 34.2 to 50.6% of total corn NSP at plant X, but only 9.2 to 13.5% at plant Z (Table V). This reflected the additional heat and shear stresses used during nixtamalization at plant X. The large dissolved NSP losses for process X-F implied that the longer cooking treatment promoted hydrolysis of pericarp. Overall NSP losses (Table V) were 50.4–68.4% for the four long steep processes and 28.7% for the short steep process. Eight hours of steeping was clearly not sufficient time for extensive pericarp removal (Fig. 2B). High lime levels were most likely responsible for the high proportion of dissolved NSP losses observed in process Z-Tl even though total NSP losses (50.4%) were relatively low. Significantly less NSP (41.2%) was observed in the suspended solids of Conlee 202 yellow corn compared to that of Asgrow 404 in the X-Ch process (Fig. 3B).

The effects of time, temperature, and lime concentration on solubilization of corn pericarp NSP were observed using light microscopy of wastewater suspended solids. Large flakes of pericarp and intact germ fragments were observed in the low-heat, low-lime conditions of process Z-Ch. High-temperature, low-lime

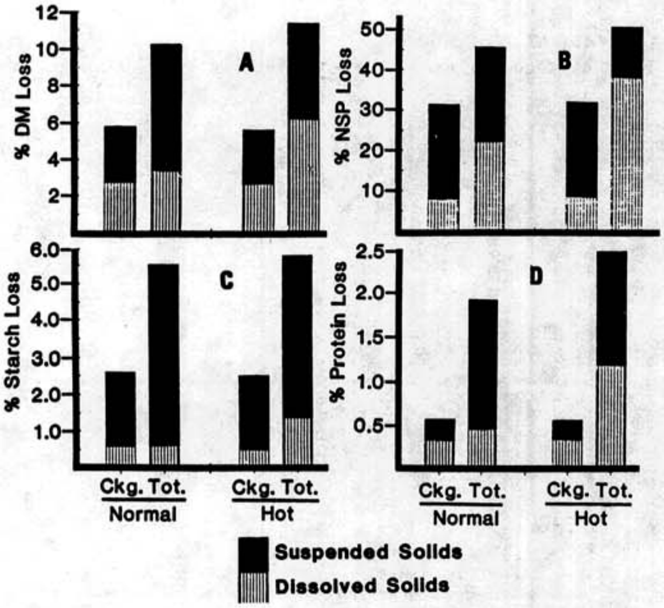

Fig. 4. Effects of steeping temperature on losses of: **A,** corn dry matter (DM); **B,** nonstarch polysaccharides (NSP); **C,** starch; and **D,** protein in process X-F. **Ckg** = Cooking loss; **Tot** = total loss; **Normal** = aerated steep (40° C minimum temperature); **Hot** = nonaerated steep (60° C minimum temperature).

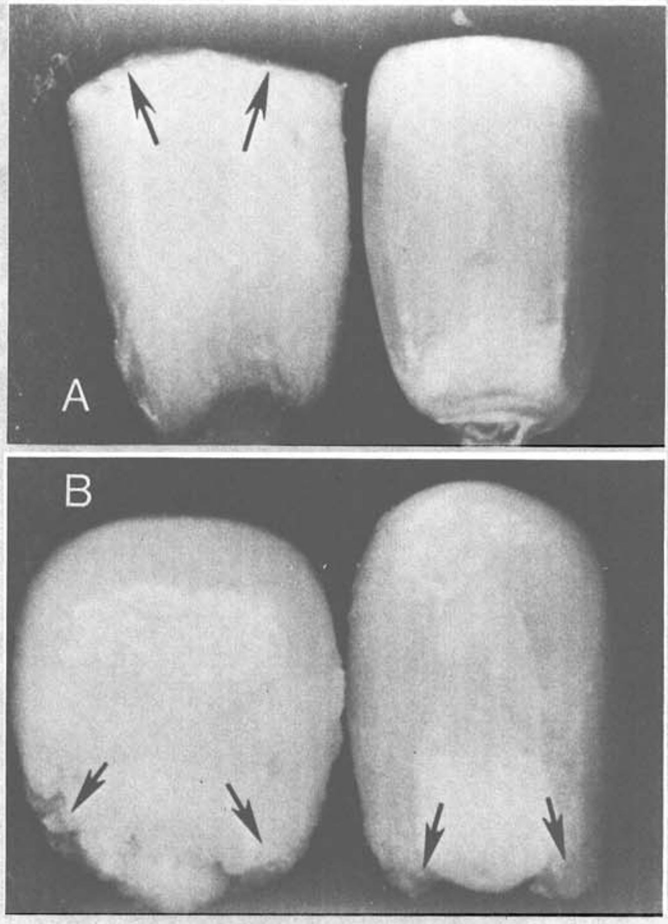

Fig. 5. Nixtamal damage observed at plant X. **A,** Pioneer 3186 raw corn (right) and nixtamal (left) showing crown-shearing damage during processing. **B,** Nixtamal (left and right) showing shearing damage to tip cap and adjacent endosperm.

TABLE IV
Composition of Wastewater Solids (%) Extracted During Nixtamalization[a]

		Commercial Process						
Component	Solids Fraction	X-Ch[b]	X-Ch[c]	X-F	Z-Ch	Z-ChS	Z-Tl	SEM[d]
NSP[e]	Total	49.8	79.1	78.6	66.4	75.7	78.7	2.1
	Dissolved	62.6	83.2	91.9	77.1	73.4	85.2	6.9
	Suspended	41.2	75.0	66.2	61.4	77.9	62.8	
Starch	Total	32.0	6.4	17.3	16.5	8.0	6.4	1.1
	Dissolved	18.8	3.5	4.6	9.0	4.4	2.4	1.9
	Suspended	40.9	9.6	27.6	21.0	11.4	19.3	
Protein	Total	1.8	1.5	1.5	1.3	1.6	2.2	0.1
	Dissolved	1.5	1.4	1.2	2.0	1.0	1.9	0.2
	Suspended	2.0	1.6	1.7	0.9	2.2	3.2	

[a] Expressed as percent of component in raw corn (dry basis).
[b] Conlee 202 yellow corn.
[c] Asgrow 404 yellow corn.
[d] Standard error of the mean ($n = 4$).
[e] NSP = Nonstarch polysaccharides.

agitated cooking treatment (process X-F) caused more pericarp and germ degradation. The low-temperature, high-lime conditions of process Z-Tl, however, caused extensive degradation of the pericarp into short fibrils. A similar disintegration of the endosperm cell walls during alkaline cooking and steeping was observed by Gomez et al (1987).

A malfunction in the steep tank aeration system at plant X illustrated the effect of steeping temperature on CDM losses (Fig. 4). Hourly surges of compressed air agitated the steeping corn, allowing it to cool from >60° C to near 40° C. Without agitation, the corn temperature was 60° C after 16 hr of steeping. Losses of CDM were increased by hot steeping. Most significantly, the proportion of total CDM, NSP, starch, and protein (Fig. 4A–D) in the dissolved form in wastewater was increased from 70 to 200% by steeping above 60° C. A practical significance of this finding is that dissolved solids are more expensive to remove from plant effluents than suspended solids.

Corn starch losses during nixtamalization were 0.3–1.2% for cooking and 0.6–4.6% total (Table VI). Starch losses during cooking were primarily in suspended form at plant X and dissolved form at plant Z. Starch losses attributable to steeping (total loss minus cooking loss) were composed mainly of suspended solids at both plants. Steeping appeared to increase endosperm friability and breakage susceptibility greatly. Most of the 4.6% starch loss seen in process X-F probably came from the softer yellow corn (Pioneer 3186), which constituted 67% of the blend. A hard yellow hybrid (Asgrow 404), given the short cook of process X-Ch, lost only 1.2% of total starch through cooking, steeping, and washing. Significantly less NSP (41.2%) and more starch (40.9%) were observed in the suspended solids of Conlee 202 yellow corn compared with those of Asgrow 404 in the X-Ch process (Fig. 3).

Less than 2% of the total protein in the corn was lost during nixtamalization (Table VII). Except for process X-F, the proteins lost during cooking were in the dissolved solids and probably reflected leaching of soluble germ proteins. Protein losses (suspended solids) increased sharply during steeping in process X-F due to loss of germ and endosperm from softened kernels. Abbreviated steeping in process Z-ChS greatly reduced the loss of soluble proteins into wastewater.

Ether extract losses averaged 17.5% at plant X and 12.2% at plant Z (Table VIII). The differences were due to loss of the germ during the vigorous handling at plant X.

CONCLUSIONS

Commercial processes for production of corn masa caused losses of 8.5–12.5% of corn dry matter. The magnitude and composition of CDM losses at each step were dependent on both

TABLE V
Distribution of Corn Nonstarch Polysaccharides (%) Lost in Wastewater During Nixtamalization[a]

Operation	Solids Fraction	Commercial Process					SEM[c]
		X-Ch[b]	X-F	Z-Ch	Z-ChS	Z-Tl	
Cooking	Total	34.2	50.6	13.5	10.5	9.2	2.7
	Dissolved	15.6	29.4	8.2	10.0	9.2	1.8
	Suspended	18.6	21.2	5.3	0.5	0	···
Total	Total	57.7	68.4	64.3	28.7	50.4	1.6
	Dissolved	31.5	41.8	29.7	13.1	38.5	2.7
	Suspended	26.2	26.6	34.6	15.6	11.9	···

[a] Expressed as percent of total nonstarch polysaccharides in raw corn.
[b] Asgrow 404 yellow corn.
[c] Standard error of the mean ($n = 4$).

TABLE VI
Distribution of Corn Starch (%) Lost in Wastewater During Nixtamalization[a]

Operation	Solids Fraction	Commercial Process					SEM[c]
		X-Ch[b]	X-F	Z-Ch	Z-ChS	Z-Tl	
Cooking	Total	0.88	1.18	0.73	0.27	0.34	0.15
	Dissolved	0.11	0.14	0.41	0.23	0.23	0.04
	Suspended	0.77	1.04	0.32	0.04	0.11	···
Total	Total	1.22	4.59	3.43	0.63	0.83	0.17
	Dissolved	0.39	0.58	0.69	0.23	0.33	0.12
	Suspended	0.83	4.01	2.74	0.40	0.50	···

[a] Expressed as percent starch in raw corn (dry basis).
[b] Asgrow 404 yellow corn.
[c] Standard error of the mean ($n = 4$).

TABLE VII
Distribution of Corn Protein (%) Lost in Wastewater During Nixtamalization[a]

Operation	Solids Fraction	Commercial Process					SEM[c]
		X-Ch[b]	X-F	Z-Ch	Z-ChS	Z-Tl	
Cooking	Total	0.17	0.20	0.18	0	0.11	0.06
	Dissolved	0.17	0.07	0.18	0	0.11	0.04
	Suspended	0	0.13	0	0	0	···
Total	Total	1.25	1.82	1.64	0.66	1.43	0.09
	Dissolved	0.58	0.61	0.92	0.19	0.92	0.09
	Suspended	0.67	1.21	0.72	0.47	0.51	···

[a] Expressed as percent protein in raw corn (dry basis).
[b] Asgrow 404 yellow corn.
[c] Standard error of the mean ($n = 4$).

TABLE VIII
Total Corn Ether Extract Lost During Nixtamalization

Process	Raw Corn Ether Extract (%, db)	Nixtamal Ether Extract (%, db)	Percent Loss[a]
X-Ch	6.15	5.45	18.1
X-F	3.92	3.78	16.9
Z-Ch	4.92	4.74	11.8
Z-Tl	5.26	4.90	12.5
SEM[b]	0.07	0.07	0.04

[a] Calculated loss of corn ether extract (%), adjusted for dry matter loss.
[b] Standard error of the mean ($n = 4$).

corn kernel characteristics and processing conditions. Corn pericarp constituted most of the dry matter lost during alkaline processing of corn. Losses of starch, protein, and lipid were much smaller but were increased by the use of softer or damaged corn and by high shear stresses during pumping and agitation. High steeping temperatures and lime levels increased dissolved solids in wastewater. Suspended solids are much easier to remove from plant effluents than dissolved solids.

Greater losses during cooking were not found to cause increased losses overall. Overnight steeping (16–24 hr) appeared to account for most of the CDM losses in a typical process. Steeping periods of 5–10 hr could produce the desired results while keeping CDM losses under 5%.

Unintentional overprocessing of corn is common in commercial masa production. Proper selection of corn hybrids and intelligent design of processing systems can produce greater masa yields and smaller effluent processing costs. For commercial processes using corn hybrids softer than food corn hybrids, the losses would undoubtedly be much higher, especially at plant X where the corn was agitated during cooking and vigorously handled between cooking, steeping, and washing. More information on actual losses under those circumstances and the extent of pericarp removal and endosperm damage of these softer corns during nixtamalization is needed.

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