

Comparison of Alkali and Conventional Corn Wet-Milling: 1-kg Procedures

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ABSTRACT

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An alkali corn wet-milling process was developed to evaluate the process as a method to produce high purity corn starch and coproducts with added value. Using a single hybrid (R1064 × LH59), the effects of alkali concentration (0.18–0.82% NaOH), time (29–61 min), and temperature (36–75°C) were investigated. Starch yield was not affected by steep time or temperature. Starch yield was optimal at 65.2% using 0.5% alkali. Increasing the concentration of alkali to 0.82% or decreasing it to 0.18% caused a decrease in starch yield of 8–10 percentage points. Other

wet-milling products (fiber, germ, and gluten) also were affected. Steep conditions of 0.5% NaOH, 60 min, and 45°C gave optimal starch yield. Comparisons between alkali and sulfur dioxide wet-milling processes, using 1-kg sample size, were performed on 10 commercial yellow dent corn hybrids. The alkali process averaged 1.7 percentage points more starch than the sulfur dioxide process. Each hybrid had a higher starch yield when wet-milled with the alkali method. Alkali wet-milling produced pure corn starch with <0.30% protein (db).

The primary objective of corn wet-milling is to provide large quantities of nearly pure starch at a low cost. Wet millers work to reduce the cost of production and increase coproduct value and quality of all products. The conventional corn wet-milling process is a capital- and energy-intensive process. A conventional 100,000 bu/day wet-milling plant producing fructose would cost \$300 million to construct and would utilize 7.5×10^5 kW electricity and 7.5×10^6 lb of steam per day (Anonymous 1993, 1995; S. R. Eckhoff, unpublished data).

The concept of using an alkali compound as a steeping agent is not a new concept and was developed by Jones (1841) to recover starch granules from grain. The first corn wet-milling plant using alkali was opened in 1842 by Thomas Kingsford in Bergen, NJ (Bensing et al 1972). The use of alkali was abandoned in favor of sulfur dioxide (SO₂) because the steeping of whole corn in alkali solution for 40–50 hr resulted in the pericarp being dissolved and solubilization of the starch.

Alkali debranning of cereal has been studied extensively (Hansen 1949, Weinecke 1962, Watson and Stewart 1969, Barta et al 1966, Morgan et al 1966, Mistry and Eckhoff 1992). The purpose of the alkali debranning was to remove the pericarp to facilitate subsequent processing rather than to recover the pericarp as a useful coproduct. Mistry and Eckhoff (1992) indicated the pericarp fraction recovered by alkali debranning contained 92% dietary fiber, 4% protein, 2.5% starch, and <0.5% fat. This dietary fiber was suggested to be a value-added coproduct of alkali-processed corn. They developed a unique debranning process but did not evaluate milling parameters to obtain starch in processes downstream of the debranning.

Mistry et al (1992) also evaluated the steeping of corn flour to extract starch and protein fractions with alkali. They reported starch protein content and recovery were affected by steeping temperature, steeping time, and alkali concentration. In a laboratory-scale process, they found the starch protein content recovered from alkali-steeped corn flour was as low as 0.1%. The alkali-soluble nature

of glutelin, the primary protein fraction in the endosperm, could explain the low protein content of the starch obtained from alkali-steeped corn flour. Starch characteristics obtained from alkali-steeped corn flour were reported to be different from those of conventional process starch. We sought to evaluate further the alkali procedure for whole corn kernels and evaluate the milling products and yields. Specific objectives were to 1) optimize the steeping conditions of the alkali corn wet-milling process, and 2) compare the yields from alkali wet-milling and conventional SO₂ wet-milling processes.

MATERIALS AND METHODS

Materials

To determine the milling response to conditions of steep temperature, time, and alkali concentration during the steeping process, yellow dent corn (FR1064 × LH59) was harvested during the fall of 1994 and ambient air-dried to ≈14% moisture content. To compare alkali milling yields to those from a conventional SO₂ process, 10 commercial hybrids representing a range of kernel characteristics were obtained. Physical properties including test weight and kernel density, and composition including protein, oil, starch, and fiber content were determined (Table I) (Illinois Crop Improvement Association, Inc., Champaign, IL). Corn moisture content was determined using the 103°C air-oven method (AACC 1995). Sodium hydroxide pellets (97.6% NaOH) were obtained from Fisher Scientific and used as the source of alkali. Unless noted otherwise, all dry solids were determined using a two-stage oven method (49°C) overnight and moisture of the dried samples was determined using an air oven at 130°C for 2 hr (AACC 1995).

Milling Processes

Conventional wet-milling process. The conventional wet-milling process was that described by Eckhoff et al (1993) using SO₂ as a steeping agent and 1 kg of corn. Batch steeping conditions used were 52°C for 24 hr in 0.5% lactic acid and 2,000 ppm of SO₂ in 1,800 mL of steeping solution.

Alkali wet-milling process. An alkali wet-milling process was developed based on previous work using a 100-g sample size and adapted to a 1-kg sample size (Fig. 1) (Du 1997, Eckhoff et al 1999). For the alkali soak step, a 2% NaOH solution was made by adding 40 g of NaOH to 2 L of water at 90°C. Corn (1 kg) was placed in a stainless steel basket and immersed in the hot alkali solution for 5 min. Soak time was considered to begin immediately after the corn was immersed in the alkali bath. After soaking was finished, the corn was raised out of the hot alkali bath and the soakwater was allowed to drain. The volume of remaining soakwater was recorded and a 25-mL sample of soakwater was used to determine the percentage of dry matter in the soakwater, using a two-stage air-oven method (AACC 1995).

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Using gentle abrasive agitation, the debranning operation served to detach the loosened pericarp from the rest of the kernel and was similar to the procedure of Mistry and Eckhoff (1992), where they used a brush rotating at 160 rpm over a 4-mesh (4.76 mm openings) standard sieve (200 mm diameter) and a continuously recirculating stream of tap water for 2–3 min. In the current study, the soaked corn was placed on a U.S. Standard 8-mesh (2.36 mm openings) standard sieve which was immersed in 7.5 L of water in a nominal 400-mm diameter 10-L plastic container. The pericarp, loosened by alkali soaking, was detached from the corn kernels using a 75W motor to rotate a 165-mm long plastic bristle brush at 250 rpm for 5 min. The corn was removed from the container, drained, and poured over a 460-mm diameter, 325-mesh vibrating screen (0.044 mm openings) (model K18-1-SS, Kason Corp., Linden, NJ). The wash water was retained and used to rinse the pericarp away from the rest of the solids. During the soaking and debranning processes, the pericarp became a clear, jelly-like mass that passed through the screen openings.

Debranned corn was cracked by passing it through a roller mill equipped with 10-cm diameter × 15-cm wide smooth rolls rotating at equal speeds of 200 rpm and with a gap setting of 2 mm. Settings used were optimized in previous studies (Du 1997, Eckhoff et al 1999). Cracked corn was transferred to a dynamic steeping apparatus consisting of a 4-L plastic bottle, immersion heater (model 70, Polyscience, Preston, IN), and 75W motor equipped with an agitator that rotated at 650 rpm. This process agitated the cracked, debranned kernels during steeping.

The steeped slurry was ground in a Waring blender (model 34BL22, Waring Products Division, Dynamics Corp. of America, New Hartford, CT) equipped with a 5-L pitcher and radially edged blades controlled by a Power Stat variable transformer (model no. 116, Superior Electric Co., Bristol, IA) for 3 min at 3,000 rpm. The germ was skimmed out of the slurry using a U.S. Standard 18-mesh (1.00-mm openings) stainless steel screen rinsed with 1 L of fresh water and drained.

To facilitate the effectiveness of grinding through a Quaker City mill (model 4E, The Straub Co., Warminster, PA), slurry remaining after germ removal was ground again in the same blender for 3 min at 8,300 rpm. The blender was rinsed using 500 mL of fresh water

after grinding; the rinse water was added to the slurry. The slurry was ground more finely using the Quaker City mill. This mill also was cleaned with 500 mL of fresh water which was added to the slurry. The slurry was poured onto the vibrating screen described above (325-mesh, 0.044-mm openings) to separate the fiber from the rest of the process solids. To remove residual protein and starch, fiber was washed with some of the wash water saved from pericarp washing, followed by 1 L of fresh water.

The slurry obtained after fiber separation, similar to that for conventional wet-milling mill starch, was processed to separate the starch from the protein following tabling procedures described in Eckhoff et al (1993). The mill starch was allowed to settle for 1 hr before the supernatant was decanted. The settled slurry was mixed and specific gravity was adjusted to 1.04–1.045 using the decanted supernatant. After the first tabling, the overflow material was pumped onto the table a second time using the same parameters on the same table. After the second tabling was complete, the supernatant from decanting was used as wash water by pumping over the table at the same rate as the mill starch. This was followed by pumping 500 mL of fresh water over the table as a final rinse. The resulting starch cake was allowed to air dry overnight and was collected and weighed. The moisture content of the starch was measured using an air oven at 135°C for 2 hr (AACC 1995).

The volume of overflow liquid (gluten) from the table was recorded. Five subsamples, each containing 75 mL of stirred gluten slurry, were used to determine the percentage of gluten dry matter by a two-stage air-oven method (AACC 1995). Pericarp, germ, and fine fiber fractions were dewatered manually and dried in a 49°C air oven overnight. The moisture content of each milling fraction was measured using an air oven at 135°C for 2 hr (AACC 1995). Soakwater, pericarp, germ, fine fiber, starch, gluten, and steepwater yield means were reported on a dry solids basis.

In the alkali process, the majority of sodium (92%) added to the process went with the soakwater fraction (66%) and gluten fraction (26%), while the remainder was distributed in the other fractions (Eckhoff et al 1999). Although the distribution of sodium among milling fractions could be expected to vary due to steep conditions, and perhaps due to hybrid, the amount of sodium in each fraction was found to be small and did not deter the comparisons made. As

TABLE I
Physical Properties and Chemical Composition
of 10 Commercial Corn Hybrids

Hybrid	Moisture Content (% wb)	Protein (% dwb)	Oil	Starch	Fiber	Test Weight (lb/bu)	Kernel Density (g/cm ³)
1	16.6	9.9	4.2	70.8	2.2	59.4	1.256
2	16.0	10.7	4.4	71.6	2.1	58.8	1.259
3	16.4	9.8	4.7	72.5	2.4	58.0	1.254
4	16.4	10.4	4.0	73.0	2.1	59.7	1.289
5	16.4	10.0	4.7	73.3	2.1	57.8	1.275
6	16.4	10.2	4.5	72.8	2.3	59.0	1.267
7	17.0	11.6	4.1	72.9	2.1	61.9	1.326
8	16.0	10.6	4.4	71.4	2.3	58.1	1.276
9	16.8	10.5	3.9	74.3	2.0	60.6	1.287
10	16.6	10.6	4.5	71.4	2.1	59.1	1.297

TABLE II
Sodium Content of Alkali Wet-Milling Fractions

Milling Fraction	Added Sodium	
	%	Wt (g)
Soakwater	65.97	18.96
Pericarp	1.09	0.31
Germ	2.05	0.59
Fiber	0.92	0.26
Starch	3.92	1.13
Gluten	26.05	7.49
Total	100.00	28.74

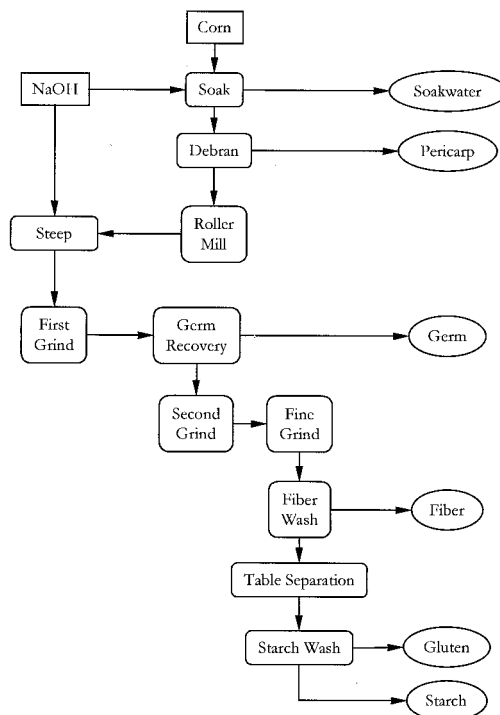


Fig. 1. Flow diagram of the alkali wet-milling process.

a result, the amount of sodium in each fraction was considered constant and not analyzed further (Table II).

Experimental Design—Method of Analysis

To determine the optimum dynamic alkali steeping conditions, steep temperature, steep time, and alkali concentration were varied within 29–61°C, 36–84 min, and 0.18–0.82% (% NaOH added to soakwater, w/v) respectively, using a single hybrid (Table III). For the comparison of milling methods using the 10 commercial hybrids, dynamic steeping was conducted at the apparent optimum steep conditions using 2 L of 0.5% alkali solution at 45°C for 60 min.

The study of parameters for steep temperature, steep time, and alkali concentration during steeping followed a modified central composite design (Cochran and Cox 1957) shown in Table II. For the comparison of alkali and SO₂ milling methods, alkali yield data were corrected for sodium content using the analysis conducted in previous studies (Du 1997, Eckhoff et al 1999) and were considered constant throughout this study (Table III). The total amount of sodium added (28.74 g) was constant for treatments soaked in 2% NaOH and steeped in 0.5% NaOH. The weight of the sodium was subtracted from each alkali milling fraction (Table III) before statistical analysis of the milling yield data. Corrections varied from rather unimportant (pericarp, germ, fiber) to relevant (soakwater) according to the amount of sodium observed in each fraction.

Differences among overall means for alkali and standard milling procedures were determined using the least significant difference method. In the alkali process, pericarp was removed before steeping. Therefore, pericarp yields were not included in the analysis of yields as affected by steep conditions. The effect of soak conditions were reported in Du (1997).

RESULTS AND DISCUSSION

Effect of Steep Conditions

Starch yield obtained from the alkali process increased as alkali concentration in the steeps increased from 0.18 to 0.5% (Fig. 2). Above 0.5%, starch yield appeared to decrease, while gluten yield continued to increase. Concentrations of 0.18–0.5% alkali increased the effectiveness of steeping in softening the endosperm matrix and the attachment of endosperm material to the kernel fiber. As a result, the highest starch yield occurred as a relatively low fiber

yield was achieved. Fiber yield decreased as alkali concentration increased from 0.18 to 0.5%, therefore, starch attached to the fiber fraction at low alkali concentrations was recovered in the starch fraction as alkali concentrations increased to 0.5%.

The change in yields >0.5% alkali was attributed to the alkali solubilizing starch in the endosperm, causing more solids to flow off the starch table with the gluten fraction. The gluten fraction varied more than the other fractions in the steep condition optimization, increasing steadily as alkali concentration increased and nearly doubling from 15 to 28%. As the gluten fraction in the alkali process is the final product of the process and is a collection of solids that do not settle to the starch table, it reflects the amount of solids that are soluble and the small suspended particulates that are not retained in other milling fractions. Fiber yields remained stable as alkali concentration increased > 0.5%. Germ yields were unaffected by alkali concentration.

For the range of temperatures used in this study (29–61°C), there was no effect of temperature on starch, germ, or fiber yields (Fig. 3). Little change was observed in any of the milling yields over the range of steep times tested (36–84 min).

As the effect of steep conditions was tested using a single hybrid, response by other corn hybrids to steep time, temperature, and alkali level may cause shifts in the milling fraction distribution, resulting in different optimum conditions for starch yield. A multivariate regression analysis was conducted on data from the steep optimization study, but it did not show a meaningful correlation to predict alkali milling yields.

Comparison of Alkali and SO₂ Processes

For the alkali milling process, starch, gluten, and germ were higher than the SO₂ wet-milling process (Table IV). Starch, gluten, and germ yields averaged 1.7, 6.2, and 1.3%, respectively, greater than the SO₂ process. Higher starch yields were in contrast to work by Eckhoff et al (1999), who observed higher starch yields for the conventional SO₂ process using a 100-g sample size. Some of the increase in starch yield may be attributed to the double-tabling technique used in the alkali method, allowing more starch to be captured on the starch table. However, this was not observed previously (Eckhoff et al 1999) using double-tabling and resulted

TABLE IV
Overall Average Wet-Milling Yields^a

Fraction	Alkali	SO ₂	LSD ^b	Industrial ^c
Soak or steepwater ^d	2.9b	4.3a	0.50	7.5
Pericarp	2.1	na ^e	na	na
Germ	8.3a	7.0b	0.64	7.5
Fiber	7.7b	13.4a	1.97	11.5
Starch	65.4a	63.7b	1.04	67.5
Gluten	15.4a	9.2b	2.11	5.8
Filtrate	na	2.6	na	na
Total	101.7a	100.1b	0.67	99.8
All solubles ^f	2.9b	7.0a	1.38	7.5
Total protein-rich ^g	15.4a	11.8b	1.34	...
Total fiber-rich ^h	9.8b	14.5a	1.71	...

^a Alkali steep conditions: 45°C, 60 min, 0.5% NaOH. SO₂ method steep conditions: 52°C, 24 hr, 0.5% lactic acid, 2,000 ppm of SO₂. Milling yields expressed as % of corn dry solids. *n* = 20. Values followed by the same letter in the same row are not significantly different (*P* < 0.05).

^b Least significant difference (*P* < 0.05).

^c Anderson and Watson (1982).

^d Soakwater from alkali wet-milling process; steepwater from SO₂ wet-milling process.

^e Not applicable.

^f Computed from yields of soakwater for the alkali wet-milling process; from yields of steepwater plus filtrate for the SO₂ wet-milling process, and from yields of steepwater for industrial process.

^g Computed from gluten for the alkali wet-milling process and from gluten plus filtrate for the SO₂ wet-milling process.

^h Computed from yields of pericarp plus fiber for the alkali wet-milling process and from yields of fiber for the SO₂ wet-milling process.

TABLE III
Experimental Design for Determining Relationships Among Corn Wet-Milling Yields and Steep Temperature, Steep Time, and Alkali Concentration

Concentration (%)	Temperature (°C)	Time (min)	Replicates	
0.18	45	60	2	
	0.3	35	45	2
		35	75	2
		45	60	2
		55	45	2
0.5	55	75	2	
	0.7	29	60	2
		35	60	2
		45	36	2
		45	45	2
		45	60	12
		45	60	2
		45	75	2
		45	84	2
		61	60	2
0.82	45	35	45	2
		35	75	2
		45	60	2
		55	45	2
		55	75	2

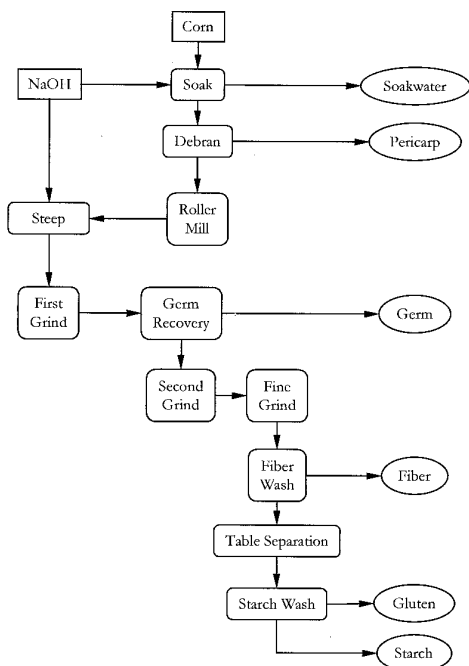


Fig. 2. Relationships among alkali concentration and germ, fiber, starch, and gluten yields when holding steep temperature at 45°C and steep time at 60 min. Relative responses were not adjusted for sodium content.

in lower alkali yields for starch than the SO₂ process. The sodium added in the form of alkali present in the starch fraction was calculated to contribute ≈0.13% to the starch yield. Protein content of the starch obtained from both wet-milling processes was >0.3% (db).

The lower combined yield of pericarp and fiber fractions (fiber-rich fraction) (Table IV) indicated alkali was effective in loosening and detaching endosperm material from the kernel fiber. This allowed a larger percentage of corn solids to move downstream in the process, manifested as higher starch and gluten yields.

More material being removed from the pericarp and fiber fractions by the alkali process can be attributed to the higher gluten yields and was supported by the lower fiber and pericarp yield for the alkali process. The gluten fraction for the alkali process did not have the small molecules filtered from it as did the gluten from the SO₂ process so that comparison of the protein-rich fraction may be more revealing. The total of protein-rich fractions, gluten, and filtrate is shown in Table IV and is higher for the alkali than the SO₂ process. This included the proteins and other soluble materials including the solids from the steeping operation that flowed down with the process water in the alkali method. Additionally, the soluble material extracted during the dynamic alkali steep that were retained in the process water during the milling procedure eventually ended up in the gluten fraction as well, in comparison to steepwater being recovered as a separate fraction in the SO₂ process. Cellulosic material may have been solubilized partially by the chemical action of the alkali and allowed some of this material to flow downstream in the process and into the gluten fraction. However, we did not investigate this possibility. The sodium added in the form of alkali present in the gluten was calculated to contribute ≈0.9% to the gluten yield.

Due to a shorter duration than for conventional SO₂ steeping, there was lower soluble material recovered in the alkali soakwater (2.9%) than in the total of steepwater and filtrate yields for the SO₂ process (7.0%) (Table IV). Both of the processes had >100% total solids recovery even after accounting for added sodium in the alkali process. This was indicative of a systematic error in determining the yields for both processes, but the source was undetermined. In the SO₂ process, the least significant difference is much larger

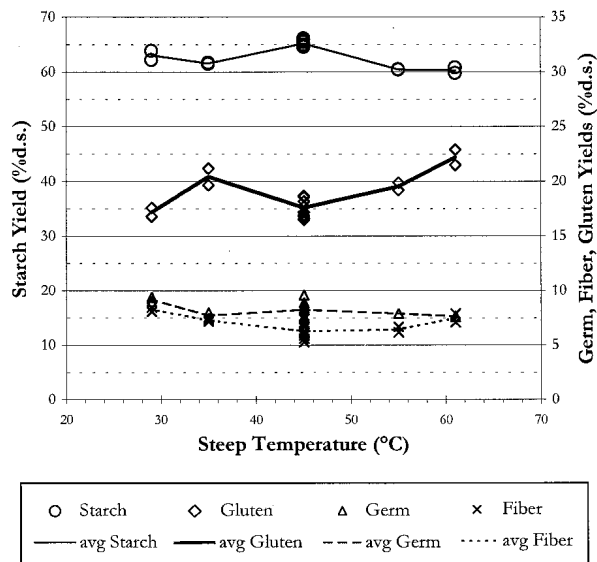


Fig. 3. Relationships among steep temperature and germ, fiber, starch, and gluten yields when holding alkali concentration at 0.5% and steep time at 60 min. Relative responses were not adjusted for sodium content.

than the error in total recovery. In other work, recovery of solids has been 97–100% for both processes.

The short soak and steep periods used by the alkali process allow less time for solubles to be leached from the germ. With shorter soak and steep times, less leaching of solids may lead to a higher germ yield, but this presents a challenge during germ separation. Whether done by hand or by using hydrocyclones, germ separation is made possible by differences in density between germ and the rest of the milling slurry.

The milling yields of 10 hybrids using each 1-kg procedure (SO₂ and alkali) are shown in Tables V and VI. As reported in the literature from work with SO₂ wet-milling processes (Zehr et al 1995, Zehr et al 1996), milling yields from the alkali process were affected by hybrid differences. However, a statistical analysis showed no consistent trends in yield distribution of either the alkali or the SO₂ method. Steepwater solids yields were similar for all 10 hybrids. Generally, hybrids with low fiber and gluten yields had higher starch yields than other hybrids.

CONCLUSIONS

An alkali wet-milling process using a 1-kg corn sample was developed. The process yielded starch fractions with 1-hr steep times that were greater than the conventional laboratory process using conventional SO₂ steeping methods. Fiber-rich fraction yields were lower and protein-rich fraction yields were higher for the alkali process than for the SO₂ process. For maximum starch yield, optimum steep conditions were 0.5% alkali, 45°C, and 60 min.

The alkali wet-milling process shows promise in producing starch yields at least as good as conventional SO₂ wet-milling with less process time needed for soaking and steeping operations. Therefore, capital costs of commercial alkali wet-milling facilities should be reduced on a per bushel capacity basis. The alkali process also had higher yields of protein-rich fractions and lower fiber-rich fractions, suggesting a cleaner separation of fiber, starch, and protein.

ACKNOWLEDGMENTS

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TABLE V
Wet-Milling Yields of 10 Corn Hybrids Using a 1-kg Alkali Procedure^a

Hybrid	Soakwater	Pericarp	Germ	Fiber	Starch	Gluten	Total Recovery ^b	Total Recovery ^c
1	5.1 ± 0.01	2.3 ± 0.08	9.3 ± 0.06	6.7 ± 0.19	66.5 ± 0.25	16.2 ± 0.31	100.1 ± 0.08	106.1 ± 0.10
2	5.0 ± 0.13	2.7 ± 0.79	8.1 ± 0.57	7.3 ± 0.08	64.2 ± 0.07	16.9 ± 0.33	98.7 ± 0.83	104.2 ± 0.54
3	5.1 ± 0.09	2.1 ± 0.44	8.9 ± 0.04	8.6 ± 0.36	64.4 ± 0.37	16.2 ± 0.98	99.3 ± 0.30	105.2 ± 0.32
4	5.2 ± 0.16	1.5 ± 0.21	8.2 ± 0.25	7.4 ± 1.24	66.6 ± 1.52	16.9 ± 0.16	99.8 ± 0.08	105.8 ± 0.08
5	5.2 ± 0.24	1.7 ± 0.59	8.7 ± 0.57	7.7 ± 0.40	66.1 ± 0.11	15.0 ± 0.08	98.7 ± 0.14	104.5 ± 0.17
6	5.1 ± 0.37	1.7 ± 0.00	9.6 ± 0.41	8.5 ± 0.36	64.0 ± 0.88	16.1 ± 0.81	99.2 ± 0.31	105.1 ± 0.33
7	5.0 ± 0.11	2.2 ± 0.06	6.6 ± 0.91	9.5 ± 0.21	64.2 ± 0.30	17.7 ± 0.09	99.1 ± 0.69	105.1 ± 0.96
8	5.3 ± 0.10	2.1 ± 0.33	7.8 ± 0.37	8.5 ± 0.14	66.0 ± 0.03	15.6 ± 0.67	99.5 ± 0.86	105.3 ± 0.90
9	4.7 ± 0.35	2.4 ± 0.61	8.2 ± 0.05	7.6 ± 0.30	65.2 ± 0.19	16.4 ± 0.86	99.1 ± 0.76	104.4 ± 1.57
10	5.2 ± 0.17	2.4 ± 0.22	8.0 ± 0.59	5.7 ± 0.07	67.9 ± 0.11	16.1 ± 0.34	99.2 ± 0.40	105.1 ± 0.36

^a Results are average of two replicates. Steep conditions: 45°C, 60 min, 0.5% NaOH. % Dry solids basis ± one standard deviation (*n* = 2). Yields not adjusted for sodium content.

^b Based on corn dry matter.

^c Based on corn dry matter and soakwater and steepwater chemical solids.

TABLE VI
Wet-Milling Yields of 10 Corn Hybrids Using a 1-kg SO₂ Procedure^a

Hybrid	Steepwater	Germ	Fiber	Starch	Gluten	Filtrate	Total Recovery ^b	Total Recovery ^c
1	4.1 ± 0.18	7.0 ± 0.08	12.1 ± 0.17	63.7 ± 0.75	10.6 ± 0.59	2.9 ± 0.45	100.3 ± 0.70	100.3 ± 0.70
2	4.4 ± 0.34	6.8 ± 0.44	13.6 ± 0.64	61.6 ± 0.45	10.6 ± 0.18	2.9 ± 0.04	99.9 ± 0.31	99.9 ± 0.31
3	4.2 ± 0.40	7.5 ± 0.02	12.4 ± 0.18	64.1 ± 0.39	8.9 ± 0.64	2.8 ± 0.11	99.9 ± 0.46	99.9 ± 0.46
4	4.2 ± 0.28	6.2 ± 0.16	13.8 ± 0.62	64.8 ± 0.77	8.6 ± 0.19	2.7 ± 0.33	100.3 ± 0.49	100.3 ± 0.49
5	4.3 ± 0.01	7.2 ± 0.23	13.3 ± 0.20	64.0 ± 0.68	8.2 ± 0.23	2.6 ± 0.49	99.5 ± 0.08	99.5 ± 0.08
6	4.5 ± 0.05	8.2 ± 0.16	13.1 ± 0.19	63.0 ± 0.19	8.8 ± 0.36	2.6 ± 0.33	100.2 ± 0.57	100.2 ± 0.57
7	4.4 ± 0.42	6.3 ± 0.09	14.2 ± 0.43	62.3 ± 0.52	10.1 ± 0.23	2.1 ± 0.30	99.4 ± 0.49	99.4 ± 0.49
8	4.2 ± 0.06	7.3 ± 0.27	13.6 ± 0.42	64.0 ± 0.42	9.3 ± 0.47	2.4 ± 0.33	100.8 ± 0.26	100.8 ± 0.25
9	4.6 ± 0.21	6.8 ± 0.42	15.8 ± 0.08	62.7 ± 0.73	8.3 ± 0.01	2.5 ± 0.14	100.7 ± 0.16	100.7 ± 0.17
10	4.5 ± 0.01	6.5 ± 0.13	11.6 ± 0.17	66.8 ± 0.39	8.2 ± 0.23	2.4 ± 0.39	100.0 ± 0.25	100.0 ± 0.26

^a Results are average of two replicates. Steep conditions: 52°C, 24 hr, 0.5% lactic acid, 2,000 ppm of SO₂. % Dry solids basis ± one standard deviation (*n* = 2). Yields not adjusted for sodium content.

^b Based on corn dry matter.

^c Based on corn dry matter and soakwater and steepwater chemical solids.

LITERATURE CITED

- American Association of Cereal Chemists. 1995. Approved Methods of the AACC, 9th ed. Method 44-15A approved October 1975, revised October 1981 and October 1994; Method 44-18 (see 8th ed.); Method 44-19 approved April 1961, revised October 1975, reviewed October 1994. The Association: St. Paul, MN.
- Anderson, R. A., and Watson, S. A. 1982. The corn milling industry. Pages 31-61 in: CRC Handbook of Processing and Utilization in Agriculture. Vol. 2. CRC Press: Boca Raton, FL.
- Anonymous. 1993. Cargill starts work on new corn refinery. July 27. Milling and Baking News 72(22):58.
- Anonymous. 1995. Co-ops into corn wet milling. March 21. Milling and Baking News 74(3):15.
- Barta, E. J. 1966. Methods of peeling wheat. U.S. patent 3,264,113.
- Bensing, H. O., Brown, D. R., and Watson, S. A. 1972. Waste utilization and pollution control in wet milling. Cereal Sci. Today 17:304-307.
- Cochran, W. G., and Cox, G. M. 1957. Some methods for the study of response surfaces. Pages 335-370 in: Experimental Design. W. G. Cox, ed. John Wiley and Sons: London.
- Du, L. 1997. Evaluation of an alkali corn wet milling process. PhD thesis. Department of Agricultural Engineering. University of Illinois at Urbana-Champaign: Urbana, IL.
- Eckhoff, S. R., Rausch, K. D., Fox, E. J., Tso, C. C., Wu, X., Pan, Z., and Buriak, P. 1993. A laboratory wet-milling procedure to increase reproducibility and accuracy of product yields. Cereal Chem. 70:723-727.
- Eckhoff, S. R., Du, L., Yang, P., Rausch, K. D., Wang, D. L., Li, B. H., and Tumbleson, M. E. 1999. Comparison between alkali and conventional corn wet milling: 100-g procedures. Cereal Chem. 76:96-99.
- Hansen, D. W. 1949. Manufacture of corn products. U.S. patent 2,472,971.
- Jones, O. 1841. Improvement in the manufacture of starch. U.S. patent 2,000.
- Mistry, A. H., and Eckhoff, S. R. 1992. Alkali debranning of corn to obtain corn bran. Cereal Chem. 69:2296-303.
- Mistry, A. H., Schmidt, S. J., Eckhoff, S. R., and Sutherland, J. W. 1992. Alkali extraction of starch from corn flour. Starch/Staerke 44:284-288.
- Morgan, A. I., Jr., Barta, E. J., and Graham, R. P. 1966. Chemical peeling of grain. Cereal Chem. 62:138-141.
- Watson, S. A., and Stewart, C. W. 1969. Corn degermination process. U.S. patent 3,474,722.
- Weinecke, L. A. 1962. Corn degermination pretreatment. U.S. patent 3,031,305.
- Zehr, B. E., Eckhoff, S. R., Singh, S. K., and Keeling, P. L. 1995. Comparison of wet-milling properties among maize inbred lines and their hybrids. Cereal Chem. 72:491-497.
- Zehr, B. E., Eckhoff, S. R., Nyquist, W. E., and Keeling, P. L. 1996. Heritability of product yields from wet-milling of maize grain. Crop Sci. 36:1159-1165.

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