Effect of Sodium Hydroxide, Calcium Hydroxide, and Potassium Hydroxide on Debranning of Corn

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ABSTRACT

The effect of sodium hydroxide, calcium hydroxide, and potassium hydroxide, and processing conditions (alkali concentration and soaking time) on corn debranning was studied at a temperature of 55°C. Fiber yield, soluble dry matter loss, and total dry matter removed were determined for different alkalies and processing conditions. Sodium hydroxide and potassium hydroxide resulted in maximum fiber yields of 3.38 and 3.48%; maximum soluble dry matter loss of 7.63 and 10.96%; and maximum total dry matter removed of 10.52 and 13.26%. Calcium hydroxide at 6% concentration level resulted in negligible fiber yield, soluble dry matter loss, and total dry matter removed with soak times up to 16 hr. Sodium hydroxide has higher debranning action than potassium hydroxide at 3 and 6% concentration levels; whereas, at 9% concentration level, potassium hydroxide has higher debranning action.

Alkali pretreatment of corn has been reported to loosen and separate the pericarp or dissolve the pericarp (Wagner 1940; Wagner 1942; Hansen 1949; Weinecke 1962; Watson and Stewart 1969; Mistry and Eckhoff 1992a,b). The pericarp-free corn can be used for further processing in wet- or dry-milling processes.

Hansen (1949) immersed the corn kernels in a 0.2% caustic alkali solution at a temperature in the range of 71.1–100°C (160–212°F) for a soaking period of 2–5 min, to loosen the pericarp and tip caps of the kernels. The corn kernels were mechanically debranned and wet milled. Blessin et al (1970) dissolved the pericarp in 3–4 min in a 15% solution of sodium hydroxide at 71.1°C (160°F) to produce pericarp-free corn. The removal of the pericarp was due to total solubilization of the pericarp rather than loosening and removing by mechanical action. Mistry and Eckhoff (1992b) developed an alkali debranning process to obtain high quality corn bran in which a hydroabrasor was used to mechanically remove the pericarp loosened by soaking of kernels in dilute NaOH solution.

The key step in the corn wet-milling process is steeping. The whole corn kernels are steeped in a weak sulfurous acid solution for 22–50 hr at 52°C in the presence of lactic acid (May 1987). SO_2 enters corn primarily through the tip cap in whole intact kernels, diffuses around the kernel in the area between the pericarp and the seed coat, and then diffuses through the seed coat into the endosperm (Cox et al 1944, Eckhoff and Okos 1989). The pericarp in the whole intact kernels provides a diffusion barrier to sulfurous acid solution. If the diffusion barrier created by the pericarp is broken, the steeping time for wet milling of corn can be reduced. Eckhoff and Okos (1989) reported increased sorption of SO_2 in kernels with apparent surface cracks or other breaks in the pericarp. The cracks provided extra entrance points for SO_2. The mechanically debranned corn obtained by Hansen (1949) required a steep time of only 10–16 hr, and resulted in greater yields of starch and oil, and lower cost of production. However, the process temperature of 71.1–100°C (160–212°F) may have a detrimental effect on the corn starch and proteins.

This study was initiated to study the effect of different alkalies (NaOH, KOH, and $Ca(OH)_2$) and processing conditions (alkali concentration and soaking time) on corn debranning in terms of fiber yield, soluble dry matter loss, and total dry matter removed.

MATERIALS AND METHODS

A single corn variety (FR27×FRMo17) was ambient air-dried to 17.7% mc (dwb). The dried corn was sieved over a 4.76-mm (12/64 in.) round-hole screen using a Gamet sieve shaker (Dean Gamet Mfg. Co., Minneapolis, MN) to remove foreign material and broken kernels. Moldy and heat-damaged kernels were handpicked and discarded. Corn samples (100 g each) were double-sealed in polyethylene bags and stored at 4°C.

Alkali treatment was performed by soaking 100 g of corn in 200 mL of alkali solution held in a waterbath adjusted to constant temperature. After treating the corn sample with alkali solution for a specific time, the corn was rinsed with cold tap water to remove any excess alkali from the surface of the corn kernel and to terminate the alkali reaction. The alkali-treated corn was mechanically debranned using the procedure of Mistry and Eckhoff (1992b). A hydroabrasor was used to remove the loosened pericarp from the kernels placed on a 4-mesh, 150-mm round screen. The pericarp (fiber), which peeled off because of the abrasive action, was collected over a 150-µm screen. The solubles were lost in the water continuously recirculated on the top screen.

Preliminary studies were done to determine optimum temperature for further experiments to study the effect of alkali type, alkali concentration, and soaking time. Mistry and Eckhoff (1992b) obtained highest bran (fiber) yield at 6% NaOH solution, 9 min of soaking time and a temperature of 57°C. To determine optimum temperature for further experiments, corn was alkali-debranned at three temperature levels (52, 55, and 57°C) using a 6% NaOH solution and 9 min of soaking time.

Three different alkalies (NaOH, KOH, and $Ca(OH)_2$) were used for the study. Three alkali concentrations (3, 6, and 9%) and six soaking times (5, 7, 9, 11, 13, and 15 min) were selected as the independent variables to study the effect of NaOH and KOH. Each combination of alkali concentration and soaking time was studied in triplicate. $Ca(OH)_2$ was studied at 6% concentration level for soak times up to 16 hr, after initial tests at the same alkali concentration and soak times as NaOH and KOH showed that $Ca(OH)_2$ required longer soak times.

The debranned corn was gently rubbed in a paper towel for 1–2 min before weighing and transferring to the oven. The moisture content of whole and debranned corn was determined by drying the sample in a forced-air convection-drying oven at 103°C for 72 hr (ASAE 1984). The solids content of the pericarp was deter-

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mined by drying the samples at 49°C for 24 hr and then at 103°C for 3 hr in a forced-air convection-drying oven (AACC 1983).

The dependent variables were fiber yield (%FY), soluble dry matter loss (%SDML), and total dry matter removed (%TDMR), all expressed as percent of the initial dry weight of the corn sample. The following equations were used to obtain the mass fractions of different dependent variables on a dry basis:

$$\%FY = [\text{dry pericarp weight (g)}/\text{dry corn weight (g)}] \times 100 \quad (1)$$

$$\%TDMR = [(\text{dry corn weight (g)} - \text{dry debranned corn weight (g)})/\text{dry corn weight (g)}] \times 100 \quad (2)$$

$$\%SDML = \%TDMR - \%FY \quad (3)$$

Statistical software (SAS Institute, Cary, NC) was used to analyze the data. Two way analysis of variance (ANOVA) and least significant difference method (LSD) were used to find significant differences among various soaking times and alkali concentration combinations at a probability of α (type I error) of 5% ($P < 0.05$).

RESULTS AND DISCUSSION

Selection of Temperature

Corn debranning using 6% NaOH solution and 9 min of soaking time was done to determine optimum temperature for further experiments. It indicated that the %FY obtained at 52°C was significantly different from the %FYs obtained at 55 and 57°C; whereas, the %FYs at 55 and 57°C were not significantly different (Table I). The %SDML was not significantly different at any of the temperatures. The %TDMR at 52 and 55°C was not significantly different, but was different from that of 57°C; whereas, the %TDMR at 57°C was not significantly different from that at 55°C but was different from that at 52°C. Since %FY, %SDML, and %TDMR were not significantly different at 55 and 57°C, a temperature of 55°C was selected for further experiments.

TABLE I
Effect of Temperature on Fiber Yield (%FY), Soluble Dry Matter Loss (%SDML) and Total Dry Matter Removed (%TDMR) Using 6% NaOH and 9 Min of Soak Time

Temperature (°C)	%FY	%SDML	%TDMR
52	1.85a[a]	2.04a	3.90a
55	2.77b	2.09a	4.86ab
57	2.64b	2.86a	5.49b

[a] Means followed by the same letter in the same column are not significantly different at $\alpha = 0.05$.

%FY

The %FYs obtained using NaOH and KOH solutions are listed in Tables II and III, respectively. The maximum %FY at 3% concentration level was 3.38% for NaOH and 2.22% for KOH. The maximum %FY was obtained for 11 min of soaking time for both the 6% NaOH and KOH solutions. The 9% NaOH solution resulted in highest %FY (3.25%) at 9 min of soaking time and the 9% KOH solution resulted in highest %FY (3.48%) at 11 min of soaking time. When the corn was soaked in 6% NaOH and KOH solutions, the %FY increased up to 11 min of soaking time and then started decreasing (Figs. 1 and 2). There were no clear trends for 3 and 9% NaOH and KOH solutions.

The %FYs for NaOH at all concentration levels were not significantly different with 9, 11, and 13 min of soaking time (Table II). For KOH debranning process, the %FYs at 6 and 9% concentration levels were not significantly different at 11, 13, and 15 min of soaking time, however the %FYs were different at the 3% concentration level. The %FY with the 3% KOH solution were significantly different from those at 6 and 9% concentration level for all soaking times, except 5 min.

A statistical model equation to predict %FY for 3–9% concentration levels and 5–15 min of soaking time was determined both for NaOH ($R^2 = 0.89$) and KOH ($R^2 = 0.80$):

$$\%FY\ (NaOH) = -3.41 + 0.26(C) + 0.85(t) + 0.03(C)^2 - 0.02(t)^2 - 0.05(C)(t) \quad (4)$$

$$\%FY\ (KOH) = -4.65 + 0.90(C) + 0.74(t) - 0.03(C)^2 - 0.02(t)^2 - 0.03(C)(t) \quad (5)$$

where C is concentration in percentage values, and t is time in minutes.

TABLE II
Fiber Yields, Soluble Dry Matter Loss, and Total Dry Matter Removed in NaOH Debranning Process

	Fiber Yields NaOH Concentrations (%)			Soluble Dry Matter Loss NaOH Concentrations (%)			Total Dry Matter Removed NaOH Concentrations (%)		
Time (min)	3	6	9	3	6	9	3	6	9
5	1.07Aa[a]	1.26Aa	2.90ABb	1.69Ad	2.68Ae	2.80Ae	2.76Ag	3.94Ah	5.70Ai
7	1.00Aa	1.64Ab	3.17BCc	1.96Ad	2.80ABe	4.50Bf	2.96Ag	4.44Ah	7.67Bi
9	2.40Ba	2.70Ba	3.25Ca	2.55ABd	3.63BCe	4.39Be	4.95Bg	6.33Bh	7.64Bi
11	2.97BCa	3.27Ca	3.15BCa	3.51BCd	3.92Cd	4.85BCe	6.48Cg	7.19Bgh	8.00BCh
13	3.12BCa	2.98BCa	2.79Aa	4.04CDd	4.19Cd	5.64Ce	7.16Cg	7.17Bg	8.43Ch
15	3.38Ca	2.71Bb	2.89ABb	5.05Dd	5.46Dd	7.63De	8.43Dg	8.17Cg	10.52Dh

[a] Means followed by the same uppercase letter in the same column are not significantly different at $\alpha = 0.05$. Means followed by the same lowercase letter in the same row are not significantly different at $\alpha = 0.05$.

TABLE III
Fiber Yields, Soluble Dry Matter Loss, and Total Dry Matter Removed in KOH Debranning Process

	Fiber Yields KOH Concentrations (%)			Soluble Dry Matter Loss KOH Concentrations (%)			Total Dry Matter Removed KOH Concentrations (%)		
Time (min)	3	6	9	3	6	9	3	6	9
5	1.05Aa[a]	0.98Aa	2.74Ab	1.27Ad	1.82Ad	3.35Ae	2.32Ag	2.80Ag	6.09Ah
7	1.34ABa	2.22Bb	3.36Bc	1.59ABd	2.72Bd	4.83ABe	2.93ABCg	4.94Bh	8.19ABi
9	1.13Aa	2.74BCb	3.10ABc	1.58ABd	2.82Be	4.67ABf	2.71ABg	5.56BCh	7.77ABi
11	1.92BCa	3.36Db	3.48Bb	2.32Cd	2.47ABd	6.56Be	4.24Dg	5.83Cg	10.04Bh
13	1.73ABCa	3.20CDb	2.87Aab	2.03BCd	2.78Bd	9.82Ce	3.76BCDg	5.98CDg	12.69Ch
15	2.22Ca	2.93CDb	2.30Cab	1.81ABCd	3.78Ce	10.96Cf	4.03CDg	6.71Dh	13.26Ci

[a] Means followed by the same uppercase letter in the same column are not significantly different at $\alpha = 0.05$. Means followed by the same lowercase letter in the same row are not significantly different at $\alpha = 0.05$.

Debranning of corn using 6% $Ca(OH)_2$ solution resulted in <1% FY up to a soaking time of 16 hr. However, traditionally alkali-cooked corn for making tortillas uses a 5% solution of lime in water (which yields calcium hydroxide) near boiling for 30–50 min (Katz et al 1974). These conditions result in partial dissolution of the pericarp, implying that $Ca(OH)_2$ can be used for debranning if higher temperatures are used. Because higher temperatures (near boiling) and longer soaking times are needed for $Ca(OH)_2$ to be effective, resulting in higher absorption of alkali by the corn and possible gelatinization of starch, $Ca(OH)_2$ is not recommended for debranning of corn to be used for wet-milling.

%SDML

The %SDML increased with increasing soaking time at 3 and 6% concentration levels of NaOH debranning (Fig. 1). The %SDML increased dramatically with increasing soaking time beyond 9 min for both the 9% NaOH and KOH solutions (Figs. 1 and 2). One plausible explanation for the dramatic increase in %SDML is that the fiber starts dissolving in higher levels of alkali concentration and higher soaking times.

The %SDML for both the 6% NaOH and KOH solutions is higher than that at 3% concentration level both for NaOH and KOH at all soaking times, while the %SDML at 9% NaOH and KOH solutions is higher than that at 6% concentration level at all soaking times. The %SDML for 3 and 6% NaOH solutions was not significantly different at 11, 13, and 15 min of soaking time (Table II). %SDML for 3 and 6% KOH solutions was not significantly different at 5, 7, 11, and 13 min of soaking time (Table III).

The %SDML for 9% KOH solution is higher than that for 9% NaOH solution at all soaking times, implying that KOH has higher pericarp solubilization action than that of NaOH at the 9% concentration level. On the contrary, %SDML for 3 and 6% KOH solutions is lower than that for the 3 and 6% NaOH solutions at all soaking times, implying that KOH has lower pericarp solubilization action than that of NaOH at 3 and 6% concentration levels.

A statistical model equation to predict %SDML for 3–9% concentration levels and 5–15 min of soaking time was determined for both NaOH (R^2 = 0.94) and KOH (R^2 = 0.94):

$$\%SDML\ (NaOH) = 1.83 - 0.15(C) - 0.08(t) + 0.03(C)^2 + 0.02(t)^2 + 0.01(C)(t) \quad (6)$$

$$\%SDML\ (KOH) = 8.92 - 2.37(C) - 0.67(t) + 0.17(C)^2 + 0.01(t)^2 + 0.12(C)(t) \quad (7)$$

where C is concentration in percentage values, and t is time in minutes.

The %SDML using 6% $Ca(OH)_2$ solution for debranning also increased with increased soaking time, but the %SDML was only 1.77% after 16 hr of soak time.

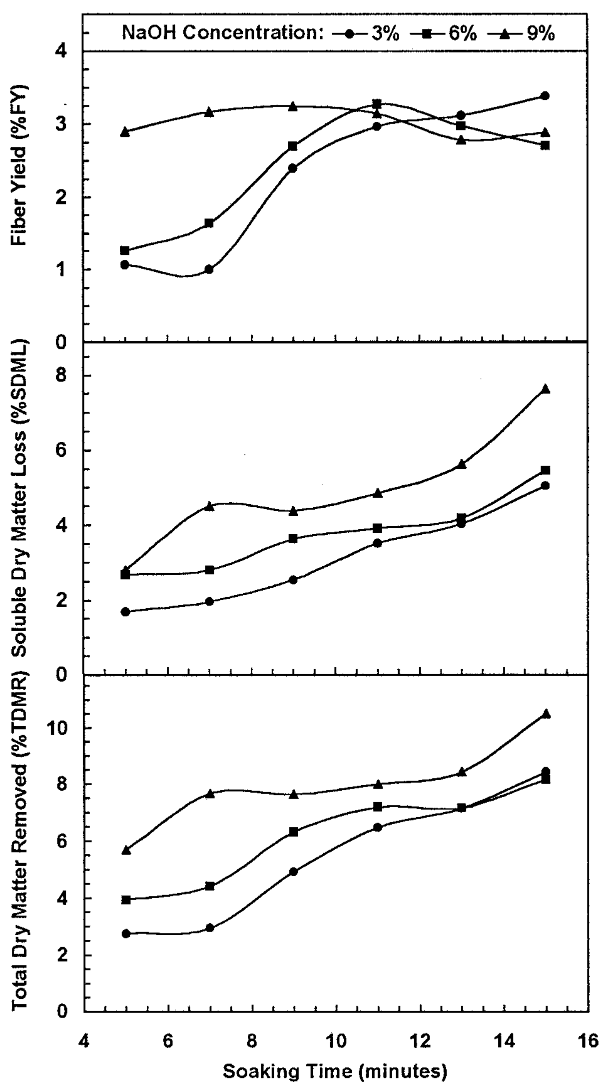

Fig. 1. Effect of NaOH concentration and soaking time on fiber yield, soluble dry matter loss, and total dry matter removed.

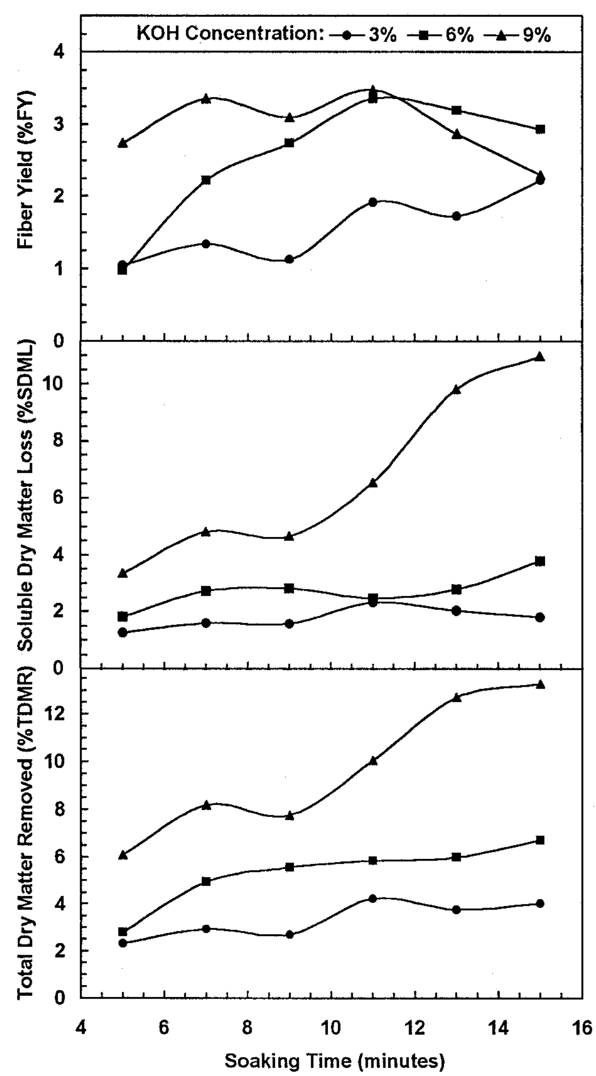

Fig. 2. Effect of KOH concentration and soaking time on fiber yield, soluble dry matter loss, and total dry matter removed.

%TDMR

The %TDMR increased with increased soaking times for the 3% concentration level of NaOH and for the 6% concentration level of KOH (Figs. 1 and 2). The %TDMR with the 9% KOH solution increased sharply with increased soaking time after 9 min (Fig. 2).

The %TDMR of the 3% and 6% NaOH solutions was not significantly different at 11, 13, and 15 min of soaking time (Table II). For KOH debranning at the 3 and 6% concentration levels, %TDMR was not significantly different at 5, 11, and 13 min of soaking time (Table III).

The %TDMR for the 9% KOH solution is higher than that for the 9% NaOH solution at all soaking times, implying that KOH has higher debranning action than does NaOH at the 9% concentration level. On the contrary, %TDMR for 3 and 6% KOH solution is lower than that for 3 and 6% NaOH solution at all soaking times except for 7 min of soak time at the 6% concentration level, implying that KOH has lower debranning action than NaOH at the 3 and 6% concentration level.

A statistical model equation to predict %TDMR for 3–9% concentration levels and 5–15 min of soaking time was determined both for NaOH ($R^2 = 0.95$) and KOH ($R^2 = 0.97$):

$$\%\text{TDMR (NaOH)} = -1.58 + 0.11(C) + 0.77(t) + 0.06(C)^2 - 0.004(t)^2 - 0.04(C)(t) \quad (8)$$

$$\%\text{TDMR (KOH)} = 4.26 - 1.47(C) + 0.07(t) + 0.13(C)^2 - 0.01(t)^2 + 0.09(C)(t) \quad (9)$$

where C is concentration in percentage values, and t is time in minutes.

The %TDMR using the 6% $Ca(OH)_2$ solution for debranning increased with increased soaking time, but %TDMR was only 1.87% after 16 hr of soaking.

CONCLUSIONS

The use of NaOH for debranning resulted in %FY up to 3.38%, %SDML up to 7.63%, and %TDMR up to 10.52%. The use of KOH for debranning resulted in %FY up to 3.48%, %SDML up to 10.96%, and %TDMR up to 13.26%. $Ca(OH)_2$ at the 6% concentration level resulted in negligible %FY, %SDML, and %TDMR. NaOH has higher pericarp solubilization and debranning action than does KOH at the 3 and 6% concentration levels, whereas KOH has higher pericarp solubilization and debranning action at the 9% concentration level. The alkali-debranning process removes pericarp from the corn and, hence, the diffusion barrier for sulfurous acid solution. This may significantly reduce the steeping time of the corn for wet milling. The response of the alkali-debranned corn to the wet-milling process is under investigation.

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