

Effect of Broken Corn Levels on Water Absorption and Steepwater Characteristics

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ABSTRACT

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Broken corn created by grounding sound corn kernels was added back at levels of 0, 4, 8, 12, or 16%, by weight, to whole kernels of three corresponding hybrids: FR27 × FRMo17 (a soft endosperm corn), FR618 × FR600 (a medium-hard endosperm corn), and FR618 × LH123 (a hard endosperm corn). The samples had been dried from 28% moisture content to 15% moisture content either by using ambient air at ≈25°C or at 110°C. Samples were steeped for 36 hr at 52°C in 0.15% sulfur dioxide and 0.5% lactic acid steeping solution. The steepwater characteristics, such as water absorption, solids and protein content in the steepwater, and steepwater pH, were measured by periodic sampling and analyzed. Broken corn level has a significant effect on the amount of solids released during steeping and steepwater protein content for all samples. Both

steepwater solids and protein content increased linearly as broken corn content increased. Corn drying temperature, kernel hardness, and interactions between drying temperature and kernel hardness has a significant effect on steepwater solids and protein content and steepwater pH in both broken and unbroken corn. Corn dried at low temperature released more soluble solids and protein into the steepwater than corn dried at high temperature. Soft endosperm and medium-hard endosperm corn released more soluble solids and protein into the steepwater than hard endosperm corn. Soft endosperm corn resulted in a higher steepwater pH than medium-hard and hard endosperm corn. No significant effect of broken corn content on final moisture content of steeped corn and steepwater pH was observed.

Steeping is the first and the most critical process in corn wet milling. The major objectives of steeping are to remove protein solubles, to soften the kernels, and to loosen the starch in the endosperm by disrupting the endosperm protein matrix and the endosperm cells using added sulfur dioxide and endogenous proteases (Watson 1984). Steeping is a complex, diffusion-limited process in which a number of chemical and biochemical reactions and structural and physical property changes occur (Cox 1944). Corn wet-milling companies are interested in corn with a low percentage of foreign material and broken, heat-damaged, and shrunken kernels; low breakage susceptibility; and a low percentage of mold (Brooker et al 1992), because these factors affect the starch quality and yield.

In the United States, test weight, broken kernel and foreign material (BCFM), heat damage, and total damage are grade-determining factors. Three of these four factors are related to kernel damage. Broken corn in the wet-milling process will greatly increase the amount of starch and free sugars that will diffuse into the steepwater (Freeman 1973). This can pose a problem because high levels of starch and sugars result in excessive bacteria activity (Roushdi et al 1979). For example, steeping conditions that produce optimum conversion of sugar to lactic acid will increase rods such as lactobacilli, and steepwater with nutrients will stimulate the growth of lactic streptococci (Watson 1984). The bacteria activity and any unconverted starch in the steepwater increases the color formation in the evaporators due to nonenzymatic browning (Watson 1984). The excessive bacteria activity also results in high levels of lactic acid, which increases the rate of evaporator fouling (Kerr 1950). As a result, broken corn affects starch yield.

Many factors cause kernel damage and broken corn. Harvesting, transporting, drying processing, and insects are the main factors (Watson 1987). High moisture of the corn at harvest, together with mechanical impact during combining, caused up to 78% kernel stress cracking and up to 67% breakage susceptibility in harvested corn (Peplinski et al 1994). Winter (1968) reported that the handling equipment could cause up to 13.8% breakage to the corn. Paulsen and

Hill (1985) reported that the broken corn and foreign materials at the farm level averaged 0.7%, while it averaged 5.0% on one export shipment. Reports of increased BCFM (4.9–20.3% and 3.4–7.6%) on overseas shipments were confirmed by Hill and Paulsen (1979, 1989). Wet millers have a vital interest regarding the effect of broken corn on the steeping process. The objective of this research was to study the effect of broken corn on water absorption and steepwater characteristics of total solids, protein content, and pH.

MATERIALS AND METHODS

Three hybrids, FR27 × FRMo17, FR618 × FRMo17, and FR618 × LH123 (soft, medium-hard, and hard endosperm corn, respectively), were used for this study. These samples were dried using either ambient air at ≈25°C or air at 110°C from ≈28% moisture content to ≈15% wb.

All samples were screened using a sieve shaker (Dean Gamet Mfg. Co., Minneapolis, MN) with a 6.25-mm round-hole sieve and were hand-picked to remove large foreign materials; corn moisture content was determined by the 103°C, 72-hr forced convention oven-drying method in a laboratory dryer (Blue M Electric Co., Blue M Island, IL). Before steeping, the moisture content of all samples was adjusted to 15% wb by either ambient drying to reduce the moisture content or by spraying with distilled water to increase the moisture content if the moisture content of the corn samples are higher or lower than 15% wb. All samples were equilibrated in the sealed bags for seven days at 4°C. Broken corn was created by grinding sound kernels in a coffee grinder with a capacity of 2.5 oz (Braun Inc., Lynnfield, MA).

Broken corn is defined as all matter that passes through the 4.85-mm (12/64 in.) round-hole sieve and over the 2.42-mm (6/64 in.) round-hole sieve (USDA 1988). However, to get uniform distribution of the particle size, the broken corn consisted of 50% broken corn particles sized between 4.85 and 3.57 mm and 50% broken corn particles sized between 3.57 and 2.42 mm. The broken corn was added to sound kernels at broken corn content levels of 0, 4, 8, 12, and 16%. Each of the corn hybrids (250 g) and drying temperature combinations were steeped in Erlenmeyer flasks for 1, 3, 5, 8, 12, 24, and 36 hr at 52 ± 1°C using steepwater containing 0.15% sulfur dioxide (SO₂) and 0.5% lactic acid. The steeping temperature was held constant by placing flasks in a water bath (model MW-1130A, Blue M Electric Co.). The total steepwater volume was 466.7 mL in each flask. When the steeping was completed, the steeped corn and steepwater was separated by a 0.79-mm sieve.

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At each steep time, three 20-g steeped corn samples were collected to determine moisture content using the 103°C, 72-hr forced-air convection oven drying method (Approved Method 44-15A, AACC 2000). Three 30-mL steepwater samples were collected and placed in a 49°C oven for 24 hr to remove most of the water before being placed in a 103°C oven for 5 hr for steepwater solids content determination (Approved Method 44-18). Two 5-mL steepwater samples were collected to measure the steepwater protein content on liquid fraction (Approved Method 46-13); 30-mL steepwater samples were collected to measure pH using a pH meter (model 120, Scientific Instruments Halstead Essex, Medford, MA). The steepwater solids content was defined as all dry matter in the steepwater divided by initial dry matter of steeped corn. The steepwater protein content is defined as protein by the dry matter in the steepwater divided by initial dry matter of steeped corn.

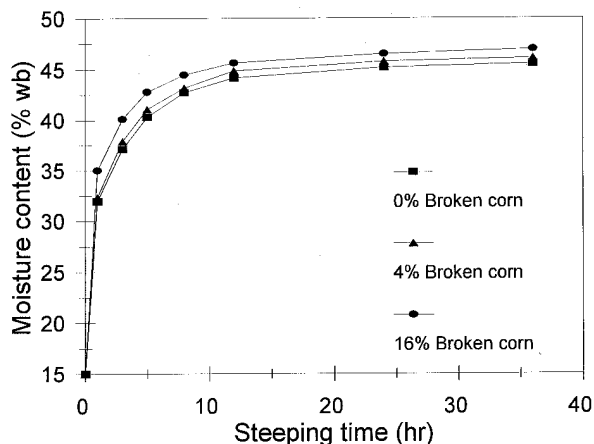


Fig. 1. Moisture content of steeped corn as a function of steeping time at 0, 4, and 16% broken corn level.

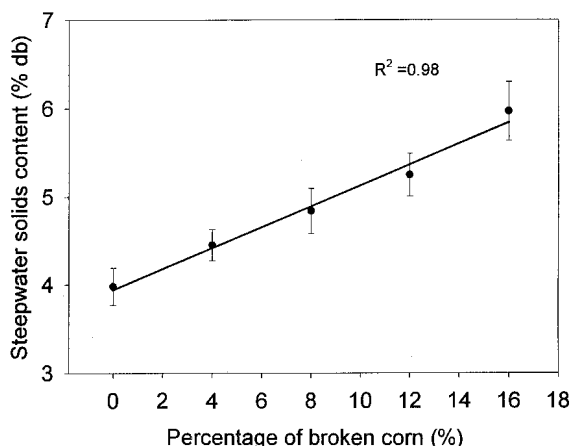


Fig. 2. Effect of broken corn level on steepwater solids content. Vertical bars represent values of 2× standard deviation.

TABLE I
Effect of Broken Corn Level on Final Corn Moisture Content, Steepwater Solids Content, Steepwater Protein Content, and pH Value of Steepwater^a

Broken Corn Levels (%)	Moisture (% wb)	Steepwater Solids (% db)	Steepwater Protein (% db)	pH of Steepwater
0	46.0a	4.0e	1.11d	3.5a
4	46.3a	4.5d	1.19cd	3.4a
8	46.5a	4.8c	1.26bc	3.6a
12	46.7a	5.3b	1.32b	3.5a
16	47.0a	6.0a	1.47a	3.5a

^a Values within the same column followed by different letters are significant at $P < 0.05$.

A cross-classified three-factorial random block design was used for each of the different experiments. The five levels of broken corn were 0, 4, 8, 12, and 16%. The three levels of corn hybrids were soft, medium-hard, and hard endosperm. The two levels of drying temperature were 110°C and ambient temperature. Results were analyzed using an SAS software package (SAS Institute Inc., Cary, NC). Analysis of variance was performed by following the general linear model (GLM) procedure. Duncan's new multiple range test ($\alpha = 0.05$) was used to differentiate treatment means determined to be significant different.

RESULTS AND DISCUSSION

Effect of Broken Corn on Water Absorption and Steepwater Characteristics

Corn moisture content with a high level of broken corn increased faster than that of corn with a low level of broken corn during the first 8 hr of steeping (Fig. 1). Corn moisture content increased faster ($\approx 3.5\%/hr$) during the first 8 hr of steeping, then it became slower at $0.14\%/hr$. The moisture content of steeped corn increased as the broken corn level increased during steeping. This was because the barrier for water diffusion had been reduced in broken corn and, hence, the water absorption rate had been increased. However, no significant difference in the final moisture content was observed between different percentages of broken corn (Table I). This is probably due to the fact that both broken and unbroken corn had the same chemical composition, and therefore, should have the same or similar water-holding ability and final equilibrium moisture content.

The effect of broken corn on solids release was significant (Table I). The average final solids content ranged from 4.0% for 0% broken corn to 6.0% for 16% broken corn. The final steepwater

TABLE II
Effect of Drying Temperature on Steepwater Solids Content, Steepwater Protein Content, and pH Value of Steepwater^a

	Broken Corn Level (%)				
	0	4	8	12	16
Solids content (% db)					
Ambient	4.2a	4.7a	5.2a	5.5a	6.2a
110°C	3.8b	4.2b	4.5b	5.1b	5.8b
Protein content (% db)					
Ambient	1.18a	1.29a	1.33a	1.39a	1.56a
110°C	1.03b	1.09b	1.17b	1.25b	1.36b
pH Value					
Ambient	3.5a	3.5a	3.7a	3.6a	3.6a
110°C	3.4a	3.4a	3.5a	3.5a	3.5a

^a Values within the same column followed by different letters are significant at $P < 0.05$.

TABLE III
Effect of Kernel Hardness on Steepwater Solids Content, Steepwater Protein Content, and pH Value of Steepwater^a

	Broken Corn Level (%)				
	0	4	8	12	16
Solids content (% db)					
Soft	4.1a	4.6a	5.0a	5.4a	6.2a
Medium	4.0a	4.5ab	4.9ab	5.3ab	6.1a
Hard	3.8b	4.3b	4.6b	5.0b	5.7b
Protein content (% db)					
Soft	1.12a	1.25a	1.35a	1.41a	1.59a
Medium	1.16a	1.25a	1.24ab	1.31ab	1.47ab
Hard	1.02b	1.07b	1.16b	1.25b	1.35b
pH Value					
Soft	3.6a	3.5a	3.7a	3.6a	3.6a
Medium	3.5ab	3.4b	3.6b	3.5b	3.5a
Hard	3.4b	3.4b	3.5b	3.5b	3.5a

^a Values within the same column followed by different letters are significant at $P < 0.05$.

solids content increased with increasing level of broken corn. There is a strong linear relationship ($R^2 = 0.98$) between the level of broken corn and final steepwater solids content (Fig. 2). This result indicates that broken corn has less resistance for soluble solids to release than sound corn.

As expected, the effect of broken corn on steepwater protein content followed trends similar to those on solids release (Table I). This result also shows the linear relationship ($R^2 = 0.96$) between the level of broken corn and steepwater protein content (Fig. 3). The steepwater protein content increased as the percentage of broken corn increased. The average final protein content was in range of 1.1% for corn containing 0% broken corn and 1.5% for corn containing 16% broken corn. However, the protein content in the steepwater solids decreased as the percentage of broken corn increased (Fig. 4). This result indicates that increasing the percentage of broken corn causes more starch loss during steeping and reduces the final starch yield.

No significant difference was observed on the effect of broken corn level on the steepwater pH (Table I). This is because this set of data was affected not only by the percentage of broken corn but also by corn drying condition and corn kernel hardness.

Effect of Corn Drying Temperature on Steepwater Characteristics

The effect of corn drying temperature on steepwater solids content, steepwater protein content, and steepwater pH at 0, 4, 8, 12, and 16% broken corn levels is shown in Table II. Drying temperature had a significant effect on steepwater solids content (Table II). Corn dried at ambient temperature released more soluble solids than corn dried at 110°C. High-temperature drying causes protein denaturation. The irreversible protein denaturation changes the native of the original folding of protein to aggregated and form unfolding rigid entity (Wall et al 1975, Wight 1981, Myers 1990). The denatured protein matrix functions to hinder or prevent the soluble solids from being released from sound and broken kernels. This result implies that it is easier to break down the protein matrix during steeping for corn dried at ambient temperature, which may give higher wet-milling yields than for corn dried at high temperature; this is consistent with other results (Mistry et al 1993).

The steepwater protein content was affected significantly by drying temperature (Table II). Corn dried at ambient temperature released more soluble protein into the steepwater than corn dried at high temperature. This is because high-temperature drying causes the formation of hydrogen and nonpolar bonds within the matrix proteins that make the protein matrix more rigid and interconnected (Watson 1984) and causes some soluble protein fraction to be insolubilized. The relationship between drying temperature and loss of protein in the steepwater has been demonstrated (Waston and Hirata 1962, Wall

et al 1978, Biss and Cogan 1988). Corn drying temperature had no significant effect on steepwater pH (Table II).

Effect of Kernel Hardness on Steepwater Characteristics

Soft endosperm and medium endosperm corn had higher steepwater solids and protein content than the hard endosperm corn (Table III). This is probably due to the fact that, for hard endosperm cells, a protein matrix continuously surrounds each starch granule (Christensen et al 1969) and, although the protein matrix also surrounds the starch granule in soft endosperm cells, it is thinner there (Wolf et al 1969). Therefore, the protein matrix of hard endosperm corn is more difficult to break down than soft and medium-hard endosperm corn. This may be a result of the need for longer steep time for harder corn samples. The high steepwater protein content for soft endosperm and medium-hard endosperm corn can be also expressed by the fact that more solids content in the steepwater resulted in the more steepwater protein content. There is a linear relationship between the protein content and solids content in the steepwater ($R^2 = 0.99$) (Fig. 5).

The effect of kernel hardness on steepwater pH follows trends similar to those on steepwater solids and protein contents. The statistical results show that soft endosperm corn resulted in significantly higher steepwater pH value than medium-hard and hard endosperm corn at broken corn levels of 0, 4, 8, and 12%. However, kernel hardness had no significant effect on the steepwater pH at a broken corn level of 16%. There may be a significant effect of kernel hardness on steepwater pH at high levels of broken corn. Future studies may be needed, using more precise pH measurement, to elucidate the effect.

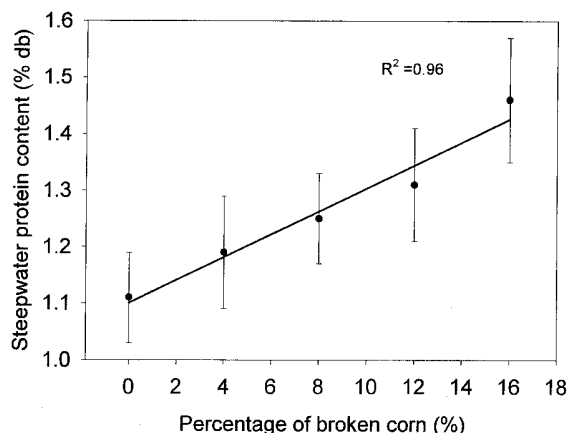


Fig. 3. Effect of broken corn level on steepwater protein content. Vertical bars represent values of 2× standard deviation.

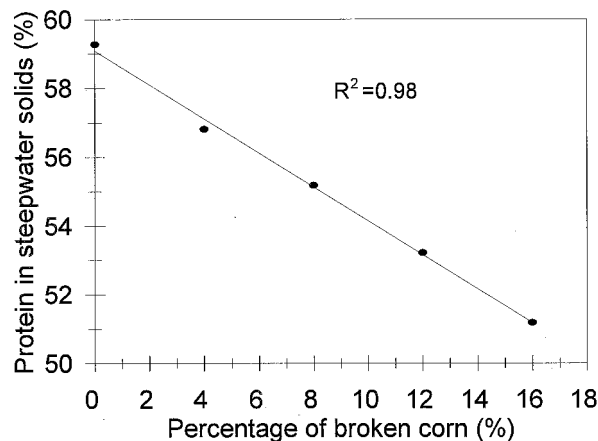


Fig. 4. Protein content in steepwater solids as a function of percentage of broken corn.

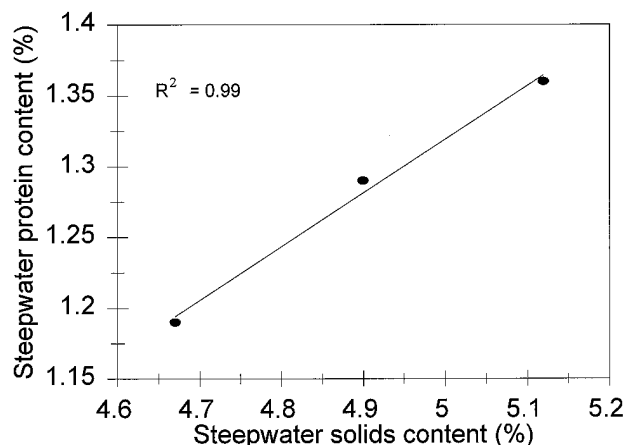


Fig. 5. Steepwater protein content as a function of steepwater solids content.

CONCLUSIONS

No significant effect of broken corn on final moisture content of steeped corn and steepwater pH was observed. The effect of broken corn on steepwater solids content and protein content were significant. Steepwater solids and protein content increased linearly as broken corn content increased. Corn drying temperature and kernel hardness had significant effect on steepwater solids and protein content and steepwater pH. Soft endosperm and medium endosperm corn had higher steepwater solids and protein content and steepwater pH than hard endosperm corn. Interaction between kernel hardness and drying temperature also had a significant effect on the solids release and protein content in the steepwater.

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