Laboratory Dry-Milling Performance of White Corn: Effect of Physical and Chemical Corn Characteristics[1]

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ABSTRACT

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Thirty-two hybrids of white dent corn were evaluated for physical and chemical properties and dry-milling yields. The physical properties studied included true density, test weight, and 100-kernel weight. The chemical composition evaluated consisted of protein, oil, and starch content. The corn samples tested were processed using a short dry-milling procedure. A micromilling method was used to evaluate the dry-milling efficiency. Over 93% of the white corn flaking grits yields were greater than 20%, and half of the flaking grits yields were greater than 30%. Large variations were found in the ratios of hard to soft and endosperm to bran, indicating that some of the hybrids had a much larger portion of hard endosperm in the endosperm. Micromilling could provide an index of the efficiency of the dry-milling test. Protein content, true density, and the ratios of hard to soft and endosperm to bran showed high correlation with dry-milling yields. A linear relationship was found between protein content of white corn and the flaking grits yield.

Corn has been referred to as "the cereal of the future" due to its high nutritional value and the wide utilization of its products and by-products (Milazzo 1986). Corn is a major contributor to the U.S. economy as a raw material for an ever-increasing array of products and as a major export commodity. The United States is a major producer of corn worldwide, producing over 256 million metric tons (10 billion bushels) in 1994.

The corn kernels are made up of three principal parts: pericarp (also referred to as hull or bran), germ, and endosperm. The objective of the dry-milling process in the United States is to separate these components with maximum yields and purity of prime products, using a minimum amount of energy. Details on the dry-milling process can be found in Brekke et al (1971), Manoharkumar et al (1978), Anderson and Watson (1982), Stroshine et al (1986), Alexander (1987), Peplinski et al (1989, 1984, 1983), Hill et al (1991), Mistry and Eckhoff (1992), and Mestres et al (1995).

The main prime product desired by the dry miller is the large-sized flaking grits because large grits can be reduced to smaller size but not vice-versa. It is suspected that hard corn will produce more flaking grits (Paulsen and Hill 1985). Although many tests for measuring the hardness have previously been developed, none is widely used at a commercial level. Some commercial dry millers prefer to keep their testing methods proprietary (Fradgley 1993).

Little or no research has been reported on dry milling of white corn even though some companies have started dry milling white corn. White corn is a major crop in Latin America and some parts of Africa and Asia. Due to its pure white color and the acceptability of its final products, it is gaining popularity in the United States as a major raw material for the snack food industry.

The lack of widely accepted methods for defining the millability of corn for dry milling, compounded with lack of knowledge on dry milling of white corn initiated this study. The objectives of this study were: 1) to evaluate the physical and chemical properties of 32 white corn hybrids; and 2) to evaluate the relationship of the dry-milling results with the physical and chemical properties of the raw white corn.

MATERIALS AND METHODS

Materials

Thirty-two white dent commercial corn hybrids were evaluated in this study. The white corn was grown, mechanically harvested, and dried in Iowa as part of the 1994 Iowa Gold Program (Iowa Department of Agriculture 1995).

Analytical Procedures

The physical properties studied included moisture content, test weight, 100-kernel weight, and true density. Moisture content was determined by using the air-oven method (AACC 1995). Test weight was determined in accordance with the USDA Official Grain Standards (USDA 1977). One hundred representative whole kernels free from defects were randomly selected from the sample by using a Count-A-Pak seed counter (Seedburo, Chicago, IL), and their weight in grams was recorded as 100-kernel weight. A nitrogen compression pycnometer (model 930, Beckman Instruments Inc., Fullerton, CA) was used to determine the true density of the samples.

The chemical properties evaluated were protein, oil, and starch content. These were measured by using a grain analyzer (Infratec-1225, Tecator AB, Sweden). Protein, starch, and oil content values were adjusted to 15% mc (wb). The instrument was calibrated in the Iowa State University Grain Quality Laboratory against the wet-chemical methods done by Woodson-Tenent, Inc. (Des Moines, IA).

Dry-Milling Procedure

A modified short dry-milling method developed by Peplinski et al (1984) was used in this study. In this procedure, a 500-g sample of cleaned corn was placed into a plastic bag and tempered to 16% mc for 16 hr, raised to 21% mc for 1.75 hr, and then to 24% mc for 15 min. before degerming. Tempered corn samples were then sent to a laboratory horizontal drum dehuller-degerminator and dried for 1 hr at 49°C to 17 ± 1% mc. The dried degermer stock was separated by using a screen shaker (Ro-Tap, W. S. Tyler, Inc., Mentor, OH) with six screens (3.5, 5, 7, 10, 25, and 50 mesh) for 10 min. Next, the fractions from the 3.5–25 mesh screens were aspirated on a laboratory aspirator (Kice Industries, Inc., Wichita,

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KS) to remove the pericarp. Finally, corn grits and germ of the fractions from the 3.5–25 mesh screens were separated using the floating method with a $NaNO_3$ solution at 1.22 specific gravity.

Micromilling

To compare the dry-milling results, a micromilling procedure was used to process the 32 samples. Ten intact, whole kernels were randomly selected from each sample. Kernels were soaked in distilled water for 12 hr at room temperature (25 ± 2°C), and the bran and germ were removed with a scalpel. The hard and soft endosperm were separated using hand-dissection. Each portion was dried in an air oven for 48 hr at 50°C and weighed separately to determine its proportion in the whole kernel. Ratios of hard to soft endosperm (H/S), and endosperm to bran (E/B) were calculated for each sample.

Experimental Design and Statistical Analysis

A completely randomized design was used in this investigation. Each measurement and experiment had three repetitions and three replicates, respectively. Statistical analyses were performed by using the Statistical Analysis System software package (SAS 1992). A general linear model (GLM) procedure was performed on the data collected, and correlation analyses were run to obtain regression and correlation coefficients.

RESULTS AND DISCUSSION

Physical Properties Tests

The physical properties of white corn are summarized in Table I. These results are also compared with average values of yellow corn from the Iowa Gold Program (Iowa Department of Agriculture 1995). Differences were observed between white and yellow dent corn in all three tests. The average white corn samples had higher values of true density, test weight, and 100-kernel weight than the average for yellow corn, indicating that, as a group, the white corn hybrids are different from yellow hybrids.

Chemical Composition Tests

Table II shows the analytical results for white corn chemical composition compared with the averages for yellow corn. Data for the yellow corn came from the Iowa Gold Program (Iowa Department of Agriculture 1995) and from the 1988 national corn quality surveys (Hurburgh 1989). The chemical compositions of the white and yellow corn from the Iowa Gold Program were very

TABLE I
Physical Properties of White and Yellow Dent Corn

Corn	True Density (g/cm^3)		Test Weight (kg/m^3)		Test Weight (lb/bu)		100-Kernel Weight (g)	
	Average	Range	Average	Range	Average	Range	Average	Range
White[a]	1.298a[b]	1.276–1.317	772.98a	743.7–805.6	59.96a	57.0–62.5	31.7a	27.2–35.0
Yellow[c]	1.269b	1.249–1.290	728.18b	695.71–770.4	56.52b	54.0–59.8	26.2b	22.9–29.3

[a] 12.5 ± 0.5% moisture content (wb).
[b] Averages in a column followed by the same letter are not significantly different at the 5% significance level.
[c] Iowa Department of Agriculture (1995).

TABLE II
Composition of White and Yellow Dent Corn

Corn	Protein (%)		Oil (%)		Starch (%)	
	Average	Range	Average	Range	Average	Range
White[a]	7.7a[b]	7.3–8.5	3.6a	3.2–4.3	61.5a	60.8–62.1
Yellow[c]	7.8a	7.1–8.5	3.6a	3.2–4.0	61.6a	61.1–62.7
Yellow[d]	7.98	5.2–10.1	3.55	2.9–5.5	60.17	45.7–61.7

[a] 15% moisture content (wb).
[b] Averages in a column followed by the same letter are not significantly different at the 5% significance level.
[c] Iowa Department of Agriculture (1995).
[d] Hurburgh (1989).

TABLE III
Dry Milling Results (%) of White and Yellow Corn

Corn	Flaking Grits		Total Grits		Meal and Flour		Prime		Bran		Germ	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
White[a]	24.64	10.98–36.42	67.27	58.90–77.43	5.69	4.37–8.31	72.95	65.9–82.11	9.17	4.37–13.32	17.89	10.24–27.99
Yellow[b]	12		53		7		60		na[c]		na	

[a] 12.5% moisture (wb).
[b] From Brekke (1970), moisture not indicated.
[c] Not applicable.

TABLE IV
Micromilling Analysis (%) of White Corn[a]

	Endosperm	Bran	Germ	H/S Ratio[b]	E/B Ratio[c]
Average	82.99	4.84	12.29	2.35	17.66
Range	80.46–82.99	3.31–6.27	10.05–14.29	1.32–4.82	13.15–25.45

[a] 12.5% moisture (wb).
[b] Ratio of hard to soft endosperm.
[c] Ratio of endosperm to bran.

close. The white corn average values of protein and starch content were 0.1% lower than that of the yellow corn. However, large differences were observed between white corn values and yellow corn results from the 1988 national corn quality surveys. The 1.2% difference in the ranges of white corn protein content was narrower than the 5.3% for yellow corn. The white corn average protein content of 7.7% was lower than the value for corn protein of 8.8% reported by Ensminger and Olentine (1978), and lower than the 7.98% for the 1988 corn data (Hurburgh 1989). This data shows that corn from the Iowa Gold Program had slightly higher average oil and starch content than the corn from the 1988 data, although the ranges of values were narrower than the latter.

Dry-Milled Corn Grits Yields

The value of dry-milled products depends on the market. The value of grits is related to size. In general, the larger the grits the greater the value. The larger grits or flaking grits are used primarily for corn-flaking production. Consequently, the yield of flaking grits is an important factor in corn dry-milling. The yields of the dry-milled products are summarized in Table III. The yield of products was reported as the percentage of the milled product retained on a sieve of a specific mesh size. The yield includes flaking grits (grit size over 5W), total grits (grit size through 5W but over 25W), meal and flour (products through 25W), and prime products (mixture of all the grits, meal, and flour). All the dry-milling results are reported at 12.5% mc.

Because of the difference in experimental procedures, it is difficult to compare the product yields of this study with those in previous works. For example, some researchers (Brekke et al 1972, Wu and Bergquist 1991, Peplinski et al 1992) used different milling flows; thus different product streams were obtained (no flaking grits were produced, meal and flour products were divided into two groups as low fat or high fat). Also, dry-milled product yields were reported at various moisture contents. But, the corn dry-milled product yields reported by Brekke (1970) have been used as the typical values by several studies (Shukla 1981, Watson 1988, Hill et al 1991, Willm 1994). Thus the Brekke (1970) results were compared with the results of this study in Table III. The average flaking grits yields from white corn were about two times greater than those for yellow corn. Also, white corn produced ≈15% more grits and ≈12% more prime products; consequently, fewer meal and flour products were obtained.

Figures 1 and 2 show the frequency distribution of flaking grits and total grits yields of white corn, respectively. Among 32 white corn hybrids, only two had flaking grits yields <20%, and half of the samples (16) had flaking grits yields >30%. For total grits yields, only four hybrids were <66.3%, and about two thirds of the samples (20) were >70%.

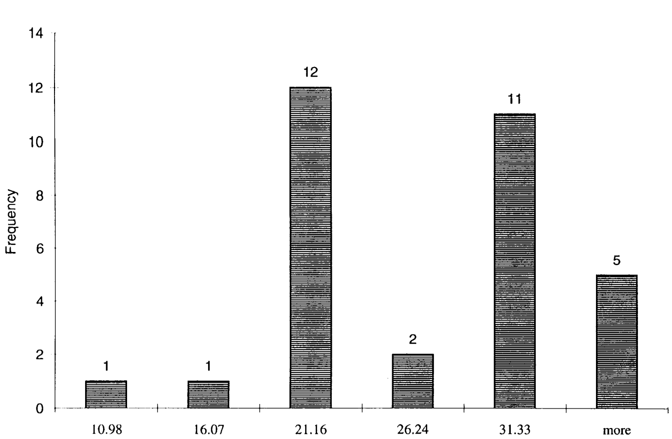

Fig. 1. Frequency distribution of flaking grits yields for 32 white corn samples.

Micromilling Yields and Dry-Milling Efficiency

It is assumed that the micromilling evaluation can achieve a close to perfect separation of the bran, germ, and endosperm. Thus, micromilling could provide an index of the efficiency of the dry-milling test. The separation of the endosperm between hard and soft is a more subjective determination. However, the test in this study was performed by the same trained researcher to provide for a standardized comparison. Table IV shows the micromilling results of white corn. The prime product yields from the micromilling includes endosperm, bran, and germ yield. Also, ratios of hard to soft endosperm and endosperm to bran were evaluated. All the endosperm yields were >80%, and the bran and germ products yields were <5% and <13%, respectively. As shown in Table IV, considerable variation was found in the hard-to-soft and endosperm-to-bran ratios. The highest ratios of hard to soft and endosperm to bran were almost four times and two times greater than the lowest one, respectively. This indicated that some hybrids had a much larger portion of hard than soft endosperm in the kernel.

To evaluate the dry-milling response with the micromilling yields, dry-milling efficiency was determined by using three indexes: endosperm removal, bran removal, and germ removal.

TABLE V
Dry Milling Test Efficiency (%)

	Min.	Max.	Avg.	Std. Dev.
Endosperm removal	79.72	99.10	87.93	4.49
Bran removal	86.61	308.88	192.52	51.24
Germ removal	72.57	276.81	148.15	44.65

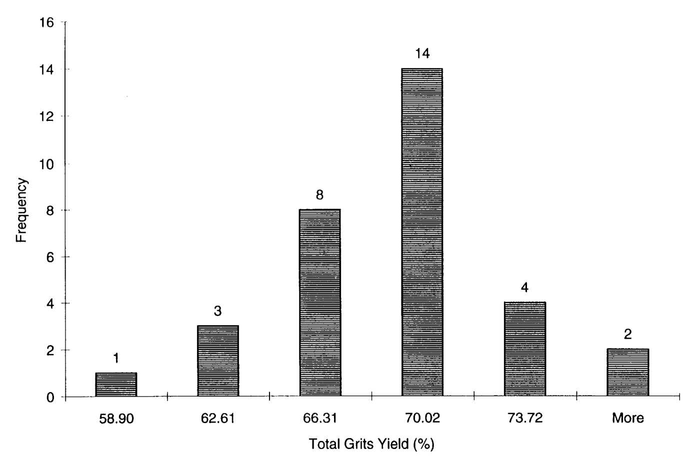

Fig. 2. Frequency distribution of total grits yields for 32 white corn samples.

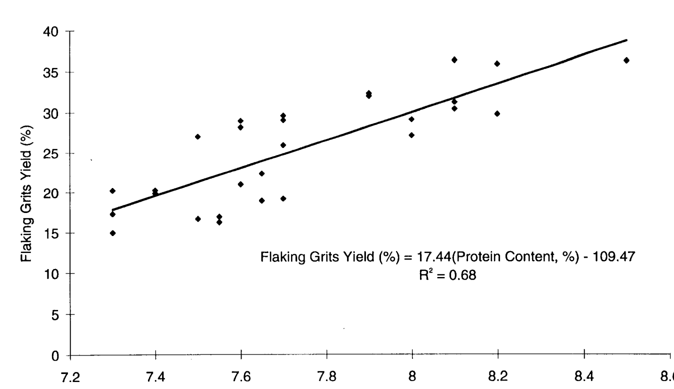

Fig. 3. Relationship of flaking grits yield and protein content (at 15% mc) for 32 white corn samples.

TABLE VI
Correlation Analysis Between Physical, Chemical, and Dry Milling Test for White Corn

	True Density	Test Weight	Protein	Germ	H/S	E/B
Protein	0.65	0.23	…	–0.50	0.13	0.23
Flaking grits	0.51	0.02	0.78	–0.50	0.44	0.44
Total grits	0.55	0.15	0.52	–0.80	0.58	0.74
Prime	0.50	0.01	0.44	–0.79	0.61	0.74
Meal and flour	–0.48	–0.62	–0.55	0.53	–0.23	–0.43

Endosperm removal = Endosperm obtained from the short dry-milling test (%) / Endosperm obtained from micromilling (%) × 100%.

Bran removal = Bran obtained from the short dry-milling test (%) / Bran obtained from micromilling (%) × 100%.

Germ removal = Germ obtained from the short dry-milling test (%) / Germ obtained from micromilling (%) × 100%.

As shown in Table V, endosperm removal efficiency for almost all of the corn samples tested was >80%, only one had a value of 79.72%. This indicates that in the dry-milling process, >80% of endosperm was successfully separated from the germ and bran and recovered. Consequently, <20% of the endosperm could go to the bran or the germ portion. This indicates that more bran and germ fractions were produced in dry milling as compared with micromilling. The bran and germ removal efficiencies had the average values of 192.52 and 148.15%, respectively. Therefore, the bran and germ fractions carried two times and one and one-half times more endosperm, respectively, than the actual amount of bran and germ.

Correlation Analysis

Correlation coefficients were calculated for all variables reported in Tables I–IV. Table VI gives the most relevant correlation coefficients. The data indicate that the protein content showed a high positive correlation with true density (r = 0.65), flaking grits (r = 0.78), and other dry-milled product yields except with meal and flour yield (r = –0.55). This may indicate that high protein content kernels had higher density and, therefore, could produce more flaking grits, total grits, and prime products along with less meal and flour products. Similar results, regarding the influence of protein content, were reported by Manoharkumar et al (1978) for yellow corn. Hamilton et al (1951) reported that changes in total protein content are primarily changes in endosperm protein content, mainly zein. As the protein content increases, the amount of hard endosperm increases. Figure 3 shows the relationship between the protein content of the white corn samples and flaking grits yield; a linear relationship (R^2 = 0.68) was observed. In other words, for each 0.1% in protein content, flaking grits yield could increase ≈1.7%.

According to Watson (1987), test weight, a traditional commercial measure of density, has been an important criterion for dry millers. Rutledge (1978) states that corn of lower test weight has a lesser percentage of hard endosperm and, therefore, produces lower yields of prime, large grits. Various studies (Brekke et al 1971, Paulsen and Hill 1985, Stroshine et al 1986, Hill et al 1991) have reported a higher correlation between test weight and flaking grits yield for yellow corn. However, in this study, the test weight of white corn did not show a high correlation with either true density or dry-milling yields, other than with the yield of meal and flour (r = –0.62). One possible reason may be that all white corn samples studied had test weights higher than 743.7 kg/m^3 (57 lb/bu). Watson (1987) indicated that a corn dry miller would make a satisfactory yield of grits with corn tested unless the test weight was <670.36 kg/m^3 (52 lb/bu). Also, test weight is criticized as a useful measurement because it is a combination of the densities of the kernels and the way they pack in a container (Watson 1987). True density, on the other hand, proved to be a more accurate measuring method. It demonstrated a stronger correlation with flaking grits yield (r = 0.51) and other dry-milling yields such as total grits yield (r = 0.55) and prime products yield (r = 0.50). There is a trend in international trade to use true density instead of test weight. For example, dry millers in Japan use true density as their prime index and prefer corn within a density range of 1.25–1.28 g/cm^3 (Paulsen et al 1995).

Total products yield (including water loss and gain, and processing losses) must equal 100%. Therefore, an increase in the yield of one product would result in a decrease in the yield of one or more of the other products. The yield of germ showed a negative correlation with dry-milled product yields, particularly with total grits yield (r = –0.80) and prime products yield (r = –0.79). This negative correlation reflected the fact that a higher total grits yield or prime products yield generally indicates a lower germ yield. With more endosperm products recovered, less endosperm is available to be mixed and separated out with the germ.

The estimation of the hard to soft ratio and endosperm to bran ratio by hand-dissection is very time-consuming and subjective. Better methods are being developed to estimate those ratios, especially the computer-enhanced digital imaging technology. Nevertheless, these reported white corn ratios showed reasonably higher correlation with total grits yields (H/S r = 0.58, E/B r = 0.74) and prime products yield (H/S r = 0.61, E/B r = 0.74) as shown in Table VI.

CONCLUSIONS

Thirty-two white dent commercial corn hybrids were evaluated for physical and chemical, and dry-milling characteristics. The white corn with different physical and chemical characteristics yielded different dry-milling results. Over 93% of the white corn samples had flaking grits yields >20%, and half of the samples' flaking grits yields were >30%. Considerable variations were found in the ratios of hard to soft and endosperm to bran, indicating that some of hybrids had a much larger portion of hard endosperm in the endosperm. Micromilling could provide an index of the efficiency of the dry-milling test. Protein content, true density, ratios of hard to soft and endosperm to bran were highly correlated with dry-milling yields. A linear relationship was found between the protein content of white corn and flaking grits yield.

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