Physical Properties and Dry-Milling Characteristics of Six Selected High-Oil Maize Hybrids

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ABSTRACT

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The physical properties and dry-milling characteristics of six low-temperature-dried, high-oil maize (corn) hybrids (HOC) were evaluated and compared to three regular yellow dent hybrids (YDC) representing a range of endosperm hardness that were not selected for dry-milling characteristics. The test weights, true densities, and 100-kernel weights of the six HOC hybrids ranged from 732.8 to 758.6 kg/m^3, 1.272 to 1.291 g/cm^3, and 26.6 to 28.2 g, respectively (12.5% mc). Test weights and densities for HOC were higher than for two of the three YDC hybrids, 100-kernel weights were lower than all three YDC hybrids. The HOC hybrids had higher test weights and true densities than two of the YDC hybrids. The HOC hybrids had higher prime grit yield, milling evaluation factors, and oil yields than the YDC. The flaking grit yield and milling evaluation factor (MEF3) increased, and the pericarp yield decreased with increasing test weight of the HOC. The dry mill products of the HOC had higher crude fat and crude fiber contents, but lower ash contents than those of the YDC. The germ and pericarp fractions of the HOC had lower crude protein contents than those of the YDC. The HOC hybrids tested resulted in high grit yields but also high oil content in the grit fractions. Unless the source of the higher oil content in the grits can be elucidated and corrected, the HOC hybrids tested would not be satisfactory for most dry-milling applications.

The oil contents of most Corn Belt yellow dent maize (corn) hybrids (YDC) range from 4 to 5% (Alexander 1988), although with selective breeding, oil contents 6% or higher can be achieved. The oil content of the corn affects the physical properties of the grain and, by implication, dry-milling characteristics. Dorsey-Redding et al (1990) found that oil content correlated with density and starch content for YDC. Corn with low test weight contained lower percentages of hard endosperm, and produced lower yields of prime grits when dry milled (Rutledge 1978). Paulsen and Hill (1985) found that yields of large flaking grits were significantly increased by low breakage susceptibilities and high test weights. Kirleis and Stroshine (1990) reported that the test weight, kernel density, and Stenvert hardness test were positively and significantly correlated with the milling evaluation factor (MEF) determined by a short-flow milling process. The Stein breakage test was negatively correlated with MEF at the 99% confidence level.

Mestres et al (1991) found that chemical compositions (ash and protein contents) and physical properties (sphericity or dent kernel percentage) could be used to predict dry-milling characteristics (semolina quality and quantity) of different YDC hybrids. The protein content of the semolina was highly correlated with the initial protein content of the corn kernel, whereas the lipid content of the semolina was positively correlated with kernel ash content.

Yuan and Flores (1995) evaluated 20 white dent and five YDC hybrids using a noncommercial horizontal drum degerminator, similar to the degerminators used by Peplinski et al (1984), Kirleis and Stroshine (1990), and Mistry and Eckhoff (1992), and found that white corn had significantly higher values of 100-kernel weight, density, and starch content. White corn also had lower test weight and protein and oil contents when compared with YDC. White corn had significantly higher flaking grits, total grits, and prime product yields.

HOC has recently increased in production primarily for livestock food but the potential for using HOC for dry milling has not been explored. The objective of this study was to evaluate and compare physical properties and laboratory-scale dry-milling characteristics of selected HOC and regular YDC hybrids. Because HOC is compositionally and structurally dissimilar to YDC, correlations determined on YDC may not relate to HOC.

MATERIALS AND METHODS

Materials

Six selected experimental HOC hybrids, SN40Z, SK63P, SK540, SK06Z, SN45Z, and SK27P from the 1989 crop year were provided by the Agricultural Products Division of E.I. Du Pont De Nemours and Company (Newark, DE) for evaluation. Hybrids were selected based upon potential for commercialization. All HOC samples had been air-dried in the laboratory within a temperature range of 35 to 43°C to a final moisture content near 12.5%. Oil contents ranged 7.7–8.5% and starch contents ranged 68.4–68.9% as estimated by near infrared reflectance (NIR) (Table I).

For comparison, five samples of three selected regular YDC hybrids (FR1141×LH123, FR1141×FR4326, FR27×FR32) representing a range of endosperm hardness were studied. These hybrids were not selected based on any dry-milling characteristics. Two of them (FR1141×FR4326 and FR27×FR32) were high-temperature dried from ≈30% harvest moisture at 105°C using a Proctor laboratory thin-layer dryer (Horsham, PA) and all three hybrids were dried using the same dryer at 30°C. The final moisture contents were 11.51% (30°C) for FR1141×LH123, 12.57% (30°C) and 9.77% (105°C) for FR1141×FR4326, and 11.45% (30°C) and 8.58% (105°C) for FR27×FR32.

TABLE I
Chemical Compositions (% db) of Whole Kernel High Oil Corn Hybrids Determined by Near-Infrared Reflectance

Hybrid	Protein	Fat	Starch	Crude Fiber
SN40Z	9.1	8.0	68.9	3.3
SK63P	10.1	7.9	68.7	3.4
SK540	8.8	7.9	68.8	3.4
SK06Z	10.1	7.8	68.9	3.3
SN45Z	9.6	7.7	68.4	3.4
SK27P	9.6	8.5	68.8	3.4

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Physical Property Measurement

Moisture content was determined in duplicate by using the official 72-hr, 103°C, 100-g whole-grain air-oven method (USDA 1976). Samples were cleaned by sieving 200 g at a time for 30 cycles on a Gamet sieve shaker (Minneapolis, MN) using a 4.76 mm (12/64") round-hole sieve. Test weight was measured following the official FGIS procedure (Anon 1980). 100-kernel weight was determined by counting out 100 whole intact kernels and weighing.

True density was measured by the ethanol column test method of Paulsen and Hill (1985) in which a 40-g sample of cleaned corn was placed into a graduated buret containing ethanol. The volume displaced by the corn sample was recorded and the density calculated in g/cm^3 as the ratio between the sample weight and displaced volume of ethanol.

Fifty intact kernels were set on a light table with the germ side down and individually checked for stress cracks (Paulsen and Hill 1985). The number of kernels with stress cracks was expressed as the percentage of total kernels. The whole kernel weight percentage was measured by visually sorting for intact undamaged kernels in a 50-g sample of cleaned corn.

Dry-Milling Procedure

The short-flow dry-milling procedure described by Peplinski et al (1984) with modifications to pericarp and germ separation procedures was used in this study. Samples (500 g) of maize were placed into plastic bags and tempered at room temperature. A three-stage tempering procedure was used: 1) from initial moisture content to 16%, 16 hr; 2) from 16 to 21%, 1.75 hr; and 3) from 21 to 24%, 0.25 hr. Moisture was added by spraying distilled water into the bag and mixing. The sample was degerminated immediately following tempering using a noncommercial horizontal drum degerminator operated at 1,732 rpm idle speed at a feed rate of 3 kg/min All tests were performed in duplicate.

The degerminated corn fraction was screened with a 3½ mesh sieve (3½W) for 1 min using a Great Western laboratory shaker (model 130-U, Leavenworth, KS). The fraction retained on the sieve was recycled back to the degerminator for a second pass. The total degerminated fraction was dried in an air oven to 17 ± 0.5% moisture content at 49°C for classification.

The dried fraction was classified by screening for 2 min using the sieve shaker with standard 5W, 7W, 10W, 18W, 38W, and 66W screens. The fractions on the 5W through the 38W screens were aspirated with a Kice laboratory aspirator (model 6DT4, Wichita, KS) to remove the pericarp fraction. After preliminary tests, the vacuum pressure of the aspirator was set at 12.7 kg/m^2 (0.5 in. water) for the 5W, 7W, and 10W fractions, 7.62 kg/m^2 (0.3 in. water) for the 18W fraction, and 3.81 kg/m^2 (0.15 in. water) for the 38W fraction. A sodium nitrate solution was used to float the germ from the 5W–38W fractions. Solution densities of 1.220 g/cm^3 for 5W fraction and 1.200 g/cm^3 for all other fractions was chosen. After germ separation, all germ and grit fractions were dried for 12 hr at 49°C. Two samples were taken from each fraction to determine moisture content for calculating product yields. All yield data were reported on a dry weight basis (dwb).

Three milling evaluation factors, labeled as MEF1, MEF2, and MEF3 based on the equations of Wichser (1961) and Emam et al (1981), were used to evaluate product yields. They are defined as:

$$\text{MEF1} = [(\%\ \text{Grits}\ (+5...+10)) \times (\%\ \text{Grits}\ (+5...+38) + \%\ \text{Meal} + \%\ \text{Flour})]/100$$

$$\text{MEF2} = [(\%\ \text{Grits}\ (+5...+38)) \times (\%\ \text{Grits}\ (+5...+38) + \%\ \text{Meal} + \%\ \text{Flour})]/100$$

$$\text{MEF3} = [(\%\ \text{Grits}\ (+5...+38)) + \%\ \text{Meal} \times (\%\ \text{Grits}\ (+5...+38) + \%\ \text{Meal} + \%\ \text{Flour})]/100$$

where % Grits = weight percentage of grits left on the top of a specified sieve; % Meal = weight percentage of corn endosperm product considered as meal (66W fraction); % Flour = weight percentage of the corn endosperm product considered as flour (pan fraction).

MEF1 evaluated the percentages of prime grits (Grit+5 – Grit+10) and total endosperm products. MEF1 will be large when both the percentages of prime grits in endosperm products and of endosperm products are large. MEF2 was used to evaluate the percentages of total grits (Grit+5 – Grit+38) and total endosperm products. MEF3 indicated the amount of flour produced. High MEF3 results from low flour yield or high total endosperm products.

Proximate analyses for protein, fat, crude fiber, and ash contents were conducted by a commercial laboratory on the fractions of Grit+5, Grit+10, Grit+18, germ and pericarp of hybrids SN40Z, SK27P, and FR27×FR32. The oil yield was calculated based on the yield and fat content in the germ fraction assuming 100% oil recovery rate. Experimental results were statistically analyzed with SAS (1985) using the Duncan's multiple range test, the least significant difference (LSD) test, and the general linear model (GLM) at a 5% level.

RESULTS AND DISCUSSION

Physical Properties

High drying temperature (Table II) caused density, test weight, and 100-kernel weight of YDC to decrease due to shrinkage, water loss, and chemical composition changes (Watson 1987). High-temperature drying also resulted in significant increases in stress cracks as previously reported by Eckhoff et al (1988), Foster (1973), and Gunasekaran et al (1985).

The six HOC hybrids had higher densities and test weights, and lower 100-kernel weights than those of the YDC hybrids. The density and test weight of the hardest endosperm YDC, FR1141×LH123, was close to the average density and test weight of the HOC, which ranged from 1.272 to 1.291 g/cm^3, and 732.8 to 758.6 kg/m^3, respectively. Based on the higher densities and test weights, and visual observation (visual amount of hard endosperm), the high-oil hybrids tested should be classified as hard endosperm corn. The 100-kernel weight of HOC was much lower than that of YDC, indicating smaller kernels. The average 100-kernel weight of the HOC hybrids ranged 26.6 to 28.2, while the YDC hybrids 100-kernel weights ranged from 29.6 to 31.8.

Although, the whole kernel percentages of the six high-oil hybrids were all >95%, there were statistically significant differences among them using the Duncan's multiple range test at a 5% level. All six high-oil hybrids had no visible stress cracks, except for hybrid SK63P, which had 0.67% stress cracks, an insignificant level. In general, the YDC had lower whole kernel percentages and higher stress cracks than HOC.

Dry-Milling Product Yields

Hybrid SK27P produced the highest flaking grit (Grit+5) yield (45.12%), and hybrid SN40Z was lowest (34.98%) (Table III). There were no significant differences among flaking grit yields of hybrids SK27P, SN45Z, SK06Z, and SK63P. The prime grit yields, which were the sums of the yields of Grit+5, Grit+7, and Grit+10, were not significantly different for hybrids SK63P, SK06Z, SN45Z, and SK27P. Hybrid SK27P was the highest (69.26%), and SN40Z was the lowest (64.86%) in prime grit yields.

Hybrid SK27P had the highest MEF1, MEF2, and MEF3 among the six hybrids. Hybrid SN40Z was the lowest in MEF1 and MEF2. Hybrid SK540 was the lowest in MEF3. Hybrid SK27P produced the highest grit yields and total endosperm products, and the lowest flour yield.

The products of hybrid SN40Z consisted of low percentages of prime grits and high flour. The lowest MEF3 value of hybrid SK540 indicated that it had high flour yield or low yield of grits. Based upon these data, hybrid SK27P was the best hybrid for dry milling among these six HOC hybrids, because the hybrid produced high percentages of prime grits and total endosperm products.

Germ yields of the HOC hybrids ranged from 17.7 to 19.5%, but no statistical differences were found among hybrids SK27P, SN45Z, SK06Z, SK63P, and SN40Z. The oil yield of hybrid SK27P (5.19%) was significantly higher than that of hybrid SN40Z (4.70%).

Pericarp yields of the six HOC hybrids ranged from 4.3 to 7.0% with hybrid SK27P being the lowest, and hybrid SK540 being the highest. Pericarp yields were apparently 50% less than those for the YDC samples, indicating very clean separation between pericarp and endosperm.

For YDC hybrids, high drying temperature resulted in significant decreases in flaking grit yield and MEF values due to high stress cracks and breakage susceptibility of the corn. For hybrids FR1141xFr4326 and FR27×FR32, the flaking grit yields from the samples dried at 105°C were only 27.8 and 39.0% of the yields from the samples dried at 30°C. Stress cracking caused by rapid removal of moisture from the endosperm weakened the endosperm structure.

High drying temperature also increased germ yields and the size of the redegerminated fraction (>3.5). Increased germ yields appeared to be due to attachment of more endosperm to the germ. The higher yield of flaking grit, total grit and pericarp, as well as the higher MEF values of YDC dried at 30°C than at 105°C demonstrates that corn dried at lower temperature has better milling characteristics than high-temperature dried corn. The results of YDC also showed that the harder endosperm corn (FR1141 ×LH123) was higher in prime grit yields and MEF values than was lower density, softer corn. The results of YDC obtained from this study were similar to results of Brekke et al (1971) and Kirleis and Stroshine (1990).

The yields of flaking grit (Grit+5), prime grit, and total grit, as well as MEF values of the HOC were higher than those of YDC. The total grit yields of the HOC hybrids were 8.0–14.3% higher than the yields of YDC hybrids dried at 30°C. The YDC had much lower MEF3 values than did the HOC. This meant that the products of the YDC contained lower percentages of endosperm products and higher percentages of flour. The YDC hybrids were chosen as representative of the range of YDC hybrids and were not selected for their dry-milling characteristics.

TABLE II

Physical Properties of Selected High Oil Corn (HOC) and Yellow Dent Corn (YDC) Hybrids[a]

Hybrid	Dry Temperature (°C)	Moisture Content (%)[b]	Density (g/cm^3)	Test Weight (kg/m^3)	100-Kernel Weight (g)	Whole Kernel Percentage (%)	Stress Cracks (%)
HOC							
SN40Z	30–43	12.5	1.273de	732.8de	26.58e	96.74b–d	0.00d
SK63P	30–43	12.5	1.272e	742.0c	28.19d	98.14ab	0.67d
SK540	30–43	12.5	1.287ab	733.9de	27.58de	96.08b–d	0.00d
SK06Z	30–43	12.5	1.281bc	747.3b	27.23de	99.19a	0.00d
SN45Z	30–43	12.5	1.280b–d	744.6bc	27.83de	96.08b–d	0.00d
SK27P	30–43	12.5	1.291a	758.6a	27.19de	97.33a–c	0.00d
YDC							
FR1141×LH123	30	11.5	1.276c–e	745.5bc	31.44ab	97.54ab	26.00c
FR1141×FR4326	30	12.5	1.255f	715.1f	30.53bc	95.67cd	46.00b
	105	9.8	1.222h	696.8g	29.53c	94.80d	73.30a
FR27×FR32	30	11.5	1.249f	737.1d	31.84a	96.74b–d	1.30d
	105	8.6	1.238g	731.4e	31.80a	96.03b–d	38.00c

[a] Means with common letters in same column are not significantly different according to Duncan's multiple range test at the 5% level.

[b] Moisture content 12.5% basis.

TABLE III

Yields of Dry Milling Products of High Oil Corn (HOC) and Yellow Dent Corn (YDC) Hybrids[a]

Hybrid	HOC						YDC				
	SN40Z	SK63P	SK540	SK06Z	SN45Z	SK27P	FR1141x LH123	FR1141xFR4326		FR27×FR32	
Drying temp.	30–43	30-43	30-43	30-43	30-43	30-43	30	30	105	30	105
Grits											
+5	35.0d	42.8ab	37.9c	42.3b	42.9ab	45.1a	29.4e	39.1c	10.9g	21.6f	8.42g
+7	22.6	19.6d	20.5d	20.1d	19.5d	18.6de	26.2ab	17.3e	24.3bc	28.2a	27.58a
+10	7.3e	6.4ef	6.9e	6.1ef	6.3ef	5.5f	8.9d	5.3f	18.4b	10.4c	19.95a
+18	3.7bc	3.1c	3.7b	3.3bc	3.4bc	3.2bc	3.7b	2.1d	5.4a	3.5bc	5.15a
+38	2.4cd	2.0cd	2.8ab	2.0cd	2.2b–d	1.9de	2. 8ab	1.3e	3.2a	1.9cde	2.58a–c
Meal											
+66	1.9ef	1.6fg	2.2de	1.4g	1.4g	1.2g	2.3cd	2.7bc	3.5a	2.6b–d	2.73b
Flour pan	1.2ef	0.9ef	1.4de	0.8f	0.8f	0.6f	1.7cd	2.1bc	2.8a	2.1bc	2.31ab
Germ pericarp over 3½	19.2bcd	18.2cd	17.7d	19.4b–d	18.9b–d	19.5bc	17.8cd	18.9bcd	21.9a	20.2ab	21.93a
	6.9cd	5.4de	7.0cd	4.7e	4.6e	4.3e	7.2c	11.4a	9.7ab	9.6b	9.37b
	11.7a–c	13.2ab	11.6a–c	11.4a–c	12.5a–c	14.1a	8.7cd	9.4bcd	11.4a–c	6.8d	9.13cd
No. of whole kernels in germ	GS[b]	21	20	22.5	21.5	GS[b]	5	4	4.5	GS[b]	5.5
Grits +5, +10	64.9b	68.8a	65.3b	68.5a	68.7a	69.3a	64.5b	61.6c	53. 6f	60.2d	55.94e
MEF 1	47.9b	52.5a	49.2b	52.0a	52.5a	52.8a	48.3b	43. 0c	36.6d	42.3c	38.44d
MEF 2	52.4c	56.4a	54.1a–c	56.0ab	56.8a	56.6a	53.2bc	45.4d	42.5e	46.1d	43.75de
MEF 3	48.6cd	68.0bc	41.3de	74.6ab	71.4a	95.5a	30.2d–f	23.0ef	16.3f	23.4ef	19.76ef
Oil yield	4.7b					5.2a				3.2c	

[a] Same superscripts in the same row indicates that the corresponding means are not significantly different according to least significant difference test at 5% level. Product yields are expressed on dry basis.

[b] Germ sample used for oil analysis.

TABLE IV
Compositions (%) of Dry Milling Products of High Oil Corn (HOC) and Yellow Dent Corn (YDC) Hybrids[a]

Product	Analysis	HOC SN40Z	HOC SK27P	YOC FR27×FR32
Germ	Yield	19.2a	19.5a	20.2a
	Crude fat	24.5b	26.6a	15.8c
	Crude protein	15.7b	16.1b	17.8a
	Crude fiber	8.4a	7.9a	7.8a
	Ash	6.6ab	5.3b	8.1a
Pericarp	Yield	6.9ab	4.3b	9.6a
	Crude fat	3.3a	3.2a	2.0a
	Crude protein	6.9c	7.2b	7.8a
	Crude fiber	9.4ab	11.6a	9.2b
	Ash	0.9a	1.0a	0.9a
Grit +5	Yield	35.0b	45.1a	21.6c
	Crude fat	2.5a	2.6a	1.1b
	Crude protein	8.6a	8.7a	8.4a
	Crude fiber	0.8a	0.8a	0.7a
	Ash	1.5a	0.9a	1.8a
Grit +7	Yield	22.6b	18.6c	28.2a
	Crude fat	1.9a	2.1a	0.8b
	Crude protein	7.9a	8.2a	7.9a
	Crude fiber	0.8a	0.7a	0.6a
	Ash	1.3ab	0.7b	1.6a
Grit +10	Yield	7.3b	5.5c	10.4a
	Crude fat	2.2a	2.4a	0.7b
	Crude protein	8.0c	9.2a	8.5b
	Crude fiber	0.6c	1.1a	0.8b
	Ash	1.4b	1.8b	2.6a
Grit +18	Yield	3.7a	3.2b	3.5ab
	Crude fat	2.3b	2.5a	0.6c
	Crude protein	9.5b	10.1a	9.5b
	Crude fiber	1.1b	1.4a	1.0b
	Ash	2.3b	1.6c	2.8a

[a] Same letters in a row indicate corresponding means are not significantly different according to least significant difference test at a 5% level.

YDC hybrids selected for dry milling characteristics would have probably yielded as well or better than the HOC hybrids.

Compared with YDC, HOC should theoretically have higher germ yields due to its larger germ proportions in the kernels, and higher pericarp yields due to its smaller kernel size. But the experiments showed that the germ yields of the HOC were close to yields of the YDC dried at 30°C. The HOC had lower pericarp yields than the YDC. The reason for this might be attributed to the pericarp fraction of YDC containing more endosperm. Some kernels were not struck hard enough to be fractured when passing through the degerminator because of smaller kernel size of HOC. Consequently, the HOC had many more intact corn kernels in the germ fraction than the YDC. This processing problem needs to be considered in industrial operations when using HOC by decreasing the screen size. Changing screen size was not possible on the laboratory degerminator, but it is possible in most commercial degerminators. The oil yields were 4.70% for hybrid SN40Z, 5.19% for SK27P, and 3.20% for FR27×FR32.

Correlations were found between the flaking grit yield, MEF3, pericarp yield, and test weight of the HOC. Flaking grit yield and MEF3 increased with increasing test weight. Regression coefficient, R^2, was 0.96 for MEF3 and 0.80 for flaking grit yield. The pericarp yields of HOC decreased with increasing test weight ($R^2 = 0.83$).

Composition Dry-Milling Products

Table IV gives the proximate analysis results of the germ, pericarp, Grit+5, Grit+7, Grit+10, and Grit+18 fractions for SK27P, SN40Z, and FR27×FR32 (dried at 30°C) hybrids. The two HOC hybrids contained considerably more crude fat than did the YDC in all fractions. This may be due to high crude fat content in the germ and endosperm, or due to incomplete separation of the germ from the other components of corn kernels. Release of fat from the germ into the endosperm due to breakage of the germ during degermination is not a plausible explanation because visual observation of the germ fraction did not indicate excessive germ breakage. High fat contents (1.9–2.6%) in grits shortens shelf life due to rancidity. Crude fat contents in the germ fractions of hybrids SN40Z, SK27P, and FR27×FR32 were 24.5, 26.6, and 15.8%, respectively.

The HOC hybrids were lower than the FR27×FR32 hybrid in crude protein contents of germ and pericarp fractions, but generally had higher crude fiber contents. This indicates that the fiber was not completely removed from the germ. The HOC had higher crude fiber contents in the germ, pericarp, Grit+5, Grit+7, and Grit+18 fractions than did the YDC fractions. Hybrid SK27P had the highest crude fiber content in Grit+10 fraction. The lower pericarp yields and higher crude fiber contents in the pericarp fractions indicated that the pericarp fractions of the HOC contained less endosperm milling products than those of the YDC. Higher crude fiber contents in the grit fractions of the HOC meant that it was difficult to separate pericarp fraction from grits to obtain clean grits. The ash contents of the germ and grit fractions of the HOC were lower than those of YDC. No significant differences were found in the ash contents of the pericarp fractions.

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