Physical, Chemical, and Dry-Milling Properties of Corn of Varying Density and Breakage Susceptibility[1]

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ABSTRACT

Seven lots of yellow dent corn varying in kernel density and breakage susceptibility were tested for chemical composition, physical properties, and dry-milling response. Whole-kernel nitrogen content varied among lots from 1.35 to 1.48%, fat content ranged from 4.3 to 5.6%, starch from 70 to 78%, and ash from 1.3 to 1.6%. Physical analyses showed test weights of 732–762 kg/m^3 (56.9–59.2 lb/bu), 100-kernel weights from 29.0 to 32.2 g, 11–64% floating kernels, and 14–33% broken kernels. Kernel breakage susceptibility correlated statistically ($P \leq 0.05$) with test weight, percentage of floating kernels, and percentage of stress-cracked kernels. Percentage of floating kernels was a more precise indicator of kernel density, breakage susceptibility, and hardness than was test weight. Dry-milling response showed that first-break grit yield was higher for corn with test weight above 747 kg/m^3 (58.0 lb/bu), percentage of floating kernels below 36%, and percentage of broken kernels below 16% as measured by the Stein breakage test. Hull (pericarp) yield was positively correlated ($P \leq 0.05$) with breakage susceptibility, stress cracks, floating kernels, and degermer throughput. The results indicate that corn is less susceptible to breakage when its density is high, as measured by low flotation and high test weight, and when the percentage of stress-cracked kernels is low.

The importance of corn as a major food, feed, and export commodity is demonstrated by the average U.S. production of 178 million metric tons (seven billion bushels) per year from 1977 to 1986 (USDA 1987). Corn varieties grown in the United States vary in kernel chemical composition and in physical characteristics, such as density and hardness (Peplinski et al 1989). Corn kernel characteristics can also be affected by sheller damage if grain is harvested at high moisture content, by postharvest handling, and by drying air temperatures (Peplinski et al 1975, 1982, 1989). Differences in kernel characteristics caused by genetic inheritance, environment, or handling can influence the processing and utilization of corn.

Corn breakage susceptibility and hardness have been studied for some years with varying success. Paulsen et al (1983) investigated breakage susceptibility of midwestern corn genotypes; Pomeranz et al (1984) looked at corn hardness as measured by density and near-infrared reflectance; Stroshine et al (1986) measured density and breakage susceptibility of selected hybrids; and Kirleis and Stroshine (1990) checked the effect of hardness on corn breakage susceptibility and dry-milling response.

The broad objective of this work was to study how kernel density and breakage susceptibility are related to kernel chemical composition, physical characteristics, and dry-milling response.

MATERIALS AND METHODS

Corn

Market-grade yellow dent corn was obtained from commercial elevators in Illinois and was segregated by incoming truckload before it was unloaded. Corn on each truckload was tested at the elevator for test weight and breakage susceptibility and was separated into four groups: high-test-weight kernels with low breakage susceptibility; low-test-weight kernels with medium breakage susceptibility; high-test-weight kernels with high breakage susceptibility; and low-test-weight kernels with high breakage susceptibility (Paulsen and Hill 1985). Each truckload was sampled by probing. Samples were checked immediately for test weight and breakage with a Wisconsin-type tester until 2,286-t (90,000-bu) lots were obtained for each commercial milling run.

After sampling, the corn was transferred to holding bins, conveyed to a commercial dry-milling plant (Lauhoff Grain Co., Danville, IL), cleaned on 6.35-mm sieves, and sent to degermers. Each corn lot was sampled at 10-min intervals before and after cleaning to provide one 2-kg sample every 30 min. A representative 45.4-kg (100-lb) portion of the pooled 2-kg samples from each lot was retained for testing at the Northern Regional Research Center, Peoria, IL. The corn was further blended and cleaned by aspiration and screening over a 4.76-mm (12/64-in.) round-hole-perforated sieve to remove fine material. This cleaning removed 1% or less fine material from each lot.

Analytical Procedures and Calculations

Ash, fiber, nitrogen, and starch contents of whole corn were determined by AACC-approved methods (AACC 1983). The fat content of whole corn and germ fractions was determined from pentane-hexane extraction by the Butt procedure (AACC 1983), and the fat content of the other roller-milled fractions was assayed by gas chromatography (Black et al 1967) as modified by Nielsen et al (1979). Moisture contents were determined gravimetrically after 10-g ground samples were dried at 130°C for 60 min in a forced-air oven. Yield of recoverable oil was calculated based on yield of recovered germ fraction and its fat and moisture contents and assuming that residual germ cake contained 5% oil (db) (Reitmeier and Prusa 1990). Dry-milling product yields were calculated with samples air-dried at 25°C and 50% relative humidity to 9 ± 1.0% moisture. At this humidity and temperature, the final water content of the dry-milled fractions ranged from 8 to 10%.

All physical tests were done on whole, sound corn kernels equilibrated to 9 ± 0.5% moisture. Test weight was determined in accordance with USDA Official Grain Standards (USDA 1977). Weight per 100 kernels was determined for sound kernels visibly free from chips, cracks, and other defects. Stress-cracked kernels (sum of single, multiple, and checked kernels) were counted for 50-g samples of whole corn by the method of Thompson and Foster (1963) under ×3 magnification. Kernel breakage susceptibility was tested with a Stein breakage tester (model CK2) on 100-g portions of whole corn impacted for 2 min; breakage was determined as the percentage of sample passing through a 4.76-mm (12/64-in.) round-hole-perforated sieve. Kernel hardness index was determined on 150-g samples by the "floaters test" (Wichser 1961) with a sodium nitrate solution of specific gravity 1.275 (Peplinski et al 1989); the hardest kernels were assigned a value of 9 and the softest kernels a value of 1. Kernel size was determined by hand-screening of 200-g samples for 2 min on 0.33-m (13-in.)-square round-hole-perforated screens. All tests were replicated two or more times.

[1]The mention of firm names or trade products does not imply that they are endorsed or recommended by the U.S. Department of Agriculture over other firms or similar products not mentioned.

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Statistical Analysis

Samples from corn lots A–G were tested with two or more replications for every chemical and physical characteristic and every roller-milling product yield and fat value. The general linear models (GLM) procedure was used to obtain least significant difference values, and correlation analyses were run to obtain Pearson correlation coefficients between all pairs of variables listed in Tables I–IV. Statistically significant coefficients ($P \leq 0.05$) are listed in Table VI. Analysis of variance with the GLM procedure was used to compare values for corn lots with low, medium, and high breakage susceptibility (Table V).

Degermation

Each corn lot at 9–12% moisture was tempered by addition of water to 16% moisture, held for 16 hr, further tempered to 21% moisture, and held for 1.75 hr. Finally, to loosen the hulls (pericarp), kernel moisture was increased to 24% for 15 min. Corn was then ground in a horizontal rotor degermer (HRD). The tempering steps allow adequate moisture penetration with minimal internal stress-crack formation in the endosperm. Corn was fed to the HRD while it operated at 1,750 rpm, and the net motor load was kept constant at 0.26 kW. Corn throughputs from the HRD ranged from 1.54 to 1.93 kg/min. Details of the tempering process and of the design and use of the HRD and the dry-milling flow were published previously (Brekke et al 1972, Peplinski et al 1984). The degermer throughput (broken pieces of endosperm, germ, and hull) was dried with 38°C (100°F) air in a forced-air, flow-through tray dryer to 17 ± 1% moisture. The throughput was further processed by roller milling to low-fat food-grade products (prime products), feed products, and corn germ (Peplinski et al 1982, 1984, 1989). All tempering and roller milling were done at 25°C and 50% relative humidity.

TABLE I
Chemical Composition of Whole Corn (db)

Corn Lot	Type[a]	Nitrogen (%)	Fat (%)	Starch (%)	Ash (%)	Fiber (%)
A	HTW-LB	1.39	4.9	76	1.3	2
B	HTW-LB	1.48	4.3	78	1.4	2
C	HTW-LB	1.40	5.6	75	1.6	2
D	LTW-MB	1.45	5.0	75	1.4	2
E	HTW-HB	1.40	4.4	70	1.3	2
F	LTW-HB	1.40	4.6	76	1.4	2
G	LTW-HB	1.35	5.0	74	1.3	2
LSD[b]		0.06	0.1	2	0.1	0.1

[a]HTW and LTW indicate high and low test weight, respectively. LB, MB, and HB indicate low, medium, and high breakage susceptibility, respectively.
[b]Least significant difference at $P \leq 0.05$.

RESULTS AND DISCUSSION

Chemical Composition of Whole Corn

Corn lots differed in composition (Table I). Nitrogen content ranged from 1.35% for lot G to 1.48% for lot B, a difference of 10% based on lot G. Fat content varied from 4.3% for lot B to 5.6% for lot C, a 30% difference based on lot B. Starch ranged from 70 to 78% and ash from 1.3 to 1.6%. Fiber was unchanged at 2%. These chemical composition data are similar to previously reported values (Peplinski et al 1982, 1984, 1989).

Physical Analyses of Whole Corn

Corn test weights ranged from 732 to 762 kg/m^3 (56.9–59.2 lb/bu) (Table II). Breakage susceptibility of these corn lots increased sharply as test weight fell to 747 kg/m^3 (58 lb/bu) or

TABLE II
Physical Analysis of Whole Corn[a]

Corn Lot	Type[b]	Test Weight (kg/m^3)	Test Weight (lb/bu)	Weight per 100 Kernels (g)	Floaters (%)	Hardness Index[c]	Stress Cracks (%)	Stein Breakage (%)
A	HTW-LB	762	59.2	32.2	16	8	8	14
B	HTW-LB	754	58.6	30.9	36	6	24	15
C	HTW-LB	754	58.6	31.7	16	8	33	16
D	LTW-MB	740	57.5	31.7	11	9	19	22
E	HTW-HB	747	58.0	29.9	52	4	62	33
F	LTW-HB	733	57.0	29.0	64	3	59	31
G	LTW-HB	732	56.9	29.9	62	3	61	33
LSD[d]		8	0.6	1.5	4	2	3	3

[a]9 ± 0.5% moisture.
[b]HTW and LTW indicate high and low test weight, respectively. LB, MB, and HB indicate low, medium, and high breakage susceptibility, respectively.
[c]9 = hardest, 1 = softest.
[d]Least significant difference at $P \leq 0.05$.

TABLE III
Degermer Throughput[a] and Yield of Roller-Milled Products[b]

Corn Lot	Type[c]	Degermer Throughput (kg/min)	First-Break Grits (%)	Second- and Third-Break Grits (%)	Low-Fat Meal and Flour (%)	Prime Products (%)	High-Fat Meal and Flour (%)	Degermer Fines (%)	Bran Meal (%)	Hull (%)	Germ (%)
A	HTW-LB	1.54	10	31	14	55	13	4	5	8	15
B	HTW-LB	1.67	12	33	14	59	12	4	6	7	12
C	HTW-LB	1.77	9	31	16	56	13	4	5	8	14
D	LTW-MB	1.60	7	32	16	55	13	4	5	8	15
E	HTW-HB	1.93	6	31	14	51	15	4	6	9	14
F	LTW-HB	1.78	6	30	14	50	15	4	6	9	15
G	LTW-HB	1.74	7	30	15	52	15	5	6	9	13
LSD[d]		0.2	1.5	2	1.4	3.3	1.2	0.5	1.2	1.1	1.9

[a]22.5 ± 1.0% moisture.
[b]9 ± 1.0% moisture.
[c]HTW and LTW indicate high and low test weight, respectively. LB, MB, and HB indicate low, medium, and high breakage susceptibility, respectively.
[d]Least significant difference at $P \leq 0.05$.

less. We therefore used 747 kg/m³ (58 lb/bu) as the test weight dividing high- and low-test-weight corn in this study. According to this measure, lots A, B, C, and E fall into the high-test-weight category. Paulsen and Hill (1985) suggested a dividing test weight of about 733 kg/m³ (57 lb/bu) in their work on kernel breakage and density.

Weight per 100 kernels was above 30 g for lots A–D. The percentage of floating kernels was lowest (≤ 36%) for these four lots. Corn with a low percentage of floaters is denser than corn with a high percentage of floaters and tends to have more horny, vitreous endosperm, which is harder and more resistant to breakage than less dense, softer, floury endosperm. The floaters test rated lots A, C, and D as hard, lots B and E as intermediate, and lots F and G as soft. Stress-crack values for lots A–D were 33% or less, whereas lots E–G each contained 59–62% stress-cracked kernels. Stress-cracked kernels tend to break or chip more readily during handling than kernels without stress cracks. Kernel breakage susceptibility, assessed by the Stein breakage test, ranged from 14–16% for lots A–C to 22% for lot D and 31–33% for lots E–G.

Degermation, Roller Milling, and Grading of Degermed Corn

Degermer throughputs from the HRD and yields of roller-milled products from the grinding and grading process are shown in Table III. Throughput, or the output of ground corn from the HRD at a constant net motor load of 0.26 kW, ranged from a low of 1.54 kg/min for lot A (corn with the highest test weight and lowest stress-crack and breakage percentages) to 1.93 kg/min for lot E. Throughput is influenced by kernel density, hardness, stress cracks, hull (pericarp) thickness, shape, size, and percentage of horny endosperm.

First-break grit yield, an indicator of endosperm hardness, was highest for lots A and B (10–12%), intermediate for lot C (9%), and lowest for lots D–G (6–7%). Prime products were highest from lots A–D (55–59%) and lower from lots E–G (50–52%). The prime products are a mixture of low-fat grits, meal, and flour used by cereal, malted beverage, and other related food processors. Yields of first-break grits and prime products were directly correlated with density as measured by the floaters test and negatively correlated with breakage susceptibility as measured by the Stein breakage test.

The germ fraction containing the oil varied little among corn lots; yields ranged from 12 to 15%. The remaining fractions are generally high in fat content and have less economic value than the lower-fat fractions; they are generally used in animal feed products. Their yields were as follows: high-fat meal and flour, 12–15%; degermer fines, 4–5%; bran meal, 5–6%; and hull, 7–9%.

The fat content of roller-milled products did not appear to be related to corn hardness or breakage (Table IV). Fat content of the first-break grits, prime products, and germ fractions was highest in lots B, E, and G and much lower in lots A, D, and F; lot C had low fat content in the first-break grits and prime products but high fat content in the germ fraction. Recoverable oil yield from the germ fraction varied directly with the percentage of floating kernels and inversely with test weight and ranged from 1.8 to 2.3 kg of oil per 100 kg of corn. These yields are comparable to those previously reported (Peplinski et al 1989). The calculated recoverable oil yields are an indicator of the oil that can theoretically be extracted from the germ by commercial oil processors.

Kernel Breakage Susceptibility

The seven corn lots were divided into three groups with low, medium, and high mean breakage susceptibility for statistical evaluation. Corns with low and high breakage susceptibility were significantly different ($P \leq 0.05$) in all variables listed in Table V. Test weight, 100-kernel weight, hardness index, and yields of first-break grits and prime products increased as breakage susceptibility decreased. Corns with low breakage susceptibility had the highest mean values for test weight (757 kg/m³, 58.8 lb/bu), 100-kernel weight (31.6 g), first-break grit yield (10.6%), and prime product yield (57.0%). Corns with high breakage susceptibility had the highest mean values for percentage of floating kernels

TABLE IV
Fat Content of Roller-Milled Products[a]

Corn Lot	Type[b]	First-Break Grits (%)	Second- and Third-Break Grits (%)	Low-Fat Meal and Flour (%)	Prime Products (%)	High-Fat Meal and Flour (%)	Degermer Fines (%)	Bran Meal (%)	Hull (%)	Germ (%)	Calculated Recoverable Oil (kg/100 kg of corn)
A	HTW-LB	0.45	0.56	0.54	0.53	1.17	0.71	3.64	1.58	20.9	1.8
B	HTW-LB	0.80	0.89	1.07	0.91	2.08	1.30	4.50	2.78	24.6	2.1
C	HTW-LB	0.47	0.49	0.40	0.46	0.69	0.69	3.08	2.08	23.1	2.0
D	LTW-MB	0.39	0.46	0.36	0.42	0.73	0.37	1.89	1.36	21.0	2.0
E	HTW-HB	0.84	0.88	1.39	1.02	0.84	0.77	2.64	3.38	24.8	2.2
F	LTW-HB	0.55	0.63	0.62	0.62	0.97	0.88	2.28	2.07	21.4	2.2
G	LTW-HB	0.76	0.81	0.94	0.84	1.46	0.94	2.05	3.42	24.5	2.3
LSD[c]		0.2	0.2	0.3	0.14	0.5	0.15	1.6	1.5	2.5	...

[a] Moisture-free basis.
[b] HTW and LTW indicate high and low test weight, respectively. LB, MB, and HB indicate low, medium, and high breakage susceptibility, respectively.
[c] Least significant difference at $P \leq 0.05$.

TABLE V
Characteristics of Corn Lots with Low, Medium, and High Breakage Susceptibility[a]

Breakage Susceptibility[b] (%)	Test Weight		Weight per 100 Kernels (g)	Floaters (%)	Hardness Index[c]	Stress Cracks (%)	Degermer Throughput (kg/min)[d]	Yield[e]		
	(kg/m³)	(lb/bu)						First-Break Grits (%)	Prime Products (%)	Hull (%)
14.9	757 a	58.8	31.6 a	22.9 a	7.2 a	21.8 a	1.66 a	10.6 a	57.0 a	7.5 a
22.4	739 b	57.4	31.6 a	10.8 a	8.5 a	18.8 a	1.60 a	7.0 b	54.3 a	7.8 a
32.3	738 b	57.3	29.6 b	59.4 b	3.5 b	60.8 b	1.81 b	6.4 b	51.0 b	9.4 b

[a] Means in a column followed by different letters are significantly different ($P \leq 0.05$) as determined by protected (0.05) least significant difference. Corn lots were tested at 9 ± 0.5% moisture unless otherwise indicated.
[b] Corn lots A–C (average breakage susceptibility 14.9%) were classified as low in breakage susceptibility; lot D (22.4%) was classified as medium; and lots E–G (32.3%) were classified as high.
[c] 9 = hardest, 1 = softest.
[d] 22.5 ± 1.0% moisture.
[e] 9 ± 1.0% moisture.

TABLE VI
Correlation Coefficients[a] of Selected Variables

Variable	Test Weight	Weight per 100 Kernels	Floaters	Hardness Index	Stress Cracks	Stein Breakage	Degermer Throughput	First-Break Grit Yield	Prime Products Yield
Weight per 100 kernels	0.73	···	···	···	···	···	···	···	···
Floaters	−0.65	−0.96**	···	···	···	···	···	···	···
Hardness index	0.65	0.95**	−0.99**	···	···	···	···	···	···
Stress cracks	−0.69	−0.90**	0.89**	−0.86**	···	···	···	···	···
Stein breakage	−0.82*	−0.85*	0.81*	−0.77	0.90**	···	···	···	···
Degermer throughput	−0.31	−0.69	0.63	−0.59	0.85*	0.67	···	···	···
First-break grit yield	0.73	0.59	−0.47	0.41	−0.70	−0.88**	−0.55	···	···
Prime product yield	0.69	0.69	−0.64	0.58	−0.78	−0.92**	−0.56	0.95**	···
Hull yield	−0.71	−0.88**	0.86**	−0.82*	0.95**	0.97**	0.75	−0.83*	−0.92**

[a]* and ** denote statistical significance at $P \leq 0.05$ and $P \leq 0.01$, respectively.

(59.4%), percentage of stress-cracked kernels (60.8%), degermer throughput (1.81 kg/min), and hull yield (9.4%).

Correlations Among Variables

Correlation coefficients were calculated for all variables reported in Tables I–IV, and some statistically significant coefficients are listed in Table VI. Hull yield and Stein breakage were each significantly correlated with seven of the other parameters. Hull yield was positively correlated with percentage of floaters, stress cracks, and breakage and negatively correlated with 100-kernel weight, hardness, first-break grit yield, and prime product yield. Stein breakage was positively correlated with percentage of floaters, stress cracks, and hull yield and negatively correlated with test weight, 100-kernel weight, first-break grit yield, and prime product yield. Paulsen et al (1983) showed a correlation between kernel thickness and density, and Kirleis and Stroshine (1990) noted that kernel hardness was correlated with breakage susceptibility.

Based on the strength of our data, we believe that the hull (pericarp), because of its amount, structure, or adherence to endosperm or germ, has a large but unexplained influence on kernel hardness, breakage susceptibility, and milling response. The other variables with statistically significant correlation coefficients ($P \leq 0.05$) were stress cracks, related to six variables; floaters and 100-kernel weight, five variables each; and hardness, four variables. Kernel chemical composition, fat contents of dry-milled fractions, and the remaining fraction yields showed little or no significant statistical correlation with other tested parameters and are not shown in Table VI.

CONCLUSIONS

Seven corn lots varying in density and kernel breakage susceptibility differed extensively in chemical composition, dry-milling response, and physical characteristics. Whole-kernel fat content varied by up to 30% and nitrogen content by up to 10%.

Roller-milling response studies indicated that grit yield was significantly higher for corn lots with test weight above 740 kg/m^3 (57.5 lb/bu), fewer than 36% floating kernels, less than 22% kernel breakage in the Stein test, and fewer than 34% stress-cracked kernels. Recoverable germ oil varied directly with percentage of floating kernels and inversely with test weight.

Corn hardness is related to breakage, density, and dry-milling response and is very difficult to determine with present test methods. The percentage of floating kernels correlates with hardness and breakage susceptibility more precisely than does test weight. Corn kernels resist breaking and cracking when their density is high, as measured by high test weight and low flotation, and when the percentage of stress-cracked kernels is low. Hull amount, structure, or adherence to endosperm or germ appears to have a large but unexplained influence on kernel hardness, breakage susceptibility, and milling response.

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