Physical, Chemical, and Dry-Milling Characteristics of Corn Hybrids from Various Genotypes

A. J. PEPLINSKI,[1] M. R. PAULSEN,[2] R. A. ANDERSON,[1] and W. F. KWOLEK[1]

Cereal Chem. 66(2):117–120

ABSTRACT

We investigated the viability, physical properties, chemical position, and dry-milling responses of six yellow dent corn hybrids having various genotype parents. The experimental design included 1) kernel size, hardness index, breakage susceptibility, flotation, bulk density, 100-kernel weight, and percent stress cracks as the major physical properties; 2) percent nitrogen, fat, starch, ash, fiber, linoleic acid, fat acidity, and nitrogen solubility index as compositional parameters; 3) pilot-plant roll-dry-milling; and 4) the effects of hybrid and drying temperature on the various properties and dry-milling response. Increasing drying air temperature from 25 to 60° C increased percent kernel stress cracks from 0–3% to 23–74%, respectively, depending on hybrid variety. For Stein breakage, the range at 25° C was 1–7% and at 60° C, 3–9%. The dry-milled grit yield was decreased for every corn hybrid by raising drying temperature from 25 to 60° C. Drying air temperature had little or no effect on any other physical or chemical characteristic studied, although these other properties did vary significantly with hybrid type.

The importance of corn to the United States as an export commodity and as a domestic food and feed commodity is well documented. Corn that has been chipped, cracked, or physically or chemically changed may lose economic value. Corn hybrids have generally been developed to show increased field yields rather than quality as related to milling, storage, and shipping properties. One purpose of this study was to examine physical and chemical characteristics of some corn hybrids from various genotype parents. This work also related kernel breakage and stress cracking to the corn dry-milling process, and indicated which of these corn hybrids will be able to withstand the rigorous degerming, grinding, and sieving steps necessary to yield large grits desired by the food and beverage industries.

Objectives of this research were 1) to determine physical and chemical characteristics of six corn hybrids dried with 25 and 60° C air, and 2) to correlate dry-milling response based on kernel breakage and other physical characteristics.

MATERIALS AND METHODS

Corn

Six 1981 crop year yellow dent corn hybrids (Table I) of different relative maturity ratings were grown, harvested, and dried at the University of Illinois, Champaign-Urbana. Genotype parents were selected to give a wide range of kernel physical and chemical composition characteristics. Each hybrid was planted at a rate of 68,500 kernels per hectare (27,700 kernels per acre) on approximately 0.06-ha (0.15-acre) plots.

After physiological maturity was reached, the corn was hand harvested at 20–24% moisture and hand shelled to minimize physical damage to the corn.

Each hybrid was divided into two sublots; one sublot was dried with ambient (~25° C) air and the other with air heated to 60° C. Corn was dried in an experimental batch dryer at the University of Illinois by passing ambient temperature or heated air at 60° C up through the grain bed at a constant airflow rate of 2.0 $m^3/(min/m^3)$ of corn. Final moisture content of all samples ranged from 10 to 13%.

After drying, the oversize and broken kernels were removed by passing corn over 1.1-cm and 0.55-cm diameter round-hole perforated (RHP) screens. Beeswing and adhering fines were removed by aspiration. Corn was stored at 1° C and brought up to 25° C before all test work was performed.

Degerming Corn

Lots (6 kg) of cleaned corn at 10–13% moisture were tempered by adding water to 16% moisture, held for 16 hr, additionally tempered to 21% moisture, and held for 1.75 hr. A final temper to loosen the hull (pericarp) was performed by increasing the moisture to 24% for 15 min before grindinq in the degermer mill. These temper steps adequately allowed moisture penetration with minimal internal stress cracks developing in the endosperm. Corn was then fed to the horizontal rotor degermer (HRD) operating at 1,750 rpm while keeping a constant net motor load of 0.26 kW. Corn throughputs from the degermer ranged from 63 to 91 kg/hr. Details of the tempering steps and on the design and use of the HRD and dry milling flow were published previously (Brekke et al 1972). After degerming, the degermer stock containing broken pieces of endosperm, germ, and hull was dried with 38° C air in a forced-air flow-through-tray dryer to 17 ± 1% moisture and was then further processed by a roller-milling procedure to produce low-fat, food-grade products (prime products), feed products, and corn germ (Peplinski et al 1984). All tempering and roller milling steps were performed in a room kept at 25° C with a 50% relative humidity. Product yields were calculated on a 9% moisture basis, and product fat contents were calculated on a moisture-free basis.

Analytical Procedures and Calculations

Ash, fiber, nitrogen, nitrogen solubility index, and starch contents of whole corn were determined by American Association of Cereal Chemists approved methods (AACC 1962). The nitrogen solubility index method was modified by adjusting the extraction water to pH 7.2 and using a sample ground to less than 0.149-mm (100-mesh). Fat content of whole corn and germ fractions was obtained by pentane-hexane extraction in the Butt procedure (AOAC 1960), whereas fat content of the other roller-milled fractions was assayed by the gas chromatography method of Black et al (1967) as modified by Nielsen et al (1979). Fat acidity values were determined by an AOAC method (AOAC 1960). Linoleic acid content of pentane-hexane-extracted fats was determined by the gas-liquid chromotography method of Black et al (1967). Moisture values were obtained by heating a 10-g ground sample at 130° C for 30 min in a forced-air oven. Calculated yield of recoverable oil was based on yield of recovered germ fraction and its fat and moisture contents, with residual germ cake assumed to contain 5% oil, dry basis.

All tests for physical analysis were performed on corn that had been equilibrated to 10 ± 0.5% moisture. Test weight was determined by using USDA "Official Grain Standards" (1970). Stress-crack counts were obtained on 50-g samples of whole

[1]Chemical engineer, chemical engineer (retired), and biometrician (retired), respectively, U.S. Department of Agriculture, Agricultural Research Service, Southern Regional Research Center, 1815 North University Street, Peoria, IL 61604.

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.

[2]Professor of Agricultural Engineering, Department of Agricultural Engineering, University of Illinois, Urbana 61801.

unbroken corn by the method of Thompson and Foster (1963) under 3× magnification. Breakage susceptibility tests were run with the Stein breakage tester, model CK2, on 100-g portions of corn impacted for 2 min, with breakage determined as percentage of the sample passing through a 0.48-cm (12/64-in.) RHP screen. Kernel-hardness index was determined on 150-g samples with the floaters test described by Wichser (1961) in which a sodium nitrate solution of 1.275 specific gravity is used for floatation. Germination was determined for 400 seeds in accordance with the rules for seed testing adopted by the Association of Official Seed Analysts (AOSA 1970). Kernel size was obtained by hand screening 200-g samples for 2 min. Two or more samples from each hybrid were replicated, and hybrid means were compared by least significant differences within an analysis of variance after an overall hybrid effect of $P \leqslant 0.05$ was determined (protected LSD).

RESULTS AND DISCUSSION

Chemical Composition

Chemical makeup varied between hybrids but was essentially unaffected by the temperature of drying air used (Table I). Nitrogen content ranged from 1.6% for hybrids 1 and 2 down to 1.2% for 6, a decrease of 25%. Fat content varied from a low of 3.9% in corns 1 and 5 to a high of 5% fat in 6. Levels of starch (76–77%), ash (1.3–1.5%), fiber (2%), fat acidity (14–18%), and nitrogen solubility index (13–16%) were essentially the same for all hybrids and are similar to previously reported values (Peplinski et al 1975, 1982). Fat acidity measures the degree of oil ester linkage hydrolysis, and nitrogen solubility index estimates protein denaturation caused mainly by elevated drying temperatures (Peplinski et al 1975).

Linoleic acid ($C_{18:2}$), an essential component for human nutrition, was lowest in corn 6 (55% of total fat) and medium in corn 4 (60%), whereas the other four hybrids contained 65–66% linoleic acid in their fatty acid composition. These values are similar to those reported by Peplinski et al (1983).

TABLE I
Chemical Composition of Whole Corn[a]

	Dry Basis							
Hybrid[b]	Nitrogen (%)	Fat (%)	Starch (%)	Ash (%)	Fiber (%)	Linoleic Acid (%)	Fat Acidity[c]	Nitrogen Solubility Index
1	1.6	3.9	77	1.5	2	65	18	16
2	1.6	4.3	76	1.5	2	65	17	16
3	1.5	4.3	77	1.3	2	65	15	14
4	1.5	4.5	76	1.4	2	60	16	13
5	1.4	3.9	76	1.5	2	66	14	14
6	1.2	5.0	77	1.5	2	55	16	16
LSD[d]	0.2	0.9	4	0.06	0.6	1	2	5

[a] Values are average of 25 and 60°C drying temperatures.
[b] Genotype identity: 1, (4A × 4C) × Mo17; 2, Mo17 × 634; 3, B73 × Mo17; 4, B73 × 19; 5, Mo17 × H100; 6, B73 × Pa91.
[c] In mg of KOH/100 g dry matter.
[d] Least significant difference at $P \leqslant 0.05$.

Physical Analysis

Corn test weight did not vary greatly for any hybrid after drying with 60°C air compared with drying at 25°C (Table II). Peplinski et al (1975) and Brekke et al (1973) showed that test weight is lowered when corn is dried with air heated at 82°C or higher. Weight per hundred kernels was slightly increased for hybrids 1 and 2 when dried at 60 instead of 25°C, whereas the other corns had decreased kernel weight when dried at the higher temperature. Percentage of floaters (except for hybrid 5), stress-cracked kernels, and Stein breakage susceptibility were increased in every corn dried with 60°C air.

Kernel stress cracks were increased a magnitude of 20 to 30 times by raising drying air temperatures from 25 to 60°C. As stress-lined kernels tend to break more readily during transfer and processing, the dry-milling industry objects to purchasing such affected corn and some processors have set upper limits of 25% stress-cracked kernels. Kernel breakage susceptibility was increased up to threefold as measured by the Stein breakage test with corn dried at 60°C. By use of the floaters test, every corn sample had a hardness index rated as soft, except for number 4 dried with 25°C air, which was rated at medium hardness.

Corn viability as measured by the germination test was greater than 90% for all lots except for hybrid 1 dried with 60°C air. Hybrid 5 had the largest kernels, and type 6 had the smallest kernels as measured by kernels retained on a 0.79-cm (20/64-in.) RHP screen. Kernel size varied inversely with fat content for all hybrids, with a correlation coefficient of $r = 0.89$ at $P \leqslant 0.05$, indicating that the smaller kernels contained a greater amount of germ on a weight percentage basis.

Roller Milling of Degermed Corn

Table III lists the degermer throughput, yield, and fat contents of the roller-milled products, and recoverable oil from the germ.

Degermer throughput from the HRD was significantly increased for every corn that had been dried at 60°C compared with corn dried at 25°C, except for hybrid 2, which had the same throughput rate at both drying temperatures. This increased corn throughput of up to 35% can be attributed to the large kernel stress crack increase caused by the 60°C drying temperature. The large number of fissures produced in the kernels at 60°C allowed the

TABLE II
Physical Analyses of Whole Corn

Hybrid	Test Weight (kg/m³)	100-Kernel Weight (g)	Floaters (%)	Hardness Index[a]	Stress Cracks (%)	Stein Breakage (%)	Germination (%)	Kernels on 0.79-cm Screen (%)
25°C Drying temperature								
1	762	32	87	S	3	1	96	86
2	777	35	96	S	3	1	97	81
3	790	34	76	S	2	1	99	70
4	790	31	62	M	3	2	100	22
5	736	39	100	S	0	1	96	92
6	766	28	80	S	2	7	99	19
60°C Drying temperature								
1	763	33	95	S	69	3	86	87
2	772	36	97	S	65	3	97	82
3	786	33	87	S	66	3	100	67
4	784	30	82	S	74	5	99	20
5	729	37	100	S	23	3	95	91
6	768	27	86	S	50	9	91	17
LSD[b]	3	0.7	5	···	3	1.6	7	3

[a] S = soft; M = medium
[b] Least significant difference at $P \leqslant 0.05$.

TABLE III
Degermer Throughput, Yield, and Fat Content of Roller-Milled Products, and Germ Recoverable Oil

		Yield[a] (%)			Fat[b] (%)			
Hybrid	Degermer Throughout (kg/min)	First-Break Grits	Prime Product Mix[c]	Germ	First-Break Grits	Prime Product Mix[c]	Germ	Calculated Recoverable Oil (kg/100 kg corn)
25° C Drying temperature								
1	1.1	9	54	11	0.6	0.7	23	1.9
2	1.3	4	53	12	0.7	0.7	25	2.2
3	1.1	10	56	12	0.4	0.4	24	2.1
4	1.2	7	54	11	0.5	0.5	23	2.2
5	1.2	3	50	12	0.9	0.9	23	2.0
6	1.2	5	40	11	0.8	1.1	25	2.2
60° C Drying temperature								
1	1.2	3	50	11	0.6	0.7	23	1.9
2	1.3	2	52	11	0.9	0.7	25	2.0
3	1.5	3	50	13	0.5	0.4	24	2.4
4	1.5	3	52	12	0.5	0.7	23	2.0
5	1.3	1	42	13	1.0	0.7	18	1.5
6	1.4	4	45	11	0.7	1.2	26	2.2
LSD[d]	0.16	2.3	4	2.6	0.15	0.3	3	0.42

[a] 9% Moisture basis.
[b] Dry moisture basis.
[c] First-, second-, and third-break grits, low-fat meal, and low-fat flour.
[d] Least significant difference at $P \leq 0.05$.

corn to be broken at a faster rate and pass through the perforated screens of the HRD more rapidly.

Yield of first-break grits ranged from 1 to 7 percentage points higher from corn dried at 25° C compared with corn dried at 60° C. First-break grits from our flow are sized through a U.S. 10-mesh and on a U.S. 16-mesh and should correlate with the yield of commercial flaking grits produced by commercial millers. Peplinski et al (1982) found grit yields increased by 4 to 12 percentage points from corn dried at or below 82° C compared with grit yields from corn dried at 150° C, and Stroshine et al (1986) also found milling yields increased from field-dried corn compared with corn dried at 93° C, based on his milling evaluation factor. Yield of prime product mix (grits, low-fat meal and flour) followed a trend similar to the grits, except for hybrid 6, which had a higher prime product mix yield, 45%, from corn dried at 60° C compared with 40% yield from corn dried at 25° C. Germ (corn oil source) fraction yield (11–13%) showed little variation due to hybrid type or drying temperature. Other fractions from the roller-milling flow were slightly affected, with no trends observed. Yields and ranges of fractions obtained were 13–21% for high-fat meal and flour, 5–8% for bran meal, 7–10% for hull, and 4–9% for degermer fines. These fractions, which are of less economic value, generally go into animal feed products.

Fat content of grits, prime products, and germ were affected mainly by hybrid type. Fat content of prime products was lowest from corn type 3 (0.4%) and highest from corn type 6 (1.2%), regardless of the air temperature at which the corn had been dried. Fat content of germ showed no trend, ranging from 23 to 26% for all corns except number 5 dried at 60° C, which contained only 18% fat. Recoverable oil yields from the germ fraction varied with hybrid type but showed no trend. With elevation of drying temperature from 25 to 60° C, recoverable oil yield increased for hybrid 3, remained the same for 1 and 6, and decreased for 2, 4, and 5.

Conclusions

Increasing drying air temperature from 25 to 60°C had no apparent effect on kernel chemical makeup or test weight but lowered germination up to 10 percentage points while increasing percentage floating kernels up to 20 points, stress-cracked kernels by 23 to 71 percentage points, and breakage susceptibility by 2–3 percentage points.

Kernel hybrid showed more significant effect on the whole corn chemical composition than drying temperatures in nitrogen, fat, and linoleic acid content. Hybrid difference was also pronounced in kernel physical analyses as shown by differences of up to 57 kg/m^3 in test weight, 9 g per 100 kernels for kernel weight, 38 percentage points for floaters test, 51 percentage points for stress-cracked kernels, and 74 percentage points for kernels sized on a 0.79-cm RHP screen.

Roller milling response of corn varied greatly with hybrid type and drying air temperature. Corn hybrid type showed the greatest effect on product yields and fat contents, whereas drying temperature showed a lesser effect. Raising corn drying air temperatures from 25 to 60° C decreased first break grit yields from 1 to 7 percentage points, but increased degermer throughput of ground corn from the HRD from 0.1 to 0.4 kg/min, both probably due to increased stress-cracked kernels in the corn dried at 60° C.

This study demonstrates that genotype parentage may be marked as a selective indicator of the corn hybrid that can be used by the dry miller, the feeder, the exporter, and other end users with regard to the corn chemical or physical properties desired. As more corn hybrids and their genotype parentage are studied, it should be possible to grow hybrid corn based on selected genotype characteristics with the corn quality adapted for each grain user.

ACKNOWLEDGMENTS

The authors gratefully acknowledge F. B. Alaksiewicz, L. T. Black, J. D. Glover, R. L. Haig, P. L. Milroy, M. E. Riggen, and M. I. Schulte for their help in conducting the milling study and the chemical and physical analyses, and Wilma Bailey, who assisted in the statistical evaluation.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1962. Cereal Laboratory Methods. Method 08-16, approved May 1960; Method 30-20, approved April 1961; Method 32-15, approved April 1961; Method 46-10, approved April 1961; Method 46-23, approved April 1965; Method 76-20, approved May 1969. The Association: St. Paul, MN.

ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. 1960. Official Methods of Analysis, 9th ed. The Association: Washington, DC.

ASSOCIATION OF OFFICIAL SEED ANALYSTS. 1970. Rules for testing seed. Proc. Assoc. Seed Anal. 60(2).

BLACK, L. T., SPYRES, G. G., and BREKKE, O. L. 1967. Determination of oil contents of dry-milled corn fraction by gas-liquid chrcmatography. Cereal Chem. 44:152.

BREKKE, O. L., GRIFFIN, E. L., JR., and SHOVE, G. G. 1973. Dry milling of corn artificially dried at various temperatures. Trans. ASAE 16:761.

BREKKE, O. L., PEPLINSKI, A. J., GRIFFIN, E. L., JR., and ELLIS, J. J. 1972. Dry-milling of corn attacked by Southern leaf blight. Cereal Chem. 49:466.

NIELSEN, H. C., WALL, J. S., and INGLETT, G. E. 1979. Flour containing protein and fiber made from wet-milled corn germ with

potential food use. Cereal Chem. 56:144.
PEPLINSKI, A. J., BREKKE, O. L., GRIFFIN, E. L., JR., HALL, G., and HILL, L. D. 1975. Corn quality as influenced by harvest and drying conditions. Cereal Foods World 20:145, 154.
PEPLINSKI, A. J., ANDERSON, R. A., and BREKKE, O. L. 1982. Corn dry milling as influenced by harvest and drying conditions. Trans. ASAE 25:1114.
PEPLINSKI, A. J., ECKHOFF, S. R., WARNER, K., and ANDERSON, R. A. 1983. Physical testing and dry milling of high-moisture corn preserved with ammonia while drying with ambient air. Cereal Chem. 60:442.
PEPLINSKI, A. J., ANDERSON, R. A., and ECKHOFF, S. R. 1984. A dry-milling evaluation of trickle sulfur dioxide-treated corn. Cereal Chem. 61:289.
STROSHINE, R. L., KIRLEIS, A. W., TUITE, J. F., BAUMAN, L. F., and EMAM, A. 1986. Differences in grain quality among selected corn hybrids. Cereal Foods World 31:311.
THOMPSON, R. A., and FOSTER, G. H. 1963. Stress Crack and Breakage in Artificially Dried Corn. Mark. Res. Rep. no. 631. Government Printing Office: Washington, DC.
U. S. DEPARTMENT OF AGRICULTURE, FEDERAL GRAIN INSPECTION SERVICE, INSPECTION DIVISION. 1977. Official Grain Standards of the U.S.
WICHSER, W. R. 1961. The world of corn processing. Am. Miller 89:29.

[Received March 30, 1988. Revision received November 16, 1988. Accepted November 18, 1988.]