Breakage Susceptibility and Hardness of Corn Kernels of Various Sizes and Shapes

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ABSTRACT

BREAKAGE susceptibility and hardness of three yellow dent corn hybrids were determined for kernels separated into 6 size and shape categories and equilibrated to 12.3 and 14.7% moisture (wet basis). Measurements for breakage susceptibility by severe impact from the Wisconsin Breakage Tester (WBT) and by a grinding action from the Stein Breakage Tester (SBT) were determined by sieve and by a green dye test to analyze for severe, moderate, and minor breakage. Measurements for hardness by grinding were determined by near infrared reflectance wave-length of 1680 nm and Stenvert Hardness Tester parameters. Mechanical breakage at harvest was influenced more by kernel size, shape and structure characteristics then by kernel hardness properties. There were high correlations between and among physical properties (test weight and kernel density), composition (oil, protein, ash, and carbohydrate), hardness, and SBT values. Size and shape of the kernel and of the germ were interrelated and related to severe and moderate breakage from WBT and severe breakage from SBT. Results suggest that the 6.35-mm round hole sieve could be used along with the 4.76-mm sieve to provide SBT data on both hardness and brittleness. WBT results were several times higher than SBT results at both moistures.

INTRODUCTION

The initial operations, combine harvesting and drying, have a great influence on subsequent handling commitment to corn quality.

When corn is harvested, combine shelling creates visible damage and hidden cracks (Chowdhury and Buchele, 1978). These mechanically damaged kernels are exposed to further stress during transfer handling that approximates grinding (Martin and Stephens, 1977).

The AACC method 55-20 (AACC, 1981) defines corn breakage susceptibility as the potential for kernel fragmentation when subjected to impact forces during handling or transport. Breakage is important because small fragments affect the price by influencing the grade factors of test weight and broken corn and foreign material (BCFM). Small kernel pieces plus BCFM segregate during bin filling and create resistence to air flow in the stored grain. Without adequate air movement to control temperature and moisture, the segregated material will promote the development of molds and insects. Therefore, the evaluation of breakage susceptibility would be helpful in assessing corn suitable for handling and transport.

A kernel will break upon impact when the maximum stress required for breakage to occur is exceeded (Rumpf, 1959). Direct measurement of stress is difficult because gross composition (protein, oil, carbohydrate, and moisture) is not homogeneous; structure (seed coat, horny endosperm, starchy endosperm, and germ) is not constant, and size, shape, and intercellular space is not uniform within and among kernels (MacMasters, 1962). Density of a kernel and resultant structure varies between hybrids and is affected by growing conditions. By classifying different corn hybrid kernels from different hybrids by size and shape, stress physical failure (brittleness) can be determined indirectly by subjecting a large number of similar kernels to random stress in a breakage tester and measuring the breakage (Paulsen et al., 1983).

Hardness is defined as resistance to grinding. When kernels are processed by grinding, size and shape of particles before and after grinding are related to resistance to grinding; particle size and shape after grinding affect product packing or fluffiness (Pfost, 1970). Pomeranz et at. (1984) reported the affect of hardness characteristics of corn on grinding properties. Kernel composition, structure, and density affect hardness characteristics. Kernel density, in turn, is affected by the relative amounts of the major components and their packing, and test weight is an apparent measure of grain density. By classifying kernels from different hybrids by size and shape, hardness variations within a size category can be identified while individual hybrid distinctions can be retained (Pomeranz et al., 1985).

Harvesting and drying operations are the major contributors to breakage potential. High temperature, rapid drying methods cause stress cracks, internal fissures in the starch structure of whole kernels. Careless combine adjustments may add physical kernel damage and increase the BCFM. One combine with a skilled experienced operator was used to harvest all the corn hybrids in this investigation. The normal stress cracks associated with rapid high temperature drying (Thompson and Foster, 1963) were minimized by natural air high airflow drying.

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The objectives of this study were to determine the effects of, and interrelationships among, physical properties (test weight and density), gross composition, kernal size and shape, and moisture content on corn hardness and breakage susceptibility. Corn hardness was determined by near infrared reflectance and the Stenvert Hardness Tester. Breakage susceptibility was determined by the Stein and Wisconsin breakage testers and by visual analysis of broken kernels after staining.

METHODS AND MATERIALS

The Stein breakage tester (SBT) and the Wisconsin breakage tester (WBT) were used to study breakage susceptibility of three hybrids (samples in triplicate) used in the determination of corn hardness by the Stenvert hardness tester (SHT). Breakage was compared for kernels of various size and shape that had been equilibrated at two moisture levels. The kernels (samples in duplicate) were examined before and after they were subjected to the breakage tests.

Breakage Tests

The Stein breakage tester (CK-2-131) subjects a 100-g grain sample to repeated impacting by an impeller and to abrading by continuous stirring caused by the impeller rotation for 2 min. This test involves small impacts and a mixer abrading action.

The Wisconsin breakage tester subjects individual kernels from a 200-g sample to severe impact after accelerating the kernels by a centrifugal force. This impact usually causes the kernel or its fragments to rebound several times before falling from the impact zone.

The usual procedure for measuring breakage susceptibility includes sieving samples with a 4.76-mm (12/64-in.) round hold sieve to remove BCFM. In this study, the separation of kernels by size and shape removed BCFM in addition to small fragments and small kernels that passed through a 6.75-mm (17/64-in.) round hole screen. A 4.76-mm round hole sieve was used to separate fine breakage after the test. All samples were equilibrated at constant temperature and relative humidity for at least 3 weeks before testing (as described by Miller et al., 1979). We used 60% RH and 26 °C (12.3% moisture) and 80% RH and 20 °C (about 14.7% moisture) settings.

Breakage Analysis

Breakage anlysis of corn kernels was made on samples before and after separation by size and shape. The analysis included a visual inspection of individual kernels to evaluate severity of breakage. A representative portion of about 100 g was treated with a fast green dye (Chowdhury and Buchele, 1976) to accentuate breakge and aid in visual separation into categories. Breakage categories, expressed as % by weight, were as follows:

Breakage	Description
Fine	through the 4.76-mm (12/64-in.) round hole sieve
Severe	broken pieces, less than 1/2 kernel
Moderate	broken pieces, more than 1/2 kernel
Minor	whole kernel with cracked seed coat or endosperm (mechanically induced stress crack)
Minimum	sound kernels - no easily visible breakage.

Hardness

The Stenvert hardness test involves grinding a 20-g sample in a Glen-Creston 14-580 mill (Stenvert, 1974; Stenvert and Kingswood, 1977).

The information recorded includes:

Time (s)	Resistance to grinding.
Column height	**Height** in receptacle (mm) of freshly ground product.
Volume C/F	**Coarse** to **Fine** particle ratio determined by height of freshly ground corn in the receptacle; visual distinction was made by yellow color of horny endosperm.
Weight C/F	**Coarse** to **Fine** particle ratio determined by weight of sieved fractions; particles larger than the 0.71-mm sieve opening were coarse and mostly horny endosperm; particles smaller than the 0.5-mm sieve opening were fine and mostly starch.

Near-infrared reflectance (NIR) at 1680 nm was determined with a Technicon Infralyzer after samples were ground on a modified Weber Mill (McGinty et al., 1977) using the 1 mm screen. Reflectance was recorded as log (1/R) which was a measure of fineness of grind. Pomeranz et al. (1986) reported that NIR was related to the hardness of corn; the higher the value, the harder the corn.

Composition

Oil (petroleum ether extract), ash, and protein (N × 6.25) were determined by AACC methods 30-20, 08-01, and 46-10, respectively (AACC, 1961). Results are expressed on a 13% moisture wet basis. Whole kernels were tested for moisture (72 h at 103 °C in a forced air ovem) by ASAE Method S352 (Agricultural Engineering Yearbook, 1983). All analytical assays were made at least in duplicate. Carbohydrate content was calculated by difference (100% minus oil, protein, ash, and moisture).

Density

Kernel density was determined with a Quantachrom stereopycnometer using helium (Thompson and Isaacs, 1967). The gas pycnometer is sensitive to porosity of materials being measured and corn kernels are permeable to helium. Density was measured of 200 kernels that had no visible damage. The procedure was to purge the sample with helium three times and record values after 1 min. Test weight was reported as the average of three measurements by the official Federal Grain Inspection Service method (USDA, 1980).

Commercial Hybrid Corn

Three yellow dent corn hybrids were grown on surface irrigated fields near Manhattan, KS in 1983. Growing conditions were similar. Settings on the combine cylinder were made to minimize field loss. Hybrid A (Stauffer 8100) was harvested last and dried in the field at lower temperature to a moisture content of 19.1 to 20.9% (average 19.92%). Hybrid C (Bo Jac 562) was harvested first at a moisture range between 19.3 to 20.4% (average 19.94%). Hybrid B (Stauffer 8500) was harvested second at a moisture range between 21.1 to 23.1% (average 22.17%). Test lots were hauled by trucks from the combine to the U. S. Grain Marketing Research Laboratory and put into a drying bin with a minimum of

TABLE 1. KERNEL CLASSIFICATION ACCORDING TO SIZE AND SHAPE

	Through round holes						
Hole dia., mm	6.75*	8.33	11.11	8.33	8.33	11.11	11.11
		Round kernels over slots		Flat kernels through slots			
Slot thickness, mm†		5.16	5.95	4.76	5.16	5.16	5.95
Kernel Denotation		Small Round	Large Round	Small Flat	Medium Flat	Large Flat	Extra Large Flat
3 hybrid average							
Weight, mg		286	367	250	281	318	353
Sphericity		0.760	0.838	0.653	0.630	0.645	0.753
Percent of sample							
Hybrid A, %	4.5	19.0	3.0	39.2	18.4	11.8	4.1
Hybrid B, %	8.0	13.0	4.0	38.6	6.4	24.8	5.2
Hybrid C, %	5.9	11.3	2.2	43.3	15.8	18.2	3.2

*Removed from test.
†All slots 32-mm long.

handling. The 46-tonne test lots were dried with ambient air in 4 to 5 days during the last half of September to an average moisture below 14%.

Kernel Classification

After 2 months of storage, about 90 kg from each lot was separated into six size categories according to the scheme and denotations described in Table 1. BCFM, small broken pieces, and small kernels that passed through the 6.75-mm (17/64-in.) round hole sieve were removed in this separation. Kernels were classified into two sets based on width and then into a total of six subsets based on thickness. Assuming the corn kernel is a triaxial ellipsoid with intercepts a, b, and c and the diameter of the circumscribed sphere is the longest intercept of the elipsoid, the degree of sphericaity can be expressed according to Mohsenin (1970) as

$$\text{sphericity} = \left(\frac{\text{Volume of solid}}{\text{Volume of circumscribed sphere}}\right)^{1/3} = \frac{(a\ b\ c)^{1/3}}{a}$$

where
- a = longest intercept,
- b = longest intercept normal to a,
- c = longest intercept normal to a and b.

Kernel dimensions a, b, and c were determined by hand with a caliper for 25 kernels. Average kernel weight was calculated after weighing 200 kernels selected to have no visible damage. Germ shape and weight were determined for 10 kernels after manually removing the germ. Germ shape was defined as the length to width ratio of the germ.

RESULTS

Physical and Compositional Characteristics

The data describing test weight, density, oil, protein, carbohydrates, and ash are shown in Table 2. When all kernel sizes and shape values were averaged by hybrid, hybrid A was highest, hybrid C was lowest and hybrid B was intermediate in test weight, kernel density, oil, and protein content. The gas pycnometer was sensitive to the differences between the amount of packed structure (mostly horny endosperm) and open structure (mostly starchy endosperm). Thus, hybrid A was highest, hybrid C lowest, and hybrid B intermediate in the amount of packed structure.

Grinding Characteristics

Grinding characteristics (as determined by NIR and SHT) at 12.3% moisture are shown in Table 3. Differences in packed structure determined by density were further confirmed by the indirect method of hardness determination on the basis of grinding characteristics. For all kernel class values averaged by hybrid, hybrid A was highest, hybrid C was lowest, and hybrid B intermediate to resistance to grinding (s), particle size (NIR, and weight C/F), and column packing.

Breakage Susceptibility Charactersitics After Combine Harvest

Hybrid A was lowest, hybrid C was highest, and hybrid B was intermediate in minor, moderate, and total breakage categories before classification (Table 4). Most of the breakage in the hybrids as received before kernel classification, was mechanical breakage caused by combine shelling at harvest. Because BCFM measurement also included foreign material (according to U. S. grain standards) it cannot be considered indicative of kernel breakage susceptibility. Still, foreign material is undesirable, because it also contributes to problems related to segregation. Table 4 shows that the separator device for classifying by size and shape removed combine BCFM and severe breakage from large round, extra large flat, and small round kernels because of the 6.75-mm (17/64-in.) round hole sieve. Some severe breakage fragments from large kernels would have been classified as moderate breakage of small flat kernels. The screening also removed very small unbroken kernels. Total percentages of material removed by classification were 4.5, 8.0, and 5.9 for hybrids A, B, and C respectively (Table 1). Hybrid B, with the most BCFM and severe breakage as received, had the largest

TABLE 2. PHYSICAL AND COMPOSITIONAL CHARACTERISTICS OF CORN AT 13.0% MOISTURE (WET BASIS)

Grain characteristics		Round Kernels Small	Round Kernels Large	Flat Kernels Small	Flat Kernels Medium	Flat Kernels Large	Flat Kernels Extra Large	Average
Hybrid A								
Test weight,	kg/m^3	811	800	791	802	794	807	801
Density,	g/cc	1.34	1.34	1.34	1.34	1.33	1.34	1.34
Oil,	%	4.13	4.09	3.99	4.21	4.18	4.22	4.14
Protein,	%	8.49	9.16	8.72	8.75	8.73	8.95	8.80
Ash,	%	1.21	1.23	1.26	1.22	1.24	1.25	1.24
Carbohydrates*	%	73.3	72.5	73.0	72.8	72.9	72.6	72.9
Hybrid B								
Test weight,	kg/m^3	796	785	771	787	760	783	780
Density,	g/cc	1.34	1.32	1.31	1.33	1.30	1.31	1.32
Oil,	%	3.83	3.65	3.75	3.90	3.54	3.65	3.72
Protein,	%	8.42	8.67	7.94	8.32	8.06	8.33	8.29
Ash,	%	1.25	1.15	1.15	1.21	1.12	1.16	1.17
Carbohydrates,*	%	73.5	73.5	74.2	73.6	74.3	73.9	73.8
Hybrid C								
Test weight,	kg/m^3	756	767	728	739	739	754	747
Density,	g/cc	1.29	1.30	1.28	1.28	1.28	1.29	1.29
Oil,	%	3.67	3.63	3.70	3.67	3.76	3.58	3.67
Protein,	%	8.24	8.43	8.11	8.04	8.00	8.20	8.17
Ash,	%	1.25	1.23	1.18	1.23	1.20	1.21	1.22
Carbohydrates,*	%	73.8	73.7	74.0	74.0	74.0	74.0	73.9

*By difference.

TABLE 3. HARDNESS CHARACTERISTICS OF CORN EQUILIBRATED AT 12.3% MOISTURE

Hardness characteristics	Round Kernels Small	Round Kernels Large	Flat Kernels Small	Flat Kernels Medium	Flat Kernels Large	Flat Kernels Extra Large	Average
Hybrid A							
NIR at 1680 nm*	357	402	328	353	370	339	358
Stenvert time, s	18.1	15.3	15.9	16.7	16.8	16.6	16.6
Weight C/F, %	1.44	1.30	1.41	1.43	1.38	1.42	1.40
Volume C/F, %	0.92	0.86	0.84	0.92	0.80	1.01	0.89
Column height, mm	89.9	91.8	90.8	91.3	92.5	89.4	91.0
Hybrid B							
NIR at 1680 nm*	367	353	320	362	321	338	344
Stenvert time, s	14.7	14.6	13.0	13.1	10.3	13.7	13.2
Weight C/F, %	1.25	1.22	1.19	1.22	0.99	1.12	1.17
Volume C/F, %	0.63	0.56	0.60	0.53	0.45	0.60	0.56
Column height, mm	93.3	92.8	94.3	92.6	97.5	94.6	94.2
Hybrid C							
NIR at 1680 nm*	293	315	279	293	296	312	257
Stenvert time, s	11.5	14.3	11.5	11.4	10.8	12.9	12.1
Weight C/F, %	1.04	1.15	0.97	0.99	0.98	1.07	1.03
Volume C/F, %	0.49	0.65	0.59	0.60	0.58	0.52	0.57
Column height, mm	98.9	94.1	97.9	96.9	98.4	98.3	97.4

*Arbitrary units.

proportion of large round, extra large flat, and large flat kernels with the highest corresponding kernel weight and/or sphericity values (Table 5) and the same kernels also had the largest proportion of minor breakage (Table 4). Hybrid B had the lowest average ash content (Table 2), the lowest average volume C/F ratio (Table 3), and the smallest proportion of germ (Table 5). The large flat kernels from hybrid B had the lowest oil and ash contents (Table 2) and the lowest resistance to grinding and volume C/F ratio (Table 3) among the kernel classes. In hybrid B 24.8% of the kernels were large flat kernels with a high sphericity, proportionally small germs, small amounts of horny endosperm, and large amounts of floury endosperm. Thus, mechanical breakage at harvest was influenced more by kernel size, shape and structure characteristics than by kernel hardness properties.

TABLE 4. BREAKAGE IN CORN AFTER COMBINE HARVEST

Breakage, %*	Round Kernels Small	Round Kernels Large	Flat Kernels Small	Flat Kernels Medium	Flat Kernels Large	Flat Kernels Extra large	Average
Hybrid A							
Fraction of sample, %	19.0	3.0	39.2	18.4	11.8	4.1	
None	90.7	89.2	97.7	88.0	90.5	89.1	82.7
Minor	4.6	9.0	5.2	5.0	5.5	7.4	5.8
Moderate	4.7	1.8	3.8	7.0	3.5	3.5	4.8
Severe	0.0	0.0	3.3	0.0	0.5	0.0	3.5
BCFM							3.2
Hybrid B							
Fraction of sample, %	13.0	4.0	38.6	6.4	24.8	5.2	
None	84.5	81.3	84.1	85.7	80.4	79.4	77.1
Minor	9.1	15.2	5.0	7.2	11.1	10.8	7.2
Moderate	6.4	3.5	8.1	6.1	8.2	9.8	7.8
Severe	0.0	0.0	2.8	1.0	0.3	0.0	5.2
BCFM							2.7
Hybrid C							
Fraction of sample, %	11.3	2.2	43.4	15.8	18.2	3.2	
None	87.3	83.7	83.7	88.8	81.8	83.6	73.5
Minor	8.9	10.9	6.5	6.7	7.4	11.1	11.3
Moderate	3.8	5.4	6.8	4.4	10.4	5.3	8.2
Severe	0.0	0.0	2.1	0.1	0.4	.0.	4.0
BCFM							3.0

*Determined by the dye test, except for BCFM.

TABLE 5. KERNEL AND GERM SIZE AND SHAPE CHARACTERISTICS

Size and shape	Round Kernels Small	Round Kernels Large	Flat Kernels Small	Flat Kernels Medium	Flat Kernels Large	Flat Kernels Extra large	Average
Hybrid A							
Kernel weight, mg	298	370	254	292	326	356	361
Length, mm	9.9	9.8	10.9	11.1	11.5	10.9	10.7
Width, mm	7.4	8.6	7.5	7.5	8.4	8.5	8.0
Thickness, mm	6.0	6.9	4.3	4.7	4.4	5.6	5.3
Sphericity*	0.775	0.853	0.654	0.662	0.652	0.741	0.732
Germ shape ratio	2.1	1.7	2.5	2.1	2.5	2.3	2.2
Germ, %	10.7	11.0	11.2	11.2	11.8	11.3	11.2
Hybrid B							
Kernel weight, mg	294	379	252	283	322	364	316
Length, mm	9.7	9.9	11.5	11.5	11.6	10.3	10.8
Width, mm	7.4	8.5	7.6	7.6	8.7	8.7	8.1
Thickness, mm	6.1	6.9	4.2	4.9	4.4	5.5	5.3
Sphericity*	0.789	0.843	0.628	0.656	0.659	0.768	0.724
Germ shape ratio	2.3	1.9	2.7	2.6	2.6	2.1	2.4
Germ, %	10.6	10.4	11.0	11.5	10.8	10.6	10.8
Hybrid C							
Kernel weight, mg	285	361	246	270	312	346	303
Length, mm	10.9	10.2	11.2	11.7	12.3	10.8	11.2
Width, mm	7.3	8.4	7.5	7.2	8.4	8.5	7.9
Thickness, mm	5.9	6.8	4.2	5.0	4.3	5.8	5.3
Sphericity*	0.716	0.817	0.607	0.641	0.624	0.750	0.696
Germ shape ratio	2.1	2.0	3.1	2.6	3.0	2.4	2.5
Germ, %	10.1	10.7	11.3	11.3	11.4	11.0	11.0

*For definition, see text.

Breakage Susceptibility After Kernel Classifying

Tables 6 and 7 show results recorded when two breakage testers were used: SBT, Tables 6 a-b and WBT, Tables 7 a-b. For each tester, corn samples equilibrated to an average moisture content of 12.3% (12.67% to 12.12% range) and 14.7% (14.95% to 14.58%) range were used.

When kernel size and shape values were averaged by hybrid, hybrid A was lowest, hybrid C was highest and hybrid B was intermediate in fine, moderate, minor, and total breakage categories after the SBT tests (Tables 6a and 6b) of the samples at both moistures. Large round

TABLE 6A. BREAKAGE IN CORN EQUILIBRATED AT 12.3% MOISTURE AFTER STEIN BREAKAGE TEST

	Round Kernels		Flat Kernels				
Breakage, %*	Small	Large	Small	Medium	Large	Extra large	Average
Hybrid A							
None	88.8	76.9	85.4	88.5	86.3	87.7	85.6
Minor	3.7	11.0	3.0	5.2	2.9	3.9	5.0
Moderate	5.4	5.1	8.0	4.3	7.7	3.5	5.7
Severe	0.8	4.6	2.2	0.6	1.3	3.0	2.1
Fine	1.3	2.4	1.4	1.4	1.8	1.9	1.7
Hybrid B							
None	79.8	65.5	69.8	74.8	58.4	71.0	69.9
Minor	4.3	14.1	11.4	8.1	12.2	8.8	9.8
Moderate	10.5	8.3	12.9	10.8	23.6	9.7	12.6
Severe	2.6	8.2	2.4	3.5	1.9	6.9	4.3
Fine	2.8	3.9	3.5	2.8	3.9	3.6	3.4
Hybrid C							
None	71.6	59.9	64.1	66.6	55.4	54.4	62.0
Minor	10.6	15.9	12.2	7.8	21.4	21.4	14.9
Moderate	11.7	9.1	17.6	20.5	19.5	17.6	16.0
Severe	3.1	9.8	2.4	1.5	1.0	3.6	3.6
Fine	3.0	5.3	3.7	3.6	2.9	3.0	3.6

*Determined by the dye test, except for fine.

TABLE 6B. BREAKAGE IN CORN EQUILIBRATED AT 14.7% MOISTURE AFTER STEIN BREAKAGE TEST

	Round Kernels		Flat Kernels				
Breakage, %*	Small	Large	Small	Medium	Large	Extra large	Average
Hybrid A							
None	89.7	84.8	88.2	91.8	87.3	91.2	88.8
Minor	5.4	6.2	4.1	3.4	3.9	1.0	4.0
Moderate	2.5	4.3	5.9	3.5	6.0	4.2	4.4
Severe	1.4	3.2	0.6	0.7	0.8	2.0	1.5
Fine	1.0	1.5	1.2	0.6	1.0	1.2	1.1
Hybrid B							
None	82.9	78.0	82.2	83.9	75.4	78.6	80.2
Minor	7.9	10.4	6.7	3.8	7.9	9.4	7.7
Moderate	6.3	6.0	8.7	9.7	14.1	8.4	8.9
Severe	1.6	3.5	0.8	1.1	0.9	2.0	1.7
Fine	1.3	2.1	1.6	1.5	1.7	1.7	1.7
Hybrid C							
None	80.9	76.8	74.3	76.1	69.0	75.3	75.4
Minor	8.1	11.8	10.7	8.6	14.0	10.4	10.6
Moderate	7.4	6.0	11.6	12.2	13.3	10.2	10.1
Severe	1.9	3.3	1.0	1.1	1.2	2.2	1.1
Fine	1.7	2.1	2.5	2.0	2.4	1.9	2.1

*Determined by the dye test, except for fine.

kernels from all three hybrids had the most severe breakage and usually the most fine breakage at both moistures while the least severe and fine breakage varied among kernels of various sizes and shapes. Large kernels were broken into large pieces that did not pass through the standard 4.76-mm (12/64-in.) sieve for measuring breakage susceptibility. Large broken pieces were fragments of horny endosperm with exposed starchy endosperm on one or more surfaces. Exposed starchy endosperm abrades easily and quickly with the potential to contribute to segregation and dust emission problems. These results suggest that the 6.35-mm (16/64-in.) could be used along with the 4.76-mm sieve to provide data on both hardness and brittleness. Large flat kernels from hybrid B had more moderate breakage at both moisture levels than the large flat kernels from hybrids A or C. By comparing breakage measurements after the SBT (Tables 6a and 6b) to measurements recorded in Table 4, the degree of breakage caused by the SBT was evaluated. In some kernel classes there was a decrease of minor breakage value because few whole kernels showed minor breakage. There was a greater decrease in percentage of

TABLE 7A. BREAKAGE IN CORN EQUILIBRATED AT 12.3% MOISTURE CORN AFTER WISCONSIN BREAKAGE TEST

	Round Kernels		Flat Kernels				
Breakage, %*	Small	Large	Small	Medium	Large	Extra large	Average
Hybrid A							
None	17.6	11.6	12.7	21.9	9.3	14.6	14.6
Minor	9.1	7.1	11.4	12.1	12.4	10.1	10.4
Moderate	13.0	9.0	29.2	24.9	31.0	23.1	21.7
Severe	50.1	58.8	37.4	32.4	37.0	41.8	42.9
Fine	10.2	13.5	9.3	8.7	10.3	10.4	10.4
Hybrid B							
None	11.6	5.6	12.0	15.6	6.6	5.9	9.6
Minor	9.4	3.5	8.0	8.5	6.2	7.1	7.1
Moderate	11.5	7.8	35.3	19.3	38.0	15.2	21.2
Severe	52.2	64.5	32.7	42.3	35.9	56.4	47.3
Fine	15.3	18.6	12.0	14.3	13.3	15.4	14.8
Hybrid C							
None	13.9	6.2	4.8	9.7	12.7	11.3	9.8
Minor	7.9	6.0	10.8	8.8	9.2	8.6	8.6
Moderate	13.9	11.2	42.4	32.8	35.2	16.8	25.4
Severe	50.0	60.7	29.2	34.6	31.4	49.6	42.6
Fine	14.3	15.9	12.8	14.1	11.5	13.7	13.7

*Determined by the dye test, except for fine.

TABLE 7B. BREAKAGE IN CORN EQUILIBRATED AT 14.7% MOISTURE AFTER WISCONSIN BREAKAGE TEST

	Round Kernels		Flat Kernels				
Breakage, %*	Small	Large	Small	Medium	Large	Extra large	Average
Hybrid A							
None	23.0	13.9	16.9	13.3	15.2	15.0	16.2
Minor	11.1	6.8	18.8	18.4	16.5	14.2	14.3
Moderate	12.2	8.3	28.0	30.1	29.2	19.3	21.2
Severe	46.1	61.3	29.5	31.5	32.2	43.2	40.6
Fine	7.6	9.7	6.8	6.7	6.9	8.3	7.7
Hybrid B							
None	14.5	9.7	12.5	13.0	11.6	12.0	12.2
Minor	13.2	9.3	20.6	19.0	17.1	13.1	15.4
Moderate	14.5	7.5	36.0	25.3	33.3	18.9	22.6
Severe	49.1	61.8	22.7	34.5	29.9	46.1	40.7
Fine	8.7	11.7	8.2	8.2	8.1	9.9	9.1
Hybrid C							
None	13.6	9.1	16.1	12.2	13.6	18.6	13.9
Minor	19.2	12.3	24.6	22.5	21.7	12.8	18.9
Moderate	21.9	12.1	33.0	27.0	31.0	18.7	24.0
Severe	36.7	55.7	19.3	30.0	25.8	41.3	34.8
Fine	8.6	10.8	7.0	8.3	7.9	8.6	8.5

*Determined by the dye test, except for fine.

minor breakage, at both moistures, in most large round, extra large flat, and large flat kernels from hybrid A than hybrid B. Minor breakage in hybrid C increased for most kernel classes at both moisture levels. Thus, the SBT results at the two moistures were sensitive to a difference in breakage susceptibility as related to the difference in hybrid hardness properties and the difference in breakage susceptibility of various kernel size, shape, and structure characteristics.

When kernel size and shape values were averaged by hybrid, hybrid B was highest, hybrid A was lowest and hybrid C was intermediate in fine, severe, and total breakage categories for samples at both moistures after the WBT (Tables 7a and 7b). Large round kernels from all three hybrids had the most severe and fine breakage at both moistures while the least severe and fine breakage varied among flat kernels of various sizes. Thus, the WBT results at the two moistures were influenced more by kernel size, shape, and structure than kernel hardness properties.

When the results of the two testers were considered, it can be seen that at both moisture levels the WBT results

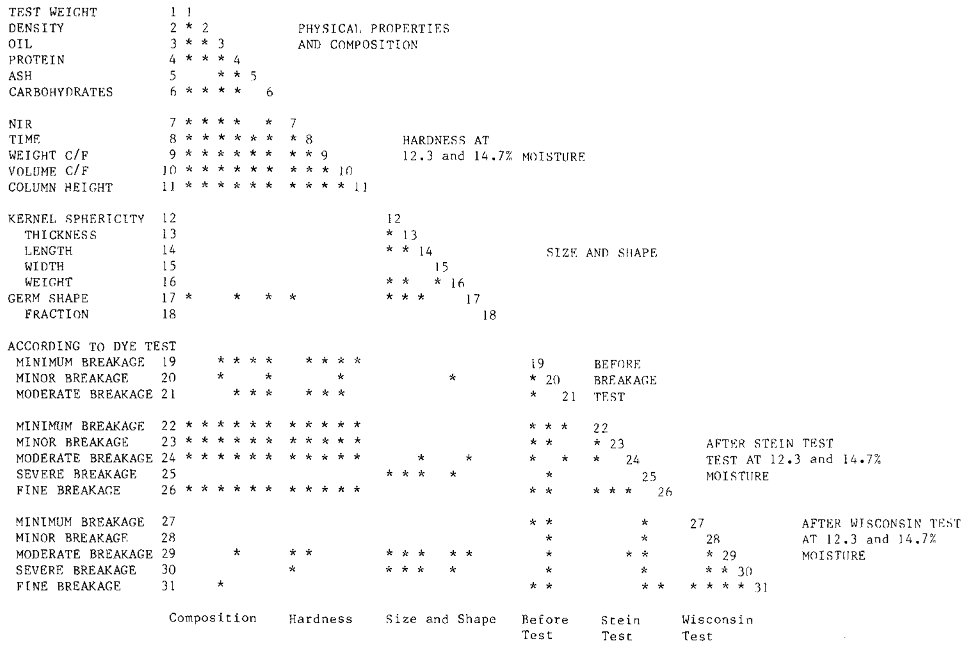

Fig. 1—Statistical significance (at the 0.01 level) of simple correlations across three 1983 crop year yellow dent corn hybrids between physical properties and composition, hardness, kernel size and shape, and breakage (according to dye test) characteristics. Tests were made on large and small round, and extra-large, large, medium and small flat kernels.

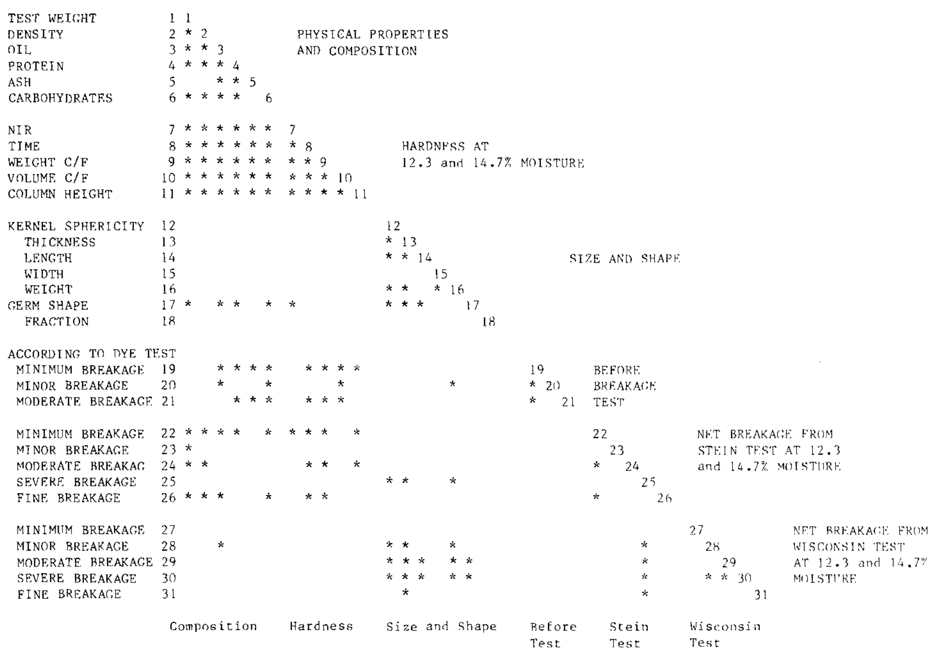

Fig. 2—Statistical significance (at the 0.01 level) of simple correlations across three 1983 crop year yellow dent corn hybrids between physical properties and composition, hardness, kernel size and shape, and breakage (according to dye test) characteristics. Tests were made on large and small round, and extra-large, large, medium, and small flat kernels. Breakage before testing was subtracted to obtain net breakage from Stein and Wisconsin testers.

were several times higher than SBT results. For instance, small round kernels from hybrid A showed a 7.8 times higher fine breakage for WBT than for SBT at the 12.3% moisture level. For round kernels at the lower moisture level, the percent unbroken kernels was about 5 times more for SBT then WBT.

All data from replicated measurements on individual kernel classes were evaluated statistically to determine simple correlations between and among physical and compositional characteristics, grinding characteristics (at both moistures), size and shape, breakage tester and five breakage categories (at both moistures). Only data with correlation coefficients that were significant at the 99% confidence level (at both moisture levels for grinding and breakage measurements) are reported in Figs. 1, 2, and 3. These figures were used to determine the significance of the observations and statements made in the results. By observing the consistency with which a

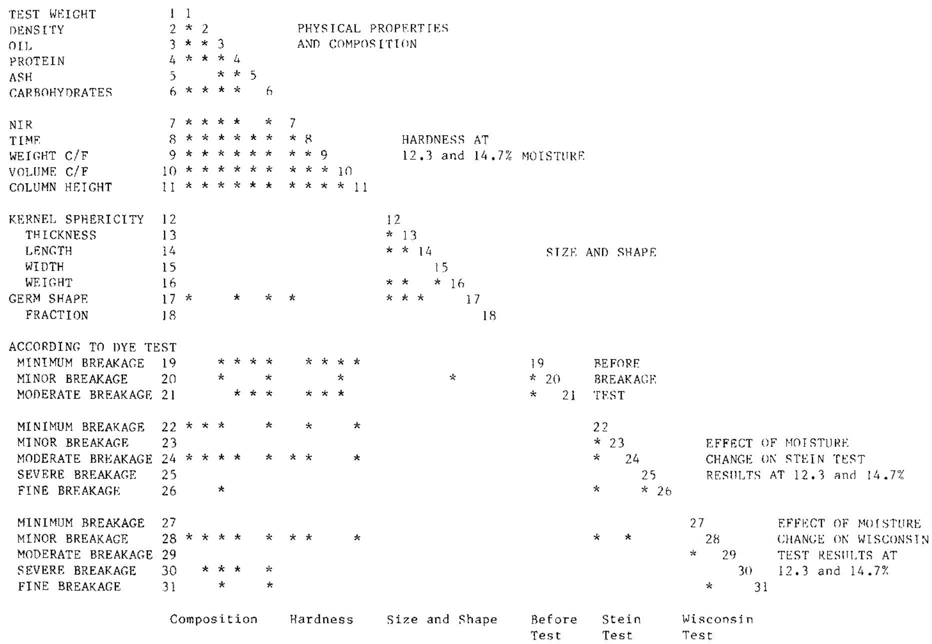

Fig. 3—Statistical significance (at the 0.01 level) of simple correlations across three 1983 crop year yellow dent corn hybrids between physical properties and composition, hardness, kernel size and shape, and breakage (according to dye test) characteristics. Tests were made on large and small round, and extra-large, large, medium, and small flat kernels. Breakage at 12.3% M.C. was subtracted from breakage at 14.7% M.C. to obtain effect of moisture content.

measured variable correlated with remaining variables, the importance of this variable with respect to evaluating corn quality was analyzed.

The figures indicate the statistically significant (at the 0.01 level) simple correlations for pairs of varibles for the three hybrids separated into six classes by sieving. The number of degrees of freedom for calculation of statistical significance was $(3 \times 6) - 2 = 16$. In Fig. 1, the recorded significant correlations are for sieved and classified samples after harvest. In Fig. 2 the correlations were computed after subtracting the breakage of harvested corn. This was done to calculate the effect of passing corn through the SBT and WBT, independent of the original breakage (after harvest). In Fig. 3 the correlations were computed after subtracting breakage at 12.3% moisture from breakage at 14.7% moisture. This was done to calculate the effect of moisture on breakage.

In each of the three figures, we indicate significant correlations among pairs of variables from the following categories: physical properties and gross composition (test weight, density, oil, protein, ash, and carbohydrates - by difference), hardness (as determined by NIR reflectance at 1680 nm and Stenvert Hardness Tester parameters: time, C/F by weight, C/F by volume, and column height), size and shape of kernel and germ, and three examinations according to the green dye test: before the breakage test, after the Stein breakage test (at the 12.3 and 14.7% moisture levels) and after the Wisconsin breakage test (at the 12.3 and 14.7% moisture levels).

Examination of Fig. 1 indicated high correlations between and among physical properties, composition, and hardness parameters. Similarly, results of breakage determined by the green dye test were correlated with physical properties, composition and hardness of corn after harvest and especially after the SBT but not after the WBT. Size and shape of the kernel and of the germ were interrelated and related to breakage after the WBT. Finally, results of the dye test were related to those after the SBT.

A comparison of Figs. 1 and 2 indicates that when the breakage parameters after harvest were subtracted, any of the correlations of the dye test after the SBT and many of the physical properties, composition, and kernel and germ size and shape parameters were no longer significant. This indicates the breakage susceptibility as related to the physical, chemical, and kernel-germ-size-shape parameters is rendered ineffective by, or cannot be expressed in the SBT.

A similar conclusion can be reached with regard to the effect of moisture on the relation between breakage susceptibility as measured by the dye test after the SBT and physical properties, composition, and kernel and germ size and shape (compare Fig. 1 and Fig. 3).

CONCLUSIONS

1. The three corn hybrids were consistent in their average differences in physical, compositional, and hardness characteristics across the six kernel classes separated by size and shape.
2. Mechanical breakage at harvest was influenced more by kernel size, shape, and structure characteristics than by kernel hardness properties.
3. Large round kernels were consistently the most susceptible to severe breakage while fine breakage and moderate breakage were influenced by kernel size, shape, and structure as determined by the dye test.
4. Fine breakage from the Stein breakage tester and other breakage measurements (according to the dye test) were correlated more with physical, compositional, and hardness characteristics than with kernel size and shape characteristics.

5. Degrees of breakage from the Wisconsin breakage tester was significantly correlated with kernel size and shape characterisitics as determined by dye test.

6. The 6.35-mm sieve used along with the 4.76-mm sieve could provide data on both hardness and breakage susceptibility from the Stein breakage tester.

7. The effect of moisture on fine breakage and other breakage according to the dye test was related to physical, compositional, and hardness characteristics.

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