Comparison of Methods for Determination of Hardness and Breakage Susceptibility of Commercially Dried Corn[1]

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ABSTRACT

Cereal Chem. 63(1):39–43

Hardness and breakage susceptibility were determined in eight samples of corn dried under commercial conditions and equilibrated to 12.2–12.4% and 16.1–16.5% moisture. Hardness was determined by density, the Stenvert Hardness Tester (SHT), near-infrared reflectance (NIR) at 1,680 nm, and ratio of coarse to fine in the SHT-ground corn. Breakage susceptibility was measured by the Stein tester (with a shear-grinding action), the centrifugal impact Wisconsin tester (WBT), and the U.S. Grain Marketing Research Laboratory (USGMRL) corn-on-corn impact tester. The higher moisture decreased density, increased NIR, and increased the time to grind in the SHT. Breakage susceptibility was much higher for the corn at 12% than for the 16% moisture corn. Susceptibility to breakage at either moisture level was about six times higher in the WBT than in the USGMRL tester. The large effect of moisture was consistent for the three mechanical methods of testing breakage susceptibility. Additional differentiation among the samples (especially those with low damage levels) was obtained by a green dye test on corn retained on a 12/64-in. screen after the grain was passed through the WBT and USGMRL tester. Correlation coefficients among and between hardness and breakage susceptibility parameters were much higher for the 12% than for the 16% moisture corn.

Two important characteristics of combine-harvested and dried corn are breakage susceptibility and hardness. Most corn breakage is caused by random impact during harvesting and handling (Keller et al 1972, Thompson and Foster 1963). Breakage susceptibility measures stress cracks formed during drying at elevated temperatures. The cracks can be observed visually or estimated by instrumental methods. Results for breakage susceptibility measured with a Stein breakage tester correlated with actual breakage during handling of grain in an elevator (Stephens and Foster 1976). The original instrument (McGinty 1970) was modified to obtain more reproducible results (Miller et al 1981a) and approved as AACC method 55-20 (1983). Herum and Hamdy (1981) found low but positive correlations between breakage of corn in a small elevator and breakage susceptibility values predicted by three breakage testers (Stein CK-2M, modified Stein, and a centrifugal impacter).

Miller et al (1979) emphasized the need to develop a method that could measure potential breakage under simulated elevator conditions, a method that would duplicate conditions in a grain elevator and also test relatively small samples under defined conditions. Such a test could serve as a reference method and be useful in determining breakage of samples from plant breeding programs. To simulate a normal grain handling operation, Miller et al (1979) built and tested a grain acceleration device (U.S. Grain Marketing Research Laboratory [USGMRL] breakage tester) that impacts corn against corn at velocities both above and below that attained by corn falling vertically 30.5 m (100 ft). The velocity can be varied in the range between 19.5 and 42.8 m/sec; for a free-fall of 30.5 m, the impact velocity is 24.5 m/sec. Breakage susceptibility values of commercial corn samples determined with a model CK2 Stein breakage tester correlated highly with those obtained with the grain acceleration device (Miller et al 1981b).

Sharda and Herum (1977) reported that a centrifugal impeller, in which kernels impinge randomly against a steel surface, is more sensitive to breakage susceptibility than the Stein breakage tester, which subjects the kernels to a shear-grinding action. Herum and Blaisdell (1981) determined corn breakage in three testers to evaluate the effects of moisture content, sample temperature, test duration, and sieve size. The principal effect resulted from differences in moisture content, especially around 13%. Below 13% moisture, the Stein testers gave substantially higher breakage values than a centrifugal impact tester; above 13%, the differences between the testers were relatively small.

TABLE I
Characteristics of the Corn Samples

Sample	Description of Drying Conditions	Test Weight (kg/hl)	Internal Fractures (%)	Floaters (%)	1,000-Kernel Weight (g)
A	Low temperature	79.8	19	19	293.1
B	Low temperature	79.2	8	69	254.7
Annex	Dried at 52°C, Cooled in bin	77.9	23	30	314.7
3780(2)	Dried at 52°C, Cooled in bin	77.2	51	64	329.9
3780(3)	Dried at 52°C, Cooled in bin	77.6	39	69	312.7
Brovold	Bin dried with some heat ~55°C	78.5	41	51	297.1
Franseed	Conventional dried, 82–93°C	74.0	83	94	338.0
Hall	Conventional dried, 82–93°C	73.4	92	95	310.0

TABLE II
Protein, Oil, and Ash Contents of the Corn Samples[a]

Sample	Protein (N × 6.25, %)	Oil (%)	Ash (%)
A	8.0	3.46	1.22
B	8.7	4.01	1.12
Annex	9.2	3.51	1.32
3780(2)	9.4	3.54	1.23
3780(3)	9.0	3.53	1.33
Brovold	9.3	3.95	1.23
Franseed	8.3	3.60	1.13
Hall	9.4	3.66	1.25

[a]Expressed on a 14% moisture basis.

[1]Cooperative investigations, U.S. Grain Marketing Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Manhattan, KS 66502 and the Kansas Agricultural Experiment Station, Kansas State University, Manhattan, 66506. Contribution 85-256-J of the Kansas Agricultural Experiment Station.

Mention of firm names or trade products does not constitute endorsement by the U.S. Department of Agriculture over others not mentioned.

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TABLE III
Some Hardness Characteristics of Corn Equilibrated to Two Moisture Levels[a]

	Density (g/cc) at MC[b]		NIR at 1,680 nm at MC		Stenvert Mill Characteristics: Time (sec) at MC		Stenvert Mill Characteristics: Ratio Coarse/Fine by Weight at MC	
Sample	Low	High	Low	High	Low	High	Low	High
A	1.335	1.329	329	363	18.0	20.5	1.558	1.508
B	1.285	1.275	310	314	15.5	17.2	1.315	1.303
Annex	1.317	1.310	305	325	17.1	18.0	1.353	1.310
3780(2)	1.320	1.314	325	331	17.8	20.0	1.449	1.395
3780(3)	1.314	1.301	296	309	16.7	17.2	1.289	1.265
Brovold	1.300	1.293	312	329	17.1	18.2	1.303	1.371
Franseed	1.263	1.258	286	304	14.9	23.0	1.338	1.346
Hall	1.284	1.271	288	307	15.0	24.3	1.386	1.431
LSD[c]	0.004	0.003	2.1	2.3	0.31	0.53	0.026	0.028
Average	1.302A[d]	1.293B	306A	323B	16.5A	19.8B	1.373A	1.366A

[a] 12.2–12.4% = Low moisture content; 16.1–16.5% = high.
[b] MC = Moisture content.
[c] Least significant difference for samples within a moisture level.
[d] Different letters denote statistically significant differences at the 0.05 level between the two moisture levels.

TABLE IV
Breakage Susceptibility of Corn Equilibrated to Two Moisture Levels[a]

	Stein Breakage Tester % Throughs at MC[b]		Wisconsin Breakage Tester % Throughs at MC		USGMRL Breakage Tester % Throughs at MC	
Sample	Low	High	Low	High	Low	High
A	1.9f[c]	0.5ef	13.8d	2.8e	2.0e	0.5b
B	1.8f	0.5ef	10.7e	2.3g	1.0g	0.4b
Annex	4.7d	0.9c	14.9c	3.7c	3.1c	0.4b
3780(2)	1.8f	0.4f	9.9f	2.9e	1.6f	0.2b
3780(3)	5.7c	0.8cd	13.9d	4.0b	2.7d	0.4b
Brovold	3.1e	0.7de	9.7f	2.5f	1.5f	0.4b
Franseed	13.1b	1.4b	19.6b	3.4d	3.8b	0.6b
Hall	13.9a	1.7a	22.9a	4.4a	4.6a	1.1a
Average	5.8	0.9	14.4	3.3	2.5	0.5

[a] 12.2–12.4% = Low; 16.1–16.5% = High.
[b] MC = Moisture content.
[c] Different letters denote statistically significant differences at the 0.05 level for samples within a moisture level.

Recently, Singh and Finner (1983) developed the Wisconsin breakage tester (WBT). This centrifugal impacter detected breakage susceptibility in corn that was highly resistant to breakage. This tester also was evaluated in a collaborative study (Watson et al 1983).

Corn hardness is of significance to producers, processors, and workers in the grain trade. Hardness is related to classification, kernel and bulk density, attack by storage insects, dust formation, and processing into starch, dry milled products, and special foods (Wichser 1961, Thompson and Isaacs 1967, Freeman 1973, Stroshine et al 1981, Emam et al 1981, Paulsen et al 1983, Pomeranz et al 1984). There is little information on breakage susceptibility and hardness of corn dried commercially. Such a comparison is presented in this paper.

Corn samples were dried under four systems (low temperature, 52°C and cooled in the bin, at 55°C in the bin, and conventionally dried at 82–93°C) and evaluated by: three breakage susceptibility tests (Stein, Wisconsin centrifugal impacter, and USGMRL acceleration device); five hardness tests (density and resistance to grinding of whole corn, particle size of ground corn as determined by near-infrared reflectance (NIR) at 1,680 nm, and ratio by weight and volume of coarse to fine); percentage of cracked kernels; and percentage of "floaters" (an index of hardness accepted by the grain trade). The kernels subjected to the WBT and USGMRL tester were classed as broken, cracked, or whole kernels with the aid of a dye test.

Grain was equilibrated to 12.2–12.4% and 16.1-16.5% moisture to determine the effect of moisture content on breakage susceptibility and hardness parameters. The samples were equilibrated as described by Miller et al (1979). For equilibration to 12% moisture, the chamber was maintained at 60% rh and 26°C; for 16% moisture at 88% rh and 20°C.

MATERIALS AND METHODS

Materials

The eight commercially dried corn samples studied are described in Table I. The determinations listed in Table I, except for 1,000-kernel weight, were made in the laboratories of the De Long Co., Inc., Clinton, WI, which provided the samples.

Analytical Methods

Internal fissuring of kernels was determined by visual observation. For the floaters test, the method described by Wichser (1961) and the chemical solution described by Emam et al (1981) were used.

Whole kernels were analyzed for moisture by the ASAE method (ASAE 1982). Ash, oil, and protein were determined by AACC methods 08-01, 30-20, and 46-10, respectively (AACC 1983).

Corn density was determined on whole, sound kernels by the method described by Pomeranz et al (1984). NIR data at 1,680 nm of corn, ground on the modified Weber Mill (McGinty et al 1977) at 1-mm mesh setting, were measured with a Technicon Infralyzer.

Breakage susceptibility was determined by the CK2 Stein breakage tester as described by Miller et al (1981b), by the USGMRL tester as described by Miller et al (1979), and by the WBT as described by Watson et al (1983).

The Stenvert measure of hardness (Stenvert 1974) was determined as described by Lai et al (1983) and Pomeranz et al (1985). The time required to collect 17 ml of ground meal (an index of resistance to grinding) and coarse/fine (C/F) ratios were measured. Weight C/F denotes the ratio of sieved fractions after grinding on the tester; fraction C is larger than 0.7 mm in diameter, and fraction F is smaller than 0.5 mm in diameter. The amount of the intermediate fraction is small. Volume C/F denotes the ratio of fractions C and F determined visually by volume immediately after grinding on the Stenvert hardness tester.

Percentages of broken (less or more than half), cracked, and whole kernels were determined visually by the green dye method of Chowdury and Buchele (1976). Corn retained on a 12/64-in. sieve was examined after the grain was passed through the WBT or USGMRL tester. The green dye test was of particular value in differentiation among slightly damaged samples that were passed through the USGMRL tester.

All determinations were made in triplicate.

RESULTS AND DISCUSSION

Gross composition (protein, oil, and ash—all expressed on a 14% moisture basis) of the samples is given in Table II. The range for protein content was 8.0–9.4%, for oil 3.46–4.01%, and for ash 1.12–1.33%.

The results of four hardness and three breakage susceptibility measurements of the eight corn samples are summarized in Tables III and IV, respectively. Increasing the moisture content from 12 to 16% decreased density (presumably from swelling of kernels), increased NIR at 1,680 nm (presumably a result of decreased fragility and increased particle size at the higher moisture), and increased the time required to grind in the Stenvert mill (caused by greater resilience and resistance to grinding); the effect on the ratio weight C/F was inconsistent (Table III). The ranking of the extreme (in hardness) samples at the two moisture levels was similar, but there were exceptions in the intermediate range. The C/F ratio and total amounts of the two fractions are important indices of corn quality in dry milling.

The effect of increasing the moisture content on breakage susceptibility by the three methods was highly consistent and great (Table IV). Breakage was several times higher at the 12% than at the 16% level.

The average ratio of breakage at the 12 and 16% moisture levels was 8.3 for the Stein, 5.0 for the USGMRL tester, and 4.4 for the WBT. The values from the WBT, at both moisture levels, were about six times higher than the breakage from the USGMRL tester, which was designed to duplicate on a small scale the

TABLE V
Examination by the Green Dye Test of Samples Passed Through the WBT and U.S. Grain Marketing Research Laboratory (USGMRL) Tester

	Wisconsin Breakage Tester				USGMRL Breakage Tester			
Sample	Whole (%)	Cracked (%)	More Than 1/2 Kernel (%)	Less Than 1/2 Kernel (%)	Whole (%)	Cracked (%)	More Than 1/2 Kernel (%)	Less Than 1/2 Kernel (%)
Corn Equilibrated at 12% Moisture								
A	14.2	13.3	28.0	44.5	79.7	11.0	5.1	4.2
B	14.8	12.9	33.0	39.3	74.4	16.1	7.3	2.2
Annex	9.6	14.9	27.4	48.1	58.4	24.8	12.1	4.7
3780(2)	13.8	17.8	31.3	37.1	70.4	17.8	9.0	2.8
3780(3)	9.2	15.0	30.1	45.7	57.2	25.3	12.1	5.4
Brovold	14.3	18.3	36.4	31.0	62.7	21.9	12.3	3.1
Franseed	6.0	6.5	18.0	69.6	62.9	19.1	10.3	7.7
Hall	6.6	10.0	21.8	61.6	58.2	19.1	13.2	9.5
LSD[a]	0.91	0.36	0.70	1.11	2.05	2.10	1.69	0.90
Corn Equilibrated at 16% Moisture								
A	28.9	35.9	20.7	14.5	88.1	7.7	2.5	1.7
B	27.8	41.1	18.2	12.9	84.0	10.7	4.2	1.1
Annex	21.3	41.4	21.7	15.6	73.7	21.3	4.6	0.4
3780(2)	25.5	35.4	22.3	16.8	82.8	14.1	2.6	0.5
3780(3)	22.3	28.8	27.8	21.1	77.9	14.3	6.7	1.1
Brovold	27.0	46.5	15.4	11.1	76.7	12.6	9.2	1.5
Franseed	20.1	42.5	23.0	14.4	80.4	13.0	4.5	2.1
Hall	18.3	36.8	24.6	20.3	74.9	15.6	6.3	3.2
LSD	1.25	0.91	1.36	1.12	1.54	1.72	0.97	0.33

[a] Least significant difference at the 0.05 level.

TABLE VI
Analysis of Variance (*F* Values)[a] for Hardness and Breakage Susceptibility—Parameters as Affected by Corn Drying Conditions and Corn Moisture

	Hardness			Breakage Susceptibility			USGMRL[b] Passed			Wisconsin Passed		
	S[c]	M[c]	S × M[c]	S	M	S × M	S	M	S × M	S	M	S × M
DF	7	1	7	7	1	7	7	1	7	7	1	7
Density	1,012.8	358.6	7.8[d]									
NIR at 1,680 nm	1,054.2	1,975.0	82.4									
Stenvert hardness tester (sec)	137.0	2,101.4	284.2									
Coarse/fine weight	166.6	2.8[e]	13.1									
Coarse/fine volume	407.3	2,556.0	67.6									
Stein breakage tester				736.8	4,739.8	518.8						
USGMRL				97.6	1,218.8	34.8						
Wisconsin breakage tester				531.2	18,915.2	328.4						
Green dye test												
<1/2							123.4	1,124.2	41.9	894.8	33,352.0	605.2
>1/2							63.4	574.2	10.1	128.4	1,661.5	325.9
Cracked							96.4	381.2	12.6	476.0	56,107.8	542.2
Whole							4.3[f]	27.8	1.3[g]	249.0	5,912.9	6.0[h]

[a] Pr > *F* 0.0001 except where noted.
[b] USGMRL = U.S. Grain Marketing Research Laboratory.
[c] S = Sample; M = moisture; and S × M = interaction.
[d] Pr > *F* 0.0004.
[e] Pr > *F* 0.1063.
[f] Pr > *F* 0.0099.
[g] Pr > *F* 0.3231.
[h] Pr > *F* 0.0015.

TABLE VII
Correlation Coefficients Between Various Hardness and Corn Breakage Susceptibility Parameters[a]

	Hardness					Breakage Susceptibility		
	Density	NIR at 1,680 nm	Stenvert Hardness Tester (sec)	Coarse/Fine weight	Coarse/Fine Volume	Stein Breakage Tester	U.S. Grain Marketing Research Laboratory	Wisconsin Breakage Tester
	←			12% Moisture				→
Density		**0.756**	**0.928**	*0.535*	**0.764**	**−0.686**	*−0.423*	*−0.490*
NIR at 1,680 nm	**0.774**		**0.835**	*0.620*	**0.791**	**−0.881**	**−0.797**	**−0.753**
Stenvert hardness tester	*−0.436*	*−0.157*		*0.498*	**0.826**	**−0.768**	*−0.521*	**−0.646**
Coarse/fine weight	*0.234*	**0.653**	*0.571*		**0.724**	*−0.225*	*−0.020*	*0.017*
Coarse/fine volume	*0.564*	**0.638**	*0.281*	**0.699**		*−0.555*	*−0.296*	*−0.404*
Stein breakage tester	**−0.633**	*−0.586*	**0.757**	*0.077*	*−0.042*		**0.927**	**0.928**
U.S. Grain Marketing Research Lab	*−0.559*	*−0.306*	**0.660**	*0.296*	*0.057*	**0.788**		**0.951**
Wisconsin breakage tester	*−0.127*	*−0.466*	*0.412*	*−0.128*	*0.021*	**0.724**	*0.545*	
	←			16% Moisture				→

[a]Bold print significant at 0.1 or better; italicized, not significant at 0.1.

conditions in a commercial elevator. Based on the results for corn conditioned to 12% moisture, the samples A and 3780(2) were considered as hard and low in breakage susceptibility; the samples Franseed and Hall were considered as soft and high in breakage susceptibility; and the other four samples were intermediate in hardness and/or breakage susceptibility. Germinability was 98–99% in samples A and 3780(2), dried at low temperature, and only 5% in Hall dried at high temperature.

Results of the examination by the green dye test of the samples passed through the WBT and USGMRL tester are summarized in Table V. The results show the distribution of whole corn, cracked kernels, and pieces larger or smaller than 1/2 kernel in material retained on a 12/64-in. sieve. The results point to the very high damage in samples passed through the WBT. The green dye test seems particularly useful in differentiating among the samples equilibrated at 16% moisture and passed through the USGMRL tester. These samples showed little damage and could not be differentiated well on the basis of percent throughs (Table IV).

The great effect of moisture is shown by the results of analysis of variance (Table VI). Analysis of variance was calculated to determine the effects of sample, moisture, and sample × moisture interactions. The combined effects of sample and moisture on hardness parameters varied with the method. Density and C/F weight ratio were affected much more by the sample than by the moisture level; however, the time to grind in the Stenvert mill and the C/F volume ratio were affected much more by the moisture level.

Interrelations among the hardness and corn breakage characteristics at the 12 and 16% moisture levels are summarized in Table VII. Correlation coefficients of 0.622, 0.707, and 0.834 were required for significance at the 0.1, 0.05, and 0.01 levels, respectively. Generally, the correlation coefficients were much higher in the 12% than in the 16% moisture samples.

CONCLUSIONS

An examination of the data in Table VII and the other findings in this report suggest that: 1) low moisture levels have a great effect on corn breakage, 2) at low moisture levels measures of hardness or breakage susceptibility based on different principles are highly correlated, 3) at low moisture levels there is a high correlation between corn hardness and susceptibility to breakage, and 4) the green dye test is useful in fine differentiation among slightly damaged samples.

ACKNOWLEDGMENT

The De Long Company, Inc., Clinton, WI is thanked for the corn samples used in this study.

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[Received January 18, 1985. Revision received April 30, 1985. Accepted May 7, 1985.]