Comparison of Eight Devices for Measuring Breakage Susceptibility of Shelled Corn[1]

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ABSTRACT

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Eight instruments developed for evaluating breakage susceptibility of corn under commercial conditions were compared in several collaborative studies. Six of the devices subjected the shelled corn to impact against a hard surface, which is thought to most closely simulate the damaging stresses that occur in commercial handling of corn. The kernels were subjected to impact velocities of 18–31 m/sec. The Stein breakage tester (SBT) and an SBT modified by increasing the impeller diameter by 24% subjected the kernels to a combination of impact and abrasion. Screening the corn samples passed through the impact devices indicated 41–68% more broken material with a 6.35-mm sieve (16/64-in.) than a 4.76-mm sieve (12/64-in.), whereas discharge from the standard SBT showed only an 8% increase, indicating a significant difference in types of breakage produced. The best precision, indicated by low coefficients of variability, was shown in all tests by the device developed at the University of Wisconsin. It had the fastest throughput time (600 g/min) and a sturdy and patentable design. This device was selected for further study and development.

Fundamental studies on the strength characteristics of corn endosperm have been made over many years. Many studies reported measurements of individual kernels after applying one or more static or dynamic forces with specific instruments (Srivastava et al 1976; Jindal and Mohsenin 1976, 1978; Jindal et al 1979).

From field to ultimate user, the process of harvesting, drying, storing, and handling corn physically stresses the kernels by a combination of forces including compression, impact, shear, and abrasion. Opinions differ as to which force in commercial handling is most important to breakage, but most agree that impact probably is the greatest contributor to corn breakage. The only commercially available device for routine measurement of grain breakage susceptibility, the Stein breakage tester (SBT), is not primarily an impact device. Thus, there is a need to develop a commercially acceptable instrument to test for susceptibility to routine breakage on impact. The SBT has been available since about 1962 (McGinty 1970) and has been found useful in many laboratory studies of corn breakage. The SBT has found little acceptance in commercial corn marketing, possibly because the test takes approximately 5 min to complete and requires a number of manipulations.

Because of the inadequacies of the SBT and the hypothesis that testing pure impact is more useful, a number of different devices for measuring grain breakage susceptibility have been developed (McGinty 1970, Cooke and Dickens 1971, Sharda and Herum 1977, Paulsen et al 1981, Singh and Finner 1983). A companion collaborative study (Watson et al 1986) lead to the development of a standard laboratory procedure for measuring corn breakage susceptibility. The purpose of this study was comparative evaluation of available corn breakage devices that appeared to be useful under commercial grain handling conditions. It was conducted by participants in the North Central Regional Research Committee, NC-151, of the Cooperative States Research Service, USDA.

MATERIALS AND METHODS

Grain Samples

For this study, corn subsamples were taken from samples of the 1979 and 1980 corn crops collected at The Andersons, Maumee, OH, in December of each crop year. All evaluations were made at the moisture content as received by each participant.

Equipment

Seven of the breakage testers were developed in different laboratories. Three of the intruments would be classified as centrifugal impact devices based on the principal described by Cooke and Dickens (1981). Corn kernels are dropped individually into a spinning tube and projected against a cylindrical metal wall. These are the instruments developed by the Cargill Grain Lab., Minneapolis, MN, and the Department of Agricultural Engineering, University of Illinois, Urbana (Paulsen et al 1981). The third device of this type, developed at the University of Wisconsin, Madison (Singh and Finner 1983) uses a unique impeller having four channels cut in a metal disk through which the kernels are accelerated toward the impact zone. The Wisconsin device is the only one covered by a patent (Finner and Singh 1983).

Another impact device, the Missouri cracker, was developed at the University of Missouri (L. L. Darrah 1979, *personal communication*; Moentono 1982). This tester consisted of a centrifugal fan direct driven by a motor and enclosed in a metal housing . A vibrating feeder drops kernels onto the impeller where they are subjected to several impacts, first on the metal blades and then against the wall of the fan housing. The Ohio Impacter is based on a similar principle but is more compact in design. Kernels are dropped into the center of rotating impeller blades, impinged against a steel cylinder wall, and discharged out the bottom (Sharda and Herum 1977).

A different type of breakage tester, based on the concept that most breakage of corn in commercial operations is caused by the impact of kernels upon kernels rather than on a container surface, was designed at the U.S. Grain Marketing Research Laboratory (USGMRL), Manhattan, KS (Miller et al 1979, 1981). In this instrument, the flow of corn kernels is accelerated as they pass between rubber-covered rollers and are hurled onto a bed of corn at the bottom of a shaft.

An SBT, model CK-2M, was included in the comparison as a control device, but a modified type of SBT was also included. To increase the velocity of the grain on impact, the diameter of an SBT impeller was increased by 24%, thus increasing the impact velocity of the tip of the impeller. A cup of appropriate size was fashioned to hold the grain. A 30-sec holding time in this modified SBT gave results roughly equivalent to 2 min in the standard SBT (F. L. Herum 1980, *personal communication*).

Breakage Procedure

Testing procedures were similar to those described elsewhere (Watson et al, in press) Eight machines were evaluated in six laboratories, but only one machine of each kind was tested in each laboratory. Four corn samples were tested in 1979 and six samples

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in 1980. All samples were separated from the main lot with a Boerner divider. Results were evaluated statistically by an analysis of variance method using individual randomized block designs in which location and machine effects were combined. Means were compared using Duncan's multiple range test at the 0.05 level of probability. Combining data over machine differences and attempting to pull out location and machine effects would not be valid. Sample sizes varied from 100 to 200 g among laboratories, but the procedure was the same; a slightly larger sample was first sieved on a precision sieve with round holes 4.76 mm (12/64-in.) in diameter, then the exact weight was determined, and the sample was passed through the tester. The discharge was again sieved and overs weighed. The difference between the original sample and the overs was assumed to represent the fines and was calculated as percent breakage. Weighing the overs is more convenient than attempting to retain and weigh all of the throughs, some of which are very fine. Some tests were also made using a 6.35-mm (16/64-in.) round-hole sieve.

RESULTS AND DISCUSSION

Operating Parameters

Table I displays data on the physical characteristics and operating parameters of the eight devices tested. The Illinois, Cargill, Ohio, and Wisconsin impacters and the USGMRL grain accelerator could be operated at any desired rotational velocity by means of voltage regulators. The velocities were chosen as appropriate for satisfactory corn breakage results and were equivalent to the impact force of grain dropping vertically onto a hard surface from 50 to 170 ft. Six of the eight devices involve essentially pure impact of grain against a surface. The SBT and modified SBTs differ in that the grain is impacted and abraded in the cup for a given period of time. When kernels are added to the cup at the start, they are accelerated by the blade, but subsequently much of the breakage is caused by abrasion against the cup wall and other kernels. This probably explains why the SBT causes little damage to sound (unstressed) corn kernels.

Breakage Susceptibility Measurements

Table II provides data on the eight breakage devices tested with the 1979 corn. Because operating parameters were different on each instrument, it is not possible to compare the average breakage of the four samples of corn, but comparisons must be made on the mean breakage susceptibility values for each instrument. Precision of results was determined by the coefficient of variability (CV). The Wisconsin breakage tester, with a CV of 1.4%, was most precise, followed by the Cargill grain lab tester at 2.5%, and the Missouri tester at 6.0%. All three of these instruments identified significant differences between all four samples of grain. The USGMRL grain accelerator also had a low CV of 5.8%, but the breakage values were low and separation of the four samples was not obtained at the 95% confidence level. The Ohio impacter, with a CV of 7.5%, was also able to show separation of the four samples. Although the SBT gave a CV of 5.5% in this test, average CVs of 9.0 to 11.8% were found by Watson et al, in press. The SBT data shown here identified samples 79-2 and 79-3 as different, but in the companion report (Watson et al 1986) only two of the six laboratories differentiated between samples 79-2 and 79-3 with the SBT.

The actual kernel velocity in the Cargill grain tester measured by high-speed cinematography was 24 m/sec (4,600 ft/min) at the lower impeller speed, and 29 m/sec (5,700 ft/min) at the higher speed. These velocities are equivalent to the terminal velocities of

TABLE I
Physical Characteristics and Operating Conditions of Eight Grain Breakage Testers

Name	Rotor		Impact Surface Diameter (cm)	Corn Sample	
	Diameter (cm)	Tangential Velocity (m/sec)		Weight (g)	Discharge Rate, (g/min)
Illinois impacter	20.3	30.3	25.4	200	100
Cargill impacter	25.4	17.0	28.6	100	200
	25.4	20.5	28.6	100	200
Ohio impacter	8.2	25.8	15.2	100	100
Wisconsin breakage tester	25.4	23.9	30.5	200	600
	25.4	31.9	30.5	200	600
Missouri cracker	19.5	18.4	24.5	180	200
Stein tester	8.9	8.0	9.2	100	NA[a]
Modified Stein (Ohio)	11.0	9.9	12.2	100	NA
USGMRL grain accelerator	10.6[b]	30.5[c]	NA	200	400

[a]NA = not applicable.
[b]Distance from rollers to impact surface.
[c]Linear velocity at discharge.

TABLE II
Comparison of Eight Devices to Determine Breakage Susceptibility of 1979 Crop Corn Using a 4.76-mm Sieve

Corn Sample Number	Cargill Impacter 17 m/sec (%)	Cargill Impacter 20.5 m/sec (%)	Illinois Impacter (%)	Missouri Cracker (%)	Ohio Impacter (%)	Ohio Modified Stein[a] (%)	Ohio Stein CK-2M[b] (%)	USGMRL[c] Grain Accelerator (%)	Wisconsin Breakage Tester[d] (%)
79-1	1.5 c[e]	5.8 d	2.3 c	10.6 d	17.4 d	2.2 c	6.2 d	1.3 c	23.8 d
79-2	4.1 b	9.1 c	3.6 bc	15.5 c	21.8 c	9.9 b	21.5 b	2.6 b	31.2 c
79-3	3.9 b	10.9 b	5.0 b	19.0 b	27.4 b	8.5 b	20.2 c	2.9 b	35.2 b
79-4	13.7 a	24.6 a	16.5 a	44.7 a	49.1 a	37.8 a	60.5 a	11.6 a	54.8 a
n	12	12	12	12	12	12	12	12	12
$\bar{x}$	5.79	12.59	6.83	22.44	28.92	14.58	27.10	4.62	36.25
SD	0.353	0.314	0.823	1.343	2.157	1.24	1.49	0.266	0.523
CV,%	6.1	2.5	12.0	6.0	7.5	8.5	5.5	5.8	1.4

[a]Thirty-second operation.
[b]Two-minute operation.
[c]U.S. Grain Marketing Research Laboratory.
[d]Operated at 31.9 m/sec.
[e]Ducan's multiple range test. Values in the same column having different letters are significantly different ($P<0.05$). Values are means of three identical runs.

TABLE III
Breakage Susceptibility of 1979 Crop Corn Using Seven Devices and a 6.35-mm Sieve

Corn Sample Number	Cargill Impacter 17 m/sec (%)	Cargill Impacter 20.5 m/sec (%)	Illinois Impacter (%)	Missouri Cracker (%)	Ohio Impacter 25.8 m/sec (%)	Ohio Modified Stein[a] 9.9 m/sec (%)	Ohio Stein CK-2M[b] 8.0 m/sec (%)	USGMRL[c] Grain Accelerator (%)
79-1	2.5 c[d]	9.2 c	3.6 c	20.9 d	35.3 d	2.6 c	5.8 a	2.3 c
79-2	7.8 b	16.5 b	5.9 c	27.8 c	41.1 c	11.1 b	25.1 c	4.3 b
79-3	8.9 b	17.1 b	10.8 b	34.5 b	50.8 b	11.5 b	20.0 b	4.4 b
79-4	27.1 a	41.0 a	28.6 a	69.4 a	77.4 a	52.7 a	67.1 a	17.73 a
n	12	12	12	12	12	12	12	12
$\bar{x}$	11.58	20.97	12.23	38.18	51.16	19.48	29.51	7.19
SD	0.986	1.846	1.891	1.591	1.033	0.652	1.44	0.463
CV,%	8.5	8.8	15.5	4.2	2.0	3.3	4.9	6.4

[a]Thirty-second operation.
[b]Two-minute operation.
[c]U.S. Grain Marketing Research Laboratory.
[d]Duncan's multiple range test. Values in the same column having different letters are significantly different ($P<0.05$). Values are means of three identical runs.

TABLE IV
Breakage Susceptibility of 1980 Crop Corn Using Six Devices and a 4.76-mm Sieve

Corn Sample Number	Cargill Impacter 17.0 m/sec (%)	Cargill Impacter 20.5 m/sec (%)	Illinois Impacter (%)	Missouri Cracker (%)	Ohio Impacter (%)	Ohio Modified Stein[a] (%)	Wisconsin Breakage Tester 23.9 m/sec (%)	Wisconsin Breakage Tester 31.9 m/sec (%)
80-1	12.3 a [b]	36.6 a	36.6 a	44.3 a	37.7 a	29.4 a	28.6 a	47.7 a
80-2	7.3 b	25.6 b	26.3 b	29.4 b	27.2 b	14.8 b	18.4 b	35.9 b
80-3[c]	3.5 c	17.3 c	19.4 c	20.3 c	21.0 c	9.0 c	10.4 c	24.4 c
80-4[c]	2.9 cd	15.2 d	16.7 d	17.9 d	18.5 d	9.2 c	10.3 c	24.1 c
80-5	2.1 de	10.2 e	14.0 e	12.4 e	14.5 e	5.2 d	6.0 d	17.3 d
80-6	1.6 e	8.9 e	11.5 f	10.4 f	8.9 f	2.8 d	4.9 e	14.5 d
n	24	24	24	24	24	24	24	24
$\bar{x}$	4.94	18.95	20.73	22.43	21.12	11.73	12.40	27.28
SD	0.628	1.065	0.793	1.119	1.007	1.789	0.443	0.887
CV,%	12.7	5.6	3.8	5.0	4.8	15.3	3.6	3.3

[a]Thirty-second operation.
[b]Duncan's multiple range test. Values in the same column having different letters are significantly different ($P<0.05$). Values are means of four identical runs.
[c]Hidden duplicates.

an 8-in. column of corn dropped 30.4 m (100 ft) and 45.7 m (150 ft), respectively (F. J. Wade and J. A. Johnston, Cargill, Inc., Minneapolis, MN, *personal communication*; Fiscus et al 1971). They observed that the angle of discharge was about 45°. If this is presumed to be true for all devices, dividing the tangential velocity by the sine of 45°, 0.707, will approximate kernel velocity.

The four 1979 corn samples were also tested by six of the instruments using a 6.35-mm (16/64-inch) round-hole sieve for separating broken grain from whole grain (Table III). All instruments gave higher breakage values, and four devices, the Ohio impacter, the Missouri Cracker, the SBT CK-2M, and the modified SBT, gave lower CVs. All impact devices showed large increases (41–68%) in broken corn through the 6.35-mm sieve compared with the 4.76-mm sieve, whereas the increase in the SBT CK-2M was only 8% and that of the modified SBT only 25%. These data emphasize the difference in type of breakage obtained in the two types of devices. The impact devices produce a greater assortment of sizes, whereas the SBT produces a blend of mostly fine material and whole kernels.

The results of a more rigorous comparison test of six instruments on the six 1980 corn samples are given in Table IV. Again, the Wisconsin breakage tester gave the lowest CV and, at the lower speed, showed a significant difference between each of the samples known to have different breakage susceptibilities. Only the Wisconsin and Ohio modified SBT instruments were able to show that samples 80-3 and 80-4 were identical, but the modified SBT did not distinguish between samples 80-5 and 80-6 because of the high standard deviation. The Illinois impacter had the next lowest CV but indicated a significant difference between the identical samples 80-3 and 80-4. The Ohio impacter and the Missouri Cracker both showed a similar pattern of results.

This study was conducted to select the best device for measuring corn breakage susceptibility for more intensive evaluation and development. A tester that is adaptable to commercial elevator use as well as laboratory investigations is needed. The SBT has been shown to be adequate for laboratory evaluation of stress-cracked kernels and causes very little breakage of sound kernels. On the other hand, the impact devices do break sound grain that has been carefully dried and contains no stress cracks. Thus, the SBT gives a more exact estimate of stress-cracked kernels. However, for commercial use, in which only broad categories of breakage are to be identified in market corn, speed of throughput is more important than precision of results. Herum and Hamdy (1981) have shown good correlation of Wisconsin breakage tester results on commercial corn with breakage produced in a grain elevator.

Another consideration in developing a device for commercial use is its adaptability for automation. A pass-through operation would be most suitable for this purpose, because the sample could be discharged onto a vibrating screen, one fraction automatically weighed, electronically recorded, and breakage susceptibility calculated and displayed. All impact devices tested qualified in this respect.

CONCLUSION

Based on the results of this study, the NC-151 Committee selected the Wisconsin breakage tester as the best all-around device for eventual commercial development. It consistently gave the best precision and always identified the hidden duplicates. It has the fastest throughput, is of a sturdy design that has been awarded a U.S. patent, and is adaptable to automated operation. Therefore, additional Wisconsin breakage tester units have been manufactured and are undergoing collaborative testing.

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