Evaluation and Comparison of Wisconsin and Stein Breakage Testers on Corn[1]

S. GUNASEKARAN[2]

Cereal Chem. 65(4):287–291

ABSTRACT

Breakage susceptibilities (BS) of two corn genotypes, each dried at four temperatures, were investigated using the Wisconsin breakage tester (WBT) and the Stein CK-2M breakage tester (SBT) at various operating conditions. Particle size characteristics of the samples impacted with the WBT and the SBT were determined using a set of U.S. standard sieves. The BS and fineness modulus were independent of sample feed rate in the WBT. In the SBT, BS increased and FM decreased with increasing impacting times. Six minutes of impacting in the SBT produced corn breakage levels approximately equivalent to those in the WBT. Based on the wide variations in the results it appears that correlation between actual corn breakage and the BS values obtained with the WBT and the SBT may depend on the type of handling, and this may have implications for those who wish to use a breakage test as an information factor in U.S. corn grading factors.

Breakage susceptibility (BS) can be defined as the potential for kernel fragmentation or breakage when the kernels are subjected to impact forces during handling and transport (AACC 1983). BS is a significant factor in judging the quality of corn. Because corn may be handled as many as 20 times from harvest to export (Miller et al 1981), domestic and foreign buyers prefer corn that is not susceptible to breakage during handling. The official U.S. standards for grain grading include broken corn and foreign material (BCFM) as a major grading factor (USDA 1980). According to this standard, BCFM is the fraction that passes through a 4.76-mm (12/64-in.) round hole sieve and the foreign material that remains on top of the sieve. A major drawback in this grading standard is that it ignores the potential for breakage of kernels upon subsequent handling. For example, the Federal Grain Inspection Service grades corn as it is loaded onto ships. When the shipment arrives at its destination, the grain quality of the corn changes as a result of subsequent handling and transportation. For certain end uses, the value of this corn to the buyer may decrease as a result of the breakage that is not reflected by the current grading standard.

There have been several investigations reporting the extent of kernel damage at various handling operations (Fiscus et al 1971, Hall 1974, Paulsen and Hill 1977, Paulsen and Nave 1980, Pierce and Hanna 1985). These studies indicate an increase in percent BCFM with an increased number of handlings, depending on the severity of the handling operation. BS values have been reported to positively correlate with increases in BCFM value (Stephens and Foster 1976, Herum and Hamdy 1981, Paulsen and Hill 1983). Therefore BS, in addition to the BCFM value, should be considered as a valid information factor in the U.S. corn grading standards.

If the BS value is to be included as an information factor, standardization of the testing procedure and equipment will be required. The need for a standard BS testing has long been recognized (McGinty 1970). The breakage testers proposed are basically of two types. The first type utilizes impacting action of a moving blade or impeller on a confined grain sample (McGinty 1970, Watson and Herum 1986). The second type utilizes the effect of centrifugal impaction of individual kernels against a stationary surface (Sharda and Herum 1977, Miller et al 1979, Singh 1980, Paulsen et al 1981). Of the various breakage tester designs, the Stein CK-2M (SBT) and the Wisconsin breakage tester (WBT) are the most widely used. The mechanisms involved, and the types of damage created in these two testers are quite different. The SBT produces an abrasive type of pericarp damage created by multiple impact of a fast moving blade in a sample holder cup. The WBT impinges individual kernels against a stationary metal surface at a high velocity and thereby tends to crack the kernels or chip small pieces from the crown.

The SBT has been in use longer than the WBT. Several researchers have found that the BS value obtained with the SBT is satisfactory in correlating with the percent BCFM produced by handling (Thompson and Foster 1963, McGinty 1970). The AACC method 55-20 recommendation for BS testing with the SBT is to impact 100 g of corn at 13% wet basis moisture (maximum of 18%) for 2 min and then sieve with a 4.76-mm (12/64-in.) round hole sieve in a Gamet shaker for 30 cycles to separate the broken fraction (AACC 1983). However, impacting times and sieve sizes other than the recommended standard have also been investigated. McGinty (1970) found an impacting time of 2 min to be adequate compared to 10, 20, and 30 min of impacting. Paulsen and Hill (1983) observed that impacting the kernels for 4 min produced BS values twice as high as the BS values obtained with 2 min of impacting. Herum and Blaidsdell (1981) used a 6.35-mm (16/64-in.) sieve to get a better measure of BS. The 6.35-mm sieve tended to pass a greater amount of corn and thus gives larger BS values compared to those obtained with 4.76-mm sieve.

The results of studies comparing the performances of the SBT and WBT are varied. Miller et al (1981) reported that the harsh action of the SBT produced a much greater percentage of broken corn than the grain accelerator type testers. The SBT apparently accentuates small differences, and thus has a greater potential for differentiating among samples. Paulsen and Hill (1983) reported that a 2-min test with the SBT on commercial corn produced 35–85% higher BS values than those obtained with centrifugal type impactors but also had a larger variation in the BS values. Conversely, Martin et al (1984) reported less damage and breakage with the SBT than with the WBT for 12.6% moisture corn. Paulsen et al (1983) reported that the SBT does not easily distinguish differences in breakage susceptibility among hand-shelled, low-temperature dried genotypes even though it showed more significant differences than the WBT. Gunasekaran and Paulsen (1985) observed that the SBT produced lower BS values for corn dried at 20 and 35° C than the WBT; and for corn dried at 50 and 65° C the values were higher than the WBT. In general corn dried at low temperature has higher BS with the WBT than the SBT, and the opposite is true for commercial corn dried at high temperature. These investigations apparently indicate that there is no standard BS test equipment and method currently available. There has not been much work relating the BS values to the actual grades of corn samples. Miller et al (1981) reported that there is no consistent relationship between the commercial grain grade and the BS values obtained with SBT. Watson and Herum (1986) compared the performance of eight BS measuring devices and selected the WBT as the best all-around device for eventual commercial

[1]Published as Miscellaneous Paper no. 1216 of the Delaware Agricultural Experiment Station.

Mention of trade names in this publication is solely for the purpose of providing specific information and does not constitute endorsement by the University of Delaware over others of a similar nature not mentioned.

[2]Assistant professor, Agricultural Engineering Department, Delaware Agricultural Experiment Station, University of Delaware, Newark 19711.

development. The Federal Grain Inspection Service is looking into the prospect of using BS values obtained with the WBT as one of the grain grading factors.

This paper investigates the relative performance of the WBT and the SBT in predicting BS values of corn samples of two genotypes dried at four drying air temperatures. The effects of corn temperature and moisture on BS were kept to a minimum by conducting the tests in a controlled environment and maintaining a narrow moisture content range for all samples. Sieve analysis with a set of U.S. standard sieves was used to evaluate the particle size characteristics of the broken fractions in both the breakage testers.

Objectives

The objectives of this investigation were to determine the performance of the WBT and the SBT at various operating conditions, the operating conditions producing equivalent breakage levels in both the WBT and the SBT, the particle size characteristics of the corn samples impacted with the WBT and the SBT, and the relative severities of the breakage produced in the WBT and the SBT.

MATERIALS AND METHODS

Sample Preparation

Two corn genotypes, FRB27 × Mo17 and FRB27 × Va22, were used in this investigation. These corn genotypes were grown on the Agricultural Engineering Research Farm at the University of Illinois. The corn was handpicked at about 27% moisture content and then hand-shelled to avoid mechanical damage to the kernels. Four lots of shelled corn of each genotype were obtained. Using laboratory dryers, these corn samples were dried to a final moisture content of about 15% using air at 20, 35, 50, and 65°C. A constant airflow rate of about 2.0 $(m^3/min)/m^3$ of corn was used for all the drying tests. Further details of the drying procedure and the drying rates obtained are reported in Gunasekaran and Paulsen (1985).

Breakage Susceptibility Tests

Samples of corn dried at different temperatures were split into four parts using a Gamet precision divider. Three of the subsamples were used to replicate all the experiments three times. For all BS tests, subsamples of 100 g were presieved on a Gamet shaker for 30 cycles using a 6.35-mm (16/64-in.) round hole sieve.

The WBT had a 254-mm diameter impeller that, operating at 1,800 rpm, centrifugally propelled kernels against the inside surface of a 305-mm diameter vertical cylinder. The Tecatur vibratory feeder used with the WBT was adjusted to obtain feed rates of 400, 600, and 800 g/min. For the SBT, the timer was set for impacting times of 2, 4, 6, and 8 min. Three replications of BS tests at each of four drying temperatures and for each test variable provided a total of 36 tests with the WBT, and 48 tests with the SBT, respectively, for each hybrid.

The BS tests were conducted in an environmentally controlled room maintained at 20°C. The corn samples were stored at this condition for 72 hr prior to the BS tests. Moisture contents of the samples were determined according to the ASAE standard S352.1 (ASAE 1984) using 15-g samples. The moisture content of all samples ranged from 12.9 to 14.0% wet basis, which is near the 13% wet basis moisture recommended by the AACC (AACC 1983).

After impacting in the breakage testers, the samples were presieved for 30 cycles on the 6.35-mm sieve. The corn fraction retained by the sieve was weighed and recorded. A similar measurement was made on the same impacted sample using a 4.76-mm sieve. Percent BS was calculated as:

$$\%\ BS = \frac{100 \times (\text{original weight} - \text{weight retained by the sieve})}{\text{original weight}}$$

Sieve Analysis

The samples comminuted in the WBT and SBT, after BS determination, were further analyzed for their particle size characteristics using a set of U.S. standard sieves in a Ro-Tap shaking machine with a bottom pan. The mesh openings of the sieves used were 7.94-mm (20/64-in.), 6.35-mm (16/64-in.), 4.75-mm (12/64-in.), 3.37-mm (8.5/64-in.), 2.38-mm (6/64-in.) and 1.19-mm (3/64-in.). Based on preliminary tests, a shaking time of 2 min was found to be sufficient. After each test, the corn fractions retained on each of the six sieves and the pan were weighed and recorded.

Based on the weight fractions retained in each of the six sieves and pan, the fineness modulus was determined as described by Henderson and Perry (1982). Weighting factors of zero through six were used for weight fraction retained in the pan through the 7.94-mm sieve, respectively. Fineness modulus is a measure of the average particle size in a mixture of particles of varied sizes (i.e., the larger the average particle size the larger the fineness modulus), and therefore can be used in evaluating the breaking action of the WBT and the SBT at different operating conditions.

The BS and fineness modulus values were compared using analysis of variance and Duncan's multiple range test statistical procedure (SAS 1982) to test the effects of drying air temperature, time of impacting in the SBT, and the feed rate in the WBT.

RESULTS AND DISCUSSION

Breakage Susceptibility

The BS values for all samples determined using the 4.76-mm sieve (BS1) and 6.35-mm (BS2) at different feed rates in the WBT and at different impacting times in the SBT are presented in Tables I and II, respectively. According to the Duncan's multiple range test at the 5% level of significance, the following trends can be generalized for both the corn genotypes: 1) In both the WBT and the SBT, the BS increased as the corn was dried at higher temperatures. 2) In the WBT, the BS was independent of the sample feed rate within the range tested. 3) In the SBT, the BS increased as the impacting time increased from 2 to 8 min.

Increase in BS as corn is dried at higher temperatures has been documented by several researchers. The reason for this may be the formation of multiple stress cracks in the kernels that potentially reduce the kernel strength (Gunasekaran and Paulsen 1985). There was a considerable increase in BS values as the drying temperature increased from 35 to 50°C (Tables I and II). This was perhaps caused by a decrease in kernel strength below a level at which the kernel could reasonably withstand impact forces. The increase in BS values between 35 and 50°C was more dramatic in the WBT than in the SBT, which indicates that the action of the WBT may be harsher than that of the SBT under normal operating conditions. Comparing the BS values from the WBT and the SBT, it appears that 6 min of impacting is required in the SBT to obtain a breakage approximately equivalent to that in the WBT under the conditions of these tests.

As already mentioned, the impacting mechanisms in the WBT

TABLE I
Breakage Susceptibility (BS) Values Obtained Using the Wisconsin Breakage Tester

Drying Air Temperature (°C)	Feed Rate (g/min)	Corn Genotype FRB27 × Mo17 BS1[a] (%)	FRB27 × Mo17 BS2[b] (%)	FRB27 × Va22 BS1[a] (%)	FRB27 × Va22 BS2[b] (%)
20	400	4.7	11.1	9.9	35.4
20	600	4.4	11.6	10.8	35.6
20	800	4.5	11.7	10.4	35.5
35	400	5.7	16.6	14.0	36.2
35	600	5.3	14.6	13.6	36.2
35	800	6.5	17.1	14.1	38.3
50	400	11.9	28.4	17.7	43.2
50	600	12.7	29.6	17.0	40.6
50	800	12.9	29.0	18.0	42.7
65	400	12.6	31.7	18.2	53.5
65	600	12.6	31.1	17.8	55.7
65	800	12.9	31.6	20.5	53.2

[a] BS values obtained using 4.76-mm sieve.
[b] BS values obtained using 6.35-mm sieve.

and SBT are quite different. Because the WBT discharges the kernels individually, it presumably exerts a similar impacting force on every kernel. Therefore it seems likely that the BS in the WBT is independent of feed rate. This characteristic is desirable if fast BS determination is important. Also, because of the speed of operation, large samples can be tested in a limited time to obtain a more representative BS estimation than with smaller samples. Increasing the impacting time in the SBT is equivalent to increased handling of a given sample. Since the breakage occurring is cumulative over the number of handlings, the increase in BS values at greater impacting times is expected.

The 6.35-mm sieve used for BS determination passed greater amounts of corn through and thus produced higher BS values (BS2) compared to the corresponding values obtained with 4.76-mm sieve (BS1). However, the general effects of changing drying temperature, impacting times, and feed rate are the same for both BS1 and BS2.

Sieve Analysis

Fineness modulus. The fineness modulus values obtained for all samples comminuted using the WBT and SBT are presented in Tables III and IV, respectively. According to the Duncan's multiple range test at a 5% level of significance, the general observations can be listed as: 1) In both the WBT and the SBT, the fineness modulus decreased (i.e., smaller average particle size) as the corn was dried at higher temperatures. 2) In the WBT, the fineness modulus was independent of the feed rate. 3) In the SBT, the fineness modulus decreased as the impacting time increased from 2 to 8 min.

These relationships complement those obtained with the BS values. Because a small fineness modulus value represents a small average particle size, the BS will be high. Therefore, the BS values were inversely related to the fineness modulus values. In other words, kernels susceptible to high breakage tend to yield a broken sample with small average particle size.

The observation that 6 min of impacting in the SBT produced results equivalent to those obtained in the WBT was further substantiated by the fineness modulus values (Tables III and IV).

Weight retained by the sieves. Weight retained by only the top three sieves (7.94, 6.35, and 4.76 mm) was considered, as they represent fairly large fractions. The percent of the total sample weight retained by these three sieves from the samples impacted in the SBT and the WBT are shown in Figures 1 and 2, respectively. These figures are for FRB27 × Mo17 corn only, but the FRB27 × Va22 corn exhibited similar trends. The SBT tests indicate that, at a given impacting time, as drying temperature increased the weight fraction retained by the 7.94 and 4.76-mm sieves changed only by a small amount; however, the weight retained by the 6.35-mm sieve declined steadily. Figure 1 represents the data obtained with samples after 4 min of impacting. Corn retained by the 7.94-mm

TABLE II
Breakage Susceptibility (BS) Values Obtained Using the Stein CK-2M Breakage Tester

Drying Air Temperature (°C)	Impacting Time (min)	Corn Genotype FRB27 × Mo17 BS1[a] (%)	FRB27 × Mo17 BS2[b] (%)	FRB27 × Va22 BS1[a] (%)	FRB27 × Va22 BS2[b] (%)
20	2	0.3	0.5	0.6	1.3
20	4	2.8	3.5	3.2	6.8
20	6	5.8	7.5	5.8	17.9
20	8	11.6	15.3	11.4	22.8
35	2	0.5	1.0	3.5	8.4
35	4	4.9	7.2	11.3	32.5
35	6	10.8	15.4	21.6	43.9
35	8	18.4	27.5	24.9	55.9
50	2	3.4	5.7	7.9	13.9
50	4	13.6	18.4	20.4	31.3
50	6	23.0	30.5	29.0	44.5
50	8	38.7	50.7	40.9	59.1
65	2	5.3	7.4	11.5	18.7
65	4	14.8	21.6	29.5	41.4
65	6	31.1	38.6	43.3	56.7
65	8	43.6	53.8	49.9	65.1

[a] BS values obtained using 4.76-mm sieve.
[b] BS values obtained using 6.35-mm sieve.

TABLE III
Fineness Modulus Values of Corn Samples Impacted in the Wisconsin Breakage Tester

Drying Air Temperature (°C)	Feed Rate (g/min)	Fineness Modulus FRB27 × Mo17	FRB27 × Va22
20	400	4.8	4.1
20	600	4.8	4.2
20	800	4.8	4.1
35	400	4.7	4.1
35	600	4.7	4.1
35	800	4.8	4.1
50	400	4.2	3.9
50	600	4.2	3.9
50	800	4.2	3.9
65	400	4.1	3.7
65	600	4.2	3.7
65	800	4.2	3.7

TABLE IV
Fineness Modulus Values of Corn Samples Impacted in the Stein CK-2K Breakage Tester

Drying Air Temperature (°C)	Impacting Time (min)	Fineness Modulus FRB27 × Mo17	FRB27 × Va22
20	2	5.2	5.2
20	4	5.1	5.0
20	6	4.9	4.7
20	8	4.6	4.5
35	2	5.3	5.0
35	4	5.0	4.3
35	6	4.7	4.0
35	8	4.4	3.6
50	2	5.1	5.1
50	4	4.5	4.3
50	6	4.2	3.9
50	8	3.5	3.3
65	2	5.1	4.8
65	4	4.5	3.9
65	6	3.9	3.5
65	8	3.3	3.0

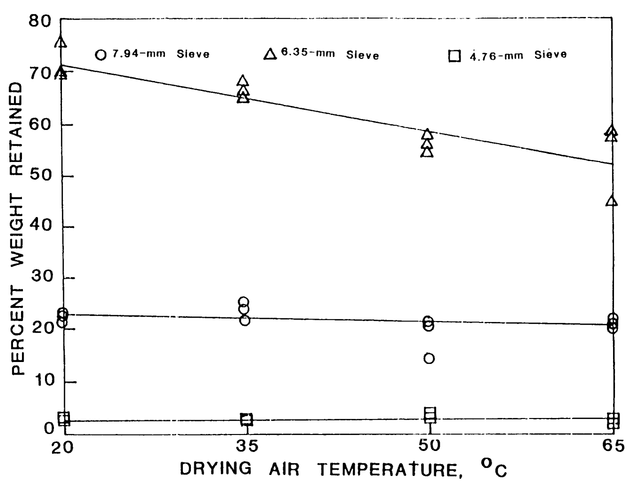

Fig. 1. Percent weight retained by 7.94, 6.35, and 4.76-mm sieves from FRB27 × Mo17 corn samples impacted in a Stein CK-2M breakage tester for 4 min. (The results for the samples impacted for 2, 6, and 8 min are similar.)

sieve can be considered whole or nearly whole kernels. Therefore, drying corn at higher temperatures resulted in additional breakage of the already broken fraction (represented by the decrease in weight retained by the 6.35-mm sieve) rather than new breakage of whole kernels.

However, results of the WBT tests (Fig. 2) indicate different relationships. As the drying temperature increased the weight fraction retained by the 7.94 and 6.35-mm sieves decreased, but weight retained by the 4.76-mm sieve increased. This indicates that the impacting action of the WBT tended to discriminate the breakage tendency of the kernels more closely than the SBT. Notice that as the drying temperature increased, decrease in the weight retained by the 6.35-mm sieve was more than that in the 7.94-mm sieve, again indicating that higher drying air temperatures caused more additional breakage of already broken kernels than new breakage of whole kernels. The weights retained by the top two sieves from samples of the WBT are smaller than their SBT counterparts. This implies that the action of the WBT may be harsher on the kernels than that of the SBT, causing a large proportion of the kernels to break up as well as increasing the proportions of fine fractions in the sample. The results from both the WBT and the SBT indicate that a 6.35-mm sieve is more discriminating than a 4.76-mm sieve. Another noticeable point is the dramatic reduction in the weight retained by the top sieve as the drying air temperatures increased from 35 to 50°C. This observation, as explained previously, was probably due to the potential decrease in kernel impact strength at 35 to 50°C temperature transition.

All the above observations indicate that a general estimate of tendency for kernel breakage is very difficult. An increase in the BS values in the SBT with increasing impacting times suggests that corn subjected to repeated handling may need a different set of standards than a sample that is not handled as often. Higher BS values in the WBT, which uses a harsher impacting action than the SBT, suggest that a sample subjected to severe handling needs a different set of standards than a sample that is subjected to a less severe handling operation. Therefore, the correlations between the BS values obtained with the WBT and the SBT and handling damage may depend on the type of handling, and this may have implications for those who wish to use a breakage test as an information factor in U.S. corn grading factors.

CONCLUSIONS

Based on the breakage susceptibility and fineness modulus values, an impacting time of 6 min in the SBT produced breakage levels approximately equivalent to those in the WBT. A 6.35-mm sieve was more discriminating than a 4.76-mm sieve for use in determining the breakage susceptibility. The WBT action was harsher than that of the SBT and hence can be used to discriminate samples based on breakage susceptibility more closely. Increase in drying air temperature caused additional breakage to the already broken kernels rather than new breakage of whole kernels.

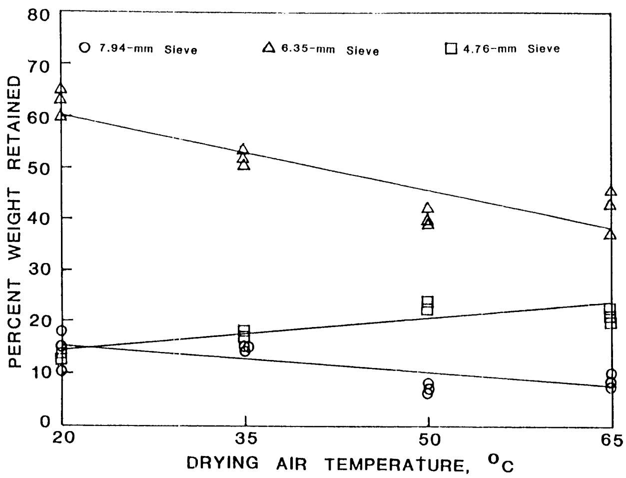

Fig. 2. Percent weight retained by 7.94, 6.35, and 4.76-mm sieves from FRB27 × Mo17 corn samples impacted in a Wisconsin breakage tester at a feed rate of 600 g/min. (The results for the samples fed at 400 and 800 g/min are similar.)

ACKNOWLEDGMENTS

The author sincerely appreciates the assistance and cooperation of M. R. Paulsen, Agricultural Engineering Department, University of Illinois, Urbana. Use of breakage testers at the Grain Quality Laboratory of the University of Illinois is also greatly appreciated.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC. Method 55-20, approved November 1981. The Association: St. Paul, MN.

AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS. 1984. Moisture measurement—grain and seeds, ASAE S352.1. Page 328 in: Agricultural Engineers Yearbook of Standards. The Society: St. Joseph, MI.

FISCUS, D. E., FOSTER, G. H., and KAUFMAN, H. H. 1971. Physical damage of grain caused by various handling techniques. Trans. ASAE 14(3):480-485.

FOSTER, G. H., and HOLMAN, L. E. 1973. Grain breakage caused by commercial handling methods. Marketing Res. Rep. 968. Agricultural Research Service, USDA. U.S. Government Printing Office: Washington, DC.

GUNASEKARAN, S., and PAULSEN, M. R. 1985. Breakage resistance of corn as a function of drying rates. Trans. ASAE 28(6):2071-2076.

HALL, G. E. 1974. Damage during handling of shelled corn and soybeans. Trans. ASAE 17(2):335-338.

HENDERSON, S. M., and PERRY, R. L. 1982. Agricultural Process Engineering, 3rd ed. The Avi Publishing Co.: Westport, CT. 136 pp.

HERUM, F. L., and BLAISDELL, J. L. 1981. Effects of moisture content, temperature, and test variables on results with grain breakage testers. Am. Soc. Agric. Eng. Paper 81-3030. The Society: St. Joseph, MI.

HERUM, F. L., and HAMDY, M. Y. 1981. Actual grain handling breakage compared to predictions by breakage susceptibility testers. Am. Soc. Agric. Eng. Paper 81-3031. The Society: St. Joseph, MI.

MARTIN, C. R., CONVERSE, H. H., CZUCHAJOWSKA, Z., LAI, F. S., and POMERANZ, Y. 1984. Characteristics, handling, processing, of corn of various size and shape. (Am. Soc. Agric. Eng. Paper 84-3600. The Society: St. Joseph, MI.

McGINTY, R. J. 1970. Development of a standard grain breakage test. ARS 51-34. Agricultural Research Service, USDA. U.S. Government Printing Office: Washington, DC.

MILLER, B. S., HUGHES, J. W., ROUSSER, R., and POMERANZ, Y. 1979. Note on a method for measuring breakage susceptibility of shelled corn during handling. Cereal Chem. 56(3):213-216.

MILLER, B. S., HUGHES, J. W., ROUSSER, R., and POMERANZ, Y. 1981. Measuring breakage susceptibility of shelled corn during handling. Cereal Foods World 26:75-80.

MILLER, B. S., HUGHES, J. W., and ROUSSER, R. 1982. Effects of modifications of a model CK2 stein breakage tester on corn breakage. Cereal Chem. 58:201.

PAULSEN, M. R., and HILL, L. D. 1977. Corn breakage in overseas shipments—two case studies. Trans. ASAE 20(3):550-557.

PAULSEN, M. R., and HILL, L. D. 1983. Breakage susceptibility of exported corn at origin and destination. Trans. ASAE 26(1):265-269, 274.

PAULSEN, M. R., and NAVE, W. R. 1980. Corn damage from conventional and rotary combines. Trans. ASAE 23(5):1110-1116.

PAULSEN, M. R., NAVE, W. R., and GRAY, L. E. 1981. Soybean seed quality as affected by impact damage. Trans. ASAE 24(6):1577-1582, 1589.

PAULSEN, M. R., HILL, L. D., WHITE, D. G., and SPRAGUE, G. F. 1983. Breakage susceptibility of corn-belt genotypes. Trans. ASAE 26(6):1830-1836, 1841.

PIERCE, R. O., and HANNA, M. A. 1985. Corn kernel damage during on-farm handling. Trans. ASAE 28(1):239-241, 245.

SAS. 1982. SAS User's Guide: Statistics. SAS Institute Inc.: Cary, NC.

SHARDA, R., and HERUM, F. L. 1977. A mechanical damage susceptibility tester for shelled corn. Am. Soc. Agric. Eng. Paper 77-3504. The Society: St. Joseph, MI.

SINGH, S. S. 1980. Development of a Centrifugal Corn Breakage Tester. M.S. thesis. University of Wisconsin, Madison.

STEPHENS, L. E., and FOSTER, G. H. 1976. Breakage Tester Predicts Handling Damage in Corn. ARS-NC-49. Agricultural Research Service, USDA. U.S. Government Printing Office: Washington, DC.
THOMPSON, R. A., and FOSTER, G. H. 1963. Stress cracks and breakage in artificially dried corn. Marketing Res. Rep. 631. Agricultural Research Service, USDA. U.S. Government Printing Office: Washington, DC.
USDA. 1980. Grain Grading Procedures, Book II. Federal Grain Inspection Service: Washington, DC.
WATSON, S. A., and HERUM, F. L. 1986. Comparison of eight devices for measuring breakage susceptibility of shelled corn. Cereal Chem. 63(2):139-142.

[Received September 28, 1987. Revision received January 19, 1988. Accepted January 21, 1988.]