Magnitude and Sources of Error in Wisconsin Breakage Tester Results

S. R. Eckhoff, P. C. Wu, D. S. Chung, H. H. Converse
ASSOC. MEMBER ASAE — MEMBER ASAE — MEMBER ASAE

ABSTRACT

THIS study was undertaken in order to evaluate the machine and operator sources of error affecting the Wisconsin Breakage Tester values on corn. The average standard deviation of the breakage values measured with a 4.76 mm (12/64 in.) sieve was found to be 0.505% but ranged from 0.06% to 1.98% for different levels of breakage susceptibility. The breakage values using a 6.35 mm (16/64 in.) sieve were nearly double the 4.76 mm sieve values, averaging 1.012% with a range from 0.1% to 4.8%. Mold damage and kernel feed rate into the instrument were insignificant on breakage susceptibility values. Error introduced by operator differences was found to be statistically significant although the magnitude of the error was small.

INTRODUCTION

Breakage susceptibility in corn is a measure of the ability of the corn kernel to retain its integrity while being subjected to various forces during handling through market channels. Present commercial grading and pricing of corn does not account for differences in breakage susceptibility although such differences can greatly impact the ultimate utility and value of the corn after moving through the market channel. The Wisconsin Breakage Tester (WBT) (Singh and Finner, 1983) has been developed as a means to evaluate the breakage susceptibility of corn. Use of such an instrument in the grading of corn would allow segregation of similar quality corn and would more equitably compensate producers for the quality of the corn delivered. However, to use the WBT in routine grading, the reproducibility limits and sources of error in measurement must be evaluated.

This study was initiated to analyze the standard error associated with measuring the breakage susceptibility of corn samples using the WBT as a function of corn moisture content, temperature, and breakage susceptibility levels. The study also evaluated inherent machine and operator sources of error.

Article was submitted for publication in August, 1987; reviewed and approved for publication by the Food and Process Engineering Institute of ASAE in July, 1988.

Contribution No. 88-37-J of the Kansas Agricultural Experiment Station.

The authors are: S. R. ECKHOFF, Associate Professor, Agricultural Engineering Dept., University of Illinois, Urbana (formerly Associate Professor, Agricultural Engineering Dept., Kansas State University Manhattan); P. C. WU, Graduate Research Assistant, and D. S. CHUNG, Professor, Agricultural Engineering Dept., Kansas State University, Manhattan; and H. H. CONVERSE, Agricultural Engineer, USDA-ARS, U.S. Grain Marketing Research Lab., Manhattan, KS.

Acknowledgments: The authors would like to thank Dr. F. S. Lai, Marty Criswell, Jian Hua, Leonard Obaldo, and Suzanna McMillan for their contributions to the project. This project was funded by the Federal Grain Inspection Service, Contract No. 54-6395-6-40.

LITERATURE REVIEW

Schmidt (1987) reported the coefficients of variation, LSD, the general mean, and standard deviation of a Wisconsin Breakage Tester collaborative study. He found the coefficients of variation for all breakage data are low but the range of average values is quite large. The standard deviation was 0.67% and 1.32% for a single value determination using the 4.67 mm and 6.35 mm sieving screen, respectively. These results indicate a significnant interaction between the samples and the laboratories that cooperated in the study.

Singh and Finner (1983) and Paulsen (1983) showed that a centrifugal impact tester such as the WBT produced breakage values with lower coefficients of variation than the Stein Breakage Tester (SBT). In general, the coefficient of variation for the SBT was double that of the WBT.

The kernel feed rate into the WBT or similar centrifugal impactors has been shown to not affect the resultant breakage susceptibility value (Sharda and Herum, 1977; Gunasekaran and Paulsen, 1986; Singh and Finner, 1983). Sharda and Herum (1977) studied the range of feed rates available by the vibrating feeder. Singh and Finner (1983) studied rates over the range 450 to 1365 g/m.

METHODS AND PROCEDURES

Breakage Susceptibility

Samples were pre-sieved on a Gamet sieve shaker (30 strokes) using a 4.76 mm precision round hole sieve. Each sample was subdivided into 200 g subsamples weighed to the nearest 0.01 g. Samples were randomized and tests were performed with the instrument at approximately 25°C(±3°C). The operation procedure of the WBT was as described by Gunasekaran and Paulsen (1986) with a feed rate around 200 g/min.

Out of the WBT, the samples were sieved on a Gamat sieve shaker (30 strokes) using a 4.76 mm precision round hole sieve and the overs being weighed. The overs were sieved (30 strokes) using a 6.35 mm round hole sieve. The breakage susceptibility of the smaples was taken as the percentage of the sample able to pass through a sieve. Moisture content was determined by the standard 103°C, 72 h oven method, and reported on a wet basis.

Factors Inherent to the Design and Construction of the WBT

Three Wisconsin Breakage Testers, No. C007P, No.

C006P, and No. C019P were used to evaluate the factors inherent in the design and construction of Wisconsin Breakage Tester that contribute to error in the measured value. A single corn sample (11.59% m.c.) was divided into nine subsamples with subsamples randomly assigned to each treatment combination (3 Wisconsin Breakage testers VS 3 vibratory feeders). Six replicates were run at each treatment combination.

A two-way ANOVA statistical test was used to analyze for significant differences between Wisconsin breakage testers and vibratory feeders. A Fisher's LSD pairwise comparison (95% level) was made to check for performance differences among the three Wisconsin Breakage Testers.

Effect of the Grain Feeding Rate into the Tester

Samples from two corn varieties, Pioneer 3377 and Dekalb 711, were sub-divided into four 1.2 kg lots using a Boerner divider. The four corn lots were randomly assigned to one of four different feeding rates. The feed rates were randomly chosen and ranged from 78 g/min to 727 g/min. The Fisher's LSD pairwise comparison (95% level) was used to compare the CV values and the mean of breakage susceptibility at different feeding rates.

Evaluation of the Standard Deviation for Corn Breakage Susceptibility

Identity preserved samples were prepared from five commercially available varieties grown near Wamego, KS: Pioneer 3377, PayMaster 7990, Keltgon KS-1151, Northrup King PX 9540, and Dekalb 711. The varieties were machine harvested at approximately 25% moisture content and dried to produce four 1.25 kg subsamples having different levels of breakage susceptibility. Drying was accomplished with an Aeroglide cross-flow laboratory dryer model No. 25498-1 was used, which is capable of drying approximately 60 kg of corn at any one time in thin layers of 2 in. Four different breakage susceptibility levels were produced in duplicate using four different drying conditions. The four drying methods were:

1. High temperature drying at 110°C to 15% moisture content.
2. High temperature drying at 110°C to 21% moisture content followed by ambient air drying to 15% moisture content.
3. High temperature drying at 110°C to 18% moisture content followed by ambient air drying to 15% moisture content.
4. Ambient air drying to 15% moisture content.

Samples from each drying condition were also dried to different moisture levels ranging from 7% to 20% in order to study the interaction between moisture content and standard error of breakage susceptibility measurement.

Before testing, samples were equilibrated 48 h at room temperature. Breakage susceptibility was determined by measuring five replicates of each sample.

The SAS statistical package (SAS Institute, 1985) was used to ascertain the standard deviation for each sample and to determine how moisture content, corn temperature, and breakage susceptibility levels affected the standard deviation.

Operator Induced Error

Five lots of corn of approximately 10 kg were sub-divided into four samples of 2.5 kg each using a Boerner divider. Four different inexperienced operators ran the samples throught the same Wisconsin Breakage Tester with ten replicates per sample. Prior to testing, each operator was given instructions on the operating procedure used for Wisconsin Breakage Tester.

Effect of Mold Damage

Three identically preserved corn samples (Dekalb 711, Pioneer 3377, and Northrup King PX 9540) were rewetted from 10% to 18% moisture content and divided into two sublots for each variety using a Boerner divider. One sublot was stored at 4°C and the other was stored at 28°C in temperature controlled incubators. After 60 days, the samples were equilibrated to room temperature for about 48 h before conducting the breakage tests. A sample of corn from each subsample was taken for moisture determination before each test. Breakage susceptibility was determined by five replicates for each sample.

RESULTS AND DISCUSSION

Factors Inherent to the Design and Construction of the WBT

A complete listing of experimental results and a discussion of the results can be found in Wu (1987). The basic dimensions and impeller speed of the three Wisconsin Breakage Testers were checked. The fluctuation in impeller speed was less than 14 rpm with a mean of 1800 rpm (±0.8%). The dimensions of the circular opening of the impeller and height between the cover plate and impeller were different for the three testers. The hole diameter (Fig. 1) in the rotating plexiglass plate ranged from 45 mm on the Nos. C006P and C007P testers, to 35 mm on the No. C019P tester. The height between the bottom of the top plexiglass plate and the top of the rotating plexiglass plate ranged from 35 mm on Nos. C006P and C007P testers, to 40 mm on No. C019P.

A smoke generator was employed to monitor the air flow inside the tester. The air flows down the four impeller channels and then back to the rotating plexiglass plate hole through the gap space between the two plates. Sealing of the instrument with duct tape at all

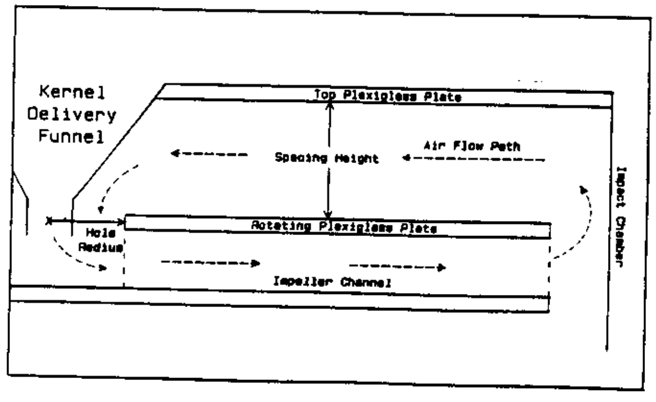

Fig. 1—Schematic of Wisconsin breakage tester impeller section showing air flow path.

TABLE 1. BREAKAGE SUSCEPTIBILITY RESULTS FROM NINE COMBINATIONS OF WBT AND VIBRATORY FEEDERS USING THE IDENTICAL SAMPLE

Feeder		Wisconsin Breakage Tester		
		C006P	C019P	C007P
A	Avg.	10.59	9.81	10.66
	S.D.	0.63	0.41	0.35
B	Avg.	10.30	9.50	10.46
	S.D.	0.46	0.31	0.46
C	Avg.	10.83	9.52	10.66
	S.D.	0.41	0.12	0.63
Mean(%)		10.57a	9.61b	10.59a
C.V. (%)		4.73a	2.91b	4.54a
Hole diameter		45 mm	35 mm	45 mm
Spacing height		35 mm	40 mm	35 mm

Means and CV values with the same letter are not significantly different on the basis of LSD pairwise comparison at p = 0.05 (DF = 45) for Wisconsin Breakage Tester.

seams increases the amount of air recycled within the instrument. Obstruction of the air path into the hole in the rotating plexiglass plate reduces the velocity of the air flow down the impeller channel and thus could reduce the kernel impact velocity.

As the spacing between the two plexiglass plates decreases, the kernel delivery funnel acts as more of an obstruction in the rotating plexiglass plate hole.

The breakage susceptibility results measured by the Wisconsin Breakage Testers with different vibratory feeders are listed in Table 1. A two-tailed T test at the 95% level indicates that there are significant differences among the three machines. The coefficient of variation is statistically different machines (Table 1). There is no significnt difference among feeders, and no significant interaction between the WBT and the feeder.

The design difference in some of the dimension of the instruments is highly significant. Therefore, the testing on reliability was performed using only the No. C006 instrument.

A survey of WBT owners was performed to determine the extent of the variability between testers. It was found that instruments C001 through C011 had the same hole diameters (44.5 mm) although the spacing between the two plexiglass plates varied from 19.1 mm to 40.5 mm. Instrument C012 through C024 had hole diameters that varied from 31.8 mm to 38.5 mm and plate spacings that varied from 25.4 mm to 63.5 mm. Four instrument owners did not respond to the survey.

It was postulated that the difference in the dimensions may have caused part of the high variability Schmidt (1987) and Watson (1985) observed between laboratories. An effort was extended to identify a trend between the their results and the two instrument dimensions measured. No clear trend was observable. The amount of sealing on the instruments may be a confounding factor in the correlation.

Effect of the Grain Feeding Rate into the Tester

The mean breakage susceptibility values and coefficient of correlation values were analyzed and showed that the effect of the feed rate is insignificant over feed rates ranging from 94 to 727 g/m. These results support those reported by Sharda and Herum (1977), Gunasekaran and Paulsen (1986), and Singh and Finner (1983).

Evaluation of the Standard Deviation for Corn Breakage Susceptibility

The standard deviation for the samples tested ranged from 0.06% to 1.98% with an average value of 0.505% when using a 4.76 mm sieve at room temperature. The standard deviation for a 6.35 mm sieve ranged from 0.1% to 4.8% with an average of 1.012%. The breakage values measured using the 6.35 mm sieve are almost double the values from the 4.76 mm sieve. The average coefficient of variation (CV) with the 4.76 mm sieve was 6.07%; this is almost equal to the coefficient of variation for the 6.35 mm sieve (6.05%). Because of the larger values resulting from the 6.35 mm sieve, it may be more discriminating. These results are similar to those of Schmidt (1987).

Standard statistical methods were used to determine the correlation among the standard deviation, temperature, breakage susceptibility, and moisture content. Results of the statistical test showed that the correlation between standard deviation and breakage susceptibility levels was more significant than the correlation between standard deviation and moisture content or temperature. Breakage susceptibility was lightly correlated with moisture and temperature. The correlation between the standard deviation and breakage susceptibility values are 0.61 and 0.39 for the 4.76 mm and the 6.35 mm sieve measurement, respectively. Fig. 2 shows the variability of the standard deviation for the 4.76 mm sieve. A similar variability was observed with the 6.35 mm sieve although the correlation coefficient was lower. The correlation coefficient for moisture content is −0.54 and −0.38 for the 4.76 mm and 6.35 mm sieves, respectively. The temperature correlation coefficients are −0.45 and −0.47.

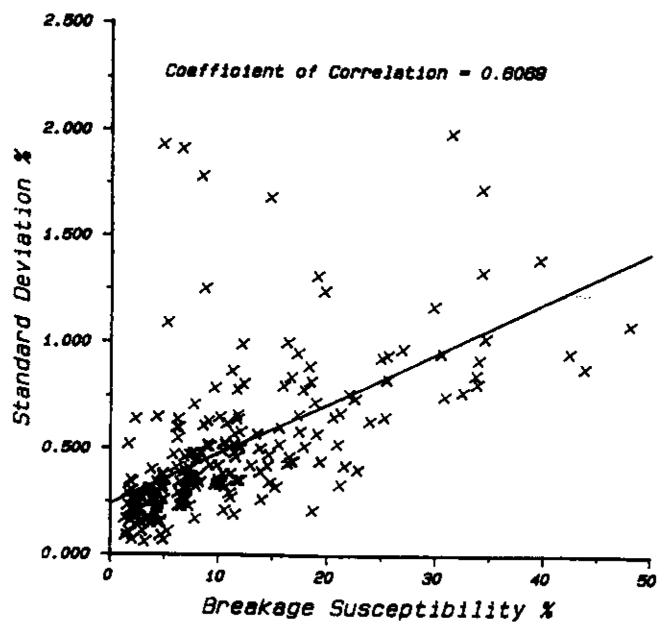

Fig. 2—Breakage susceptibility VS standard deviation using a 4.76 mm sieve at 25°C ± 3°C.

TABLE 2. BREAKAGE SUSCEPTIBILITY RESULTS (4.76 mm SIEVE) SHOWING VARIABILITY IN RESULTS BETWEEN OPERATORS

Operator		Sample 1	2	3	4	5	Mean	CV
1	Avg.	27.17	37.14	30.44	42.35	25.89	32.64a	
	S.D.	0.64	1.31	0.49	1.23	1.01	0.94	
2	Avg.	27.26	35.61	30.17	41.52	24.81	31.87b	
	S.D.	0.74	0.95	1.88	0.87	0.60	1.01	
3	Avg.	25.23	35.55	31.46	43.29	24.85	32.08b	
	S.D.	1.16	1.03	0.45	0.82	0.76	0.84	
4	Avg.	25.49	36.62	31.11	43.73	26.22	32.64a	
	S.D.	0.85	0.90	0.64	1.50	0.86	0.95	

Means with the same letter are not significantly different on the basis of LSD pairwise comparison at p = 0.05 (DF = 180) for Human Factors using 4.76 mm sieve.

Operator Induced Error

Significant differences were observed among the average reading of the operators using either the 4.76 mm or the 6.35 mm sieves. Table 2 shows the results for the 4.76 mm sieve with results from the 6.35 mm sieve comparable. Operators readings, 1 and 4 are similar and operators 2 and 3 are similar but the two groups are significantly different from each other at the 95% confidence level.

This result was unexpected since the testing procedure appears highly objective. The statistical analysis indicats a significant difference between values measured by different operators even at the 99.95% level. Although there is a significant difference among operators, the average magnitude of the difference is only approximately 0.8% at a 32% breakage level. Observation of the procedures used by the operators indicates that the differences observed may be due to the care in handling the sample in and out of the sieve shaker.

The results suggest that a specific models of sieve shakers should be used to help insure uniformity in handling by the operator. It also suggests that some training be given to the operators and that consistent protocol be used by all operators when handling the samples.

Effect of Mold Damage

After 60 days storage, some "blue-eye" and discoloration was found on the surface of the germ and under the pericarp in the samples stored at 28°C. Many of the cracked and broken kernels were molded in the area of the exposed endosperm. No mold was found in the corn samples which had been stored at 4°C. The breakage susceptibility results show no significant trends at the 99% level. For example, the breakage susceptibility of the molded and unmolded Dekalb 711 samples using a 4.76 mm sieve were 5.71% and 6.12%, respectively, while the Pioneer 3377 had values of 5.90% and 6.07%. This agrees with the findings of Exkhoff et al. (1984) who found that breakage susceptibility only increased slightly for extensively molded corn.

Mold might change the biochemical structure but does not appear to change the physical structure. The horny endosperm of the corn is the major contributor to mnechanical properties (Balastreire, 1982a;b), and mold does not appear to cause changes in the horny endosperm characteristics.

SUMMARY AND CONCLUSIONS

Differences in the construction between the 24 Wisconsin Breakage Testers have been found which many cause test results to vary with each instrument. In order to insure uniformity of breakage results, all the current instruments should be modified to the same dimensions. Also, a consistent level of recycled air should be maintained.

The standard deviation for the samples ranged from 0.06% to 1.98% with an average of 0.505% for the 4.76 mm sieve at room temperature. The average standard deviation for the 6.35 mm sieve was 1.012% with a range of 0.1% to 4.8%. The average coefficient of variation value for the 4.76 mm sieve (6.07%) was almost equal to that for the 6.35 mm sieve (6.05%) over the range of breakage susceptibility values studied. The standard deviation of the Wisconsin Breakage Test was more closely correlated to the breakage susceptibility value than to either moisture content or temperature. Standard deviation increased with increasing breakage susceptibility.

Human factors influence the breakage susceptibility results at the 95% confidence level although the magnitude of the average difference is only 0.8% at a breakage susceptibility level of 32%. Improvement is expected if care is taken in handling of the samples to and from the sieve shaker.

Mold damage does not significantly affect the breakage susceptibility results. The results were found to be fairly independent of the effect of the grain feed rate into the tester at rates between 78.3 and 727.3 g/min.

References

1. Balastreire, L. A., F. L. Herum, K. K. Stevens, and J. L. Blaisdell. 1982a. Fracture of corn endosperm in bending. Part I. Fracture parameters. TRANSACTIONS of the ASAE 25(4):1057-1061, 1065.

2. Balastreire, L. A., F. L. Herum, K. K. Stevens, and J. L. Blaisdell. 1982b. Fracture of corn endosperm in bending. Part II. Fracture analysis by fractography and optical microscopy. TRANSACTIONS of the ASAE 25(4):1062-1065.

3. Eckhoff, S. R., J. Tuite, G. H. Foster, R. A. Anderson, and M. R. Okos. 1984. Inhibition of microbial growth during ambient air corn drying using sulfur dioxide. TRANSACTIONS of the ASAE 27(3):907-914.

4. Gunasekaran, S., and M. R. Paulsen. 1986. Standardizing corn breakage susceptibility testing. ASAE Paper No. 86-3035, St. Joseph, MI 49085.

5. Paulsen, M. R. 1983. Corn breakage susceptibility as a function of moisture content. ASAE Paper No. 83-3078, St. Joseph, MI 49085.

6. SAS Institute. 1985. User's guide: Statistics, Version 5 Edition. SAS Institute, Inc., Cary, NC.

7. Schmidt, D. 1987. The 1985-86 NC-151 Wisconsin breakage tester collaborative study. The Ohio State University, Wooster, OH 44691-6900.

8. Sharda, R., and F. L. Herum. 1977. A mechanical damage susceptibility tester for shelled corn. ASAE Paper No. 77-3504, St. Joseph, MI 49085.

9. Singh, S. S., and M. F. Finner. 1983. A centrifugal impacter for damage susceptibility evaluation of shelled corn. TRANSACTIONS of the ASAE 26(6):1858-1863.

10. Watson, S. A. 1985. The effect of fines on corn and soybean processing. NC-151 Grain Quality Newsletter 7:18-19.

11. Wu, P. C. 1987. Factors affecting the breakage suseptibility measured by the Wisconsin breakage tester. M.S. thesis, Kansas State University, Manhattan, KS.