Sieving Effects on Breakage Susceptibility Measurements[1, 2]

F. L. HERUM,[3] N. D. SCHMIDT,[4] and E. L. McCOY[4]

Cereal Chem. 67(6):548–550

ABSTRACT

The effect of sieving of corn (maize) on the assessment of breakage susceptibility with two breakage testers was examined. Five corn samples of known diverse breakage susceptibilities were subjected to breakage testing in both the Wisconsin and Stein CK-2M instruments. The resulting samples were then sieved with differing numbers of sieving cycles. The results were fit to a mathematical expression describing the sieving process. Sieving action generated further breakage at a rate somewhat proportional to the breakage susceptibility of the samples. The model yielded estimates for the breakage of the sample before sieving and gave the sieving breakage rate. The appropriate number of sieving cycles to determine the initial breakage of the samples varied with both sample and instrument. The results of this study demonstrate that the number of sieving cycles should not be chosen arbitrarily and should be examined at the outset of any breakage testing procedure.

Sieving is a process that separates particles of various sizes and shapes into two or more fractions. Each sieve permits the "throughs" to pass while retaining the "overs." Standard sieves with various hole sizes and shapes are specified for grading agricultural commodities. A 4.76-mm round-hole sieve is used in the United States in grading to determine the proportion of broken corn and foreign material (BCFM) in yellow dent shelled corn (maize) (FGIS 1980). As one factor used to describe the grade of market corn, BCFM may not exceed 3% for U.S. No. 2 corn or 4% for U.S. No. 3 corn. BCFM is the throughs plus hand-picked nongrain material expressed as a percent of the original sample weight.

Modern methods of field shelling, drying, and handling result in shelled corn that is susceptible to breakage during handling. Excessive levels of BCFM must be removed and disposed of to maintain the desired grade. Corn lots that are more resistant to breakage are therefore of greater value for most end-uses, but this property has been neither routinely determined nor rewarded in marketing channels.

A Midwest cooperative research project, designated NC-151, has pursued the development and evaluation of experimental and commercial instruments for measuring grain breakage susceptibility (Watson and Herum 1986, Watson et al 1986). Several collaborative tests have been conducted, in which samples from common lots were provided to each cooperating research station. Test conditions and procedures were specified. Variations in results between stations were larger than expected, even when presumably identical instruments were used. Of the possible sources of this variability, failure to utilize recommended sieving equipment and procedures appeared to be the greatest contributor.

Corn breakage susceptibility is an important criterion in judging grain quality. As such, a standard method for measuring breakage susceptibility in the market channel would be very desirable. This study was conducted to evaluate sieving efficiency and generation of BCFM in sieving for two breakage testers. The evaluation was determined by examining the relationships between number of sieving cycles and weight of overs as influenced by test equipment and sample properties.

MATERIALS AND METHODS

Five samples of yellow dent shelled corn, previously identified as greatly different in breakage susceptibility, were each divided by a Boerner divider into eight sublots. These provided two replicates each, for both precision and commercial 4.76-mm round-hole sieves, for tests of two breakage susceptibility instruments: the Wisconsin breakage tester (WBT) and the Stein CK-2M. The WBT is a single-pass instrument in which the kernels are metered into the center of a rotor and propelled radially against a surrounding cylinder (Singh and Finner 1983). Fracture occurs principally due to impact, giving a large proportion of larger, sharp-cornered particles. The standard test, AACC Method 55-20 (AACC 1983), was conducted with the Stein CK-2M, in which kernel disintegration is due to a combination of impact and abrasion.

Before breakage testing, all samples were prescreened with a 4.76-mm round-hole precision sieve using 30 cycles (60 strokes) on a Strand shaker. Motomco moisture contents of the corn samples were 12.7, 16.0, 12.9, 12.2, and 17.2% wb for samples 1–5, respectively. Sample size was 200.0 g for the WBT (Singh and Finner 1983) and 100.0 g for the Stein CK-2M (AACC 1983). After subjecting samples to breakage susceptibility testing, overs were weighed for the precision or the commercial sieve after 1, 2, 4, 8, 16, 32, 64, 128, and 256 cycles on the shaker.

Experimental data, expressed as weight of overs (W_o) vs number of cycles (CY), was fit to the equation

$$W_O = \frac{W_i - W_z}{(1 + K_1 \cdot \mathrm{CY})} + W_z - K_2 \cdot \mathrm{CY} \quad , \tag{1}$$

where W_o is the predicted weight of the overs (g), W_i is the initial sample weight (g), W_z is the zero-cycle weight of overs (i.e., the weight of overs in the absence of sieving breakage) (g), and K_1 and K_2 are empirical coefficients. The coefficient K_2 is the rate of weight loss of the overs with continued sieving and may be thought of as the sieving breakage rate. The equation parameters W_z, K_1, and K_2 were identified by nonlinear least squares regression. The coefficient search employed the nonderivative search procedure of Hook and Jeeves (Bazaraa and Shetty 1979). The model was fit to each replicate test for the five corn samples, two breakage testers, and two sieves, resulting in 40 individual coefficient searches.

The BCFM in the absence of sieving breakage corresponds to the difference between the initial weight (W_i) and the zero-cycle weight of overs (W_z). This value was calculated, normalized relative to the initial weight, and expressed as a percent using the equation

$$\mathrm{ZBCFM} = \frac{W_i - W_z}{W_i} \cdot 100 \quad , \tag{2}$$

where ZBCFM is the percent of zero-cycle BCFM. Statistical comparisons between corn samples, breakage testers, and sieves were conducted for the zero-cycle BCFM and sieving breakage rate values, using SAS (SAS, 1988) with a full factorial analysis of variance design.

---

[1]Contribution of the Ohio Agricultural Research and Development Center, manuscript 373-89. Research support provided by state and federal funds appropriated to the Ohio Agricultural Research and Development Center, Wooster.

[2]Use of brand names does not constitute endorsement by the Ohio Agricultural Research and Development Center to the exclusion of any similar product.

[3]Emeritus professor, Department of Agricultural Engineering, The Ohio State University, Columbus 43210.

[4]Coordinator, Project NC-151, and assistant professor, Department of Agronomy, respectively, Ohio Agricultural Research and Development Center, Wooster 44691.

RESULTS

No statistical difference was found between data resulting from the commercial and the precision sieves. Therefore, the data were pooled to give four replications in all subsequent analyses.

Experimental observations are shown in Fig. 1. The individual curves given in this figure were calculated by employing the mean of the three adjustable coefficients of equation 1 from the four replicate coefficient searches. Comparison of the experimental observations and the regression analyses demonstrates the excellent agreement of the data and the model for both breakage testers and all corn samples. The mean R^2 value for the 40 searches equaled 0.95, also indicating excellent agreement. This demonstrates the adequacy of equation 1 in describing the data of this experiment.

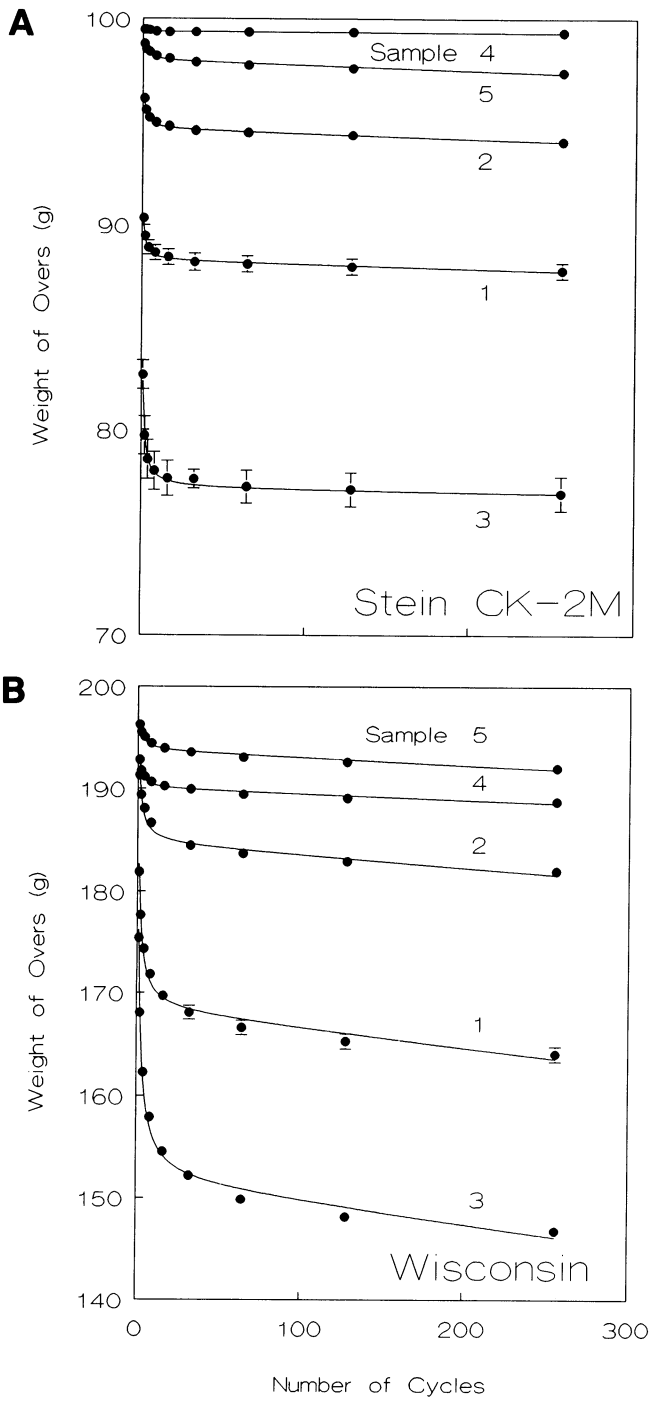

Fig. 1. Weight of overs as a function of number of sieving cycles for five samples of corn grain evaluated on Stein CK-2M (**A**) and Wisconsin (**B**) breakage testers. Data points are means of four observations, and the solid line depicts the fit of equation 1. Error bars show one standard error when its magnitude is not encompassed by the dot.

Equation 1 consists of two expressions, a reciprocal expression describing the early phases of the sieving process (first term on the left-hand side of the equation), and a linear relation describing the latter phases of the sieving process (second and third terms on the left-hand side of the equation). The linear relation has an intercept at the zero cycle weight and a slope corresponding to the sieving breakage rate.

The relationships between the weight of overs and the number of shaker cycles for the WBT and the Stein CK-2M (Fig. 1) illustrate several results. The weight of overs asymptotically approached a linear relationship as the number of shaking cycles increased. This line was, however, not horizontal, indicating that the sieving process itself introduces additional corn breakage. The number of cycles required for the weight of overs to become arbitrarily close to a linear relation was somewhat proportional to the amount of BCFM present (compare between samples in Fig. 1). Samples containing a higher BCFM required a higher number of sieving cycles, whereas samples with lower BCFM required fewer cycles. In addition, the more irregularly shaped fractures from the WBT clearly required more shaking cycles to approach the linear relation (compare between testers in Fig. 1).

If we assume that the linear portion of the relation between weight of overs vs. sieving cycles represents generation of throughs due to sieving, then the initial weight of overs is represented by the intersection of this line with the zero-cycle axis. Based upon this assumption, the initial BCFM is determined from the estimated zero-cycle value. The zero-cycle BCFM expressed as a percent is calculated from equation 2 (Table I). Statistical analysis indicates a significant difference in zero-cycle BCFM for the same corn sample tested on the WBT and the Stein CK-2M breakage testers. Samples run on the WBT had approximately 2.7 times more zero-cycle BCFM over the range of corn samples in this study. A significant difference was also evident in the zero-cycle BCFM between the individual corn samples.

The slope of the linear portion of the curves corresponds to a sieving breakage rate (Table I). Statistical analysis indicates a significant difference in the sieving breakage rate for the same corn sample tested on the WBT and Stein CK-2M breakage testers. Samples run on the WBT were approximately eight times more susceptible to further breakage during sieving over the range of corn samples in this study. A significant difference in the sieving breakage rate was also found between the individual corn samples.

For the WBT, a close correspondence was evident between the zero-cycle BCFM value and the sieving breakage rate for the three samples most susceptible to breakage (samples 1–3). However, as samples became more resistant to breakage this relation broke down. For the Stein CK-2M, no relationship was apparent between the zero-cycle BCFM value and sieving breakage rate, indicating that this breakage tester does not predispose the samples to sieving breakage.

The goal of breakage testing is to determine the breakage susceptibility of samples independent of the effects of sieving.

TABLE I
Mean Percent of Zero-Cycle Broken Corn and Foreign Material (BCFM) and Sieving Breakage Rate for the Stein CK-2M and Wisconsin Breakage Susceptibility Testers

Corn Sample	Zero-Cycle BCFM (%) Wisconsin	Zero-Cycle BCFM (%) Stein CK-2M	Sieving Breakage Rate (g per cycle $\times 10^{-3}$) Wisconsin	Sieving Breakage Rate (g per cycle $\times 10^{-3}$) Stein CK-2M
1	15.9	11.8	18.5	2.20
2	7.70	5.32	11.8	2.48
3	24.3	22.9	21.8	1.06
4	5.00	0.638	5.65	0.17
5	3.15	2.02	7.24	2.48
LSD (0.05)				
Tester	0.54		1.1	
Sample	0.86		1.7	

This corresponds to the initial or zero-cycle BCFM. From Fig. 1 we can see that successive measurements beyond 30 cycles were adequate and appropriate to determine the slope of the linear portion of the curve and hence the initial BCFM for all but the most breakage-susceptible sample in the Stein CK-2M. However, successive measurements beyond 60 cycles were needed to determine the initial BCFM with samples from the WBT, even those that were most breakage-resistant.

The effects of the type of breakage susceptibility instrument used are further indicated by the reversal in susceptibility ranking between samples 4 and 5, as shown in Fig. 1. Clearly, different instruments can have dissimilar effects on the samples tested.

DISCUSSION

Researchers in NC-151 had specified that sieving should consist of 30 cycles (60 strokes), at approximately 1 Hz, using precision 4.8-mm round-hole sieves of 330-mm diameter, in the equivalent of Gamet or Strand mechanical shakers. Although it did not conform to the Federal Grain Inspection Handbook specification of 15 cycles (FGIS 1980), the greater sieving duration was included in AACC Method 55-20 (AACC 1983). The selection of 30 cycles was based upon studies by Miller et al (1981) with the Stein CK-2M instrument.

Thirty sieving cycles would appear to underestimate the breakage susceptibility of many corn samples in the WBT. This is most likely due to the larger sample size (200 g) used in the WBT, requiring more sieving cycles to adequately separate throughs and overs. In addition, the selection of a single number of sieving cycles in breakage susceptibility measurements would mask the effects of sieving breakage demonstrated in this study. For the Stein CK-2M, a sequence of at least three weight measurements beyond 30 cycles (e.g., at 40, 80, and 120 cycles) would be required to estimate the linear relation of equation 1 and hence the initial BCFM from this tester. A sequence of at least three weight measurements beyond 60 cycles (e.g., at 70, 140, and 210 cycles) would be required for the WBT to estimate the linear relation of equation 1 and hence the initial BCFM from this tester.

The validity of the zero-cycle BCFM and sieving breakage rate values given in Table I rests entirely with the appropriateness of equation 1 to describe the experimental observations. The excellent agreement (mean $R^2 = 0.95$) with the experimental data throughout all portions of the curve justify this approach.

The rate of separation during sieving diminishes with time and approaches zero as some final equilibrium weight of overs is reached (provided no disintegration due to sieving occurs). This rate is, of course, influenced by overall sample size and the proportion and shape of fines and overs. In this work we demonstrate that the apparent abrasion and collisions occurring during sieving clearly cause further disintegration of overs. Thus, in breakage susceptibility determinations, the sieving operation affects the value it is intended to measure.

CONCLUSIONS

Based upon the results of this study, four conclusions were reached. First, the process of separation by sieving is described by a reciprocal process in which the rate of separation diminishes asymptotically with increasing number of cycles. Second, sieving breaks and abrades the corn grains, causing a gradual reduction of overs at a rate approximately proportional to the breakage susceptibility of the samples. This rate of further breakage is also influenced by sample pretreatment such as the type of breakage tester. Third, there is no single "correct" number of sieving cycles that will identify the initial BCFM content for all samples. This varies with the breakage susceptibility of the samples and the type of instrument used. Fourth, although the scope of this study encompassed two breakage testers and five corn samples, similar effects of sieving on experimental results may be expected in other studies.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. Method 55-20, approved November 1981. The Association: St. Paul, MN.

BAZARAA, M. S., and SHETTY, C. M. 1979. Nonlinear Programming: Theory and Algorithms. John Wiley & Sons: New York. 560 pp.

FEDERAL GRAIN INSPECTION SERVICE. 1980. Grain Inspection Handbook, Book II. U.S. Department of Agriculture. U.S. Government Printing Office: Washington, DC.

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

SAS INSTITUTE INC. 1988. SAS/STAT Guide for Personal Computers, Release 6.03 edition. SAS Institute Inc.: Cary, NC.

SINGH, S. S., and FINNER, M. F. 1983. A centrifugal impactor for damage susceptibility evaluation of shelled corn. Trans. ASAE 26:1858-1863.

WATSON, S. A., and HERUM, F. L. 1986. Comparison of eight devices for measuring breakage susceptibility of shelled corn. Cereal Chem. 63:139-142.

WATSON, S. A., DARRAH, L. L., and HERUM, F. L. 1986. Measurement of corn breakage susceptibility with the Stein breakage tester: A collaborative study. Cereal Foods World 31:366-372.

[Received November 27, 1989. Accepted May 30, 1990.]