# Breakage Susceptibility of Rewetted and Blended Corn Samples



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## ABSTRACT

THE measurement and prediction of breakage susceptibility of rewetted and blended corn in the market channel were studied. The interaction of drying method (high-temperature dried, high-ambient air dried, or ambient-air dried) with rewetting was not statistically significant. The differences between the measured breakage percentages on rewetted samples and the breakage values for samples initially dried to the rewetted moisture level were random, varying from −1.10 to + 4.05. The blending of corn samples at the same moisture but different breakage susceptibility levels was found to cause an increase in breakage susceptibility as compared to a mass weighted average of the individual sample breakage values. This was apparently due to a transfer of moisture from the high temperature dried portion of the sample, which had a lower equilibrium moisture isotherm, to the ambient-air dried portion of the sample.

## INTRODUCTION

Corn lots of different moisture contents are routinely blended together in the market channels. Dry corn with a moisture content of less than 15% can be blended with wetter corn to obtain 15.5% moisture that meets the standard for U.S. Corn No. 2. Nguyen et al. (1984) found that samples prepared by the blending of corn lots with different moistures resulted in Stein breakage tester values 0.74 to 10.6 percentage points higher than the weighted average of the breakage values determined on the individual components of the sample. They also found that breakage susceptibility increased with a decrease in the moisture content of the dry portion of the blend and that this effect was greater for the higher moisture blends.

Salter and Pierce (1987) showed with a Stein breakage tester that rewetting by water addition resulted in slightly higher breakage susceptibility values as compared to corn initially dried to that moisture content. They determined that the rate of water addition was important, since water addition above 1.5% m.c. resulted in a significant increase in breakage susceptibility. Breakage susceptibility initially decreased after water addition then slightly increased to the final value after 8 h of tempering. Mixtures of two corn samples with different moisture contents had breakage susceptibility values that were not significantly different from a mixture of the same two corn samples dried to the same moisture content. All samples they studied were field dried to 18% m.c., then low-temperature dried (28°C) to the desired moisture content. Their results did not agree with those of Miller et al. (1981), who reported that the breakage susceptibility of mixtures could be estimated by taking a weighted average of the susceptibility values of the individual components.

In the market channel, corn of the same moisture content but different breakage susceptibility levels usually get blended together due to routine handling. The effect this blending has on the resultant breakage susceptibility of the blended sample has not been studied.

Eckhoff et al. (1988b) showed that the moisture dependence for breakage susceptibility of corn is a function of drying condition. The objective of this study was to investigate the effect of rewetting on breakage susceptibility as a function of drying condition and the effect of blending corn samples that had the same moisture contents but different individual breakage susceptibility values.

## PROCEDURES

One identity-preserved corn lot (Pioneer 3377 variety) was machine harvested at 25% moisture content. Samples of the corn were pre-sieved through a 4.76 mm round hole sieve, and foreign material was removed by hand.

### Breakage Susceptibility of Rewetted Corn

Samples were dried to 10%, 12%, or 14% m.c. using the following drying conditions: (a) high-temperature drying at 110°C to the desired moisture content; (b) high-temperature drying at 110°C to 18% m.c. followed by ambient-air drying (25° ± 3°C) to the desired moisture content; and (c) ambient-air drying (25° ± 3°C) to the desired content. The corn and drying conditions used in this study were identical to those reported by Eckhoff et al. (1988b). There were two replicates for each drying condition.

These samples were then rewetted from their dried moisture content by 2% or 4% m.c.(w.b.). Rewetting was performed by the addition of the appropriate

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amount of moisture to the corn in a plastic bag. Final moisture content increase was variable. In some samples, the initial moisture content of a replicate was considerably different (> 1% m.c.) and was excluded from the study. The desired final weight of samples was at least 1150 g, which included 1000 g for the breakage test (five replicates) and 150 g for moisture determination. After rewetting, samples were held in the plastic bags and stored at room temperature (25°C ± 3°C) for 6 days before moisture measurement (103°C, 72 h air oven method) and breakage testing. During the equilibrating period, the rewetted samples were mixed three times every day by turning the bags upside down five times.

Breakage susceptibility was determined on a Wisconsin Breakage Tester at 25°C (±3°C) using a Gamet sieve shaker following the procedure of Paulsen (1983). Breakage was reported for both 4.76 mm (12/64'') and 6.35 mm (16/64'') round hole sieves. The effect of rewetting was determined by comparing the breakage values of rewetted samples to the breakage values of samples originally dried to that moisture content.

The models used to estimate the breakage level (4.76 mm sieve) of originally dried samples were:

$$BrSu\% = 533.79\ EXP\ (-0.2956\ M) \qquad [1]$$

for the corn dried by high temperature (110°C) to the final moisture content,

$$BrSu\% = 352.13\ EXP\ (-0.2730\ M) \qquad [2]$$

for the corn dried by high temperature (110°C) to 18% moisture content and then ambient-air dried (25°C± 3°C) to the final moisture content, and

$$BrSu\% = 173.99\ EXP\ (-0.2293\ M) \qquad [3]$$

for the ambient-air dried (25°C± 3°C) corn samples. In the equations, M is the moisture content in percent, wet basis. The development of the equations was described in Eckhoff et al. (1988b).

### Breakage Susceptibility of Blended Corn

Four 7.5 kg corn lots were dried in duplicate using two different drying conditions: (a) high-temperature drying at 110°C to appropriate moisture contents of 10%, 12%, 14%, 16%, and 18%. Breakage values were determined on each individual sample prior to blending.

Corn samples with the same moisture content but different drying treatments were then blended in equal proportions (equal dried weight) to obtain samples at five moisture levels of approximately 10%, 12%, 14%, 16%, and 18%. Samples were not blended together if the moisture contents of the individual samples were not within 0.5% (w.b.) of each other. A total of 11 samples could be prepared from the individually dried samples. These blended samples were held in plastic bags and stored at room temperature (25°C± 3°C) for 6 days prior to final moisture measurement and breakage testing. During the equilibrating period, the blended samples were thoroughly mixed three times each day. The breakage susceptibility values of the blended samples were compared to the breakage values of unblended corn samples.

## RESULTS AND DISCUSSION

### Breakage Susceptibility of Rewetted Corn

Previously, it was shown that breakage susceptibility was dependent upon the drying condition used (Stroshine et al., 1981; Eckhoff et al., 1988b). The effect of rewetting on breakage susceptibility is shown in Tables 1 to 3 for the three drying treatments using a 4.76 mm sieve. Similar results were obtained with the 6.35 mm sieve. A complete listing of the data and results can be found in Wu (1987). The results are somewhat random, with the difference values (rewetted-calculated) varying from −1.10 to + 4.05. The rewetted samples consistently had lower standard deveiations than the unwetted samples. This is not totally unexpected, since Exkhoff et al. (1988a) found that the standard deviation for the Wisconsin breakage tester was a function of both the moisture content of the sample and the breakage susceptibility level. However, the decrease in the standard deviation for rewetted samples was larger than that for unwetted samples dried to similar moisture contents. In Table 1, we can observe this by comparing the standard deviations of several rewetted samples and unwetted samples at comparable moisture contents. The unwetted sample at 11.17% m.c. had a standard

TABLE 1. THE EFFECT OF REWETTING ON BREAKAGE SUSCEPTIBILITY VALUES FOR HIGH-TEMPERATURE DRIED CORN USING 4.76 mm SIEVE

| Unwetted sample moisture content, % w.b. | Rewetted sample moisture content, % w.b. | Breakage susceptibility, % Unwetted sample Avg. | Unwetted sample S.D. | Rewetted sample Avg. | Rewetted sample S.D. | Calculated values* | Difference (rewetted-calculated) |
|---|---|---|---|---|---|---|---|
| 8.79 | 11.29 | 33.91 | 0.81 | 23.02 | 0.31 | 18.97 | +4.05 |
| 8.79 | 13.43 | 33.91 | 0.81 | 13.72 | 0.49 | 10.08 | +3.64 |
| 9.85 | 12.59 | 25.62 | 0.94 | 12.62 | 0.82 | 12.92 | -0.30 |
| 9.85 | 14.44 | 25.62 | 0.94 | 7.32 | 0.26 | 7.47 | -0.15 |
| 11.17 | 13.39 | 25.32 | 0.65 | 13.33 | 0.39 | 10.20 | +3.13 |
| 11.17 | 16.59 | 25.32 | 0.65 | 5.29 | 0.24 | 3.96 | +1.33 |
| 12.43 | 14.37 | 14.78 | 1.68 | 7.48 | 0.22 | 7.63 | -0.15 |
| 12.43 | 17.20 | 14.78 | 1.68 | 3.18 | 0.39 | 3.31 | -0.13 |
| 13.26 | 16.65 | 14.55 | 0.42 | 4.12 | 0.40 | 3.89 | +0.23 |
| 14.20 | 16.88 | 8.28 | 0.34 | 2.53 | 0.26 | 3.63 | -1.10 |
| 14.20 | 19.50 | 8.28 | 0.34 | 1.48 | 0.16 | 1.67 | -0.19 |

*BrSu % = 533.79 EXP(-0.2956 M)

TABLE 2. THE EFFECT OF REWETTING ON BREAKAGE SUSCEPTIBILITY VALUES FOR HIGH-AMBIENT DRIED CORN USING 4.76 mm SIEVE

| Unwetted sample moisture content, % w.b. | Rewetted sample moisture content, % w.b. | Breakage susceptibility, % | | | | | |
|---|---|---|---|---|---|---|---|
| | | Unwetted sample, | | Rewetted sample | | Calculated values* | Difference (rewetted-calculated) |
| | | Avg. | S.D. | Avg. | S.D. | | |
| 10.47 | 11.09 | 18.49 | 0.82 | 17.68 | 0.70 | 17.05 | +0.65 |
| 10.47 | 14.04 | 18.49 | 0.82 | 10.14 | 0.48 | 7.62 | +2.52 |
| 10.68 | 10.99 | 18.89 | 0.72 | 17.86 | 0.40 | 17.53 | +0.33 |
| 10.68 | 14.11 | 18.89 | 0.72 | 9.93 | 0.37 | 7.48 | +2.45 |
| 10.90 | 14.01 | 17.32 | 0.95 | 9.89 | 0.46 | 7.69 | +2.20 |
| 10.90 | 16.86 | 17.31 | 0.95 | 3.94 | 0.27 | 3.53 | +0.41 |
| 10.95 | 13.91 | 16.69 | 0.84 | 10.06 | 0.45 | 7.90 | +2.16 |
| 10.95 | 16.68 | 16.69 | 0.84 | 4.08 | 0.34 | 3.71 | +0.38 |
| 13.77 | 16.45 | 8.50 | 1.78 | 3.59 | 0.22 | 3.95 | -0.36 |
| 13.90 | 16.77 | 7.45 | 0.37 | 2.70 | 0.22 | 3.62 | -0.92 |

*BrSu % = 352.13 EXP(-0.2730 M)

deviation of 0.65 compared to 0.31 for the rewetted sample at 11.29% m.c. Similarly, the unwetted sample at 12.43% m.c. had a standard deviation of 1.68 compared to 0.82 for the rewetted sample at 12.59% m.c.

There was no consistent trend for the high-temperature or ambient-air dried corn as to the direction (positive or negative) of the difference value. The high-ambient air dried corn, however, did show an increased breakage susceptibility for the rewetted samples over that expected for samples originally dried to the same moisture. Only 2 out of the 10 samples were negative for the 4.76 mm sieve and for the 6.35 mm sieve. Although there was a trend, no statistical difference was observed.

**Breakage Susceptibility of Blended Corn**

Table 4 shows the results of blending corn of similar moisture contents but of different susceptibility values. The difference between the measured and expected values ranged from + 0.11 to + 2.19 for the 4.76 mm sieve, with the largest differences resulting by blending the lowest moisture corn. Similar results were obtained from the 6.35 mm sieve with the difference values ranging from + 0.63 to + 4.90. All of the blended samples had breakage susceptibility values higher than the average of the two original breakage susceptibility values. The magnitude above the average breakage value was not strongly correlated with the moisture content blended. The coefficients of correlation were −0.757 and −0.679 for the 4.76 mm and the 6.35 mm sieves, respectively. This result is inconsistent with that reported by Miller et al. (1981) but more consistent with the results of Salter and Pierce (1987).

The difference between the measured breakage and the expected average breakage was generally larger than the average standard deviation of the two individual blended components for the samples with moisture contents below 15.0%. Above 15.0% m.c. the difference was generally of a similar magnitude as the standard deviation of the blended components.

At 14.75% m.c. and above, the breakage susceptibility of the low-temperature dried corn was higher than that of the high-temperature dried corn. This is consistent with the results of Eckhoff et al. (1988b), in which the curves relating breakage susceptibility to moisture for different drying conditions crossed in the moisture range of 15% to 17%. No plausible explanation for this phenomenon is obvious. However, it is interesting to note that the difference observed between the measured and the expected breakage susceptibility for the blended samples was positive, even though the low-temperature dried corn had the higher breakage values.

The consistently positive differences observed in the blending study were apparently due to the moisture equilibrium difference between high-temperature dried corn and ambient-air dried corn. High-temperature dried corn has a lower moisture content at any given

TABLE 3. THE EFFECT OF REWETTING ON BREAKAGE SUSCEPTIBILITY VALUES FOR AMBIENT TEMPERATURE DRIED CORN USING 4.76 mm SIEVE

| Unwetted sample moisture content, % w.b. | Rewetted sample moisture content, % w.b. | Breakage susceptibility, % | | | | | |
|---|---|---|---|---|---|---|---|
| | | Unwetted sample | | Rewetted sample, | | Calculated values* | Difference (rewetted-calculated) |
| | | Avg. | S.D. | Avg. | S.D. | | |
| 11.42 | 12.42 | 11.77 | 0.66 | 9.54 | 0.32 | 10.09 | -0.55 |
| 11.42 | 13.47 | 11.77 | 0.66 | 8.74 | 0.29 | 7.93 | +0.81 |
| 11.48 | 11.97 | 11.80 | 0.78 | 10.22 | 0.66 | 11.18 | -0.96 |
| 11.48 | 14.45 | 11.80 | 0.78 | 7.21 | 0.29 | 6.33 | +0.88 |
| 12.02 | 14.46 | 11.05 | 0.29 | 7.24 | 0.15 | 6.32 | +0.92 |
| 12.02 | 17.24 | 11.05 | 0.29 | 3.97 | 0.21 | 3.34 | +0.63 |
| 12.49 | 13.56 | 10.28 | 0.33 | 7.44 | 0.25 | 7.77 | -0.33 |
| 12.49 | 15.68 | 10.28 | 0.33 | 5.40 | 0.46 | 4.78 | +0.62 |
| 13.53 | 15.74 | 8.10 | 0.37 | 4.59 | 0.32 | 4.71 | -0.12 |
| 13.53 | 17.18 | 8.10 | 0.37 | 3.39 | 0.32 | 3.38 | 0 |
| 14.44 | 16.95 | 7.80 | 0.71 | 3.06 | 0.25 | 3.57 | -0.51 |
| 14.44 | 17.80 | 7.80 | 0.71 | 2.55 | 0.30 | 2.94 | -0.39 |

*BrSu % = 173.99 EXP (-0.2293M)

TABLE 4. THE EFFECT OF BLENDING ON CORN BREAKAGE SUSCEPTIBILITY MEASURED USING A 4.76 mm SIEVE

| Average moisture content, % w.b. | Breakage susceptibility, % | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | High-temperature dried | | Low-temperature dried | | Expected blended value* | Measured value | | Difference (measured-blended) |
| | Avg | S.D. | Avg. | S.D. | | Avg. | S.D. | |
| 11.32 | 20.95 | 0.52 | 12.04 | 0.51 | 16.50 | 17.53 | 0.61 | +1.03 |
| 11.87 | 18.65 | 0.21 | 12.33 | 0.81 | 15.49 | 17.47 | 0.84 | +1.98 |
| 12.42 | 14.78 | 1.68 | 11.05 | 0.28 | 12.92 | 14.63 | 0.61 | +1.71 |
| 13.10 | 13.51 | 0.57 | 9.79 | 0.33 | 11.56 | 13.56 | 0.36 | +2.00 |
| 13.76 | 10.55 | 0.21 | 8.10 | 0.37 | 9.33 | 11.52 | 0.37 | +2.19 |
| 14.75 | 6.93 | 0.39 | 7.80 | 0.71 | 7.37 | 8.36 | 0.64 | +0.99 |
| 15.67 | 6.91 | 0.46 | 4.92 | 0.26 | 5.92 | 6.29 | 0.47 | +0.37 |
| 16.71 | 3.47 | 0.30 | 4.95 | 0.26 | 4.21 | 4.68 | 0.23 | +0.47 |
| 16.72 | 3.47 | 0.30 | 4.67 | 0.09 | 4.07 | 4.18 | 0.24 | +0.11 |
| 17.07 | 2.82 | 0.16 | 3.53 | 0.29 | 3.18 | 4.01 | 0.20 | +0.83 |
| 17.09 | 3.01 | 0.16 | 3.00 | 0.15 | 3.00 | 4.04 | 0.27 | +1.04 |
| 18.82 | 1.61 | 0.11 | 2.56 | 0.21 | 2.09 | 2.37 | 0.30 | +0.28 |

*Expected value is the average of the HT and LT dried values.

equilibrium relative humidity. This means that although the two samples were blended together at the same moisture, they were not at the same moisture when the test was run because they were equilibrated 6 days prior to testing. Because of the more pronounced exponential moisture relationship for the high-temperature dried corn (Eckhoff et al., 1988b), the blended sample increased in breakage because the breakage increased due to moisture loss in the high-temperature dried corn at a faster rate than the low-temperature corn decreased in breakage because of its increased moisture content. To illustrate this effect, a blended sample of 12% m.c. corn can be adjusted by using the exponential regression equations developed for the high-temperature and low-temperature dried corn equation [1] and [3], respectively). If the moisture did not migrate in the blended sample, the high-temperature dried corn would have a breakage susceptibility of 15.4%, and the low-temperature dried corn would have a breakage value of 11.1%. The expected value for the blend would be 13.3%. If moisture transfer occurred such that the high-temperature dried corn lost 0.5% moisture content and the low-temperature dried corn increased by 0.5% moisture content, then the breakage values would be 17.8% for the high-temperature dried corn and 9.95% for the low-temperature dried corn. The average then would be 13.9%, or an increased breakage value, as was observed in the experimetnal data.

The magnitude of the observed difference between the measured value and the calculated blended value should remain positive as long as the individual samples from the blends were dried by different enough methods to affect the moisture isotherms. Moisture dependence was greater for the high-temperature dried corn than for the low-temperature dried corn, and a decrease in moisture for the high-temperature dried corn would always result in a greater increase in breakage susceptibility than could be compensated by the low-temperature dried corn.

## CONCLUSIONS

Rewetted samples had a lower standard deviation for the measured Wisconsin breakage values as compared to samples originally dried to the same moisture content. Rewetting did not appear to consistently affect breakage values. There was no clear trend as to the sign of the difference between the rewetted corn values and the values of samples originally dried to that moisture content.

Blending of samples that had the same moisture content but that were dried by different methods and had different breakage susceptibility levels resulted in breakage values for the blended samples that were higher than a linear weighted average of the two individual components. The difference between the measured breakage and the expected average value was generally greater than the standard deviation for samples with a moisture content below 15% and was of the same magnitude as the standard deviation for samples above 15% moisture content.

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