Moisture Content and Temperature Effects on Wisconsin Breakage Tester Results

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ABSTRACT

THE factors affecting breakage susceptibility on corn were determined over the temperature range −13°C to 90°C, and moisture contents 7.18% to 19.66% (w.b.). Breakage susceptibility increased exponentially with decreasing moisture content and decreasing temperature. The effect of moisture content and temperature on breakage susceptibility was strongly dependent on corn variety and drying condition. Significant interaction was also found between moisture content and temperature on breakage susceptibility. Based upon the strong moisture dependence and its interaction with drying condition and variety, the utility of the Wisconsin Breakage Tester in the market channel is questioned.

INTRODUCTION

In order for results from a breakage susceptibility tester to be used as part of the grade determining factors for corn, it is be important to know the dependence of the breakage susceptibility value upon the kernel moisture content and temperature. Corn brought into an elevator where a market grade is determined is often tested at or near outside ambient conditions. This may be considerably different from the temperature or moisture content at which the corn is ultimately stored or handled. The breakage value measured may need to be adjusted to a standard temperature and moisture in order for the test to be meaningful in the grain trade. This study was undertaken to determine the temperature and moisture content dependence of breakage values determined by the Wisconsin Breakage Tester.

REVIEW

Herum and Blaisdell (1981) reported that corn breakage susceptibility, as measured in three instruments (Stein CK-2M, Stein CK-2, and a centrifugal impacter), is greatly influenced by sample moisture content. Small changes in moisture content within the range of 12% to 14% corresponded to large differences in the measured breakage susceptibility. They also found that a major reduction in breakage susceptibility occurred as the moisture content increased to 13% and that the breakage susceptibility approached zero near 25% m.c. for the centrifugal impactor. They inferred that the breakage mechanism in corn might be expected to change as water mobility changes in the product. Tran et al. (1981) concluded that corn at higher moisture contents has a more plastic bran and a softer endosperm than at lower moisture contents.

Thompson and Foster (1963) found that there was a slight increase in damage at moisture contents above 25% and at lower rotational speeds when using a centrifugal impact tester. Jindahl et al. (1979) showed that the rate of corn breakage was lowest at 25% m.c. Paulsen (1983) found slightly higher breakage at moistures above 25% m.c. and explained this result due to the soft nature of the pericarp at moisture contents above 26%.

Regression models were developed by several researchers. Sharda and Herum (1977) and Singh and Finner (1983) developed a two-way polynomial regression model that combined the effects of kernel moisture content and impeller rotational velocity. Paulsen (1983) developed a family of exponentially decaying equations of the form $y = a\ \exp(-CM)$ to express breakage susceptibility of corn for moisture contents between 8% to 21% for the Wisconsin Breakage Tester. Others have used a similar exponential model (Herum and Hamdy, 1985; Moes, 1986; Singh and Finner, 1983; Thompson and Foster, 1963; Tran et al., 1981).

The effect of temperature on breakage susceptibility is not as pronounced as the effect of moisture content. Gunasekaran and Paulsen (1985) reported that the lower temperatures increased the breakage susceptibility values. Thompson and Foster (1963) reported that the amount of breakage doubled when the temperature of some samples of corn was reduced from 29°C to 5.5°C. Herum and Blaisdell (1981) conducted tests with three instruments (Stein CK-2M, Stein CK-2, and a centrifugal impactor) using samples at 4.4°C, 22.2°C, and 37.8°C. They found BCFM diminished an average of 2.1%/°C from 4.4°C to 22.2°C and 1.8%/°C from 22.2°C to 37.8°C. Jindal et al. (1979) reported the impact damage to corn increases with decreasing temperatures according to an exponential relationship when using a small rigid-hammer mill. Herum and Blaisdell (1981) suggested that a moisture-temperature interaction may exists.

METHODS AND PROCEDURES

Effect of Moisture Content

Samples of five varieties (Pioneer 3377, PayMaster 7990, Keltgen KS-1151, Northrup King PX 9540, and

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Dekalb 711) of corn were dried, using three different methods, to five target moisture content levels (18%, 16%, 14%, 12%, and 10%). Actual moisture varied from 7.18% to 19.66%. The five varieties were machine harvested at approximately 25% moisture content and dried (Eckhoff et al., 1988). The samples were dried by one of the following three drying methods:

1. High temperature drying at 110°C to the desired moisture content.
2. High temperature drying at 110°C to 18% m.c. followed by ambient air drying (25°C ± 3°C) to the desired moisture content.
3. Ambient air drying (25°C ± 3°C) to the desired moisture content.

Samples at each drying condition were prepared in duplicate.

Five replicates of each sample were measured for breakage susceptibility using the WBT (Singh and Finner, 1983) following the procedure of Gunasekaran and Paulsen (1985) with a feed rate of approximately 200 g/min. Two sieves were used, a 4.76 mm (12/64 in.) precision round hole sieve and a 6.35 mm (16/64 in.) sieve to measure breakage.

Samples of the five varieties were also hand harvested and hand shelled at 25% moisture content. The samples were dried by natural convection to 15% m.c. in the laboratory. Values determined from these samples served to evaluate the effect mechanical harvesting had on breakage susceptibility.

Effect of Temperature

Two corn varieties, Pioneer 3377 and PayMaster 7990, were machine harvested as previously described and dried to produce four subsamples having different levels of breakage susceptibility. These four different levels of breakage susceptibility were produced by using different drying conditions (Eckhoff et al., 1988). Each drying condition was run in duplicate. The four drying conditions 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 (25°C ± 3°C) to 15% moisture content.
3. High temperature drying at 110°C to 18% moisture content followed by ambient air drying (25°C ± 3°C) to 15% moisture content.
4. Ambient air drying (25°C ± 3°C) to 15% moisture content.

Each sample was divided into eight subsamples with a Boerner grain divider with seven of the eight subsamples randomly selected for use. Seven temperatures, −13°C, 2°C, 14°C, 22°C, 34°C, 64°C, and 90°C, were chosen to be evaluated with the seven subsamples randomly assigned to the various temperature levels. For temperatures below 40°C, the samples were held in temperature controlled incubators for 24 h prior to testing. To keep the quality and moisture content of the samples unchanged, the samples above 40°C were held in a temperature controlled oven 3 h prior to testing. The samples were periodically mixed to insure uniform temperature.

Interaction between Moisture Content and Temperature

One corn variety, Pioneer 3377, was selected for testing the moisture-temperature interaction. Five temperatures (−13°C, 2°C, 14°C, 22°C, and 34°C) and two moisture contents (9.95% and 14.59%) were studied. Samples were machine harvested and shelled at approximately 25% moisture content and then dried 110°C. A two-way ANOVA was used to analyze for moisture-temperature interaction.

RESULTS AND DISCUSSIONS

Effect of Moisture Content

A complete analysis of the experimental results has been published by Wu (1987), including a listing of the original experimental data.

The data show that moisture content has a strong influence on corn breakage susceptibility. For the data of the five corn varieties, the breakage susceptibility values range between 1.15% − 49.56% and 2.86% − 78.82%, for the 4.76 mm and the 6.35 mm sieve measurements, respectively.

The data of the five corn varieties was pooled in order to determine an overall correlation between the moisture content and breakage susceptibility. Fig. 1 shows the pooled data for the 4.76 mm sieve. Results for the 6.35 mm sieve are similar. Both quadric and exponential regression models were tested. The exponential model of the form $y = a \exp(-CM)$ has the highest coefficients of correlation, and thus was chosen as the test model. This correlates with the results of Paulsen (1983) and Moes (1986). In the model, "a" and "C" are variables and "M" is the moisture content in percentage wet basis. The best fit regression equations determined from the pooled

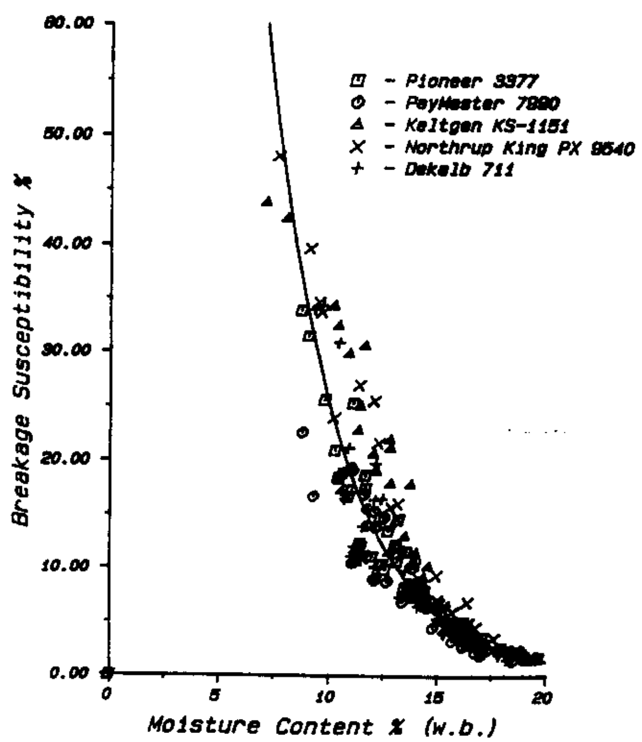

Fig. 1—Effect of moisture content on breakage susceptibility of five corn varieties using a 4.76 mm sieve.

data are:

$$BrSu\,\% = 511.8\ EXP(-0.298\ M);\ R^2 = 0.89;\ (4.76\text{ mm Sieve}) \qquad [1]$$

$$BrSu\,\% = 652.0\ EXP(-0.257\ M);\ R^2 = 0.86;\ (6.35\text{ mm Sieve}) \qquad [2]$$

The R-square value appears high but observation at one moisture content shows that there is a high degree of variation. For example, at 12.5% moisture in Fig. 1, the breakage susceptibility value ranges from approximately 8% to almost 25%. The R-square is a measurement of the sum of squares error from the model divided by the total sum of squares of each observation from the mean value. When there is a strong dependence (in this case with moisture content), a high R-square value can be misleading and one needs to focus on absolute error or absolute variability as an indicator. The large absolute variability is highly undesirable and indicates that in the use of the WBT, adjustment for moisture content will not be possible without knowledge of the factors causing the range of values observed.

Significant differences in breakage susceptibility among corn genotypes has previously been reported (Stroshine et al., 1981 & 1986; Paulsen et al., 1983; Vyn and Moes, 1986; Moes, 1986). Five individual regression models were established in this study for breakage susceptibility as a function of moisture for each corn hybrid. The exponential regression models for each corn variety are presented in Table 1 for the 4.76 mm sieve show that the R-square value for each individual variety is generally higher than when all the varieties were considered together. Similar results were observed for the 6.35 mm sieve.

Fig. 2 shows that the breakage susceptibility for the Pioneer 3377 variety is strongly dependent on the drying condition, especially when the moisture content, of the corn is below 14%. The results for the other four varieties are similar. When drying condition and variety are held constant, the R-square values range from 0.88 to 0.98 for the 4.76 mm sieve and 0.86 to 0.97 for the 6.35 mm sieve over all five varieties and all three drying conditions. Table 2 shows the best fit models for each constant variety and drying condition for the 4.76 mm sieve. Similar results were observed for the 6.35 mm sieve. When all the varieties are included along with drying condition as the only variable, the R-square values decrease (Table 3).

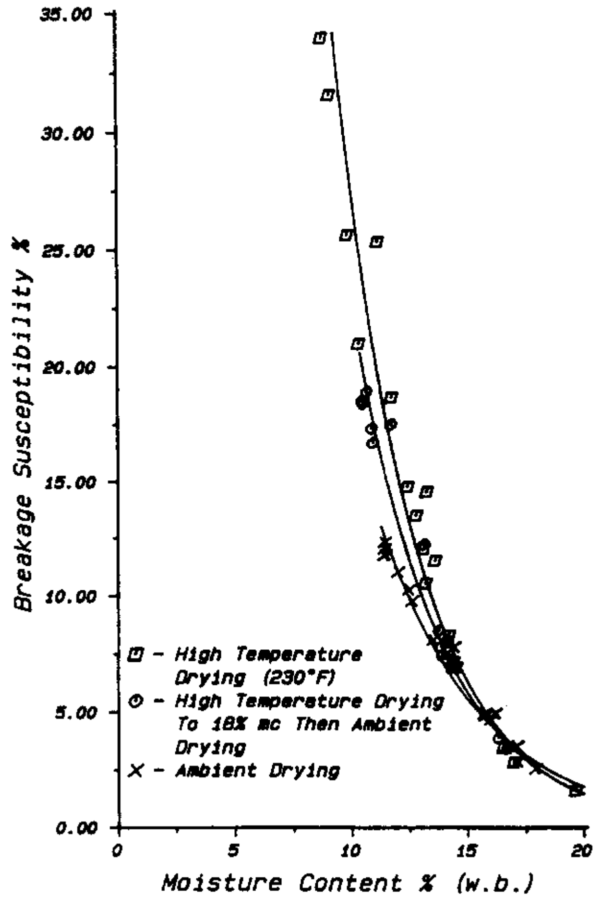

Fig. 2—Effect of moisture content on breakage susceptibility of the Pioneer 3377 variety using a 4.76 mm sieve.

Fig. 2 also show that as the moisture content increases to 15% to 17%, the effect of variety and drying condition is minimized and the curves seem to coincide. Similar results were observed for the other four varieties. This indicates that at 15% moisture content, the drying condition used does not affect breakage susceptibility.

TABLE 1. EXPONENTIAL REGRESSION EQUATIONS REPRESENTING MOISTURE CONTENT RELATIONS WITH BREAKAGE SUSCEPTIBILITY % OF VARIOUS CORN VARIETIES MEASURED WITH THE WISCONSIN BREAKAGE TESTER USING A 4.76 mm SIEVE

Model: BrSu % = A EXP(–CM)

Corn variety	Estimate of parameters A	C	R-SQUARE
Overall	511.83	0.2982	0.89
Pioneer 3377	374.65	0.2762	0.94
PayMaster	413.64	0.2962	0.88
Keltgen KS-1151	627.03	0.3038	0.88
Northrup King PX9540	566.80	0.2958	0.91
Dekalb 711	672.50	0.3239	0.93

TABLE 2. EXPONENTIAL REGRESSION EQUATIONS REPRESENTING MOISTURE CONTENT RELATIONS WITH BREAKAGE SUSCEPTIBILITY % OF VARIOUS CORN VARIETIES AND VARIOUS DRYING CONDITIONS MEASURED WITH THE WISCONSIN BREAKAGE TESTER USING A 4.76 mm SIEVE

Model: BrSu % = A EXP(–CM)

Corn variety	Drying condition	Estimate of parameters A	C	R-SQUARE
Pioneer 3377	110°C	533.79	0.2956	0.96
	110°C ambient	352.13	0.2730	0.96
	ambient	173.99	0.2293	0.96
PayMaster 7990	110°C	492.26	0.3169	0.94
	110°C ambient	1203.51	0.3573	0.92
	ambient	149.31	0.2319	0.95
Keltgen KS-1151	110°C	799.51	0.3144	0.90
	110°C ambient	826.33	0.3162	0.90
	ambient	156.80	0.2267	0.98
Northrup King PX 9540	110°C	863.51	0.3218	0.95
	110°C ambient	622.66	0.3010	0.93
	ambient	137.14	0.2068	0.88
Dekalb 711	110°C	1298.55	0.3634	0.97
	110°C ambient	836.31	0.3382	0.96
	ambient	188.48	0.2437	0.95

TABLE 3. EXPONENTIAL REGRESSION EQUATIONS REPRESENTING MOISTURE CONTENT RELATIONS WITH BREAKAGE SUSCEPTIBILITY % OF VARIOUS DRYING CONDITIONS MEASURED WITH THE WISCONSIN BREAKAGE TESTER USING A 4.76 mm SIEVE

Model: BrSu % = A EXP(-CM)			
Drying condition	Estimate of parameters A	C	R-SQUARE
Overall	511.83	0.2982	0.89
110°C	750.70	0.3218	0.91
110°C ambient	636.51	0.3095	0.90
ambient	156.65	0.2257	0.92

Practical experiences by the authors suggests that this is not true.

Other factors beyond corn variety and drying conditions are likely to have an effect on the relationship between breakage susceptibility and moisture content. For the same corn hybrid, the breakage susceptibility and moisture content. For the same corn hybrid, the breakage susceptibility changes with the growing conditions, geography, climate, etc. (Stroshine et al., 1986). Development of a general equation which can predict the effect of moisture content accurately will thus be difficult. In this study, only five corn varieties and three drying conditions for corn grown at one location in one year were considered. If more corn varieties and drying conditions or even other management factors are considered, the coefficient of determination would likely decrease. If a general equation can be developed regionally, the variation will still be considerable because several factors will always be unknown for the incoming corn samples. Stroshine et al. (1986) found a remarkable difference in different growing years (1980 and 1981) even for the same corn hybrid and drying treatment. Based on the experimental data in this test, the variation in breakage susceptibility can be as large as 15 percentage points at 12% m.c. due to different drying conditions (see Pioneer 3377 variety, Fig. 2). This large variation is not equitable to both the buyer and the seller. Development of a classification system where breakage susceptibility is adjusted to a standard moisture is not feasible because the buyer needs to know both the variety and the drying condition.

The only reasonable alternative is to report the breakage susceptibility along with the test moisture content and temperature. If the breakage value correlates with the amount of broken corn generated as the corn is handled at that moisture content and temperature, it could then be useful. However, the purchaser of the corn will not be able to accurately predict the amount of potential damage generated if the corn is conditioned to another moisture content or temperature.

Due to the strong effect of moisture content, the determination of sample moisture content is very important to the breakage susceptibility test. For the Dekalb 711 variety dried at a high temperature to 13% moisture level, a 0.5% error in the moisture measurement can cause a change in the breakage value of 1.6%. The magnitude of this error will increase at lower moisture contents, especially for the high temperature dried samples.

TABLE 4. THE EFFECT OF MECHANICAL HARVESTING AND SHELLING ON BREAKAGE SUSCEPTIBILITY FOR FIVE DIFFERENT CORN VARIETIES USING A 4.76 mm SIEVE

		Breakage susceptibility		
Variety	Moisture content % w.b.	Hand harvesting & shelling	*Adjusted machine harvesting & shelling	Difference (machine-hand)
Pioneer 3377	14.13	7.29	7.19	-0.10
	14.13	7.73	7.07	-0.66
PayMaster 7990	14.42	4.63	5.56	+0.93
	14.50	5.08	4.78	-0.30
Keltgen KS-1151	15.19	4.00	5.24	+1.24
	15.19	4.00	5.05	+1.05
Northrup King PX 9540	15.32	4.01	5.75	+1.74
	15.32	3.87	8.52	+4.65
Dekalb 711	14.30	4.15	6.21	+2.06
	14.42	4.36	6.01	+1.65

*Adjusted using the equation BS% = 156.65 EXP(-0.2257 MC).

Machine harvesting and shelling increases the susceptibility of the kernels to breakage as compared to hand harvesting and shelling (Table 4). In general, the machine harvested and shelled samples had higher breakage susceptibility values than the hand harvested and shelled samples. Similar results were observed for the 6.35 mm sieve where only one sample had a negative difference. The machine harvested and shelled samples' breakage susceptibility values were adjusted to the same moisture content as the hand harvested and shelled samples using the equation BrSU % = 156.65 EXP(−0.2257 M), which was the best fit model for natural air-dried machine-harvested corn when using a 4.76 mm sieve. The increase in breakage susceptibility due to machine harvesting is small in relation to the amount of increased breakage susceptibility due to drying.

Effect of Temperature

A least square regression of the experimental data indicated that breakage susceptibility increases exponentially with decreasing temperature. The breakage susceptibility values ranged between 1.58% to 21.4% for the 4.76 mm sieve, and 4.1% to 41.77% for the 6.35 mm sieve. The temperature effect observed by Jindal et al. (1979) was similar, although they used the Stein Breakage Tester.

Using all the experimental data, the best fit exponential models developed are:

$$\text{BrSu \%} = 10.14\ \text{EXP}(-0.019\ T);\ R^2 = 0.78;\ (4.76\ \text{mm Sieve}) \quad [3]$$

$$\text{BrSu \%} = 21.26\ \text{EXP}(-0.018\ T);\ R^2 = 0.81;\ (6.35\ \text{mm Sieve}) \quad [4]$$

These models do not accurately predict the breakage susceptibility based on corn temperature due to the confounding effects of variety and drying condition. There was a large divergence in the breakage susceptibility results, especially at low temperatures. When the experimental data were separated by corn variety and drying condition, the predictive capabilities of the equations improved. However, the coefficient of determination was not greatly improved when the

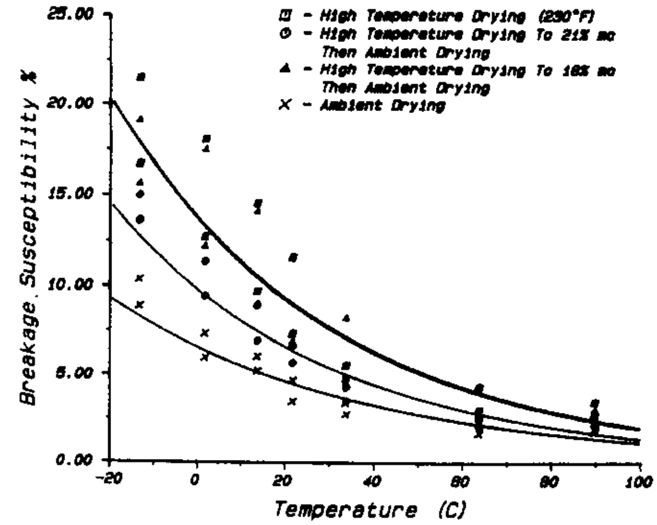

Fig. 3—Effect of temperature on breakage susceptibility of the Pioneer 3377 variety dried at four different drying conditions using a 4.76 mm sieve.

regression equations were developed using data grouped by corn variety alone. Fig. 3 shows the temperature dependence of the Pioneer 3377 using a 4.76 mm sieve. Similar results were observed for the 6.35 mm sieve and for PayMaster 7990. Table 5 shows the best fit models for when the data are separated by variety and drying condition for the 4.76 mm sieve.

The breakage susceptibility values at 90°C are slightly higher than those at 64°C, as can be observed in Fig. 3. The variations observed at these higher temperatures might be caused by experimental error due to loss of sample moisture because of difficulties in sealing the glass bottles. Small changes in moisture can greatly affect breakage values as shown previously.

Drying condition is more significant than the corn hybrid in estimating the temperature effect on breakage susceptibility. Because the temperature dependence is a function of the drying method and because the curves for each drying condition are not parallel, the usefulness of a temperature compensation equation is limited.

Interaction between Moisture Content and Temperature

A significant interaction between moisture content and temperature was observed (Fig. 4). Herum and Blaisdell (1981) inferred that the breakage mechanism might be expected to change as water mobility changes in the product.

TABLE 5. EXPONENTIAL REGRESSION EQUATIONS REPRESENTING TEMPERATURE RELATIONS WITH BREAKAGE SUSCEPTIBILITY % OF VARIOUS CORN VARIETIES AND VARIOUS DRYING CONDITIONS MEASURED WITH THE WISCONSIN BREAKAGE TESTER USING A 4.76 mm SIEVE

Model: BrSu % = A EXP(-CT)

Corn variety	Drying condition	Estimate of parameters A	C	R-SQUARE
Pioneer 3377	110°C	13.8599	0.0194	0.81
	110°C ambient(21)	9.8257	0.0198	0.91
	110°C ambient(18)	13.7357	0.0197	0.88
	ambient	6.5601	0.0175	0.87
PayMaster 7990	110°C	13.0137	0.0203	0.95
	110°C ambient(21)	10.2267	0.0202	0.91
	110°C ambient(18)	10.0041	0.0205	0.90
	ambient	7.0569	0.0182	0.85

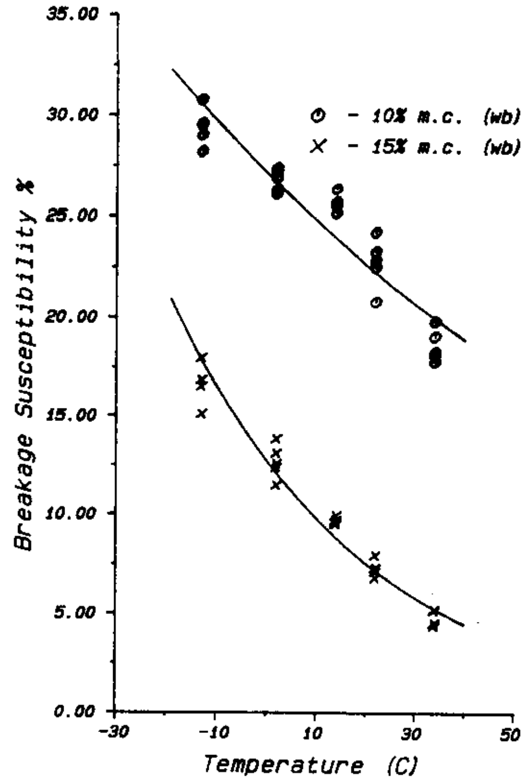

Fig. 4—Temperature and moisture interaction on breakage susceptibility of the Pioneer 3377 variety.

The data was fit to the exponential model with the following values:

$$BrSu\,\% = 12.74\ EXP(-0.026\ T);\ R^2 = 0.96;\ (14.59\,\%\ m.c.) \quad [5]$$

$$BrSu\,\% = 27.14\ EXP(-0.009\ T);\ R^2 = 0.87;\ (9.95\,\%\ m.c.) \quad [6]$$

An analysis of variance was performed on the data showing that there are significant moisture content and temperature interactions at the 99% level. There is also likely to exist an interaction between moisture content temperature and drying condition. These interactions would need to be pursued in greater detail if moisture content and temperature compensation models were to be developed.

SUMMARY AND CONCLUSIONS

Corn breakage susceptibility is greatly affected by both moisture content and temperature. The relationships between breakage susceptibility and moisture content is best fit by an exponential model as previous investigation has found (Paulsen, 1983; Moes, 1986). Breakage susceptibility values increased with decreasing temperature and can be modeled with a similar exponential relationship. Both the moisture content and temperature relationship to breakage susceptibility are functions of the drying procedure used. The curves for the drying conditions are not parallel to each other but tend to cross or converge at a moisture content of 15% to 17% and at high temperatures (90°C). Significant moisture content and temperature interactions were observed.

Development of a single model or set of models which can be used in the market channel to predict breakage susceptibility values does not seem plausible because of the dependence of the relationship upon knowledge of the drying condition. These models may be useful for research purposes.

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