3d

FACTORS AFFECTING WISCONSIN BREAKAGE TESTER RESULTS ON CORN

by

PO-CHING JOHNNY WU

B.S., National Taiwan University, 1981

A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1987

Approved by:

Steven R. Eckhoff
Major Professor

ACKNOWLEDGEMENTS

Completion of a research project requires the assistance of many individuals. I would like to express my gratitude to all who contributed to the completion of my master's degree.

My deepest appreciation goes to Dr. Steven R. Eckhoff as major advisor for his encouragement and guidence during my graduate program. I also wish to acknowledge Dr. Do Sup Chung and Dr. Joseph P. Harner as members of my graduate committee for their guidance and instruction.

Special thanks go to Marty Criswell, Jian Hua, and Suzie Ivy for their careful help during the collection of data. I would also like to thank Leonard Obaldo for his help with the preparation of samples. I also wish to acknowledge the financial support provided by the Federal Grain Inspection Service.

My most sincere thanks go to my lovely wife, Ya-chen. Without her support and encouragement, I never would have made it. Last, but certainly not least, I wish to particularly thank my parents, Wa-chou and Li-tsai Wu. Their love and encouragement have been a constant source of strength throughout my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

In the calendar years 1984 and 1985 the volume of the United States grain exports dropped significantly from earlier record tonnages. The pattern has persisted into 1987. While a variety of factors have contributed to this loss of export market, one complaint that is heard from importing countries is that the quality of U.S. grain is low and has been decreasing. While quality covers a broad area including microbial damage, insect damage, and foreign material, the amount of broken corn that is found in overseas shipments is of considerable concern.

Harvesting and drying methods are the major contributors to breakage potential, even though actual breakage will occur farther down through the market channel with additional handling. Stress cracks and internal fissures in the starch structure of corn consistently increase the chances of breakage during handling. Rougher or more severe handling also increases the amount of breakage.

Broken corn which is generated by handling has a detrimental economic effect due to loss of market value, susceptibility to microbiological damage, loss of value for food purposes, and the cost of removal. Broken corn and the dust generated during breaking is also believed to be a primarily cause of elevator explosions and fires.

In commercial handling, corn kernels are physically stressed by a combination of forces including compression, impact, shear, and abrasion, but most researchers agree that impact probably is the greatest contributor to corn breakage. The only commercially available device for routine measurement of grain breakage susceptibility is the Stein Breakage Tester (SBT) which is not primarily an impact device. The Wisconsin Breakage Tester (WBT) is an impact device developed for quality testing shown considerable promise in assessing corn breakage susceptibility in the market channel. This thesis work was undertaken to evaluate the reliability of the Wisconsin Breakage Tester and to evaluate the dependence of its results upon the factors of moisture content, temperature, rewetting, and blending.

II. OBJECTIVES

1. To evaluate the reliability and consistency of the results from the Wisconsin Breakage Tester (WBT).
2. To establish the reproducibility limits of the WBT as a function of corn moisture content, temperature, and breakage susceptibility level.
3. To define the relationship between corn moisture content, temperature, and breakage susceptibility as measured by the Wisconsin Breakage Tester.
4. To determine the effect of rewetting and blending on the measured corn breakage susceptibility.

III. REVIEW OF LITERATURE

Breakage Susceptibility of Corn

Breakage susceptibility can be defined as the potential for kernel fragmentation or breakage when subjected to impact forces during handling and transport (AACC, 1983). Breakage susceptibility has been referred to by many terms such as breakage proneness, kernel resilience, brittleness, and breakability, etc. Factors which affect kernel breakage susceptibility include stress cracks, moisture content, grain temperature, corn genotype, thickness of horny endosperm, drying method and seasonal growing conditions. The official U.S. Standards for corn grading includes broken corn and foreign material (BCFM) as a major grading factor (USDA, 1978). 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 portion that remain on the top of the sieve. A major drawback in this grading standard is that it ignores the potential of kernels to break upon subsequent handling (Gunasekaran and Paulsen 1986). Adapting breakage susceptibility as part of the U.S. grading standard for corn would provide purchasers with additional information concerning corn quality and end use acceptibility.

Buyers, domestic and foreign, prefer corn that is not susceptible to breakage during handling. Recent advances in mechanization of grain production and handling have resulted in a significant increase in physical damage to corn. The progressive increase in broken corn and foreign materials during transit between the origins and destinations has been a major concern to buyers, special to the foreign buyers. Although the broken corn, depending on use, may not be of any lower value than whole corn, the present of broken corn and foreign materials results in lower grain quality, lower market value and increased processing, handling, and storage problems. For both wet and dry milling, numerous problems can be caused by broken corn in process. Corn may be handled as many as 20 times from harvest to export and thus there is considerable opportunity for breakage. There have been several investigations reporting the extent of kernel damage due to various handling operations (Fiscus et al., 1971; Hall, 1974; Paulsen and Hill, 1977; Paulsen and Nave, 1980; Pierce and Hanna, 1985). These studies indicate that BCFM increases with an increased number of handlings, depending on the severity of the handling operation.

Stephens and Foster (1976) provided the first correlative study between actual breakage due to various spout configurations and values predicted by the Stein CK-2 tester, showing acceptable precision (r = 0.87 to 0.99) for market grain. Herum and Hamdy (1981) reported that the difference between actual and predicted breakage is diminished with more breakable corn. They concluded that the inconsistencies between actual damage and that predicted by the instruments is sufficiently large to imply that breakage prediction remains poorly understood. They suggestes that more testing be performed.

Gunasekaran and Paulsen (1986) concluded that a general estimation of tendency for kernel breakage is very difficult. An increase in the breakage susceptibility in the SBT with increasing times shows that repeated handling of corn needs a different set of standards than a sample that may not be handled as often. Higher breakage susceptibility values from a WBT, which uses a harsher impacting action than the SBT, colaborates their conclusion. They suggested that it is not appropriate to choose a single type of breakage tester or testing conditions as a standard for corn grading. More than one set of testing standards is necessary depending on the anticipated severity and number of handlings.

Significant differences in breakage susceptibility were also obtained among various corn genotypes. Vyn and Moes (1986) found that there were greater differences in breakage susceptibility values among different corn hybrids than between different levels of any other management factors (e.g. population, harvesting stage, and drying temperature). Certain interactions among the management factors were also significant including an interaction between corn hybrid and drying temperature. They suggested that corn hybrids differ in their response to drying at high temperatures and consequently that the effect of high drying temperatures on physical quality may be more critical with certain hybrids (e.g. First Line 1636) than with others (e.g. Pioneer 3707).

In their analysis, there was also a significant interaction in breakage susceptibility between harvest moisture content and drying temperature. Breakage susceptibility increased more with drying temperature for corn harvested at 24% than for corn harvested at 30% grain moisture. They concluded that the choice of variety appeared to be the single-most important management criteria affecting grain corn quality as determined by analyses of test weight, breakage susceptibility and kernel stress cracks. The second-most important criteria affecting grain corn quality was harvest moisture content. Harvesting wetter corn generally resulted in greater mechanical damage, lower test weights, increased stress cracking, and higher breakage susceptibility values.

Stroshine et al. (1981 & 1986) evaluated 13 corn inbreds or hybrids for storability, milling quality, drying rate, and breakage susceptibility. They found the inbred B73 and the hybrid B73 x Mo17 to be relatively high in breakage susceptibility and relatively low in milling quality.

Paulsen et al. (1983) concluded the breakage susceptibility obtained by centrifugal impacting widely grown Corn-Belt genotypes varies significantly. Genotypes with FR4A x FR4C as a female parent were usually low in breakage susceptibility. They also found the corneous endosperm thickness varies greatly within genotypes but generally increases as kernel density increases.

Since corn with low amounts of corneous endosperm appears to be soft and easily damaged during handling, it was thought that tests for kernel hardness might be of value in understanding why genotypes vary in breakage susceptibility. Typically the ratio of corneous-to floury endosperm is about 2 to 1 in dent corn (Wolf et al., 1952).

Stress Cracking of Corn

Stress cracks are fissures in the endosperm caused by thermal or mechanical stresses, that are beneath a sound intact seed coat. Stress cracks can be distinquished from mechanical damage which includes a rupture or fracture in the seedcoat of the corn kernel. When the seed coat of stress cracked kernels are removed by soaking or scraping, the endosperm breaks easily at the points of the stress cracks. Stress cracks are readily visible under bright light by a simple candling process or using Fast Green FCF dye analysis. The stress cracks are classified, according to the stress pattern (single, multiple, or checked) formed in the kernel.

Balastreire et al. (1982) studied the fracture in corn endosperm in bending. They found the fracture in corn endosperm initiates in the center of the kernel, apparently due to internal flaws in the weaker region of floury endosperm, and propagate toward the outside through the cell walls and around the starch granules.

Bilanski (1966) determined the energies and forces required to initiate fracture in grains, using three loading conditions of gradually applied load, low-velocity impact and high-velocity impact. For the corn kernels tested with germ side down, the energy to initiate fracture ranged from 0.023 to 0.068 J, (0.2 to 0.6 lb-in) within the range of moisture contents studied, 1 to 17 percent on wet basis. For kernels on edge and same range of moisture contents the energy required varied from 0.0023 to 0.0046 J, (0.02 to 0.04 lb-in.).

Thompson and Foster (1963) found none of the dried test samples had an equal distribution of single crack, multiple cracks, and checked kernels. Large numbers of checked kernels and kernels with single or no stress cracks in the same lot might indicate that overdried and underdried corn were mixed. The first indication of drying stress was a single crack, usually extending from the tip toward the crown of the kernel and visible on the side of the kernel opposite the germ. As stress increased, multiple cracks appeared, some kernels developed a checked or crazed appearance.

Thompson and Foster (1963) investigated the relationship between the formation of stress cracks and the breakage susceptibility in artificially dried corn. They found that the susceptibility to breakage increased as the number of stress cracks in the corn increased. The correlation coefficient of this relationship is 0.79 and the standard error from the regression was ±2.58 (% breakage). Large round kernels were more subject to stress cracks than flat kernels. Drying speed, expressed in term of moisture loss in percentage points per hour, was the most significant factor in stress crack development. The number of stress cracks increased with increased drying temperatures and air flow rate, both contributors to drying speed. The amount of drying (the number of percentage points the moisture content is reduced) as well as the speed appears to affect stress crack development. Puffing of kernels is more damaging than stress cracks. When drying from initial moisture levels near 30%, puffing started at drying speeds of 8 to 10 percentage points per hour. The internal structure of the puffed kernel was changed sufficiently which reduced the development of stress cracks.

Thompson and Foster (1963) also found most of the stress crack developed when the corn was drying through the range of 19 to 14 percent with 160°F drying air. Drying from higher moisture levels or with different drying air temperatures may or may not show the same critical moisture range for stress crack development. For the corn field-shelled at 30% moisture content, machine harvesting contributed about as much to the breakage as artificial drying. More stress cracks formed in shelled corn dried at room temperature (80°F) than in ear corn dried at 160°F. They also confirmed that slow cooling was helpful in preventing stress-crack formation, and concluded the stress cracks in artificial dried corn are reduced (1) at slow drying speed (especially through the range of 19 to 14% moisture content) and (2) when cooling of the dried corn is delayed until after a tempering period.

Mechanical Breakage Testers

The methods to measure breakage susceptibility can be classified into two group: 1) subjective methods that measure the extent to which whole kernels show stress cracks, and 2) methods that measure the amount of cracked grain formed when whole grains are impacted or ground. The latter methods are preferred because they are quite simple to operate, objective, and reproduciable (Miller et al, 1981).

There are basically two types of breakage testers. The first type utilizes impacting action of a moving blade or impeller on a stationary 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). Several researchers have employed pendulum type apparatus for determining impact damage resistance of grain (Zoerb and Hall, 1960; Bilansk, 1966; Srivastava et al., 1976; Mensah et al., 1976). But most of these testers have not been used in market channels because they employ sophisticated instrumentation and elaborate testing procedures resulting in their unsuitability. McGinty (1970) reported that other proposed testing devices produced inconsistent results with no standard with which to compare the results, and recommended a standard breakage test using the Stein grain breakage tester.

Of the various breakage tester designs the Stein CK-2M Breakage Tester (SBT) and the Wisconsin Breakage Tester (WBT) are the most popular. The mechanism involved, and the types of damage created in these two testers are quite different. the WBT impinges individual kernels on a stationary surface at a high velocity and thereby tend to crack or chip small pieces from the crown of the kernel. Whereas, the SBT produces an abrasive type of pericarp damage created by multiple impact of a fast moving blade in a sample holder cup.

From field to ultimate user, the process of harvesting, drying, storing, and handling corn physically stresses the kernels by a combination of forces including compression, impact, shear, and abrasion. Opinions differ as to which force in commercial handling is most important to breakage, but most agree that impact probably is the greatest contributor to corn breakage (Watson and Herum 1986).

The only commercially available device for routine measurement of grain breakage susceptibility, the Stein Breakage Tester (SBT), is not primarily an impact device. Thus, there was a need to develop a commercially acceptable instrument to test for susceptibility to routine breakage on impact (Watson and Herum 1986).

When kernels are added to the cup of the Stein tester at the start they are accelerated by the blade, but subsequently much of the breakage is caused by abrasion against the cup wall and other kernels. This probably explains why the SBT causes little damage to sound (unstressed) corn kernels (Watson and Herum 1986).

Herum and Hamdy (1981) concluded that all three instruments (Stein CK-2M, Modified Stein, and Centrifugal-impact) they tested could detect differences in corn breakage susceptibility as determined by actual passes through a conventional feed elevator. They concluded an instrument that more nearly duplicates actual handling damage will inherently be a better predictor of damage susceptibility over the broad range of variables affecting kernel resistance to breakage.

Miller et al. (1981) reported that there was no consistent relationship with the commercial grain grade and the breakage susceptibility values obtained with the Stein Breakage Tester (SBT). Sharda (1976) observed breakage with the Stein Breakage Tester of less than 1% in kernels which had been carefully dried and hand-shelled, and stated the STB is incapable of differentiating between levels of high quality corn. They also suggested that the centrifugal impact device was a simple tester and testing technique which would subject the kernels of a corn sample to more rigorous impact, and less abrasion, than the Stein tester, and broaden the range of kernel strengths which could be evaluated.

Miller et al. (1979) built a grain acceleration device to approach a normal grain handling operation. Their tester accelerated kernels at velocities from 19.5 to 42.8 m/sec (64.0 - 14.04 ft/sec) and impacting them against corn from the same sample. The velocity of 31.5 m/sec (103.3 ft/sec) was selected because the speed gave reasonable breakage for damaged corn and didn't break sound corn extensively. It exceeded the theoretical velocity of 24.4 m/sec which was calculated for corn free falling velocity vertically over

30.5 m. The Stein Breakage Tester accentuated differences between samples and had a greater potential for differentiating among samples. The Stein Breakage Tester produced about three times more brokens than the grain accelerator even though their results highly correlated (r = 0.98, DF = 7).

Gunasekaran and Paulsen (1986) investigated breakage susceptibility of two corn genotypes using the WBT and the SBT. Their results showed that a sample subjected to more severe handling needs a different set of standards than a sample subjected to a less severe handling operation. They felt it may not be appropriate to choose a single type of breakage tester or testing conditions as a grading standard for all corn samples. Depending on the anticipated severity and number of handlings, the corn may be classified under two or more groups and breakage susceptibility testing standards can be developed appropriately.

Paulsen (1983) determined the breakage susceptibility relationship between the Wisconsin, Illinois, and Model CK-2M Stein testers over the range of 8 to 21 percent moisture for one corn variety. The relatively low breakage susceptibility values compared to the centrifugal impactors indicated that the CK-2M Stein tester did not adequately distinguish between high quality corn lots that were naturally or low-temperature dried.

Schmidt et al. (1968) evaluated the precision of estimating mechanical damage in shelled corn by visual means and found that the main sources of variation were differences in operator performance, and sampling differences. The men used in their experiment had no former experience in reading damage, and were taught what constitutes damage in test runs and then began reading samples. Observed differences resulted largely from decisions on the minute fractures. The test concluded that the precision of estimating a corn lot could be improved by (1) increasing sample size, (2) increasing the number of people reading the samples, or (3) increasing the number of subsamples tested per sample.

Wisconsin Breakage Tester

The Wisconsin Breakage Tester was originally developed at the University of Wisconsin, Madison (Singh and Finner 1983) as a device for rapidly testing the susceptibility of grain to handling breakage. It's a centrifugal impeller device which is specially constructed to cause a single impact to each kernel tested.

Watson and Herum (1986) compared eight devices for measuring breakage susceptibility of shelled corn. They found that the Wisconsin Breakage Tester, with a CV of 1.4%, was the most precise. Precision of results was determined by the coefficient of variability (CV). Table 3.1 displays the mean breakage value, standard deviation, and coefficient of variance for the eight breakage devices tested. They selected the Wisconsin Breakage Tester as the best all-round device for eventual commercial development.

Table 3.1 Comparison of eight devices using a 12/64" sieve

	Breakage Susceptibility %		
Breakage Testers	Mean	S.D.	C.V.
Cargill Impacter 17.0 m/sec	5.79	0.353	6.1
20.5 m/sec	12.59	0.314	2.5
Illinois Impacter	6.83	0.823	12.0
Missouri Cracker	22.44	1.343	6.0
Ohio Impacter	28.92	2.157	7.5
Modified Stein	14.58	1.24	8.5
Stein CK-2M	27.10	1.49	5.5
USGMRL Grain Accelerator	4.62	0.266	5.8
Wisconsin Breakage Tester	36.25	0.523	1.4

Miller et al. (1981) reported that the harsh action of the SBT produced a greater percentage of broken corn than did the grain accelerator (Miller et al. 1979). The grain accelerator they used, which throws corn against corn at a velocity approximating the speed of corn free falling 100 feet, is different from Wisconsin Breakage Tester. Paulsen and Hill (1983) reported that SBT (2-min) test on commercial corn produced 35 to 85% higher breakage susceptibility values than those obtained with centrifugal impactor types but also had a larger variation in the breakage susceptibility values.

Martin et al. (1984), on the other hand, reported less damage and breakage for 12.6% moisture corn with the SBT than with the WBT. Even though the SBT showed a larger difference in the breakage susceptibility values. It also showed a more significant difference among the various hybrids of corn tested than the WBT. Paulsen et al. (1983) reported that the SBT does not easily distinguish differences in breakage susceptibility among hand-shelled, low-temperature dried genotypes. Gunasekaran and Paulsen (1985) observed that the SBT produced lower breakage susceptibility values for corn dried at 20 and 35°C, and higher values for corn dried at 50 and 65°C than the WBT. In general low-temperature dried corn has higher breakage susceptibility with WBT than with SBT and the opposite is true for high-temperature dried commerical corn.

Gunasekaran and Paulsen (1986) found a considerable increase in breakage susceptibility values as the drying temperature increased from 35 to 50°C. This is perhaps due to a decrease in kernel strength below a level at which the kernel can reasonably withstand impact forces. The reduction in breakage susceptibility values between 35 and 50°C was more dramatic in the WBT than in the SBT which indicates that the action of WBT is much harsher than that of SBT under normal operating conditions. Comparing the breakage susceptibility values from the WBT to SBT, it appears that 6-min of impacting is required in the SBT to obtain a breakage equivalent to that in the WBT.

Herum and Hamdy (1981) reported that the single-impact type of instrument causes greater breakage than the Stein when testing low-susceptibility kernels. But this difference disappears as susceptibility increases. Neither type showed a clear advantage over the other for predicting actual damage on the market grain studied.

Eckhoff et al. (1985) stated that the weakness of the Wisconsin Breakage Tester is that only a single impact is applied on each kernel. The actual loading that the kernels are subjected to during actual handling and transport is variable in frequency and magnitude. In this respect, the Stein Breakage Tester is a more realistic estimate of breakage susceptibility than the Wisconsin Breakage Tester. Eckhoff, et al (1985) suggested that breakage susceptibility be measured by studing the maximum force required to break individual kernels in a sample. A maximum breakage force distribution curve can be generated by breaking a statistically large enough number of kernels. In this way, the ability of the grain to withstand impact can be described by the force distribution curve. They modified a Tag-Heppenstahl moisture tester to measure the force encountered by a corn kernel during crushing. Corn kernels were individually dropped into the rollers and the resultant forces on the rollers recorded by a load cell. They also suggested a similar situation can be observed using a individual kernel in the Stein breakage tester.

Size Distribution of Broken Corn and Foreign Material

Herum and Hamdy (1981) reported that the selection of the sieve size for describing BCFM is influenced by the distribution of particle sizes. Their results indicated that handling in the feed elevator caused a greater proportion of finer particles than either the Stein CK-2M or the centrifugal-impact tester. The 12/64" sieve is likely adequate for measuring broken proportions from actual handling damage, but greatly underestimates total broken material with the breakability testers, especially the impact type. Large size sieves may be more appropriate for describing BCFM from the test instruments.

All impact devices showed large increases (41-68%) in broken corn through the 6.35-mm sieve compared to the 4.76-mm sieve, whereas the increased percentage in the Stein CK-2M tester was only 8% and in the modified SBT was only 25%. These data emphasize the difference in types of devices. The impact devices produce a greater assortment of sizes, whereas the SBT produces a blend of mostly fine material and whole kernels (Watson and Herum 1986).

Herum and Blausdell (1981) concluded that samples from the single-impact type of device contain a greater proportion of larger particles and therefore breakage results are more affected by sieve size used. They also found that an interaction exists between the type of instrument used and the effects of sieve size due to differences in particle size distribution. They suggested that sieve size larger than the standard 12/64" round-hole sieve, up to 16/64" at which some smaller whole kernels will pass, pass a greater proportion of visibly-damaged kernels and could be expected to provide a better measure of breakage. Miller et al. (1981) also stated that the advantage of 16/64" sieve is that broken kernels and small sound kernels are removed.

Gunasekaran and Paulsen (1986) used the Fineness Modulus in evaluating the overall effect of breaking action in WBT and SBT at different operating conditions. Fineness modulus is a measure of average particle size in a mixture of particles of varied sizes. Since a small FM value represents a small average particle size, the breakage susceptibility will be high. Therefore, the breakage susceptibility values were inversely related to the FM values. In other words, kernels susceptible to high breakage tend to yield a broken sample with small average particle size.

Gunasekaran and Paulsen (1986) determined that the impacting action of the WBT tends to discriminate the breakage tendency of the kernels more closely than the SBT. They also found that increasing the drying air temperature did not cause a corresponding increase in the proportion of kernels that tend to break; but only caused additional breakage of the already broken kernels. The action of the WBT is much harsher on the kernels than that of the SBT causing a large proportion of the kernels to break up, as well as causing finer fraction in the sample. From their results, they suggested a 16/64" sieve is more discriminating than a 12/64" sieve for use in determining the breakage susceptibility. Stroshine (1986) determined that breakage susceptibilities were not well correlated with percentages of fine material in the samples of corn (R-square = .092) or soybeans (R-square = .00013).

The SBT has been shown to be adequate for laboratory evaluation of stress-cracked kernels and causes very little breakage of sound kernels. The impact devices such as the WBT do break sound grain that has been carefully dried and contains no stress cracks. Thus, the SBT gives a more precise estimate of stress-cracked kernels. However, for commercial use, in which only broad categories of breakage are to be identified in market corn, speed of throughput is more important than precision of results. Another consideration in developing a device for commercial use is its adaptability for automation. All impact devices tested qualified in this respect (Watson and Herum 1986).

Vyn and Moes (1986) concluded that measuring the extent of breakage after placing samples through the WBT with a 12/64" screen may not have been able to accurately assess the extent of kernel damage. Although use of the 12/64" screen is the accepted procedure, cooperative work with other corn quality labs in the United States may lead to modifications to the WBT itself or to the screen size (e.g. from 12/64" to 16/64" diameter openings).

Schmidt (1987) determined the breakage values using the 16/64" sieve's values and CV's are similar but standard deviation and standard errors are higher. Statistial data indicated standard deviations of 1.32, 0.67, and 0.63 for single values in the 16/64", 12/64" (14 labs), and 12/64" (12 labs), respectively. Gunasekaran and Paulsen (1986) concluded a 16/64" sieve is more discriminating than 12/64" sieve for use in determining the breakage susceptibility. Eckhoff et al. (1985) also stated the use of a 12/64" sieve to measure damage is rather arbitrary. When a kernel breaks in half in either kinds of the breakage testers, it is still classified as a whole good kernel because it does not go through a 12/64" sieve.

Effect of Moisture Content on Corn Breakage Susceptibility

Thompson and Foster (1963) determined that the moisture content and temperature of the sample at the time the test is made influenced the breakage perhaps even more than the usual variations in the drying treatment. The kernel became more friable as the moisture content was reduced. When moisture content was reduced below about 13 percent, breakage increased rapidly. For this reason, all breakage comparisons were at moistures of approximately 13.5 percent. When breakage susceptibility tests are used to indicate the breakage expected in the commercial channel, the moisture level is an important test factor and should be representative of the lot of corn under consideration.

Hoki and Pickett (1973) evaluated the factors affecting mechanical damage of navy beans using a laboratory impact tester. They observed that moisture content and temperature played a major role in determining the impact strength of beans. A decrease in moisture content appeared to greatly increase the brittleness of the bean. Beans with a low moisture content were very susceptibile to splitting when impacted from the side. They referred that this was probably due to either the space between the two cotyledons or internal cracks in the cotyledons. Bean moisture should not be lowered to a point that will cause internal cracking or a large space between the cotyledons.

Jindal et al. (1979) found specific rate of corn breakage was lowest at 25% m.c. and increased as moisture increased to 26% m.c. or decreased to 24% m.c.. Paulsen (1983) also had the similar result with slightly higher breakage at moistures above 25% m.c.. They explained this might be due to the soft nature of the pericarp at 26% m.c.. Therefore, a complete calibration procedure, including selection of rotational speeds to reflect kernel strength differences due to moisture content and to temperature (Jindal et al., 1979), also must be performed before the tester can serve the market grain industry.

Herum and Blaisdell (1981) reported corn breakage susceptibility, as measured in three instruments (Stein CK-2M, Stein CK-2, and Centrifugal Impacter) is greatly influenced by sample moisture content. Small change in moisture content within the range of 12 to 14%, representing much of the corn in market channels, correspond with large differences in indicated breakage susceptiblity. They found a major reduction in breakage susceptibility occurred as moisture content increases at about 13% moisture, but the severity of breakage changes between instruments or test mechanism utilized. The single-impact appeared to be less sensitive to moisture content, tending to induce greater breakage and hence more capable in differentiating quality levels of higher moisture corn samples. They also found breakage approached zero near 25% m.c. on centrifugal impactor. The shape of the breakage versus moisture content curves is similar to that of the latent heat of drying versus free moisture relationship reported by Kumar et al., (1978) with the points of inflection in the same moisture region.

From drying studies, moisture binding is believed to increase as moisture content decreases, due to changes in moisture state within the product. At moisture of 20% and above in corn, the water is likely to be physically entrapped only in the interstices. At somewhat lower moisture contents, equilibrium moisture curve shapes suggest that the moisture is present in multiple layers and consequently has lower displacement mobility. Moisture content of about 12%, depending upon temperature and cultivar, appear to be at the boundary between monolayer water, which is relatively immobile, and multiple layer or more mobile water. BET (Brunauer, Emmett and Teller) isotherms and similar isotherms show a breakage in shape at this point. From this, Herum and Blaisdell (1981) inferred that the breakage mechanism might be expected to change as water mobility changes in the product. It appears that increased moisture premits energy to be absorbed without fracture of the layers between starch granules and tearing of the cell walls of the epidermal layers. Tran et al. (1981) concluded that corn at higher moisture content has more plastic bran and softer endosperm than at low moisture content.

A two-way regression model combined effects of kernel moisture content (M) and impeller rotational velocity (S) was developed by Sharda and Herum (1977). For the hand-shelled corn:

$$\text{Damage} = 49.83 + 0.0186\,(S) - 8.68\,(M) + 0.19\,(M)^2 \qquad (3.1)$$

(r = 0.88; all coefficients are significant at 99.78% level)

While for the machine-shelled corn,

$$\text{Damage} = 71.00 + 0.224\,(S) - 11.67\,(M) + 0.26\,(M)^2 \qquad (3.2)$$

(r = 0.91; all coefficients are significant at 99.99% level)

The results clearly indicated that kernels with large moisture contents can absorb greater impact forces without mechanical damage. For machine-shelled corn sample, their results also showed some slight increase in damage at moisture contents above 25% and at the lower rotational speeds.

Singh and Finner (1983) also developed a model for the experimental data using peripheral speed of the impeller (m/s) and moisture content (% w.b.) as regressors in a centrifugal impactor. The best fit polynomial model derived was:

$$\text{BS}\ \% = -39.94 + 2.7189\ S - 0.0621\ S\ M + 0.022\ M^2 \qquad (3.3)$$

(R-Square = 96.3%; all coefficients are significant at 99.5%)

Paulsen (1983) measured breakage susceptibility using two sieve sizes, 12/64" and 16/64", as a function of moisture content. The percentages of breakage susceptibility measured by the Wisconsin Breakage Tester with 16/64" sieve decreased exponentially from 17 percent at 9% m.c. to 0.7 percent at 21% m.c.. Breakage susceptibility values using a 16/64" sieve were about 80 percent higher than using the 12/64" sieve over all moistures. The breakage susceptibility values for WBT follow a family of exponentially decaying equations of the form y = a exp(-CM) for moisture content between 8 to 21 percent moisture (Figure 3.1). For hand-shelled FRB73 x MO17 corn, the regression equations are

$$BS\ \% = 171.3\ EXP(-0.280\ M) \quad R^2 = 0.89\ (12/64"\ \text{Sieve}) \qquad (3.4)$$

$$BS\ \% = 290.2\ EXP(-0.283\ M) \quad R^2 = 0.93\ (16/64"\ \text{Sieve}) \qquad (3.5)$$

The CK-2M Stein tester fits a quadratic equation as below:

$$BS\ \% = 9.6 - 1.07\ M + 0.030\ M^2 \qquad (3.6)$$

$$R^2 = 0.85\ (16/64"\ \text{Sieve})$$

$$BS\ \% = 8.7 - 0.98\ M + 0.028\ M^2 \qquad (3.7)$$

$$R^2 = 0.83\ (12/64"\ \text{Sieve})$$

Herum and Hamdy (1985) used Paulsen's exponential regression equation to develop an equation for predicting breakage susceptibility at a reference moisture content

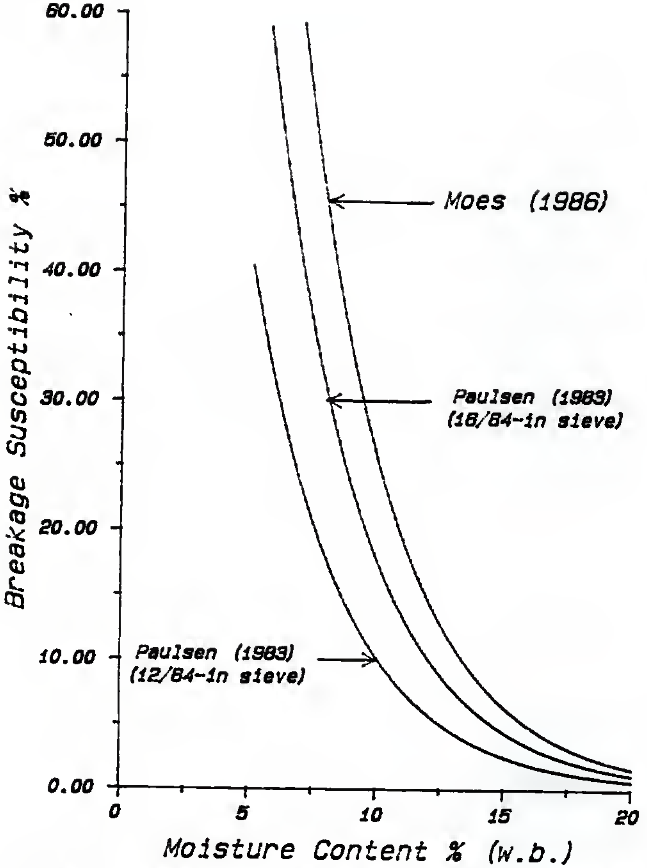

Figure 3.1 Comparison of the regression equation of breakage susceptibility vs. moisture content determined in the literature for the Wisconsin Breakage Tester.

from breakage susceptibility measured from another moisture content.

$$(BS\ \%)_r = (BS\ \%)_m \times EXP[0.29(Mm - Mr)] \qquad (3.8)$$

where the subscripts r and m refer to reference and given moisture contents, respectively.

Moes (1986) investigated the relationship between breakage susceptibility and moisture content. Five corn hybrids, two drying temperature and two harvest moisture content were used in the regression study. The regression equation which best fit all the data was exponential in form and agreed well with previous work reported by Paulsen (1983) was

$$BS\ \% = 419.9\ EXP(-0.280\ M) \qquad (R^2 = 0.683) \qquad (3.9)$$

A similar equation with Herum and Hamdy's (1985) was also developed from data collected in the study and is as follows:

$$(BS\ \%)_r = (BS\ \%)_m \times EXP[0.29(Mm - Mr)] \qquad (3.10)$$

where the subscripts r and m refer to reference and given moisture contents, respectively. The use of the equation which adjust breakage susceptibility values to a reference moisture content is necessary to the use of a breakage test in a commercial grading situation.

Figure 3.1 also shows a comparison of the regression equations determined from the data in the literature for the Wisconsin Breakage Tester. The breakage susceptibility values are expressed as functions of moisture content.

Several other researchers have reported results similar to an exponential decay type of response, in that the increase in breakage susceptibility with decreasing moisture content becomes more pronounced at lower moisture content (Gustafson and Morey, 1979; Singh and Finner, 1983; Thompson and Foster, 1963; Tran et al., 1981).

Vyn and Moes (1986) found that there were greater differences in breakage susceptibility values among different corn hybrids than between different levels of any other management factors. Singh et al. (1986) determined the differences resulting from different corn hybrids, one dummy variable was employed for the analysis as the responses of two dent corn hybrids could be represented by a single response curve. Singh (1985) established a regression model for each parameter as a function of moisture for individual corn hybrids.

Some studies about the relationship between corn's mechanical properties and moisture content were reported by several researchers. Zoerb and Hall (1960) determined basic mechanical properties of corn. They observed that the mechanical properties such as modulus of elasticity, maximum compressive stress and shear stress generally increase as moisture increased. Shelef and Mohsenin (1969) determined the effect of moisture on mechanical properties of corn endosperms. The linear limit load, modulus of elasticity, and modulus of deformability decresed with an increase in kernel moisture. They found the major contributer to mechanical properties was the horny endosperm. At low levels of moisture content, the horny endosperm was very stiff or non-elastic.

Balastreire et al. (1982) studied the fracture of corn endosperm in bending. They found the stresses and energies required for initiation and propagation of cracks in corn horny endosperm are independent of kernel moisture content and temperature over the range of 10 to 20 percent moisture content (db). Thus, the progressive fracture in handling is proportional to kernel modulus of elasticity which is strongly influenced by both moisture content and temperature. They concluded that increases in breakage susceptibility to mechanical damage in handling with diminishing moisture content are probably due to increasing modulii of elasticity resulting in greater stresses due to given impact forces or strains.

Singh et al. (1986) studied the mechanical behavior of dent and flint corn hybrids in the moisture range of 6-34% wb. The rewetted corn samples were used in their study. The mechanical strengh parameters such as ultimate stress, modulus of elasticity, modulus of toughness, and modulus of resilience decreased exponentially as kernel moisture increased. The ultimate stress, modulus of elasticity, modulus of toughness, and modulus of resilience were determined using the standard definitions for these properties (Mohsening, 1980). Both modulus of toughness and utimate stress appeared to be highly correlated to the breakage susceptibility. The coefficients of correlation were significant only for the modulus of toughness in the acceptable moisture range (12-18% wb) for the Wisconsin breakage measurements. Therefore, the modulus of toughness might be taken as a measure of kernel resistance to impact damage. An exponential model representing the decay of corn modulus of toughness as a function of moisture was established. The regression model was

$$M_T = EXP(1.70 - 0.0576M + 0.106Z) \quad R^2 = 93.7 \qquad (3.11)$$

Z = 0 For Dent Corn

Z = 1 For Flint Corn

Effect of Temperature on Corn Breakage Susceptibility

Thompson and Foster (1963) found that lowering the temperature of the corn sample tested made it more brittle. When the temperature of some samples of corn was reduced from 84 to 42°F, the amount of breakage doubled. If the breakage susceptibility test is used to predict breakage in a lot of corn to be handled, the test sample should be at the same temperature as the mass of corn to be handled.

They concluded the sample moisture content and temperature during testing influenced the breakage perhaps even more than usual variations in the drying treatment.

Hoki and Pickett (1973) observed that moisture content and temperature played a major role in determining the impact strength of beans. Amount of damage increased rapidly as temperature was decreased particularly for temperatures below 50°F. Gunasekaran and Paulsen (1985) reported that decreasing corn temperature increased the breakage susceptibility values. The effect of temperature was not as pronounced as the effect of moisture content.

Herum and Blaisdell (1981) conducted tests in three instruments (Stein CK-2M, Stein CK-2, and Centrifugal Impactor) with samples at 4.4, 22.2, and 37.8°C. They found BCFM diminished an average of 2.1%/°C from 4.4 to 22.2°C; and the equivalent decrease was 1.8%/°C from 22.2 to 37.8°C. From these data, it is apparent that temperature correction factors are essential to standardize breakage test results, regardless of the type of breakage instrument function. They also suggested that a moisture-temperature interaction likely exists and may be practically important. The future tests to determine temperature correction factors should include moisture as a variable, as changes in sensitivity and perhaps mechanism of damage, with moisture mobility. At lower moistures, fracture susceptibility, elastic-like moduli, and brittle fracture growth are potential parameters with different temperature coefficients than those of viscous displacement and membrane elasticity.

Since frictional heat is generated in the Stein cups during the 1/2 to four-minute tests, some reduction in breakage susceptibility might occur during the course of a test. Rises of 2.1 to 4.9°C were noted but these are compounded by the fact that the cup itself warms over time, due to repeated use and by conducted heat from the drive unit above. Presumably, heat generated by the sample under test is a function of the degree of breakage, moisture content, and test duration, but no data to quantify this were obtained. An ideal instrument would presumably avoid or minimize this problem (Herum and Blaisdell 1981).

Jindal et al. (1979) reported the impact damage to corn increases with decreasing temperatures according to an exponential relationship. A generally linear inverse relationship existed between temperature and logarithm of specific breakage rate. The specific rate of breakage using a small rigid-hammer mill was determined at several kernel temperatures ranged from 0 to 60°C.

Miller et al. (1979 & 1981) found greater susceptibility of corn to breakage at low temperature using a CK-2 Stein tester. The breakage-prone corn decreased in breakage susceptibility (12/64" sieve) by 0.23 percentage per degree C increase in corn temperature over the range of

0 to 40°C, and sound corn decreased by 0.06 percentage per degree C.

Breakage Susceptibility of Rewetted Corn

Bemis and Huelsen (1955) studied the fracture of popcorn endosperm in relation to drying and rehydration. They found the amount and severity of endosperm fracture were found to be directly related to the rate of moisture uptake and inversely related to the initial moisture content of the unconditioned kernels.

The pattern of stress cracks caused by rewetting and rehydration is very similar to that reported by Kunze (1979) in discussing the development of fissures in rice grain. He observed that rice grains were not fissured at the end of drying, but that fissures developed after some period of time had elapsed. On this basis, he hypothesized that fissuring of rice after drying is caused by a diffusion of moisture within the grain resulting from the moisture gradient existing in the grain when it is removed from the dryer. He referred that the external cells expand as they absorb moisture from central portions of the grain while the cells in the central portion contract as they lose moisture. The net result is the development of compressive stresses near the surface and tensile stresses near the center which (if large enough) can lead to internal fissuring.

Kunze (1979) also reported that a low moisture grain surface may pick up additional moisture from environment and, thereby, hasten the development of fissures. It follows that a low moisture grain with no initial moisture gradient could also fissure by being exposed to a high humidity environment provided the rate of moisture gain by the external grain cells is rapid enough to cause high tensile stresses to develop in the center portion of the grain. White et al. (1982) observed that stress cracks can also develop in popcorn while it is being reconditioned to a high moisture content. These cracks tend to develop during the reconditioning process rather than afterwards.

White et al. (1982) investigated the stress crack development in popcorn as influenced by drying and rehydration processes. Their results indicated the lower the initial moisture content and the faster the conditioning rate, the higher the incidence of stress cracks. Stress cracks in popcorn were apparently caused by moisture stresses which develop during rehydration process. This supported the concept that popcorn can fissure whenever the external cells absorb moisture rapidly and expand, thereby causing high tensile stresses to develop in the center of the grain.

Brekke (1968) studied stress crack formation caused by rewetting low-moisture corn. Corn with initial moisture contents of 10% to 20% was rewetted by the addition of 11 cc. of tap water per 100 gram corn d.b. at 24°C. This amount is equivalent to an 8-9% moisture addition. Rewetting corn with an initial moisture content of 20.1% produced no stress cracks in a 6-hour period. For 14.6% corn, almost 50% of the kernels developed stress cracks in 2 hours. The rate of stress crack formation showed further increases as initial moisture of corn was lowered to 10.1%. When 13.4% moisture corn was rewetted at 24°C to moisture levels of 15, 16, 18, and 21%, no stress cracks developed at 15% moisture, but stress cracking increased as moisture levels were progressively raised to 21%. For 21% moisture, approximately 60% of the kernels had stress cracks after 2 hours.

Salter (1986) studied the rehydration of corn and found rehydration reduced the breakage susceptibility. He found the rehydrated corn had higher breakage susceptibility values than the directly drying down breakage susceptibility. The breakage susceptibility values decreased to a minimum, before increasing to an equilibrium value. The equilibrium breakage susceptibility was reached at approximately the same time as the electronic moisture meter agreed with the oven determined moisture content. All stress cracks seemed to be formed during the first hour after blending with water. The non-uniform distribution of water in the first hour was reflected in the high variability of the stress crack content.

Breakage Susceptibility of Blended Corn

Hoki and Pickett (1973) evaluated the factors affecting mechanical damage of navy beans using a laboratory impact tester, with four levels of dry corn (8, 9, 11, and 8.9% desiccant) blended with 24.4% moisture corn to two theoretical moisture levels (15.5 and 20%). They found blending wet and dry corn increases breakage susceptibility but probably not enough to result in a discount at the time of first sale. When blending corn to 15.5% moisture, the lower the moisture content of dry portion, the higher the susceptibility of the blend to breakage. Similar results appeared in blending corn to 20% moisture. Blending wet and dry corn to 15.5% results in less breakage than blending to 20% moisture. All the extra breakage for the 20% blend is in the dry portion. Drying corn from 24.4% to 11% or less and then rewetting it to 20% probably stresses kernels more than drying to 11% or less and then rewetting to only 15.5%. The breakage susceptibility values of blended samples was not proportional to the ratio, but less than the average, of blending of wet and dry portions. It may be that the wet kernels act as a cushion in the blend and reduces breakage of the dry portion during breakage tests.

Nguyen et al. (1981) investigated the breakage susceptibility of blended corn which was conducted with four moisture levels of dried corn (8, 9, 11, and 8.9%

desiccant) blended with 24.4% moisture corn to two theoretical moisture levels (15.5 and 20%). Their results showed that blending wet and dry corn increases the Stein breakage 0.74 to 4.74 points for a 15.5% blend and 1.54 to 10.6 points for a 20% moisture blend. The breakage susceptibility of blends of wet and dry corn increases with a decrease in moisture content of the dry portion, and this breakage susceptibility is higher for a 20% moisture blend than for a 15.5% moisture blend. They also found the breakage in local handling due to blending wet and dry corn is likely to be from 0.1 to 1.7%, which will probably not result in a discount at the time of sale. Miller et al. (1981) reported the breakage susceptiblity of a mixture of corn can be estimated from both the proportions and the breakage susceptibilities of the components of the mixture, by using a linear relationship.

Salter (1986) studied the moisture content, breakage susceptibility, and stress content of blending corn. The breakage susceptibility values for the 10% rehydrated blended corn coincided with the breakage susceptibility values of directly drying down corn. The breakage susceptibility of the low moisture corn decreased slowly toward the equilibrium value. The breakage susceptibility of the high moisture portion reaches its equilibrium rapidly. The magnitude of change from the initial breakage susceptibility to the final breakage susceptibility was greater for the low moisture portion. In his experiment, the equilibrium breakage susceptibility values in rewetting or blending were less than half of the initial breakage susceptibility values. The main difference between rewetting and blending was that the stress cracks in the rewetting are mainly multiple cracks where the stress cracks in blended corn were mainly single cracks.

References

AACC. 1983. American Association of Cereal Chemists. Method 55-20. Corn Breakage Susceptibility. St. Paul, MN 55121.

Balastreire, L. A., F. L. Herum, K. K. Stevens, and J. L. Blaisdell. 1982. Fracture of Corn Endosperm in Bending. Part I. Fracture Parameters. TRANSACTION of the ASAE 25(4): 1057-1061, 1065.

Balastreire, L. A., F. L. Herum, K. K. Stevens, and J. L. Blaisdell. 1982. Fracture of Corn Endosperm in Bending. Part II. Fracture Analysis by Fractography and Optical Microscopy. TRANSACTION of the ASAE 25(4): 1062-1065.

Bemis, W. P. and W. A. Huelsen. 1955. Dehydration and Rehydration in Relation to Endosperm Fracturing of Popcorn. Proceedings of the American Society for Horticultural Science. 65: 371-380.

Bilanski, W. K. 1966. Damage Resistance of Seed Grains. TRANSACTION of the ASAE 9(3): 360-363.

Brekke, O. L. 1968. Corn Dry Milling: Stress Crack Formation in Tempering of Low Moisture Corn and Effect on Degerminator Performance. Cereal Chemistry. 45: 291-303.

Eckhoff, R. S., A. B. Davis, K. C. Behnke, and P. J. Barry. 1985. Measuring Breakage Susceptibility using an Individual Kernel Tester. Presented at NC-151 Workshop on Technologies for Grain Quality Evaluation. Toledo, OH, July 24-26.

Emam, A., M. R. Okos, G. H. Foster, and M. Fostes. 1979. Effect of Tempering Time on Quality Dried Corn. ASAE Paper No. 82-3015. ASAE, St. Joseph, Michigan 49085.

Fiscus, D. E., G. H. Foster, and H. H. Kaufman. 1971. Pysical Damage of Grain Caused by Various Handling Techniques. TRANSACTION of the ASAE 14(3): 480-485.

Gunasekaran, S., and M. R. Paulsen. 1985. Breakage Resistance of Corn as a Function of Drying Rates. TRANSACTION of the ASAE 28(6): 2071-2076.

Gunasekaran, S. and M. R. Paulsen. 1985. Breakage Resistance of Corn as a Function of Drying Rate. ASAE Paper No. 85-3024. St. Joseph, Michigan 49085.

Gunasekaran, S., and M. R. Paulsen. 1986. Standardizing Corn Breakage Susceptibility Testing. ASAE Paper 86-3035. St. Joseph, Michigan 49085.

Gustafson, R. J., R. V. Morey, C. M. Christensen, and R. A. Meronuck. 1978. Quality Changes during High-Low Temperature Drying. TRANSACTION of the ASAE 19(1): 162-169.

Gustafson, R. J. and R. V. Morey. 1980. Moisture and Quality Variation across the Column of a Crossflow Grain Dryer. ASAE Paper No.80-3513. St. Joseph, Michigan 49085.

Hall, G. E. 1974. Damage during Handling of Shelled Corn and Soybeans. TRANSACTION of the ASAE 17(2): 335-338.

Herum, F. L., J. L. Blaisdell. 1981. Effects of Moisture Content, Temperature, and test Variables on Results with Grain Breakage Testers. ASAE Paper 81-3030. St. Joseph, Michigan 49085.

Herum, F. L., M. Y. Hamdy. 1981. Actual Grain Handling Breakage Compared to predictions by Breakage Susceptibility Testers. ASAE Paper 81-3031. St. Joseph, Michigan 49085.

Hoki, M. and L. K. Pickett. 1973. Factors Affecting Mechanical Damage of Navy Beans. TRANSACTION of the ASAE 16(2): 1154-1157.

Jindal, V. K., F. L. Herum, and M. Y. Hamdy. 1979. Selected Breakage Characteristics of Corn. TRANSACTION of the ASAE 22(5): 1193-1196.

Kumar, A., F. L. Herum, and J. L. Blaisdell. 1978. Equilibrium Moisture Contents of Intact Corn Ears and Component Parts. ASAE Paper 78-3054. Logan, Utah.

Kunze, O. R. 1979. Fissuring of the Rice Grain after Heated Air Drying. TRANSACTIONS of the ASAE 22(5): 1197-1201, 1207.

Martin, C. R., H. H. Converse, Z. Czuchajowska, F. S. Lai, and Y. Pomeranz. 1984. Characteristics, Handling, Processing, of Corn of Various Size and Shape. Paper presented at the 1984 Winter Meeting of the ASAE. December 11-14, 1984.

McGinty, R. J. 1970. Development of a Standard Grain Breakage Test. ARS 51-34, Agricultural Research Service, USDA.

Mensah, J. K., F. L. Herum, J. L. Blaisdell, and K. K. Stevens. 1976. Impact Fracture Resistance of Selected Corn Varieties due to Drying Conditions. ASAE Paper 76-3042. St. Joseph, Michigan 49085.

Miller, B. S., J. W. Hughes, R. Rousser, and Y. Pomeranz. 1979. A Standard Method for Measuring Breakage Susceptibility of Shelled Corn. ASAE PAper 79-3087. St. Joseph, Michigan 49085.

Miller, B. S., J. W. Hughes, R. Rousser, and Y. Pomeranz. 1979. Note on a Method for Measuring Breakage Susceptibility of Shelled Corn during Handling. Cereal Chemistry 56(3): 213-216.

Miller, B. S., J. W. Hughes, R. Rousser, and Y. Pomeranz. 1981. Measuing Breakage Susceptibility of Shelled Corn. Cereal Food World 26(2): 75-80.

Moes, Jack. 1986. Grain Corn Breakage Susceptibility: Effects of Hybrid, Planting Density, Harvest Moisture Content, and Drying Temperature. Unpublished Master Thesis. University of Guelph.

Mohsenin, N.N. 1980. Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers, New York.

Nguyen, V. T., C. J. Bern, W. F. Wilcke, and M. E. Anderson. 1984. Breakage Susceptibility of Blended Corn. TRANSACTIONS of the ASAE 27(1): 209-213.

Paulsen, M. R., and L. D. Hill. 1977. Corn Breakage in Overseas Shipments - Two Case Studies. TRANSACTION of the ASAE 20(3): 550-557.

Paulsen, M. R., and W. R. Nave. 1980. Corn Damage from Conventional and Rotary Combines. TRANSACTION of the ASAE 23(5): 1110-1116.

Paulsen, M. R., W. R. Nave, and L. E. Gray. 1981. Soybean Seed Quality as Affected by Impact Damage. TRANSACTION of the ASAE 24(6): 1577-1582, 1589.

Paulsen, M. R., and L. D. Hill. 1983. Breakage Susceptibility of Exported Corn at Origin and Destination. TRANSACTION of the ASAE 26(1): 265-269, 274.

Paulsen, M. R., L. D. Hill, D. G. White, and G. F. Sprague. 1983. Breakage Susceptibility of Corn Belt Genotypes. TRANSACTION of the ASAE 26: 1830-1836, 1841.

Peplinski, A. J., O. L. Brekke, E. L. Griffin, G. Hall, and L. D. Hill. 1975. Corn Quality as Influenced by Harvest and Drying Conditions. Cereal Foods World. 20(3): 145-149, 154.

Pierce, R. O., and M. A. Hanna. 1985. Corn Kernel Damage during On-Farm Handling. TRANSACTION of the ASAE 28(1): 239-241, 245.

Salter, Kevin L. 1986. Rehydration of Corn: Effects of Time on Moisture Content, Breakage Susceptibility, and Stress Crack Content. Unpublished preliminary report. Department of Agricultural Engineering, University of Nebraska, Lincoln.

Schmidt, J. L., R. A. Saul, and J. L. Steele. 1968. Precision of Estimating Mechanical Damage in Shelled Corn. USDA Agricultural Research Service, ARS 42-142.

Schmidt, Dave. 1987. The 1985-86 Wisconsin Breakage Tster Collaborative Study. The Ohio State University, Wooster, Ohio 44691-6900.

Sharda, R., and F. L. Herum. 1977. A Mechanical Damage Susceptibility Tester for Shelled Corn. ASAE PAper 77-3504. St. Joseph, Michigan 49085.

Singh, S. S. 1980. Development of a Centrifugal Corn Breakage Tester. Unpublished M.S. Thesis. University of Wisconsin, Madison, Wisconsin.

Singh, S. S., and M. F. Finner. 1983. A Centrifugal Impacter for Damage Susceptibility Evaluation of Shelled Corn. TRANSACTION of the ASAE 26(6): 1858-1863.

Srivastava, A. K., F. L. Herum, and K. K. Stevens. 1976. Impact Parameters Related to Physical Damage to Corn Kernels. TRANSACTION of the ASAE 19(6): 1147-1151.

Stephens, L. E., and G. H. Foster. 1976. Breakage Tester Predicts Handling Damage in Corn. ARS-NC-49. Agricultural Research Service, USDA.

Stroshine, R. L., A. Eman, J. F. Tuite, A. W. Kirleis, L. F. Bauman, and M. Okos. 1981. Comparison of Drying Rates and Quality Parameters for Selected Corn Inbreds/Hybrids. ASAE Paper No. 81-3529. St. Joseph, Michigan 49085.

Stroshine, Richard L., Allen W. Kirleis, John F. Tuite, Loyal F. Bauman, and Abdalla. Eman, 1986. Differences in Grain Quality among Selected Corn Hybrids. Cereal Foods World 31(4): 311-316.

Stroshine, R. 1986. Breakage Susceptibility of Market Corn. Department of Agricultural Engineering, Purdue University, W. Lafayette, IN 47907.

Thompson, Ralph A., and George H. Foster. 1963. Stress Cracks and Breakage in Artificially Dried Corn. Marketing Research Report No. 631. Agricultural Marketing Service, USDA.

Tran, T. L., J. M. DeMan, and V. F. Raspar. 1981. Measurement of Corn Kernel Hardness. Cdn. Inst. Food Science Technology Journal 14: 42-48.

White, G. M., I. J. Ross, and C. G. Poneleit. 1980. Influence of Drying Parameters on the Expansion Volume of Popcorn. TRANSACTIONS of the ASAE 23(5): 1272-1276.

White, G. M., I. J. Ross, and C. G. Poneleit. 1981. Stress Crack Development in Popcorn as influenced by Drying Conditions. ASAE Paper No. 81-3032. St. Joseph, Michigan 49085.

White, G. M., I. J. Ross, and C. G. Poneleit. 1982. Stress Crack Development in Popcorn as Influenced by Drying and Rehydration Processes. TRANSACTIONS of the ASAE 25(3): 768-772.

Watson, S. A., F. L. Herum. 1986. Comparison of Eight Devices for Measuring Breakage Susceptibility of Shelled Corn. Cereal Chemistry. 63(2): 139-142.

USDA. 1978. The Official United States Standards for Grain. Federal Grain Inspection Service, Inspection Division, USDA.

Vyn, T. J., and J. Mose. 1986. Producing and Assessing High Quality Corn for Wet Milling in Ontario - Final . Report. Crop Science Department, University of Guelph.

Zoerb, G. C., and C. W. Hall. 1960. Some Mechanical and Rheological Properties of Grains. Journal of Agricultural Engineering Research 5(1): 83-93.

IV. MAGNITUDE AND SOURCES OF ERROR IN WISCONSIN BREAKAGE TESTER RESULTS

INTRODUCTION

The Wisconsin Breakage Tester (WBT) has been developed to evaluate the susceptibility of corn breakage during handling. Correlation of Wisconsin Breakage Tester results to the generation of broken corn would allow a method to be available to grain handlers for determining the quality of incoming corn and to separate the corn according to its potential to break up during subsequent handling. In order to use the Wisconsin Breakage Tester in routine testing of corn quality, its reproducibility limits need to 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 evaluated machine and non-machine source of error.

REVIEW

Schmidt (1987) reported the coefficients of variation, LSD, the general mean, and standard deviation of the 1985-86 NC-151 Wisconsin Breakage Tester Collaborative Study. He found the coefficients of variation for all breakage data were quite low but the range of average values for all 14 laboratories was quite large. Standard deviations were 0.67 and 1.32 for single value determination when using the 12/64" and 16/64" sieving screen, respectively. His results indicated a significant interaction between the samples and labs.

Singh and Finner (1983) reported on a centrifugal impacter that produced breakage values with lower coefficients of variation than the Stein Breakage Tester (SBT). The overall coefficient of variation for the Stein tester was 1.96 and 2.40 times greater than the values shown by the centrifugal tester at impeller speeds of 23.9 and 31.9 m/sec. Statistical analyses also indicated that an increase in impeller speed resulted in a greater consistency in the results, especially at higher moisture contents.

Paulsen (1983) compared the reliability of two WBT's. He compared samples at four moisture levels, ranging from 19 to 26 percent, and found that there was no significant differences between the two machines using either the

12/64" or 16/64" screen. He also found the impeller tended to force a large volume of air out the sample discharge opening, which necessitated the use of an enclosed sample collection pan.

Paulsen (1983) studied the coefficients of variation (CV) on both the WBT and the SBT using a 12/64" screen. The Stein tester consistently had the highest coefficient of variation. Coefficients of variation for the Wisconsin Breakage Tester ranged from 1 to 51 percent for the 12/64" sieve and from 2 to 31 percent for the 16/64" sieve. For the CK-2M Stein tester, the 12/64" sieve showed a CV less than or equal to the 16/64" sieve at values ranging from 0.8 to 50.6%.

Sharda and Herum (1977) studied the effect of feed rate on observed breakage using a WBT and found that the feed rate had no effect on the measured breakage susceptibility value over the range of feed rates provided by the vibratory feeder. Gunasekaran and Paulsen (1986) also found that the breakage susceptibility is independent of the WBT sample feed rate. A 4-way factorial experiment was performed by Singh and Finner (1983) to test the effects of sample size, feeding rate, kernel moisture, and impeller speed on the breakage results. The analysis of results showed that the effect of feeding rate was insignificant in the range of 450-1365 g/min.

METHODS AND PROCEDURES

Wisconsin Breakage Susceptibility

All the samples tested were pre-sieved on a Gamet sieve shaker using a 12/64" precision round hole sieve for 30 strokes. Each sample was subdivided into 200 gram subsamples weighed to the nearest 0.01 gram. All samples were randomized for testing with all tests performed with the instrument at approximately 21°C (±3°C). The WBT operation procedure was as described by Gunasekaran and Paulsen (1985) with a feeding rate around 200 g/min which was recommended for each run.

After being run through the WBT the samples were sieved for 30 strokes on a Gamet sieve shaker using a 12/64" precision round hole sieve with the overs being weighed, followed by sieving for 30 strokes using a 16/64" round hole sieve. The breakage susceptibility (%) of the sample was taken as the percentage of the sample able to pass through the sieve. Moisture content was determined using the standard 103°C, 72 hours oven method, and percent moisture was reported on a wet basis.

Factors Inherent to the Design and Construction of the WBT

Three Wisconsin Breakage Testers on temporary loan from the University of Missouri, Columbia, MO. (No. C006P), Identity Seed & Grain Company, Bloomington, IL. (No.

C019P), and the USDA Grain Marketing Research Lab, Manhattan, KS. (No. C007P), were used to evaluate the factors inherent in the design and construction of Wisconsin Breakage Tester that contribute to error in the measured value. The model numbers of the vibratory feeders were 413, 346, and 412, respectively. A single corn sample (11.59% m.c.) which had been divided into nine subsamples was randomly assigned to each treatment combination (Wisconsin Breakage testers X vibratory feeder). 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. Also, a Fisher's LSD pairwise comparison was used 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. These four corn lots were randomly assigned to one of four different feeding rates. The feeding rates used in the study were randomly chosen but covered the range 78 g/min to 727 g/min. The Fisher's LSD pairwise comparison (at 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 representing a range of agronomic characteristics that had been grown at the same location near Wamego, Kansas. The five varieties were Pioneer 3377, PayMaster 7990, Keltgen KS-1151, Northrup King PX 9540, and Dekalb 711.

The five varieties were machine harvested at approximately 25% moisture content and dried to produce four 1.25 kg subsamples having different levels of breakage susceptibility. An Aeroglide cross-flow laboratory dryer model No. 25498-1 was used, which was capable of thin layer drying approximately 60 kg of corn at any one time. The four different breakage susceptibility levels were produced through the use of four different drying conditions. Each drying condition was run in duplicate. The four methods used were:

(A) High temperature drying at 230°F to 15% moisture content.

(B) High temperature drying at 230°F to 21% moisture content followed by ambient air drying to 15% moisture content.

(C) High temperature drying at 230°F to 18% moisture content followed by ambient air drying to 15% moisture content.

(D) Ambient air drying to 15% moisture content.

Samples from each drying condition were also laboratory 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.

The samples were coded using the coding method in Appendix 1. All samples were sealed in plastic bags where were then stored in individual 5 gallon buckets. Only samples of the same variety at the same moisture and treatment were stored in a given bucket. The high temperature dried samples below 15% w.b. were stored in 5 gallon buckets at room temperature (25°C) and the rest of the samples were stored in incubators at a controlled temperature of 4°C to control insect growth. Before testing, samples were equilibrated 48 hours at room temperature. Breakage susceptibility was determined by 5 replicates for each sample.

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

Human Factors

Five lots of corn of approximately 10 kilogram each were sub-divided into four samples of 2.5 kg each using a Boerner divider. Four different operators ran the samples through the same Wisconsin Breakage Tester with ten replicates per sample. Prior to runing the samples, each operator was given instruction on the the operational procedure used with the Wisconsin Breakage Tester, but the operators were not highly experienced.

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, all the samples were equilibrated to room temperature for about 48 hours 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 5 replicates for each sample.

RESULTS AND DISCUSSIONS

Factors Inherent to the Design and Construction of the WBT

The basic dimensions and impeller speed of the three Wisconsin Breakage Testers were checked. The fluctuations of impeller speed was less than 14 rpm with a mean of around 1800 rpm. The dimensions of the circular opening of impeller and height between the cover plate and impeller were different for the three testers. The hole diameter (see Figure 4.1) in the rotating plexiglass plate is 45 mm on the Nos. C006P and C007P testers, and is 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 is 35 mm on Nos. C006P and C007P testers, and is 40 mm on No. C019P tester.

Using a smoke generator to monitor the air flow inside the tester, the air flowed 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 using duct tape at all seams increases the amount of air recycled within the instrument. Obstruction of the air path into the hole in the rotating plexiglass plate would appear to reduce the velocity of the air flow down the impeller channel and thus could reduce the kernel impact velocity.

If the spacing between the two plexiglass plates

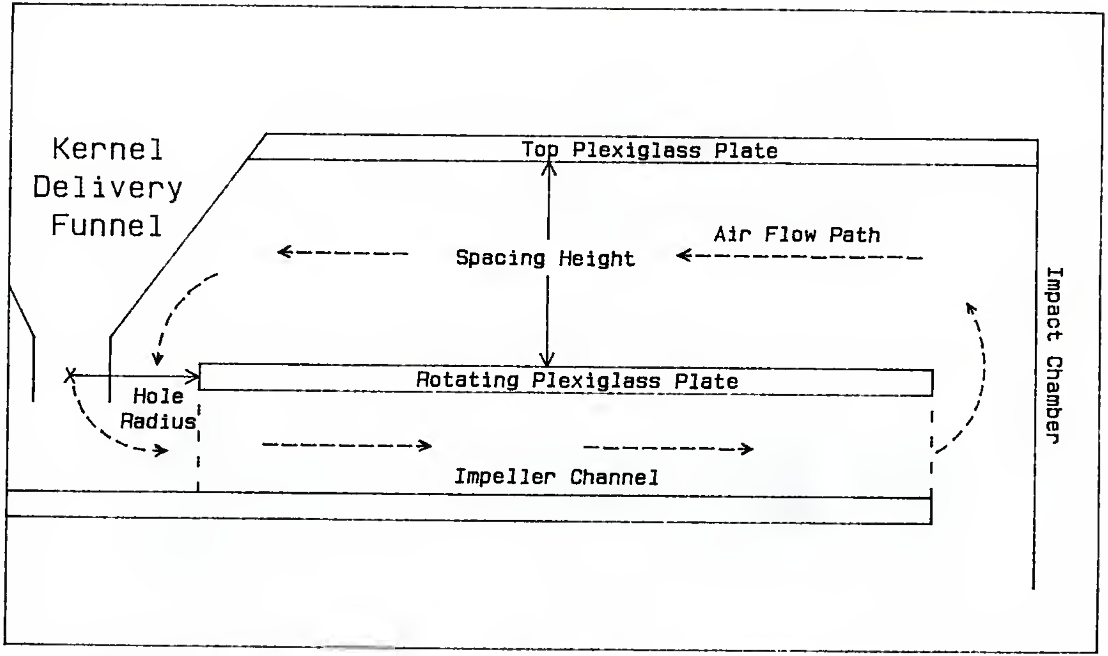

Figure 4.1 Schematic of Wisconsin Breakage Tester Impeller Section Showing Air Flow Path.

varied, the kernel delivery funnel would act as an obstruction in the rotating plexiglass plate hole. As the spacing decreases the funnel acts more as an obstruction.

The breakage susceptibility results measured by the Wisconsin Breakage Testers with different vibratory feeders are listed in Table 4.1. Two-tailed T tests at the 95% level (Table 4.2) indicated that there were significant

Table 4.1 Breakage susceptibility results from nine combinations of WBT and Vibratory Feeders using the identical sample.

Feeder		Wisconsin Breakage Tester		
		C006P	C019P	C007P
A	Ave.	10.59	9.81	10.66
	S.D.	0.63	0.41	0.35
B	Ave.	10.30	9.50	10.46
	S.D.	0.46	0.31	0.46
C	Ave.	10.83	9.52	10.66
	S.D.	0.41	0.12	0.63
Mean (%)		10.57 a	9.61 b	10.59 a
C.V. (%)		4.73 a	2.91 b	4.54 a
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.

Table 4.2 Analysis of Variance Table for three Wisconsin Breakage Testers.

SOURCE	DF	SS	MS	F-VALUE	PR > F
MODEL	8	12.7627	1.5953	7.96	0.0001
WBT	2	11.3855	5.6928	28.39	0.0001
FEEDER	2	0.8276	0.4138	2.06	0.1389
W * F	4	0.5495	0.1374	0.69	0.6060
ERROR	45	9.0243	0.2005		
TOTAL	53	21.7870			

differences among the three machines. The result from instrument No. C019P was different than from instrument Nos. C006P and C007P. The coefficient of variation was also statistically different between machines (Table 4.1). Instrument number C019P had lower CV values. There were no significant differences among feeders and no significant interaction between the WBT and the feeder.

The design differences in the dimension of the No. C007 and C006 instruments as compared to the No. C019 instrument appear highly significant. The No. C019 instrument had the most restriction of air flow into the hole in the rotating plexiglass plate and gave lower results. All future testing on reliability reported in this study was performed using the No. C006 instrument.

A survey of all 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 these differences in construction dimensions may have caused part of the high variability Schmidt (1987) and Watson (1985) observed between laboratories in the NC-151 collaborative studies. Effort was extended to identify any trends between the collaborative study results and the two instrument dimensions measured. No clear trend was observable.

Effect of the Grain Feeding Rate into the Tester

The mean breakage susceptibility values and coefficient of correlation values for two varieties tested at different feeding rate are presented in Table 4.3 and 4.4 for the 12/64" sieve. Analysis of the results showed that the effect of feeding rate was insignificant over the range of feed rates tested. The results indicated low correlation coefficient (0.2595 and 0.1283) between breakage susceptibility results and feeding rate using the 12/64" sieve.

The results on feeding rate effects support those

Table 4.3 Breakage susceptibility values for Dekalb 711 (10.20% m.c.) determined using 12/64" sieve at different feeding rates in the Wisconsin Breakage tester.

Scale	Feeding Rate (g/min)	Mean (%)	S.D. (%)	C.V. (%)
F4	94.5	25.26 a b	1.12	4.43
F5	171.8	25.54 a	0.99	3.88
F6	268.7	24.18 b	0.51	2.11
F10	727.3	25.54 a	1.01	3.95

Means with the same letter are not significantly different on the basis of LSD pairwise comparison at $p = 0.05$ (DF = 20) for Feeding Rate using 12/64" sieve.

Table 4.4 Breakage susceptibility values for Pioneer 3377 (9.58% m.c.) determined using 12/64" sieve at different feeding rates in the Wisconsin Breakage tester.

Scale	Feeding Rate (g/min)	Mean (%)	S.D. (%)	C.V. (%)
F4	78.3	35.12 a	0.99	2.82
F5	156.5	36.07 a	0.99	2.74
F6	310.3	35.74 a	0.49	1.37
F10	666.7	36.05 a	0.88	2.44

Means with the same letter are not significantly different on the basis of LSD pairwise comparison at $p = 0.05$ (DF = 20) for Feeding Rate using 12/64" sieve.

reported by Gunasekaran and Paulsen (1986) and Singh and Finner (1983). Because the WBT handles the kernels individually and exerts a similar impacting force on every kernel, the result are as expected. Although the breakage susceptibility results were independent of the effect of feeding rate in the statistical analysis, there is evidence from Table 4.3 and 4.4 of a trend toward minimum breakage susceptibility results and coefficient of correlation at the feeding rate of about 300 g/min.

Evaluation of the Standard Deviation for Corn Breakage Susceptibility

The standard deviations for the tests ranged from 0.06 to 1.98 with an average of 0.505 using the 12/64" sieve at room temperature (Appendices 2 - 7). The standard deviation for the 16/64" sieve ranged from 0.1 to 4.8 with an average of 1.012. The breakage values measured using the 16/64" sieve were almost exactly double the values from the 12/64" sieve. The average coefficient of variation (CV) values using the 12/64" sieve was 6.07% and was almost equal to the coefficient of variation for the 16/64" sieve (6.05%). The 16/64" sieve appearred to be more discriminating than the 12/64" sieve for use in determining the breakage susceptibility. These results were similar to those described by Schmidt (1987).

Standard statistical methods were used to determine the correlation among the standard deviation, breakage susceptibility, and moisture content at different levels at room temperature. The results (Table 4.5) show the correlation between standard deviation and breakage susceptibility levels was more significant than the correlation between standard deviation and moisture content on either 12/64" or 16/64" sieve measurement although breakage susceptibility was lightly correlated with moisture. Testing at room temperature, the coefficients of correlation between standard deviation and breakage susceptibility values were 0.6069 and 0.3931 on the 12/64" and the 16/64" sieve measurement respectively (Figure 4.2 and 4.3).

Table 4.5 The coefficient of correlation values among Moisture Content, Temperature, Breakage Susceptibility, and Standard Deviation (12/64" sieve).

	Moisture Content % w.b.	Temperature C	Breakage Susceptibility %	Standard Deviation
Moisture Content	1	-	-0.8491 (-0.8581)*	-0.5495 (-0.3821)
Temp.	-	1	-0.8093 (-0.8231)	-0.4474 (-0.4678)
Breakage Suscept.	-	-	1	0.6069 (0.3931)
Standard Deviation	-	-	-	1

* The coefficient of correlation was shown in parenthesis for the 16/64" sieve.

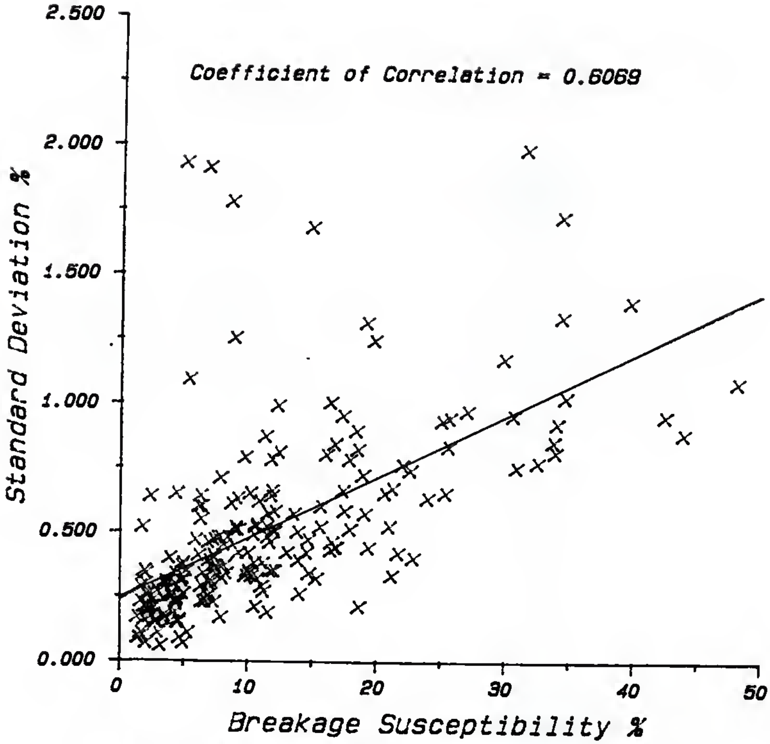

Figure 4.2 The relationship between breakege susceptibility and standard deviation using 12/64-in sieve at room temperature.

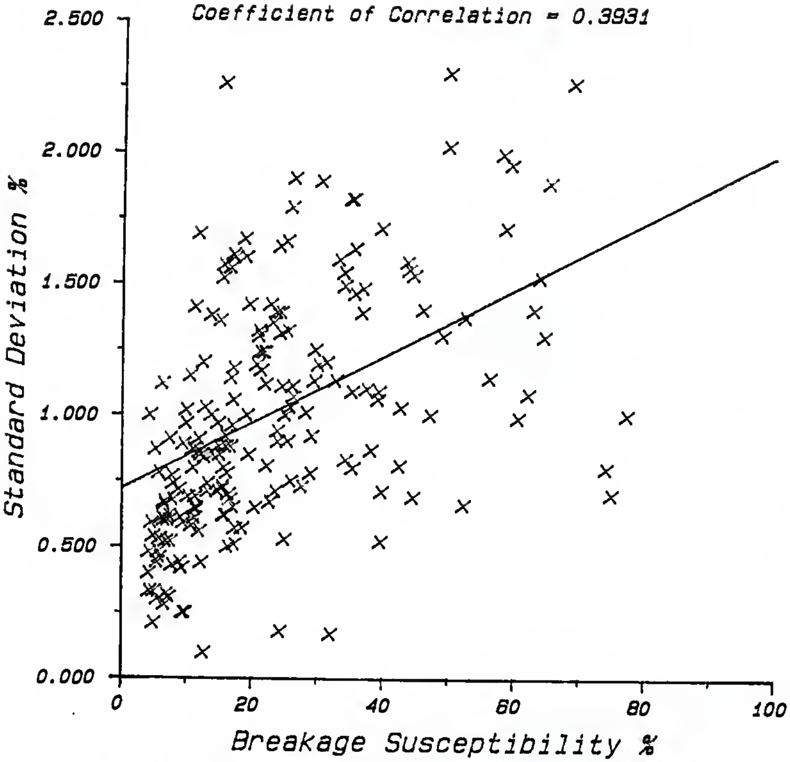

Figure 4.3 The relationship between breakage susceptibility and standard deviation using 16/64-in sieve at room temperature.

Human Factors

An important sources of variation affecting the estimates of breakage susceptibility in different corn samples was operator differences and operator and sample interaction (Table 4.6). Significant differences were observed among the average reading of the operators using either 12/64" or 16/64" sieve (Table 4.7 and 4.8). Operators 1 and 4 were similar and operators 2 and 3 were similar but the two groups were significantly different from each other at the 95% level.

Table 4.6 Analysis of Variance Table for Human Factors

SOURCE	DF	SS	MS	F-VALUE	PR > F
MODEL	19	8511.5646	447.9771	462.80	0.0001
OPER	3	22.8829	7.6276	7.88	0.0001
SAMPLE	4	8398.817	2049.7043	2169.20	0.0001
O * S	12	89.8648	7.4887	7.74	0.0001
ERROR	180	174.2334	0.9680		
TOTAL	199	8685.7980			

This result was unexpected since the testing procedure is highly objective. The statistical analysis indicated there were significant different between values measured by different operators even at the 99.95% level. Although there were significant differences among operators, the

Table 4.7 Breakage susceptibility results (12/64" sieve) for the experiment of Human Factors.

Operator		Sample						
		1	2	3	4	5	Mean	CV
1	Ave.	27.17	37.14	30.44	42.35	25.89	32.64 a	2.87
	S.D.	0.64	1.31	0.49	1.23	1.01	0.94	
2	Ave.	27.26	35.61	30.17	41.52	24.81	31.87 b	3.16
	S.D.	0.74	0.95	1.88	0.87	0.60	1.01	
3	Ave.	25.23	35.55	31.46	43.29	24.85	32.08 b	2.63
	S.D.	1.16	1.03	0.45	0.82	0.76	0.84	
4	Ave.	25.49	36.62	31.11	43.73	26.22	32.64 a	2.91
	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 12/64" sieve.

average magnitude of the difference was only approximately 0.8% at 32% breakage. Observation of the procedures used by the operators indicate that the differences observed may be due to their care in handling the sample in and out of the sieve shaker. They were not all equally meticulous in caring for the sample.

Lower CV values were found when using the 16/64" sieve rather than the 12/64" sieve. The mean CV value for the 16/64" sieve was 2.29%, which was less than the CV value (2.90%) for the 12/64" sieve.

Table 4.8 Breakage susceptibility results (16/64" sieve) for the experiment of Human Factors.

Operator		Sample 1	2	3	4	5	Mean	CV
1	Ave.	63.83	69.22	63.51	73.17	56.89	65.32 a	2.11
	S.D.	1.21	1.48	1.32	1.46	1.43	1.38	
2	Ave.	62.81	67.56	63.65	73.34	54.51	64.37 b	2.37
	S.D.	1.70	1.38	2.28	0.74	1.53	1.53	
3	Ave.	59.75	67.09	65.35	74.85	54.97	64.40 b	2.35
	S.D.	2.00	1.59	1.37	1.30	1.30	1.51	
4	Ave.	60.65	68.45	65.07	75.05	57.53	65.35 a	2.32
	S.D.	1.98	1.57	1.39	1.29	1.36	1.52	

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 16/64" sieve.

Effect of Mold Damage

After 60 days storage, some "blue-eye" and discoloration was found on the surface of the germ under the pericarp in the samples which stored at 28°C. Most 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 are listed in Table 4.9 and 4.10 for the 12/64" and 16/64" sieves respectively.

Table 4.9 Breakage susceptibility results for the effect of mold damage using 12/64" sieve.

Corn Variety		M.C. %	Non-mold	Mold
Dekalb 711	Ave.	17.87	6.12	5.71
	S.D.		0.43	0.46
Pioneer 3377	Ave.	17.60	5.90	6.07
	S.D.		0.42	0.30
NK PX 9540	Ave.	17.77	7.01	7.03
	S.D.		0.44	0.56

Table 4.10 Breakage susceptibility results for the effect of mold damage using 16/64" sieve.

Corn Variety		M.C. %	non-mold	Mold
Dekalb 711	Ave.	17.87	18.31	16.45
	S.D.		0.98	0.91
Pioneer 3377	Ave.	17.60	12.60	13.16
	S.D.		0.93	1.02
NK PX 9540	Ave.	17.77	14.01	15.18
	S.D.		0.72	1.05

No significant differences were found at the 99% level between non-mold and mold samples except for the Dekalb 711 sample when using the 16/64" sieve. Mold might change the biochemical structure but did not appear to change the physical structure. The horny endosperm of the corn is the major contributor to mechanical properties (Balastreire, 1982), 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 could cause the test results to vary with each instrument. In order to insure uniformity of breakage results by different instruments, all the current instruments should be modified to the same dimensions.

The standard deviation for the samples tested ranged from 0.06 to 1.98 with an average over all the samples tested of 0.505 when using a 12/64" sieve at room temperature. The 16/64" sieve had an average of 1.012 with a range of 0.1 to 4.8. The average coefficient of variation value for the 12/64" sieve (6.07%) was almost equal to that for the 16/64" 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 were found to influence the breakage susceptibility results in the statistical analysis at the 95% level although the magnitude of the average difference was 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 was not significant in the breakage susceptibility results. The breakage susceptibility results was found to be fairly independent of the effect of the grain feeding rate into the tester over the range 78.3 to 727.3 g/min which supports the results of Gunasekaran and Paulsen (1986) and Singh and Finner (1983).

References

Balastreire, L. A., F. L. Herum, K. K. Stevens, and J. L. Blaisdell. 1982. Fracture of Corn Endosperm in Bending. Part I. Fracture Parameters. TRANSACTION of the ASAE 25(4): 1057-1061, 1065.

Balastreire, L. A., F. L. Herum, K. K. Stevens, and J. L. Blaisdell. 1982. Fracture of Corn Endosperm in Bending. Part II. Fracture Analysis by Fractography and Optical Microscopy. TRANSACTION of the ASAE 25(4): 1062-1065.

Gunasekaran, S., and M. R. Paulsen. 1986. Standardizing Corn Breakage Susceptibility Testing. ASAE Paper 86-3035. St. Joseph, Michigan 49085.

Miller, B. S., J. W. Hughes, R. Rousser, and Y. P. Meranz. 1979. Note on a Method for Measuring Breakage Susceptibility of Shelled Corn During Handling. Cereal Chemistry 56(3): 213-215.

Paulsen, M. R. 1983. Corn Breakage Susceptibility as a Function of Moisture Content. ASAE Paper No. 83-3078, ASAE, St. Joseph, MI 49085.

Schmidt, Dave. 1987. The 1985-86 NC-151 Wisconsin breakage Tester Collaborative Study. The Ohio State University, Wooster, Ohio 44691-6900.

Schmidt, J. L., R. A. Saul, and J. L. Steele. 1968. Precision of Estimating Mechanical Damage in Shelled Corn. USDA Agricultural Research Service, ARS 42-142.

Sharda, R. and F. L. Herum. 1977. A Mechanical Damage Susceptibility Tester for Shelled Corn. ASAE Paper No. 77-3504, ASAE, St. Joseph, MI 49085.

Singh, S. S. and M. F. Finner. 1983. A Centrifugal Impacter for Damage Susceptibility Evaluation of Shelled Corn. TRANSACTION of ASAE 26(6): 1858-1863.

Watson, S. A. 1985. The Effect of Fines on Corn and Soybean Processing. NC-151 Grain Quality Newsletter 7: 18-19.

V. EFFECT OF MOISTURE CONTENT AND TEMPERATURE ON CORN BREAKAGE SUSCEPTIBILITY

INTRODUCTION

If results from a breakage susceptibility tester are to be used as part of the grade determining factors for corn, it will 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 grade is being determined is often tested at near outside ambient conditions. This may be considerably different from the temperature at which the corn is ultimately stored or handled. The breakage value measured will need to be adjusted to a standard temperature for the test to be equitable and meaningful to the grain trade. Similarily, moisture changes in the corn will cause changes in the corn's breakage susceptibility. It would be desireable to be able to predict how moisture changes will affect the breakage susceptibility. This study was undertaken to elucidate temperature and moisture content dependence of the breakage values determined by the Wisconsin Breakage Tester.

REVIEW

Moisture content and temperature have a substantial effect on breakage susceptibility. Herum and Blaisdell (1981) inferred that the breakage mechanism might be expected to change as water mobility changes in the product. Tran et al. (1981) concluded that corn at higher moisture content has more plastic bran and softer endosperm than at low moisture content.

Herum and Blaisdell (1981) reported that corn breakage susceptibility, as measured in three instruments (Stein CK-2M, Stein CK-2, and Centrifugal Impacter), is greatly influenced by sample moisture content. Small changes in moisture content within the range of 12 to 14% correspond to large differences in the measured breakage susceptiblity. 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. when testing the centrifugal impactor.

Tompson and Foster (1963) found that there was a slight increase in damage at moisture contents above 25% and at the lower rotational speeds using an centrifugal impact tester. Jindal et al. (1979) found similar results and showed the rate of corn breakage was lowest at 25% m.c. and increased as the moisture content increased to 26% or decreased to 24%. Paulsen (1983) also found slightly higher breakage at moistures above 25% m.c. and explained this results as due to the soft nature of the pericarp at moisture contents above 26%.

Regression models were develpoed by several researchers. To mathematically model the effect of moisture on the breakage tester results, 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 for moisture contents between 8% to 21%. Others have used a similar exponential model (Herum and Hamdy, 1985; Moes, 1986; Gustafson and Morey, 1979; 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 decreasing corn temperature increased the breakage susceptibility values. Thompson and Foster (1963) reported the amount of breakage doubled when the temperature of some samples of corn was reduced from 84 to 42°F. Herum and Blaisdell (1981) conducted tests in three instruments (Stein CK-2M, Stein CK-2, and Centrifugal Impactor) with samples at 4.4, 22.2, and 37.8°C. They found BCFM diminished an average of 2.1%/°C from 4.4 to 22.2°C; and the equivalent decrease was 1.8%/°C from 22.2 to 37.8°C. Jindal et al. (1979) reported the impact damage to corn increases with decreasing temperatures according to an exponential relationship using a small rigid-hammer mill.

Herum and Blaisdell (1981) suggested that a moisture-temperature interaction likely exists and may be practically important.

METHODS AND PROCEDURES

Effect of Moisture Content

Samples of five varieties (Pioneer 3377, PayMaster 7990, Keltgen KS-1151, Northrup King PX 9540, and Dekalb 711) of identity preserved corn were dried using three different methods to 5 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 to the desired moisture using one of the following three drying methods:

(A) High temperature drying at 230°F to the desired moisture content.

(B) High temperature drying at 230°F to 18% m.c. followed ambient air drying to the desired moisture content.

(C) Ambient air drying to the desired moisture content.

Two replicates for each drying condition were used. For the high temperature drying treatment, a moisture meter could not be accurately used without cooling the sample to 40°C. In order to monitor the moisture content of drying corn, small subsamples of the corn were placed into cylinderical steel screen containers and place back into the drying layer. Drying rate was determined from knowing the initial weight and moisture content of the subsample and by monitoring the weight of the sample during drying.

Five replicates of each sample were run through the WBT to determine breakage susceptibility using the procedure of Gunasekaran and Paulsen (1985) with a feeding rate around 200 g/min. Two sieves, a 12/64" precision round hole sieves and a 16/64" sieve, were used in this study.

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 prepared to study the effect of corn temperature on the breakage values determined. These two varieties were machine harvested and shelled as previously described and dried to produce four subsamples having different levels of breakage susceptibility. The four different levels of breakage susceptibility were produced by four different drying conditions. Each drying condition was be run in replicate. The four drying conditions were:

(A) High temperature drying at 230°F to 15% moisture content.

(B) High temperature drying at 230°F to 21% moisture content followed by ambient air drying to 15% moisture content.

(C) High temperature drying at 230°F to 18% moisture content followed by ambient air drying to 15% moisture content.

(D) Ambient air drying to 15% moisture content.

Each sample was divided into eight subsamples with a Boerner grain divider with seven of the eight subsamples being selected randomly for this experiment. Seven temperatures, -13°C, 2°C, 14°C, 22°C, 34°C, 64°C, and 90°C, were chosen to be evaluated. The seven subsamples were randomly assigned to the temperature levels. Inorder to avoid the loss of moisture content in the test, each 200 g sample was put into a 500 ml glass bottle and sealed with a plastic cap. For the temperatures below 40°C, the samples were held in temperature controlled incubators at the desired temperature 24 hours prior to testing. To keep the quality and moisture content of samples unchange, the samples above 40°C were held in a temperature controlled oven at the desired temperature 3 hours prior to testing. Breakage susceptibility of each sample was determined using the Wisconsin Breakage Tester with five replicates per sample.

Interaction between Moisture Content and Temperature

One corn variety, Pioneer 3377, was selected for testing the moisture-temperature interaction. Five temperatures (-13, 2, 14, 22, 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 with a high temperature drier at 230 F to the desired moisture content. A two-way ANOVA was used to analyze for moisture-temperature interaction.

RESULTS AND DISCUSSIONS

Effect of Moisture Content

Moisture content has a strong influence on the corn breakage susceptibility. For all five corn varieties, the observed breakage susceptibility values ranged between 1.15 - 49.56% and 2.86 - 78.82%, respectively, for 12/64" and

16/64" sieve measurements over the range of moisture content studied. Figure 5.1 - 5.10 show the moisture dependence of each variety at each drying conditions studied. It can be seen that there is a strong dependence of drying treatment and variety on moisture dependence.

In order to determine an overall correlation between the moisture content and breakage susceptibility, the data obtained for the five corn varieties were pooled (Figure 5.11 and 5.12). Both quadric and exponential regression models were tested. The exponential model of the form $y = a \exp(-CM)$ had the highest coefficients of correlation and was thus 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 this pooled data are:

$$BS\ \% = 511.8\ EXP(-0.298\ M) \qquad R^2 = 0.89\ (12/64"\ \text{Sieve}) \qquad (5.1)$$

$$BS\ \% = 652.0\ EXP(-0.257\ M) \qquad R^2 = 0.86\ (16/64"\ \text{Sieve}) \qquad (5.2)$$

The R-square value appears high but observation at any one given moisture content shows that there is a high degree of variation due to the different varieties and drying procedures. For example, at 12.5% moisture on Figure 5.11 the breakage susceptibility value ranged from approximately 8% to almost 25%. R-square is a measurement of the sum of squares error from the model divided by the

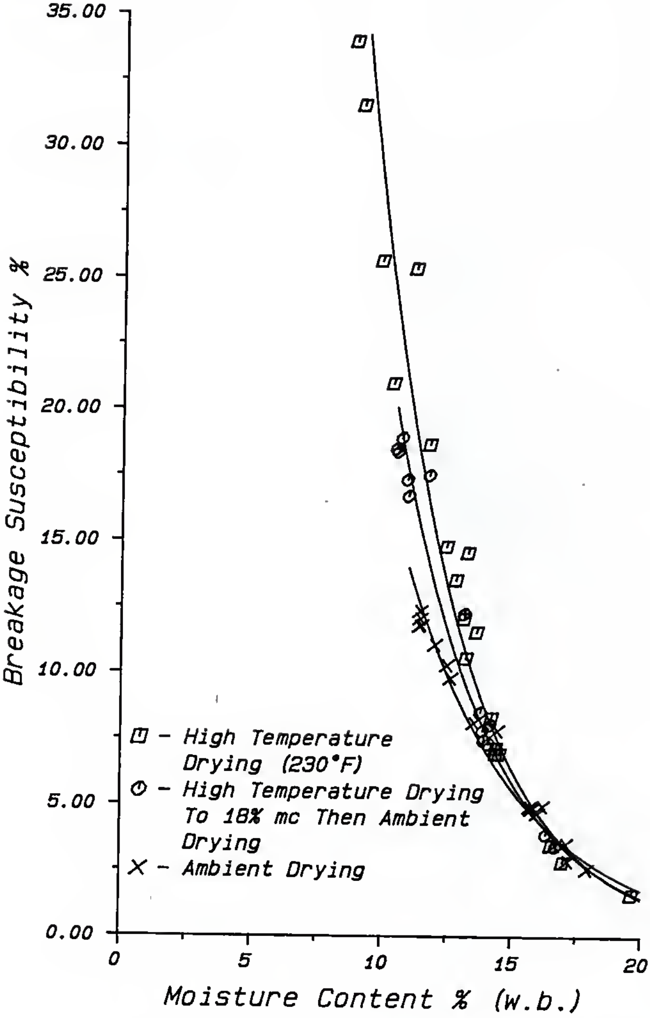

Figure 5.1 Effect of moisture content on breakage susceptibility for Pioneer 3377 using 12/64-in sieve.

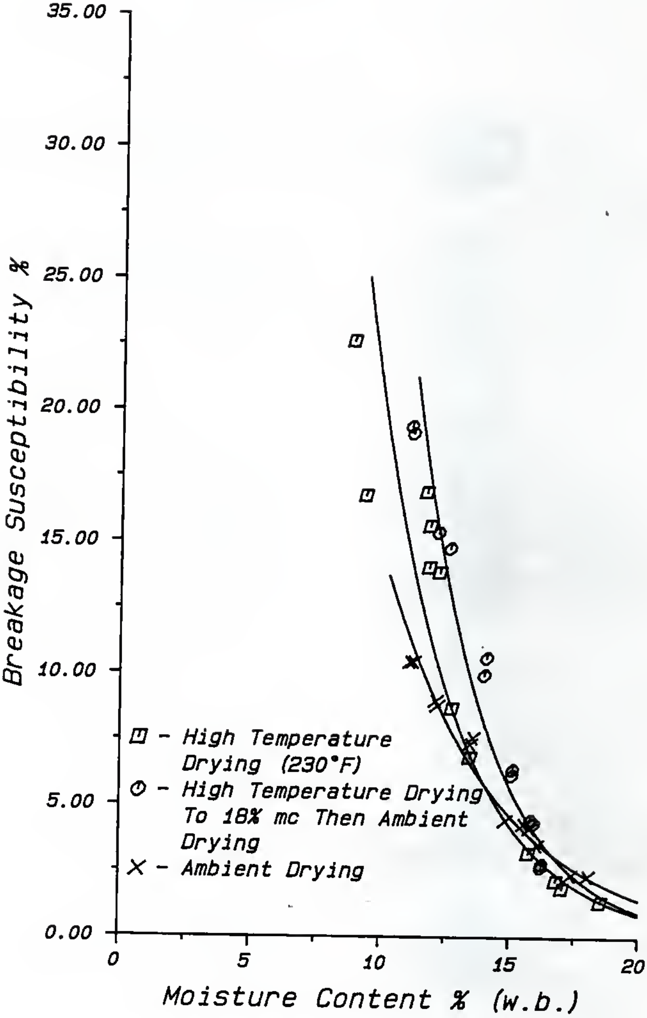

Figure 5.2 Effect of moisture content on breakage susceptibility for PayMaster 7980 using 12/64-in sieve.

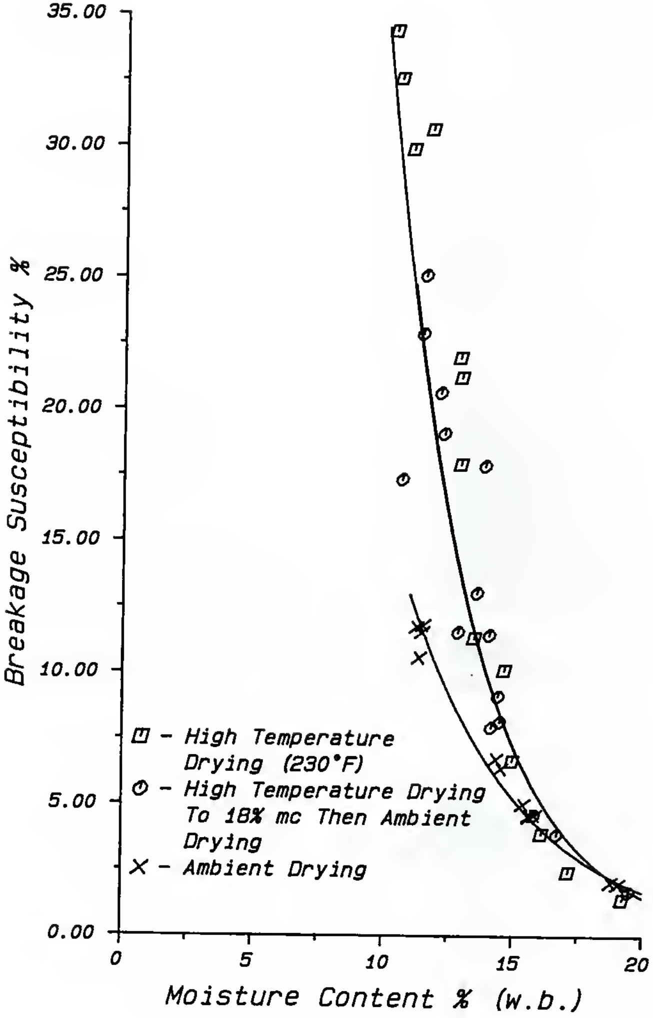

Figure 5.3 Effect of moisture content on breakage susceptibility for Keltgen KS-1151 using 12/64-in sieve.

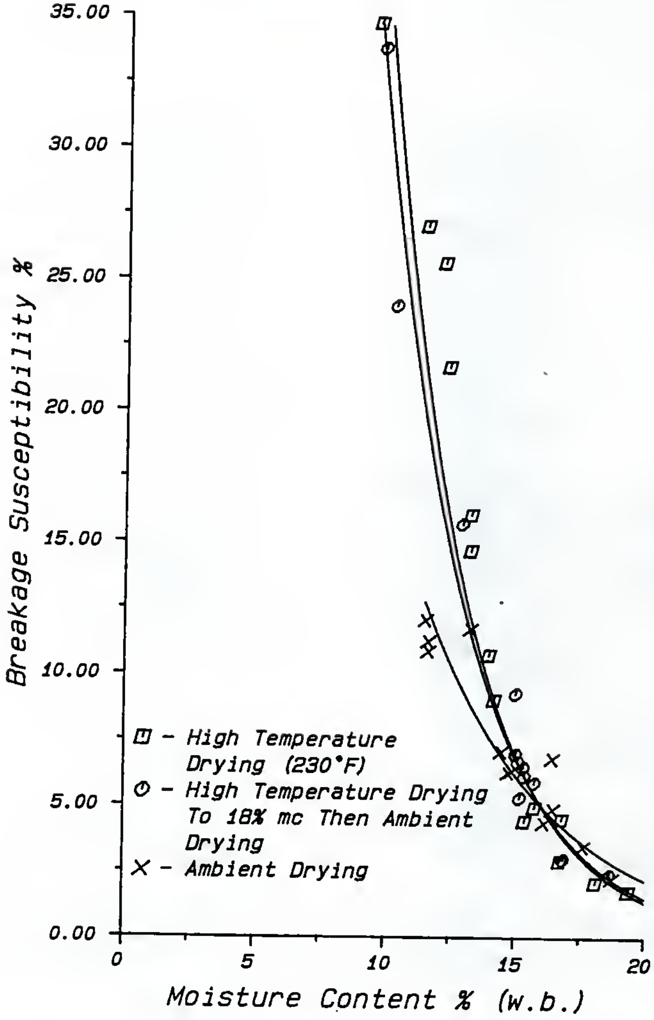

Figure 5.4 Effect of moisture content on breakage susceptibility for Northrup King PX 9540 using 12/64-in sieve.

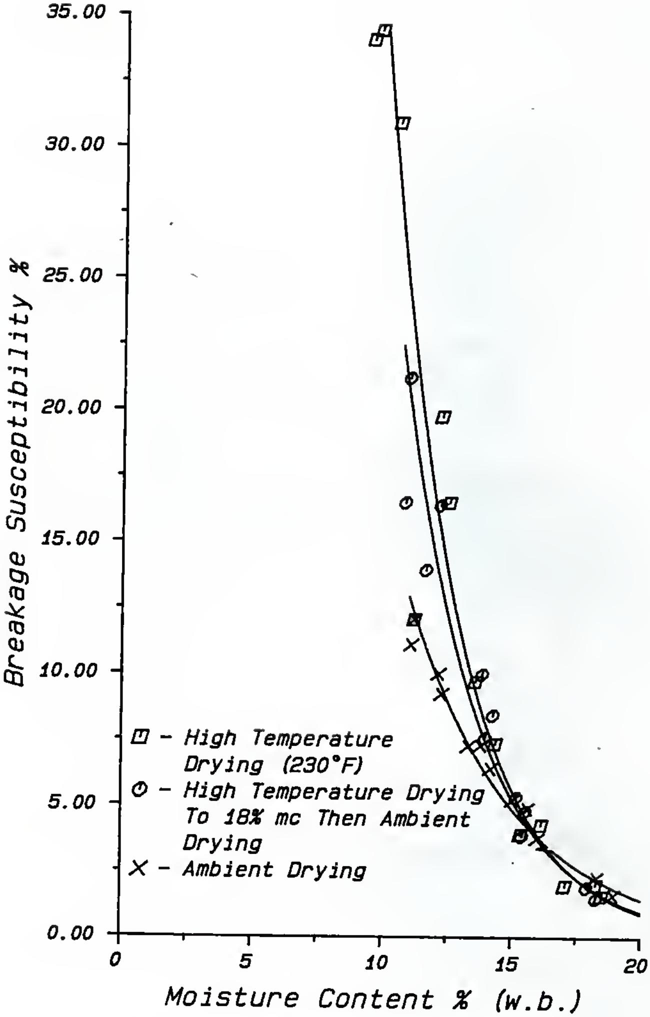

Figure 5.5 Effect of moisture content on breakage susceptibility for Dekalb 711 using 12/64-in sieve.

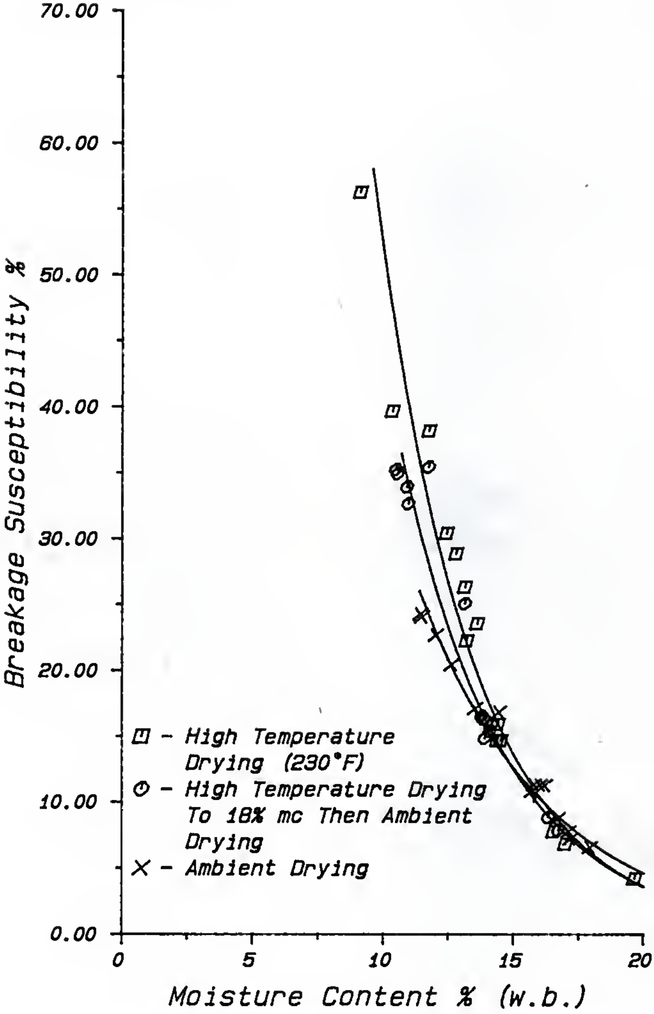

Figure 5.6 Effect of moisture content on breakage susceptibility for Pioneer 3377 using 16/64-in sieve.

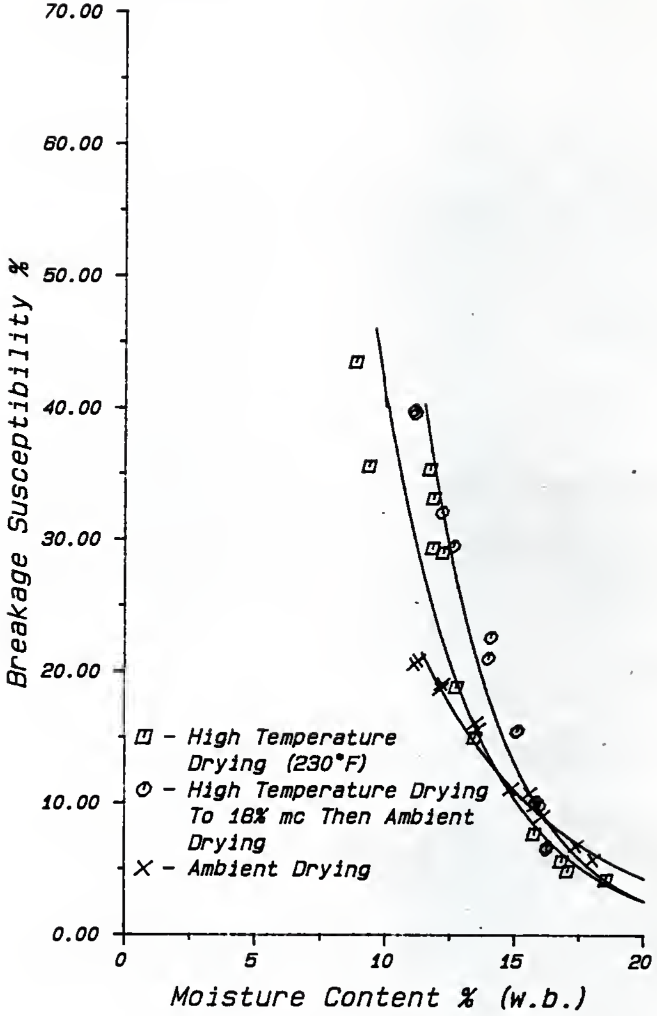

Figure 5.7 Effect of moisture content on breakage susceptibility for PayMaster 7990 using 18/64-in sieve.

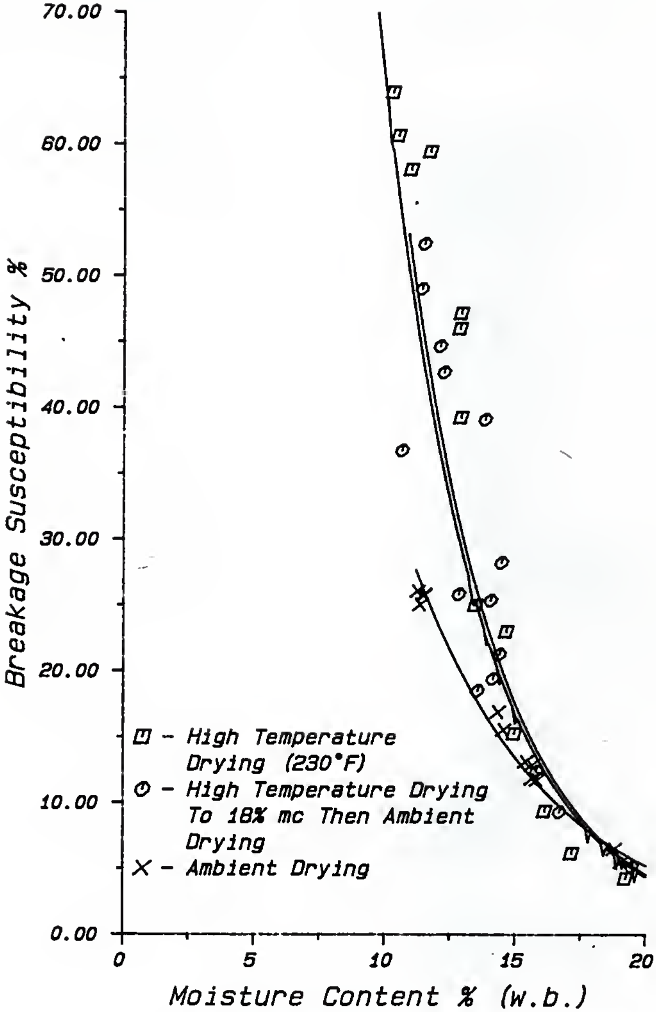

Figure 5.8 Effect of moisture content on breakage susceptibility for Keltgen KS-1151 using 18/64-in sieve.

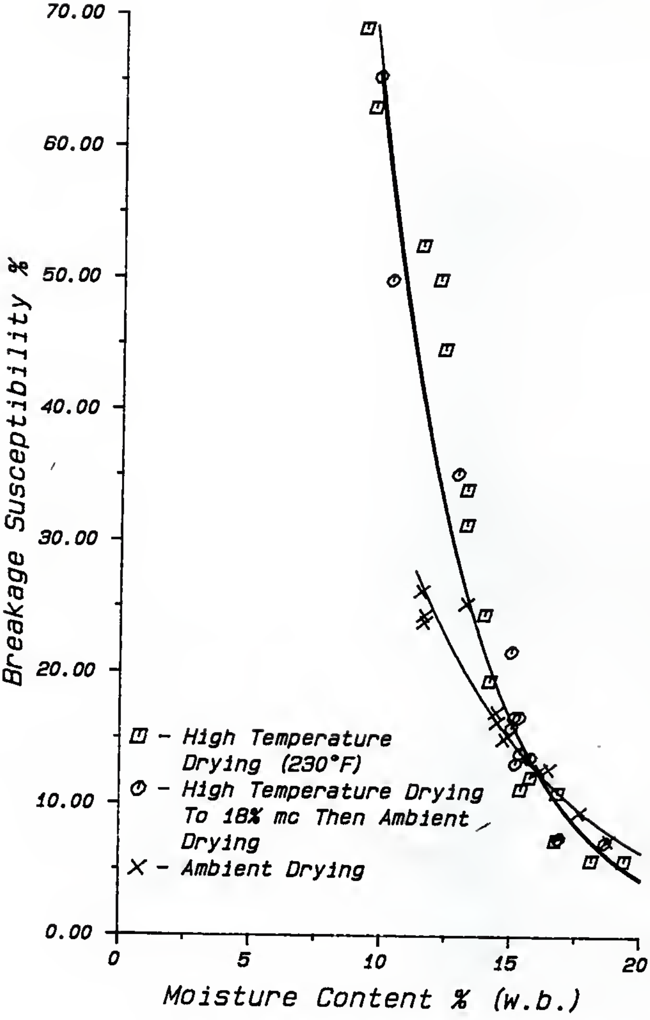

Figure 5.8 Effect of moisture content on breakage susceptibility for Northrup King PX 8540 using 18/64-in sieve.

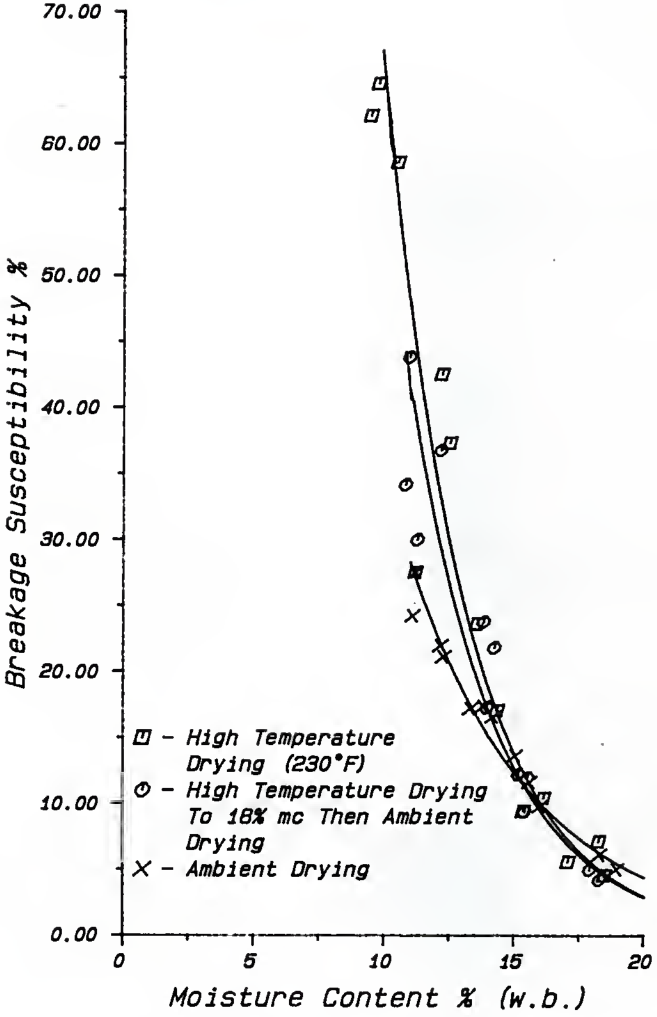

Figure 5.10 Effect of moisture content on breakage susceptibility for Dekalb 711 using 18/64-in sieve.

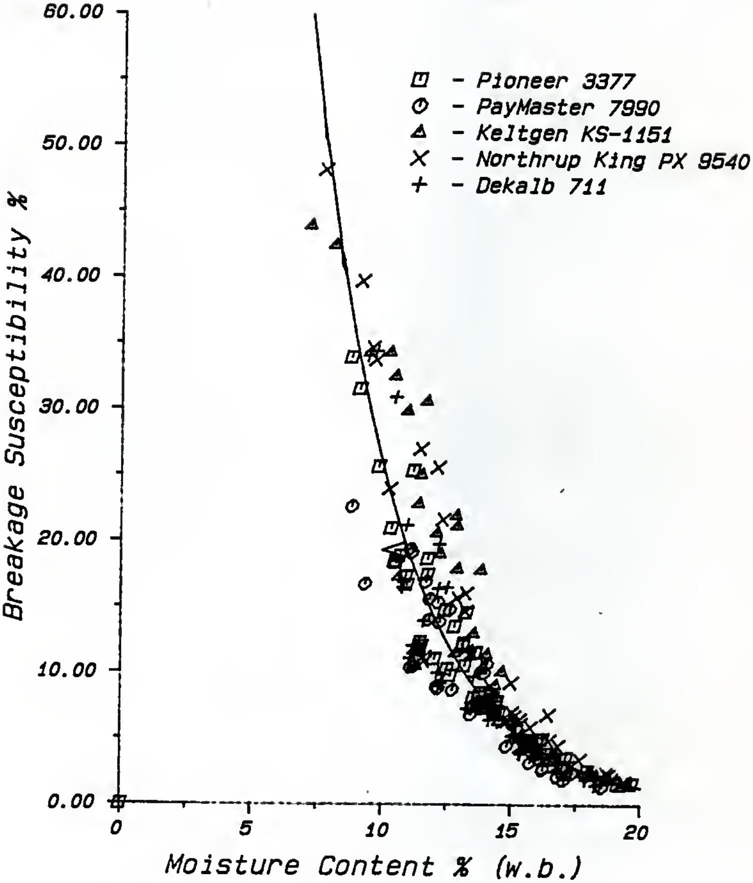

Figure 5.11 Effect of moisture content on breakage susceptibility for five corn varieties using 12/64-in sieve.

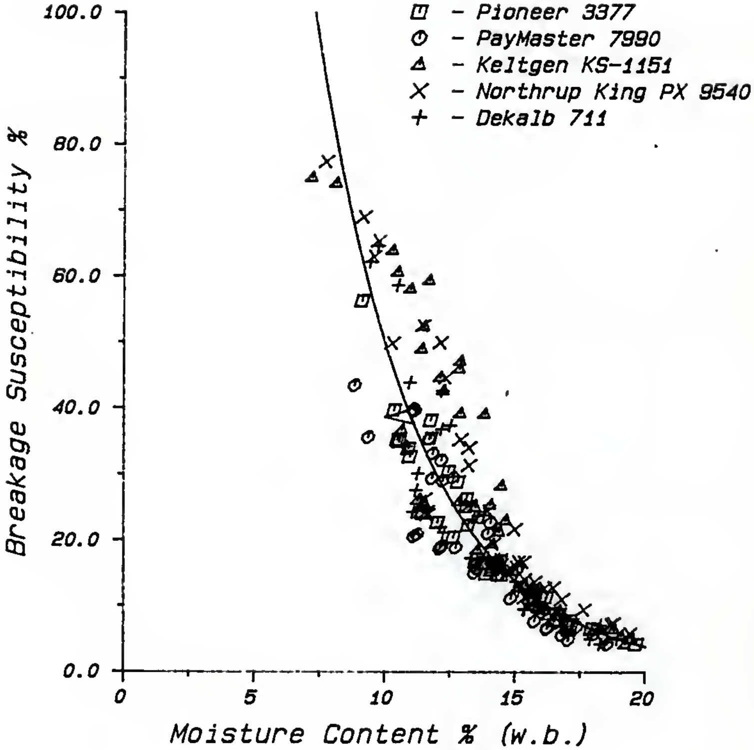

Figure 5.12 Effect of moisture content on breakage susceptibility for five corn varieties using 16/64-in sieve.

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 we observed is highly undesirable and indicates that in the use of the WBT adjustment for moisture content will not be possible since knowledge of the variety and the drying conditions would be necessary for an accurate prediction. These would not be available in the market channel.

Figure 5.1 through 5.10 also show that as the moisture content increases to 15% - 17% the effect of variety and drying condition is minimized and the curves seem to come together . This indicates that at 15% moisture content, the drying conditionused does not affect breakage susceptibility. Practical experience indicates that this is not true.

Significant differences in breakage susceptibility obtained among various corn genotypes had previously been reported (Stroshine et al., 1981 & 1986; Paulsen et al., 1983; Vyn and Moes, 1986; Moes, 1986). Using the current data, five individual regression models were established for breakage susceptibility as a function of moisture for each corn hybrids. The exponential regression models for each corn variety are presented in Table 5.1 and 5.2. Tables 5.1 and 5.2 show that the R-square value for each

Table 5.1 Exponential regression equations representing moisture content relations with breakage susceptibility % of various corn varieties measured with the Wisconsin Breakage Tester using a 12/64" sieve.

Model: BS% = 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 7990	413.64	0.2962	0.88
Keltgen KS-1151	627.03	0.3038	0.88
Northrup King PX 9540	566.80	0.2958	0.91
Dekalb 711	672.50	0.3239	0.93

individual variety is higher than for when all the varieties were considered.

Figure 5.1 through 5.10 show the breakage susceptibility was strongly dependent on the drying condition, especially when the moisture content of the corn was below 14%. When drying condition and variety were held constant the R-square values ranged from 0.88 to 0.98, 0.86 to 0.97, over all five varieties and all three drying conditions for the 12/64" and 16/64" sieve, respectively. Tables 5.3 and 5.4 show the best fit models for each constant variety and drying condition for the 12/64" and 16/64" sieve, respectively.

Table 5.2 Exponential regression equations representing moisture content relations with breakage susceptibility % of various corn varieties measured with the Wisconsin Breakage Tester using a 16/64" sieve.

Model: BS% = A EXP(-CM)

Corn Variety	Estimate of Parameters A	C	R-SQUARE
Overall	651.97	0.2567	0.86
Pioneer 3377	507.76	0.2440	0.94
PayMaster 7990	543.48	0.2570	0.86
Keltgen KS-1151	762.04	0.2571	0.85
Northrup King PX 9540	651.97	0.2473	0.90
Dekalb 711	842.19	0.2784	0.91

When all the variety are included together with drying condition as the only variable the R-square values decrease as can be seen in Tables 5.5 and 5.6.

Other factors beyond corn variety and drying condition are likely to have some effects on the relationship between breakage susceptibility and moisture content. Even for the same corn hybrid, the breakage susceptibility might be significantly different due to the growing conditions, geography, climate, etc (Stroshine et al. 1986). This makes it difficult to develop a general equation which can predict the effect of moisture content accurately. In this

Table 5.3 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 12/64" sieve.

Model: BS% = A EXP(-CM)

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

Table 5.4 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 16/64" sieve.

Model: BS% = A EXP(-CM)

Corn Variety	Drying Condition	Estimate of Parameters A	C	R-SQUARE
Pioneer 3377	B	759.00	0.2679	0.96
	D	520.61	0.2486	0.95
	E	257.24	0.2011	0.95
PayMaster 7990	B	655.89	0.2769	0.93
	D	1657.39	0.3233	0.92
	E	180.19	0.1868	0.95
Keltgen KS-1151	B	949.56	0.2690	0.87
	D	1008.28	0.2701	0.86
	E	231.37	0.1897	0.97
Northrup King PX 9540	B	896.95	0.2669	0.93
	D	827.99	0.2613	0.94
	E	184.20	0.1676	0.93
Dekalb 711	B	1439.43	0.3098	0.94
	D	1087.90	0.2966	0.93
	E	276.44	0.2073	0.96

Table 5.5 Exponential regression equations representing moisture content relations with breakage susceptibility % of various drying conditions measured with the Wisconsin Breakage Tester using a 12/64" sieve.

Model: BS% = A EXP(-CM)

Drying Condition	Estimate of Parameters A	C	R-SQUARE
Overall	511.83	0.2982	0.89
B	750.70	0.3218	0.91
D	636.51	0.3095	0.90
E	156.65	0.2257	0.92

Table 5.6 Exponential regression equations representing moisture content relations with breakage susceptibility % of various drying conditions measured with the Wisconsin Breakage Tester using a 16/64" sieve.

Model: BS% = A EXP(-CM)

Drying Condition	Estimate of Parameters A	C	R-SQUARE
Overall	651.97	0.2567	0.86
B	912.33	0.2778	0.89
D	833.81	0.2703	0.86
E	218.33	0.1892	0.91

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 from the incoming corn samples. Stroshine et al. (1986) found a remarkable difference in different growing years (1980 and 1981) even when using the same corn hybrid and drying treatments. Based on the experimental data in this test, the variation in breakage susceptibility could be as large as 15% at 12% m.c. due to different drying conditions for the Pioneer 3377 variety (Figure 5.1). This large variation is not equiltable for both the buyer and the seller. Development of a classification system where breakage susceptibility is adjusted to a standard moisture will be unfeasible. The only reasonable alternative is to report the breakage susceptibility at 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 then could 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 appears very important to the breakage susceptibility test. For Dekalb 711, high temperature dried sample at 13% moisture level, 0.5% error of moisture measurement can cause 1.6% error on breakage susceptibility value using 12/64" sieve. The magnitude of this error will increase at lower moisture content using 16/64" sieve, special for the high temperature dried sample.

The breakage susceptibility results (Appendix 2 and 3) for all five corn varieties at 15% m.c. (wb) shows that machine harvesting and shelling increases the susceptibility of the kernels to breakage as compared to hand harvesting and shelling (Table 5.7 and 5.8).

In General the machine harvested and shelled samples had higher breakage susceptibility values than the hand harvested and shelled samples. 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 BS% = 156.65 EXP(-0.2257 MC) which was developed during the study for natural air dried machine harvested corn. The increase in breakage susceptibility is small in relation to the amount of increased breakage susceptibility due to drying.

Table 5.7 The effect of mechanical harvesting and shelling on breakage susceptibility for five different corn varieties using a 12/64" sieve.

Varity	Moisture Content % wb	Breakage Susceptibility %		
		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-1161	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).

Table 5.8 The effect of mechanical harvesting and shelling on breakage susceptibility for five different corn varieties using a 16/64" sieve.

Varity	Moisture Content % wb	Breakage Susceptibility %		
		Hand Harvesting & Shelling	* Adjusted Machine Harvesting & Shelling	Difference (Machine-Hand)
Pioneer 3377	14.13	14.65	16.45	+1.80
	14.13	15.85	17.04	+1.19
PayMaster 7990	14.42	9.61	13.20	+3.59
	14.50	13.32	11.80	-1.52
Keltgen KS-1161	15.19	10.26	13.61	+3.35
	15.19	11.37	13.96	+2.59
Northrup King PX 9540	15.32	10.31	14.16	+3.85
	15.32	9.80	20.44	+10.64
Dekalb 711	14.30	9.51	16.13	+6.62
	14.42	10.55	15.46	+4.91

* Adjusted using the equation BS% = 218.33 EXP(-0.1892 MC).

Effect of Temperature

Figure 5.13 and 5.14 shows the effect of temperature on breakage susceptibility. A least square regression was run on the results and indicated that breakage susceptibility increases with decreasing temperature according to an exponential relationship. The prediction equation used was of the same form as used for the moisture

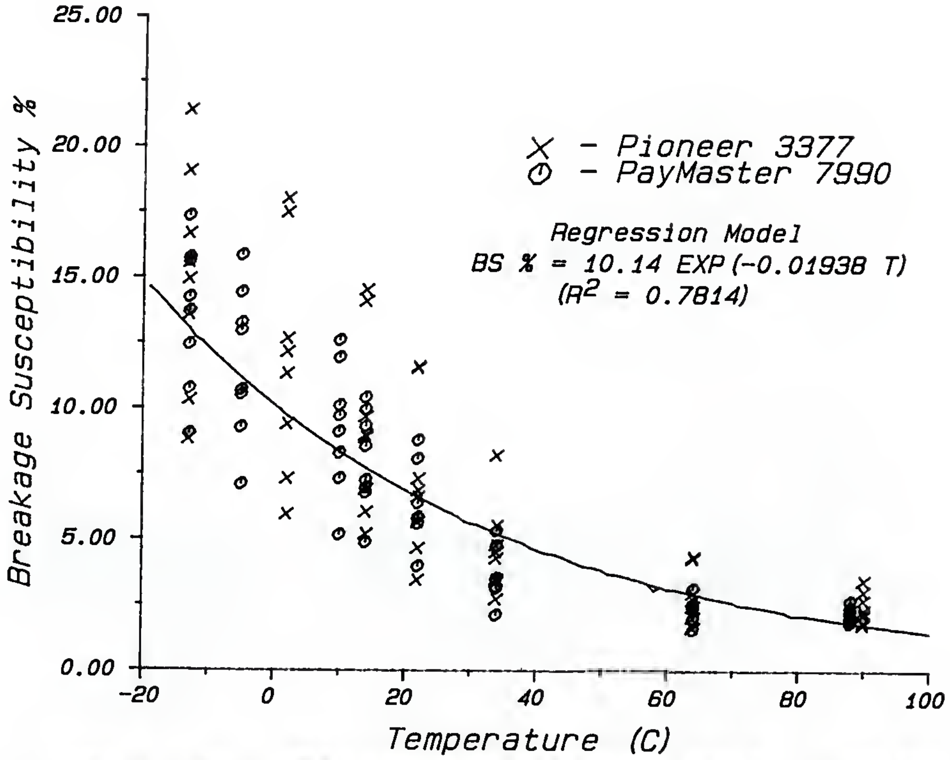

Figure 5.13 Effect of temperature on breakage susceptibility results for Pioneer 3377 and PayMaster 7990 using 12/64-in sieve.

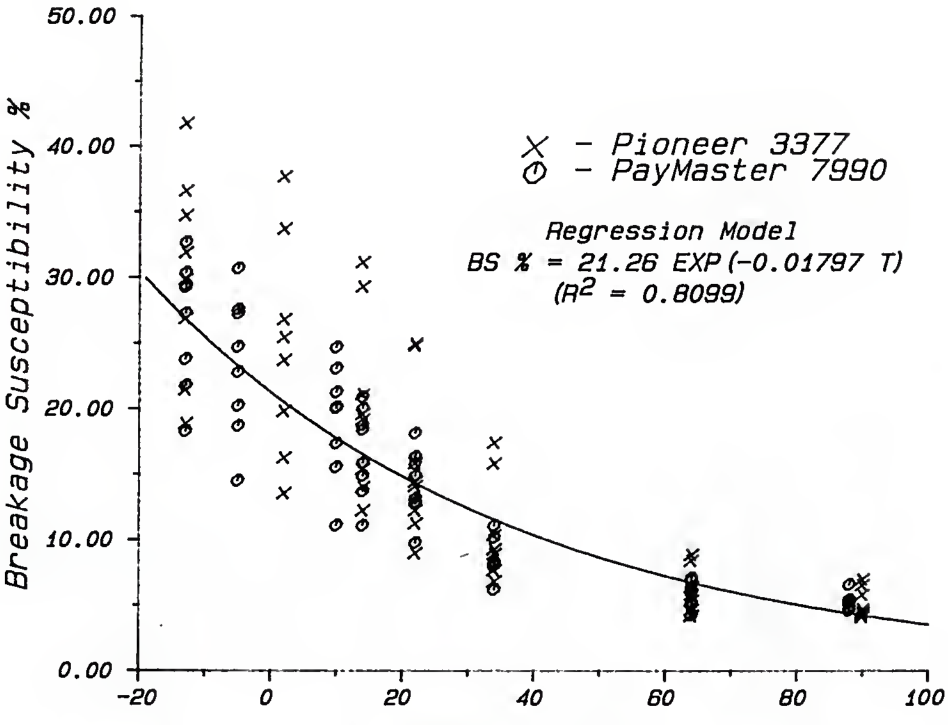

Figure 5.14 Effect of temperature on breakage susceptibility results for Pioneer 3377 and PayMaster 7990 using 16/64-in sieve.

effect. The observed breakage susceptibility values ranged between 1.58 - 21.4% and 4.1 - 41.77% for 12/64" and 16.64" sieve measurement, respectively. Although Jindal et al. (1979) studied the Stein Breakage Tester, the temperature effect observed in this study was similar to what they observed. No previous researcher as developed a prediction equation for the temperature effect. temperature effect.

Using all the experimental data grouped together, the best fit exponential models developed were:

BS % = 10.14 EXP(-0.019 T) R^2 = 0.78 (12/64" Sieve) (5.3)
BS % = 21.26 EXP(-0.018 T) R^2 = 0.81 (16/64" Sieve) (5.4)

These models do not accurately predict the breakage susceptibility based on corn temperature due to the confounding effects of variety and drying condition. Figure 5.13 and 5.14 show a large divergence in breakage susceptibility results, especially at low temperature. When the experimental data were separated by corn variety and drying condition, the predictive capabilities of the equation improved. For the Pioneer 3377 variety using the 12/64" and 16/64" sieves, the best fit regression for variety effect alone were:

BS % = 10.53 EXP(-0.019 T) R^2 = 0.74 (12/64" Sieve) (5.5)
BS % = 22.67 EXP(-0.019 T) R^2 = 0.79 (16/64" Sieve) (5.6)

The regression equations for the PayMaster 7990 variety were:

$$BS\ \% = 9.85\ EXP(-0.020\ T) \quad R^2 = 0.83\ (12/64"\ Sieve) \quad (5.7)$$

$$BS\ \% = 20.19\ EXP(-0.017\ T) \quad R^2 = 0.85\ (16/64"\ Sieve) \quad (5.8)$$

The coefficient of determination was not greatly improved when the regression equations were developed using data grouped by corn variety alone. By grouping the data for each individual variety and drying condition, the predictive capabilities of the model could be greatly enhanced (Figure 5.15 - 5.18). Tables 5.9 and 5.10 show the coefficient of determinations for each drying condition with data for both varieties combined. The coefficient of determination improved by this grouping of the data. Tables 5.11 and 5.12 show the best fit models for when the data are seperated by variety and drying condition for the 12/64" and 16/64" sieve, respectively.

Breakage susceptibility values at 90°C were slightly higher than those at 64°C as can be observed in Figure 5.15 to 5.18. 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 already has been discussed.

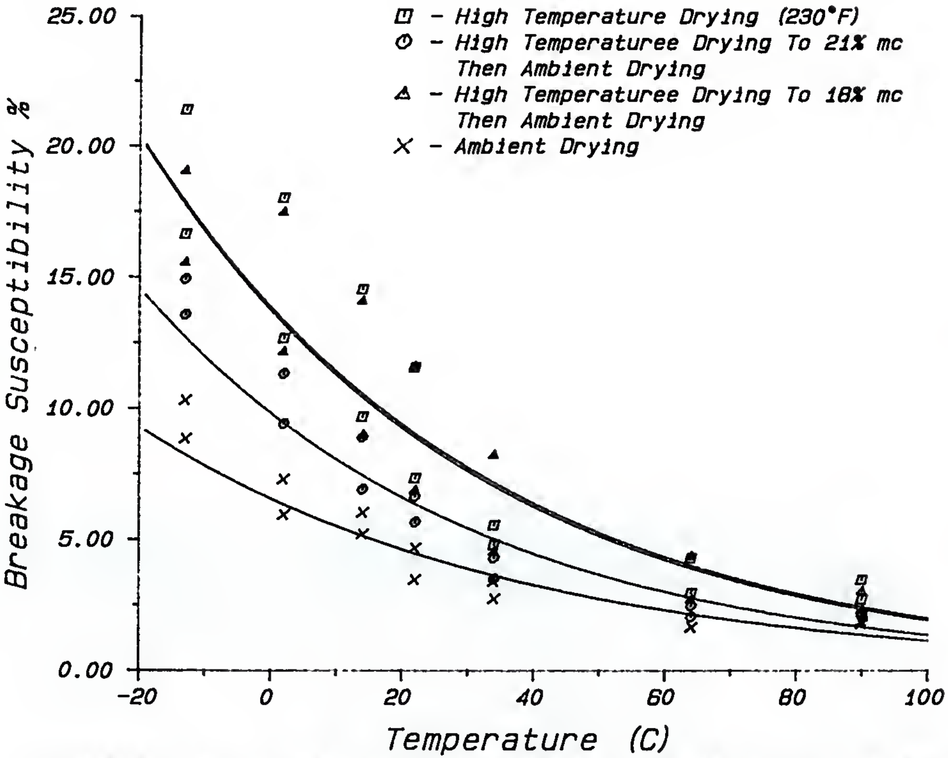

Figure 5.15 Effect of temperature on breakage susceptibility results for Pioneer 3377 under four different drying conditions using 12/64-in sieve.

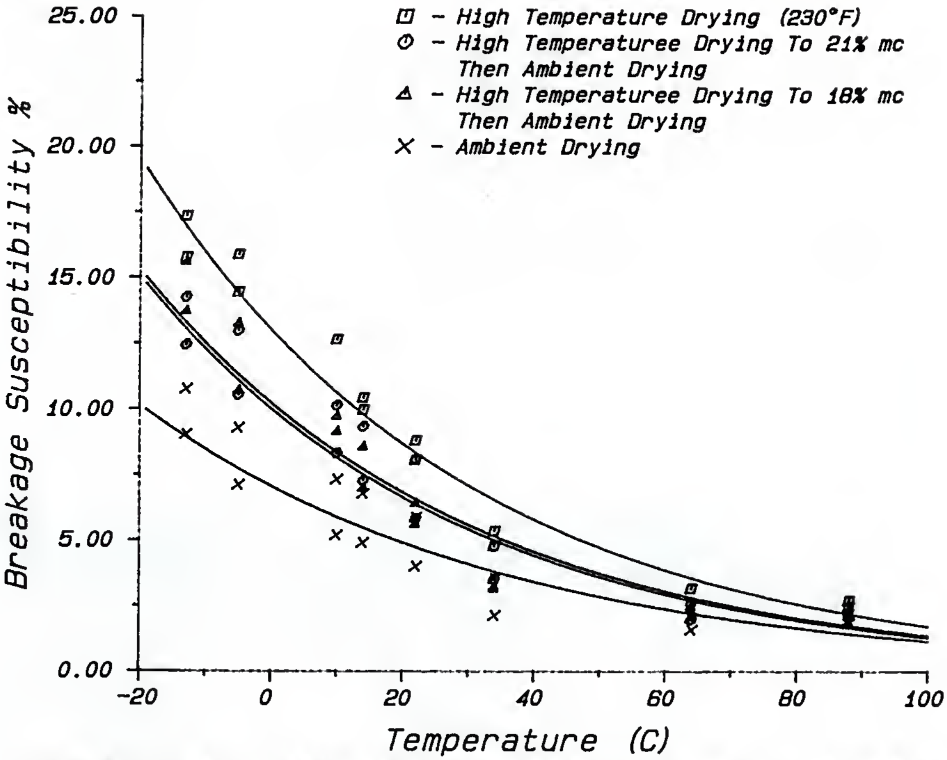

Figure 5.18 Effect of temperature on breakage susceptibility results for PayMaster 7880 under four different drying conditions using 12/64-in sieve.

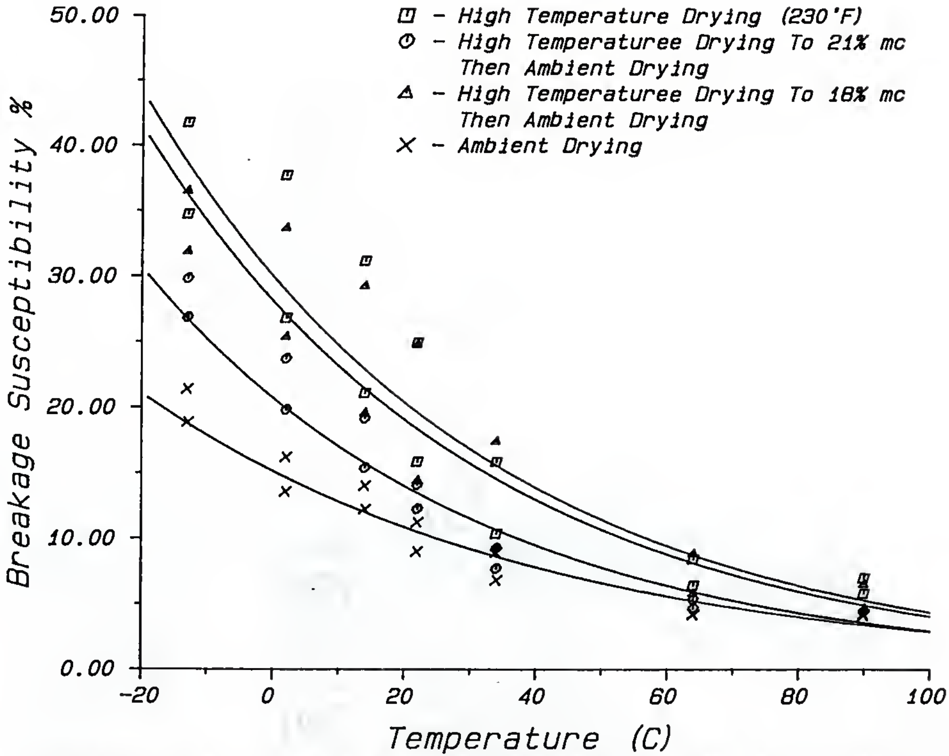

Figure 5.17 Effect of temperature on breakage susceptibility results for Pioneer 3377 under four different drying conditions using 18/64-in sieve.

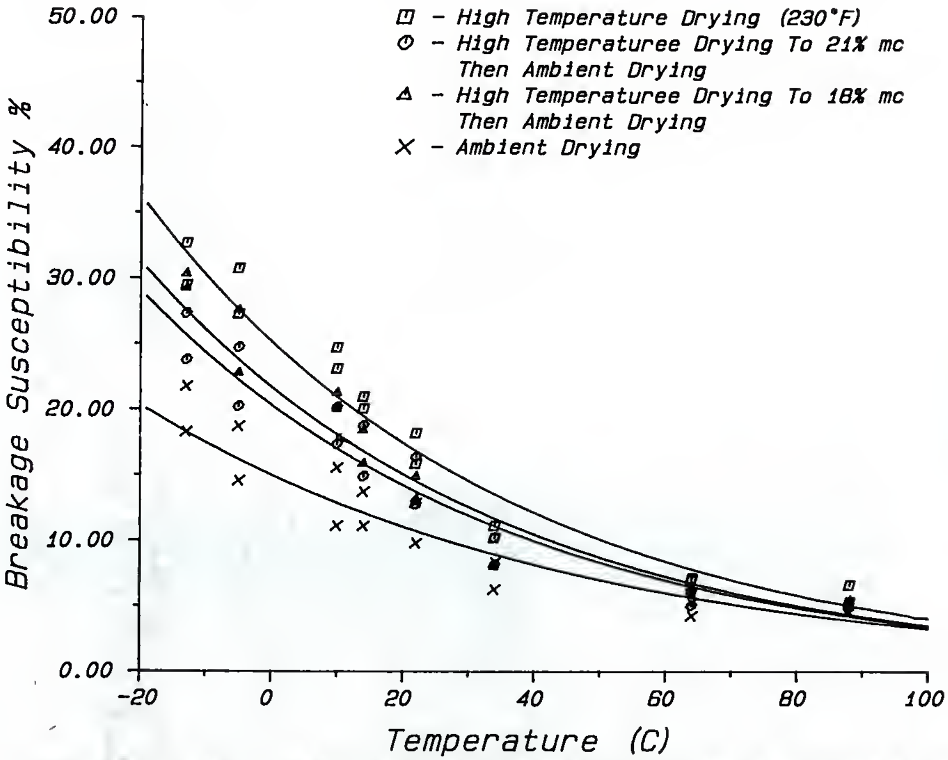

Figure 5.16 Effect of temperature on breakage susceptibility results for PayMaster 7990 under four different drying conditions using 16/64-in sieve.

Table 5.9 Exponential regression equations representing Temperature relations with breakage susceptibility % of various drying conditions measured with the Wisconsin Breakage Tester using a 12/64" sieve.

Model: BS% = A EXP(-CT)

Drying Condition	Estimate of Parameters A	C	R-SQUARE
Overall	10.1351	0.01938	0.7814
B	13.3832	0.01978	0.8768
C	10.0442	0.02003	0.9130
D	11.5075	0.01983	0.8359
E	6.8346	0.01788	0.8609

Table 5.10 Exponential regression equations representing temperature relations with breakage susceptibility % of various drying conditions measured with the Wisconsin Breakage Tester using a 16/64" sieve.

Model: BS% = A EXP(-CT)

Drying Condition	Estimate of Parameters A	C	R-SQUARE
Overall	21.2637	0.01797	0.8089
B	27.1941	0.01863	0.8955
C	20.5118	0.01872	0.9232
D	24.3371	0.01860	0.8634
E	15.0594	0.01595	0.8894

Table 5.11 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 12/64" sieve.

Model: BS% = A EXP(-CT)

Corn Variety	Drying Condition	Estimate of Parameters A	C	R-SQUARE
Pioneer 3377	B	13.8599	0.0194	0.81
	C	9.8257	0.0198	0.91
	D	13.7357	0.0197	0.88
	E	6.5601	0.0175	0.87
PayMaster 7990	B	13.0137	0.0203	0.95
	C	10.2267	0.0202	0.91
	D	10.0041	0.0205	0.90
	E	7.0569	0.0182	0.85

Based on the above analyses, drying condition is more significant than the corn hybrid in estimating the temperature effect for 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 functionality of a temperature compensation equation is limited.

Table 5.12 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 16/64" sieve.

Model: $BS\% = A\ EXP(-CT)$

Corn Variety	Drying Condition	Estimate of Parameters A	C	R-SQUARE
Pioneer 3377	B	29.9941	0.0193	0.88
	C	20.7179	0.0196	0.93
	D	28.1065	0.0194	0.88
	E	15.1348	0.0166	0.91
PayMaster 7990	B	25.1536	0.0183	0.94
	C	20.3280	0.0179	0.92
	D	21.6932	0.0183	0.91
	E	14.9843	0.0153	0.87

Interaction between Moisture Content and Temperature

A significant interaction between moisture content and temperature was observed (Figure 5.19). Herum and Blaisdell (1981) inferred that the breakage mechanism might be expected to change as water mobility changes in the product. In the same moisture content, the water mobility might change as a function of temperature inside the corn kernel and make the kernel elastic enough to absorb higher energy at high temperature.

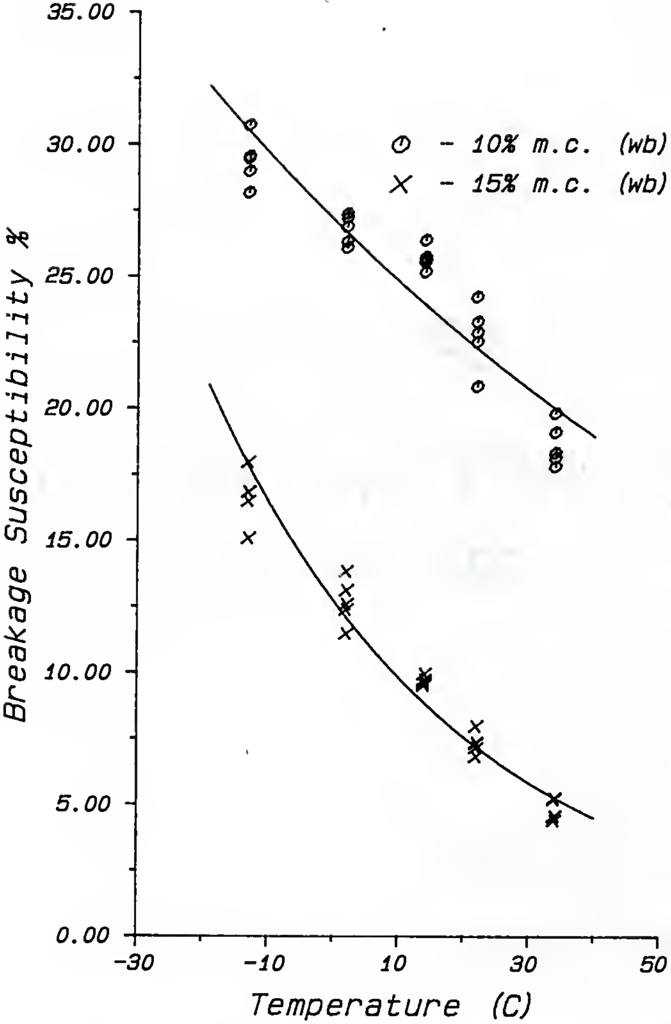

Figure 5.18 Two regression equations of temperature effect on breakage susceptibility indicate the interaction between moisture content and temperature.

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

$$\text{BS \%} = 12.74\ \text{EXP}(-0.026\ T) \quad R^2 = 0.96\ (14.59\%\ \text{m.c.}) \qquad (5.9)$$

$$\text{BS \%} = 27.14\ \text{EXP}(-0.009\ T) \quad R^2 = 0.87\ (\ 9.95\%\ \text{m.c.}) \qquad (5.10)$$

An analysis of variance was performed on the data with the results in Table 5.13 showing that are significant moisture content and temperature interaction at the 99% level. The amount of data collected to study this interaction is limited and would need to be pursued in greater detail if moisture content and temperature compensation models were to be developed.

Table 5.13 Analysis of variance table for the interaction between moisture content and temperature.

SOURCE	DF	SS	MS	F-VALUE	PR > F
MODEL	9	3366.2765	374.0307	654.06	0.0001
MC	1	2599.7818	2599.7818	4546.16	0.0001
TEMP	4	749.7366	187.4342	327.76	0.0001
MC*TEMP	4	16.7581	4.1895	7.33	0.0011
ERROR	40	22.8745	0.5719		
TOTAL	49	3389.1510			

SUMMARY AND CONCLUSIONS

Corn breakage susceptibility is greatly affected by both moisture content and temperature. The relationship between breakage susceptibility and moisture content is best fit by an exponential model as privious investigation had found Tester (Paulsen, 1983; Moes, 1986). Breakage susceptibility values increased with decreasing temperature and could be modeled with a similar exponential relationship. Both the moisture content and temperature relationship to breakage susceptibility are functions of the drying procedure used and the relationship 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 temperature (90°C). Significant moisture content and temperature interaction were observed.

Development of a single model or set of models which could be used in the market channel to predict breakage susceptibility values does not seem plausible because of the dependence of the relationship opon knowledge of the drying conditions used. These models may be useful for research purposes but have little application in the market channel.

REFERENCES

Balastreire, L. A., F. L. Herum, K. K. Stevens, and J. L. Blaisdell. 1982. Fracture of Corn Endosperm in Bending. Part I. Fracture Parameters. TRANSACTION of the ASAE 25(4): 1057-1061, 1065.

Balastreire, L. A., F. L. Herum, K. K. Stevens, and J. L. Blaisdell. 1982. Fracture of Corn Endosperm in Bending. Part II. Fracture Analysis by Fractography and Optical Microscopy. TRANSACTION of the ASAE 25(4): 1062-1065.

Emam, A., M. R. Okos, G. H. Foster, and M. Fostes. 1979. Effect of Tempering Time on Quality Dried Corn. ASAE Paper No. 82-3015. ASAE, St. Joseph, Michigan 49085.

Gunasekaran, S. and M. R. Paulsen. 1985. Breakage Resistance of Corn as a Function of Drying Rate. ASAE Paper No. 85-3024. St. Joseph, Michigan 49085.

Gustafson, R. J., R. V. Morey, C. M. Christensen, and R. A. Meronuck. 1978. Quality Changes during High-Low Temperature Drying. TRANSACTION of the ASAE 19(1): 162-169.

Gustafson, R. J. and R. V. Morey. 1980. Moisture and Quality Variation across the Column of a Crossflow Grain Dryer. ASAE Paper No.80-3513. St. Joseph, Michigan 49085.

Herum, F. L., J. L. Blaisdell. 1981. Effects of Moisture Content, Temperature, and Test Variables on Results with Grain Breakage Testers. ASAE Paper 81-3030. St. Joseph, Michigan 49085.

Hoki, M. and L. K. Pickett. 1973. Factors Affecting Mechanical Damage of Navy Beans. TRANSACTION of the ASAE 16(2): 1154-1157.

Jindal, V. K., F. L. Herum, and M. Y. Hamdy. 1979. Selected Breakage Characteristics of Corn. TRANSACTION of the ASAE 22(5): 1193-1196.

Kumar, A., F. L. Herum, and J. L. Blaisdell. 1978. Equilibrium Moisture Contents of Intact Corn Ears and Component Parts. ASAE Paper 78-3054. Logan, Utah.

Miller, B. S., J. W. Hughes, R. Rousser, and Y. Pomeranz. 1979. A Standard Method for Measuring Breakage Susceptibility of Shelled Corn. ASAE Paper No. 79-3087. St. Joseph, Michigan 49085.

Miller, B. S., J. W. Hughes, R. Rousser, and Y. Pomeranz. 1981. Measuring the Breakage Susceptibility of Shelled Corn. Cereal Foods World 26(2): 75-80.

Moes, Jack. 1986. Grain Corn Breakage Susceptibility: Effects of Hybrid, Planting Density, harvest Moisture Content, and Drying Temperature. Unpublished Master Thesis. University of Guelph.

Mohsenin, N.N. 1980. Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers, New York.

Peplinski, A. J., O. L. Brekke, E. L. Griffin, G. Hall, and L. D. Hill. 1975. Corn Quality as Influenced by Harvest and Drying Conditions. Cereal Foods World. 20(3): 145-149, 154.

Schmidt, Dave. 1987. The 1985-86 Wisconsin breakage Tester Collaborative Study. The Ohio State University, Wooster, Ohio 44691-6900.

Singh, S. S., and M. F. Finner. 1983. A Centrifugal Impacter for Damage Susceptibility evaluation of Shelled Corn. TRANSACTION of the ASAE 26: 1858-1863.

Thompson, Ralph A. and George H. Foster. 1963. Stress Cracks and Breakage in Artifically dried Corn. Marketing Research Report No. 631. USDA Agricultural Marketing Service.

Tran, T. L., J. M. DeMan, and V. F. Raspar. 1981. Measurement of Corn Kernel Hardness. Cdn. Inst. Food Science Technology Journal 14: 42-48.

White, G. M., I. J. Ross, and C. G. Poneleit. 1981. Stress Crack Development in Popcorn as influenced by Drying Conditions. ASAE Paper No. 81-3032. St. Joseph, Michigan 49085.

VI. BREAKAGE SUSCEPTIBILITY OF REWETTED AND BLENDED CORN SAMPLES

INTRODUCTION

Two important questions that relate to corn moving through market channels were investigated in this study. The first is whether corn which is rewetted has the same breakage susceptibility as the identical corn dried to the same moisture content. The second is the effect of blending on the breakage susceptibility values from the blended samples.

Corn of different moisture contents are routinely blended together in the market channels. Dry corn with a moisture content less than 15.5% is blended with wetter corn corn to obtain an optimal 15.5% moisture blend for number 2 corn marketing. Nguyen et al. (1981) found that blending of different moisture corn resulted in Stein Breakage tester values 0.1 to 1.7 percentage point higher than estimated from the individual components.

Rehydration or rewetting of corn samples occurs often due to moisture blending of corn samples. Salter (1986) studied the rewetting of corn and its affect on the Stein Breakage tester results. He found that rewetted corn had higher breakage values than corn dried down to the same

moisture content.

The purpose of this investigation was to valuate the effect of blending to samples of corn together with the same moisture content but different breakage susceptibility values and to study the effect of rehydration on the breakage susceptibility values determined by the Wisconsin Breakage tester.

METHODS AND PROCEDURES

Samples of one identity preserved corn lot (Pioneer 3377) were harvested by machine at 25% moisture content. All the corn samples were pre-sieved through 12/64" in round hole sieve and picked by hand to remove the foreign material.

Breakage Susceptibility of Rewetted Corn

The samples were then rewetted 2 or 4 percentage points. Samples were dried to 10, 12, or 14% m.c. using three different drying conditions. For example, samples dried to 10% were rewetted to 12% and 14%, those at 12% were rewetted to 14% and 16%, and so on for the other dried moisture levels up to 14%. The three drying conditions used were:

(A) High temperature drying at 230°F to the desired

moisture content.

(B) High temperature drying at 230°F to 18% m.c. followed ambient air drying to the desired moisture content.

(C) Abient air dried to the desired moisture conten.

There were two replicates for each drying condition.

Rewetting was performed by the addition of the appropriate amount of moisture to the corn in a plastic bag. The desired final weight of samples was at least 1150 g which contained 1000 g for breakage test (five replicates) and 150 g for moisture determinations. After rewetting, samples were held in the plastic bags and stored at room temperature (23°C) for six days before moisture measurement 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 using the procedure of Paulsen (1983) with both 12/64" and 16/64" 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.

Breakage Susceptibility of Blended Corn

Two 15 kg corn lots were dried using two drying conditions:

(a) High temperature drying at 230°F to the desired

moisture content.

(b) Ambient air drying to the desired moisture content.

Breakage values were determined 5 replicates for each individual sample prior to blending.

Corn samples with the same moisture content but different drying treatments were then blended in equal proportions to obtained samples at 5 levels of moisture content (10%, 12%, 14%, 16%, and 18%). These blended samples were held in plastic bags and stored at room temperature six days before final moisture measurement (103°C for 72 hours) and breakage testing. During the equilibrating period, the blended samples were mixed three times every day by turning the bags upside down five times. Breakage susceptibility was determined by the procedure of Paulsen (1983) on both 12/64" and 16/64" sieves. The breakage susceptibility values of the blended corn were compared to the breakage values of the unblended corn samples dried to that moisture content.

RESULTS AND DISCUSSION

Some samples were omitted in the rewetting procedure due to drying beyond tolerance which was set to be within 0.5% for the two samples to be blended together.

Breakage Susceptibility of Rewetted Corn

From a previous study, it was determined that breakage susceptibility was strongly dependent on the drying condition. In order to eliminate the variation due to different drying condition, six groups of data were obtained from the three different drying treatments and each had two replicates. The experimental data were reorganized and listed in Tables 6.1 - 6.6 and analyzed separately for each drying condition and replicate. The lower the moisture content, the bigger the difference of breakage susceptibility between rewetted and originally dried samples. The results (Table 6.1 to 6.6) using both the 12/64" and the 16/64" sieve have the same tendency for the effect of rewetting, but using 16/64" sieve measurement can easily differentate the rewetted samples from the samples originally dried. The raw data of experiment are listed in Appendices 9 and 10 for 12/64" and 16/64" sieve measurement, respectively.

The magnitude of the difference between unwetted and rewetted samples was random to the initial moisture content, final moisture content, and rehydration difference. Thus, there were three different tendancy due to three different drying conditions. For high temperature (230° F) dried samples and high-ambient dried samples, the magnitude of the difference between unwetted and rewetted samples was correlated with the initial moisture content.

Table 6.1 The Effect of Rewetting on Breakage Susceptibility Values for High Temperature Dried Corn Using 12/64" Sieve

Replicate	Unwetted Sample Moisture Content % w.b.	Rewetted Sample Moisture Content % w.b.	Breakage Susceptibility %					
			Unwetted Sample		Expected Values	Measured Values		Difference (Measured-Expected)
			Ave.	S.D.		Ave.	S.D.	
1	8.79	11.29	33.91	0.81	25.32	23.02	0.31	-2.30
1	8.79	13.43	33.91	0.81	14.55	13.72	0.49	-0.83
1	11.17	13.39	25.32	0.65	10.55	13.33	0.39	+2.78
1	11.17	16.59	25.32	0.65	3.47	5.29	0.24	+1.82
1	13.26	16.65	14.55	0.42	3.47	4.12	0.40	+0.65
2	9.85	12.59	25.62	0.94	14.78	12.62	0.82	-2.16
2	9.85	14.44	25.62	0.94	8.28	7.32	0.26	-0.96
2	12.43	14.37	14.78	1.68	8.28	7.48	0.22	-0.80
2	12.43	17.20	14.78	1.68	2.82	3.18	0.39	+0.36
2	14.20	16.88	8.28	0.34	2.82	2.53	0.26	-0.29
2	14.20	19.50	8.28	0.34	1.61	1.48	0.16	-0.13

* The highest coefficient of correlation ($R = 0.6469$ and 0.7290) was found between the difference (Measured-Expected) and the initial moisture content.

Table 6.2 The Effect of Rewetting on Breakage Susceptibility Values for High-Ambient Temperature Dried Corn Using 12/64" Sieve

Replicate	Unwetted Sample Moisture Content % w.b.	Rewetted Sample Moisture Content % w.b.	Breakage Susceptibility %					
			Unwetted Sample Ave.	Unwetted Sample S.D.	Expected Values	Measured Values Ave.	Measured Values S.D.	Difference (Measured-Expected)
1	10.47	11.09	18.49	0.82	16.69	17.68	0.70	+0.99
1	10.47	14.04	18.49	0.82	8.50	10.14	0.48	+1.64
1	10.95	13.91	16.69	0.84	8.50	10.06	0.45	+1.56
1	10.95	16.68	16.69	0.84	3.89	4.08	0.34	+0.19
1	13.77	16.45	8.50	1.78	3.89	3.59	0.22	+0.30
2	10.68	10.99	18.89	0.72	17.31	17.86	0.40	+0.55
2	10.68	14.11	18.89	0.72	7.45	9.93	0.37	+2.48
2	10.90	14.01	17.31	0.95	7.45	9.89	0.46	+2.44
2	10.90	16.86	17.31	0.95	3.43	3.94	0.27	+0.51
2	13.90	16.77	7.45	0.37	3.43	2.70	0.22	-0.73

* The highest coefficient of correlation (R = -0.7092 and -0.7987 was found between the difference (Measured-Expected) and the initial moisture content.

Table 6.3 The Effect of Rewetting on Breakage Susceptibility Values for Ambient Temperature Dried Corn Using 12/64" Sieve

Replicate	Unwetted Sample Moisture Content % w.b.	Rewetted Sample Moisture Content % w.b.	Breakage Susceptibility %					
			Unwetted Sample Ave.	Unwetted Sample S.D.	Expected Values	Measured Values Ave.	Measured Values S.D.	Difference (Measured-Expected)
1	11.42	12.42	11.77	0.66	10.28	9.54	0.32	-0.74
1	11.42	13.47	11.77	0.66	8.10	8.74	0.29	+0.64
1	12.49	13.56	10.28	0.33	8.10	7.44	0.25	-0.66
1	12.49	15.68	10.28	0.33	4.92	5.40	0.46	+0.48
1	13.53	15.74	8.10	0.37	4.92	4.59	0.32	-0.33
1	13.53	17.18	8.10	0.37	2.88	3.39	0.32	+0.51
2	11.48	11.97	11.80	0.78	11.05	10.22	0.66	-0.83
2	11.48	14.45	11.80	0.78	7.80	7.21	0.29	-0.59
2	12.02	14.46	11.05	0.29	7.80	7.24	0.15	-0.56
2	12.02	17.24	11.05	0.29	3.53	3.97	0.21	+0.44
2	14.44	16.95	7.80	0.71	3.53	3.06	0.25	-0.47
2	14.44	17.80	7.80	0.71	2.56	2.55	0.30	-0.01

* The highest coefficient of correlation (R = 0.8074 and 0.9183 was found between the difference (Measured-Expected) and the percentage of moisture increased.

Table 6.4 The Effect of Rewetting on Breakage Susceptibility Values for High Temperature Dried Corn Using 16/64" Sieve

Replicate	Unwetted Sample Moisture Content % w.b.	Rewetted Sample Moisture Content % w.b.	Breakage Susceptibility %					
			Unwetted Sample Ave.	Unwetted Sample S.D.	Expected Values	Measured Values Ave.	Measured Values S.D.	Difference (Measured-Expected)
1	8.79	11.29	61.68	1.24	48.25	44.13	1.07	-4.12
1	8.79	13.43	61.68	1.24	24.40	26.25	0.65	+1.85
1	11.17	13.39	48.25	1.12	22.21	27.53	1.89	+5.32
1	11.17	16.59	48.25	1.12	7.77	10.51	0.51	+2.74
1	13.26	16.65	24.40	0.95	7.77	8.77	0.94	+1.00
2	9.85	12.59	48.66	2.11	30.36	26.35	0.84	-4.01
2	9.85	14.44	48.66	2.11	17.26	14.72	0.67	-2.54
2	12.43	14.37	30.36	1.89	17.26	15.74	0.58	-1.52
2	12.43	17.20	30.36	1.89	6.80	6.77	0.69	-0.03
2	14.20	16.88	17.26	0.90	6.80	5.92	0.66	-0.88
2	14.20	19.50	17.26	0.90	4.21	3.75	0.53	-0.46

* The highest coefficient of correlation (R = 0.4249 and 0.8422 was found between the difference (Measured-Expected) and the initial moisture content.

Table 6.5 The Effect of Rewetting on Breakage Susceptibility Values for High-Ambient Temperature Dried Corn Using 16/64" Sieve

Replicate	Unwetted Sample Moisture Content % w.b.	Rewetted Sample Moisture Content % w.b.	Breakage Susceptibility %					
			Unwetted Sample		Expected Values	Measured Values		Difference (Measured-Expected)
			Ave.	S.D.		Ave.	S.D.	
1	10.47	11.09	35.21	1.82	32.62	34.07	1.28	+1.45
1	10.47	14.04	35.21	1.82	16.51	21.79	1.23	+5.28
1	10.95	13.91	32.62	1.13	16.51	21.71	0.94	+5.20
1	10.95	16.68	32.62	1.13	8.85	8.90	0.92	+0.05
1	13.77	16.45	16.51	1.56	8.85	7.30	0.44	-1.55
2	10.68	10.99	35.93	1.07	33.88	34.34	0.72	+0.46
2	10.68	14.11	35.93	1.07	14.83	17.11	1.59	+2.28
2	10.90	14.01	33.88	1.54	14.83	20.60	0.55	+5.77
2	10.90	16.86	33.88	1.54	7.86	8.51	1.09	+0.65
2	13.90	16.77	14.83	0.88	7.86	6.16	0.89	-1.70

* The highest coefficient of correlation (R = -0.6732 and -0.6141 was found between the difference (Measured-Expected) and the initial moisture content.

Table 6.6 The Effect of Rewetting on Breakage Susceptibility Values for Ambient Temperature Dried Corn Using 16/64" Sieve

Replicate	Unwetted Sample Moisture Content % w.b.	Rewetted Sample Moisture Content % w.b.	Breakage Susceptibility %					
			Unwetted Sample Ave.	Unwetted Sample S.D.	Expected Values	Measured Values Ave.	Measured Values S.D.	Difference (Measured-Expected)
1	11.42	12.42	24.23	1.31	21.54	20.11	0.62	-1.43
1	11.42	13.47	24.23	1.31	17.07	19.82	0.62	+2.75
1	12.49	13.56	21.54	1.89	17.07	16.08	0.59	-0.99
1	12.49	15.68	21.54	1.89	10.81	13.47	1.19	+2.66
1	13.53	15.74	17.07	1.06	10.81	10.71	0.66	-0.10
1	13.53	17.18	17.07	1.06	7.19	8.01	0.98	+0.82
2	11.48	11.97	24.02	1.64	22.63	20.80	1.27	-1.83
2	11.48	14.45	24.02	1.64	16.80	17.00	1.36	-0.20
2	12.02	14.46	22.63	0.67	16.80	16.66	0.81	-0.14
2	12.02	17.24	22.63	0.67	7.75	9.85	1.00	+2.10
2	14.44	16.95	16.80	1.61	7.75	7.84	0.97	+0.09
2	14.44	17.80	16.80	1.61	6.54	6.87	0.67	+0.33

* The highest coefficient of correlation (R = 0.6478 and 0.9826 was found between the difference (Measured-Expected) and the percentage of moisture increased.

But the high-ambient dried samples have a negative coefficient of correlation. For example, the magnitude of the difference between unwetted and rewetted samples was decreasing with the increasing initial moisture content.

For ambient dried samples, the magnitude of the difference between unwetted and rewetted samples was correlated with the percentage of moisture increasing. More water as added which might cause high rehydration rate and large moisture gradient inside the corn kernel. Therefore, more stress cracks and additional breakage susceptibility were induced.

In several previous studies, rehydration rate and moisture gradient play an important role in rewetting blending processes. Actually, rewetting process through different paths yielded basically the same results with blending process which had different moisture content, but blending process had lower rehydration rate and lower moisture gradient. In overall view of this study, the breakage susceptibility of low moisture sample can be recovered to the high moisture sample's by rewetting for both high temperature dried and ambient dried samples, except the high-ambient dried samples.

Breakage Susceptibility of Blended Corn

The experimental data are reorganized and listed in Table 6.7 and 6.8 for the 12/64" and the 16/64" sieve

Table 6.7 The Effect of Blending on Corn Breakage Susceptibility Using 12/64" Sieve

Moisture Content % w.b.	Breakage Susceptibility %							
	High Temperature Dried		Low Temperature Dried		Expected Values	Measured Values		Difference (Measured-Expected)
	Ave.	S.D.	Ave.	S.D.		Ave.	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
18.82	1.61	0.11	2.56	0.21	2.09	2.37	0.30	+0.28

Table 6.8 The Effect of Blending on Corn Breakage Susceptibility Using 16/64" Sieve

Moisture Content % w.b.	Breakage Susceptibility %							
	High Temperature Dried		Low Temperature Dried		Expected Values	Measured Values		Difference (Measured-Expected)
	Ave.	S.D.	Ave.	S.D.		Ave.	S.D.	
11.32	39.61	0.52	24.67	1.18	32.14	34.55	1.52	+2.41
11.87	38.10	0.87	24.49	1.93	31.30	34.81	1.26	+3.51
12.42	30.36	1.89	22.63	0.67	26.50	30.08	1.35	+3.58
13.10	28.81	0.78	20.41	0.65	24.61	28.49	0.93	+3.88
13.76	22.21	0.81	17.07	1.06	19.64	24.54	0.91	+4.90
14.75	15.87	0.88	16.80	1.61	16.34	18.52	1.95	+2.18
15.67	14.64	0.97	10.81	0.87	12.73	14.07	0.85	+1.34
16.71	7.77	0.68	11.24	0.69	9.51	10.97	0.69	+1.46
16.72	7.77	0.68	11.27	0.64	9.52	10.15	0.95	+0.63
17.07	6.80	0.32	7.75	0.43	7.28	9.52	0.48	+2.24
18.82	4.21	0.40	6.54	0.66	5.38	6.51	0.49	+1.13

measurement, respectively. The levels of moisture content ranged from 11.32% to 18.82% m.c. in this study. Compared to the values of the unblended samples, the standard deviaton of blended samples didn't change too much on breakage susceptibility values and moisture content. It's evident that there was a completely blending of corn samples in blending process. Because every two samples which had moisture contents within an acceptable tolerance with different drying treatments were chosen for blending, we can assume there was no additional breakage caused by moisture gradient and rehydration in the blending process. The raw data from the experiment are listed in Appendices 11 and 12 in detail.

The results showed the same tendency on breakage susceptibility for both the 12/64" and the 16/64" sieves. All of the blended samples had higher breakage susceptibility values than the average of two original breakage susceptibility values. It seemed the breakage susceptibility of blended corn could not be estimated mathematically. The magnitude above the average breakage value was not correlated with the moisture content blended. The coefficients of correlation were -0.7568 and -0.679 for both the 12/64" and the 16/64" sieves, respectively.

This result was inconsistent with those reported by Hoki and Pickett (1973), Miller et al, (1981), but they were blending corn samples of different moistures in their studies. Hoki and Pickett (1973) found breakage measured by the Stein Breakage tester of blended samples was less than the average of the individual unblended of wet and dry portions. They explained that the wet kernels act as a cushion in the blend and reduces breakage of the dry portion during breakage tests. But this may not happen with the Wisconsin Breakage Tester due to different impacting mechanisms. Miller et al. (1981) reported the breakage susceptiblity of a mixture of corn can be estimated from both the proportions and the breakage susceptibilities of the components of the mixture, by using a linear relationship.

SUMMARY AND CONCLUSIONS

This study investigated two important questions that relate to corn moving through market channels. The first is whether corn which is rewetted has the same breakage susceptibility as the identical corn dried to the same moisture content. The second is the effect of blending on the breakage susceptibility values.

In the rewetting study, six groups of data with three different drying conditions and two replicates were analyzed. It seemed to have the same tendency for the effect of rewetting using both 12/64" and 16/64" sieve, but using 16/64" sieve measurement can easily differentiate the rewetted samples from the samples which were originally dried. The tendency was dependent on the drying condition. Rewetted samples with different drying conditions have different tendency on breakage susceptibility. In overall view, the lower the moisture content, the bigger the difference of breakage susceptibility between rewetted and originally dried samples. The breakage susceptibility can be recovered by rewetting for both high temperature dried and ambient dried samples, except the high-ambient dried samples.

In the blending study, we supposed there was no additional breakage caused by moisture gradient and rehydration in the blending process because every two samples were blended in the same level of moisture content. The levels of moisture content ranged from 11.32% to 18.82% m.c.. Both 12/64" and 16/64" sieve have the same tendency on breakage susceptibility for the effect of blending.

The results of blending tests indicated that all the blended samples had higher breakage susceptibility values than the average of two original breakage susceptibility values. Therefore, the breakage susceptibility of blended corn can't be estimated mathematically. The magnitude above the average breakage value was a little bit correlated with the moisture content blended.

REFERENCES

Hoki, M. and L. K. Pickett. 1973. Factors Affecting Mechanical Damage of Navy Beans. TRANSACTIONS of the ASAE 16(2): 1154-1157.

Miller, B. S., J. W. Hughes, R. Rousser, and Y. Pomeranz. 1981. Measuring the Breakage Susceptibility of Shelled Corn. Cereal Foods World 26(2): 75-80.

Nguyen, V. T., C. J. Bern, W. F. Wilcke, and M. E. Anderson. 1984. Breakage Susceptibility of Blended Corn. TRANSACTIONS of the ASAE 27(1): 209-213.

Salter, Kevin L. 1986. Rehydration of Corn: Effects of Time on Moisture Content, Breakage Susceptibility, and Stress Crack Content. Unpublished preliminary report. Department of Agricultural Engineering, University of Nebraska, Lincoln.

VII. RECOMMENDATIONS FOR FUTURE STUDY

Our experimental data indicated that the different dimensions of Wisconsin Breakage Tester caused different breakage susceptibility results. Therefore, the design of Wisconsin Breakage Tester is needed to be evaluated again in order to getting a consistent and reliable result. In the NC-151 Wisconsin Breakage Tester Collaborative Study, effort was extended to identify any trends among the collaborative study results with the instrument dimensions measured. Therefore, some modification of the experimental results on these differences of construction dimensions can be done.

A Split-plot experimental design is recommended to evaluate the human factors in the future study. The sample effects are the "whole-plot" treatment; the human factors are the "split-plot" treatment. The split-plot design is advantageous because the human factors and the interaction between operator and sample are of greater interest than the sample effects.

One laboratory study of interest would be other parameters except moisture in corn blending. Several reseachers (Hoki and Pickett. 1973; Miller et al, 1981; Nguyen et al, 1984; Salter, 1986) have worked on moisture blending of corn, but other blending parameters has not been studied thoroughly. Blending is done to match delivered quality to specified quality and to provide uniform lots. Therefore, other blending parameter such as foreign material, dust, insect infestation, and breakage susceptibility should be evaluated to see if they affect blending. Mathematically, one part corn with 20% breakage susceptibility can be mixed with four parts corn with 14% breakage susceptibility to give an average of 15% breakage susceptibility.

Other recommended research for the future study would involve a detailed evaluation of the interaction between moisture content and temperature. A general predicting equation for breakage susceptibility can be developed based on the combined effects of moisture content and temperature.

Although these studies could be done and need to be done to enhance the acceptibility of the Wisconsin Breakage Tester as a laboratory instrument. The strong dependence of the instrument's results upon variety and drying condition appear to negate its potential utilization in the market channel for grade determination.

REFERENCE

Commitment To Quality. 1986. A Consensus Report of the Grain Quality Workshops.

Hoki, M. and L. K. Pickett. 1973. Factors Affecting Mechanical Damage of Navy Beans. TRANSACTIONS of the ASAE 16(2): 1154-1157.

Miller, B. S., J. W. Hughes, R. Rousser, and Y. Pomeranz. 1981. Measuring the Breakage Susceptibility of Shelled Corn. Cereal Foods World 26(2): 75-80.

Nguyen, V. T., C. J. Bern, W. F. Wilcke, and M. E. Anderson. 1984. Breakage Susceptibility of Blended Corn. TRANSACTIONS of the ASAE 27(1): 209-213.

Salter, Kevin L. 1986. Rehydration of Corn: Effects of Time on Moisture Content, Breakage Susceptibility, and Stress Crack Content. Unpublished preliminary report. Department of Agricultural Engineering, University of Nebraska, Lincoln.

APPENDIX 1

Sample Coding Method

Example: 3A-AD1-14

Notation:

3A - Objective No. : 2A, 2B, 3A. 3B, 3C, 3D

- 2A - To analyze the standard error of measuring breakage susceptibility.
- 2B - The effect of Temperature on breakage susceptibility.
- 3A - The effect of moisture content on breakage susceptibility.
- 3B - The effect of rewetting on breakage susceptibility.
- 3C - The effect of blending on breakage susceptibility.
- 3D - The interaction between moisture content and temperature.

A - Corn Variety : A, B, C, D, E

- A: Pioneer 3377
- B: PayMaster 7990
- C: Keltgen KS-1161
- D: Northrup King PX 9540
- E: Dekalb 711

D - Drying Condition : A, B, C, D, E

- A: Hand harvested and shelled; Ambient air drying to the desired moisture content.
- B: Machine harvested and shelled; High temperature drying at 230'F to the desired moisture content.
- C: Machine harvested and shelled; High temperature drying at 230'F to 21% m.c. followed by ambient air drying to the desired moisture content.
- D: Machine harvested and shelled; High temperature drying at 230'F to 18% m.c. followed by ambient air drying to the desired moisture content.
- E: Machine harvested and shelled; Ambient air drying to the desired moisture content.

1 - Drying Replicate No. : 1, 2

14 - Moisture content % (wet basis)

(* For rewetted samples, the number after moisture content is rewetted moisture contetn.)

APPENDIX 2

Data for Evaluation of the Standard Deviation on Corn Breakage Susceptibility Using 12/64" Sieve

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
2A-AA1-15	14.13	22	7.52	7.28	7.19	7.43	7.06	7.29	0.18
2A-AA2-15	14.13	20	7.28	8.19	7.39	7.96	7.83	7.73	0.39
2A-AB1-15a	13.13	22	12.26	12.00	11.86	12.84	11.26	12.04	0.58
2A-AB1-15c	12.80	21	12.75	13.44	13.94	14.18	13.22	13.51	0.57
2A-AB2-15a	14.40	21	6.88	6.34	7.00	7.01	7.43	6.93	0.39
2A-AB2-15c	14.52	22	7.69	6.84	6.57	6.88	6.58	6.91	0.46
2A-AC1-15a	14.31	23	6.60	6.09	6.33	6.78	6.47	6.45	0.26
2A-AC2-15a	15.21	23	5.42	5.92	5.46	5.88	6.15	5.77	0.32
2A-AD1-15a	13.86	22	8.28	7.44	7.55	8.39	7.40	7.81	0.48
2A-AD2-15a	14.09	22	7.14	7.52	6.96	6.86	8.02	7.30	0.47
2A-AE1-15a	16.01	22	4.56	4.61	4.79	4.73	4.63	4.67	0.09
2A-AE1-15e	15.78	23	4.68	4.40	4.92	5.01	5.21	4.84	0.31
2A-AE2-15a	16.70	23	3.17	3.22	3.88	3.72	3.42	3.48	0.31
3A-AE2-15d	16.20	21	5.25	4.75	5.17	4.65	4.95	4.95	0.26
2A-BA1-15b	14.42	21	4.39	4.54	4.75	4.62	4.82	4.63	0.17
2A-BA2-15	14.50	20	4.53	5.62	5.19	5.01	5.04	5.08	0.39
2A-BB1-15b	13.44	21	6.69	6.76	6.39	7.11	7.14	6.82	0.31
2A-BB2-15e	12.72	21	8.11	8.23	8.64	8.79	9.64	8.68	0.61
2A-BC1-15e	15.04	21	5.38	5.48	5.69	5.82	5.28	5.53	0.22
2A-BC2-15e	14.12	21	8.39	8.24	7.79	8.25	8.31	8.19	0.23
2A-BD1-15d	15.07	21	6.27	6.29	5.58	5.60	7.02	6.15	0.60
2A-BD2-15a	15.09	21	5.64	6.46	5.86	6.77	7.07	6.36	0.60
2A-BE1-15e	15.54	21	4.55	4.07	3.93	4.26	4.63	4.29	0.30
2A-BE2-15a	14.84	21	4.05	4.57	4.53	4.54	4.39	4.42	0.22
2A-CA1-15	15.19	20	4.01	4.16	4.52	3.73	3.57	4.00	0.37
2A-CA2-15	15.19	20	4.47	4.59	5.11	4.37	4.67	4.64	0.29
2A-CB3-15	14.96	22	6.79	6.41	6.29	6.86	6.86	6.64	0.27
2A-CC1-15	15.47	20	5.15	4.74	4.60	5.86	4.72	5.01	0.52
2A-CC2-15	16.04	20	4.48	4.35	5.10	4.44	4.25	4.53	0.33
2A-CD3-15	15.82	21	4.43	4.77	4.68	4.42	4.62	4.58	0.16
2A-CE1-15	15.40	21	5.09	5.03	4.91	5.03	4.94	5.00	0.07
2A-CE2-15	15.64	21	4.42	4.77	4.39	4.59	4.61	4.56	0.15
2A-DA1-15	15.32	21	4.10	3.69	3.95	4.02	4.30	4.01	0.22
2A-DA1-15	15.32	21	3.73	3.83	3.97	3.85	3.95	3.87	0.10
2A DB2-15	13.23	22	15.90	16.73	14.81	15.95	16.78	16.03	0.80
2A-DB3-15	15.39	21	4.12	4.47	4.38	4.23	4.72	4.38	0.23
2A-DC1-15	14.78	20	12.24	12.22	12.14	12.51	12.09	12.24	0.16
2A-DC2-15	15.46	21	5.85	6.67	5.68	5.89	5.81	5.98	0.39
2A-DD1-15	15.18	21	6.23	5.36	3.44	5.50	5.91	5.29	1.09
2A-DD2-15	15.31	20	6.58	6.40	6.56	5.88	6.78	6.44	0.34
2A-DE1-15a	14.88	20	6.13	6.96	6.77	5.61	6.05	6.30	0.55
2A-DE2-15b	16.42	20	6.51	6.99	6.83	6.55	7.05	6.79	0.25

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
2A-EA1-15	14.30	19	4.08	4.07	4.08	4.27	4.24	4.15	0.10
2A-EA2-15	14.42	18	4.60	4.56	4.22	4.06	4.37	4.36	0.23
2A-EB1-15	13.57	17	10.14	9.53	8.38	10.27	10.12	9.69	0.79
2A-EB2-15	16.13	18	4.27	4.21	3.95	4.06	4.82	4.26	0.34
2A-EC1-15	14.93	18	7.17	6.05	6.57	6.65	6.86	6.66	0.41
2A-EC2-15	14.77	18	7.50	7.94	7.20	7.42	8.16	7.64	0.39
2A-ED1-15	15.16	18	5.36	5.21	5.41	5.15	5.37	5.30	0.11
2A-ED2-15	14.24	19	8.84	8.94	8.24	7.75	8.30	8.41	0.48
2A-EE1-15	14.17	19	6.55	6.26	6.19	6.22	6.71	6.39	0.23
2A-EE2-15	15.03	19	5.44	4.95	5.56	4.73	5.34	5.20	0.35

APPENDIX 3

Data for Evaluation of the Standard Deviation on Corn Breakage Susceptibility Using 16/64" Sieve

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
2A-AA1-15	14.13	22	14.32	14.34	14.67	15.34	14.58	14.65	0.41
2A-AA2-15	14.13	20	16.53	15.98	15.22	16.33	15.18	15.85	0.62
2A-AB1-15a	13.13	22	27.14	28.15	25.89	26.88	23.16	26.24	1.90
2A-AB1-15c	12.80	21	27.52	29.61	28.81	29.15	28.97	28.81	0.78
2A-AB2-15a	14.40	21	16.84	14.61	16.54	15.76	15.60	15.87	0.88
2A-AB2-15c	14.52	22	15.76	14.67	13.13	14.53	15.13	14.64	0.97
2A-AC1-15a	14.31	23	14.33	13.53	14.08	14.54	13.85	14.07	0.40
2A-AC2-15a	15.21	23	13.70	12.68	12.91	14.67	14.81	13.76	0.98
2A-AD1-15a	13.86	22	15.87	16.40	15.95	17.50	15.83	16.31	0.70
2A-AD2-15a	14.09	22	15.77	16.21	15.34	12.81	16.71	15.37	1.52
2A-AE1-15a	16.01	22	11.10	12.36	11.29	10.80	10.80	11.27	0.64
2A-AE1-15e	15.78	23	11.15	10.28	11.94	11.74	11.35	11.29	0.65
2A-AE2-15a	16.70	23	8.66	8.22	9.85	8.90	8.01	8.73	0.72
3A-AE2-15d	16.20	21	11.49	11.88	10.99	10.16	11.67	11.24	0.69
2A-BA1-15b	14.42	21	8.84	9.58	10.15	9.45	10.01	9.61	0.52
2A-BA2-15	14.42	21	25.15	11.26	10.89	10.15	9.15	13.32	6.66
2A-BB1-15b	13.44	21	15.49	13.93	14.16	15.70	15.53	14.96	0.85
2A-BB2-15e	12.72	21	16.94	17.47	20.75	19.88	18.86	18.78	1.60
2A-BC1-15e	15.04	21	12.12	12.22	12.37	13.77	12.32	12.56	0.68
2A-BC2-15e	14.12	21	19.71	19.35	16.93	18.24	17.74	18.39	1.14
2A-BD1-15d	15.07	21	14.54	15.96	15.12	13.75	17.85	15.45	1.57
2A-BD2-15a	15.09	21	12.61	15.32	14.48	16.30	18.73	15.49	2.26
2A-BE1-15e	15.54	21	10.25	10.06	11.02	11.50	10.73	10.71	0.58
2A-BE2-15a	14.84	21	8.99	11.32	11.25	10.87	12.93	11.07	1.41
2A-CA1-15	15.19	20	9.96	10.48	10.75	10.49	9.62	10.26	0.46
2A-CA2-15	15.19	20	11.54	11.01	12.00	11.00	11.32	11.37	0.41
2A-CB3-15	14.96	22	16.41	14.91	14.47	15.36	15.02	15.23	0.73
2A-CC1-15	15.47	20	13.05	11.88	13.73	15.71	13.33	13.54	1.40
2A-CC2-15	16.04	20	11.52	13.11	14.25	13.13	11.79	12.76	1.11
2A-CD3-15	15.82	21	12.15	13.28	13.10	10.36	12.88	12.35	1.20
2A-CE1-15	15.40	21	14.33	12.86	12.41	12.76	13.05	13.08	0.74
2A-CE2-15	15.64	21	12.68	12.87	12.75	12.86	12.92	12.82	0.10
2A-DA1-15	15.32	21	11.50	9.77	9.32	10.15	10.82	10.31	0.86
2A-DA2-15	15.32	21	9.27	10.31	9.80	9.76	9.87	9.80	0.37
2A-DB2-15	13.23	22	34.27	35.45	31.49	33.85	34.64	33.94	1.49
2A-DB3-15	15.39	21	11.95	10.34	10.87	11.15	11.48	11.16	0.61
2A-DC1-15	14.78	20	27.81	26.85	28.01	28.08	28.25	27.80	0.55
2A-DC2-15	15.46	21	15.29	15.11	14.79	14.75	16.00	15.19	0.51
2A-DD1-15	15.18	21	13.91	12.31	12.44	13.55	13.44	13.13	0.71
2A-DD2-15	15.31	20	17.21	16.43	15.15	16.84	17.36	16.60	0.88
2A-DE1-15a	14.88	20	14.12	16.07	15.22	15.63	15.19	15.24	0.72
2A-DE2-15b	16.42	20	16.44	15.79	16.27	18.50	17.98	17.00	1.18

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
2A-EA1-15	14.30	19	10.49	9.25	8.45	9.70	9.68	9.51	0.74
2A-EA2-15	14.42	18	11.23	10.41	10.37	10.25	10.47	10.55	0.39
2A-EB1-15	13.57	17	24.73	23.08	21.39	24.63	24.10	23.59	1.39
2A-EB2-15	16.13	18	9.46	10.73	9.10	10.61	12.01	10.38	1.15
2A-EC1-15	14.93	18	18.37	19.66	17.28	18.79	19.99	18.82	1.08
2A-EC2-15	14.77	18	15.60	14.43	14.36	15.92	16.43	15.35	0.92
2A-ED1-15	15.16	18	12.56	11.45	12.26	12.24	12.49	12.20	0.44
2A-ED2-15	14.24	19	22.21	23.33	22.16	20.06	21.13	21.78	1.24
2A-EE1-15	14.17	19	17.32	15.80	16.34	16.13	17.26	16.57	0.68
2A-EE2-15	15.03	19	14.38	13.06	13.12	12.59	14.97	13.62	1.00

APPENDIX 4

Data for the Effect of Temperature on Corn Breakage Susceptibility Using 12/64" Sieve

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
2B-AB1-15	13.12	-13	21.86	20.60	21.12	21.64	21.81	21.40	0.54
2B-AB1-15	13.12	02	16.58	17.43	18.43	18.83	18.80	18.01	0.98
2B-AB1-15	13.12	14	14.52	13.80	14.92	14.92	14.57	14.54	0.45
2B-AB1-15	13.12	22	12.03	11.26	11.18	12.16	11.16	11.56	0.49
2B-AB1-15	13.12	34	1.98	2.53	7.07	7.83	8.29	5.54	3.04
2B-AB1-15	13.12	64	4.20	4.39	4.46	4.14	4.28	4.29	0.13
2B-AB1-15	13.12	90	3.38	3.92	3.59	3.37	3.03	3.46	0.33
2B-AB2-15	14.59	-13	16.85	16.48	15.08	17.96	16.82	16.64	1.04
2B-AB2-15	14.59	02	12.38	11.47	13.10	13.83	12.58	12.67	0.88
2B-AB2-15	14.59	14	9.59	9.73	9.52	9.65	9.95	9.69	0.17
2B-AB2-15	14.59	22	7.31	7.97	7.15	6.82	7.35	7.32	0.42
2B-AB2-15	14.59	34	5.24	4.54	4.40	5.19	4.57	4.79	0.39
2B-AB2-15	14.59	64	2.88	3.17	2.50	2.98	3.27	2.96	0.30
2B-AB2-15	14.59	90	2.90	2.45	2.82	2.90	2.46	2.71	0.23
2B-AC1-15	14.49	-13	14.99	14.92	14.70	15.13	14.98	14.94	0.16
2B-AC1-15	14.49	02	10.66	10.70	12.61	11.46	11.19	11.32	0.80
2B-AC1-15	14.49	14	8.48	8.63	8.84	9.51	9.07	8.90	0.40
2B-AC1-15	14.49	22	6.33	6.55	6.44	6.59	7.24	6.63	0.36
2B-AC1-15	14.49	34	3.94	4.53	4.16	4.29	4.51	4.29	0.25
2B-AC1-15	14.49	64	2.24	2.16	2.77	2.47	2.71	2.47	0.27
2B-AC1-15	14.49	90	2.13	2.10	2.00	2.45	2.32	2.20	0.18
2B-AC2-15	15.36	-13	14.46	14.78	12.48	13.08	13.03	13.57	1.00
2B-AC2-15	15.36	02	8.33	9.58	10.11	10.09	8.89	9.40	0.78
2B-AC2-15	15.36	14	7.03	6.92	7.44	7.80	5.34	6.91	0.94
2B-AC2-15	15.36	22	6.29	5.96	5.05	5.82	5.19	5.66	0.52
2B-AC2-15	15.36	34	3.64	3.78	3.25	3.52	3.23	3.48	0.24
2B-AC2-15	15.36	64	2.11	2.18	1.92	1.97	2.03	2.04	0.10
2B-AC2-15	15.36	90	2.25	2.10	2.01	2.05	2.18	2.12	0.10
2B-AD1-15	12.63	-13	19.39	19.98	18.81	19.00	18.10	19.06	0.70
2B-AD1-15	12.63	02	16.45	15.87	18.43	19.33	17.27	17.47	1.42
2B-AD1-15	12.63	14	14.19	13.52	13.91	14.93	13.93	14.10	0.52
2B-AD1-15	12.63	22	11.31	10.85	11.75	12.13	12.03	11.61	0.53
2B-AD1-15	12.63	34	8.51	8.01	8.46	7.69	8.42	8.22	0.36
2B-AD1-15	12.63	64	4.47	4.69	4.29	4.05	4.32	4.36	0.24
2B-AD1-15	12.63	90	2.98	3.05	3.03	3.05	3.01	3.03	0.03
2B-AD2-15	14.10	-13	14.55	16.09	15.55	15.91	15.68	15.56	0.60
2B-AD2-15	14.10	02	11.21	11.92	12.78	12.98	11.97	12.17	0.72
2B-AD2-15	14.10	14	9.23	9.07	9.45	8.93	8.24	8.99	0.46
2B-AD2-15	14.10	22	7.27	7.29	6.47	6.56	6.74	6.87	0.39
2B-AD2-15	14.10	34	4.73	4.82	4.15	4.53	4.41	4.53	0.26
2B-AD2-15	14.10	64	2.51	2.58	2.97	2.81	2.65	2.71	0.18
2B-AD2-15	14.10	90	2.22	2.31	2.13	2.51	2.40	2.32	0.15

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
2B-AE1-15	15.82	-13	10.90	10.15	9.95	11.01	9.57	10.32	0.62
2B-AE1-15	15.82	02	6.81	7.12	7.11	8.10	7.34	7.30	0.49
2B-AE1-15	15.82	14	5.66	6.24	6.33	6.03	5.88	6.03	0.27
2B-AE1-15	15.82	22	4.46	4.49	4.77	4.74	4.89	4.67	0.19
2B-AE1-15	15.82	34	3.67	3.58	3.33	3.00	3.35	3.39	0.26
2B-AE1-15	15.82	64	1.79	1.52	1.61	1.69	1.67	1.66	0.10
2B-AE1-15	15.82	90	1.98	1.76	1.78	1.73	1.62	1.77	0.13
2B-AE2-15	16.53	-13	9.36	8.56	9.02	8.55	8.68	8.83	0.35
2B-AE2-15	16.53	02	5.46	5.69	5.99	6.40	6.14	5.94	0.37
2B-AE2-15	16.53	14	5.15	4.99	5.05	5.02	5.79	5.20	0.33
2B-AE2-15	16.53	22	4.12	3.37	2.27	3.67	3.85	3.46	0.72
2B-AE2-15	16.53	34	3.04	2.37	2.54	2.68	3.03	2.73	0.30
2B-AE2-15	16.53	64	1.76	1.63	1.82	1.38	1.62	1.64	0.17
2B-AE2-15	16.53	90	1.75	1.96	1.92	1.82	1.95	1.88	0.09
2B-BB1-15	13.57	-13	16.01	16.22	15.16	16.86	14.58	15.77	0.90
2B-BB1-15	13.57	-05	14.29	13.70	13.87	16.10	14.24	14.44	0.96
2B-BB1-15	13.57	10	11.37	12.40	12.45	11.57	12.07	11.97	0.48
2B-BB1-15	13.57	14	10.47	10.25	9.81	9.46	9.84	9.97	0.40
2B-BB1-15	13.57	22	7.78	8.28	8.03	7.95	8.29	8.06	0.22
2B-BB1-15	13.57	34	5.05	4.43	4.54	4.78	5.11	4.78	0.30
2B-BB1-15	13.57	64	3.36	3.39	3.05	3.00	2.94	3.15	0.21
2B-BB1-15	13.57	88	3.46	2.27	2.88	2.47	2.34	2.69	0.50
2B-BB2-15	13.31	-13	17.30	17.18	18.06	17.58	16.59	17.34	0.54
2B-BB2-15	13.31	-05	16.14	15.97	16.00	15.08	16.12	15.86	0.44
2B-BB2-15	13.31	10	12.99	12.08	12.34	12.53	13.20	12.63	0.46
2B-BB2-15	13.31	14	11.30	9.91	10.41	10.27	10.26	10.43	0.52
2B-BB2-15	13.31	22	8.48	8.09	9.52	8.80	9.09	8.80	0.55
2B-BB2-15	13.31	34	6.03	5.43	5.28	4.74	5.21	5.34	0.47
2B-BB2-15	13.31	64	2.79	3.22	3.15	3.20	3.39	3.15	0.22
2B-BB2-15	13.31	88	2.31	2.29	2.49	2.56	2.66	2.46	0.16
2B-BC1-15	14.96	-13	12.39	12.68	12.30	12.41	12.47	12.45	0.14
2B-BC1-15	14.96	-05	9.69	10.39	10.56	11.42	10.65	10.54	0.62
2B-BC1-15	14.96	10	8.49	7.85	8.34	8.48	8.39	8.31	0.26
2B-BC1-15	14.96	14	7.48	7.48	7.13	7.65	6.67	7.28	0.39
2B-BC1-15	14.96	22	5.81	5.60	5.94	5.80	5.94	5.82	0.14
2B-BC1-15	14.96	34	3.89	3.08	3.83	3.68	3.08	3.51	0.40
2B-BC1-15	14.96	64	2.12	2.03	1.81	1.71	2.16	1.97	0.20
2B-BC1-15	14.96	88	2.07	1.97	1.83	1.97	2.35	2.04	0.19
2B-BC2-15	14.16	-13	13.35	14.65	14.59	14.55	14.11	14.25	0.55
2B-BC2-15	14.16	-05	12.83	13.03	12.79	12.79	13.48	12.98	0.30
2B-BC2-15	14.16	10	8.96	10.42	10.62	10.59	10.06	10.13	0.69
2B-BC2-15	14.16	14	9.63	8.97	9.56	9.29	9.20	9.33	0.27
2B-BC2-15	14.16	22	8.73	7.59	7.91	8.07	8.15	8.09	0.42
2B-BC2-15	14.16	34	4.74	4.38	4.91	4.65	5.10	4.76	0.27
2B-BC2-15	14.16	64	2.31	2.39	2.72	2.66	2.78	2.58	0.21
2B-BC2-15	14.16	88	2.67	2.27	2.20	2.18	2.26	2.32	0.20
2B-BD1-15	15.48	-13	14.92	19.27	15.00	14.44	14.42	15.61	2.06
2B-BD1-15	15.48	-05	9.93	10.47	10.91	11.86	10.38	10.71	0.73
2B-BD1-15	15.48	10	8.93	8.72	9.45	9.39	9.19	9.14	0.31
2B-BD1-15	15.48	14	6.76	7.37	7.23	7.03	6.55	6.99	0.34
2B-BD1-15	15.48	22	5.82	5.95	5.39	5.29	5.60	5.61	0.28

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
2B-BD1-15	15.48	34	3.45	3.24	3.01	3.06	3.31	3.22	0.18
2B-BD1-15	15.48	64	2.41	2.37	2.30	2.22	2.41	2.34	0.08
2B-BD1-15	15.48	88	2.05	2.33	2.22	2.31	2.28	2.24	0.11
2B-BD2-15	15.09	-13	13.09	13.12	13.55	14.54	14.31	13.72	0.67
2B-BD2-15	15.09	-05	13.14	12.72	13.22	13.64	13.65	13.27	0.39
2B-BD2-15	15.09	10	9.65	9.44	8.87	10.22	10.46	9.73	0.63
2B-BD2-15	15.09	14	7.93	7.85	9.77	8.31	8.92	8.56	0.80
2B-BD2-15	15.09	22	6.19	6.68	6.18	6.51	6.44	6.40	0.21
2B-BD2-15	15.09	34	2.93	3.68	2.93	2.89	3.33	3.15	0.35
2B-BD2-15	15.09	64	2.29	2.58	2.39	2.60	2.51	2.47	0.13
2B-BD2-15	15.09	88	2.05	2.04	1.95	2.14	2.25	2.09	0.11
2B-BE1-15	15.91	-13	8.96	9.17	8.72	9.23	9.10	9.04	0.20
2B-BE1-15	15.91	-05	6.35	6.71	7.44	7.66	7.39	7.11	0.55
2B-BE1-15	15.91	10	4.74	5.26	4.91	5.48	5.53	5.19	0.35
2B-BE1-15	15.91	14	5.04	4.94	4.78	4.79	4.93	4.89	0.11
2B-BE1-15	15.91	22	4.05	3.88	4.22	3.70	4.11	3.99	0.20
2B-BE1-15	15.91	34	2.10	2.29	2.18	1.81	2.24	2.13	0.19
2B-BE1-15	15.91	64	1.69	1.47	1.48	1.64	1.59	1.58	0.10
2B-BE1-15	15.91	88	1.78	1.77	1.95	1.90	1.79	1.84	0.08
2B-BE2-15	14.73	-13	9.93	10.52	11.07	10.54	11.70	10.75	0.67
2B-BE2-15	14.73	-05	9.34	8.65	10.14	9.75	8.58	9.29	0.68
2B-BE2-15	14.73	10	6.96	7.19	7.72	7.21	7.55	7.32	0.30
2B-BE2-15	14.73	14	6.97	6.79	6.78	6.93	6.41	6.78	0.22
2B-BE2-15	14.73	22	5.51	5.98	5.35	5.96	6.52	5.87	0.46
2B-BE2-15	14.73	34	3.84	3.28	3.76	3.62	3.20	3.54	0.29
2B-BE2-15	14.73	64	1.93	1.79	1.93	2.13	2.37	2.03	0.23
2B-BE2-15	14.73	88	1.88	2.02	1.88	2.05	1.86	1.94	0.09

APPENDIX 5

Data for the Effect of Temperature on Corn Breakage Susceptibility Using 16/64" Sieve

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
2B-AB1-15	13.12	-13	42.42	40.60	40.78	44.34	40.67	41.77	1.62
2B-AB1-15	13.12	02	35.12	37.39	38.00	38.48	39.35	37.67	1.60
2B-AB1-15	13.12	14	30.85	30.15	31.95	32.05	30.76	31.15	0.82
2B-AB1-15	13.12	22	25.03	25.33	24.14	24.99	25.31	24.96	0.48
2B-AB1-15	13.12	34	9.51	20.70	16.61	15.75	16.56	15.83	4.02
2B-AB1-15	13.12	64	8.53	8.84	8.05	8.22	8.44	8.41	0.30
2B-AB1-15	13.12	90	6.91	7.65	7.01	7.04	6.26	6.97	0.49
2B-AB2-15	14.59	-13	34.65	33.47	34.28	34.61	36.55	34.71	1.13
2B-AB2-15	14.59	02	25.29	25.07	28.59	28.97	26.09	26.80	1.85
2B-AB2-15	14.59	14	21.95	21.26	20.06	19.55	22.63	21.09	1.28
2B-AB2-15	14.59	22	14.61	17.30	16.11	14.78	16.40	15.84	1.13
2B-AB2-15	14.59	34	11.20	9.82	10.02	11.03	9.69	10.35	0.71
2B-AB2-15	14.59	64	5.81	6.41	5.85	6.83	7.09	6.40	0.58
2B-AB2-15	14.59	90	5.39	4.86	5.97	7.07	5.73	5.80	0.82
2B-AC1-15	14.49	-13	30.17	30.10	29.87	29.68	29.31	29.83	0.35
2B-AC1-15	14.49	02	22.41	23.34	25.13	23.46	24.22	23.71	1.02
2B-AC1-15	14.49	14	17.84	18.28	20.02	20.69	19.03	19.17	1.18
2B-AC1-15	14.49	22	13.47	14.08	13.95	13.28	15.73	14.10	0.97
2B-AC1-15	14.49	34	8.33	9.35	9.34	9.24	9.97	9.25	0.59
2B-AC1-15	14.49	64	4.62	4.38	5.63	6.19	6.00	5.36	0.82
2B-AC1-15	14.49	90	3.88	4.16	3.97	4.94	5.14	4.42	0.58
2B-AC2-15	15.36	-13	27.37	28.42	25.58	27.39	25.52	26.86	1.27
2B-AC2-15	15.36	02	18.18	19.93	20.66	21.31	18.99	19.81	1.26
2B-AC2-15	15.36	14	15.27	15.24	16.17	15.64	14.64	15.39	0.56
2B-AC2-15	15.36	22	12.28	13.80	11.26	12.10	11.82	12.25	0.95
2B-AC2-15	15.36	34	7.60	8.23	7.13	8.93	6.51	7.68	0.94
2B-AC2-15	15.36	64	4.17	5.43	4.47	4.21	5.08	4.67	0.55
2B-AC2-15	15.36	90	4.32	5.01	4.22	3.85	4.83	4.45	0.47
2B-AD1-15	12.63	-13	38.59	37.79	36.11	35.95	34.19	36.53	1.72
2B-AD1-15	12.63	02	33.50	30.58	34.76	36.13	33.52	33.70	2.05
2B-AD1-15	12.63	14	28.96	27.23	29.97	30.59	29.76	29.30	1.30
2B-AD1-15	12.63	22	25.61	21.54	24.97	25.96	26.00	24.82	1.88
2B-AD1-15	12.63	34	17.60	17.37	17.18	17.20	17.68	17.41	0.23
2B-AD1-15	12.63	64	8.29	9.45	8.82	8.39	9.27	8.85	0.51
2B-AD1-15	12.63	90	6.07	5.78	6.91	7.23	6.65	6.53	0.59
2B-AD2-15	14.10	-13	30.44	32.57	33.45	31.98	31.02	31.89	1.20
2B-AD2-15	14.10	02	25.91	24.29	25.96	26.10	24.79	25.41	0.82
2B-AD2-15	14.10	14	19.49	20.65	19.47	20.08	18.25	19.59	0.89
2B-AD2-15	14.10	22	14.47	15.10	13.78	14.60	14.19	14.43	0.49
2B-AD2-15	14.10	34	8.80	10.37	9.54	8.86	8.81	9.28	0.69
2B-AD2-15	14.10	64	5.04	5.53	6.34	5.69	6.51	5.82	0.60
2B-AD2-15	14.10	90	4.21	5.16	4.26	5.24	4.52	4.68	0.49

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
2B-AE1-15	15.82	-13	22.20	22.16	20.14	22.27	20.45	21.44	1.06
2B-AE1-15	15.82	02	14.54	16.42	15.88	17.32	16.94	16.22	1.08
2B-AE1-15	15.82	14	14.01	14.89	14.82	12.91	13.47	14.02	0.85
2B-AE1-15	15.82	22	11.24	10.46	12.02	11.25	11.17	11.23	0.55
2B-AE1-15	15.82	34	9.41	10.17	8.22	7.69	9.08	8.91	0.98
2B-AE1-15	15.82	64	4.35	4.17	4.05	4.10	4.41	4.22	0.16
2B-AE1-15	15.82	90	3.95	4.01	3.96	4.68	3.91	4.10	0.32
2B-AE2-15	16.53	-13	18.67	18.73	18.45	18.91	19.55	18.86	0.42
2B-AE2-15	16.53	02	12.37	13.40	14.13	13.92	14.03	13.57	0.73
2B-AE2-15	16.53	14	11.30	11.82	13.16	11.57	13.33	12.24	0.94
2B-AE2-15	16.53	22	9.70	9.03	7.65	8.46	10.06	8.98	0.97
2B-AE2-15	16.53	34	7.37	5.58	6.61	6.89	7.57	6.81	0.78
2B-AE2-15	16.53	64	4.21	3.81	4.48	3.96	4.40	4.17	0.28
2B-AE2-15	16.53	90	3.99	4.01	3.76	4.05	5.36	4.23	0.64
2B-BB1-15	13.57	-13	30.27	29.78	29.75	30.10	27.46	29.47	1.14
2B-BB1-15	13.57	-5	27.54	25.83	26.32	29.95	26.73	27.27	1.62
2B-BB1-15	13.57	10	22.13	23.80	23.74	22.34	23.52	23.10	0.81
2B-BB1-15	13.57	14	20.27	19.96	21.03	19.74	19.19	20.04	0.68
2B-BB1-15	13.57	22	14.69	15.72	17.53	15.06	16.16	15.83	1.11
2B-BB1-15	13.57	34	10.66	9.08	9.92	10.10	11.10	10.17	0.77
2B-BB1-15	13.57	64	7.29	6.91	7.67	6.40	7.28	7.11	0.48
2B-BB1-15	13.57	88	7.77	5.77	8.04	6.12	5.23	6.59	1.25
2B-BB2-15	13.31	-13	34.14	31.68	33.10	32.87	31.46	32.65	1.10
2B-BB2-15	13.31	-5	31.58	31.27	30.03	29.15	31.51	30.71	1.07
2B-BB2-15	13.31	10	25.98	23.69	23.44	24.74	25.72	24.71	1.15
2B-BB2-15	13.31	14	22.23	18.62	21.14	22.06	20.62	20.93	1.45
2B-BB2-15	13.31	22	16.95	16.92	19.86	17.79	19.21	18.15	1.33
2B-BB2-15	13.31	34	11.37	11.12	10.29	11.34	11.36	11.10	0.46
2B-BB2-15	13.31	64	6.27	5.89	6.86	8.08	7.67	6.95	0.92
2B-BB2-15	13.31	88	4.58	4.83	5.97	5.79	5.32	5.30	0.60
2B-BC1-15	14.96	-13	24.08	23.92	23.30	23.64	24.08	23.81	0.33
2B-BC1-15	14.96	-5	18.63	19.09	20.30	22.16	21.00	20.24	1.43
2B-BC1-15	14.96	10	16.30	17.38	16.76	18.08	18.33	17.37	0.86
2B-BC1-15	14.96	14	13.81	15.76	15.01	16.43	13.45	14.89	1.26
2B-BC1-15	14.96	22	13.98	11.27	12.87	13.35	12.37	12.77	1.03
2B-BC1-15	14.96	34	7.81	7.48	8.35	8.89	8.10	8.13	0.54
2B-BC1-15	14.96	64	4.95	5.30	4.44	4.96	5.55	5.04	0.42
2B-BC1-15	14.96	88	4.90	4.68	3.78	5.00	5.78	4.83	0.72
2B-BC2-15	14.16	-13	24.87	27.72	28.61	27.59	27.67	27.29	1.41
2B-BC2-15	14.16	-5	23.90	25.08	23.44	24.84	26.45	24.74	1.17
2B-BC2-15	14.16	10	18.74	20.30	20.88	20.22	20.66	20.16	0.84
2B-BC2-15	14.16	14	17.92	18.25	18.40	19.94	19.34	18.77	0.84
2B-BC2-15	14.16	22	16.82	15.93	16.34	16.27	16.48	16.37	0.32
2B-BC2-15	14.16	34	10.32	8.59	11.29	10.26	10.51	10.20	0.98
2B-BC2-15	14.16	64	5.40	5.80	6.42	6.06	6.77	6.09	0.53
2B-BC2-15	14.16	88	5.83	4.90	4.35	5.37	5.28	5.14	0.56
2B-BD1-15	15.48	-13	30.01	33.25	29.07	30.75	28.73	30.36	1.80
2B-BD1-15	15.48	-5	21.26	21.84	24.29	25.25	21.41	22.81	1.84
2B-BD1-15	15.48	10	19.62	19.09	19.68	19.45	22.51	20.07	1.38
2B-BD1-15	15.48	14	15.32	16.19	15.80	17.15	15.01	15.89	0.84
2B-BD1-15	15.48	22	14.10	13.52	12.95	11.96	13.43	13.19	0.80

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
2B-BD1-15	15.48	34	8.19	8.11	7.50	8.82	7.99	8.12	0.47
2B-BD1-15	15.48	64	5.97	5.95	5.19	6.18	6.44	5.95	0.47
2B-BD1-15	15.48	88	4.73	5.03	4.83	5.47	6.55	5.32	0.74
2B-BD2-15	15.09	-13	28.00	28.47	28.61	31.77	29.43	29.26	1.50
2B-BD2-15	15.09	-5	26.97	26.10	27.33	28.91	28.65	27.59	1.18
2B-BD2-15	15.09	10	21.86	21.22	18.95	21.86	22.53	21.28	1.38
2B-BD2-15	15.09	14	16.32	16.72	19.09	19.57	20.41	18.42	1.81
2B-BD2-15	15.09	22	15.35	15.64	15.00	13.83	14.70	14.90	0.70
2B-BD2-15	15.09	34	7.40	9.01	7.85	7.68	8.10	8.01	0.62
2B-BD2-15	15.09	64	6.15	6.23	6.39	6.97	6.52	6.45	0.32
2B-BD2-15	15.09	88	5.21	5.74	4.55	5.72	6.10	5.46	0.60
2B-BE1-15	15.91	-13	18.03	19.16	15.64	18.83	19.78	18.29	1.61
2B-BE1-15	15.91	-5	13.35	13.75	14.32	16.79	14.61	14.56	1.34
2B-BE1-15	15.91	10	10.64	10.57	10.44	11.86	11.98	11.10	0.75
2B-BE1-15	15.91	14	10.93	10.91	11.28	10.96	11.43	11.10	0.24
2A-BE1-15	15.91	22	9.55	9.22	10.05	10.15	9.91	9.78	0.39
2A-BE1-15	15.91	34	6.24	6.48	6.30	5.79	6.29	6.22	0.26
2B-BE1-15	15.91	64	4.08	4.57	4.16	4.18	4.28	4.25	0.19
2B-BE1-15	15.91	88	3.77	5.05	4.60	4.84	4.72	4.60	0.49
2B-BE2-15	14.73	-13	19.71	21.91	22.38	21.98	22.94	21.78	1.23
2B-BE2-15	14.73	-5	17.94	17.98	19.33	20.47	17.79	18.70	1.17
2B-BE2-15	14.73	10	14.40	15.08	17.68	14.92	15.86	15.59	1.28
2B-BE2-15	14.73	14	14.70	14.07	14.18	13.27	12.36	13.72	0.92
2B-BE2-15	14.73	22	11.34	13.81	11.32	14.15	13.74	12.87	1.42
2B-BE2-15	14.73	34	9.18	7.66	8.26	8.12	8.30	8.31	0.55
2B-BE2-15	14.73	64	4.20	5.04	5.44	6.11	5.41	5.24	0.70
2B-BE2-15	14.73	88	4.43	4.98	5.60	4.95	5.92	5.18	0.59

APPENDIX 6

Data for the Effect of Moisture Content on Corn Breakage Susceptibility Using 12/64" Sieve

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3A-AB1-18	16.55	22	3.32	3.54	3.21	3.95	3.32	3.47	0.30
3A-AB1-16	13.20	20	10.33	10.70	10.73	10.31	10.69	10.55	0.21
3A-AB1-15a	13.13	22	12.26	12.00	11.86	12.84	11.26	12.04	0.58
3A-AB1-15c	12.80	21	12.75	13.44	13.94	14.18	13.22	13.51	0.57
3A-AB1-14a	11.75	22	18.50	18.91	18.38	18.69	18.77	18.65	0.21
3A-A81-14b	11.17	21	25.29	24.36	25.91	25.93	25.11	25.32	0.65
3A-AB1-12a	13.61	22	11.66	12.23	11.46	11.40	10.91	11.53	0.48
3A-AB1-12ab	13.26	21	14.65	13.92	14.97	14.84	14.34	14.55	0.42
3A-AB1-10a	8.79	21	34.41	35.01	33.58	32.93	33.62	33.91	0.81
3A-A81-10b	9.11	22	30.03	31.82	30.34	30.58	34.86	31.52	1.98
3A-AB2-18	19.66	20	1.54	1.58	1.60	1.80	1.54	1.61	0.11
3A-AB2-16	17.00	23	3.01	2.89	2.89	2.60	2.72	2.82	0.16
3A-AB2-15a	14.40	21	6.88	6.34	7.00	7.01	7.43	6.93	0.39
3A-AB2-15c	14.52	22	7.69	6.84	6.57	6.88	6.58	6.91	0.46
3A-AB2-14a	14.38	22	7.20	6.87	7.10	6.89	7.64	7.14	0.31
3A-AB2-14b	14.20	21	8.46	7.79	8.14	8.70	8.31	8.28	0.34
3A-AB2-12a	12.43	22	14.36	13.61	14.80	13.51	17.63	14.78	1.68
3A-AB2-10ac	9.85	21	26.84	26.38	25.24	24.95	24.71	25.62	0.94
3A-AB2-10d	10.34	22	20.82	20.84	21.30	20.21	21.58	20.95	0.52
3A-AD1-18	13.13	22	12.49	11.04	13.69	12.21	11.69	12.23	0.99
3A-AD1-16	16.34	23	3.88	3.97	3.95	3.47	4.18	3.89	0.26
3A-AD1-15a	13.86	22	8.28	7.44	7.55	8.39	7.40	7.81	0.48
3A-AD1-14	13.77	22	8.32	7.70	7.72	7.16	11.61	8.50	1.78
3A-AD1-12	10.95	22	15.73	16.62	17.34	17.71	16.04	16.69	0.84
3A-AD1-10a	10.47	21	19.45	17.86	18.19	19.28	17.67	18.49	0.82
3A-AD2-18	11.74	22	18.22	17.03	16.85	17.92	17.37	17.48	0.58
3A-AD2-16a	16.72	23	3.38	3.21	3.53	3.39	3.63	3.43	0.16
3A-AD2-16b	14.15	22	8.29	7.56	8.30	8.10	7.81	8.01	0.32
3A-AD2-15a	14.09	22	7.14	7.52	6.96	6.86	8.02	7.30	0.47
3A-AD2-14	13.90	22	7.94	7.50	7.10	7.07	7.62	7.45	0.37
3A-AD2-12	10.90	21	15.63	17.74	17.93	17.74	17.50	17.31	0.95
3A-AD2-10a	10.54	21	19.57	17.63	17.37	18.80	18.51	18.37	0.89
3A-AD2-10b	10.68	21	18.17	19.97	18.37	19.16	18.79	18.89	0.72
3A-AE1-18	17.18	21	3.00	2.69	3.04	2.75	2.90	2.88	0.15
3A-AE1-16	15.71	21	4.57	5.04	4.73	5.05	5.21	4.92	0.26
3A-AE1-15a	16.01	22	4.56	4.61	4.79	4.73	4.63	4.67	0.09
3A-AE1-15e	15.78	23	4.68	4.40	4.92	5.01	5.21	4.84	0.31
3A-AE1-14	13.53	21	7.83	8.47	7.85	8.52	7.81	8.10	0.37
3A-AE1-12a	12.63	20	9.48	9.48	9.81	10.27	9.93	9.79	0.33
3A-AE1-12ab	12.49	21	10.31	10.73	9.87	10.42	10.04	10.28	0.33
3A-AE1-10a	11.43	21	11.93	11.12	12.55	13.16	12.85	12.33	0.81
3A-AE1-10b	11.42	21	12.40	11.40	12.52	11.46	11.04	11.77	0.66

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3A-AE2-18	17.94	22	2.86	2.60	2.59	2.49	2.27	2.56	0.21
3A-AE2-16	17.11	21	3.16	3.65	3.35	3.57	3.93	3.53	0.29
3A-AE2-15a	16.70	23	3.17	3.22	3.88	3.72	3.42	3.48	0.31
3A-AE2-15d	16.20	21	5.25	4.75	5.17	4.65	4.95	4.95	0.26
3A-AE2-14	14.44	21	7.10	8.18	8.09	7.01	8.60	7.80	0.71
3A-AE2-12	12.02	21	10.69	11.18	11.34	10.80	11.25	11.05	0.29
3A-AE2-10a	11.48	21	11.07	10.94	12.78	12.04	12.16	11.80	0.78
3A-AE2-10b	11.44	22	12.83	12.17	11.75	11.95	11.49	12.04	0.51
3A-BB1-18	16.80	21	2.00	2.30	1.86	2.33	2.23	2.15	0.21
3A-BB1-16	15.74	21	3.20	3.19	3.13	3.30	3.17	3.20	0.06
3A-B81-15b	13.44	21	6.69	6.76	6.39	7.11	7.14	6.82	0.31
3A-BB1-14	11.80	21	13.72	14.06	14.32	14.18	13.79	14.01	0.26
3A-BB1-12	12.22	21	13.28	13.66	13.71	13.88	14.63	13.83	0.50
3A-B81-10	8.83	21	21.37	22.44	23.24	22.85	23.04	22.59	0.74
3A-B82-18	18.54	21	1.35	1.57	1.48	1.15	1.25	1.36	0.17
3A-BB2-16	17.05	21	1.70	1.61	2.47	1.66	1.83	1.86	0.35
3A-BB2-15e	12.72	21	8.11	8.23	8.64	8.79	9.64	8.68	0.61
3A-BB2-14	11.83	21	15.86	16.01	14.70	15.76	15.64	15.59	0.52
3A-BB2-12	11.69	20	16.75	17.09	17.53	16.65	16.40	16.88	0.44
3A-B82-10a	9.35	20	16.37	16.83	17.37	16.81	16.27	16.73	0.44
3A-BD1-18	16.23	21	2.42	2.71	2.90	2.40	2.84	2.66	0.24
3A-BD1-16	15.79	20	4.63	4.21	4.35	4.75	4.33	4.45	0.22
3A-BD1-15d	15.07	21	6.27	6.29	5.58	5.60	7.02	6.15	0.60
3A-BD1-14	14.06	20	10.37	10.54	9.97	11.42	10.68	10.60	0.53
3A-BD1-12	12.61	22	14.46	14.57	15.09	15.12	14.45	14.74	0.34
3A-BD1-10a	11.08	24	18.73	19.47	19.71	19.81	19.15	19.37	0.44
3A-BD2-18	16.24	20	2.48	2.78	3.07	2.69	2.86	2.78	0.21
3A-BD2-16	15.94	20	4.21	4.06	4.31	4.40	4.55	4.31	0.19
3A-BD2-15a	15.09	21	5.64	6.46	5.86	6.77	7.07	6.36	0.60
3A-BD2-14	13.96	20	9.99	10.35	9.44	10.18	9.82	9.95	0.35
3A-3D2-12	12.16	22	15.57	15.43	14.89	15.13	15.64	15.33	0.32
3A-BD2-10	11.15	22	19.58	19.11	20.63	17.02	19.14	19.10	1.31
3A-BE1-18	18.03	20	3.45	1.92	2.27	1.93	2.13	2.34	0.64
3A-BE1-16	16.06	23	3.51	3.45	3.30	3.45	3.77	3.50	0.17
3A-BE1-15e	15.54	21	4.55	4.07	3.93	4.26	4.63	4.29	0.30
3A-BE1-14	13.46	22	7.34	7.49	6.95	6.95	7.90	7.33	0.40
3A-8E1-12	12.11	22	8.72	8.29	8.85	9.56	9.40	8.96	0.52
3A-BE1-10a	11.11	22	10.35	9.96	10.46	10.35	11.02	10.43	0.38
3A-BE2-18	17.37	20	2.10	2.33	2.53	2.45	2.44	2.37	0.17
3A-BE2-16	15.79	20	3.81	4.22	4.33	3.92	4.37	4.13	0.25
3A-BE2-15a	14.84	21	4.05	4.57	4.53	4.54	4.39	4.42	0.22
3A-BE2-14	13.55	22	8.13	7.60	7.19	7.54	7.33	7.56	0.36
3A-BE2-12	12.18	22	8.63	8.79	9.93	6.79	9.73	8.78	1.25
3A-BE2-10	11.24	22	10.64	10.05	11.09	9.86	10.55	10.44	0.49
3A-CB1-18	14.64	21	10.30	10.83	10.56	9.27	9.62	10.12	0.65
3A-CB1-16	12.90	21	20.78	21.40	21.27	20.93	21.59	21.19	0.33
3A-CB1-12	11.70	22	30.10	31.51	31.76	29.64	30.11	30.62	0.95
3A-CB1-10a	8.11	23	43.83	42.26	42.23	42.67	41.21	42.44	0.95
3A-CB2-18	16.12	21	4.01	4.12	3.98	3.72	3.49	3.87	0.26
3A-CB2-16	12.90	21	17.87	18.71	17.86	17.30	17.76	17.90	0.51
3A-CB2-14	10.97	22	28.47	31.12	29.87	28.95	30.93	29.87	1.17

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3A-CB2-12	10.28	22	33.09	33.12	33.24	35.36	36.91	34.34	1.72
3A-CB2-10	7.18	23	42.39	44.30	43.72	44.41	44.49	43.86	0.88
3A-CB3-18	19.24	22	1.29	1.52	1.37	1.47	1.37	1.40	0.09
3A-CB3-16	17.16	22	2.41	2.19	2.36	2.39	2.77	2.43	0.21
3A-CB3-15	14.96	22	6.79	6.41	6.29	6.86	6.86	6.64	0.27
3A-CB3-14	13.47	22	11.99	11.99	10.90	9.96	11.65	11.30	0.87
3A-CB3-12	12.86	21	23.24	21.36	21.42	21.91	21.83	21.95	0.76
3A-CB3-10	10.49	22	33.19	31.74	32.43	33.45	31.87	32.53	0.77
3A-CD1-18a	14.06	22	11.62	12.05	10.64	11.49	11.28	11.42	0.52
3A-CD1-18b	13.82	22	18.98	17.51	18.34	17.25	17.17	17.85	0.78
3A-CD1-14a	13.56	23	13.16	13.70	12.74	12.72	12.77	13.02	0.42
3A-CD1-12	12.11	24	21.30	21.22	19.84	20.11	20.62	20.62	0.65
3A-CD1-10	11.50	24	26.12	24.34	23.99	25.86	24.94	25.05	0.93
3A-CD2-18	14.40	21	8.18	8.76	9.47	9.25	9.79	9.09	0.63
3A-CD2-14a	14.47	23	8.51	7.78	8.63	8.09	7.58	8.12	0.45
3A-CD2-12	12.25	24	19.41	19.81	19.00	18.71	18.36	19.06	0.57
3A-CD2-10	11.40	24	23.20	23.14	22.24	22.64	22.96	22.84	0.40
3A-CD3-18	19.49	22	1.46	2.61	1.43	1.54	1.42	1.69	0.52
3A-CD3-16	16.70	22	4.04	3.88	3.63	3.79	3.88	3.84	0.15
3A-CD3-15	15.82	21	4.43	4.77	4.68	4.42	4.62	4.58	0.16
3A-CD3-14	14.14	21	7.89	7.76	7.82	8.20	7.86	7.91	0.17
3A-CD3-12	12.85	21	11.69	11.34	11.56	11.70	11.30	11.52	0.19
3A-CD3-10a	10.64	22	17.86	17.67	16.79	17.84	16.45	17.32	0.66
3A-CE1-18	19.08	21	1.80	1.91	1.71	2.01	2.47	1.98	0.30
3A-CE1-16	15.65	21	4.44	4.61	4.73	4.48	4.35	4.52	0.15
3A-CE1-15	15.40	21	5.09	5.03	4.91	5.03	4.94	5.00	0.07
3A-CE1-14	14.55	21	6.60	6.09	6.46	5.99	6.61	6.35	0.29
3A-CE1-12	11.47	21	11.31	11.46	10.87	11.55	12.43	11.52	0.57
3A-CE1-10a	11.25	21	11.86	12.26	11.45	11.49	11.51	11.72	0.35
3A-CE2-18	18.80	21	1.88	1.72	2.04	2.15	2.39	2.04	0.26
3A-CE2-16	15.85	21	4.45	4.82	4.86	4.48	4.31	4.58	0.24
3A-CE2-15	15.64	21	4.42	4.77	4.39	4.59	4.61	4.56	0.15
3A-CE2-14	14.34	21	6.84	6.73	6.74	6.93	6.32	6.71	0.23
3A-CE2-12	11.50	21	11.73	11.01	11.50	11.94	12.76	11.79	0.64
3A-CE2-10	11.36	22	9.72	10.77	10.58	11.16	10.59	10.56	0.52
3A-DB1-18	15.76	21	4.48	4.94	5.03	4.90	5.36	4.94	0.32
3A-DB1-14	13.95	23	10.86	10.30	10.80	10.48	11.12	10.71	0.32
3A-DB1-12	12.33	21	21.41	22.05	21.00	21.76	21.89	21.62	0.42
3A-DB1-10a	9.17	23	41.64	40.23	38.33	39.81	38.34	39.67	1.39
3A-DB2-18	16.75	21	2.73	3.12	2.56	3.21	2.87	2.90	0.27
3A-DB2-16	16.80	20	4.49	4.08	4.66	4.49	4.69	4.48	0.24
3A-DB2-15	13.23	22	15.90	16.73	14.81	15.95	16.78	16.03	0.80
3A-DB2-14	13.23	24	13.91	14.85	15.19	14.70	14.65	14.66	0.47
3A-DB2-12	11.44	25	25.87	26.80	28.55	26.74	26.94	26.98	0.97
3A-DB2-10	7.72	23	46.99	47.93	49.56	47.22	48.83	48.11	1.08
3A-DB3-18	19.39	22	1.75	1.82	1.59	1.76	1.87	1.76	0.10
3A-DB3-16	18.12	22	2.07	2.04	1.97	2.17	2.10	2.07	0.07
3A-DB3-15	15.39	21	4.12	4.47	4.38	4.23	4.72	4.38	0.23
3A-DB3-14	14.16	21	8.34	9.63	9.28	9.08	8.66	9.00	0.51
3A-DB3-12	12.13	21	24.33	26.37	25.12	26.10	25.94	25.57	0.83
3A-DB3-10	9.56	21	35.53	33.52	33.93	34.41	35.90	34.66	1.02

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3A-DD1-18	15.74	20	5.82	5.09	6.29	5.97	6.19	5.87	0.47
3A-DD1-16	15.10	20	8.66	6.44	3.57	7.52	7.15	6.67	1.91
3A-DD1-15	15.18	21	6.23	5.36	3.44	5.50	5.91	5.29	1.09
3A-DD1-14	15.01	22	7.29	6.79	7.26	6.80	6.62	6.95	0.30
3A-DD1-12	15.35	21	6.22	6.32	6.39	5.39	6.26	6.11	0.41
3A-DD1-10	9.73	20	33.77	34.05	32.79	33.04	34.92	33.72	0.85
3A-DD2-18	16.87	22	2.86	3.05	2.88	3.11	2.92	2.97	0.11
3A-DD2-16	18.65	20	2.48	2.21	2.69	2.21	2.37	2.39	0.20
3A-DD2-15	15.31	20	6.58	6.40	6.56	5.88	6.78	6.44	0.34
3A-DD2-14	14.99	22	8.97	9.58	9.78	9.10	8.78	9.24	0.42
3A-DD2-12	12.89	22	15.35	16.52	15.38	16.05	15.05	15.67	0.60
3A-DD2-10	10.27	20	23.86	24.70	24.47	23.41	23.29	23.95	0.63
3A-DE1-18	18.76	20	2.14	2.33	1.97	2.40	2.38	2.25	0.19
3A-DE1-16	16.12	22	5.06	4.24	4.40	3.33	4.68	4.34	0.65
3A-DE1-15a	14.88	20	6.13	6.96	6.77	5.61	6.05	6.30	0.55
3A-DE1-14	14.46	22	7.48	6.83	7.00	6.99	6.88	7.04	0.26
3A-DE1-12	11.63	22	10.05	10.45	11.33	10.81	11.55	10.84	0.62
3A-DE1-10	13.24	21	11.80	10.98	11.57	11.92	12.19	11.69	0.46
3A-DE2-13	17.64	20	3.29	3.50	3.66	3.21	3.52	3.44	0.18
3A-DE2-16	16.45	20	4.43	4.99	4.68	4.75	5.44	4.86	0.38
3A-DE2-15b	16.42	20	6.51	6.99	6.83	6.55	7.05	6.79	0.25
3A-DE2-14	14.74	21	6.31	6.05	7.17	6.30	5.38	6.24	0.64
3A-DE2-12	11.62	22	11.03	11.45	11.36	10.85	11.42	11.22	0.27
3A-DE2-10	11.51	21	11.81	11.76	11.91	11.98	12.62	12.02	0.35
3A-EB1-18	18.26	21	1.80	1.84	1.72	2.54	2.11	2.00	0.34
3A-EB1-16	15.35	22	3.94	4.19	3.74	3.54	4.03	3.89	0.25
3A-EB1-15	13.57	17	10.14	9.53	8.38	10.27	10.12	9.69	0.79
3A-EB1-14	12.20	19	18.78	21.87	19.32	19.02	19.73	19.74	1.24
3A-EB1-12	10.49	20	30.37	30.07	31.23	30.75	31.96	30.88	0.75
3A-EB1-10	9.45	20	35.36	32.82	33.90	33.80	34.22	34.02	0.92
3A-EB2-18	18.49	22	1.37	1.56	1.36	1.50	2.07	1.57	0.29
3A-EB2-16	17.08	22	2.15	2.03	1.74	1.91	1.84	1.93	0.16
3A-EB2-15	16.13	18	4.27	4.21	3.95	4.06	4.82	4.26	0.34
3A-EB2-14	14.34	18	7.68	7.32	7.39	7.11	7.13	7.33	0.23
3A-EB2-12	12.51	19	16.36	16.83	16.44	16.94	15.77	16.47	0.46
3A-EB2-10	9.75	20	34.78	36.24	32.91	33.27	34.62	34.37	1.33
3A-ED1-18	17.91	21	1.80	1.84	1.97	2.22	1.67	1.90	0.21
3A-ED1-16	15.40	21	4.22	3.57	4.29	3.68	3.41	3.83	0.40
3A-ED1-15	15.16	18	5.36	5.21	5.41	5.15	5.37	5.30	0.11
3A-ED1-14	13.94	18	7.78	7.00	7.21	8.22	7.54	7.55	0.48
3A-ED1-12	11.62	18	14.38	13.76	14.00	13.33	14.08	13.91	0.39
3A-ED1-10	10.80	19	16.71	16.25	15.92	16.33	17.04	16.45	0.43
3A-ED2-18	18.28	21	1.43	1.58	1.44	1.55	1.38	1.48	0.09
3A-ED2-16	15.52	21	4.92	4.19	4.80	5.19	4.69	4.76	0.37
3A-ED2-15	14.24	19	8.84	8.94	8.24	7.75	8.30	8.41	0.48
3A-ED2-14	13.82	18	9.61	9.97	9.68	9.92	10.68	9.97	0.42
3A-ED2-12	12.17	18	17.34	16.23	16.29	17.18	14.82	16.37	1.00
3A-ED2-10	10.95	18	20.34	21.88	20.81	21.06	21.85	21.19	0.67
3A-EE1-18	18.28	21	2.22	2.02	2.69	2.30	2.11	2.27	0.26
3A-EE1-16	15.99	21	3.40	4.21	3.59	3.86	3.63	3.74	0.31
3A-EE1-15	14.17	19	6.55	6.26	6.19	6.22	6.71	6.39	0.23

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3A-EE1-14	13.30	19	7.33	7.51	6.80	6.82	7.72	7.24	0.41
3A-EE1-12	12.26	19	8.41	9.39	9.13	9.36	9.81	9.22	0.51
3A-EE1-10	11.08	19	10.77	11.14	11.36	10.66	11.54	11.09	0.38
3A-EE2-18	18.94	21	1.85	1.54	1.83	1.34	1.48	1.61	0.23
3A-EE2-16	15.59	21	4.13	4.03	4.32	3.63	8.31	4.88	1.93
3A-EE2-15	15.03	19	5.44	4.95	5.56	4.73	5.34	5.20	0.35
3A-EE2-14	13.80	19	7.09	7.19	6.83	7.73	7.49	7.27	0.35
3A-EE2-12	12.15	18	10.47	9.61	10.04	10.12	9.71	9.99	0.34
3A-EE2-10	11.19	18	11.58	11.68	11.81	12.67	12.50	12.04	0.50

APPENDIX 7

Data for the Effect of Moisture Content on Corn Breakage Susceptibility Using 16/64" Sieve

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3A-AB1-18	16.55	22	7.66	8.22	6.62	8.28	8.07	7.77	0.68
3A-AB1-16	13.20	20	21.76	22.77	23.31	21.30	21.90	22.21	0.81
3A-AB1-15a	13.13	22	27.14	28.15	25.89	26.88	23.16	26.24	1.90
3A-AB1-15c	12.80	21	27.52	29.61	28.81	29.15	28.97	28.81	0.78
3A-AB1-14a	11.75	22	38.75	38.15	37.40	39.12	37.07	38.10	0.87
3A-AB1-12a	13.61	22	24.15	24.04	22.39	23.22	23.54	23.47	0.71
3A-AB1-10b	9.11	22	55.23	56.36	55.13	56.31	57.95	56.20	1.14
3A-AB2-18	19.66	20	3.85	4.04	4.16	4.89	4.11	4.21	0.40
3A-AB2-16	17.00	23	6.92	6.32	7.19	6.73	6.82	6.80	0.32
3A-AB2-15a	14.40	21	16.84	14.61	16.54	15.76	15.60	15.87	0.88
3A-AB2-15c	14.52	22	15.76	14.67	13.13	14.53	15.13	14.64	0.97
3A-AB2-14a	14.38	22	13.73	14.10	15.23	15.28	15.01	14.67	0.71
3A-AB2-12a	12.43	22	29.76	28.71	29.87	29.84	33.62	30.36	1.89
3A-AB2-10d	10.34	22	38.91	40.22	39.61	39.32	39.99	39.61	0.52
3A-AD1-18	13.13	22	24.80	23.56	27.57	25.62	23.64	25.04	1.66
3A-AD1-16	16.34	23	8.69	9.31	8.99	8.17	9.09	8.85	0.44
3A-AD1-15a	13.86	22	15.87	16.40	15.95	17.50	15.83	16.31	0.70
3A-AD1-14	13.77	22	17.01	15.27	15.35	15.91	19.00	16.51	1.56
3A-AD1-12	10.95	22	32.44	32.40	32.66	34.38	31.23	32.62	1.13
3A-AD1-10a	10.47	21	36.74	33.49	33.86	37.56	34.38	35.21	1.82
3A-AD2-18	11.74	22	37.54	33.04	35.05	35.48	35.96	35.41	1.63
3A-AD2-16a	16.72	23	7.54	7.89	7.23	7.52	9.12	7.86	0.74
3A-AD2-16b	14.15	22	16.27	15.15	15.96	16.58	15.29	15.85	0.62
3A-AD2-15a	14.09	22	15.77	16.21	15.34	12.81	16.71	15.37	1.52
3A-AD2-14	13.90	22	15.84	14.31	14.28	13.99	15.71	14.83	0.88
3A-AD2-12	10.90	21	31.14	34.22	34.79	34.71	34.52	33.88	1.54
3A-AD2-10a	10.54	21	37.96	34.10	33.14	34.51	34.80	34.90	1.82
3A-AE1-18	17.18	21	8.07	6.46	7.44	7.01	6.96	7.19	0.60
3A-AE1-16	15.71	21	10.59	9.94	10.14	11.36	12.03	10.81	0.87
3A-AE1-15a	16.01	22	11.10	12.36	11.29	10.80	10.80	11.27	0.64
3A-AE1-15e	15.78	23	11.15	10.28	11.94	11.74	11.35	11.29	0.65
3A-AE1-14	13.53	21	16.35	16.10	18.75	16.76	17.39	17.07	1.06
3A-AE1-12a	12.63	20	19.64	19.76	20.84	20.80	20.99	20.41	0.65
3A-AE1-10b	11.42	21	24.43	24.10	26.34	23.05	23.25	24.23	1.31
3A-AE2-18	17.94	22	7.21	7.18	6.24	6.37	5.68	6.54	0.66
3A-AE2-16	17.11	21	8.07	7.44	7.53	7.36	8.35	7.75	0.43
3A-AE2-15a	16.70	23	8.66	8.22	9.85	8.90	8.01	8.73	0.72
3A-AE2-15d	16.20	21	11.49	11.88	10.99	10.16	11.67	11.24	0.69
3A-AE2-14	14.44	21	15.12	18.07	17.67	14.97	18.15	16.80	1.61
3A-AE2-12	12.02	21	22.09	22.79	22.07	22.52	23.70	22.63	0.67
3A-AE2-10a	11.48	21	22.25	22.80	25.93	23.57	25.55	24.02	1.64
3A-BB1-18	16.80	21	5.47	6.17	4.97	5.98	5.41	5.60	0.48

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3A-BB1-16	15.74	21	6.39	7.80	7.58	8.21	8.31	7.66	0.77
3A-BB1-15b	13.44	21	15.49	13.93	14.16	15.70	15.53	14.96	0.85
3A-BB1-14	11.80	21	28.21	29.09	29.85	30.98	28.45	29.32	1.13
3A-BB1-12	12.22	21	28.33	27.77	30.01	29.13	29.65	28.98	0.92
3A-BB1-10	8.83	21	40.76	43.79	43.74	45.01	43.82	43.42	1.58
3A-BB2-18	18.54	21	3.94	4.46	5.62	2.86	4.07	4.19	1.00
3A-BB2-16	17.05	21	4.51	4.39	5.24	5.58	4.45	4.83	0.54
3A-BB2-15e	12.72	21	16.94	17.47	20.75	19.88	18.86	18.78	1.60
3A-BB2-14	11.83	21	34.13	35.24	31.25	32.23	32.59	33.09	1.59
3A-BB2-12	11.69	20	35.15	36.62	35.20	35.09	34.45	35.30	0.80
3A-BB2-10a	9.35	20	33.30	36.62	36.01	36.87	34.96	35.55	1.46
3A-BD1-18	16.23	21	6.39	6.43	6.14	6.11	7.57	6.53	0.60
3A-BD1-16	15.79	20	10.13	9.47	10.03	11.22	9.62	10.10	0.69
3A-BD1-15d	15.07	21	14.54	15.96	15.12	13.75	17.85	15.45	1.57
3A-BD1-14	14.06	20	21.22	23.15	21.05	24.41	23.02	22.57	1.42
3A-BD1-12	12.61	22	28.34	27.85	30.45	30.41	30.18	29.45	1.25
3A-BD1-10a	11.08	24	39.77	39.59	39.74	40.87	38.89	39.77	0.71
3A-BD2-18	16.24	20	6.44	6.55	7.14	6.55	6.73	6.68	0.28
3A-BD2-16	15.94	20	9.88	9.66	9.73	9.45	10.11	9.77	0.25
3A-BD2-15a	15.09	21	12.61	15.32	14.48	16.30	18.73	15.49	2.26
3A-BD2-14	13.96	20	22.09	21.88	18.82	21.22	20.85	20.97	1.30
3A-BD2-12	12.16	22	32.15	31.85	32.26	31.92	31.99	32.04	0.17
3A-BD2-10	11.15	22	39.10	39.19	41.33	37.06	40.98	39.53	1.71
3A-BE1-18	18.03	20	6.25	4.57	6.58	5.45	5.68	5.71	0.78
3A-BE1-16	16.06	23	8.15	9.64	8.68	8.99	9.50	8.99	0.61
3A-BE1-15e	15.54	21	10.25	10.06	11.02	11.50	10.73	10.71	0.58
3A-BE1-14	13.46	22	15.40	16.02	15.33	16.35	17.24	16.07	0.78
3A-BE1-12	12.11	22	18.66	17.04	16.92	20.36	20.26	18.65	1.67
3A-BE1-10a	11.11	22	20.57	18.69	20.20	21.39	21.73	20.52	1.19
3A-BE2-18	17.37	20	6.42	6.22	6.58	7.25	7.38	6.77	0.52
3A-BE2-16	15.79	20	8.13	10.38	10.04	10.22	10.44	9.84	0.97
3A-BE2-15a	14.84	21	8.99	11.32	11.25	10.87	12.93	11.07	1.41
3A-BE2-14	13.55	22	16.41	15.77	15.27	15.81	14.76	15.61	0.62
3A-BE2-12	12.18	22	17.30	19.59	19.52	19.73	18.99	19.03	1.00
3A-BE2-10	11.24	22	21.16	20.33	22.96	19.78	19.87	20.82	1.32
3A-CB1-18	14.64	21	24.15	24.28	23.43	21.46	21.68	23.00	1.35
3A-CB1-16	12.90	21	48.03	45.71	48.13	46.75	46.94	47.11	1.00
3A-CB1-12	11.70	22	56.14	59.39	61.37	60.20	59.70	59.36	1.95
3A-CB1-10a	8.11	23	73.35	74.80	74.89	73.19	74.36	74.12	0.80
3A-CB2-18	16.12	21	9.22	10.05	9.34	8.97	9.10	9.34	0.42
3A-CB2-16	12.90	21	41.00	38.96	38.05	38.79	39.19	39.20	1.09
3A-CB2-14	10.97	22	55.89	59.78	57.21	56.79	60.49	58.03	1.99
3A-CB2-12	10.28	22	65.52	62.36	62.39	63.72	65.31	63.86	1.52
3A-CB2-10	7.18	23	73.75	75.26	75.52	74.83	75.25	74.92	0.70
3A-CB3-18	19.24	22	4.14	3.86	4.51	4.03	4.66	4.24	0.33
3A-CB3-16	17.16	22	6.25	5.57	6.38	5.46	6.93	6.12	0.61
3A-CB3-15	14.96	22	16.41	14.91	14.47	15.36	15.02	15.23	0.73
3A-CB3-14	13.47	22	25.31	26.53	24.49	23.96	24.56	24.97	1.00
3A-CB3-12	12.86	21	47.33	44.63	44.52	47.42	45.76	45.93	1.40
3A-CB3-10	10.49	22	61.11	58.84	60.86	60.82	61.28	60.58	0.99
3A-CD1-18a	14.06	22	25.10	26.80	24.44	24.89	25.41	25.33	0.90

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3A-CD1-18b	13.82	22	40.15	39.35	39.81	38.62	37.50	39.09	1.06
3A-CD1-14a	13.56	23	17.54	18.82	18.32	18.79	18.89	18.47	0.57
3A-CD1-12	12.11	24	44.20	45.45	43.75	44.51	45.14	44.61	0.69
3A-CD1-10	11.50	24	53.08	51.56	52.01	52.12	53.01	52.36	0.66
3A-CD2-18	14.40	21	20.03	20.48	20.96	21.65	23.04	21.23	1.17
3A-CD2-14a	14.47	23	29.42	28.97	28.18	27.37	27.04	28.20	1.01
3A-CD2-12	12.25	24	42.59	44.24	41.87	42.74	41.63	42.61	1.03
3A-CD2-10	11.40	24	49.63	49.57	46.62	49.45	49.49	48.95	1.30
3A-CD3-18	19.49	22	5.93	6.17	4.89	4.20	4.53	5.14	0.87
3A-CD3-16	16.70	22	8.82	9.19	8.90	9.62	9.77	9.26	0.42
3A-CD3-15	15.82	21	12.15	13.28	13.10	10.36	12.88	12.35	1.20
3A-CD3-14	14.14	21	20.66	19.22	17.92	20.97	18.07	19.37	1.42
3A-CD3-12	12.85	21	25.89	26.78	26.02	25.60	24.72	25.80	0.75
3A-CD3-10a	10.64	22	36.86	37.49	34.63	36.23	38.31	36.70	1.39
3A-CE1-18	19.08	21	5.29	5.17	5.14	5.86	6.11	5.51	0.44
3A-CE1-16	15.65	21	10.98	11.99	13.14	11.82	11.12	11.81	0.86
3A-CE1-15	15.40	21	14.33	12.86	12.41	12.76	13.05	13.08	0.74
3A-CE1-14	14.55	21	16.57	14.68	15.64	14.73	15.91	15.51	0.80
3A-CE1-12	11.50	21	26.14	25.68	23.08	25.93	28.10	25.78	1.79
3A-CE1-10a	11.25	21	26.09	27.73	25.85	24.63	25.79	26.02	1.11
3A-CE2-18	18.80	21	6.65	6.25	5.42	6.88	7.15	6.47	0.67
3A-CE2-16	15.85	21	12.55	11.98	12.28	11.51	10.23	11.71	0.91
3A-CE2-15	15.64	21	12.68	12.87	12.75	12.86	12.92	12.82	0.10
3A-CE2-14	14.34	21	16.77	18.38	15.82	17.00	16.31	16.86	0.96
3A-CE2-12	11.50	21	25.24	25.40	24.49	26.21	27.19	25.70	1.03
3A-CE1-10	11.36	22	24.12	25.49	25.02	25.32	25.09	25.01	0.53
3A-DB1-18	15.76	21	11.89	11.23	12.70	11.43	13.23	12.10	0.85
3A-DB1-14	13.95	23	25.88	24.01	24.16	22.93	25.06	24.41	1.11
3A-DB1-12	12.33	21	45.55	45.81	42.25	43.71	45.41	44.55	1.53
3A-DB1-10a	9.17	23	71.42	71.27	67.72	67.48	66.67	68.91	2.26
3A-DB2-18	16.75	21	7.35	6.92	7.77	7.25	7.15	7.29	0.31
3A-DB2-16	16.80	20	11.25	9.55	10.91	11.24	11.60	10.91	0.80
3A-DB2-15	13.23	22	34.27	35.45	31.49	33.85	34.64	33.94	1.49
3A-DB1-14	13.23	24	29.63	32.26	32.41	31.46	30.41	31.23	1.20
3A-DB2-12	11.44	25	51.40	51.88	54.77	51.64	52.50	52.44	1.37
3A-DB2-10	7.72	23	77.37	77.46	76.48	76.30	78.82	77.29	1.00
3A-DB3-18	19.39	22	5.33	5.78	5.37	6.41	6.02	5.78	0.46
3A-DB3-16	18.12	22	5.36	5.92	5.24	6.56	5.87	5.79	0.53
3A-DB3-15	15.39	21	11.95	10.34	10.87	11.15	11.48	11.16	0.61
3A-DB3-14	14.16	21	18.81	20.14	20.31	18.34	19.29	19.38	0.85
3A-DB3-12	12.13	21	46.34	49.44	52.58	50.98	49.96	49.86	2.30
3A-DB3-10	9.56	21	64.68	62.59	61.93	61.36	64.05	62.92	1.40
3A-DD1-18	15.74	20	13.65	11.44	15.17	13.25	14.25	13.55	1.38
3A-DD1-16	15.10	20	18.18	15.10	16.53	17.17	16.25	16.65	1.14
3A-DD1-15	15.18	21	13.91	12.31	12.44	13.55	13.44	13.13	0.71
3A-DD1-14	15.01	22	17.36	15.69	15.25	15.01	15.98	15.86	0.92
3A-DD1-12	15.35	21	13.65	14.73	14.75	12.73	13.69	13.91	0.85
3A-DD1-10	9.73	20	63.82	67.13	64.35	63.51	67.44	65.25	1.88
3A-DD2-18	16.87	22	8.25	7.54	6.88	7.48	7.13	7.45	0.52
3A-DD2-16	18.65	20	6.33	6.73	7.74	7.29	7.71	7.16	0.62
3A-DD2-15	15.31	20	17.21	16.43	15.15	16.84	17.36	16.60	0.88

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3A-DD2-14	14.99	22	22.61	22.79	21.83	20.95	19.81	21.60	1.24
3A-DD2-12	12.89	22	35.57	34.38	36.47	35.50	33.70	35.12	1.09
3A-DD2-10	10.27	20	47.69	52.39	51.32	49.24	48.24	49.77	2.02
3A-DE1-18	18.76	20	6.66	8.14	6.09	7.42	8.13	7.29	0.91
3A-DE1-16	16.12	22	13.71	12.95	11.19	11.99	13.33	12.63	1.03
3A-DE1-15a	14.88	20	14.12	16.07	15.22	15.63	15.19	15.24	0.72
3A-DE1-14	14.46	22	16.51	16.86	15.52	16.09	16.16	16.23	0.50
3A-DEA-12	11.63	22	22.50	24.19	23.85	23.55	24.97	23.81	0.90
3A-DE1-10	13.24	21	26.12	23.11	25.12	25.22	26.50	25.22	1.32
3A-DE2-18	17.64	20	9.76	9.37	9.04	8.70	10.18	9.41	0.59
3A-DE2-16	16.45	20	11.94	12.84	12.15	12.43	14.07	12.68	0.84
3A-DE2-15b	14.42	20	16.44	15.79	16.27	18.50	17.98	17.00	1.18
3A-DE2-14	14.74	21	16.00	15.42	16.14	14.33	12.87	14.95	1.36
3A-DE2-12	11.62	22	24.46	24.50	24.11	24.16	24.36	24.32	0.18
3A-DE2-10	11.51	21	25.66	25.45	25.49	26.30	28.00	26.18	1.07
3A-EB1-18	18.26	21	4.50	5.28	4.34	15.64	5.80	7.11	4.80
3A-EB1-16	15.35	22	9.33	9.10	9.26	9.62	9.69	9.40	0.25
3A-EB1-15	13.57	17	24.73	23.08	21.39	24.63	24.10	23.59	1.39
3A-EB1-14	12.20	19	41.88	42.65	43.66	42.70	41.59	42.50	0.81
3A-EB1-12	10.49	20	57.99	57.84	56.49	59.48	60.97	58.55	1.71
3A-EB1-10	9.45	20	63.88	61.37	62.00	62.08	61.11	62.09	1.08
3A-EB2-18	18.49	22	4.48	5.09	3.82	4.10	5.17	4.53	0.59
3A-EB2-16	17.08	22	5.42	5.72	5.10	5.60	5.88	5.54	0.30
3A-EB2-15	16.13	18	9.46	10.73	9.10	10.61	12.01	10.38	1.15
3A-EB2-14	14.34	18	17.75	16.97	17.61	16.64	16.20	17.04	0.65
3A-EB2-12	12.51	19	35.84	38.92	37.15	37.44	37.15	37.30	1.10
3A-EB2-10	9.75	20	65.00	66.49	63.22	63.59	64.33	64.52	1.30
3A-ED1-18	17.91	21	4.58	4.76	5.26	5.35	4.92	4.97	0.33
3A-ED1-16	15.40	21	9.85	8.70	10.70	8.79	8.77	9.36	0.89
3A-ED1-15	15.16	18	12.56	11.45	12.26	12.24	12.49	12.20	0.44
3A-ED1-14	13.94	18	16.57	17.70	16.89	17.75	17.37	17.26	0.51
3A-ED1-12	11.26	18	31.78	30.55	29.47	28.93	29.11	29.97	1.19
3A-ED1-10	10.80	19	35.02	33.55	33.02	34.65	34.53	34.16	0.83
3A-DE2-18	18.28	21	4.08	4.81	3.52	4.46	4.13	4.20	0.48
3A-ED2-16	15.52	21	12.15	11.67	11.62	12.77	11.36	11.92	0.56
3A-ED2-15	14.24	19	22.21	23.33	22.16	20.06	21.13	21.78	1.24
3A-ED2-14	13.82	18	23.23	23.50	22.57	24.51	24.87	23.74	0.94
3A-ED2-12	12.17	18	37.98	37.10	37.04	37.45	34.18	36.75	1.48
3A-ED2-10	10.95	18	41.58	45.64	43.02	44.58	44.13	43.79	1.55
3A-EE1-18	18.28	21	5.75	5.27	7.66	5.00	6.83	6.10	1.12
3A-EE1-16	15.99	21	8.31	10.93	9.66	10.48	9.34	9.75	1.02
3A-EE1-15	14.17	19	17.32	15.80	16.34	16.13	17.26	16.57	0.68
3A-EE1-14	13.30	19	17.70	17.71	17.44	14.44	18.62	17.18	1.60
3A-EE1-12	12.26	19	20.19	20.99	19.84	21.43	23.00	21.09	1.24
3A-EE1-10	11.08	19	22.96	24.30	26.41	23.06	24.34	24.21	1.39
3A-EE2-18	18.94	21	5.01	4.69	4.99	5.00	5.28	4.99	0.21
3A-EE2-16	15.59	21	10.80	12.15	11.23	9.61	14.14	11.59	1.69
3A-EE2-15	15.03	19	14.38	13.06	13.12	12.59	14.97	13.62	1.00
3A-EE2-14	13.80	19	17.41	17.31	16.75	18.26	17.03	17.35	0.57
3A-EE2-12	12.15	18	23.07	21.08	21.99	22.99	20.57	21.94	1.12
3A-EE2-10	11.19	18	27.84	27.26	26.51	27.41	28.49	27.50	0.73

APPENDIX 8

Data for the Interaction between Moisture Content and Temperature on Corn Breakage Susceptibility Using 12/64" Sieve

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3D-AB2-15	14.59	-13	16.85	16.48	15.08	17.96	16.82	16.64	1.04
3D-AB2-15	14.59	02	12.38	11.47	13.10	13.83	12.58	12.67	0.88
3D-AB2-15	14.59	14	9.59	9.73	9.52	9.65	9.95	9.69	0.17
3D-AB2-15	14.59	22	7.31	7.97	7.15	6.82	7.35	7.32	0.42
3D-AB2-15	14.59	34	5.24	4.54	4.40	5.19	4.57	4.79	0.39
3D-AB2-10	9.95	-13	30.73	28.18	29.47	29.55	28.98	29.38	0.93
3D-AB2-10	9.95	02	27.38	26.33	26.09	26.88	27.23	26.78	0.56
3D-AB2-10	9.95	14	26.37	25.73	25.17	25.62	25.56	25.69	0.43
3D-AB2-10	9.95	22	22.87	23.28	24.13	22.52	20.82	22.72	1.22
3D-AB2-10	9.95	34	18.32	17.81	18.13	19.82	19.10	18.64	0.81

APPENDIX 9

Data for the Effect of Rewetting on Corn Breakage Susceptibility Using 12/64" Sieve

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3B-AB1-18	16.55	22	3.32	3.54	3.21	3.95	3.32	3.47	0.30
3B-AB1-14-18	16.59	20	5.41	4.89	5.49	5.38	5.30	5.29	0.24
3B-AB1-12-18	16.65	21	4.00	3.72	3.80	4.63	4.44	4.12	0.40
3B-AB1-16	13.20	20	10.33	10.70	10.73	10.31	10.69	10.55	0.21
3B-AB1-14-16	13.39	20	13.21	12.82	13.83	13.59	13.18	13.33	0.39
3B-AB1-12-16	13.60	21	11.80	11.53	13.22	12.95	13.60	12.62	0.91
3B-AB1-14	11.17	21	25.29	24.36	25.91	25.93	25.11	25.32	0.65
3B-AB1-10-14	11.29	21	23.01	23.05	23.34	22.51	23.18	23.02	0.31
3B-AB1-12	13.26	21	14.65	13.92	14.97	14.84	14.34	14.55	0.42
3B-AB1-10-12	13.43	21	13.77	14.32	13.15	13.32	14.04	13.72	0.49
3B-AB1-10	8.79	21	34.41	35.01	33.58	32.93	33.62	33.91	0.81
3B-AB2-18	19.66	20	1.54	1.58	1.60	1.80	1.54	1.61	0.11
3B-AB2-14-18	19.50	21	1.66	1.22	1.47	1.50	1.51	1.48	0.16
3B-AB2-16	17.00	23	3.01	2.89	2.89	2.60	2.72	2.82	0.16
3B-AB2-14-16	16.88	21	2.15	2.47	2.82	2.71	2.49	2.53	0.26
3B-AB2-12-16	17.20	21	3.42	2.64	2.95	3.27	3.61	3.18	0.39
3B-AB2-14	14.20	21	8.46	7.79	8.14	8.70	8.31	8.28	0.34
3B-AB2-12-14	14.37	21	7.62	7.61	7.60	7.46	7.10	7.48	0.22
3B-AB2-10-14	14.44	21	7.16	7.75	7.34	7.11	7.23	7.32	0.26
3B-AB2-12	12.43	22	14.36	13.61	14.80	13.51	17.63	14.78	1.68
3B-AB2-10-12	12.59	21	11.38	12.31	13.36	13.31	12.76	12.62	0.82
3B-AB2-10	9.85	21	26.84	26.38	25.24	24.95	24.71	25.62	0.94

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3B-AD1-18	13.13	22	12.49	11.04	13.69	12.21	11.69	12.23	0.99
3B-AD1-16	16.34	23	3.88	3.97	3.95	3.47	4.18	3.89	0.26
3B-AD1-14-16	16.45	20	3.35	3.77	3.42	3.87	3.55	3.59	0.22
3B-AD1-12-16	16.68	20	4.58	4.29	3.86	3.82	3.84	4.08	0.34
3B-AD1-14	13.77	22	8.32	7.70	7.72	7.16	11.61	8.50	1.78
3B-AD1-12-14	13.91	20	10.12	9.47	10.48	10.48	9.73	10.06	0.45
3B-AD1-10-14	14.04	20	10.64	9.82	9.48	10.34	10.42	10.14	0.48
3B-AD1-12	10.95	22	15.73	16.62	17.34	17.71	16.04	16.69	0.84
3B-AD1-10-12	11.09	20	18.43	17.76	16.79	18.26	17.14	17.68	0.70
3B-AD1-10	10.47	21	19.45	17.86	18.19	19.28	17.67	18.49	0.82
3B-AD2-18	11.74	22	18.22	17.03	16.85	17.92	17.37	17.48	0.58
3B-AD2-16	16.72	23	3.38	3.21	3.53	3.39	3.63	3.43	0.16
3B-AD2-14-16	16.77	20	2.94	2.41	2.88	2.54	2.74	2.70	0.22
3B-AD2-12-16	16.86	20	4.26	4.07	4.02	3.58	3.76	3.94	0.27
3B-AD2-14	13.90	22	7.94	7.50	7.10	7.07	7.62	7.45	0.37
3B-AD2-12-14	14.01	20	10.16	10.19	9.19	9.65	10.23	9.89	0.46
3B-AD2-10-14	14.11	20	10.11	9.49	9.61	10.38	10.03	9.93	0.37
3B-AD2-12	10.90	21	15.63	17.74	17.93	17.74	17.50	17.31	0.95
3B-AD2-10-12	10.99	20	17.73	18.54	17.49	17.69	17.84	17.86	0.40
3B-AD2-10	10.68	21	18.17	19.97	18.37	19.16	18.79	18.89	0.72

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3B-AE1-18	17.18	21	3.00	2.69	3.04	2.75	2.90	2.88	0.15
3B-AE1-14-18	17.18	21	3.55	3.10	3.68	3.62	2.99	3.39	0.32
3B-AE1-16	15.71	21	4.57	5.04	4.73	5.05	5.21	4.92	0.26
3B-AE1-14-16	15.74	21	4.44	5.07	4.27	4.74	4.41	4.59	0.32
3B-AE1-12-16	15.68	21	5.05	5.09	5.18	5.54	6.15	5.40	0.46
3B-AE1-14	13.53	21	7.83	8.47	7.85	8.52	7.81	8.10	0.37
3B-AE1-12-14	13.56	21	7.36	7.06	7.64	7.45	7.70	7.44	0.25
3B-AE1-10-14	13.47	21	8.26	8.77	9.00	8.89	8.76	8.74	0.29
3B-AE1-12	12.49	21	10.31	10.73	9.87	10.42	10.04	10.28	0.33
3B-AE1-10-12	12.42	21	9.38	10.03	9.18	9.52	9.58	9.54	0.32
3B-AE1-10	11.42	21	12.40	11.40	13.52	11.46	11.04	11.77	0.66
3B-AE2-18	17.94	22	2.86	2.60	2.59	2.49	2.27	2.56	0.21
3B-AE2-14-18	17.80	22	2.40	2.17	2.89	2.48	2.81	2.55	0.30
3B-AE2-16	17.11	21	3.16	3.65	3.35	3.57	3.93	3.53	0.29
3B-AE2-14-16	16.95	22	3.45	2.95	2.92	2.82	3.16	3.06	0.25
3B-AE2-12-16	17.24	22	4.07	4.19	3.89	3.64	4.06	3.97	0.21
3B-AE2-14	14.44	21	7.10	8.18	8.09	7.01	8.61	7.80	0.71
3B-AE2-12-14	14.46	22	7.49	7.16	7.30	7.12	7.15	7.24	0.15
3B-AE2-10-14	14.45	22	6.76	7.12	7.30	7.54	7.33	7.21	0.29
3B-AE2-12	12.02	21	10.69	11.18	11.34	11.80	11.25	11.05	0.29
3B-AE2-10-12	11.97	22	10.22	9.77	11.17	9.47	10.49	10.22	0.66
3B-AE2-10	11.48	21	11.07	10.94	12.78	12.04	12.16	11.80	0.78

APPENDIX 10

Data for the Effect of Rewetting on Corn Breakage Susceptibility Using 16/64" Sieve

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3B-AB1-18	16.55	22	7.66	8.22	6.62	8.28	8.07	7.77	0.68
3B-AB1-14-18	16.59	20	10.32	9.73	10.80	10.64	11.05	10.51	0.51
3B-AB1-12-18	16.65	21	10.09	7.88	7.94	9.30	8.65	8.77	0.94
3B-AB1-16	13.20	20	21.76	22.77	23.31	21.30	21.90	22.21	0.81
38-AB1-14-16	13.39	20	26.47	26.44	28.13	28.63	26.03	27.14	1.15
3B-AB1-12-16	13.60	21	25.88	25.41	27.85	28.56	29.96	27.53	1.89
3B-AB1-14	11.17	21	48.53	46.41	48.97	49.24	48.08	48.25	1.12
3B-AB1-10-14	11.29	21	43.44	44.44	43.74	43.20	45.86	44.13	1.07
3B-AB1-12	13.26	21	25.46	25.21	23.11	24.05	24.18	24.40	0.95
3B-AB1-10-12	13.43	21	26.51	26.57	25.09	26.51	26.55	26.25	0.65
3B-AB1-10	8.79	21	62.97	61.45	62.93	60.24	60.79	61.68	1.24
3B-AB2-18	19.66	20	3.85	4.04	4.16	4.89	4.11	4.21	0.40
38-AB2-14-18	19.50	21	4.24	3.20	3.20	3.83	4.27	3.75	0.53
3B-AB2-16	17.00	23	6.92	6.32	7.19	6.73	6.82	6.80	0.32
3B-A82-14-16	16.88	21	5.57	5.96	5.48	7.06	5.54	5.92	0.66
3B-AB2-12-16	17.20	21	6.52	5.90	6.49	7.44	7.53	6.77	0.69
3B-AB2-14	14.20	21	18.27	16.41	16.48	18.16	16.96	17.26	0.90
3B-AB2-12-14	14.37	21	15.70	16.19	16.42	15.00	15.40	15.74	0.58
3B-AB2-10-14	14.44	21	13.60	15.09	15.37	14.79	14.74	14.72	0.67
3B-AB2-12	12.43	22	29.76	28.71	29.87	29.84	33.62	30.36	1.89
38-AB2-10-12	12.59	21	24.96	26.17	26.99	26.78	26.85	26.35	0.84
38-AB2-10	9.85	21	51.72	49.94	47.80	46.81	47.01	48.66	2.11

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3B-AD1-18	13.13	22	24.80	23.56	27.57	25.62	23.64	25.04	1.66
3B-AD1-16	16.34	23	8.69	9.31	8.99	8.17	9.09	8.85	0.44
3B-AD1-14-16	16.45	20	6.92	7.23	7.07	8.04	7.22	7.30	0.44
3B-AD1-12-16	16.68	20	10.17	9.59	8.17	8.20	8.39	8.90	0.92
3B-AD1-14	13.77	22	17.01	15.27	15.35	15.91	19.00	16.51	1.56
3B-AD1-12-14	13.91	20	22.01	20.81	23.00	21.98	20.75	21.71	0.94
3B-AD1-10-14	14.04	20	23.22	20.71	20.45	21.77	22.81	21.79	1.23
3B-AD1-12	10.95	22	32.44	32.40	32.66	34.38	31.23	32.62	1.13
3B-AD1-10-12	11.09	20	34.87	33.15	32.30	35.24	34.81	34.07	1.28
3B-AD1-10	10.47	21	36.74	33.49	33.86	37.56	34.38	35.21	1.82
3B-AD2-18	11.74	22	37.54	33.04	35.05	35.48	35.96	35.41	1.63
3B-AD2-16	16.72	23	7.54	7.89	7.23	7.52	9.12	7.86	0.74
3B-AD2-14-16	16.77	20	7.38	5.42	6.81	5.72	5.45	6.16	0.89
3B-AD2-12-16	16.86	20	8.77	9.39	9.63	7.12	7.67	8.51	1.09
3B-AD2-14	13.90	22	15.84	14.31	14.28	13.99	15.71	14.83	0.88
3B-AD2-12-14	14.01	20	21.55	20.35	20.20	20.33	20.58	20.60	0.55
3B-AD2-10-14	14.11	20	14.74	17.17	17.37	17.07	19.21	17.11	1.59
3B-AD2-12	10.90	21	31.14	34.22	34.79	34.71	34.52	33.88	1.54
3B-AD2-10-12	10.99	20	34.86	35.29	33.89	34.11	33.54	34.34	0.72
3B-AD2-10	10.68	21	35.08	37.41	34.92	36.67	35.55	35.93	1.07

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3B-AE1-18	17.18	21	8.07	6.46	7.44	7.01	6.96	7.19	0.60
3B-AE1-14-18	17.18	21	9.13	7.34	8.19	8.68	6.73	8.01	0.98
3B-AE1-16	15.71	21	10.59	9.94	10.14	11.36	12.03	10.81	0.87
3B-AE1-14-16	15.74	21	10.46	11.03	10.09	11.71	10.27	10.71	0.66
3B-AE1-12-16	15.68	21	13.74	11.97	12.56	14.18	14.88	13.47	1.19
3B-AE1-14	13.53	21	16.35	16.10	18.75	16.76	17.39	17.07	1.06
3B-AE1-12-14	13.56	21	16.36	15.07	16.52	16.40	16.06	16.08	0.59
3B-AE1-10-14	13.47	21	19.21	19.23	20.66	20.13	19.89	19.82	0.62
3B-AE1-12	12.49	21	20.53	24.69	21.89	20.25	20.33	21.54	1.89
3B-AE1-10-12	12.42	21	19.40	20.98	19.71	20.03	20.43	20.11	0.62
3B-AE1-10	11.42	21	24.43	24.10	26.34	23.05	23.25	24.23	1.31
3B-AE2-18	17.94	22	7.21	7.18	6.24	6.37	5.68	6.54	0.66
3B-AE2-14-18	17.80	22	6.26	6.23	7.56	6.71	7.60	6.87	0.67
3B-AE2-16	17.11	21	8.07	7.44	7.53	7.36	8.35	7.75	0.43
3B-AE2-14-16	16.95	22	9.51	7.32	7.60	7.07	7.70	7.84	0.97
3B-AE2-12-16	17.24	22	10.09	11.03	8.97	8.69	10.47	9.85	1.00
3B-AE2-14	14.44	21	15.12	18.07	17.67	14.97	18.15	16.80	1.61
3B-AE2-12-14	14.46	22	17.37	16.17	17.22	17.04	15.47	16.66	0.81
3B-AE2-10-14	14.45	22	14.78	17.37	17.65	16.85	18.38	17.00	1.36
3B-AE2-12	12.02	21	22.09	22.79	22.07	22.52	23.70	22.63	0.67
3B-AE2-10-12	11.97	22	20.29	19.72	22.08	19.68	22.24	20.80	1.27
38-AE2-10	11.48	21	22.25	22.80	25.93	23.57	25.55	24.02	1.64

APPENDIX 11

Data for the Effect of Blending on Corn Breakage Susceptibility Using 12/64" Sieve

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3C-AB1-15	12.80	21	12.75	13.44	13.94	14.18	13.22	13.51	0.57
3C-AE1-12	12.63	20	9.48	9.48	9.81	10.27	9.93	9.79	0.33
	13.10	21	13.70	14.23	13.26	13.55	13.50	13.65	0.36
3C-AB2-15	14.40	21	6.88	6.34	7.00	7.01	7.43	6.93	0.39
3C-AE2-14	14.44	21	7.10	8.18	8.09	7.01	8.60	7.80	0.71
	14.75	21	8.79	8.88	8.61	7.31	8.19	8.36	0.64
3C-AB2-12	12.43	22	14.36	13.61	14.80	13.51	17.63	14.78	1.68
3C-AE2-12	12.02	21	10.69	11.18	11.34	10.80	11.25	11.05	0.28
	12.42	22	15.45	15.07	14.34	14.25	14.04	14.63	0.61
3C-AB2-15	14.52	22	7.69	6.84	6.57	6.88	6.58	6.91	0.46
3C-AE1-16	15.71	21	4.57	5.04	4.73	5.05	5.21	4.92	0.26
	15.67	21	7.03	6.07	6.38	6.16	5.78	6.29	0.47
3C-AB1-18	16.55	22	3.32	3.54	3.21	3.95	3.32	3.47	0.30
3C-AE2-15	16.70	23	3.17	3.22	3.88	3.72	3.42	3.48	0.31
	17.07	20	3.43	3.39	3.95	3.66	3.51	3.59	0.22
3C-AB1-18	16.55	22	3.32	3.54	3.21	3.95	3.32	3.47	0.30
3C-AE1-15	16.01	22	4.56	4.61	4.79	4.73	4.63	4.67	0.09
	16.72	21	4.02	4.60	4.08	4.07	4.14	4.18	0.24

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3C-AB1-18	16.55	22	3.32	3.54	3.21	3.95	3.32	3.47	0.30
3C-AE2-15	16.20	21	5.25	4.75	5.17	4.65	4.94	4.95	0.26
	16.71	20	4.59	4.58	4.94	4.88	4.39	4.68	0.23
3C-AB1-16	13.20	20	10.33	10.70	10.73	10.31	10.69	10.55	0.21
3C-AE1-14	13.53	21	7.83	8.47	7.85	8.52	7.81	8.10	0.37
	13.76	21	11.93	11.19	11.79	11.60	11.08	11.52	0.37
3C-AB2-16	17.00	23	3.01	2.89	2.89	2.60	2.72	2.82	0.16
3C-AE1-18	17.18	21	3.00	2.69	3.04	2.75	2.90	2.88	0.15
	17.09	21	3.91	3.97	4.11	3.74	4.40	4.04	0.27
3C-AB2-16	17.00	23	3.01	2.89	2.89	2.60	2.72	2.82	0.16
3C-AE2-16	17.11	21	3.16	3.65	3.35	3.57	3.93	3.53	0.29
	17.07	20	4.13	4.03	3.68	4.21	4.02	4.01	0.20
3C-AB2-10	10.34	22	20.82	20.84	21.30	20.21	21.58	20.95	0.52
3C-AE2-10	11.44	22	12.83	12.17	11.75	11.95	11.49	12.04	0.51
	11.32	22	17.27	18.44	16.79	17.72	17.44	17.53	0.61
3C-AB1-14	11.75	22	18.50	18.91	18.38	18.69	18.77	18.65	0.21
3C-AE1-10	11.43	21	11.12	12.55	13.16	12.85	11.93	12.33	0.81
	11.87	22	17.55	16.30	18.62	17.21	17.67	17.47	0.84
3C-AB2-18	19.66	20	1.54	1.58	1.60	1.80	1.54	1.61	0.11
3C-AE2-18	17.94	22	2.86	2.60	2.59	2.49	2.27	2.56	0.21
	18.82	20	2.37	2.01	2.17	2.78	2.54	2.37	0.30

APPENDIX 12

Data for the Effect of Blending on Corn Breakage Susceptibility Using 16/64" Sieve

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3C-AB1-15	12.80	21	27.52	29.61	28.81	29.15	28.97	28.81	0.78
3C-AE1-12	12.63	20	19.64	19.76	20.84	20.80	20.99	20.41	0.65
	13.10	21	28.09	29.01	27.04	29.27	29.06	28.49	0.93
3C-AB2-15	14.40	21	16.84	14.61	16.54	15.76	15.60	15.87	0.88
3C-AE2-14	14.44	21	15.21	16.07	17.67	14.97	18.15	16.80	1.61
	14.75	21	20.14	20.58	18.71	15.99	17.16	18.52	1.95
3C-AB2-12	12.43	22	29.76	28.71	29.87	29.84	33.62	30.36	1.89
3C-AE2-12	12.02	21	22.09	22.79	22.07	22.52	23.70	22.63	0.67
	12.42	22	32.14	30.61	29.18	29.74	28.72	30.08	1.35
3C-AB2-15	14.52	22	15.76	14.67	13.13	14.53	15.13	14.64	0.97
3C-AE1-16	15.71	21	10.59	9.94	10.14	11.36	12.03	10.81	0.87
	15.67	21	15.23	13.36	14.22	14.45	13.12	14.07	0.85
3C-AB1-18	16.55	22	7.66	8.22	6.62	8.28	8.07	7.77	0.68
3C-AE2-15	16.70	23	8.66	8.22	9.85	8.90	8.01	8.73	0.72
	17.07	20	7.60	8.43	9.76	8.83	8.76	8.68	0.78
3C-AB1-18	16.55	22	7.66	8.22	6.62	8.28	8.07	7.77	0.68
3C-AE1-15	16.01	22	11.10	12.36	11.29	10.80	10.80	11.27	0.64
	16.72	21	8.82	11.45	10.50	9.98	10.03	10.15	0.95

Sample No.	mc %	Temp	Rep.1	Rep.2	Rep.3	Rep.4	Rep.5	Ave.%	SD %
3C-AB1-18	16.55	22	7.66	8.22	6.62	8.28	8.07	7.77	0.68
3C-AE2-15	16.20	21	11.49	11.88	10.99	10.16	11.67	11.24	0.69
	16.71	20	11.00	10.05	11.84	11.39	10.59	10.97	0.69
3C-AB1-16	13.20	20	21.76	22.77	23.31	21.30	21.90	22.21	0.81
3C-AE1-14	13.53	21	16.35	16.10	18.75	16.76	17.39	17.07	1.06
	13.76	21	25.88	23.46	24.75	24.64	24.00	24.54	0.91
3C-AB2-16	17.00	23	6.92	6.32	7.19	6.73	6.82	6.80	0.32
3C-AE1-18	17.18	21	8.07	6.46	7.44	7.01	6.96	7.19	0.60
	17.09	21	9.49	9.11	9.79	8.95	9.96	9.46	0.43
3C-AB2-16	17.00	23	6.92	6.32	7.19	6.73	6.82	6.80	0.32
3C-AE2-16	17.11	21	8.07	7.44	7.53	7.36	8.35	7.75	0.43
	17.07	20	9.44	8.93	9.34	9.65	10.25	9.52	0.48
3C-AB2-10	10.34	22	38.91	40.22	39.61	39.32	39.99	39.61	0.52
3C-AE2-10	11.44	22	26.07	25.51	23.24	24.79	23.74	24.67	1.18
	11.32	22	34.78	37.02	33.02	34.00	33.94	34.55	1.52
3C-AB1-14	11.75	22	38.75	38.15	37.40	39.12	37.07	38.10	0.87
3C-AE1-10	11.43	21	21.40	24.99	26.60	25.24	24.24	24.49	1.93
	11.87	22	33.70	34.08	36.80	35.30	34.18	34.81	1.26
3C-AB2-18	19.66	20	3.85	4.04	4.16	4.89	4.11	4.21	0.40
3C-AE2-18	17.94	22	7.21	7.18	6.24	6.37	5.68	6.54	0.66
	18.82	20	6.96	5.78	6.35	6.96	6.51	6.51	0.49

APPENDIX 13

Data for.Human Factors on Corn Breakage Susceptibility Using 12/64" Sieve

	Operator 1	Operator 2	Operator 3	Operator 4
Sample No.	1	1	1	1
mc %	10.22	10.24	10.30	10.31
Temp	19.00	20.00	21.50	20.00
Rep.1	27.69	27.20	24.56	23.53
Rep.2	25.58	26.63	25.50	25.72
Rep.3	24.49	27.37	27.52	25.71
Rep.4	26.95	28.53	26.45	25.61
Rep.5	26.36	25.87	25.12	26.43
Rep.6	24.34	26.94	25.38	25.40
Rep.7	25.69	27.46	25.35	25.65
Rep.8	25.67	26.94	23.32	24.92
Rep.9	26.25	27.90	24.92	25.33
Rep.10	25.85	27.78	24.18	26.60
Ave.%	25.89	27.26	25.23	25.49
SD %	1.01	0.74	1.16	0.85

	Operator 1	Operator 2	Operator 3	Operator 4
Sample No.	2	2	2	2
mc %	9.59	9.61	9.58	9.55
Temp	20.00	20.00	21.50	20.00
Rep.1	38.14	34.41	36.21	37.98
Rep.2	38.04	34.91	35.06	35.97
Rep.3	37.25	35.21	35.61	37.38
Rep.4	35.20	34.48	35.50	36.10
Rep.5	37.59	36.36	35.83	37.59
Rep.6	36.60	35.02	37.90	36.95
Rep.7	35.09	36.19	34.34	34.98
Rep.8	37.32	37.31	34.63	36.78
Rep.9	39.38	35.81	34.57	36.42
Rep.10	39.38	36.38	35.84	36.04
Ave.%	36.81	35.61	35.55	36.62
SD %	1.31	0.95	1.03	0.90

	Operator 1	Operator 2	Operator 3	Operator 4
Sample No.	3	3	3	3
mc %	10.20	10.29	10.23	10.26
Temp	23.00	23.00	21.50	21.00
Rep.1	30.59	32.99	30.78	32.01
Rep.2	30.50	28.95	31.96	29.91
Rep.3	30.04	31.12	31.67	31.13
Rep.4	30.86	27.57	31.66	30.97
Rep.5	30.72	32.02	31.62	30.81
Rep.6	30.48	28.68	32.08	31.73
Rep.7	30.73	31.53	31.12	30.36
Rep.8	29.65	31.61	31.70	31.65
Rep.9	31.11	28.16	31.13	31.44
Rep.10	29.68	29.09	31.01	31.11
Ave.%	30.44	30.17	31.46	31.11
SD %	0.49	1.88	0.45	0.64

	Operator 1	Operator 2	Operator 3	Operator 4
Sample No.	4	4	4	4
mc %	9.43	9.34	9.36	9.35
Temp	23.00	23.00	21.50	21.00
Rep.1	42.82	42.60	43.69	46.29
Rep.2	41.72	41.51	43.44	42.84
Rep.3	43.32	42.13	43.41	42.49
Rep.4	42.50	40.39	44.84	44.59
Rep.5	40.72	41.20	44.00	45.78
Rep.6	41.18	40.42	42.43	42.51
Rep.7	44.41	43.04	43.56	41.69
Rep.8	43.51	41.49	42.08	43.95
Rep.9	42.50	40.97	43.01	42.97
Rep.10	40.83	41.46	42.49	44.23
Ave.%	42.35	41.52	43.29	43.73
SD %	1.23	0.87	0.82	1.50

	Operator 1	Operator 2	Operator 3	Operator 4
Sample No.	5	5	5	5
mc %	10.17	10.24	10.17	10.22
Temp	20.00	22.00	22.00	20.00
Rep.1	27.69	25.01	24.09	25.58
Rep.2	25.58	25.04	25.74	26.45
Rep.3	24.49	25.06	23.86	25.51
Rep.4	26.95	24.71	26.39	25.66
Rep.5	26.36	25.55	24.20	26.82
Rep.6	24.34	23.60	24.96	25.77
Rep.7	25.69	24.35	24.59	26.68
Rep.8	25.67	25.67	24.82	25.86
Rep.9	26.25	24.62	24.99	28.25
Rep.10	25.85	24.46	24.83	25.66
Ave.%	25.89	24.81	24.85	26.22
SD %	1.01	0.60	0.76	0.86

APPENDIX 14

Data for Human Factors on Corn Breakage Susceptibility Using 16/64" Sieve

	Operator 1	Operator 2	Operator 3	Operator 4
Sample No.	1	1	1	1
mc %	10.22	10.24	10.30	10.31
Temp	19.00	20.00	21.50	20.00
Rep.1	63.21	61.62	58.18	56.12
Rep.2	64.94	61.84	60.66	61.31
Rep.3	62.79	60.68	61.80	62.04
Rep.4	66.43	66.16	62.43	58.75
Rep.5	63.39	61.56	59.81	62.76
Rep.6	62.84	61.76	62.06	59.95
Rep.7	63.15	62.21	58.59	61.54
Rep.8	63.44	64.13	57.23	60.28
Rep.9	65.03	63.44	59.84	61.87
Rep.10	63.09	65.69	56.88	61.82
Ave.%	63.83	62.81	59.75	60.65
SD %	1.21	1.70	2.00	1.98

	Operator 1	Operator 2	Operator 3	Operator 4
Sample No.	2	2	2	2
mc %	9.59	9.61	9.58	9.55
Temp	20.00	20.00	21.50	20.00
Rep.1	70.20	65.82	68.57	70.74
Rep.2	70.72	66.32	66.49	69.43
Rep.3	68.88	67.80	67.58	68.61
Rep.4	68.85	68.90	67.85	69.95
Rep.5	69.39	68.29	66.06	68.46
Rep.6	69.03	65.21	68.11	69.04
Rep.7	65.55	67.88	65.82	66.08
Rep.8	68.98	69.60	65.45	69.05
Rep.9	70.64	68.13	64.98	66.89
Rep.10	69.96	67.66	69.98	66.23
Ave.%	69.22	67.56	67.09	68.45
SD %	1.48	1.38	1.59	1.57

	Operator 1	Operator 2	Operator 3	Operator 4
Sample No.	3	3	3	3
mc %	10.20	10.29	10.23	10.26
Temp	23.00	23.00	21.50	21.00
Rep.1	61.47	67.60	63.57	65.92
Rep.2	62.70	61.46	66.90	64.51
Rep.3	63.88	65.47	65.27	65.10
Rep.4	63.76	61.68	65.74	64.76
Rep.5	65.03	65.13	65.38	65.58
Rep.6	62.26	61.61	66.08	67.86
Rep.7	63.16	64.86	64.78	64.11
Rep.8	62.59	65.33	65.77	64.20
Rep.9	65.75	61.12	67.21	65.97
Rep.10	64.47	62.21	62.77	62.70
Ave.%	63.51	63.65	65.35	65.07
SD %	1.32	2.28	1.37	1.39

	Operator 1	Operator 2	Operator 3	Operator 4
Sample No.	4	4	4	4
mc %	9.43	9.34	9.36	9.35
Temp	23.00	23.00	21.50	21.00
Rep.1	72.32	73.65	74.37	76.15
Rep.2	72.63	72.44	75.08	75.11
Rep.3	74.20	73.98	75.32	73.83
Rep.4	74.97	72.20	76.43	76.58
Rep.5	71.66	73.96	75.78	76.53
Rep.6	71.28	73.50	74.21	74.61
Rep.7	74.91	74.20	75.98	74.08
Rep.8	73.60	72.53	72.14	73.82
Rep.9	74.58	73.02	75.68	73.31
Rep.10	71.53	73.95	73.57	76.52
Ave.%	73.17	73.34	74.85	75.05
SD %	1.46	0.74	1.30	1.29

	Operator 1	Operator 2	Operator 3	Operator 4
Sample No.	5	5	5	5
mc %	10.17	10.24	10.17	10.22
Temp	20.00	22.00	22.00	20.00
Rep.1	58.56	54.07	54.15	56.24
Rep.2	55.81	55.59	56.11	58.05
Rep.3	55.39	55.52	53.41	56.68
Rep.4	57.66	55.72	57.46	56.25
Rep.5	59.34	55.57	54.69	57.95
Rep.6	54.87	52.77	53.92	56.68
Rep.7	57.03	55.67	53.79	55.92
Rep.8	56.33	55.69	54.96	58.42
Rep.9	57.74	52.16	54.78	59.54
Rep.10	56.15	52.32	56.40	59.57
Ave.%	56.89	54.51	54.97	57.53
SD %	1.43	1.53	1.30	1.36

FACTORS AFFECTING
WISCONSIN BREAKAGE TESTER RESULTS ON CORN

by

PO-CHING JOHNNY WU

B.S., National Taiwan University, 1981

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1987

ABSTRACT

This study was undertaken inorder to evaluate the factors affecting the Wisconsin Breakage Tester values on corn. Machine and non-machine source of error were investigated, including operator error and the factors of moisture content, temperature, rewetting, and blending.

The average of standard deviations, range from 0.06 to 1.98, is 0.505 on different levels of breakage susceptibility for 12/64" sieve measurement at room temperature. For 16/64" sieve measurement, the average of standard deviations, range from 0.1 to 4.8, is 1.012. The breakage values using the 16/64" sieve are almost exactly double the 12/64" sieve's. The average of CV values (6.07%) using 12/64" sieve is almost equal to the 16/64" sieve's (6.05%) over a large range of breakage susceptibility values. Human factors, mold damage, and feeding rate were insignificant on corn breakage susceptibility values.

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%. The exponential model of the form $y = a \exp(-CM)$ had the highest coefficients of correlation and was thus chosen as the test model. This correlates with the results of Paulsen (1983). Significant interaction was found between moisture content

and temperature on breakage susceptibility. The effect of moisture content and temperature on Breakage susceptibility was strongly dependent on corn variety and drying condition.

In both rewetting and blending study, the results using both 12/64" and 16/64" sieve seemed to have the same tendency, but using 16/64" sieve measurement can easily differentiate the rewetted samples from the unwetted samples. The tendency was strongly dependent on the drying condition. Rewetted samples with different drying conditions have different tendency on breakage susceptibility. In overall view, the lower the moisture content, the bigger the difference of breakage susceptibility between rewetted and originally dried samples. The breakage susceptibility can be recovered by rewetting for both high temperature dried and ambient dried samples, except the high-ambient dried samples.

The results of blending tests indicated that all the blended samples had higher breakage susceptibility values than the average of two original breakage susceptibility values. Therefore, the breakage susceptibility of blended corn can't be estimated mathematically. The magnitude above the average breakage value was a little bit correlated with the moisture content blended.