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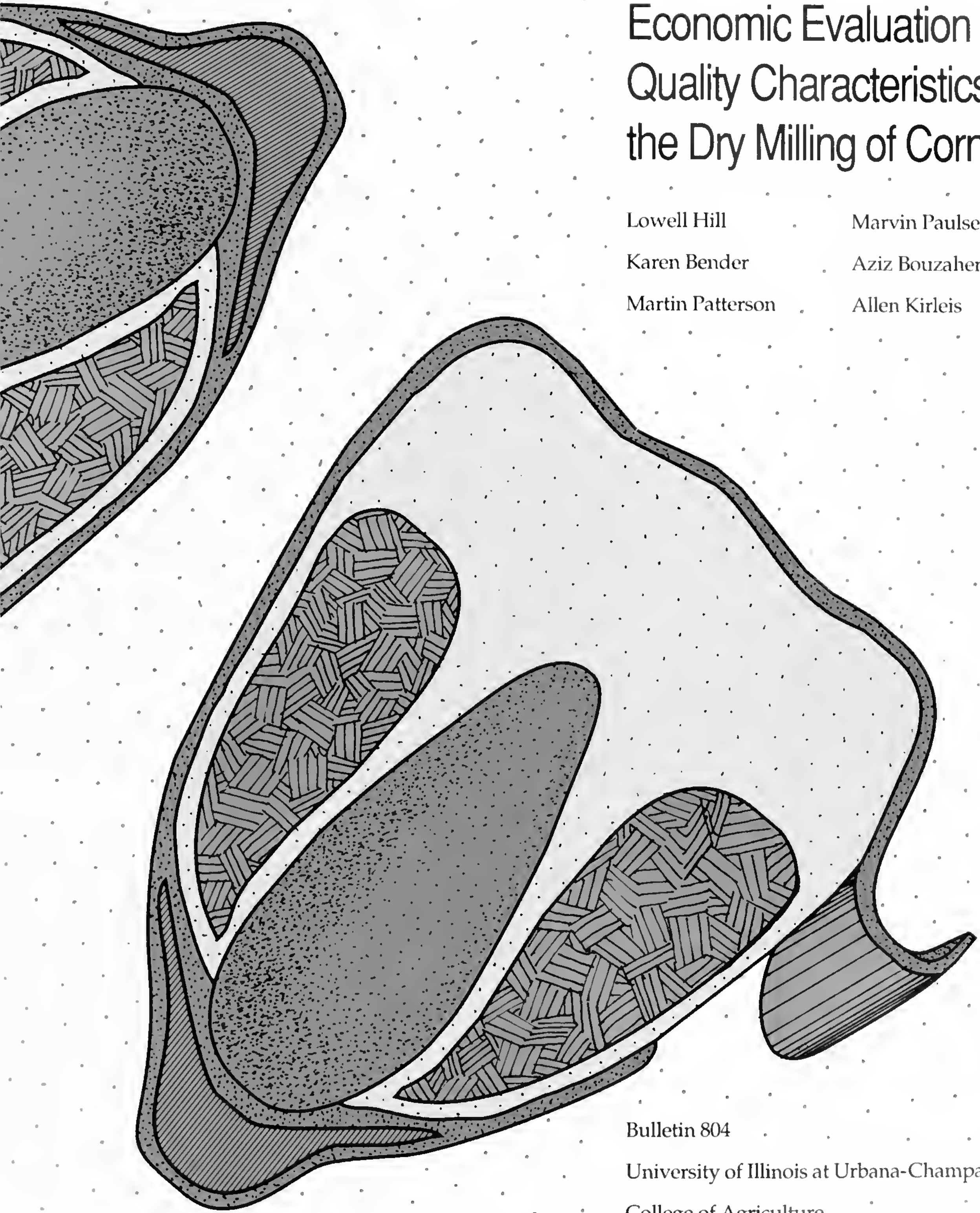

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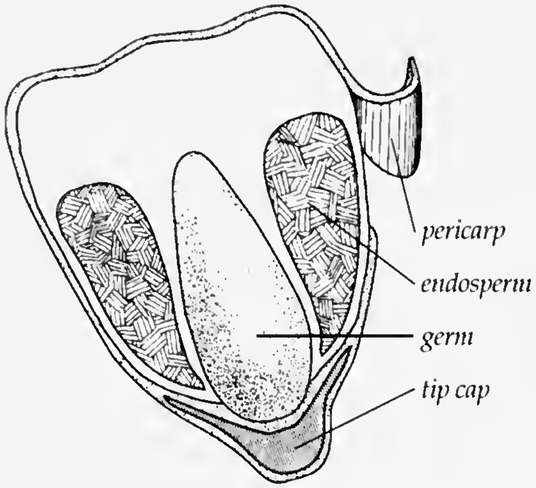

Economic Evaluation of Quality Characteristics in the Dry Milling of Corn

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Introduction

The yield of products in the corn dry milling industry is largely determined by the physical properties of the corn kernel. Kernels with a high proportion of hard vitreous endosperm and a minimum of internal stress cracks provide the highest yield of the more valuable flaking grits. Larger kernels, other things being equal, also produce larger grits. Ease of separation of the germ and endosperm, and a minimum amount of bran, also increase the value. Most of these traits, with the exception of stress cracks, are genetically determined. Although some dry milling firms contract with growers to control variety and handling practices, most continue to buy No. 2 corn in the market and to search for measurement technology to identify and segregate desirable from undesirable lots. The purpose of the research reported in this bulletin is to identify the corn characteristics that provide the best prediction of the yield of products from dry milling.

The dry milling industry in the United States consumes approximately 160 million bushels of corn annually, less than 5 percent of the total corn produced (Corn Annual 1991). But dry milling, an important link in the food chain, connects farmers to consumers. Although a large number of small mills grind whole corn directly for use in corn meal and grits, most of the large modern mills use a degerminating/roller milling process to separate germ and the pericarp (bran) from the endosperm (grits, meal, and flour).

The value of a bushel of corn to a dry miller is directly related to the yield of the products that can be derived from it and the prices of those products at the time they are sold. It is well known that not all corn produces the same mix of dry milling products. The value of corn varies not only among hybrids, but from one farmer's field to another, and from one crop year to the next depending upon growing conditions. Many dry millers buy corn on the basis of numerical grade, paying the market price or bidding slightly above the market price in cases where they are familiar with the sellers and the quality of corn delivered by them. However, most of the corn characteristics that influence the yield of dry milled products are not entirely reflected by numerical grade. Thus, domestic millers find that No. 1 corn is not necessarily better than No. 2, and foreign buyers often settle for No. 3 corn, knowing that many of the characteristics which they need are as likely to be present in No. 3 as in No. 2.

Fluctuations in the intrinsic properties of corn for dry milling purposes result in fluctuations in the mill in the quantity and quality of products produced. This increases the difficulty of management decisions in trying to adjust mill technology to meet a nonuniform stream of incoming corn. Many of the basic characteristics related to yield are unknown at the time the corn is purchased and sometimes even at the time the corn is processed. If the characteristics that determine the yield of primary products could be identified and accurate measurements could be provided, then efficiency within the mill could increase. More important, the pricing efficiency of selecting corn and pricing it accordingly would dramatically improve. Pricing on the basis of these measurable, economically important characteristics would quickly send signals back to producers, and from producers to plant breeders, that would in turn result in the production and delivery of corn to the dry miller with characteristics that would increase its value in terms of the products produced.

The objectives of this research were to identify some of those characteristics in the laboratory and relate these findings to results in full-scale milling trials. The research involved the Departments of Food Science, Agricultural Engineering, Agricultural Economics, and Agronomy. The study was conducted over a three-year period at the University of Illinois under a grant from the Illinois Corn Marketing Board in cooperation with the Department of Food Science at Purdue University. The specific objectives were to: (1) determine the physical characteristics of corn that influence the quantity and quality of dry milling products, (2) identify characteristics correlated with the laboratory properties that can be readily measured in commercial channels, (3) identify the management practices and genetic history that influence these properties and, therefore, the value of corn for dry milling, (4) test these properties in a full-scale mill, and (5) calculate the cost and value of corn with different levels of these economically important characteristics using an illustrative set of product prices.

Before addressing these objectives, a review of the history of dry milling and the physical dry milling process will provide a perspective of the industry and the scope of the project.

History of Dry Milling

The history of corn milling is closely linked to the history of the corn plant in North America. The corn plant seems to have its earliest ancestors in Mexico, where archaeologists discovered cobs of wild corn dating back as far as 5,000 B.C. (Mangelsdorf 1974). It was only a brief period of time before people discovered the value of milled corn as a human food. The earliest history of the Indians of North and South America records stone grinders or mortars and pestles for grinding corn. Naturalist Thomas Belt observed that the ancient Indians of Central America buried stone grinders used for corn along with their dead for use in the afterlife (Belt 1985).

By the early 1600s, milling technology had advanced with the invention of a type of revolving stone mill. This technology expanded to become a grist mill for grinding both corn and wheat. Power sources for these early grist mills included livestock, humans, wind, or water (Hardeman 1981).

In the early years of U.S. history, most of the grist mills were located close to a water power source, with almost all of the ground corn sold locally. Because whole corn was ground in these mills, the oil in the germ was included in the flour and meal. This limited the time that meal could be stored without becoming rancid because of high fat content.

The invention of the degerminator in the early 1900s was possibly the most significant event in the history of corn dry milling. Traditionally, a large number of small mills ground whole corn directly for use in corn meal and grits, but the trend since 1900 has been to use a degerminating process to separate the germ from the meal and grits. The degerminator allowed the milling industry to move away from the small grist mills that served the immediate needs of local consumers to the larger, more efficient plants that processed 20,000 to 70,000 bushels per day with nationwide distribution (Alexander 1987).

The true value of the degerminating process is that the miller can produce a wide variety of low-fat products with a much longer shelf life than the whole kernel products of the past. It is worth noting that as the dry millers began to adopt this technology, the number of mills declined 25 percent, from 120 mills in 1969 (Northwestern Miller 1968) to 90 mills in 1984 (Milling and Baking News 1984). At the same time, the average output of the dry milling industry has been increasing at an annual rate of 2.9 percent (Leath, Meyer, and Hill 1982). The industry is expected to continue growing at about the same rate as the U.S. population (Alexander 1987).

Dry Milling Process

The degerminating process separates the kernel into three general categories of raw materials—germ, bran, and endosperm—in preparation for further processing into the final food and feed products. The germ is used for producing corn oil and feed by-products. The bran is used primarily as livestock feed, and the endosperm is processed into a variety of food and feed products. About 50 percent of the total weight processed becomes grits for use in breakfast cereals, snack foods, and the brewing industry (Table 1). Corn meal makes up about 20 percent of the total weight and is used in corn meal mixes, cereals, bakery mixes, pancake mixes, and snacks. Yellow corn cones are a finer granulation of corn meal, with a unique, almost round shape, and are used in bakery mixes and cereals (Wells 1979). The hard and soft portions of the endosperm are also made into corn flour and meal, as well as used for a variety of nonfood products such as wallpaper paste and glucose (through direct starch hydrolysis). The proportion of the various products differs among firms and can be altered within a plant to meet demand specifications.

In the dry milling process, the corn is cleaned to remove broken kernels and foreign material, and then conditioned to about 20 to 24 percent moisture to loosen the bran and the germ from the endosperm. The first step in milling is to separate the endosperm from the germ and bran by using a degerminator, a horizontal, cone-shaped drum, covered with small steel projections that revolve within a metal housing. The housing is also studded with steel projections and covered with one or more perforated metal screens. As the bran and germ are separated from the endosperm, the corn passes from the small to the large end of the drum, the smaller particles (chiefly pericarp and germ) pass through the perforated screens (as throughstock), while the larger pieces are discharged from the end of the drum (as tailstock). The larger the percent of tailstock, the higher the yield of high-valued products in the larger particle sizes. If the endosperm is badly broken going into the degerminator, a higher percentage will pass through the screens as throughstock, reducing the output of tailstock and, therefore, the yield of large grits.

Additional grinding, screening, and aspiration take place on both the tailstock and throughstock, separating the endosperm into the various size ranges from large flaking grits to the flour and meal, and separating germ and bran for further processing. Oil is extracted from the germ by mechanical presses or solvent extraction. The germ cake remaining after the oil is removed is used in hominy feed or ground for corn germ flour (Wells 1979).

Value and Quality of Dry Milling Products

The prices of the various products derived from the dry milling process vary over a wide range. Feed is usually the lowest priced, while flaking grits are the highest priced of the endosperm products. Flour and meal are intermediate in value. The price of oil is currently more than twice the price of grits and other white goods, although the yield per bushel is small. However, dry millers often consider oil as a byproduct and may deliver whole germ to other firms in the oil industry for processing.

The value of grits is related to their size. Grit size is classified by the number of wires per inch on the screens used to retain the various grit products. The different products—flaking grits, brewers' grits, meal, and flour—are generally defined on the basis of grit size. For example, flaking grits are those particles of hard vitreous endosperm retained on a mesh with approximately five wires per square inch. Various sizes of grits are used in different products and sold in separate markets at different prices. In general, the larger the grits the greater the value. Large grits can be converted into smaller, lower valued products as market demand and supply dictate, but obviously this is a one-way transformation. Consequently, the yield of flaking grits is an important factor in determining the value of corn for dry milling.

Many factors affect the yield of flaking grits. However, a large grit can be made only if there is a large amount of hard vitreous endosperm in the kernel, and then only if that hard vitreous endosperm remains intact as the corn is degermed in the dry milling process. Therefore, the dry miller prefers large kernels with a high percentage of horny endosperm. In addition, the harvesting, handling, and drying practices should be gentle enough to leave the hard endosperm portion of the kernel intact without stress cracks.

The size of kernel and the amount of hard endosperm are primarily a function of genotype (hybrids), with some influence from growing conditions. The extent to which the hard endosperm remains intact is a function of drying temperature and handling practices. The study by Brekke, Griffin, and Shove (1973) found that as air temperature for drying yellow dent corn increased from 15°C to 143°C, the yield of large flaking grits decreased from 45 to 12 percent of total weight.

One of the factors determining the quality of flaking grits is the percent of fat; the higher the fat content the lower the quality of grits. If small pieces of free germ are retained with the flaking grits during separation, or if pieces of germ remain attached to the endosperm, the fat content of the grits will increase and shorten the shelf life of the products. The Brekke study revealed that corn dried at 143°C had more germ attached to the large flaking grits than corn dried at 15°C; thus quality as well as quantity of grits is influenced by drying temperature. Yields of the lower valued high-fat meal and flour are also increased as drying temperatures increase. Inglett reported that drying corn at 82°C prior to dry milling resulted in lower oil recovery, more flour, and lower yield of premium grits than corn dried at lower temperatures (Inglett 1970).

Determinants of Product Yield. Satisfactory technology for identifying those lots of corn best suited for dry milling is not yet available in the dry milling industry. Testing technology useful for selecting corn from the commercial market channel must be rapid, reliable, and capable of predicting yields of primary products. Many alternative tests have been used to predict the yield of large flaking grits. Manoharkumar et al. (1978) analyzed 20 maize hybrids harvested at 35 percent moisture and dried to 15 percent moisture with air temperatures between 35°C and 60°C to determine correlations between milling performance and physical and chemical characteristics. Measurement tests of quality included 1,000-kernel weight, bulk density, percent of kernels with stress cracks, percent of floaters in a 1.275 specific gravity solution, and chemical analyses for starch, fat, and protein content. Percent of floaters was significantly and negatively correlated with yield of grits having a size between 0.84mm and 1.2mm ($r=-0.69$) and positively correlated with yield of grits between 0.50mm and 0.84mm in size ($r=+0.72$). Both correlations were significant at the 0.1 percent level. An increase in the percent of floaters increased the proportion of grits in the smaller size categories. Bulk density had a significant correlation ($r=+0.75$) with grit yield. Protein content was negatively correlated with percent floaters, indicating that higher density kernels had higher protein content.

Some dry millers have tried to increase the yield of flaking grits by identifying "acceptable" and "unacceptable" varieties for delivery to their plant, thus controlling kernel size and percent of hard endosperm. Dry millers have also tried to select corn that has been dried at lower temperatures, either by measuring the percent of stress cracks or through contractual arrangements with producers. However, production contracts are costly to administer, and accurate, rapid determination of the percent of stress cracks has proven to be difficult in commercial operations. Test weight provides a good measure of genetic differences in the percent of hard endosperm, but other factors not related to yield of grits also influence test weight and reduce the effectiveness of test weight as the only selection criterion (Hall and Hill 1973). Consequently, there is continuing interest in new techniques for identifying corn that has the potential for high yields of flaking grits.

Research Methodology and Results

Previous research identified a positive relationship between density and the yield of dry milling products, while identifying a negative relationship between breakage susceptibility and yield (Stroshine et al. 1986). The methodology of this study extended the previous research to include additional measures of quality and to supplement laboratory results with full-scale plant operations under controlled conditions.

Pilot Mill. A short-flow pilot mill located in the Department of Food Science at Purdue University provided product yields from selected samples of corn representing a range of quality characteristics. For the pilot mill, a total of 98 samples were collected. Thirty-two samples of flint and dent inbred crosses planted at two locations with a high and low nitrogen application rate were selected to provide a wide range of genetic differences in percent of hard endosperm. An additional 10 samples were obtained from superior varieties selected by a dry milling plant. Thirty-nine more samples were provided by a commercial corn breeder, selected to represent a range of genetic characteristics and quality differences related to dry milling. Finally, 17 samples were collected from farmers and elevators, most of them consisting of a mixture of different varieties and a range of harvesting and drying practices.

Each of the samples was analyzed in the Agricultural Engineering Grain Quality Laboratory at the University of Illinois to identify the physical characteristics that would be used in identifying possible relationships between corn characteristics and product yield. A set of 16 tests was performed on each corn sample under controlled moisture and experimental conditions. In the commercial mill, a less complex set of tests was conducted because of time limits and financial costs. Previous research suggested possible indicators of the three physical attributes most closely related to dry milling yields—density, hardness, and breakage susceptibility (Paulsen and Hill 1985; Paulsen 1988). Appendix A provides a detailed description of all the tests conducted. The percentage of flint in each sample was determined from the genetic history rather than from a laboratory test. A list of these quality tests and their abbreviations appears in the following chart.

Descriptions and Abbreviations for Selected Quality Tests Used in This Study

Legend	Test description
TW	Test weight (lb/bu)
WBT	Wisconsin breakage test (%)
STEIN	STEIN breakage test (%)
MOIST	Moisture content (%)
SCI	Stress crack index (1.0-5.0 with 5.0 being most severely fractured)
DENS	Density-alcohol test (g/cm^3)
FLO	Floaters test (%)
STIME	Stenvert time-to-grind (seconds)
SCMF	Stenvert ratio—(coarse):(medium + fine)
SCF	Stenvert ratio—coarse:fine
S3550	Stenvert column height at 3550 rpm
PYCN	Pycnometer test (g/cm^3)
NSTAR	Starch (%) obtained by NIR
NOIL	Oil (%) obtained by NIR
NPROT	Protein (%) obtained by NIR
NMOIST	Moisture (%) obtained by NIR
FLINT%	Percent of flint genetic background in the variety (%)
MEF	Milling evaluation factor
BG	Brewers' grits
FG	Flaking grits

Each sample was equilibrated to approximately 14.5 percent moisture content in order to minimize the effect of moisture on the physical property test results. The test results for each of the 98 samples used in the pilot mill are presented in Appendix B. Samples identified as L-1 through L-32 were flint-dent crosses from experimental field plots at the University of Illinois using an Argentine flint corn with four levels of dent genetic material under two levels of nitrogen application. The high level of hard vitreous endosperm in the pure flint varieties proved to be an important determinant of yield of various products.

A summary of the 17 characteristics for all samples, dent samples, and flint samples is given in Table 2. The flint samples differed markedly from the dent samples in nearly all of the measurements.

Correlation Analysis Among Tests. The correlations matrix indicates that many of the tests are measuring the same intrinsic properties (Table 3). Since many of the tests are alternative measurement technologies for the same physical property, collinearity among the variables was inevitable in any statistical analysis.

Test weight (TW), a traditional measure of density and hardness, does not appear to be strongly related to any of the characteristics. In fact, correlations of 0.5 or less are found between test weight and all other quality tests. Although research under controlled conditions has shown significant correlations between test weight and other density measures, test weight is influenced by many environmental and handling factors. Samples from commercial sources were undoubtedly subjected to a range of these conditions.

The Wisconsin breakage test (WBT) had a high correlation (r=+0.82) with the stress crack index (SCI), which is consistent with previous research (Kirleis and Stroshine 1990). It is also correlated with the following tests: Pycnometer (PYCN), r=+0.65; the Stenvert ratio—(coarse):(medium + fine) (SCMF), r=+0.53; and the Stenvert column height (S3550), r=−0.52.

The Stein breakage test (STEIN) did not show a high correlation with any other tests. In particular, the correlation between SCI and the STEIN is surprisingly low (r=+0.44). Similar results have been reported by other researchers (Kirleis 1986).

Among the four Stenvert tests, the STEIN had the highest correlation with the coarse-to-fine ratio (SCF), r=+0.51, while the WBT had its highest correlation with the ratio of SCMF particle sizes, r=+0.53. If the samples are separated into flint and dent types, the correlations change (Appendixes C.1 and C.2). Among the flint samples, the SCF had the highest correlation with the STEIN, r=+0.64. Among the dent samples, the WBT had higher correlations with the S3550 test, r=−0.71, and the SCMF test, r=+0.70. Both breakage tests (WBT and STEIN) had significantly lower correlations with SCI with flint samples than with dent. Flint samples produced no correlations above 0.4 with the WBT; correlations with the STEIN were higher—ranging to 0.64 with SCF and 0.50 with floaters (FLO) and S3550. The relationships of current measures of breakage susceptibility are less well defined in flint samples than in dent samples.

Milling Evaluation Factor and Product Yields. The 98 samples processed in the short flow pilot mill located in the Department of Food Science at Purdue University generated a product distribution similar to that obtained from commercial mills. The milling procedure was designed to duplicate to the extent possible the mill flow process of industrial mills. Simplified diagrams of the two mill flow processes are given in Appendix D.

The Purdue pilot mill portion of the research was conducted to (1) permit a statistical analysis of a large number of variables under controlled experimental conditions, and (2) determine which of the different measurement technologies were most highly correlated with product yields. This phase of the research was conducted jointly between the University of Illinois and Purdue University. The University of Illinois provided the samples and physical and chemical measurements; Purdue University provided the product yields and an index of milling value using their short-flow laboratory dry milling procedure.

The yield of each of six products obtained from the laboratory pilot mill was reported as the percentage of the total milled corn sample retained on a sieve of a specific mesh size. These percentages were converted to pounds per bushel based on a moisture loss from 14 percent corn to 6 percent final products. In absolute terms, the yield of products may be higher than the yields from commercial mills, but the correlations between yields and quality measurements should be similar. The six products measured were flaking grits, brewers' grits, meal, flour, oil, and feed.

In addition to the six different product yields, a milling evaluation factor (MEF) index was calculated for the pilot mill samples using the formula below.

Descriptive statistics of the MEF and product yields are given in Table 4 for the corn samples milled at Purdue University. The MEF ranged from 28.5 to 59.7, and the flaking grit yield ranged from 5.7 lb/bu to 22.4 lb/bu, indicating a wide range in the quality of the corn samples that were tested.

The samples were grouped according to flint and dent type of corn when it was observed that the flint varieties had significantly different input and output characteristics. On average the flint varieties had higher MEF and higher yield of flaking grits, offset by lower yields of all other products (Table 4).

Correlation Analysis Between Product Yields and Quality Characteristics. The data set from the pilot mill study provided a wide range of values on all of the quality characteristics except moisture, which was intentionally adjusted to minimize the variability (Table 5).

The simple correlation coefficients between product yields and the traditional tests TW, WBT, and SCI were generally lower than for the more complex tests of hardness (STIME) and density (DENS, FLO). The highest correlation among the traditional tests was only 0.62 between MEF and TW.

Several of the more sophisticated tests showed correlations above 0.75. When considering all available measures of quality, the best predictors of MEF were the STIME, NOIL, FLO, and FLINT% in the genetic cross. The same four quality characteristics were most highly correlated with the yield of flaking grits. A positive correlation with MEF and flaking grits was generally accompanied by a negative correlation with the yield of meal, flour, oil, and feed. Total product yield (including water loss or gain, and milling losses) must equal 100 percent. An increase in the yield of one product necessarily results in a decrease in the yield of one or more of the other products. The negative correlations reflect the fact that a larger yield

$$\mathrm{MEF} = (\mathrm{EN}_{3\frac{1}{2}\mathrm{W}} + \mathrm{EN}_{5\mathrm{W}} + \mathrm{EN}_{7\mathrm{W}})\left(\frac{\mathrm{TEP}}{100}\right)$$

where: EN = percent of total endosperm weight remaining on the screen identified by the subscript
and TEP = percent of total sample weight recovered in all endosperm products.

of brewers' grits generally implies a lower yield of flaking grits. Thus, a lower density sample means a higher yield of brewers' grits.

The correlation of 0.78 between FLINT% and MEF suggested a separate correlation analysis be conducted for the flint and dent samples. When the data set was divided into flint corn and dent corn samples, the correlation tables (Tables 6a and 6b) supported the findings of Pomeranz et al. in which the Stenvert Hardness Tester was shown to be a good indicator of dry milling yields (Pomeranz, Czuchajowska, and Lei 1986).

The correlations using flint corn samples were generally higher than those of dent corn. For flint corn, the correlation coefficient for STIME of 0.87 and NOIL of 0.86 for all samples was lower than the STIME of 0.89 and the NOIL of 0.94. Conversely, the correlation coefficient in absolute values for most of the quality measures was higher for all samples than for the dent corn. There were a few exceptions where the separation of samples increased the strength of the dent correlations. For example, the correlation between the yield of brewers' grits (BG) and SCI increased from 0.21 for all samples to 0.48 for dent samples only.

Quality differences result in an increase in the yield of some products, offset by decreases in others. It becomes difficult to generalize the results. An index of the yield of the most important products provides an overall indication of value. The correlations between MEF and the yields of six dry milling products are given in Table 7 for all samples combined, for flint samples only, and for dent samples only.

The MEF is highly correlated with flaking grits, flour, and feed. The correlations with the samples of dent corn are much lower than with the samples of flint.

Commercial Mill. With the cooperation of a commercial dry milling plant, a research plan was developed to process and evaluate full-scale runs using corn selected on the criteria of breakage susceptibility and bulk density (test weight) to determine the effects upon yield of final products. In order to separate the effects of the two quality variables (breakage susceptibility and test weight) on the yield of products, corn samples representing the extremes in combinations of the two variables were selected. Four 24-hour tests were performed in the dry milling plant in 1983. A second series of three tests in 1985 provided an additional range of observations on the two quality variables and associated yield of products.

Samples of corn were obtained at the truck dump by a mechanical sampler under supervision of a licensed inspector. The inspector provided data on each of the grade factors and delivered file samples to the University of Illinois for additional analysis. Samples were also obtained with an Ellis cup at 10-minute intervals off the belt, transferring corn from storage bins to milling bins, and at 10-minute intervals from the discharge auger between the cleaners and the tempering chamber. The 10-minute samples from the belt auger were composited to provide one sample of approximately 4.5 pounds every 30 minutes from each location. The samples obtained just before the corn entered the milling process most closely represented the quality of the corn actually being milled. Samples were taken to the Agricultural Engineering Grain Quality Laboratory at the University of Illinois where alternative measures of density, hardness, and internal stress cracks were made.

As trucks arrived at the plant, plant employees obtained probe samples and checked them for moisture, test weight, mold-damaged kernels, and broken corn using a 16/64-inch round-hole sieve (6.35mm). The plant restricted receipts to corn with test weight above 54 pounds per bushel (as-is moisture basis). Typically, test weight for a specific variety decreases as moisture increases (Hall and Hill 1973). However, during the period of study, moisture of the corn received ranged from 12 to 18 percent, and the low correlation between the test weight of these mixed lots of commercial corn and moisture content provided no basis for adjustment. Therefore, no attempt was made to adjust test weight readings for differences in moisture or drying method. The commercial mill reported that the average test weight of all corn received by the plant in 1982 was 56.9 lb/bu. Therefore, that value was used to differentiate between "high" and "low" test weight in selecting corn for the mill runs.

Data on test weight, percent of damaged kernels, broken corn and foreign material (BCFM), and moisture were obtained from the grading certificate issued on samples taken at the truck dump. At the end of each 8-hour shift, personnel from the plant obtained data on percent tailstock, yields of grits by sizes, percent of fat in each grit size, amount of pericarp and attached germ in the flaking grits, and yield of meal, flour, white goods, hominy feed, and corn oil recorded as percentages and pounds per bushel. Weight and quality determinations were made on throughstock and tailstock from each of two degerminators with essentially the same load settings, the same screen size (14/64-inch) (5.56mm), and approximately the same wear. These measurements were repeated for each of the seven milling tests. Every effort was made to keep all of the mill settings consistent for all seven milling trials.

In addition to the quality tests conducted by plant employees at the commercial mill, breakage susceptibility using the WBT was determined on each sample at the Grain Quality Laboratory at the University of Illinois. The sample for the breakage test consisted of 200g of the corn retained on the 16/64-inch sieve (6.35mm). The percentage of breakage susceptibility was calculated by dividing the sample weight passing through the sieve after impact by the initial weight of the sample.

Procedures for Evaluating Breakage Susceptibility. Breakage susceptibility decreased as moisture content increased. The quadratic equation shown (Equation 1) was fitted to data obtained on 818 truckloads received during the period from October to December 1982.

Incoming corn was tested and labeled as high breakage susceptibility if measured breakage susceptibility was above the prediction equation, and labeled as low breakage susceptibility if it was below the prediction equation. After the first two milling tests, the moisture-breakage relationship was reexamined and an exponential equation (Equation 2), based on 1,972 truckloads, was used.

The difference between the two equations was small (Figure 1), with equation 2 lying slightly below equation 1 in the range of 12 to 15 percent moisture. Operationally, the equation was converted to numerical values of moisture and breakage susceptibility to enable the operator to compare sample values against table values in segregating low- or high-breakage corn. For example, a breakage susceptibility value of 18.5 percent would have been considered low breakage at 15.0 percent moisture, but high breakage at 15.5 percent.

Equation 1

$$Y = 262 - 25.8\ M + 0.651\ M^2$$
$$R^2 = 0.62$$

where: Y = breakage susceptibility in %, using a 16/64" sieve (6.35mm)
and M = moisture content, % wet basis.

Equation 2

$$Y = 1392^{e(-0.287M)}$$
$$R^2 = 0.56$$

Criteria for Segregating Corn. Samples from each truck were analyzed before the truck was dumped. If the sample met the selection criteria, the truck was tagged, and the corn was diverted at the dump pit to the two storage bins reserved for the test.

Once sufficient corn had been segregated for a 24-hour run plus start-up time, the mill was prepared for the test by setting all adjustments for maximum yield of flaking grits. The corn was transferred from storage bins by belt to two milling bins without pretempering. Inventory measurements were made on all products, the mill was "loaded" with a 2- to 4-hour run of the selected corn, and the 24-hour mill run under controlled conditions was begun. In the mill the corn was weighed and cleaned on a 14/64-inch sieve (5.56mm), and the screenings were weighed. After cleaning, the corn was moved to the tempering chamber and then to the degerminators.

Values for the two criteria on which samples were selected, breakage susceptibility and test weight, are given for each of the commercial mill runs in Table 8.

The standard deviation for percent stress cracks was higher than for breakage susceptibility, probably reflecting the subjectivity involved in a visual determination of stress cracks. For example, in mill run 4, the standard deviation for stress cracks was 9.8; for breakage susceptibility 2.8. Other quality characteristics of the corn used in the commercial mill tests also exhibited a range of values (Table 9).

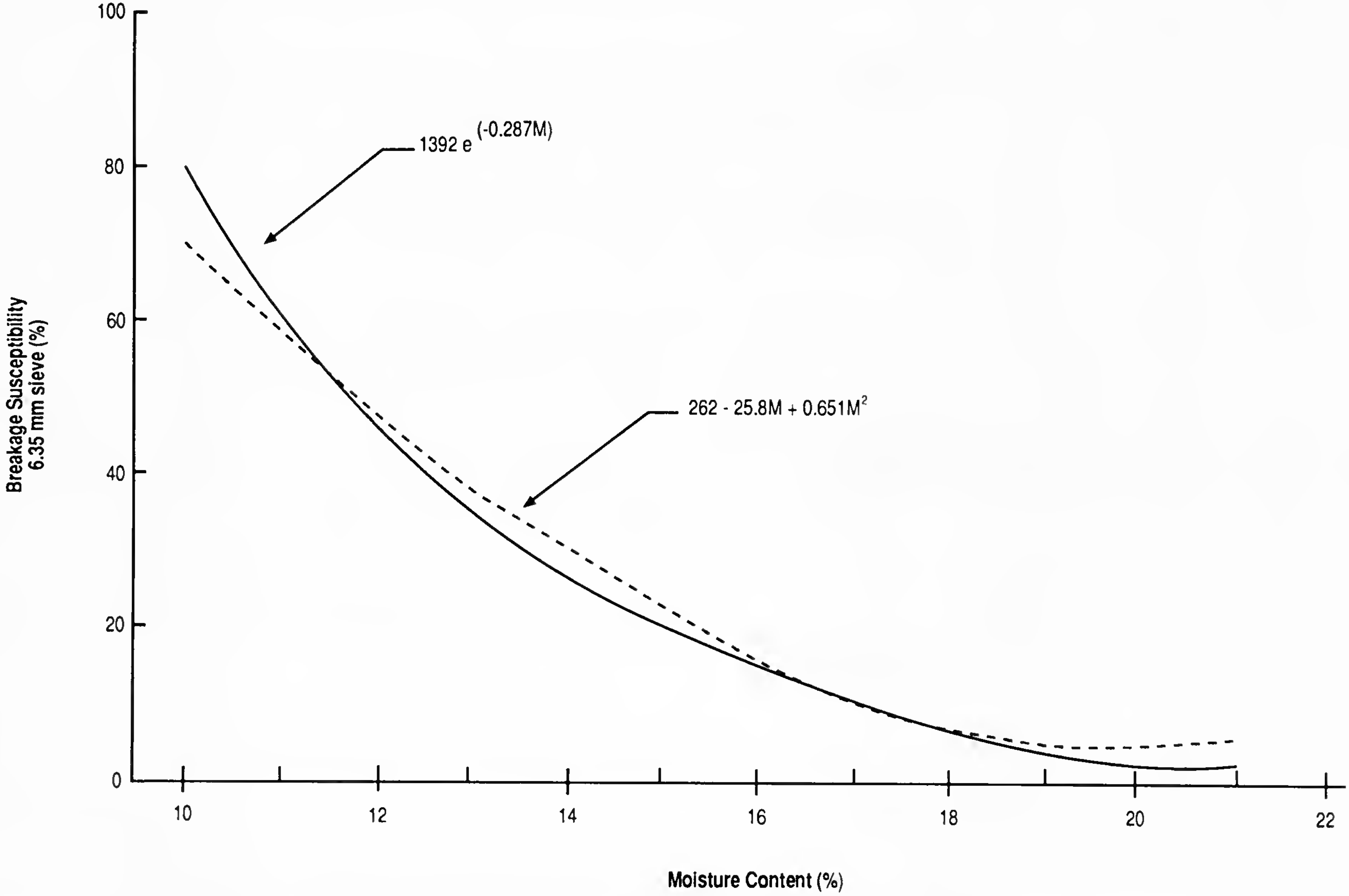
Correlation Analysis Among Tests. Correlations among measures of quality were based on individual samples that were collected immediately ahead of the mill for each of the seven tests (Table 10).

The correlations among the four measures of density (test weight, floaters, true density, and 100-kernel weight) ranged from +0.66 to −0.76. The highest correlation was between TW and FLO with an $r=-0.76$, significant at the 0.01 level. The correlation coefficient for TW and DENS was only 0.49 but still statistically significant at the 0.01 level. The correlation between 100-kernel weight and DENS was only 0.41. SCI was negatively correlated with 100-kernel dry weight, and 100-kernel dry weight was negatively correlated with floaters.

Inventory Adjustments. The value of corn in dry milling is determined primarily by the yields of white goods, hominy feed, and corn oil. Within the category of white goods (grits, meal, and flour), the large flaking grits are the most valuable. Therefore, that becomes the single most important variable in estimating the value of inbound corn.

The seven 24-hour runs provided information on the relationship between physical properties of the corn and the yield of the various products. The total yield of products from the seven runs ranged from 48.5 to 60.5 pounds from a 56-pound bushel of corn, suggesting significant measurement error in product yields. Beginning and ending inventories of all products were estimated by "soundings" of each bin to estimate the depth of the product. This depth measurement was used to calculate total volume of product in each bin. Volume was then converted to pounds, based on estimates of

Figure 1. Breakage susceptibility versus moisture content: equations used for segregating high and low breakage susceptibility corn



experienced operators in the plant. The deviations in pounds of total products per bushel above and below 56 pounds suggested errors in inventory that might be related to inventory calculations in preceding or subsequent days. This hypothesis was tested by obtaining the same type of data for the day before, day after, and run-to-date yields of products. These comparisons tended to support the hypothesis. For example, run 3 generated only 48.5 pounds of products. The yields of the day before and day after both exceeded 56 pounds per bushel, suggesting the following adjustment procedures.

1. All measurements were converted to pounds of dry matter in the grain and the products. Moisture contents of corn and products varied slightly among runs.
2. Average oil yield for the seven days of the test runs was used instead of the data provided by the mill. Germ from each test was moved to the extraction plant for extracting the oil. The production of pounds of oil was calculated on a daily basis. However, there was an indeterminate lag between the date of the test and the date that the germ from that test was processed. The corn for which oil yield was reported did not correspond with the corn for which the yield of all other products was calculated. Variation in oil content and germ size in the mixed hybrids of corn processed appeared to be small. Researchers decided to use an average value for oil yield rather than introduce a random error.
3. Product yields of day before, day of, day after, and average run-to-date were used to correct hypothesized errors in estimating inventories of each of 25 products. Changes were based on judgment after comparing each of the four data sets.

The adjustments suggested by these data are illustrated in Figure 2; the results of the adjustment are given in Figure 3. White goods yield is relatively constant for different corn qualities because the changes in flaking grit yield are offset by changes in smaller grits, flour, and meal. Run 3 (Figure 2) shows that yields from the experimental run are unusually low; day-before and day-after yields are unusually high. The total yield of all products was only 48.5 pounds from a 56-pound bushel on the day of the run. Total yields exceeded 56 pounds on day-before and day-after runs. Shifting inventory of white goods from day-before and day-after runs into the inventory for the experimental run improved the results for all 3 days. The revised percentage of white goods as a percent of total product yield is shown in Figure 3. Similar criteria were used for adjusting each individual product. While the process involved some subjective decisions, the results appeared to support the strategy—total yields for all seven runs were within ±0.7 pounds of the average; the standard deviation was reduced from 3.52 to 0.49; correlations among commercial mill and pilot mills results were increased, and correlations of product yields with quality characteristics were improved. The adjusted yield of each of six products and total products are shown in Table 11.

Product Yields. The first measure of the yield of high-valued products is the percent of tailstock and throughstock as it leaves the degerminator. The yield of high-valued products (primarily large grits) depends on the percent of tailstock through the degerminator because flaking grits can only be made from tailstock (Table 12).

The corn selected for run 1 (low breakage susceptibility and high test weight) yielded 46.0 percent tailstock. This is a significantly higher level of tailstock than the 28.6 percent that resulted from run 2 (high breakage susceptibility and low test weight). The lowest yield of tailstock was 26.6 percent from run 4 (high breakage susceptibility and low test weight). In comparison with run 2, run 4 had slightly higher breakage susceptibility (24.7 percent compared with 21.2 percent) but slightly higher test weight (56.6 compared to 56.1 lb/bu).

Figure 2. White goods as a percentage of total product yield (unadjusted data)

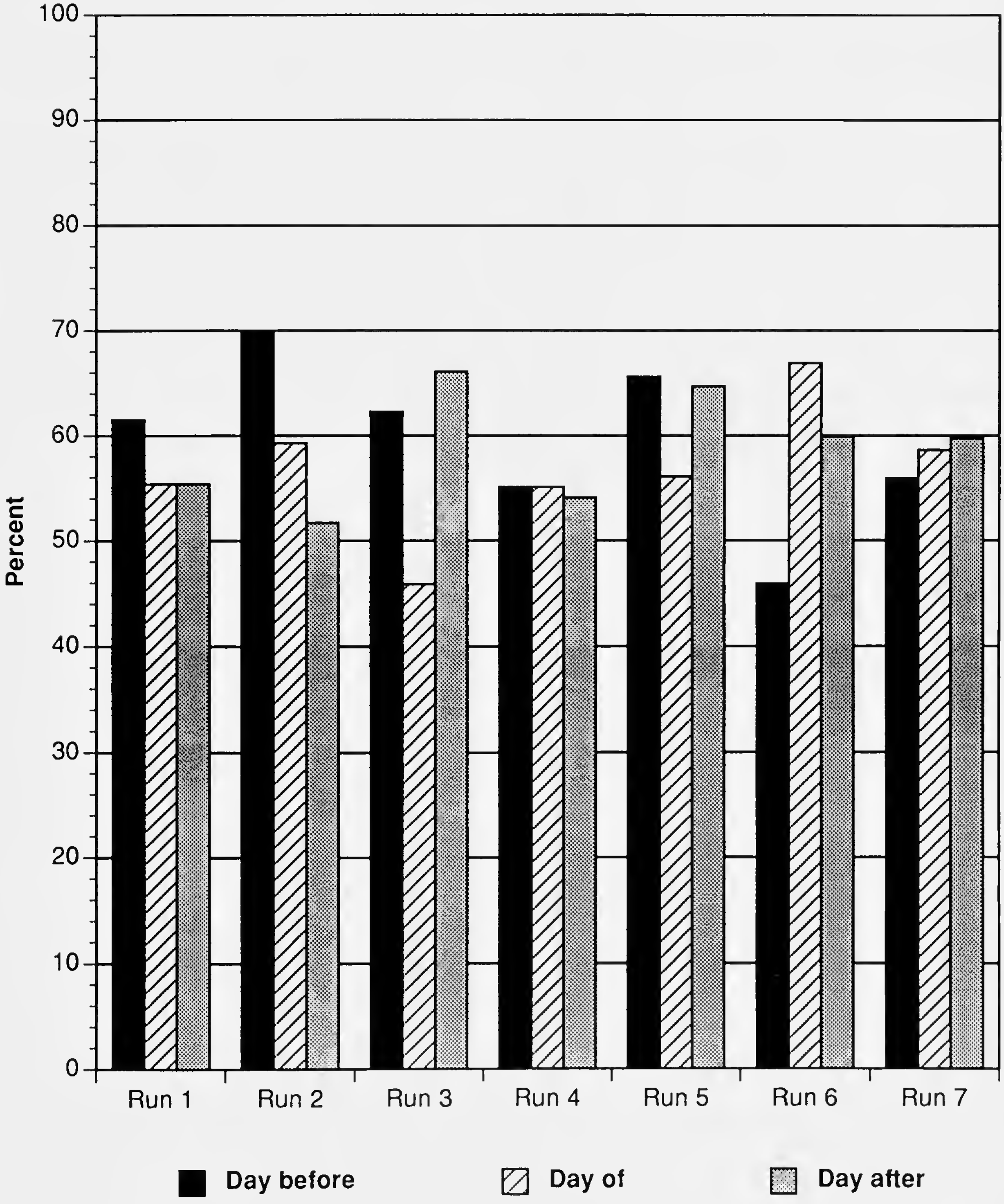
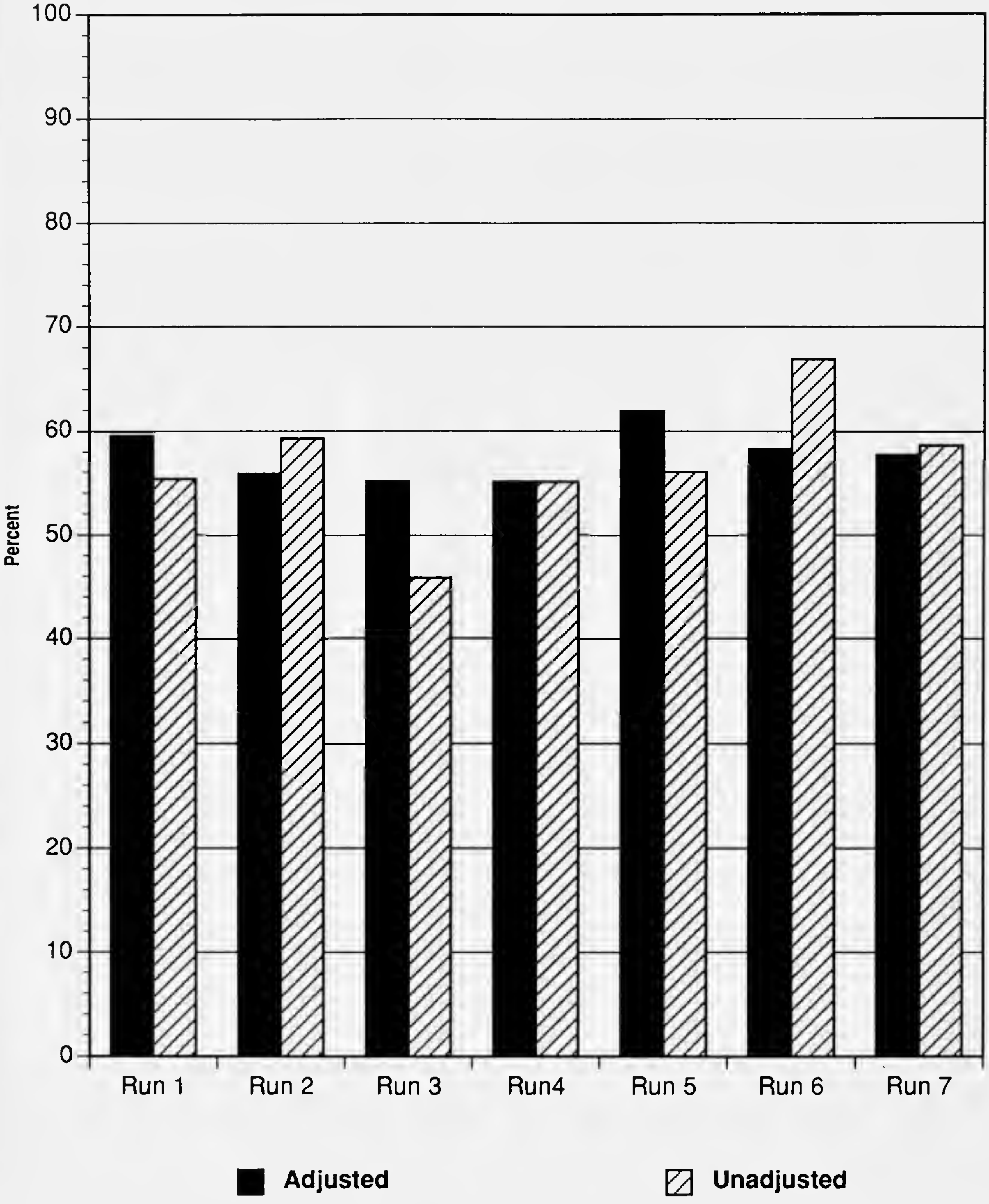


Figure 3. White goods as a percentage of total product yield (adjusted versus unadjusted data)



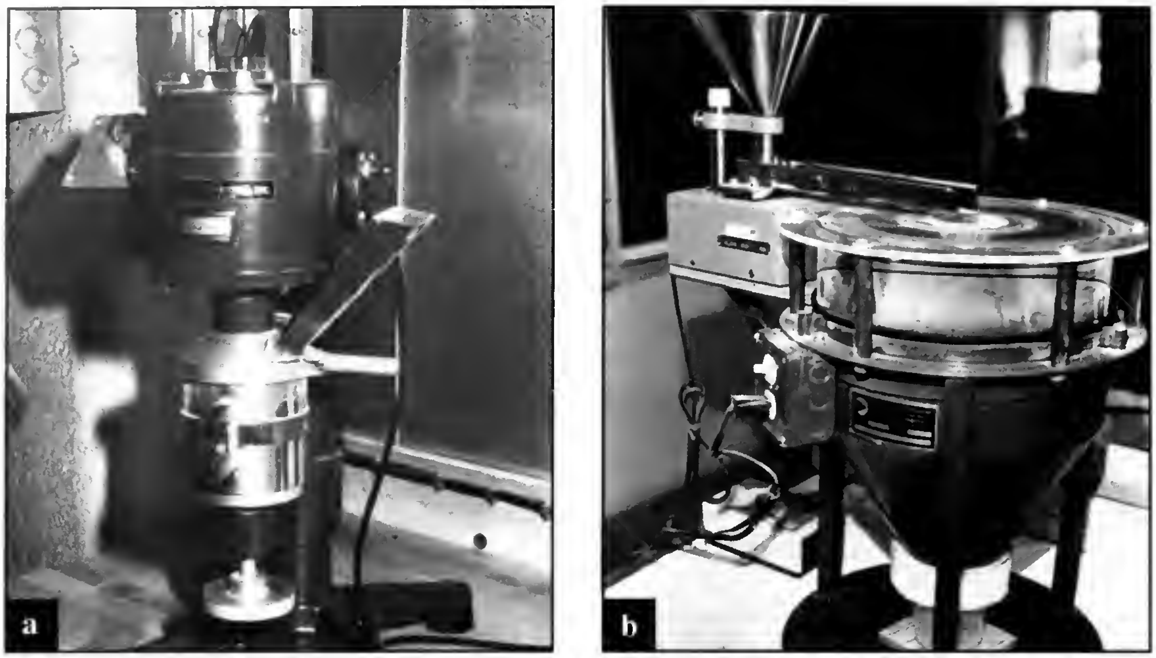
The yield of white goods varied from 55.1 percent on run 4 to 61.9 percent on run 5. There is no apparent correlation between the yield of white goods and the test weight or breakage susceptibility of the corn. High breakage susceptibility in run 5 gave a higher yield of white goods than low breakage susceptibility in run 6. However, high breakage susceptibility in runs 2, 3, and 4 had lower yields of white goods than run 6. High test weight in run 5 yielded the highest percent of white goods, 61.9; high test weight in run 3 yielded only 55.2, next to the lowest. Since test weight and breakage susceptibility affect primarily the distribution of the grit sizes within the white goods, it was not expected that these factors would influence the yield of white goods where all grit sizes are combined.

Within the category of white goods there are significant differences in the yields of the individual products between the seven test runs (Table 13). The maximum yield of flaking grits (16.8 percent) was obtained with the low breakage susceptibility and high test weight corn.

Selection of corn with high breakage susceptibility and low test-weight characteristics reduced the yield of flaking grits by 50 percent in run 2 (8.0 percent and 4.48 lb/bu). Milling runs 3 and 4 provided an opportunity to assess the impact of test weight on yield of flaking grits. The breakage susceptibility values were nearly equal (run 3 = 25.0, run 4 = 24.7), while test weight differed by 0.7 lb/bu (run 3 = 57.3, run 4 = 56.6) (Table 6). The yield of flaking grits for the higher test weight run 3 was 0.73 lb/bu higher than the yield of flaking grits for run 4 (Table 11). Meal yield from run 2 was more than three times as great as yield from run 1, indicating an increase in fine material generated with high breakage corn. Comparing run 1 with run 7, the higher meal yield indicates a higher proportion of floury endosperm present in the original kernels with low test weight. Low density corn, as measured by test weight or percent floaters, tends to have high amounts of floury endosperm that produce flour but not grits. Corn with a high percentage of stress cracks and high breakage susceptibility results in some of the available horny endosperm being broken into pieces too small for anything but flour during milling.

Quality as well as quantity of final products is important in assessing the value of inbound corn selected for its physical characteristics. Quality is measured by several factors. For maximum quality and value, it is necessary to have complete germ separation from the endosperm with resulting fat content in the grits below 0.5 percent. Ideally, the pericarp should be completely removed from the endosperm, resulting in less than 4 percent of the pericarp and attached germ in the flaking grits. When the germ is not completely separated from the endosperm in the degerminator, a dry miller not only loses oil yield but also runs the risk of having excessive oil in the grit, meal, and flour products. Finally, to make large flakes, endosperm pieces should be free of mechanically induced cracks or checks.

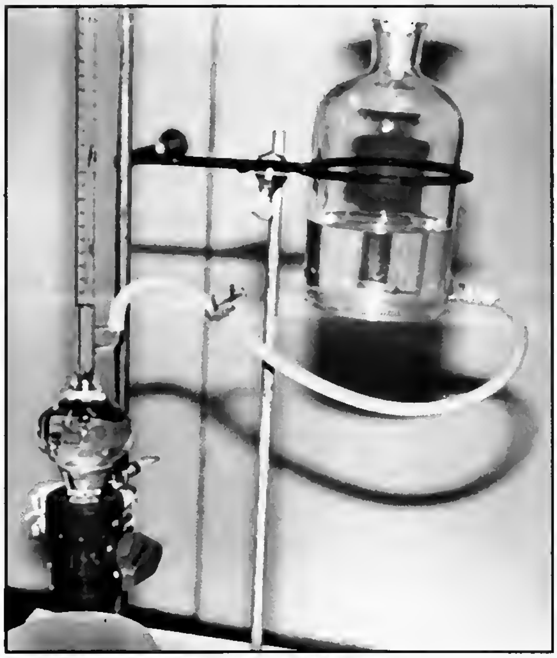
In the first commercial milling run, the tailstock yield was so high (46 percent) that at normal mill settings complete separation of the germ and the pericarp from the endosperm was not obtained. Although the first run gave high yields of flaking grits (9.24 lb/bu), Table 14 shows that the quality was low as measured by percent pericarp, percent attached germ, and percent of checks within the grits. On run 1, flaking grits had more pericarp attached than in any other run. The attached germ percent was higher than in runs 2 and 3 although not as high as in run 4 (high breakage susceptibility and low test weight). More oil than usual was left in run 1 in the grit sizes No. 12 through 20 and in the break flour. However, dry milling engineers stated that problems of attached germ and high percentage of pericarp in the flaking grits could have been reduced if they had been allowed to alter the settings after the test began. The percent of oil left in the flaking grits did not show any correlation with the selection criteria of breakage susceptibility and test



Susceptibility to breakage was measured in two ways:
a) using the Stein mill, where a corn sample was subjected to two minutes of impact and abrasion;
b) in the Wisconsin Breakage Tester, where a 200-gram sample of corn, when thrown from a rotating plate, was subjected to impact against steel.

Corn kernels with low densities float in a solution adjusted to a specific gravity of 1.275 g/cm^3; high-density kernels with a high percentage of hard endosperm sink.

Three tests for the proportion of hard endosperm corn were conducted using the Stenvert Hardness Tester—the Stenvert time-to-grind test, the Stenvert ratio of (coarse):(medium+fine), and the Stenvert ratio of coarse:fine.



True density of the corn kernels in a sample was determined by the volume of alcohol displaced by 100 grams of corn.

Bulk density of each sample was measured by the official test weight device approved by FGIS, USDA.

Percent of kernels with stress cracks was determined using a light table, reflecting light through each kernel to highlight the presence of single or multiple internal fissures.

The Boerner divider was used to divide the original sample into several representative subsamples for each of the tests.

weight. For example, in run 1 and run 3 the percent of oil in the flaking grits was identical (0.53 percent).

Predicting the Yield of Flaking Grits from Test Weight and Breakage Susceptibility. The combined effect of breakage susceptibility and test weight on yield of flaking grits can be illustrated by plotting yield against the two control variables. Without a larger number of observations, a valid statistical separation of the two variables (test weight and breakage susceptibility) is not possible. However, Figure 4 does illustrate the relationships. The effect of increased test weight is segregated in a comparison of run 3 with run 4 where breakage susceptibility was equal for both tests. The higher test weight increased the yield of flaking grits by 0.73 lb/bu (4.93 lb/bu in run 4 versus 5.66 lb/bu in run 3). Runs 5 and 6 show a difference in yield of 2.97 lb/bu (6.44 lb/bu in run 5 versus 9.41 lb/bu in run 6), due primarily to the lower breakage susceptibility of run 6; test weight was 57.0 lb/bu for both runs. It should be emphasized that the full range of test weight was not tested because the dry miller conducting the test would accept corn only if test weight were above 54 lb/bu.

Predicting Product Yields from Physical Characteristics

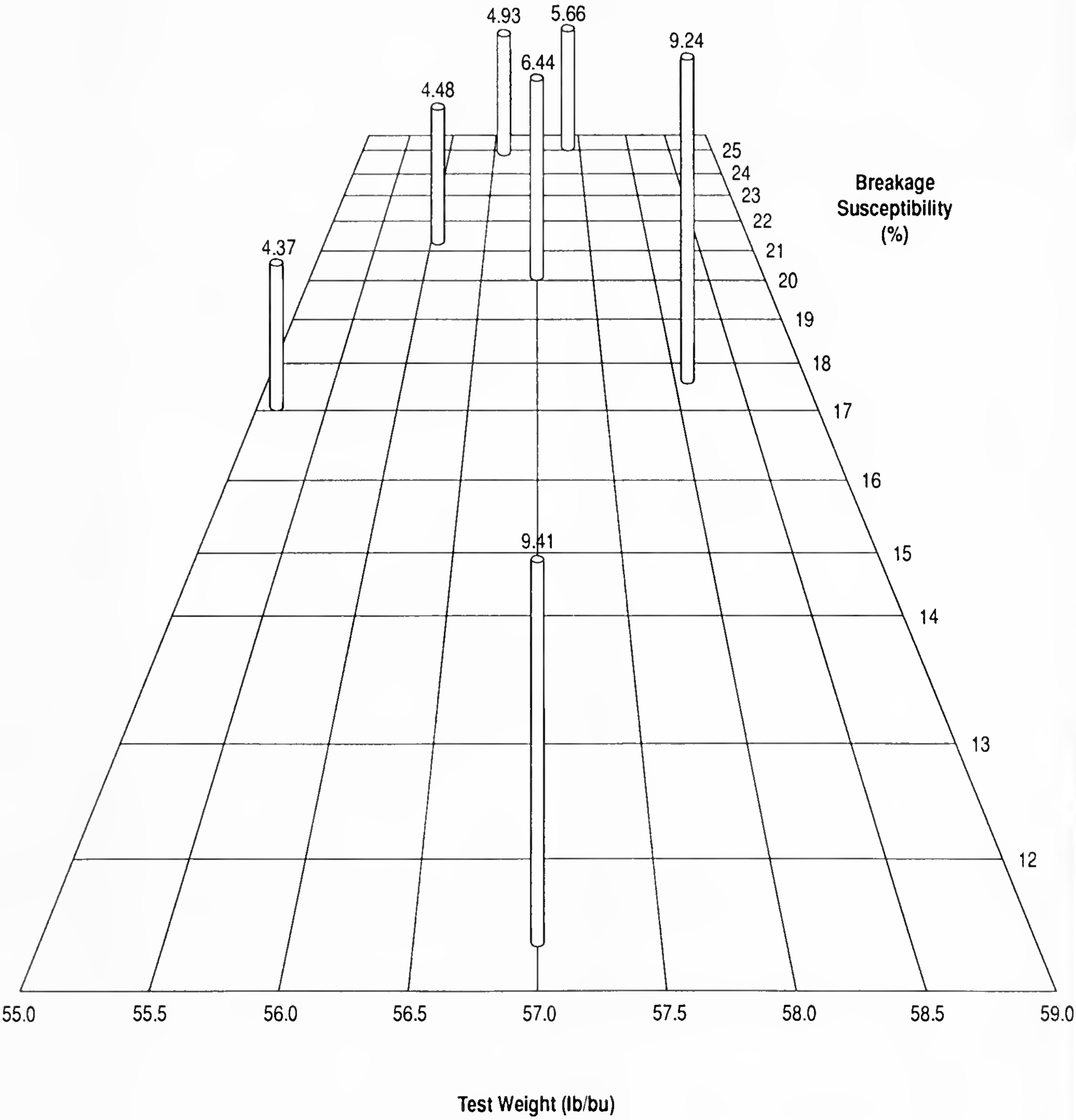
One objective of this study was to identify a set of physical characteristics of corn that dry millers could use as a guide to predict value when pricing corn for producers. The criteria for choosing among the various quality measures were (1) ability to predict the yield of flaking grits and (2) adaptability of the test to commercial corn receiving stations. Four measures of density were analyzed. These included (1) test weight, (2) percent floaters, and (3) true density as measured by liquid displacement. For kernels of similar sizes, 100-kernel dry weight also indicates density and was evaluated along with other measures, although differences in kernel size also affect yields of the larger grits.

Additional information about product yields from the corn used in the full-scale milling test was obtained by processing a composite sample in two different pilot mills. The short flow pilot mill at Purdue University processed composite samples from runs 5, 6, and 7, and provided data on the yields of six products. The Northern Regional Research Laboratory, USDA, Peoria, Illinois, provided data on brewers' grits, meal, and feed for each of the seven runs. Differences in product yields from each mill run were similar among the two pilot mills and commercial mill.

Correlation statistics between product yields from each pilot mill and the commercial mill were computed. The data were separated into four product groupings before the correlations were done: (1) No. 4 to No. 16 grits, (2) meal and flour, (3) white goods (including grits and meal), and (4) feed products. The correlations between products of the Purdue pilot mill and the commercial firm were very good, with the grits, white goods, and feed products all having correlations greater than 0.90. The results between the Peoria pilot mill and the commercial firm were somewhat lower, with a correlation statistic greater than 0.6 for grits, and greater than 0.75 for both white goods and feed products. No correlations among the three mills were established for meal and flour because of the widely differing techniques of sieving and defining meal and flour.

Simple correlations between yield of flaking grits and measures of density were calculated using the mean values from each of the seven commercial mill runs. Correlations with product yield were based on average values for each run. Test weight, true density, and percent floaters were all correlated with yield of flaking grits, with correlation coefficients above 0.70, statistically significant at the 0.05 level (Table 15). Wichser (1961) reported similar findings. Test weight was chosen as the variable to represent density in the predictive equation

Figure 4. Effect of test weight (lb/bu) and breakage susceptibility on the yield of No. 4 grits



because it is already in common use, requires simple equipment, and takes less than 30 seconds to perform. In contrast, a floaters test requires a vented hood and 5 minutes for completion. True density and 100-kernel weight also require slightly more time and are better suited for laboratory testing than for commercial operations.

Several measures were used to indicate the integrity of the hard endosperm and the drying temperatures to which the corn was subjected. These included a test for breakage susceptibility, percent whole kernels, and percent of stress cracks. In the samples from the commercial mill, only percent whole kernels had no significant correlation ($p=.05$) with the yield of flaking grits. The correlation of flaking grit yield with the percent whole kernels was +0.56; with the WBT results, −0.66; and with percent stress cracks, −0.84.

Although the percent stress cracks had a higher correlation with yield of flaking grits, breakage susceptibility was selected for use in the prediction equation for two reasons. First, data from the WBT is objectively determined, and variability is less than was found with visual determination of stress cracks. Standard deviations for stress cracks were 2½ to 4½ times larger than for breakage susceptibility. Second, breakage susceptibility is easier to determine than stress cracks, which require visual examination of individual kernels.

A linear equation was fitted to the data for the yield of flaking grits and the explanatory variables of test weight and breakage susceptibility. There were 408 observations on the two independent variables, but only seven observations on the yield of flaking grits. Average values for each of the dependent variables were calculated for each mill run. The use of seven observations on all variables produced the results shown in equation 3. Test weight and breakage susceptibility were statistically significant at the 0.10 level.

Differences in moisture affect breakage susceptibility. Because these effects were not entirely eliminated in the breakage susceptibility tests, an alternative formulation of the equation was tried (Equation 4). Using the equation in Figure 1 for moisture content versus breakage susceptibility, a new variable was constructed as the difference between the observation and the prediction equation. The simple correlation between the new variable (breakage susceptibility difference) and yield of flaking grits was −0.80 (compared with −0.66 for absolute breakage susceptibility). Using the new variable (breakage susceptibility difference) and test weight as explanatory variables for yield of flaking grits provided no improvement in the results over the previous formulation. R^2 was lower and the t-test for breakage susceptibility decreased. Coefficients were of similar magnitude to those of equations 3 and 4.

Equation 3

$$\begin{aligned}\mathrm{FG} = -146.31 &+ 0.23\mathrm{TW} - 0.54\mathrm{WBT}\\ (3.83)\quad &(12.37)\qquad (4.80)\end{aligned}$$

$$R^2 = 0.98$$

where: FG = yield of flaking grits (lb/bu)
TW = test weight (lb/bu)
WBT = Wisconsin breakage susceptibility (%), using 16/64″ sieve (6.35mm)
and numbers in parentheses are standard deviations.

Equation 4

$$\begin{array}{l} FG = -99.4 + 0.15TW - 0.55\,(WBT - Y) \\ \qquad\quad (3.83) \qquad (12.37) \qquad (4.17) \\ R^2 = 0.83 \end{array}$$

where: FG = yield of flaking grits (%)
TW = test weight (lb/bu)
WBT = measured breakage susceptibility (%)
Y = predicted breakage susceptibility (%) = $1392\ ^{e(-0.287M)}$
and numbers in parentheses are standard deviations.

Again, the variables of test weight and breakage susceptibility were statistically significant at the 0.10 level. Based on the similarity of results from the two formulations, either equation could be used to predict yield of flaking grits; equation 3 has an advantage of simplicity in calculating the independent variables and has a higher R^2.

Economic Evaluation

The economic value of corn with low breakage susceptibility and high test weight depends upon (1) the relative prices for No. 4 grits and all other products and (2) the proportion of each product in the distribution of all products derived from the milling process. As the demand and price for different dry milling products vary, the dry miller alters the relative volume of each product by changing operating procedures and mill settings. Therefore, it is difficult to directly determine the value of an increased yield of flaking grits. Since the higher yield must be offset by a decrease in the yield of some other products, the exact value of low breakage, high test weight corn could only be determined if it were possible to (1) calculate yield times price for each product for all possible mill settings and (2) subtract processing costs. Changes occur frequently in all four variables: (1) price of products, (2) yield of each product, (3) mill settings, and (4) cost of milling different qualities with different mill settings. Data are not available for the last two variables, and product prices vary widely over time. However, an approximation of value to permit a comparison among qualities was obtained by holding constant three of the four variables. The commercial mill was set for maximum yield of flaking grits, and settings were returned to the same levels for each of the seven runs. The pilot mill settings were unchanged during milling of the 98 samples. The same set of product prices were used for all calculations. Average prices of major products for January to July 1984, taken from Milling and Baking News (1984), were used in all value calculations. Other prices were estimated with advice from industry personnel. Milling costs were also assumed constant and not considered in the economic models.

The value of corn quality characteristics is dependent on the value of the end-user's products at that particular point in time. The product prices used in this study serve merely as illustrative figures in determining the value of the quality tests at a hypothetical point in time. The prices per pound for the products used in the calculation of value are:

Flaking grits = $0.12
Brewers' grits = $0.11

Meal = $0.10
Flour = $0.09
Feed = $0.05
Oil = $0.28

Commercial Mills. The total value per bushel was calculated by summing the value of each product. The value of each product for each run or sample was obtained by multiplying the product yield, lb/bu, by its price per pound (Table 16). In the commercial test a constant value was used for quantity and value of oil for all seven runs.

The total value of all products for each of the commercial mill runs ranged from a low of $4.69 per bushel to a high of $4.98, a difference of 29 cents per bushel. The size of the difference will change as prices change for dry milled products. Run 5 produced the greatest value per bushel, $4.98, as a result of a higher-than-average yield of grits and flour. Run 1, with the second highest yield of flaking grits, had the second highest total value, in part because the yield of meal was less than half the average yield.

Ranking the mill runs on the yield of flaking grits and on the total value per bushel shows the importance of the flaking grit yield. The ranking of the seven runs on flaking grit yield was 6, 1, 5, 3, 4, 2, 7; the ranking on total value was 5, 1, 6, 7, 3, 2, 4. Runs 1, 5, and 6 were above average on flaking grit yield and above average on total value.

The lowest value corn in run 4 resulted from a large quantity of lower valued meal. The 2.0 lb/bu higher test weight and 3.9 percentage points lower breakage susceptibility of run 1 compared to run 2 increased total value of milled products by 14 cents per bushel. Thus, if a mill had 10,000 bushels of corn of run 1 quality, then $1,400 more revenue could be generated than if the mill possessed the same quantity of run 2 corn, at any given price.

This 14 cents per bushel increase in value must be used to cover the extra cost of testing, selecting, and segregating the corn. The remaining value is available for use as a price incentive to producers to deliver higher quality corn and select varieties and drying techniques that will generate still higher quality corn in future years.

Pilot Mills. Value per bushel for each product and for all products obtained from the pilot mill studies was calculated in a similar manner, using the same set of prices. The only difference in methodology was in the estimated value of oil. In the pilot mill portion of the study, germ weight was determined for each sample and oil yield was assumed as a constant percentage of the germ weight. The negative correlation between germ weight and endosperm weight thus influenced total product value.

The highest value among the pilot-milled samples was L-1, which also had the highest yield of flaking grits (Table 17). Sample H-15 produced the lowest value of flaking grits, which corresponded to the lowest total value. The five samples with the highest total values (L-1, L-3, L-5, L-17, L-19) were also the samples with the highest yield of flaking grits. All of these samples were the inbred flints crossed with flint parents. The inbred flint varied from 50 percent flint genotype to 100 percent genotype. The percent of flint for the five samples varied from 75 percent to 100 percent (Appendix B).

Within the dent genotypes (experimental hybrids and commercial hybrids obtained from the market channel), the relationship was not as consistent. Using only dent varieties, four of the top five samples ranked on yield of flaking grits were in the top 20 samples ranked on total value. Only one of the samples in the top five on flaking grits was also in the top five ranked on total value (Table 17). Oil yield was an important factor in the ranking on total value because the price of oil was more than double the price of flaking grits. Several of the samples with the highest flaking grit yields were among the lowest on oil yield (e.g., A-5 and H-27). Changes in relative prices would alter the ranking. Higher prices for flaking grits or lower prices for oil would increase the degree of correspondence between flaking grit yield and total value per bushel.

The value of flaking grits per bushel ranged from \$0.52 to \$1.13 for the commercial runs (Table 16), from \$0.69 to \$1.94 for the dent samples in the pilot mill, and from \$1.07 to \$2.68 for the flint samples in the pilot mill (Table 18). If we consider the value of total products, selecting corn on the basis of the characteristics identified in this study would increase the value of products by \$0.37 per bushel in the dent varieties and \$0.40 per bushel in the flint. Flint varieties are not generally available in the United States, but the flint samples had an average value of \$0.16 per bushel greater than the dent samples.

Value of Quality Characteristics. A first indication of the imputed (or implicit) value of the various quality characteristics is given by the simple correlation with product value (Table 19).

The quality characteristic most highly correlated with the total milling value is percent of oil content (NOIL) as determined by near-infrared reflectance (NIR) (+0.84). The NOIL variable ranged from only 3.74 percent to 5.19 percent over the entire data set, but even with this small range, there is a strong positive correlation between NOIL and total milling value. One explanation for the high positive correlation is the existence of the flint samples in the data set. Brun and Dudley (1989) found that kernel protein and oil percentage decrease as the proportion of dent germplasm in the population increases. Thus, the high oil samples were generally flint varieties in this particular data set. Segregating the dent corn samples lowered the simple correlation between oil and MEF from 0.86 for all samples (Table 5) to 0.56 for dent only (Table 6b). The density-related measures (floaters, true density) and the Stenvert (time-to-grind) hardness test appear to be important in both flint and dent varieties. Segregation of flint and dent resulted in only small changes in that correlation coefficient.

Based on a set of typical product prices, the total value for one bushel of corn was calculated for each sample. The samples were then arrayed according to total value per bushel in descending order, from most valuable to least valuable. The quality characteristics associated with the "least valuable" sample, the "most valuable" sample, and the "most valuable nonflint" were floaters and the Stenvert time-to-grind tests (Table 20).

The percent floaters for the "least valuable" sample was above 70 percent; for the most valuable it was below 12 percent. The STIME for "most valuable" was nearly twice the average value for the three samples that were "least valuable" (Bouzaher 1987b).

Imputed Values of Quality Characteristics. Several characteristics simultaneously influence the yield of flaking grits. Premiums for a sample can be imputed to different quality characteristics by fitting a linear econometric model, regressing total premiums against all the physical variables. The product prices used were based on average prices from January to June 1984, with the value of flaking grits arbitrarily priced as worth one cent per pound more than brewers' grits, the next largest grit size. The prices used may not correspond exactly to current prices, but relative prices are usually close to those used in the model. Specifically, the model given below was used.

Two versions of this model were used. The first version forced all of the quality test variables into the equation. The second model chose the variables by a step-wise regression method. In either case the intercept of the linear equation is interpreted as a measure of both the cost of the grain (price) and the value of other "nonquality" characteristics (Carriquiry, Bouzaher, and Hill 1991).

The three most significant variables in both versions of the model were NOIL, FLO, and WBT (Table 21). The partial regression coefficients of these variables can be interpreted as the premiums of the associated quality char-

$$V_s = a_0 + a_1TW + a_2WBT + a_3STEIN + a_4MOIST + a_5SCI + a_6DENS + a_7FLO + a_8STIME + a_9SCMF + a_{10}SCF + a_{11}S3550 + a_{12}PYCN + a_{13}NSTAR + a_{14}NOIL + a_{15}NPROT + a_{16}NMOIST + a_{17}FLINT\%$$

where: V_s is the total value of each sample given, and a_i are the estimated coefficients (Table 15). The names of the independent variables correspond to the different quality tests described in the pilot mill section.

acteristics, because they measure the marginal economic value added at a fixed level of all the other variables.

Model (ii) seems the more suitable model for at least three reasons: (1) It is a parsimonious model; the number of quality tests the mill is required to perform is considerably fewer. (2) All of the independent variables are significantly different from zero. (3) Statistically, the model has a better linear fit, and multicollinearity among the variables is reduced. As mentioned earlier, many of the measures of physical characteristics are highly correlated.[1]

Without accurate data on the relative prices of all products and an estimate of the processing margin, it is not possible to convert the increased value of low breakage corn into an accurate premium or price differential per bushel. However, the knowledge that large flaking grits are significantly more valuable than smaller grits, meal, flour, and feed byproducts is sufficient to demonstrate that the measurement of breakage susceptibility and test weight is economically important to the dry milling industry (Bouzaher 1987a).

The premium evaluation shown in Table 21 illustrates the potential predictive power of the linear model to the dry miller. It is, however, highly important to remember that every degerminator will vary to some degree with respect to its yield of premium products. Therefore, each mill should take into account the variability of its degerminator(s) when considering the level of premium that might be offered; that is, dry millers would be well advised to test the relationship between product yields and measures of quality characteristics by using their own equipment and the methodology outlined in this report.

Summary and Conclusions

It has been demonstrated that selection of corn for its breakage susceptibility, even within a limited range of test weight above 54 lb/bu, will increase the yield of flaking grits. The breakage susceptibility test correlates with percentage of stress cracks in the kernels, indicating that it is a relative measure of drying stresses created in the corn. The high correlation of No. 4 grit yield with floaters and test weight demonstrates the importance of measuring the amount of the hard endosperm present in the kernel. A combination of breakage susceptibility and test weight enables the dry miller to select, through rapid, physical measurements, corn with desirable characteristics in terms of (1) the quantity of hard endosperm and (2) integrity, preserved through proper drying, of

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[1] A more general model with interactions and quadratic terms did not change the significance of any of the variables. A nonlinear specification also failed to improve on the linear specification.

the internal portion of the kernel. Providing a price differential to farmers on these two characteristics would generate a selection process that would be reflected back to corn breeders to provide future improvements in the quality of corn available for dry milling as well as for other industries and markets requiring corn with low breakage susceptibility.

The implication of this research is that easily measured physical characteristics in the market channel can be used to predict the yield of dry milling products. The dry miller can use these measurements to select the corn best suited to meet his contract requirements. The quality of corn needed to produce maximum grit size differs from corn that produces maximum white goods with fewer flaking grits. The marginal value of a given quality characteristic indicates the premium that could be paid to producers. Farmers will, in turn, encourage plant breeders to invest more research in the development of corn hybrids suited for dry milling. Dry millers have typically bought their corn at contracted prices above the market level. This research represents a first step toward reliance on the market to segregate corn for dry milling on the basis of its potential yield of products.

Appendix A. Description of Corn Quality Tests

The following describes corn quality tests that were performed on corn samples at the University of Illinois Agricultural Engineering Grain Quality Laboratory.

Test weight (TW). Official USDA procedures and equipment using a one-quart brass cup were employed (Paulsen and Hill 1985). A high test weight (measured in pounds per bushel) will typically indicate a corn sample of high density.

Wisconsin Breakage Tester (WBT). A Wisconsin Breakage Tester was used to determine the susceptibility of corn to breakage using a presieved 200-gram sample and measuring the percent of the total sample passing through a 16/64-inch sieve following kernel impact. Kernels were centrifugally discharged by a 10-inch diameter impeller driven at 1,800 rpm. Discharged kernels impacted against the inside wall of a vertical cylinder, 12 inches in diameter. Kernels were fed at the rate of 600 g/min. After impact, the sample was collected and resieved on a 16/64-inch sieve (Paulsen and Hill 1985).

Stein Breakage Tester (STEIN). A Stein Breakage Tester was used to determine the susceptibility of breakage using a presieved 100-gram sample and measuring the percent of the total sample passing through a 12/64-inch sieve following impact (Paulsen and Hill 1985).

Oven moisture (MOIST). One hundred grams of each sample were oven dried at 103°C for 72 hours to determine moisture content.

Stress cracks (SCI). Fifty whole kernels were candled and sorted into categories of zero, one, or multiple stress cracks on each of the samples (measured on a percentage basis) (Paulsen and Hill 1985). Multiple stress cracks often indicate that high temperature drying has occurred (Weller et al. 1987). A stress crack index was created to weight the three categories according to the severity of the effect on breakage and yield of primary products. The index was calculated as: SCI = 1 (% zero) + 3 (% one) + 5 (% multiple) where "zero," "one," and "multiple" refer to the number of stress cracks present in each kernel tested.

Ethanol column test (DENS). One hundred preweighed kernels were placed into a graduated cylinder containing ethanol. The volume displaced because of the addition of preweighed kernels provided an indication of true kernel density (measured in g/cm^3) (Paulsen and Hill 1985).

Floaters test (FLO). One hundred kernels were placed into a solution of tetrachloroethylene and deodorized kerosene adjusted to a specific gravity of 1.275. The number of kernels that floated were recorded as a percent of floaters. Floating kernels are less dense and provide an indication of the percent of kernels with a low proportion of vitreous-to-floury endosperm. Conversely, sinking kernels indicate more dense kernels (Paulsen and Hill 1985).

Stenvert Hardness Tester (STIME, SCMF, SCF, S3550). The Stenvert grinding resistance test involved grinding a 20-gram sample of corn. A hammermill with a grinding chamber fitted with a 2-mm aperture screen was used. A mill speed setting of 3,600 rpm was obtained, and the time to collect 17 ml of ground material was recorded for each sample (STIME). Other information recorded included the ratio of (coarse):(medium + fine) particle sizes (SCMF) and the ratio of coarse:fine particle sizes (SCF). The fourth measurement from the Stenvert test was the total column height of the ground corn measured in centimeters when the mill speed returned to 3,550 rpm (S3550). The time to grind provides an index of resistance to grinding, and the total column height gives an index of packing; i.e., the fluffy meal from soft corn occupies more space than the vitreous meal from hard corn (Pomeranz et al. 1985).

Pycnometer density test (PYCN). The Micromeritics Pycnometer 1305 was used to measure the volume of each ground corn sample. The true density of each sample was calculated using sample weight (measured in g/cm^3). The pycnometer measures the skeletal volumes by observing the reduction of helium gas capacity in the sample chamber caused by the sample's presence (Micromeritics Pycnometer 1305 Instruction Manual 1986).

Near Infrared Reflectance (NSTAR, NOIL, NPROT, NMOIST). The DICKEY-john Instalab 800 NIR Product Analyzer utilized near infrared reflectance technology and a statistical mathematical treatment to predict the percent of constituent concentration in each corn sample (DICKEY-john Instruction Manual). The analysis is based on the fact that each major chemical component of a sample has an absorption band that absorbs light in proportion to the quantity of a constituent present. (NSTAR is the percentage of starch; NOIL is oil/fat; NPROT is protein; and NMOIST is moisture.)

Appendix B.

Physical and Chemical Characteristics of Samples Used in the Pilot Mill

SAMPLE	TW	WISC	STEIN	MOIST	SCI	DENS	FLO	STIME
A-1	62.00	9.45	1.20	12.70	1.00	1.26	28.00	14.10
A-2	58.00	6.90	1.90	14.10	1.48	1.25	49.00	12.40
A-3	58.10	18.75	4.40	13.40	4.24	1.23	85.00	14.80
A-4	58.50	5.50	1.90	14.70	1.28	1.26	59.00	13.00
A-5	59.40	4.80	0.70	13.60	1.00	1.25	71.00	16.00
A-6	57.70	6.10	1.90	14.40	1.16	1.25	48.00	12.00
A-7	60.40	6.90	1.30	14.60	3.04	1.27	83.00	13.00
A-8	59.30	8.20	1.80	14.00	1.80	1.23	59.00	11.70
A-9	58.60	7.70	2.30	14.50	1.48	1.24	74.00	13.40
A-10	58.70	11.15	2.40	14.30	3.36	1.25	41.00	13.50
B-1	60.50	8.45	1.00	14.70	1.84	1.25	52.00	12.70
B-2	60.10	15.13	1.50	14.40	2.48	1.29	23.00	14.30
B-3	60.90	8.35	0.50	14.70	2.28	1.28	20.00	15.00
C-1	58.70	10.33	3.10	15.00	1.52	1.26	53.00	12.60
C-2	57.00	27.80	9.40	14.10	4.72	1.20	87.00	12.90
D-1	58.60	7.25	1.20	14.80	1.08	1.18	89.00	10.80
E-1	57.50	13.65	4.30	14.50	3.36	1.20	84.00	12.50
E-3	60.20	7.65	1.60	14.80	1.76	1.23	89.00	12.20
F-1	56.60	13.85	2.20	14.10	2.32	1.23	80.00	12.30
G-1	57.40	13.50	1.00	13.80	1.28	1.32	21.00	12.50
G-2	57.70	7.00	1.00	16.30	1.52	1.26	28.00	12.70
G-3	56.50	8.65	2.10	14.60	1.68	1.26	56.00	10.80
H-1	56.40	23.45	7.10	14.50	4.36	1.26	75.00	11.40
H-2	56.90	26.90	2.70	14.30	4.24	1.30	36.00	12.30
H-3	58.50	21.90	3.00	14.40	4.36	1.34	4.00	14.50
H-4	57.70	21.15	2.50	14.10	4.36	1.29	37.00	14.20
H-5	54.30	15.40	2.40	14.70	3.88	1.22	79.00	12.10
H-6	55.50	24.45	3.10	14.50	4.64	1.25	51.00	12.10
H-7	55.80	34.40	8.80	14.50	4.72	1.23	62.00	9.70
H-8	58.00	31.10	3.10	15.40	4.92	1.22	70.00	12.10
H-9	55.90	16.25	2.90	14.60	4.96	1.26	20.00	15.30
H-10	55.10	35.80	8.00	14.70	4.76	1.23	56.00	10.20
H-11	56.40	14.00	3.70	14.70	4.28	1.23	86.00	10.30
H-12	58.50	24.35	3.00	14.70	4.68	1.26	19.00	15.30
H-13	57.40	36.70	7.40	14.70	4.84	1.24	77.00	13.30
H-14	59.20	35.75	3.80	14.10	4.64	1.28	28.00	13.90
H-15	54.80	13.55	4.20	14.80	4.24	1.24	85.00	10.80
H-16	56.40	21.50	4.30	14.50	4.20	1.26	30.00	13.00
H-17	55.90	15.80	3.00	14.40	4.48	1.24	66.00	14.00
H-18	56.90	23.80	4.30	14.30	4.68	1.23	61.00	12.50
H-19	57.10	21.95	3.00	14.40	4.68	1.26	50.00	14.20
H-20	55.60	20.95	3.80	14.60	4.28	1.25	43.00	11.80
H-21	57.80	20.75	6.00	14.30	3.88	1.26	57.00	11.80
H-22	58.50	32.60	3.50	14.40	4.76	1.30	26.00	14.00
H-23	55.90	22.55	9.30	14.50	4.48	1.25	68.00	13.00
H-24	56.30	22.70	4.90	14.50	4.64	1.25	68.00	12.50
H-25	57.70	18.90	2.70	14.30	4.44	1.28	24.00	14.90
H-26	55.40	26.45	8.80	14.80	4.88	1.22	79.00	11.00
H-27	58.30	19.05	4.00	14.40	4.28	1.26	44.00	14.00

Appendix B. continued

SAMPLE	TW	WISC	STEIN	MOIST	SCI	DENS	FLO	STIME
H-28	58.10	28.00	4.10	14.30	4.56	1.30	25.00	16.10
H-29	57.10	18.70	2.10	14.60	4.60	1.28	31.00	14.00
H-30	56.40	24.55	4.90	14.30	3.92	1.25	62.00	11.50
H-31	57.60	24.90	5.20	14.20	4.68	1.22	39.00	13.30
H-32	55.40	28.70	2.70	14.70	4.76	1.27	16.00	14.50
H-33	60.10	28.20	2.70	14.40	4.20	1.25	11.00	14.60
H-34	55.60	18.45	3.40	14.30	4.16	1.19	87.00	11.80
H-35	56.40	19.00	2.30	14.50	4.12	1.22	80.00	11.30
H-36	58.50	23.50	3.00	14.20	4.72	1.26	35.00	12.70
H-37	55.70	29.15	7.10	14.70	4.88	1.23	73.00	12.40
H-38	57.00	29.15	2.50	14.40	4.72	1.28	9.00	16.30
H-39	55.30	23.90	4.60	14.50	4.68	1.20	45.00	11.90
B-4	59.70	10.95	1.20	13.90	1.00	1.26	36.00	12.00
B-5	58.90	17.70	4.40	13.90	1.84	1.22	87.00	10.40
I-1	61.40	5.00	0.20	14.20	1.00	1.29	4.00	13.60
J-1	58.90	7.30	1.30	14.90	1.12	1.25	25.00	12.30
K-1	58.40	8.70	0.80	14.60	1.36	1.26	67.00	10.90
L-1	60.40	39.75	1.20	13.90	4.88	1.31	11.00	23.60
L-2	59.40	35.90	2.40	14.90	4.60	1.27	9.00	14.00
L-3	60.30	24.80	1.90	14.80	4.76	1.33	9.00	20.20
L-4	59.10	32.25	1.90	13.60	4.28	1.27	32.00	13.00
L-5	59.70	26.85	1.50	14.40	5.00	1.32	11.00	22.00
L-6	59.80	30.30	4.60	13.70	4.72	1.28	14.00	13.50
L-7	59.80	27.30	2.40	14.40	4.80	1.31	12.00	18.30
L-8	58.10	24.45	2.90	14.70	4.20	1.25	28.00	13.70
L-9	58.90	33.50	3.40	15.10	4.48	1.31	9.00	21.80
L-10	59.20	41.10	7.10	15.00	5.00	1.30	24.00	14.30
L-11	59.80	30.95	2.30	15.10	4.52	1.31	14.00	20.30
L-12	59.30	33.00	7.00	15.20	4.48	1.28	57.00	13.40
L-13	59.20	30.90	4.20	14.80	4.88	1.25	20.00	17.00
L-14	59.00	33.85	5.80	15.10	4.44	1.23	36.00	12.90
L-15	60.20	28.65	2.40	15.10	4.92	1.29	15.00	19.30
L-16	59.60	29.10	6.80	15.20	4.48	1.25	42.00	13.50
L-17	59.20	38.50	2.50	14.20	4.92	1.31	8.00	22.20
L-18	59.40	43.80	2.90	14.30	4.68	1.30	27.00	15.50
L-19	59.20	31.75	2.00	14.40	4.92	1.28	11.00	22.70
L-20	58.10	30.50	2.10	14.50	4.72	1.26	30.00	13.30
L-21	59.60	30.35	1.60	14.40	4.76	1.30	11.00	20.50
L-22	58.30	29.55	2.00	14.40	4.84	1.27	30.00	14.00
L-23	59.70	22.60	1.10	14.30	4.24	1.28	6.00	18.20
L-24	58.60	25.95	1.60	14.70	4.52	1.28	25.00	14.00
L-25	58.90	41.80	1.70	14.50	4.92	1.28	16.00	20.20
L-26	59.80	47.25	3.60	14.60	4.88	1.24	19.00	12.20
L-27	60.40	39.50	2.10	14.30	4.68	1.30	23.00	16.90
L-28	58.40	34.45	3.50	15.00	4.64	1.26	59.00	11.00
L-29	60.20	33.45	1.30	14.50	4.88	1.28	23.00	18.00
L-30	58.40	34.25	2.70	15.00	4.84	1.27	47.00	11.40
L-31	59.80	32.20	2.40	14.60	4.76	1.28	22.00	16.80
L-32	58.30	34.10	3.30	14.70	4.60	1.25	51.00	11.40

Appendix B. continued

SAMPLE	SCMF	SCF	S3550	PYCN	NSTAR	NOIL	NPROT	NMOIST	FLINT%
A-1	1.23	5.35	9.00	1.30	68.50	4.26	7.78	14.18	0.00
A-2	0.87	4.13	9.70	1.30	69.90	3.93	8.52	13.86	0.00
A-3	1.33	5.24	9.20	1.29	69.21	4.18	8.99	13.57	0.00
A-4	1.04	2.70	9.40	1.30	68.68	4.01	9.36	14.07	0.00
A-5	1.18	4.20	9.20	1.29	67.91	4.13	9.87	13.80	0.00
A-6	1.10	4.64	9.50	1.29	69.89	4.09	8.90	13.42	0.00
A-7	1.09	4.35	9.40	1.30	68.63	4.31	8.24	13.41	0.00
A-8	1.07	4.21	9.40	1.29	71.35	4.04	7.86	13.31	0.00
A-9	1.10	4.21	9.40	1.29	70.44	4.09	8.45	13.45	0.00
A-10	1.17	4.38	9.20	1.29	70.98	4.02	8.41	13.20	0.00
B-1	1.06	2.86	9.40	1.30	69.33	4.15	8.46	13.86	0.00
B-2	1.25	3.76	8.90	1.33	68.27	4.57	8.28	13.61	0.00
B-3	1.27	3.89	8.90	1.33	69.57	4.27	7.94	13.68	0.00
C-1	1.18	4.00	9.30	1.30	70.31	4.08	8.07	13.70	0.00
C-2	1.35	5.74	9.30	1.32	69.06	4.18	8.91	13.25	0.00
D-1	0.97	4.00	9.80	1.27	71.79	3.85	7.43	13.63	0.00
E-1	1.30	4.54	9.30	1.28	69.57	4.23	8.03	13.78	0.00
E-3	1.07	3.16	9.30	1.27	69.30	4.13	7.55	14.16	0.00
F-1	1.19	3.96	9.00	1.28	68.57	4.14	8.56	14.09	0.00
G-1	1.02	3.14	9.30	1.29	69.32	4.21	7.86	14.13	0.00
G-2	1.05	2.40	9.30	1.29	68.87	4.08	8.18	14.63	0.00
G-3	1.02	3.09	9.40	1.29	68.00	4.31	7.59	14.23	0.00
H-1	1.31	3.96	8.60	1.29	72.01	4.17	7.17	13.05	0.00
H-2	1.49	3.89	8.70	1.30	71.62	4.22	7.30	13.09	0.00
H-3	1.25	2.23	8.40	1.34	71.48	4.30	7.62	13.05	0.00
H-4	1.30	3.57	8.50	1.30	71.17	4.24	7.92	13.32	0.00
H-5	1.43	5.00	8.70	1.27	70.98	4.05	7.96	13.39	0.00
H-6	1.19	2.32	8.70	1.29	71.52	4.11	7.51	13.36	0.00
H-7	1.34	4.54	8.70	1.30	72.35	4.30	6.60	13.09	0.00
H-8	1.36	4.45	8.70	1.30	73.74	3.87	7.26	13.26	0.00
H-9	1.35	4.66	8.60	1.32	69.98	4.37	7.82	13.79	0.00
H-10	1.24	4.11	8.80	1.30	71.63	4.23	6.67	13.35	0.00
H-11	1.12	3.85	9.90	1.27	71.29	3.80	7.61	14.33	0.00
H-12	1.39	4.62	8.40	1.31	70.32	4.33	8.14	13.50	0.00
H-13	1.32	4.16	8.70	1.31	69.60	4.44	6.51	13.88	0.00
H-14	1.31	4.09	8.70	1.33	69.75	4.50	7.54	13.64	0.00
H-15	1.37	4.60	9.00	1.26	71.50	3.97	7.31	13.61	0.00
H-16	1.30	5.13	8.60	1.32	69.69	4.33	7.73	13.53	0.00
H-17	1.27	4.58	8.90	1.31	69.34	4.25	7.98	13.52	0.00
H-18	1.41	4.55	8.60	1.31	69.35	4.31	7.70	13.48	0.00
H-19	1.31	4.45	8.60	1.30	70.07	4.27	8.06	13.54	0.00
H-20	1.28	4.63	8.60	1.31	68.25	4.30	8.03	13.56	0.00
H-21	1.31	4.62	8.90	1.30	69.57	4.29	7.46	13.40	0.00
H-22	1.31	4.27	8.60	1.32	71.72	4.22	7.41	13.26	0.00
H-23	1.41	4.96	8.70	1.30	71.05	4.21	7.16	13.42	0.00
H-24	1.32	4.84	8.90	1.29	69.10	4.20	7.59	13.55	0.00
H-25	1.30	4.65	8.70	1.31	71.47	4.16	7.77	13.20	0.00
H-26	1.29	5.03	8.70	1.29	70.92	4.16	6.64	13.49	0.00
H-27	1.28	3.91	8.70	1.30	68.48	4.47	7.91	13.33	0.00

Appendix B. continued

SAMPLE	SCMF	SCF	S3550	PYCN	NSTAR	NOIL	NPROT	NMOIST	FLINT%
H-28	1.31	3.94	8.50	1.33	69.09	4.34	8.00	13.40	0.00
H-29	1.26	4.68	8.70	1.31	71.44	4.12	8.00	13.48	0.00
H-30	1.35	4.83	9.10	1.30	68.87	4.37	7.64	13.57	0.00
H-31	1.33	4.40	8.70	1.31	71.15	4.19	7.46	13.62	0.00
H-32	1.32	4.09	8.60	1.34	70.24	4.30	7.51	13.78	0.00
H-33	1.32	2.37	8.40	1.33	72.35	4.25	7.47	13.29	0.00
H-34	1.14	4.25	9.00	1.29	71.36	3.98	7.53	13.64	0.00
H-35	1.08	3.84	9.20	1.27	73.61	3.74	6.98	13.57	0.00
H-36	1.31	5.41	8.90	1.30	72.12	4.18	7.23	13.31	0.00
H-37	1.34	4.68	8.90	1.31	69.37	4.38	7.55	13.64	0.00
H-38	1.37	4.02	8.40	1.34	71.34	4.36	7.31	13.24	0.00
H-39	1.30	4.70	8.90	1.30	71.03	4.07	7.02	13.55	0.00
B-4	1.16	3.37	8.90	1.30	73.24	3.85	8.37	13.56	0.00
B-5	1.09	3.04	9.30	1.27	70.31	4.06	7.68	13.80	0.00
I-1	1.21	2.73	9.20	1.29	67.72	4.44	8.12	14.09	0.00
J-1	1.02	2.62	9.40	1.28	67.90	4.12	8.86	14.32	0.00
K-1	1.04	3.58	9.50	1.27	71.23	3.99	7.78	13.77	0.00
L-1	1.53	2.64	8.20	1.36	66.64	5.00	9.36	13.50	100.00
L-2	1.22	3.57	8.80	1.34	67.52	4.56	8.63	13.79	50.00
L-3	1.47	2.35	8.40	1.35	65.14	5.00	9.73	14.10	87.50
L-4	1.21	4.61	9.30	1.24	67.89	4.57	8.53	13.45	37.50
L-5	1.50	3.00	8.30	1.35	65.62	4.89	9.71	13.84	75.00
L-6	1.23	4.12	9.10	1.33	70.11	4.36	8.24	13.21	25.00
L-7	1.35	4.31	8.40	1.35	67.59	4.67	9.07	13.46	62.50
L-8	1.21	4.42	9.00	1.32	69.40	4.38	8.45	13.28	12.50
L-9	1.46	3.11	8.40	1.34	65.86	4.73	9.31	13.90	100.00
L-10	1.27	4.54	9.00	1.33	69.57	4.43	8.02	13.28	50.00
L-11	1.50	4.33	8.50	1.35	65.67	4.71	9.80	13.90	87.50
L-12	1.26	5.10	9.10	1.33	71.05	4.18	8.27	13.13	37.50
L-13	1.41	4.56	8.80	1.34	66.94	4.54	9.63	13.41	75.00
L-14	1.21	4.38	9.30	1.33	70.26	4.25	7.98	13.27	25.00
L-15	1.43	4.39	8.60	1.34	68.09	4.64	8.68	13.37	62.50
L-16	1.26	5.63	9.30	1.32	70.44	4.24	7.49	13.84	12.50
L-17	1.38	2.29	8.50	1.37	64.34	5.19	9.91	13.76	100.00
L-18	1.29	2.34	8.80	1.34	68.26	4.60	8.28	13.43	50.00
L-19	1.53	2.64	8.30	1.36	64.68	5.06	10.15	13.67	87.50
L-20	1.17	3.36	9.10	1.34	69.94	4.41	8.36	12.98	37.50
L-21	1.44	2.30	8.50	1.36	66.99	4.95	9.66	13.34	75.00
L-22	1.14	3.12	9.10	1.33	70.69	4.36	8.46	12.94	25.00
L-23	1.33	2.73	8.80	1.35	68.33	4.70	9.01	13.21	62.50
L-24	1.17	2.74	8.90	1.33	71.95	4.11	8.05	12.85	12.50
L-25	1.46	2.67	8.40	1.35	68.86	4.88	8.22	12.96	100.00
L-26	1.16	4.52	9.10	1.34	74.03	4.07	6.79	12.52	50.00
L-27	1.35	3.61	8.60	1.35	70.23	4.67	8.07	12.85	87.50
L-28	1.09	4.00	9.20	1.33	74.50	3.98	6.70	12.51	37.50
L-29	1.34	4.11	8.70	1.37	71.67	4.57	7.46	12.75	75.00
L-30	1.10	4.39	9.50	1.33	74.90	3.93	6.93	12.50	25.00
L-31	1.31	4.44	8.80	1.34	69.46	4.62	8.64	13.00	62.50
L-32	1.10	4.81	9.40	1.32	73.63	4.01	6.97	12.57	12.50

Appendix C1.

Correlation Matrix of Flint Samples

	TW	WBT	STEIN	MOIST	SCI	DENS	FLO	STIME	SCMF	SCF	S3550	PYCN	STAR	OIL	PROT	MOIST
TW	1.00															
WBT	.09	1.00														
STEIN	-.13	.19	1.00													
MOIST	-.20	.08	.49	1.00												
SCI	.26	.38	-.13	-.09	1.00											
DENS	.51	-.06	-.37	-.22	.35	1.00										
FLO	-.52	.09	.50	.36	-.27	-.57	1.00									
STIME	.51	-.08	-.47	-.21	.36	.72	-.76	1.00								
SCMF	.61	-.07	-.31	-.12	.32	.67	-.71	.95	1.00							
SCF	-.08	-.02	.64	.40	-.24	-.54	.57	-.60	-.45	1.00						
S3550	-.54	.03	.50	.20	-.39	-.76	.78	-.94	-.91	.63	1.00					
PYCN	.35	.11	-.24	.13	.54	.40	-.46	.59	.53	-.47	-.63	1.00				
STAR	-.38	.20	.28	.22	-.11	-.62	.75	-.82	-.83	.50	.77	-.29	1.00			
OIL	.50	-.04	-.48	-.39	.30	.69	-.79	.92	.88	-.65	-.87	.45	-.90	1.00		
PROT	.32	-.33	-.34	-.23	.13	.61	-.72	.81	.81	-.52	-.76	.34	-.95	.85	1.00	
MOIST	.36	-.27	.01	.02	-.07	.52	-.56	.61	.67	-.25	-.55	.12	-.88	.67	.78	1.00

Appendix C2.

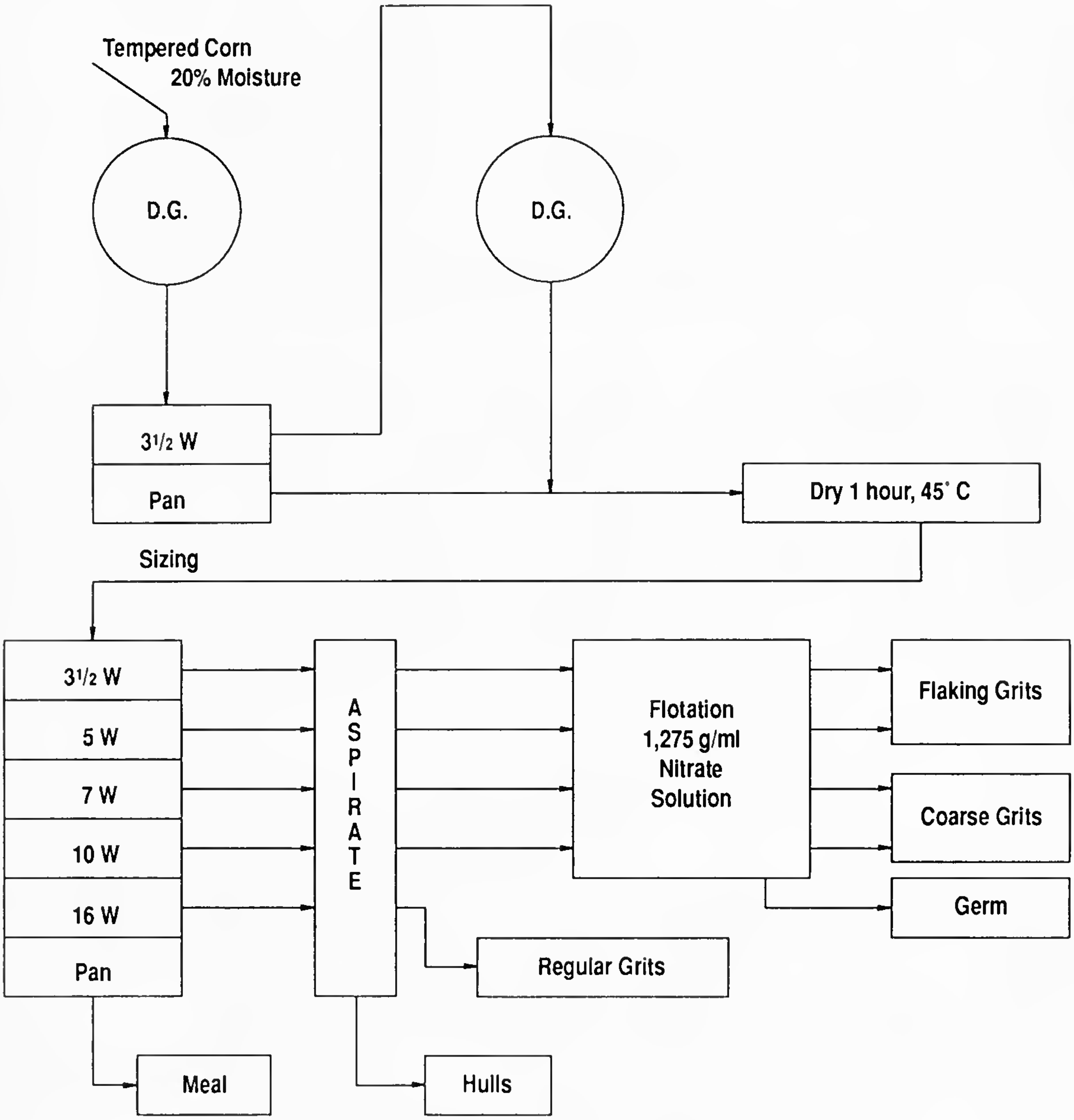
Correlation Matrix of Dent Samples

	TW	WBT	STEIN	MOIST	SCI	DENS	FLO	STIME	SCMF	SCF	S3550	PYCN	STAR	OIL	PROT	MOIST
TW	1.00															
WBT	−.45	1.00														
STEIN	−.55	.69	1.00													
MOIST	−.28	.03	.04	1.00												
SCI	−.59	.84	.63	.11	1.00											
DENS	.29	.03	−.31	−.11	−.03	1.00										
FLO	−.30	−.10	.35	.05	−.02	−.73	1.00									
STIME	.35	.05	−.28	−.23	.14	.50	−.58	1.00								
SCMF	−.35	.70	.51	−.06	.77	.10	−.15	.31	1.00							
SCF	−.33	.28	.46	−.26	.43	−.32	−.28	.03	.50	1.00						
S3550	.27	−.71	−.33	.02	−.71	−.34	.45	−.44	−.78	−.16	1.00					
PYCN	.10	.51	.11	−.06	.43	.50	−.69	.65	.48	.06	−.65	1.00				
STAR	−.24	.37	.16	.13	.35	−.15	.05	−.25	.17	.04	−.24	−.03	1.00			
OIL	.10	.37	.21	−.14	.29	.45	−.44	.46	.47	.09	−.52	.61	−.52	1.00		
PROT	.40	−.63	−.49	−.22	−.54	.10	−.04	.37	−.35	−.11	.40	−.08	−.53	−.09	1.00	
MOIST	.20	−.52	−.38	.13	−.57	−.09	.05	−.12	−.54	−.35	.54	−.38	−.54	−.12	.28	1.00

Appendix D. Mill Flow Processes

A short flow corn dry milling procedure (D1) was used to determine the milling evaluation factor (MEF), a numerical index reflecting grit and total endosperm yields. Previous work has shown that MEF values are highly correlated ($r=0.92$) with flaking grit yields obtained on a commercial corn dry mill (Kirleis 1986). Prior to milling, 1300-gram grain samples (14 percent moisture content) were conditioned to 18 percent moisture content for 1 hour, and finally to 20 percent moisture content for 15 minutes. Tempered samples were passed through a horizontal drum-type degermer, operated at 2,150 rpm, at a feed rate of 450 grams per minute. After the initial 15 seconds (the time required to equilibrate flow through the degermer), two replicate samples were collected (each sample was collected for 1.0 minute). Stock from each replicate was screened for 30 seconds over a 3½ wires-per-inch sieve on a Smico laboratory test shifter. Stock remaining over the sieve was given a second pass through the degermer, at a speed of 2,250 rpm, and combined with the stock that passed through the sieve. Combined stocks were dried for 1 hour at 45°C to a moisture content of 17±1 percent. Dried stock was separated by screening over 3½, 5, 7, 10, and 16 W sieves on a Smico laboratory test sifter for 1 minute. Fractions remaining over each sieve were aspirated on a Bates laboratory aspirator to remove hull material. After aspiration, the 5, 7, and 10 W stocks were floated in sodium nitrate solution (specific gravity of 1.275) to separate germ and endosperm pieces. All fractions were dried for 16-18 hours at 45°C and weighed. MEF was calculated using the equation: $\text{MEF} = (\text{EN}_{3\frac{1}{2}\text{W}} + \text{EN}_{5\text{W}} + \text{EN}_{7\text{W}}) \left(\frac{\text{TEP}}{100}\right)$ where EN is the percent of total endosperm weight remaining on the screen identified by the subscript and TEP is the percent of total sample weight recovered in all endosperm products. A simplified commercial mill process is illustrated in Appendix D2.

Appendix D1. Pilot Mill Flow Process



Appendix D2. Simplified Commercial Mill Flow Process

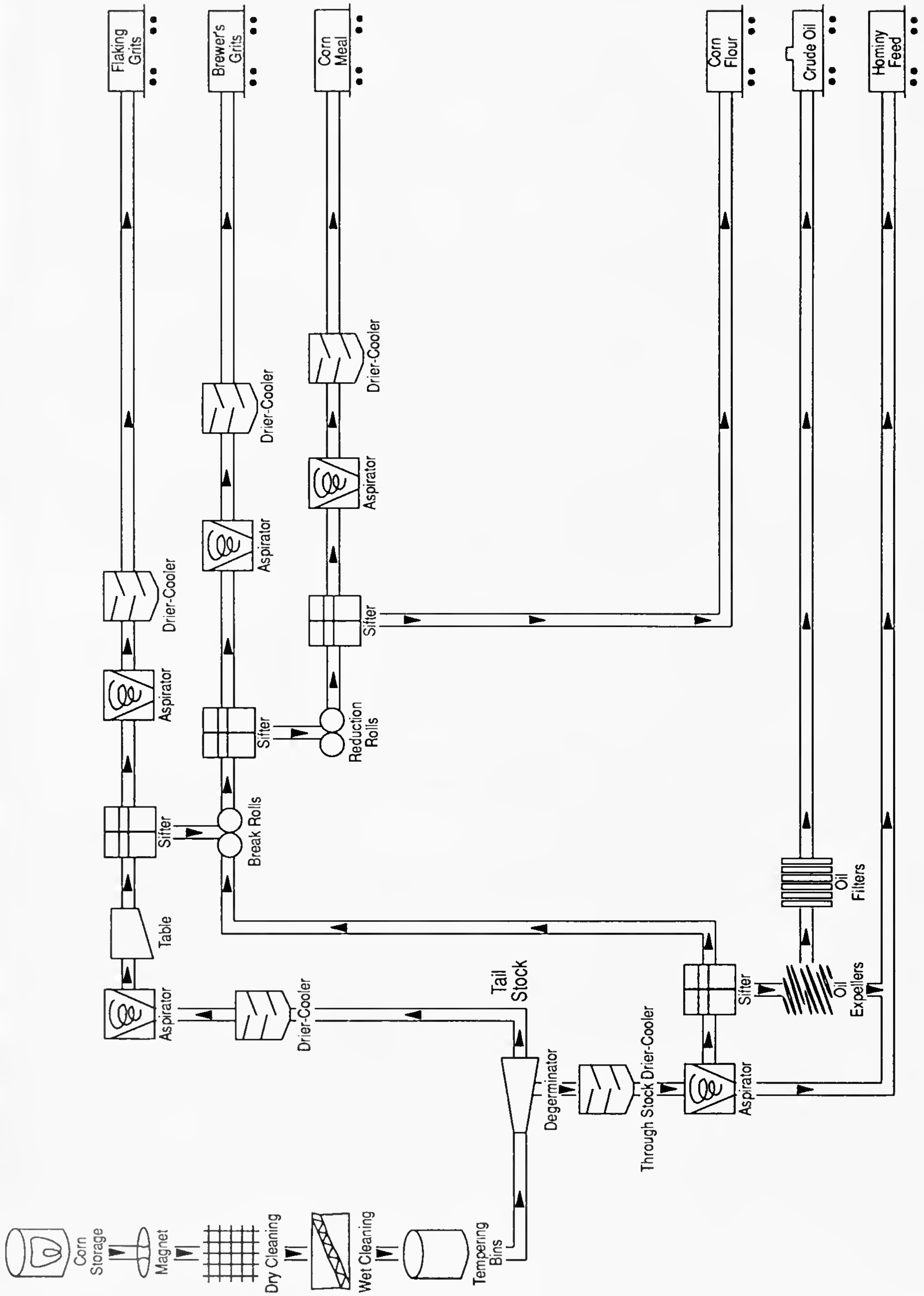


Table 1. Yield and Screen Size of Milled Corn Products

Product	Mesh	mm	Typical percent by weight	Yield lb/bu
Flaking grits	3.5-6	5.8-3.49	12	6.72
Coarse grits	8-14	2.0-1.4	15	8.40
Medium grits	12-18	1.4-1.0	13	7.28
Fine grits	18-26	1.0-0.65	10	5.60
Coarse meal	28-50	0.65-0.3	3	1.68
Fine meal	50-80	0.3-0.17	3	1.68
Corn flour	80-Pan	below 0.17	4	2.24
Oil			1	0.56
Hominy feed			37	20.72
Shrinkage			2	1.12

SOURCE: Adapted from Stanley A. Watson, "Industrial Utilization of Corn," Chapter 13 of *Corn and Corn Improvement*, ed. G.F. Sprague (Madison, WI: American Society of Agronomy, 1977), 748.

Table 2. Descriptive Statistics of Corn Quality Tests Performed at the University of Illinois Agricultural Engineering Laboratory on 98 Corn Samples

	All corn				Dent corn				Flint corn			
	Min	Max	Avg	Std dev	Min	Max	Avg	Std dev	Min	Max	Avg	Std dev
TW (lb/bu)	54.30	62.00	58.20	1.64	54.30	62.00	57.65	1.69	58.10	60.40	59.31	0.67
WBT (%)	4.80	47.25	23.14	10.43	4.80	36.70	18.41	8.80	22.60	47.25	32.90	5.71
STEIN (%)	0.20	9.40	3.25	2.05	0.20	9.40	3.40	2.20	1.10	7.10	2.94	1.64
MOIST (%)	12.70	16.30	14.49	0.44	12.70	16.30	14.44	0.44	13.60	15.20	14.61	0.41
SCI	1.00	5.00	3.86	1.32	1.00	4.96	3.45	1.43	4.20	5.00	4.70	0.21
DENS (g/cm^3)	1.18	1.34	1.26	0.03	1.18	1.34	1.25	0.29	1.23	1.33	1.28	0.03
FLO (%)	4.00	89.00	42.48	25.60	4.00	89.00	51.70	24.73	6.00	59.00	23.47	14.43
STIME (sec)	9.70	23.60	14.06	3.01	9.70	16.30	12.86	1.50	11.00	23.60	16.53	3.75
SCMF	0.87	1.53	1.26	0.14	0.87	1.49	1.23	0.13	1.09	1.53	1.31	0.13
SCF	2.23	5.74	3.97	0.86	2.23	5.74	4.09	0.80	2.29	5.63	3.72	0.93
S3550	8.20	9.90	8.92	0.37	8.40	9.90	8.97	0.37	8.20	9.50	8.82	0.36
PYCN (g/cm^3)	1.24	1.37	1.31	0.03	1.26	1.34	1.30	0.02	1.24	1.37	1.34	0.02
NSTAR (%)	64.34	74.90	69.88	2.06	67.72	73.74	70.27	1.43	64.31	74.90	69.07	2.80
NOIL (%)	3.74	5.19	4.30	0.29	3.74	4.57	4.18	0.17	3.93	5.19	4.54	0.33
NPROT (%)	6.51	10.15	8.05	0.81	6.51	9.87	7.82	0.63	6.70	10.15	8.52	0.94
NMOIST (%)	12.50	14.63	13.49	0.40	13.05	14.63	13.60	0.33	12.50	14.10	13.27	0.44
FLINT% (%)	0.00	100.00	18.37	31.04	0.00	0.00	0.00	0.00	12.50	100.00	56.25	28.64

NOTE: Std dev = standard deviation.

Table 3. Correlation of All 98 Corn Samples

	TW	WBT	STEIN	MOIST	SCI	DENS	FLO	STIME	SCMF	SCF	S3550	PYCN	NSTAR	NOIL	NPROT	NMOIST
TW	1.00															
WBT	.06	1.00														
STEIN	−.47	.38	1.00													
MOIST	−.13	.12	.13	1.00												
SCI	−.23	.82	.44	.16	1.00											
DENS	.46	.30	−.34	−.04	.19	1.00										
FLO	−.48	−.38	.37	.00	−.25	−.76	1.00									
STIME	.48	.37	−.31	−.05	.33	.65	−.66	1.00								
SCMF	−.03	.53	.25	−.03	.67	.35	−.35	.63	1.00							
SCF	−.32	.01	.51	−.07	.19	−.43	.39	−.37	.09	1.00						
S3550	.02	−.52	−.09	.04	−.61	−.49	.53	−.62	−.83	.16	1.00					
PYCN	.41	.65	−.07	.12	.54	.61	−.73	.73	.53	−.25	−.59	1.00				
NSTAR	−.32	.02	.21	.10	.05	−.41	−.35	−.67	−.36	.31	.27	−.30	1.00			
NOIL	.39	.49	−.12	−.09	.40	.63	−.64	.85	.65	−.35	−.63	.70	−.76	1.00		
NPROT	.45	−.08	−.42	−.12	−.12	.41	−.38	.71	.23	−.35	−.15	.35	−.79	.58	1.00	
NMOIST	−.02	−.55	−.19	.01	−.52	−.08	.11	.02	−.15	−.20	.18	−.37	−.53	.01	.29	1.00

NOTE: Critical value (2-tail, 0.05) = + or − 0.20.

Table 4. Milling Evaluation Factor and Product Yields of 98 Pilot Mill Samples

	MEF	FG	BG	Meal	Flour	Oil	Feed	Total
					lb/bu			
All Corn								
Minimum	28.50	5.71	15.24	2.09	2.55	0.65	6.42	51.16
Maximum	59.69	22.35	24.24	5.00	7.15	1.60	13.35	51.49
Average	41.47	13.09	19.54	3.44	4.88	1.02	9.28	51.24
Std dev	7.77	3.97	1.77	0.66	1.13	0.18	1.37	0.03
Dent Corn								
Minimum	28.50	5.71	15.24	2.61	3.65	0.65	8.08	51.16
Maximum	46.56	16.16	24.24	4.92	7.15	1.60	13.35	51.49
Average	37.78	11.44	19.86	3.64	5.36	1.08	9.86	51.24
Std dev	4.65	2.61	1.72	0.51	0.78	0.16	1.05	0.04
Flint Corn								
Minimum	30.92	8.92	16.38	2.09	2.55	0.65	6.42	51.23
Maximum	59.69	22.35	21.82	5.00	6.74	1.24	10.63	51.24
Average	49.07	16.49	18.87	3.03	3.88	0.89	8.07	51.23
Std dev	7.39	4.12	1.69	0.75	1.08	0.14	1.13	0.00

NOTE: Std dev = standard deviation.

Table 5. Correlations Between Product Yields and Selected Quality Characteristics, All Samples

	MEF	FG	BG	Meal	Flour	Oil	Feed
TW	**+.62**	**+.58**	−.32	**−.57**	−.48	**−.59**	**−.53**
WBT	+.42	+.31	+.09	−.13	−.49	−.20	**−.53**
STEIN	−.34	−.38	+.34	+.41	+.29	+.26	+.18
SCI	+.27	+.16	+.21	−.04	−.41	−.07	−.37
DENS	**+.70**	**+.67**	−.30	**−.56**	**−.72**	−.43	**−.64**
FLO	**−.79**	**−.72**	+.23	**+.61**	**+.83**	**+.52**	**+.76**
PYCN	**+.75**	**+.69**	−.23	**−.51**	**−.77**	**−.52**	**−.74**
STIME	**+.87**	**+.86**	−.46	**−.79**	**−.88**	**−.58**	**−.72**
SCMF	+.47	+.41	−.02	−.34	**−.60**	−.23	−.48
SCF	−.40	−.40	+.25	+.37	+.36	+.30	+.32
S3550	**−.51**	−.45	+.01	+.36	**+.66**	+.26	**+.54**
NSTAR	**−.64**	**−.66**	+.42	**+.72**	**+.58**	+.41	+.49
NOIL	**+.86**	**+.81**	−.35	**−.73**	**−.85**	**−.55**	**−.79**
NPROT	**+.66**	**+.71**	**−.55**	**−.73**	**−.57**	**−.52**	−.46
NMOIST	−.06	−.01	−.12	−.17	+.09	+.13	+.16
FLINT%	**+.78**	**+.78**	−.47	**−.62**	**−.75**	**−.54**	**−.67**

NOTE: Absolute values greater than .50 are shown in boldface.

Table 6a. Correlations Between Product Yields and Selected Quality Characteristics, Flint Samples

	MEF	FG	BG	Meal	Flour	Oil	Feed
TW	**+.56**	**+.62**	**−.58**	−.47	**−.54**	−.35	**−.51**
WBT	−.07	−.06	+.03	+.13	+.10	+.26	−.03
STEIN	**−.51**	−.49	+.38	+.42	+.44	+.35	+.47
SCI	+.25	+.27	−.28	−.15	−.23	−.02	−.26
DENS	**+.71**	**+.73**	**−.63**	**−.61**	**−.67**	−.42	**−.63**
FLO	**−.89**	**−.86**	**+.61**	**+.84**	**+.87**	**+.66**	**+.77**
STIME	**+.89**	**+.93**	**−.82**	**−.85**	**−.88**	**−.61**	**−.68**
SCMF	**+.85**	**+.92**	**−.83**	**−.84**	**−.87**	**−.65**	**−.63**
SCF	**−.64**	**−.60**	+.42	**+.58**	**+.59**	**+.55**	**+.53**
S3550	**−.88**	**−.92**	**+.80**	**+.86**	**+.88**	**+.65**	**+.68**
PYCN	+.47	**+.52**	**−.51**	−.39	−.46	−.37	−.37
NSTAR	**−.89**	**−.88**	**+.64**	**+.87**	**+.88**	**+.66**	**+.74**
NOIL	**+.94**	**+.94**	**−.72**	**−.89**	**−.92**	**−.64**	**−.79**
NPROT	**+.85**	**+.85**	**−.64**	**−.86**	**−.86**	**−.72**	**−.66**

NOTE: Absolute values greater than .50 are shown in boldface.

Table 6b. Correlations Between Product Yields and Selected Quality Characteristics, Dent Samples

	MEF	FG	BG	Meal	Flour	Oil	Feed
TW	**+.53**	+.47	−.19	**−.54**	−.24	−.49	−.34
WBT	−.02	−.17	+.46	+.28	−.26	+.18	−.29
STEIN	−.30	−.38	+.31	+.44	+.23	+.21	+.03
SCI	−.07	−.25	+.48	+.29	−.26	+.23	−.15
DENS	**+.57**	+.49	−.04	−.39	**−.62**	−.21	−.48
FLO	**−.71**	**−.58**	−.01	+.42	**+.79**	+.28	**+.64**
STIME	**+.71**	**+.57**	+.02	**−.61**	**−.78**	−.34	**−.53**
SCMF	+.09	−.12	+.49	+.17	+.39	+.10	−.31
SCF	−.14	−.14	+.09	+.11	+.07	+.09	+.09
S3550	−.30	−.08	−.43	−.05	**+.60**	+.01	+.49
PYCN	**+.64**	+.46	+.17	−.28	**−.75**	−.24	**−.69**
NSTAR	−.28	−.31	+.18	+.46	+.11	+.13	+.15
NOIL	**+.56**	+.39	+.17	−.32	**−.58**	−.21	**−.62**
NPROT	+.26	+.40	−.42	−.47	−.04	−.24	−.02

NOTE: Absolute values greater than .50 are shown in boldface.

Table 7. Correlations Between Milling Evaluation Factor and Product Yield for All Samples, Flint Samples, and Dent Samples

	Flaking grits	Brewers' grits	Meal	Flour	Oil	Feed
MEF/All	+.95	−.46	−.85	−.92	−.69	−.91
MEF/Flint	+.97	−.68	−.93	−.96	−.70	−.88
MEF/Dent	+.88	−.21	−.74	−.77	−.50	−.83

Table 8. Breakage Susceptibility and Test Weight for Seven Commercial Mill Runs

	Commercial mill run						
	1	2	3	4	5	6	7
Breakage susceptibility	17.3	21.2	25.0	24.7	20.0	11.4	17.0
High/low break	Low	High	High	High	High	Low	Low
Test weight	58.1	56.1	57.3	56.6	57.0	57.0	55.1
High/low break	High	Low	High	Low	High	High	Low

Table 9. Average Quality Characteristics of Corn Sampled After Cleaning, but Before Tempering in a Dry Milling Plant for Seven Milling Tests

	Commercial mill run						
	1	2	3	4	5	6	7
Number of samples	64	62	65	62	55	51	49
Test weight, kg/m^3	749	723	737	729	733	733	709
Test weight, lb/bu	58.2	56.1	57.3	56.6	57.0	57.0	55.1
Std dev	6	5	5	5	5	8	4
Breakage suscept., %	17.3	21.2	25.0	24.8	20.0	11.4	17.0
Std dev	2.2	2.8	2.9	2.8	2.0	2.3	1.9
Floaters, %	63.0	86.7	76.2	83.0	81.1	81.2	90.3
Std dev	7.0	4.7	5.2	4.6	4.7	5.0	3.3
True density, g/cm^3	1.238	1.214	1.23	1.230	1.244	1.242	1.208
Std dev	0.022	0.016	0.011	0.015	0.014	0.020	0.013
100-kernel dry wt, g	28.64	27.70	27.69	27.50	28.39	28.18	25.67
Std dev	0.67	0.49	0.57	0.58	0.83	0.70	0.66
Whole kernels, %	80.5	82.5	78.4	80.6	80.3	85.8	77.7
Std dev	5.0	3.6	3.8	3.4	3.7	3.1	3.2
Stress cracks, %	29.9	43.9	55.9	54.7	51.5	34.7	59.6
Std dev	9.7	8.8	7.6	9.8	10.1	6.7	7.8
Oven m.c., %wb	14.3	14.9	14.3	14.1	14.9	14.9	15.1
Std dev	0.3	0.2	0.2	0.1	0.2	0.5	0.2

NOTE: Std dev = standard deviation.

Table 10. Correlation Coefficients for Corn Quality Tests for Seven Dry Milling Tests

	TW	WBT	FLO	DENS	100-kernel dry wt	Whole kernels	SCI
TW	1.00						
WBT	0.04	1.00					
FLO	−0.76[a]	0.02	1.00				
DENS	0.49[a]	−0.07	−0.34[a]	1.00			
100-kernel dry wt	0.66[a]	−0.07	−0.48[a]	0.41[a]	1.00		
Whole kernels	0.11	−0.31[a]	0.07	0.08	0.24[a]	1.00	
SCI	−0.41[a]	0.46[a]	0.41[a]	−0.18[a]	−0.40[a]	−0.31[a]	1.00

NOTE: These statistics are based on measurements from 408 samples collected from the commercial mill during the seven runs.

[a] Denotes significance at the 0.01 level.

Table 11. Adjusted Clean Corn Product Yields from a Commercial Mill

	Product yield (lb/bu)						
Run No.	FG	BG	Meal	Flour	Feed	Oil	Total
Run 1	9.24	8.12	3.64	12.32	20.66	1.50	55.48
Run 2	4.48	8.79	11.20	6.83	22.34	1.50	55.14
Run 3	5.66	9.52	10.86	4.82	22.23	1.50	54.59
Run 4	4.93	9.18	5.10	11.65	22.12	1.50	54.48
Run 5	6.44	9.07	8.40	10.81	19.54	1.50	55.76
Run 6	9.41	5.77	9.13	8.34	20.55	1.50	54.70
Run 7	4.37	9.41	11.20	7.34	21.56	1.50	55.38
Minimum	4.37	5.77	3.64	4.82	19.54	N/A	54.48
Maximum	9.41	9.52	11.20	12.32	22.34	N/A	55.76
Average	6.36	8.55	8.50	8.87	21.29	1.50	55.08
Std dev	2.15	1.31	3.05	2.79	1.06	N/A	0.49

NOTE: Std dev = standard deviation; N/A = not applicable.

Table 12. Yields of Tailstock, Throughstock, White Goods, Hominy, and Oil for Seven Commercial Dry Milling Tests

Milling test	1	2	3	4	5	6	7
Breakage susceptibility	Low	High	High	High	High	Low	Low
Test weight	High	Low	High	Low	High	High	Low
				... *percent* ...			
Tailstock	46.0	28.6	30.5	26.6	31.0	41.4	26.9
Throughstock	54.0	71.4	69.5	73.4	69.0	58.6	73.1
White goods	59.5	55.9	55.2	55.1	61.9	58.3	57.7
Feed	36.9	39.9	39.7	39.5	34.9	36.7	38.5
Corn oil (avg)	2.7	2.7	2.7	2.7	2.7	2.7	2.7

Table 13. Percentages of White Goods for Seven Dry Milling Tests

White good product	Mill run						
	1	2	3	4	5	6	7
No. 4 grits	16.5	8.0	10.1	8.8	11.5	16.8	7.8
No. 6, 8, 12, 16, 20 grits	16.0	17.8	17.0	16.6	18.0	10.3	17.2
Meal	6.5	20.0	19.4	9.1	15.0	16.3	20.0
Regrind flour	3.1	2.9	1.5	2.7	2.4	3.7	3.0
Break flour	3.9	6.8	4.7	3.0	3.4	2.4	4.3
Specialty products	13.6	0.4	2.4	14.8	11.7	8.9	5.4

Table 14. Quality of Dry Milling Products from Seven Mill Runs

Product	Mill run						
	1	2	3	4	5	6	7
				... *percent* ...			
No. 4 grits							
Attached germ	5.9	2.9	2.1	8.8	2.5	2.8	2.5
Checks	0.14	0.12	0.08	0.10	0.12	0.07	0.10
% Fat in:							
No. 4 grits	0.53	0.44	0.53	0.64	0.39	0.33	0.33
No. 6 grits	0.42	0.30	0.44	0.45	0.27	0.26	0.27
No. 8 grits	0.46	0.40	0.57	0.54	—	0.52	—
No. 12 grits	1.16	0.67	0.86	0.86	0.87	0.89	0.59
No. 16 grits	1.31	0.88	0.96	1.16	0.97	1.18	0.82
No. 20 grits	1.36	0.93	0.88	1.14	0.85	0.93	0.66
Break flour	3.02	2.01	1.99	2.33	2.03	2.17	1.74

Table 15. Correlations Among Dry Milling Product Yields and Quality Characteristics for Commercial Mill Runs

	FG	BG	Meal	Flour	Special	TW	WBT	FLO	DENS	100 kern	Whole kern	Stress crack	Moist
FG	1.00												
BG	−.72	1.00											
MEAL	−.49	.10	1.00										
FLOUR	−.34	.29	.40	1.00									
SPECIAL	.46	−.18	−.89	−.65	1.00								
TW	.73	−.22	−.65	−.34	.44	1.00							
WBT	−.66	.73	−.02	−.02	−.12	.03	1.00						
FLO	−.70	.13	.68	.25	−.43	−.93	.03	1.00					
DENS	.74	−.41	−.49	−.69	.57	.81	−.14	−.62	1.00				
100 KERN	.68	−.25	−.51	−.20	.37	.88	−.06	.70	.83	1.00			
WHOLE KERN	.56	−.76	−.08	.09	.09	.22	−.56	−.01	.36	.51	1.00		
STRESS CRACK	−.84	.56	.46	−.17	−.26	−.64	.59	.63	−.44	−.69	−.69	1.00	
MOIST	−.11	−.10	.66	.38	−.43	−.62	−.59	.60	−.35	−.36	.19	.06	1.00

NOTE: Correlations are based on average data for each of the seven runs.

Table 16. Value of Products from Seven Runs of the Commercial Mill

Run No.	FG	BG	Meal	Flour	Feed	Oil	Total
			... $ *per bushel* ...				
Run 1	1.11	0.89	0.36	1.11	1.03	0.42	4.92
Run 2	0.54	0.97	1.12	0.61	1.12	0.42	4.78
Run 3	0.68	1.05	1.09	0.43	1.11	0.42	4.78
Run 4	0.59	1.01	0.51	1.05	1.11	0.42	4.69
Run 5	0.77	1.00	0.84	0.97	0.98	0.42	4.98
Run 6	1.13	0.63	0.91	0.75	1.03	0.42	4.87
Run 7	0.52	1.04	1.12	0.66	1.08	0.42	4.84
Minimum	0.52	0.63	0.36	0.43	0.98	N/A	4.69
Maximum	1.13	1.05	1.12	1.11	1.12	N/A	4.98
Average	0.76	0.94	0.85	0.80	1.07	0.42	4.84
Std dev	0.26	0.15	0.31	0.25	0.05	N/A	0.10

NOTE: Std dev = standard deviation.

Table 17. Value of Pilot Milled Products by Sample

Sample ID	FG	BG	Meal	Flour	Oil	Feed	Total
			... $ per bushel ...				
A-1	1.72	2.23	0.26	0.39	0.31	0.43	5.34
A-2	1.82	1.76	0.31	0.53	0.28	0.50	5.21
A-3	1.04	2.43	0.35	0.50	0.31	0.52	5.14
A-4	1.66	1.84	0.35	0.55	0.31	0.50	5.20
A-5	1.84	1.86	0.29	0.45	0.28	0.50	5.23
A-6	1.94	1.68	0.33	0.52	0.30	0.49	5.25
A-7	1.27	2.19	0.36	0.53	0.31	0.50	5.17
A-8	1.39	2.13	0.37	0.53	0.29	0.49	5.19
A-9	1.26	2.06	0.33	0.52	0.21	0.61	4.99
A-10	1.63	2.00	0.31	0.50	0.18	0.51	5.13
B-1	1.72	2.03	0.33	0.49	0.24	0.44	5.25
B-2	1.79	2.12	0.33	0.42	0.21	0.42	5.28
B-3	1.25	2.44	0.36	0.44	0.24	0.46	5.20
C-1	1.70	1.90	0.33	0.50	0.28	0.50	5.21
C-2	1.13	2.32	0.35	0.53	0.31	0.52	5.14
D-1	1.53	1.85	0.37	0.60	0.27	0.52	5.13
E-1	1.28	2.03	0.46	0.55	0.32	0.52	5.15
E-2	1.19	2.16	0.33	0.53	0.23	0.58	5.03
F-1	1.27	2.10	0.35	0.56	0.32	0.54	5.13
G-1	1.44	2.02	0.31	0.52	0.29	0.55	5.12
G-2	1.25	2.28	0.33	0.49	0.30	0.51	5.17
G-3	1.51	1.96	0.37	0.52	0.37	0.50	5.23
H-1	1.16	2.19	0.40	0.53	0.31	0.54	5.12
H-2	1.41	2.28	0.39	0.41	0.35	0.45	5.29
H-3	1.76	2.22	0.32	0.36	0.27	0.41	5.34
H-4	1.58	2.10	0.33	0.46	0.29	0.48	5.23
H-5	1.05	2.30	0.39	0.51	0.36	0.54	5.15
H-6	1.17	2.43	0.41	0.45	0.31	0.46	5.23
H-7	1.02	2.30	0.45	0.54	0.30	0.51	5.13
H-8	0.88	2.45	0.40	0.58	0.31	0.51	5.12
H-9	1.37	2.48	0.32	0.38	0.28	0.44	5.27
H-10	0.94	2.38	0.46	0.56	0.31	0.49	5.14
H-11	0.83	2.26	0.41	0.57	0.40	0.60	5.06
H-12	1.74	2.19	0.32	0.37	0.31	0.42	5.35
H-13	1.23	2.44	0.36	0.45	0.32	0.47	5.26
H-14	1.82	2.20	0.30	0.37	0.27	0.40	5.35
H-15	0.69	2.32	0.46	0.58	0.34	0.61	4.99
H-16	1.86	1.99	0.31	0.36	0.30	0.47	5.30
H-17	1.40	2.28	0.33	0.46	0.30	0.47	5.24
H-18	1.12	2.33	0.38	0.50	0.29	0.52	5.14
H-19	1.58	2.16	0.33	0.44	0.29	0.46	5.26
H-20	1.17	2.39	0.43	0.44	0.33	0.47	5.23
H-21	1.55	2.00	0.37	0.52	0.29	0.48	5.22
H-22	1.62	2.25	0.35	0.39	0.27	0.43	5.31
H-23	1.17	2.25	0.41	0.50	0.35	0.51	5.19
H-24	1.19	2.15	0.36	0.53	0.30	0.56	5.09
H-25	1.65	2.15	0.34	0.42	0.27	0.45	5.28
H-26	0.79	2.37	0.49	0.64	0.32	0.50	5.11
H-27	1.84	2.04	0.31	0.41	0.27	0.44	5.31

Table 17. continued

Sample ID	FG	BG	Meal	Flour	Oil	Feed	Total
				... $ per bushel ...			
H-28	1.61	2.32	0.33	0.37	0.32	0.41	5.36
H-29	1.34	2.32	0.35	0.43	0.29	0.49	5.21
H-30	1.34	2.01	0.39	0.51	0.42	0.54	5.20
H-31	1.41	2.18	0.37	0.48	0.30	0.48	5.22
H-32	1.13	2.41	0.43	0.42	0.30	0.49	5.19
H-33	1.79	2.18	0.31	0.36	0.30	0.41	5.36
H-34	1.08	2.13	0.38	0.54	0.42	0.58	5.12
H-35	0.77	2.16	0.48	0.49	0.45	0.67	5.02
H-36	1.46	2.25	0.34	0.44	0.30	0.46	5.25
H-37	1.28	2.25	0.43	0.50	0.33	0.46	5.24
H-38	1.88	2.05	0.32	0.33	0.33	0.44	5.36
H-39	1.16	2.30	0.38	0.51	0.27	0.51	5.13
B-4	1.20	2.22	0.49	0.49	0.31	0.49	5.18
B-5	0.78	2.67	0.37	0.61	0.28	0.45	5.16
I-1	1.32	2.47	0.31	0.40	0.30	0.46	5.26
J-1	1.53	1.94	0.34	0.50	0.36	0.53	5.20
K-1	1.33	2.04	0.38	0.58	0.30	0.52	5.15
L-1	2.68	1.83	0.22	0.26	0.21	0.32	5.52
L-2	2.07	2.17	0.29	0.34	0.21	0.34	5.42
L-3	2.66	1.80	0.25	0.26	0.21	0.33	5.50
L-4	1.80	2.22	0.30	0.37	0.28	0.40	5.37
L-5	2.57	1.86	0.25	0.26	0.23	0.34	5.50
L-6	1.77	2.19	0.33	0.39	0.25	0.41	5.33
L-7	2.39	1.95	0.25	0.27	0.24	0.37	5.46
L-8	1.53	2.34	0.33	0.40	0.26	0.42	5.29
L-9	2.55	1.86	0.22	0.25	0.26	0.36	5.49
L-10	1.70	2.23	0.34	0.37	0.28	0.42	5.34
L-11	2.52	1.83	0.25	0.27	0.24	0.36	5.47
L-12	1.41	2.23	0.34	0.43	0.23	0.52	5.14
L-13	2.12	1.89	0.25	0.31	0.19	0.49	5.25
L-14	1.66	2.18	0.35	0.42	0.28	0.42	5.31
L-15	2.23	1.97	0.28	0.30	0.26	0.39	5.42
L-16	1.33	2.32	0.38	0.46	0.29	0.46	5.23
L-17	2.57	1.90	0.21	0.23	0.25	0.35	5.51
L-18	2.02	2.19	0.30	0.33	0.23	0.35	5.42
L-19	2.57	1.91	0.23	0.24	0.23	0.33	5.51
L-20	1.60	2.38	0.33	0.39	0.26	0.39	5.35
L-21	2.48	1.97	0.25	0.25	0.20	0.33	5.48
L-22	1.51	2.40	0.33	0.38	0.28	0.42	5.31
L-23	2.41	1.88	0.23	0.26	0.18	0.41	5.37
L-24	1.48	2.29	0.30	0.39	0.21	0.50	5.17
L-25	2.33	1.90	0.21	0.26	0.20	0.44	5.34
L-26	1.56	2.17	0.40	0.46	0.30	0.42	5.30
L-27	2.29	1.96	0.26	0.28	0.26	0.39	5.43
L-28	1.12	2.01	0.50	0.61	0.35	0.53	5.12
L-29	1.94	2.13	0.31	0.34	0.28	0.39	5.39
L-30	1.17	2.22	0.47	0.56	0.31	0.46	5.19
L-31	2.19	1.96	0.30	0.32	0.26	0.38	5.41
L-32	1.07	2.30	0.46	0.55	0.31	0.48	5.17

Table 18. Summary of Value of Pilot Milled Products

Sample ID	FG	BG	Meal	Flour	Oil	Feed	Total
				... $ per bushel ...			
All Corn							
Minimum	0.69	1.68	0.21	0.23	0.18	0.32	4.99
Maximum	2.68	2.67	0.50	0.64	0.45	0.67	5.52
Average	1.57	2.15	0.34	0.44	0.29	0.46	5.25
Std dev	0.48	0.20	0.07	0.10	0.05	0.07	0.12
Dent Corn							
Minimum	0.69	1.68	0.26	0.33	0.18	0.40	4.99
Maximum	1.94	2.67	0.49	0.64	0.45	0.67	5.36
Average	1.37	2.18	0.36	0.48	0.30	0.49	5.20
Std dev	0.31	0.19	0.05	0.07	0.05	0.05	0.09
Flint Corn							
Minimum	1.07	1.80	0.21	0.23	0.18	0.32	5.12
Maximum	2.68	2.40	0.50	0.61	0.35	0.53	5.52
Average	1.98	2.08	0.30	0.35	0.25	0.40	5.36
Std dev	0.49	0.19	0.08	0.10	0.04	0.06	0.12

NOTE: Std dev = standard deviation.

Table 19. Correlations Between Total Milling Value ($/lb) in the Pilot Mill and Selected Quality Characteristics

Quality characteristic	Correlation coefficient
NOIL	+.84
STIME	+.81
FLO	−.78
PYCN	+.75
FLINT%	+.73
DENS	+.69
S3550	−.58
NSTAR	−.58
NPROT	+.54
TW	+.52
SCMF	+.52
WBT	+.50
MEF	+.95
FG	+.89

Table 20. Characteristics of Pilot Mill Samples with Maximum and Minimum Milling Values

	Most valuable nonflint			Most valuable overall	Least valuable overall	
Sample ID	H-28	H-33	H-38	L-1	A-9	H-10
Value ($/bu)	5.36	5.36	5.36	5.52	4.99	4.99
TW (lbs)	58.10	60.10	57.00	60.40	58.60	54.80
WBT (%)	28.00	28.20	29.15	39.75	7.70	13.50
STEIN (%)	4.10	2.70	2.50	1.20	2.30	4.20
MOIST (%)	14.30	14.40	14.40	13.90	14.50	14.80
SCI	4.56	4.20	4.72	4.88	1.48	4.24
DENS (g/cm^3)	1.30	1.25	1.28	1.31	1.24	1.24
FLO (%)	25.00	11.00	9.00	11.00	74.00	85.00
STIME (sec)	16.10	14.60	16.30	23.60	13.40	10.80
SCMF	1.31	1.32	1.37	1.53	1.10	1.37
SCF	3.94	2.37	4.02	2.64	4.03	4.60
S3550 (sec)	8.50	8.40	8.40	8.20	9.40	9.00
PYCN (g/cm^3)	1.33	1.33	1.34	1.36	1.29	1.26
NSTAR (%)	69.09	72.35	71.34	66.64	70.44	71.05
NOIL (%)	4.34	4.25	4.36	5.00	4.09	3.97
NPROT (%)	8.00	7.47	7.31	9.36	8.45	7.31
NMOIST (%)	13.40	13.29	13.24	13.50	13.45	13.61
FLINT% (%)	0.00	0.00	0.00	100.00	0.00	0.00

Table 21. Premium Evaluation of Models (i) and (ii)

	Marginal value (cents/bu)	
Characteristic	Model (i)	Model (ii)
Constant term	+355.47	+386.94
PYCN	+ 24.32	
NOIL	+ 18.05[a]	+ 18.22[b]
SCMF	+ 9.01	
DENS	+ 4.81	
S3550	− 3.40	
NPROT	+ 2.23	+ 1.98[a]
NMOIST	+ 2.14	
MOIST	− 1.32	
TW	+ 0.81	+ 0.80[a]
SCF	+ 0.80	
STEIN	− 0.49	
WBT	+ 0.30[a]	+ 0.19[b]
TIME	+ 0.26	
NSTAR	+ 0.20	
FLO	− 0.12[b]	− 0.17[b]
SCI	+ 0.07	
FLINT%	− 0.03	

[a] Significant at 0.05 level of probability.

[b] Significant at 0.01 level of probability.

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