Relationships Among Maize Quality Factors[1]

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ABSTRACT

Maize properties believed to affect yield and quality of maize products were correlated. Samples of 183 genetically diverse maize hybrids grown in central Iowa in 1987 and 195 in 1988 were analyzed for protein, oil, starch, bulk density (test weight), breakage susceptibility, kernel density, water absorptivity, hardness, and average kernel weight (1,000-grain weight). Data were adjusted to 15.5% moisture basis. Hardness showed a significant correlation ($r > 0.6$) with protein, test weight, and kernel density. Oil was correlated ($r > 0.5$) with density and starch content and, to a lesser extent ($r > 0.4$), with test weight and hardness. Prediction equations for hard-to-measure factors, hardness and density ($R^2 = 0.8$, 0.7), were developed from protein, oil, and test weight. The 1988 data were used to validate the 1987 results. The 1987 and 1988 correlation coefficients agreed in that they always had the same sign and were generally close in value. The 1987 and 1988 prediction equations also agreed in that the mean difference between predicted and actual values for both data sets were not significantly different ($P = 0.05$).

Simple, rapid, and reliable tests that will relate maize quality to product yields in various end uses are greatly needed. Prediction of end-use value is now a national policy goal for the U.S. grain standards. Intrinsic quality characteristics such as starch, oil, and protein content can be directly related to end-use value (Hurburgh 1989), and the potential for improving these characteristics through genetics is quite high (OTA 1989). Other maize properties that reportedly affect yield and quality of maize products are test weight, kernel density, breakage susceptibility, kernel hardness, water absorptivity, and average kernel weight (Paulsen and Hill 1985, Pomeranz et al 1986, Weller et al 1988).

Test weight, which is a factor in the U.S. corn standards, is not a precise indicator of any specific grain quality attribute. Test weight remains a major pricing factor because general quality defects associated with low test weight are not reflected in any other category of the official grades (Freeman 1973). Maize with low test weight often has a lower percentage of hard endosperm and therefore produces a lower yield of prime, large grits when milled (Rutledge 1978). Both density of kernels and packing in the container influence test weight measurements. Maize has an average void volume (space between kernels in a bulk) of 42.3% (Thompson and Isaacs 1967). Measurements that eliminate void spaces give a more accurate volume measurement for density calculations. The 1,000-grain weight is a function of both seed size and density.

The ratios of dense horny endosperm to floury endosperm cause variation in kernel hardness. Maize with a higher proportion of horny endosperm is typically harder by mechanical measures of hardness. Hardness is an intrinsic characteristic that can be altered by genetics and environment.

Breakage susceptibility is a function of internal stress cracks. These cracks are found in either type of endosperm starch and weaken the kernel. Breakage susceptibility is affected by mechanical damage, heat treatment, and, to a lesser extent, genetics, whereas true hardness is affected by genetics only (Pomeranz et al 1984). This is because breakage susceptibility, which is correlated ($r = 0.7$) with stress cracks (Weller et al 1988), will increase as hardness increases when stress cracks are present. Hardness and breakage susceptibility provide useful information to dry millers. Maize with a high ratio of horny endosperm free of stress cracks produces high yields of large flaking grits.

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The water absorption index (WAI) was developed by Hsu et al (1983) on soybeans. They found a negative correlation ($r = -0.53$) between absorption rate and kernel size, which was expected since smaller kernels provide more surface area per unit mass. The WAI for maize may measure steeping performance. Steeping is the first critical step to ensure a clean separation of germ, endosperm, and fiber in maize wet milling.

Various researchers have correlated quality factors in an attempt to predict properties relevant to end use from those having simple and reliable tests. Table I summarizes previous related research.

Weller et al (1988) used four hybrids of yellow dent maize to determine the effects of harvest moisture and drying air temperature on starch recovery and then correlated starch recovery with several quality factors. Starch recovery was a function of starch content, test weight, and ethanol-soluble protein. Pomeranz et al (1986) used three composite samples and 10 individual hybrids of yellow dent maize to correlate test weight, hardness, breakage susceptibility, and density characteristics. Breakage susceptibility, test weight, and percent floaters (a measurement of density) were significantly correlated with hardness. Paulsen and Hill (1985) focused on physical quality factors that affect product yield and performance in maize dry-milling operations. Yields of large flaking grits were significantly increased by low breakage susceptibility and high test-weight values.

Quality factors previously listed that have simple, rapid, and reliable testing procedures are near-infrared reflectance (NIR) estimates of protein, oil, and starch, and test weight. Factors that are time-consuming and hard to measure are kernel density, hardness, and water absorptivity.

Therefore, the objectives of this study were to increase the understanding of maize quality factor correlations and to develop prediction equations for hard-to-measure factors from more readily measurable factors. Factors included protein, oil, starch, test weight, kernel density, breakage susceptibility, kernel hardness, water absorptivity, and average kernel weight. All are believed to affect yield and quality of wet-milled maize products.

MATERIALS AND METHODS

Maize Samples

In 1987, 183 maize hybrids of known pedigree were harvested from a nursery plot at the Iowa State University Agronomy and Agricultural Engineering Research Center near Ames. From the same location, 195 maize hybrids were harvested in 1988 to validate correlation coefficients and prediction equations for hardness and density derived from the 1987 data. In 1987 and 1988 the maize was hand-picked, dried on the ear in boxes ventilated with room air, and then mechanically shelled with a laboratory sheller. The shelled maize was cleaned over a 6.35-mm screen in a Carter-Day dockage tester. Moisture readings (wet basis) were taken with a Dickey-john GAC II moisture meter before each test unless otherwise stated. Laboratory procedures were the same for the 1987 and 1988 samples unless otherwise stated.

Protein, Oil, and Starch Content

A grab sample of approximately 100 g of maize was ground to a fine flour in a Magic Mill III+ home flour mill. The flour was mixed and subsampled once for NIR analysis with a Dickey-john Instalab 800 instrument. The NIR unit was calibrated to measure protein by CRA method A-18 (CRA 1986), oil by AOAC methods 14.084 and 14.085 (AOAC 1984), and moisture content and starch by AACC methods 44-15A and 76-11, respectively (AACC 1983). Protein, oil, and starch were adjusted to 15.5% moisture content using the NIR-predicted moisture content of the ground grain.

Test Weight

Test weight was determined with the U.S. Department of Agriculture Federal Grain Inspection Service standard method (FGIS 1988) and equipment. Before test weight could be correlated with other properties, an equation to adjust the test weights to 15.5% moisture content was needed. The table for maize between 16 and 30% moisture content (Hall and Hill 1974) could not be used because our samples had less than 16% moisture content. Therefore, a test weight-moisture adjustment was determined from 20 samples randomly chosen from the 1989 nursery plot at the same location.

The initial moisture content of the 20 samples ranged from 15.4 to 17.1%. The samples were dried in mesh baskets with room air so that approximately two percentage points of moisture were removed. Test weight was measured. The entire sequence was then repeated a third time to develop a moisture adjustment equation for test weight between 11.4 and 17.1% moisture content. Each test weight and moisture content was taken in triplicate. The following equation was derived to adjust test weight to 15.5% moisture content:

$$T_f = T_i - 0.4412(15.5 - M_i) \qquad (1)$$

$$R^2 = 0.96, \text{ CV} = 0.83\%,$$

where T_f, T_i = final, initial test weight (kg/hl), and M_i = initial moisture content (%) ($17.1 > M_i > 11.4$).

The slope of the equation (0.3401) that represents the table of Hall and Hill (1974) at zero and 10% damage is within two standard deviations of the slope in equation 1. Therefore, the equations differ only in the additive constant for mechanical damage in the table of Hall and Hill. Mechanical damage was not considered in this study because maize was hand picked and laboratory shelled. Equation 1 shows that test weight continues to increase at less than 15.5% moisture.

Breakage Susceptibility

To determine breakage susceptibility, approximately 200 g of maize was poured into the Wisconsin Breakage Tester as described by Singh and Finner (1983) and Watson and Herum (1986). Dutta's equation was used to adjust the breakage susceptibility data to 15.5% moisture content (Dutta 1986):

$$B_f = B_i e^{0.29(M_i - M_f)}, \qquad (2)$$

where B_f, B_i = final, initial breakage susceptibility (%), and M_f = final moisture content, (%).

Stenvert Hardness Test

Maize (20 g, weighted to ±0.001 g) was ground at 3,600 rpm through a 2-mm screen in a Glenmills Stenvert Hardness Tester Microhammermill IV as described by Pomeranz et al (1985). The height of the ground maize in a receptacle with a diameter of 125 × 25 mm was used to measure volume. The first run for each sample was deleted because the grinding chamber and screen were cleaned between samples. Three replicates were made. Stenvert hardness (height) was adjusted to 15.5% moisture content by using the exponential equation reported by Dorsey-Redding et al (1990):

$$H_f = H_i e^{0.00855(M_f - M_i)}, \qquad (3)$$

where H_f, H_i = final, initial Stenvert hardness, cm.

Kernel Density

Approximately 33 g of maize were weighed to ±0.001 g. Volume was measured with a Beckman 930 air-comparison pycnometer (Thompson and Isaacs 1967). In 1987, one subsample was weighed and three volume measurements taken. In 1988, three subsamples were weighed, and volume was determined for each. The linear equation derived in Dorsey-Redding et al (1990) was used to

TABLE I
Previously Reported Correlation Coefficients Among Maize Quality Factors

	No. of Samples (Hybrids)	Starch	Breakage Susceptibility[a]	Test Weight	Density[b]	Hardness[c]
Weller et al (1988)[d]	4					
Density (ethanol column)			0.13	0.73		
Starch			0.25	0.04	−0.09	
Protein		−0.20	−0.26	−0.41	−0.43	
Breakage susceptibility				0.40		
Pomeranz et al (1986)[d]	13					
Density (pycnometer)				0.94		
Hardness				0.72	0.85	
Floaters[e]			0.49	−0.81	−0.83	−0.80
Kernel weight			−0.03	0.33	0.30	0.45
Breakage susceptibility (Stein)				−0.85	−0.70	−0.50
Paulsen and Hill (1985)	4					
Test weight			−0.52			
Density (ethanol column)			−0.10	0.87		
Kernel weight			−0.90*[f]	0.84	0.50	
Floaters			0.63	−0.99**	−0.81	

[a] Measured by the Wisconsin Breakage Tester unless labeled Stein (breakage tester).
[b] Measured as noted within each study.
[c] Hardness measured as the height in the column by using the Stenvert hardness tester. The results were then multiplied by −1 so that high values refer to hard maize.
[d] Significance levels not given because of low degrees of freedom.
[e] Kernel density separation described by Wichser (1961).
[f] * = Significant at the 0.10 level, ** = significant at the 0.05 level.

adjust density to 15.5% moisture content:

$$d_{kf} = d_{ki} - 0.00289(M_f - M_i)\ , \tag{4}$$

where d_{kf}, d_{ki} = final, initial kernel density, g/cm^3.

1,000-Grain Weight

From each sample, 100 whole kernels were randomly selected and placed on a counting board. The weight of the 100 kernels (to ±0.001 g) were multiplied by 10 to determine the 1,000-grain weight. Three replicates were averaged. The 1,000-grain weight was adjusted to 15.5% by multiplying the initial 1,000-grain weight by its percent of dry matter and dividing by 84.5%.

WAI

Approximately 10 g of maize (weighed to ±0.001 g) was soaked for 4 hr in a beaker of deionized water placed in a 30°C agitated water bath. The maize was surface-dried after removal from the beaker and then reweighed (Hsu et al 1983). One replicate was measured in 1987 and three in 1988. WAI is defined as the fractional increase in weight from water uptake. WAI was adjusted to 15.5% moisture by using the WAI exponential moisture adjustment equation derived by Dorsey-Redding et al (1990):

$$W_f = W_i e^{-0.0465(M_f - M_i)}\ , \tag{5}$$

where W_f, W_i = final, initial WAI.

Statistical Analysis

Replicates were averaged. Simple correlation coefficients ($r_{x1,x2}$) were then obtained for all quality factors relative to one another. All correlated quality factors were plotted against each other for general form before any regression analysis was done. Regression equations (single and multiple) were established for 1987 data based on factor pairs with correlation absolute values greater than 0.50 and significance levels less than 0.0001. The sign and magnitude of the 1987 and 1988 correlation coefficients were compared. Mean differences were computed between predicted and actual values for the 1987 equations applied to the 1988 data.

TABLE II
Characteristics of 1987 (n = 183) and 1988 (n = 195) Maize Hybrids[a]

	Mean		Standard Deviation[b]	
Variable	**1987**	**1988**	**1987**	**1988**
Oil, %	3.45	3.53	0.28	0.29
Protein, %	8.73	9.08	0.51	0.53
Starch, %	59.72	60.26	0.62	0.63
Breakage susceptibility, %	2.68	1.82	0.78	0.59
Test weight, kg/hl	76.49	74.67	1.93	2.56
Kernel density, g/cm^3	1.27	1.29	0.019	0.03
Water absorption index	0.167	0.166	0.012	0.014
Hardness, cm	10.73	10.42	0.42	0.55
1,000-grain weight, g	334.93	258.48	31.85	32.03

[a] 15% Moisture basis.
[b] Does not include within-hybrid variability.

RESULTS AND DISCUSSION

The means and standard deviations for each factor are given in Table II and the correlation coefficients among the properties for both years in Table III. The highest correlations were among hardness, density, and test weight; protein with hardness; and oil with density and starch. Protein and oil, although not significantly correlated themselves, had strong correlations with density and hardness. Starch had a high positive correlation with oil and a negative correlation with protein. Kernel weight and WAI were not related to any other quality factors; therefore, they could not be predicted from other properties.

The correlations of kernel weight (Paulsen and Hill 1985) (Table I) with breakage susceptibility ($r = -0.90$), test weight ($r = 0.84$), and density (r = 0.50) showed the greatest deviation from our data (Table III). We found no correlation with kernel weight greater than $|r|$ = 0.36. Pomeranz et al (1986) (Table I) showed breakage susceptibility (Stein) to correlate with test weight (r = −0.85), density (r = −0.70), and hardness (r = −0.50). Our correlations coefficients for these factor pairs were −0.02, −0.15, and −0.23, respectively. Test weight and density were negatively correlated with protein in the study of Weller et al (1988) and positively correlated in ours. The previous works may not have had enough samples with sufficient diversity. The correlations between kernel weight and other physical properties in the study of Pomeranz et al (1986) and between starch and other physical properties in the study of Weller et al agree with our results.

Hardness was only slightly related to breakage susceptibility. Because breakage susceptibility had low correlations with test weight, hardness, and density, factors such as genetics and post-harvest treatment had a stronger effect on breakage susceptibility than did kernel hardness. It is also interesting that test weight had a low correlation with protein and oil, whereas density and hardness had high correlations with these factors. This observation supports Freeman's statement that test weight is a poor indicator of grain quality (Freeman 1973).

Correlation coefficients for factor pairs with $|r| > 0.50$ represent relationships that might be consistent enough to have predictive value. Hardness and density are time-consuming tests that are impractical in today's market. Protein, oil, and test weight, however, can be measured with NIR technology (Hurburgh 1988) and current grading procedures. Regression equations (based on 1987 data) to predict hardness and density at 15.5% moisture basis were:

$$H = 23.78 - 0.4191{*}P - 0.1998{*}O - 0.1138{*}T \tag{6}$$

$$R^2 = 0.75,\ CV = 1.99\%$$

and

$$d_k = 0.6715 + 0.0084{*}P + 0.0140{*}O + 0.0062{*}T \tag{7}$$

$$R^2 = 0.70,\ CV = 0.82\%\ ,$$

TABLE III
Correlation Coefficients (r) for 1987 (n = 183) and 1988 (n = 195) Maize Quality Measurements

	Oil	Protein	Starch	BS[a]	Test Weight	Density	WAI[a]	Hardness[b]
Protein	0.16*/ns[c]							
Starch	0.58**/0.48**	−0.35**/−0.44**						
BS	−0.16*/ns	−0.42**/−0.42**	ns/ns					
Test weight	0.47**/0.48**	0.20*/0.15*	ns/−0.14*	ns/ns				
Density	0.54**/0.48**	0.39**/0.33**	ns/−0.17*	−0.15*/ns	0.78**/0.80**			
WAI	ns/−0.34**	−0.29**/−0.18*	0.21*/ns	ns/−0.14*	−0.28**/−0.54**	−0.30**/−0.48**		
Hardness	0.46**/0.44**	0.64**/0.41**	ns/−0.15*	−0.23*/−0.19*	0.69**/0.67**	0.81**/0.72**	−0.32**/−0.41**	
1,000-grain weight	−0.36**/ns	ns/ns	−0.31**/ns	ns/ns	ns/ns	−0.16*/ns	ns/−0.26*	ns/ns

[a] BS = breakage susceptibility (Wisconsin Breakage Tester), WAI = water absorption index.
[b] Hardness r have been multiplied by −1 so that high values of hardness refer to hard maize.
[c] * = Significant at the 0.05 level, ** = significant at the 0.0001 level, ns = not significant.

TABLE IV
Validation of 1987 (n = 183) Hardness and Density Prediction Equations on 1988 (n = 195) Maize Samples

Factors	Range 1987	Range 1988	Mean Difference from Predicted Value	CV of Difference (%)[a]
Stenvert hardness, cm	9.8–11.9	9.3–12.6	0.35	3.5
Kernel density, g/cm^3	1.198–1.304	1.196–1.370	−0.033	1.4

[a]Compared with the mean test value.

where (at 15.5% moisture basis) H = Stenvert hardness, cm; d_k = kernel density, g/cm^3; P = protein, %; O = oil, %; and T = test weight, kg/hl.

The sign of the P, O, and T coefficients is negative because smaller values of H mean harder corn. If composition enters the grading standards for maize, hardness and density could be predicted from information provided at sale. This would provide additional information on end-use value to the buyer.

Equations 6 and 7 were derived from 1987 maize and then were validated with the 1988 maize (Table IV). The mean differences of the actual data from the predicted values were not statistically significant.

CONCLUSIONS

From data on 183 hybrids harvested in 1987 and then validated with data on 195 hybrids harvested in 1988, the following conclusions were made:

1. Factor pairs with $|r| > 0.50$ one or both years were:

Starch-oil	Hardness-density
Density-oil	Hardness-protein
Density-test weight	Hardness-test weight

2. WAI and 1,000-grain weight were not highly correlated with any other factors.
3. Regression equations 6 and 7 (see above) predict hardness and density from protein, oil, and test weight at 15.5% moisture.

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