Adjustment of Maize Quality Data for Moisture Content[1]

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ABSTRACT

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Most grain properties are affected by moisture content. Previously developed moisture-correction equations for composition, kernel weight, bulk density (test weight), and breakage susceptibility are summarized. Empirical equations were derived to adjust Stenvert hardness, water absorption index (WAI), and kernel density values for moisture content differences. The data were collected on 10 selected samples from a group of 184 maize hybrids grown at one location in central Iowa. The rate of change of Stenvert hardness with respect to moisture showed a moderate amount of hybrid interaction, but a single exponential function was estimated for all hybrids. WAI exponentially decreased as moisture content increased, with little hybrid effect on rate of change. Kernel density decreased linearly as moisture content increased. Hybrids varied in density but the slope of density on moisture was the same for all hybrids. The moisture correction equations for Stenvert hardness, WAI, and kernel density were used to predict moisture-related quality changes in 10 independent samples of unknown genotype and storage history. The average errors of the equations relative to actual data were not significant.

A large volume of maize (30.5 million metric tons in 1988) is processed by wet milling for the recovery of maize starch and oil. This use has been growing steadily at a rate of 2.5 million metric tons per year. Freeman (1973) pointed out several maize quality factors that influence product yields. Test weight, which is an official grade factor, and composition (starch, oil, protein) have significant influence on the wet-milling value of maize. Laboratory testing has revealed other potentially important quality factors such as hardness, kernel density, and breakage susceptibility (Watson 1987). Most grain properties are to some extent moisture dependent. As a precursor to either pilot-scale or full-scale investigation of quality effects on grain processing, it is necessary to have physical or mathematical methods to compare data at equal moisture contents. The factors that we believe have potential significance to wet milling are nutritional composition (protein, oil, starch), kernel density, bulk density (test weight), average kernel weight (thousand grain weight), breakage susceptibility, hardness, and water absorptivity.

Properties based on weight fractions (protein, oil, starch) can be mathematically adjusted for moisture by a mass balance equation:

$$P_f = [(100 - M_f)/(100 - M_i)]\, P_i \qquad (1)$$

where M_f = final, or desired moisture level, %; P_f = final percentage at M_f; M_i = initial moisture level, %; and P_i = initial percentage at M_i.

Thousand grain weight is adjusted by the inverse of equation (1), as it measures total mass rather than relative concentration of constituents.

$$W_f = [(100 - M_i)/(100 - M_f)]\, W_i \qquad (2)$$

where W_f and W_i = final and initial thousand grain weights, respectively.

Test weight measures bulk density as the weight of a known volume of grain. Hall and Hill (1974) published a linear adjustment table for test weight as a function of moisture and physical damage. At 10% damage, the average for mechanically shelled maize, the following equation represents Hall and Hill's table:

$$\Delta T = 0.8595 + 0.3401(M_i - 15.5) \qquad (3)$$

where ΔT = test weight change for drying to 15.5% moisture at 10% damage, kg/hl; and M_i = initial moisture content, % ($30 > M_i > 16.0$).

Equation 3 can be expressed to adjust for moisture as:

$$T_f = T_i + 0.8595 + 0.3401(M_i - 15.5) \qquad (4)$$

where T_f and T_i = final and initial test weights, kg/hl.

For 0% damage, the following equation represents Hall and Hill's table:

$$T_f = T_i + 2.9189 + 0.3401(M_i - 15.5) \qquad (5)$$

Breakage susceptibility measures the potential for kernels to break on impact. As measured by the Wisconsin breakage tester (Singh and Finner 1983, Watson and Herum 1986), breakage susceptibility is very sensitive to changes in moisture. Paulsen (1983) reported the following equation relating breakage susceptibility of maize samples to moisture.

$$B = 171.3 \exp(-0.29M) \qquad (6)$$

where B = breakage susceptibility. The constant, 171.3, in this equation was a function of the specific sample set used to obtain it. Dutta (1986) validated the exponent, −0.29, and proposed the following equation,

$$B_f = B_i \exp[0.29(M_i - M_f)] \qquad (7)$$

where B_f and B_i = final and initial breakage susceptibility, % valid for Wisconsin breakage test results using a 4.76-mm screen, for moisture contents from 9 to 21%, wet basis.

Hardness is an intrinsic property of the maize endosperm. It is not the same as breakage susceptibility, although the two properties are related when the maize has been subjected to the mechanical operations (e.g., drying, harvesting) that produce internal stress cracks. Stress cracks decrease hardness and result in greater breakage susceptibility (Watson 1987). While no empirical equation for moisture-adjusting hardness tests is available, one can hypothesize that such an equation should be of the same form as equation (7).

Water absorptivity measures the rate at which water is absorbed by kernels. The first critical step in the wet milling of maize is

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steeping. Steeping changes or alters the physical condition of maize to obtain a clean separation of germ, endosperm, and bran. Hence, a measure of water absorption rate is also a measure of steeping performance. Water absorptivity concepts and the water absorption index were developed by Hsu et al (1983), but they did not give a correction equation for initial moisture content.

Kernel density can increase or decrease with moisture loss, depending on the relative weight loss compared to volume reduction. Kernels differ in the amount of void space within them and in the ratio of dense horny endosperm to softer floury endosperm, which contains more microfissures. Nelson (1980) published the following third-order polynomial equation to adjust kernel density for moisture from 10 to 35%. In Nelson's equation, density decreases with increasing moisture to 29%, then increases with moisture.

$$d_k = 1.2519 + 0.00714M - 0.0005971M^2 + 0.00001088M^3 \quad (8)$$

where d_k = kernel density, g/cm3, which can be rearranged to adjust for moisture as:

$$d_{kf} = d_{ki} + 0.00714(M_f - M_i) - 0.0005971(M_f^2 - M_i^2) + 0.00001088(M_f^3 - M_i^3) \quad (9)$$

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

Chung and Converse (1971) published a linear equation for kernel density decrease with increasing moisture from 11 to 28%.

$$d_k = 1.3279 - 0.001602M \quad (10)$$

which can be rearranged as:

$$d_{kf} = d_{ki} - 0.001602(M_f - M_i) \quad (11)$$

Both authors used a Beckman model 930 air comparison pycnometer for kernel volume measurements of accurately weighed subsamples. Equation 9 results in kernel density values about 50% greater than values calculated from equation 11.

TABLE I
Moisture Contents of the 10 Maize Hybrids

	Moisture Range[a] (% wet basis)	
Hybrid	**Lowest**	**Highest**
B76 × B92	8.86	21.31
B73 × PA878	9.12	22.77
M017 × H119	9.01	21.04
M017 × VA103	9.44	21.62
VA26 × NC256	9.25	18.66
VA26 × VA102	9.12	18.25
VA26 × VA104	8.95	19.56
B73HT × MBS301	8.92	20.55
FR1141 × FR20A	8.43	18.23
FR27rhm × FR3047	9.17	19.10

[a]Including lowest and highest, there were six moisture levels.

An alternative to correction equations is physical equilibration of grain to a uniform moisture content. In actual processing and grain inspection, this is impossible. Pomeranz et al (1984) determined breakage susceptibility, density, near-infrared reflectance, and average particle size in the laboratory on moisture-equilibrated samples. Equilibrating large samples to exactly the same moisture content is impractical and does not recognize sample-to-sample variation in equilibrium moisture content (ASAE 1988).

The objective of this study was to derive empirical moisture adjustment equations for hardness, water absorption index, and kernel density. The work was done to support research on the effects of physical properties on wet milling yields.

MATERIALS AND METHODS

Maize Samples

The 184 maize hybrids of known pedigree were grown in a plot on the Iowa State Agronomy and Agricultural Engineering farm near Ames, IA. The maize was hand-picked, then shelled with a laboratory maize sheller. Ten of the 184 hybrids were randomly selected for development of moisture correction equations. The harvest moisture contents of the samples ranged from 18.23 to 22.77% wet basis as determined by AACC method 44-15A (AACC 1983). The maize was cleaned over a 6.35-mm screen in a Carter-Day dockage tester. After laboratory tests were conducted on the maize at the harvest moisture content, the maize was dried approximately two percentage points with natural air, and the tests were repeated. This process was continued until test results were obtained at six different moisture levels (Table I) for each hybrid.

Stenvert Hardness Test

Twenty grams of maize were ground in a Glenmills Stenvert Hardness Tester Microhammermill IV. The total column height and time to grind of freshly ground maize were measured as described by Pomeranz et al (1985). Hard maize occupies less volume after grinding and requires more time to grind. The height of the ground maize in a 125 × 25-mm diameter receptacle after grinding was used to represent volume. Grinding time was the time required to collect 17 ml of ground maize into the receptacle. The Stenvert tester repeatedly bridged, particularly in wetter corn. This made the time data erratic. The same problem was reported by Pomeranz et al (1984). Therefore, the time results are not reported, and were not used in analyses.

Six replications were made at each moisture content for each sample. The grinding chamber and screen were cleaned between each replication. The 3,600 rpm mill speed was checked between samples.

Water Absorption Index

Approximately 10 g of maize, weighed to ±0.001 g, was soaked in a beaker of water, which was then placed in a 30°C agitated water bath for 4 hr. The maize was surface dried after removal from the water bath, then reweighed. This procedure was developed by Hsu et al (1983). The water absorption index (WAI)

TABLE II
Validation Data for Moisture Correction Equations

			Validation Statistics[a]			
			Average Difference from Predicted Change		SD of Difference	
Factor	Range of Data					
(unit)	Original	Validation	Linear	Exponential	Linear	Exponential
Moisture (%)	8.43–22.77	9.9–14.0				
Stenvert hardness[b] (cm)	9.8–12.38	9.9–10.93	−0.0994	−0.1046	0.2457	0.2470
WAI[c]	0.111–0.247	0.214–0.314	N/A	0.0037	N/A	0.0157
Density[d] (g/cm^3)	1.222–1.309	1.208–1.303	−0.0118	N/A	0.0114	N/A

[a]n = 20 (n = 10 for density).
[b]Equations 22 (exponential) and 23 (linear).
[c]Equation 24.
[d]Equation 25.

was defined as the fractional increase in weight from water uptake. Three replications were made at each moisture content for each sample.

Kernel Density

Approximately 33 g of whole kernels was weighed to ±0.001 g. Volume determinations were then made with a Beckman model 930 air-comparison pycnometer. Procedures for using the air-comparison pycnometer are described by Thompson and Isaacs (1967). Three replications were made at each moisture content for each sample.

Statistical Design and Functional Forms

Replications were averaged with the means used for analysis. Regression with data transformations, as needed, were used to determine linear, quadratic, exponential, semilogarithmic, and logarithmic relationships. The dependent variables were hardness (height), WAI, and kernel density. The independent variables were moisture content and hybrid. Each form was used to fit the data directly, then rearranged into a more universally applicable format to be used as a moisture adjustment equation.

Linear:

$$Y = a_1 + b_1 M \quad (12)$$

where Y = physical property value, or

$$Y_f = b_1(M_f - M_i) + Y_i \quad (13)$$

where Y_f and Y_i = final and initial physical property values.

Quadratic:

$$Y = a_2 + b_2 M + c_2 M^2 \quad (14)$$

or

$$Y_f = b_2(M_f - M_i) + c_2(M_f^2 - M_i^2) + Y_i \quad (15)$$

Exponential:

$$\ln(Y) = a_3 + b_3 M \quad (16)$$

or

$$Y_f = Yi\exp[b_3(M_f - M_i)] \quad (17)$$

Semilogarithmic:

$$Y = a_4 + b_4\ln(M) \quad (18)$$

or

$$Y_f = b_4\ln(M_f/M_i) + Y_i \quad (19)$$

Logarithmic:

$$\ln(Y) = a_5 + b_5\ln(M) \quad (20)$$

or

$$Y_f = Y_i\{\exp[\ln(M_f)]/\exp[\ln(M_i)]\} \quad (21)$$

Before choosing a functional form, literature was searched for theory relative to the form. If literature did not exist, significant improvement in fit ($P = 0.05$) had to be shown by an F test before accepting the next more complex form.

Validation

Ten maize samples of unknown genotype and storage history were collected from farms and commercial grain handlers to provide an independent validation for the equations. Drying and handling conditions were unknown. The maize was cleaned using a 6.35-m screen in a Carter-Day dockage tester. The initial moisture contents of the samples ranged from 11.83 to 14.0% wet basis. The three tests were performed at the initial moisture content. Then the samples were dried with natural air to a second moisture content and the tests repeated. A third moisture content was obtained by raising the air temperature to approximately 38°C. Again, three replications at each moisture content were made for each test. The final moisture range of the validation data was 9.9–14.0%.

RESULTS AND DISCUSSION

The range of data for the following equations is given in Table II.

Stenvert Hardness

Three of the 10 samples were chosen to illustrate the slope of Stenvert hardness (height) with moisture content, which is shown in Figure 1. Hybrid interaction was indicated by a change in slope constant. A single equation was then fit through all data. All five models resulted in an R^2 of approximately 0.88 and a standard deviation of errors of approximately 0.21 cm (CV = 1.99%). The following exponential equation was chosen to match the form previously reported for breakage susceptibility.

$$H_f = H_i \exp[0.00855(M_f - M_i)] \quad (22)$$

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

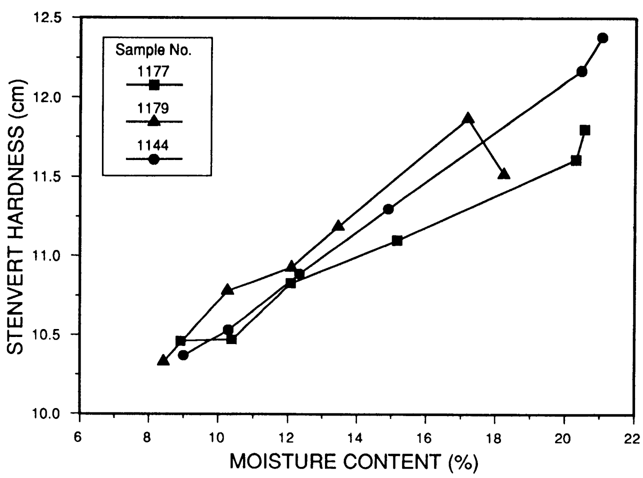

Fig. 1. Change in Stenvert hardness with moisture content for three of the 10 maize samples.

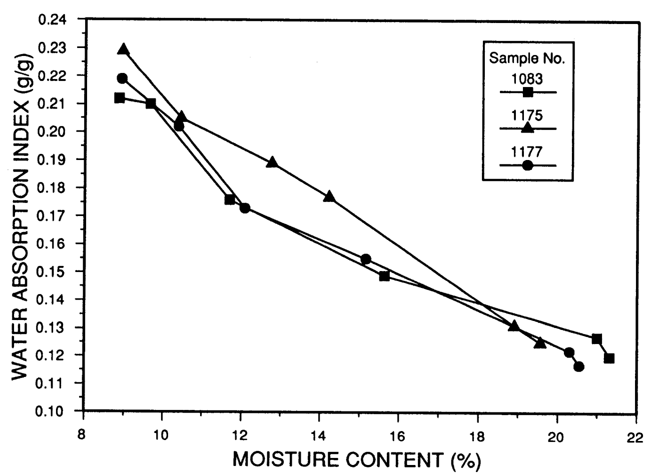

Fig. 2. Change in water absorption index with moisture content for three of the 10 maize samples.

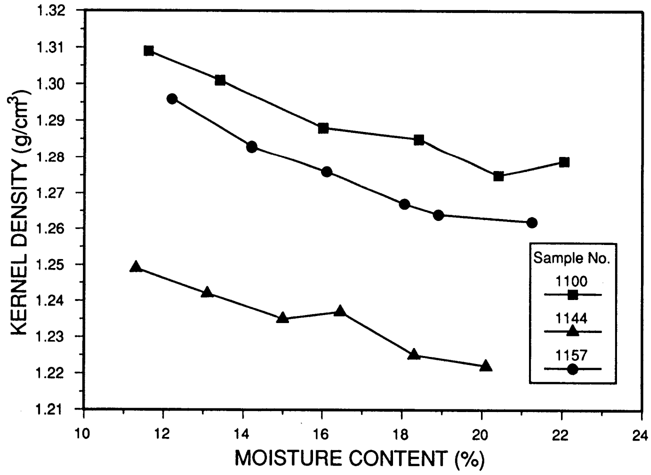

Fig. 3. Change in kernel density with moisture content for three of the 10 maize samples.

Since an improvement in fit was not shown by using a more complex form, the following linear equation is equally acceptable within the range of this data.

$$H_f = H_i + 0.092576(M_f - M_i) \quad (23)$$

WAI

Three of the 10 samples that best illustrate the slope of WAI with moisture content are shown in Figure 2. Little hybrid interaction was indicated; the slope constants did not change greatly among hybrids. The exponential form proved, by an F test and observation of the curve, to be the best equation for the WAI data. The exponential model had an R^2 of 0.96 and standard deviation of errors of 0.008 (CV = 4.3%). The moisture adjustment equation is:

$$W_f = W_i \exp[-0.0465(M_f - M_i)] \quad (24)$$

where W_f and W_i = final and initial WAI.

Density

In Figure 3, density linearly decreased as moisture content increased, as shown by the three samples chosen to illustrate the slope. The slopes of the 10 hybrids were not significantly different, yet certain hybrids were significantly denser than others. The linear model had an R^2 of 0.97 and standard deviation of errors of 0.0038 (CV = 0.3%). The moisture correction equation for density is therefore:

$$d_{kf} = d_{ki} - 0.00289(M_f - M_i) \quad (25)$$

The adjusted density values derived from equation 25 are not significantly different ($P = 0.05$) from those derived from Chung and Converse's equation (equation 11).

Validation

Equations 22, 23, 24, and 25 were used to predict changes in properties with respect to moisture for the validation data. The average difference (predicted minus actual), the standard deviation of the differences, and the range of data are given in Table II. Twenty data points were generated from the comparison of two moisture pairs (low-middle and middle-high) for each sample. A problem with the pycnometer invalidated the middle moisture for density. Only low-high comparisons were made for density. None of the average differences were significantly different from 0.00 ($P = 0.05$).

CONCLUSIONS

From data on 10 hybrids in the moisture range of 8–23% and validation with 10 market maize samples, we drew the following conclusions.

1) Stenvert hardness (height) can be adjusted to a moisture basis with an exponential equation:

$$H_f = H_i \exp[0.00855(M_f - M_i)] \quad (22)$$

or with an acceptable linear substitute:

$$H_f = H_i + 0.092576(M_f - M_i) \quad (23)$$

2) WAI can be adjusted to a moisture basis with an exponential equation:

$$W_f = W_i \exp[-0.0465(M_f - M_i)] \quad (24)$$

3) Kernel density can be adjusted to a moisture basis with a linear equation:

$$d_{kf} = d_{ki} - 0.00289(M_f - M_i) \quad (25)$$

These equations will be used in future studies of grain quality and grain processing.

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