Adjustment of Maize Quality Data for Moisture Content

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Adjustment of Maize Quality Data for Moisture Content

Abstract
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.

Disciplines
Agriculture | Bioresource and Agricultural Engineering | Food Science

Comments
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Adjustment of Maize Quality Data for Moisture Content

CECILIA DORSEY-REDDING, CHARLES R. HURBURGH, JR., LAWRENCE A. JOHNSON, and STEVEN R. FOX

ABSTRACT

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 absorptivity, 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 form as equation (1). As it measures total mass rather than relative concentration of constituents.

\[ P_i = \frac{[(100 - M_i)/(100 - M_f)]}{P_i} \]  

where \( M_i = \text{final}, \) or desired moisture level, \%; \( P_i = \text{final percentage at } M_f; M_i = \text{initial moisture level, } \%; \) and \( P_i = \text{initial percentage at } M_f. \)

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

\[ W_f = \frac{[(100 - M_i)/(100 - M_f)]}{W_i} \cdot \]  

where \( W_f \) and \( W_i = \text{final and initial thousand grain weights, respectively.} \)

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:

\[ \Delta T = 0.8595 + 0.3401(M_i - 15.5) \]  

where \( \Delta T = \text{test weight change for drying to 15.5% moisture at 10% damage, kg/hl; and } M_i = \text{initial moisture content, } \% \) (30 > \( M_i > 16.0). \)

Equation 3 can be expressed to adjust for moisture as:

\[ T_f = T_i + 0.8595 + 0.3401(M_i - 15.5) \]  

where \( T_i \) and \( T_f = \text{final and initial test weights, kg/hl.} \)

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

\[ T_i = T_i + 2.9189 + 0.3401(M_i - 15.5) \]  

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.

\[ B = 171.3 \exp[-0.29M] \]  

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

\[ B_i = B_i \exp[0.29(M_i - M_f)] \]  

where \( B_i \) and \( B_f = \text{final and initial breakage susceptibility, } \% \) 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...
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.

\[ d_k = 1.2519 + 0.00714M - 0.0005971M^2 + 0.00001088M^3 \]  

where \( d_k \) = kernel density, g/cm\(^3\), which can be rearranged to adjust for moisture as:

\[ d_{k1} = d_k + 0.00714(M_i - M_f) - 0.0005971(M_f^2 - M_i^2) + 0.00001088(M_i^3 - M_f^3) \]  

where \( d_{k1} \) and \( d_k \) = 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%.

\[ d_k = 1.3279 - 0.001602M \]  

which can be rearranged as:

\[ d_{k1} = d_k - 0.001602(M_f - M_i) \]  

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

<table>
<thead>
<tr>
<th>Hybrid</th>
<th>Moisture Rangea (% wet basis)</th>
<th>Moisture</th>
<th>Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>B76 × B92</td>
<td>8.86 - 21.31</td>
<td>Lowest</td>
<td>Highest</td>
</tr>
<tr>
<td>B73 × PA878</td>
<td>9.12 - 22.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M017 × H119</td>
<td>9.01 - 21.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M017 × VA103</td>
<td>9.44 - 21.62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VA26 × NC256</td>
<td>9.25 - 18.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VA26 × VA102</td>
<td>9.12 - 18.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VA26 × VA104</td>
<td>8.95 - 19.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B73HT × MBS301</td>
<td>8.92 - 20.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FR1141 × FR20A</td>
<td>8.43 - 18.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FR27rh × FR3047</td>
<td>9.17 - 19.10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

aIncluding lowest and highest, there were six moisture levels.

### Table II

<table>
<thead>
<tr>
<th>Factor</th>
<th>Range of Data</th>
<th>Validation Statisticsb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>Original</td>
<td>Validation</td>
</tr>
<tr>
<td></td>
<td>Linear SD</td>
<td>Exponential SD</td>
</tr>
<tr>
<td></td>
<td>Linear SD</td>
<td>Exponential SD</td>
</tr>
<tr>
<td>Stenvert hardness(^c) (cm)</td>
<td>9.8 - 12.38</td>
<td>9.9 - 10.93</td>
</tr>
<tr>
<td>WA(^d)</td>
<td>0.111 - 0.247</td>
<td>0.214 - 0.314</td>
</tr>
<tr>
<td>Density(^c) (g/cm(^3))</td>
<td>1.222 - 1.309</td>
<td>1.208 - 1.303</td>
</tr>
</tbody>
</table>

a\( n = 20 \) (\( n = 10 \) for density).

bEquations 22 (exponential) and 23 (linear).

cEquation 24.

dEquation 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:
 \[ Y = a_1 + b_1 M \]
 or
 \[ Y_f = b_1(M_f - M_i) + Y_i \]
 where \( Y_f \) and \( Y_i \) = final and initial physical property values.

 Quadratic:
 \[ Y = a_2 + b_2 M + c_2 M^2 \]
 or
 \[ Y_f = b_2(M_f - M_i) + c_2(M_f^2 - M_i^2) + Y_i \]

 Exponential:
 \[ \ln(Y) = a_3 + b_3 M \]
 or
 \[ Y_f = Y_i \exp[b_3(M_f - M_i)] \]

 Semilogarithmic:
 \[ Y = a_4 + b_4 \ln(M) \]

 or
 \[ Y_f = b_4 \ln(M_f/M_i) + Y_i \]

 Logarithmic:
 \[ \ln(Y) = a_5 + b_5 \ln(M) \]
 or
 \[ Y_f = Y_i[\exp[\ln(M_f)]/\exp[\ln(M_i)]] \]

 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.

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

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

\[ H_f = H_i + 0.092576(M_f - M_i) \]  
(23)

\section*{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:

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

where \( W_f \) and \( W_i \) = final and initial WAI.

\section*{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:

\[ d_{kf} = d_{ki} - 0.00289(M_f - M_i) \]  
(25)

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

\section*{LITERATURE CITED}


DUTTA, P. K. 1986. Effects of grain moisture, drying methods, and variety on breakage susceptibility of shelled corn as measured by the Wisconsin Breakage Tester. Ph.D thesis. Iowa State University, Ames, IA.


