NOTE

Rapid Prediction of Wheat Endosperm Compressive Strength Properties Using the Single-Kernel Characterization System

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Recent advances in the understanding of the fundamental physical properties of wheat and its mode of breakage during milling (Dobraszczyk 1994) have shown that considerable variation occurs in the mechanical strength of endosperm from different cultivars and from different kernels of the same cultivar. It has further been demonstrated (Scanlon et al 1998) that the properties of a bulk sample can be predicted from those of individual kernels within the sample. Although compressive strength measurements on endosperm specimens isolated from single kernels probably provide the best description of the mechanical properties of wheat endosperm and are useful to the understanding of milling operations, the experimental procedure is very laborious and time consuming. Thus, it would be practical to develop a rapid single-kernel method for obtaining the same information. Previously, measures of the compressive strength properties of endosperm were related to two measurements of wheat hardness: NIR reflectance on ground grain and the single-kernel characterization system (SKCS 4100) using a set of U.S. National Institute of Standards and Technology (NIST) reference materials (Delwiche 2000). The SKCS 4100 was developed to provide an objective method for classification of wheat as hard, soft, or mixed according to the distribution of hardness values for a number of individual kernels (Martin et al 1993). The hardness value is calculated from measurements of the force required to crush each kernel, expressed as a crush force profile. This article reports direct relationships between the compressive strength measurements and SKCS 4100 crush force profile data using the same set of NIST samples.

MATERIALS AND METHODS

Samples

Ten samples of U.S. wheat were obtained from the NIST (Gaithersburg, MD) as Reference Material No. 8441. These samples, covering a hardness range of 24.7–85.5 on an arbitrary scale of 0–100 (Norris et al 1989), are available for standardization of NIR hardness according to Approved Method 39-70A (AACC 2000), as well as the SKCS 4100 (Martin et al 1993). Two U.S. Soft White Spring wheats (cvs. Penawawa and Vanna) were also used because of their tendency to have similar NIR hardness values but different milling extraction efficiencies (C. F. Morris, Pullman, WA, *personal communication*). All measurements were conducted on samples from single pouches of each reference material sample.

Compressive Strength

Compressive strength measurements (maximum stress, S_{max}, MPa; work to maximum stress, $W[S_{max}]$, MJ m^{-3}; modulus of elasticity, E, MPa;) were performed on machined endosperm specimens as described by Delwiche (2000). Compressive strength values were obtained for each of the 12 samples by first-order linear regression of the mean values (8–12 individual kernel values per mean) of each compressive strength property at five moisture contents ranging from ≈3 to 28% db, then using the equation to predict the property values at 18.3% db (15.5% wb, the moisture content at which SKCS 4100 measurements were performed).

Single-Kernel Characterization System 4100

Before conducting measurements (SKCS 4100, Perten Instruments North America, Springfield, IL), each sample was conditioned to 15.5 ± 0.5% moisture content by equilibration over saturated aqueous sodium chloride at 25 ± 1°C for two weeks.

The operating principles of the SKCS 4100 have been described previously (Sissons et al 2000). The hardness index is based on the crescent load cell A/D counts measured over a period of 125 msec. These data can be recorded as a crush force time profile by manual insertion of one kernel at a time, but because their acquisition is too slow relative to the speed of the singulator, only summary data are stored for routine use. Thus, a computer file collected the averages of the variables weight (milligrams), peak force (maximum load cell force, A/D counts), area (area of the crush force profile, A/D count-second), and Gompertz function coefficients *A* and *B* (Gomp *A* and *B*). The Gompertz function provides a simple way of expressing the variation in the crush force plots by computing the differences between adjacent data points and creating a distribution plot of these differences (Psotka 1999). Gomp *A* and Gomp *B* are defined by a restricted form of the generalized Gompertz function $Y = A^{B^x}$, in which the data are normalized by dividing by the total number of A/D time periods in the crush force profile, thus making *Y* range from zero to one for all profiles. *X* is the A/D change *dy/dt* during a time period equal to the 1/frequency of the A/D values and *Y* is the fractional estimate of the number of *dy/dt* occurring up to a corresponding value of *X* (i.e., an accumulation). Gomp *A* and Gomp *B* are both dimensionless fractions.

Statistical Analysis

Simple correlations (linear, power, and exponential) between each pair of compressive strength and SKCS 4100 crush force profile measurements and multiple linear regressions of compressive strength on average weight, area, and Gomp *B* were performed using Excel (version 7; Microsoft, Redmond, WA) and Minitab (version 11.11; Minitab Inc., State College, PA), respectively.

TABLE I
Correlation Coefficients Between Single-Kernel Characterization System[a] and Compressive Strength Measurements

Strength[b]	Weight	Peak Force	Area	Gomp *A*	Gomp *B*
S_{max}	0.062	0.553	0.510	0.226	0.836
$W(S_{max})$	0.202	0.646	0.618	0.300	0.830
E	0.063	0.472	0.421	0.194	0.800

[a] SKCS 4100, Perten Instruments North America, Springfield, IL.
[b] Compressive strength; S_{max} = maximum strength (MPa), $W(S_{max})$ = work to maximum stress (MJ m^{-3}), and E = modulus of elasticity (MPa).

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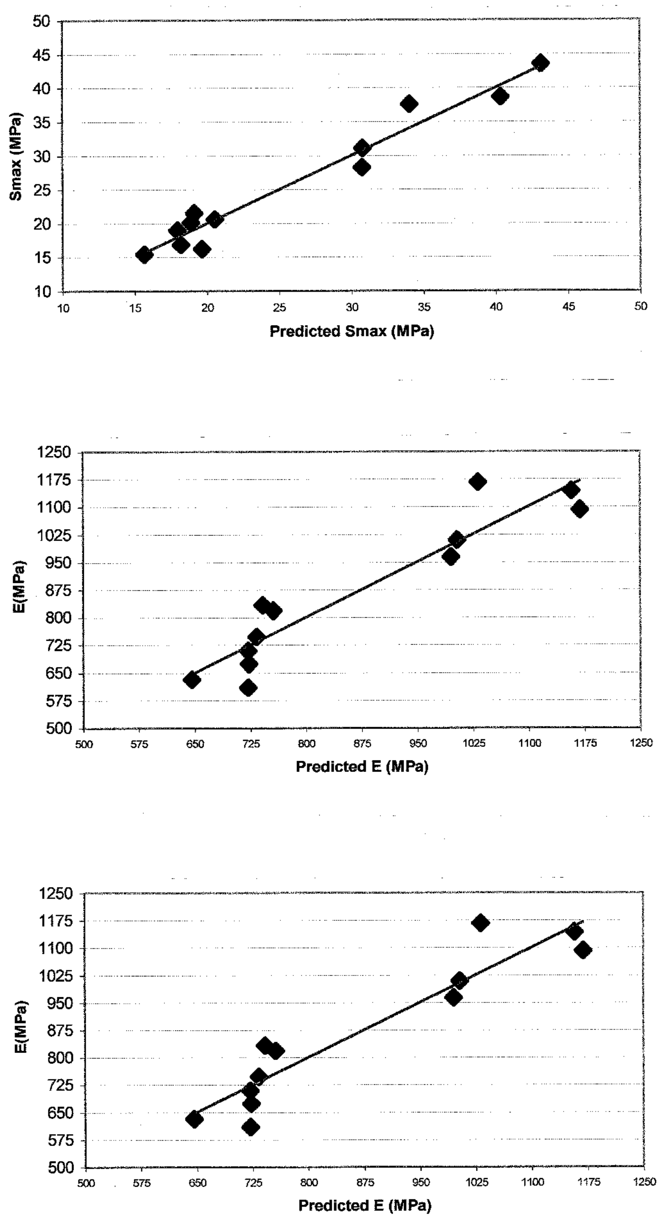

Fig. 1. Plot of measured vs. predicted compressive strength measurements. S_{max} = maximum stress, E = modulus of elasticity.

RESULTS AND DISCUSSION

The linear intercorrelations between the compressive strength and SKCS 4100 crush force profile measurements are given in Table I. No improvement was observed by fitting power or exponential functions. There was only a very low correlation between kernel weight and compressive strength because, although weight has a strong influence on the SKCS 4100 crush force profiles, it has none on the compressive strength measurements that are performed on geometrically precise cylinders of endosperm. Of the four measurements that define the SKCS 4100 crush force profiles, Gomp *A* had the lowest correlations with compressive strength and Gomp *B* the highest. Peak force and area had similar magnitudes of correlation coefficients. These observations are consistent with a report by Gaines et al (1996) that the crush force profile is best described by peak force, area, and Gomp *B*.

All possible one-, two-, three-, and four-term equations involving weight (milligrams), peak force (SKCS A/D counts), area (A/D count-second), and Gomp B (SKCS dimensionless term) were examinedand use of weight, area, and Gomp *B* resulted in the best prediction of the endosperm compressive strength properties using SKCS 4100 in multiple linear regressions using the equations:

$$\text{Predicted } S_{max} \text{ (MPa)} = 145 - 2.58 \text{ (weight)} + 0.000252 \text{ (area)} - 98.6 \text{ (Gomp } B\text{)}$$

$$\text{Predicted } W(S_{max}) \text{ (MJ m}^{-3}\text{)} = 13.1 - 0.167 \text{ (weight)} + 0.000018 \text{ (area)} - 12.3 \text{ (Gomp } B\text{)}1$$

$$\text{Predicted } E \text{ (MPa)} = 1734 - 44.0 \text{ (weight)} + 0.00390 \text{ (area)} - 187 \text{ (Gomp } B\text{)}.$$

The equations for S_{max}, $W(S_{max})$, and E had correlation coefficients R = 0.979, 0.987, and 0.939, respectively. The corresponding scatter plots are shown in Fig. 1. The magnitude of the regression constants and the data presented in Table I show that Gomp *B* has the strongest effect in the prediction of compressive strength measurements, but inclusion of kernel weight in the equation is necessary to correct for the effect of weight on the SKCS 4100 crush force profiles. Although the constants for area are small, which might suggest that this term is not significant, removal of the area term resulted in correlation coefficients of R = 0.893, 0.845, and 0.889 for S_{max}, $W(S_{max})$, and E, respectively. The relative magnitudes and signs of the coefficients for area and Gomp *B* are consistent with those reported by Gaines et al (1996) in the prediction of wheat endosperm texture. These results indicate that the SKCS 4100 may provide a simpler, more practical method for estimating wheat endosperm compressive strength than mechanical testing of machined endosperm specimens, which is difficult and time consuming. In addition, they demonstrate traceability of the SKCS 4100 data to fundamental physical measurements.

CONCLUSIONS

The results of this study suggest that the SKCS 4100 may provide a rapid means of predicting fundamental wheat physical properties on individual kernels. This could open the way to novel means of characterizing wheat milling quality for grain segregation and mill intake.

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