

Predicting Rheological Properties of Wheat Dough Based on Wheat Characteristics

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Abstract

The objective of this study is to find the relationship between rheological properties of wheat dough and some easily measured kernel properties. Hard red winter wheat samples (449) from crop years 1998-2001 were collected at grain elevators throughout the state of Oklahoma in the United States of America. The effects of single kernel characterization, test weight, and kernel protein content on dough Farinograph properties are estimated using both a four-year pooled model and single-year models. Across the Farinograph variables (absorption, peak time, and stability), the most reliable measures for predicting the dough properties were wheat protein and kernel hardness. Test weight was often significant, but test weight had reduced absorption in 1998 and increased absorption in other years. Kernel hardness is a measure that could be added to the current industry use of test weight and protein.

Keywords: Dough mixing properties, Dough quality, Farinograph, Protein, Wheat kernel characteristics

1. Introduction

Knowing the likely dough quality of wheat before it is purchased is of great value to millers. By knowing the dough quality, millers can avoid purchasing grain that does not meet their needs or can adjust the milling and blending process for given wheat properties. The milling and baking quality of wheat dough is commonly measured by its rheological properties such as viscosity, elasticity, and extensibility (Hrušková and Šmejdl 2003). The Farinograph and the Alveograph are two of the most popular instruments used to measure rheological properties (Miralbés, 2004) such as water absorption to form dough of specified consistency, tolerance of flour to mixing, and dough strength and extensibility. The drawback of these two measurement methods is that they are time consuming and costly. Both are impractical to use as a way to either pay producers premiums based on flour quality or to sort each truckload based on flour quality. A number of measures of wheat kernel quality, however, can be conducted relatively less expensively and quickly. The question then is how helpful are these wheat kernel quality measures in predicting dough quality. Xu et al. (2001) study the effect of wheat proteins, especially gluten, on the mechanism controlling flow and deformation in the dough. Several other studies evaluate the performance of aggregate kernel-level measurements for predicting wheat qualities such as flour yield (Osborne, et al., 1997; Yoon et al., 2002; Lyford et al. 2005), and baking and milling quality (Gaines et al., 1997; Ohm et al., 1998). However, there are only a few studies on using wheat characteristics to predict the rheological properties of wheat dough (Osborne et al., 2007; Anderssen and Haraszi 2009; Baker et al 1999).

This area needs more research. As research on the mechanical properties of wheat kernels and their possible relations to composition and functionality continue to expand (Figueroa et al., 2011a, 2011b), the opportunity to develop new approaches to predict dough properties based on kernel characteristics will continue to be explored.

The objective of this study is to find the relationship between the rheological properties of wheat dough as measured by the Farinograph and some easily measured wheat kernel properties. The single kernel characterization system (SKCS) measures a variety of kernel-level physical characteristics such as kernel hardness, weight, and diameter (Martins et al., 1993, Osborne et al., 2001). We focus on these three SKCS measures due to them being more widely used than the other SKCS measures. We also use two other easily measured wheat properties, wheat kernel protein and test weight. The relationship is estimated using a large data set with samples from four crop years. Of additional interest is how much the relationship changes across crop years.

2. Materials and Methods

2.1 Wheat samples

Hard red winter wheat samples from the crop years 1998, 1999, 2000, and 2001 were collected at several grain elevators throughout the state of Oklahoma in the United States. In 1998 and 1999, only truckloads were sampled. In 2000 and 2001, half of the samples were from truckloads and half from elevators. In total, 449 grain samples were collected and analyzed.

2.2 Kernel analysis

Test weight is the only independent variable that is included in United States wheat grades. Wheat test weight was analyzed using Approved Method 55-10.01 (AACCI, 2000). Single kernel characterization was measured with Approved Method 55-31.01 (AACCI, 2000). The wheat non-grade data are wheat protein and single kernel data of kernel hardness and kernel diameter as well as the standard deviations of the two kernel data variables. Protein and moisture contents of wheat and flour were analyzed by near infrared reflectance using an Inframatic 9140 (Pertin Instruments, Huddinge, Sweden) following the manufacturer's protocol. Wheat was milled into flour using Approved Method 26-50 (AACCI, 2000) in a Brabender Quadrumat Jr. mill (C.W. Brabender Instruments, Inc., South Hackensack, NJ).

2.3 Physical (rheological) properties of dough

Flours were analyzed for dough peak (development) time, stability time, and optimum water absorption (adjusted to 14% protein content) at 63 rpm and 30°C in a 300 g bowl Farinograph (C.W. Brabender Instruments, Hackensack, NJ) according to Approved Method 54-21.01 (AACCI 2000). The descriptive statistics of these variables are reported in Table 1.

2.4 Mixed models with fixed and random effects

The basic idea of the regression analysis is that each of the three dough property variables is a function of the independent variables. The regression assumes that there is a relationship between the dough property variables and the independent variables. However, the observed relationship between the dough property and the independent variables can be affected by other factors (i.e., environmental) that vary by year, but could not be measured. To correctly describe the mixed relationship between the variables, we need a mixed model that takes both the fixed and random effects into account. The mixed model generalizes the standard linear model as:

$$y_{it} = \alpha + \sum_j \beta_j X_{jit} + \gamma_t + \varepsilon_{it} \quad (1)$$

where the subscript t represents year, the i is the observation number, and the j indicates the independent variable that X represents, y represents a dough property as measured by the Farinograph. X s represent the data of test weight, wheat protein, kernel hardness, hardness standard deviation, kernel diameter, and diameter standard deviation. β s are unknown constant coefficients. γ_t s are unknown random-effects parameters. ε and γ are Gaussian random variables that are uncorrelated and have expectations 0 and constant variances σ^2 and ν^2 respectively. The conditional variance of y is therefore, $\sigma^2 + \nu^2$. Both a four-year pooled model and four single-year models are estimated. For the four-year pooled model, restricted maximum likelihood was used to estimate the parameters due to the inclusion of the year random effect. For the single-year models, ordinary least squares were used.

2.5 Elasticity index

In addition to statistical significance, a measure of the size of the effects is needed. Regression coefficients can be difficult to compare because they are in different units. We use an elasticity (not the same as dough elasticity), which is a unitless measure, to show the functional effects of the independent variables on the dough properties:

$$\text{Elasticity} = \frac{\Delta Y / \bar{Y}}{\Delta X / \bar{X}}$$

where Y is a dependent variable, X is the independent variable, Δ denotes the change in a variable, $\bar{X}$ and $\bar{Y}$ represent the mean values of the two variables. Elasticity measures the relative percentage change of the two variables. In a linear model, $\Delta Y / \Delta X$ is the coefficient of the independent variable.

2.6 Statistical analysis

The procedure PROC MIXED in SAS was used to estimate the four-year pooled model for each of the three dough quality variables (SAS statistical analysis package version 9.2, SAS Institute, Cary, North Carolina, USA). The likelihood ratio test is used to indicate the significance of the mixed model over the null model with no random effects. To estimate the four single-year models, the procedure PROC REG in SAS was used.

3. Results and Discussion

The estimated four-year pooled model is reported in Table 2. The variables that show statistically significant fixed effects on the dough properties are roughly the same in each of the Farinograph models. Across the Farinograph variables, the consistently significant variables are wheat protein and kernel hardness. Test weight is significant in the models of peak time and stability, but not in the model of water absorption. Hardness standard deviation is significant in the model of water absorption, but not in the other two models. Also, kernel diameter is significant in peak time, but not in the others. The patterns of the random effects are different for the dough property variables. The random effect variances are less than 10% of the error variances for water absorption and peak time. The random effect variance for stability, however, is more than 20% of the error variance, which indicates greater year-to-year variability that is unexplained by the model. The likelihood ratio tests clearly reject the null hypothesis of no random effects.

The estimation results for the four single-year models are reported in Table 3. With the single-year models, statistical significance of the fixed effects is largely reduced and the direction of the effect sometimes varies by year. For example, test weight has a significant effect on water absorption in 1998, 1999 and 2001, but not in 2000. The coefficient of test weight for absorption in 1998 is negative and significant, but positive and also significant in 1999 and 2001. For water absorption, the wheat protein has a significant positive effect in all four years. The coefficients of wheat protein are similar across years with values of 1.95, 1.98, 1.22 and 1.66. The kernel hardness has a significant positive effect in 1999, 2000, and 2001. The magnitudes of the effect in the three years are close at 0.05, 0.05, and 0.08, which is encouraging that the effects are so similar. There is no consistent significance pattern available for the single-year models of peak time. For 1998, no wheat characteristic has a significant effect on peak time. For stability, test weight and wheat protein have a significant effect in 1998 and 1999, but not in 2000 and 2001. The magnitudes of the effects in the two years are -0.49 and -0.55 for test weight and -1.27 and -1.17 for wheat protein. For each of the four years, the R-squared for the water absorption model is higher than the R-squareds for the other two models, which indicates that water absorption can be predicted more accurately than stability or peak time. Except in 1998, the R-squared for the peak time model is higher than the one for stability. The highest R-squared for peak time is 0.44 in 2000, which indicates there is still considerable variation that is unexplained by the model.

Osborne et al. (2007) also found kernel hardness was correlated with dough quality. Baker et al. (1999) found that protein was not a consistent predictor of dough quality. Even though we found that the effect of protein was stable over time, the results of Baker et al. suggest that may not always be true.

The elasticities (percentage changes in the dependent variables with percentage changes in the independent variables) between the wheat property and flour quality for the four years are reported in Table 4. For example, the elasticity of -0.27 for test weight and absorption means that a 1% increase in test weight would result in a 0.27% decrease in absorption. Test weight, wheat protein, and kernel hardness show the largest effects as measured by the elasticities. The highest elasticity is 4.15 for wheat protein and peak time in 2000. Elasticities are generally smaller for absorption than the other dough quality measures, but this is only due to absorption having a small standard deviation relative to its mean.

4. Conclusions and Recommendations

The relationships between the dough properties and wheat kernel properties are investigated. The results show some predictability of the wheat kernel properties for the dough properties, with absorption being the property that is most accurately predicted. By using the data of the hard red winter wheat during the four crop years in Oklahoma, it is found that the most reliable measures for predicting the dough properties are the wheat protein and kernel hardness. Test weight, hardness standard deviation and kernel diameter show some prediction power

for some dough properties. Test weight is the only measure considered that is a factor in the United States Department of Agriculture wheat grading system. Test weight and protein are commonly used measures in the wheat trade. The results here suggest that hardness is an additional measure that could be helpful in predicting dough quality. Kernel hardness could be a good candidate to consider as a measure of quality for wheat purchasers or as an addition to the wheat grading system.

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Table 1. Descriptive Statistics of Wheat and Physical (Rheological) Dough Tests Data

Variable	1998			1999			2000			2001		
	Obs ^a	Mean	SD ^b	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Test weight	116	61.15	2.12	88	59.92	2.02	130	59.33	1.87	115	60.42	1.67
Wheat protein	116	11.72	1.28	88	10.81	1.33	130	11.19	0.97	115	11.65	0.78
Kernel hardness	116	78.04	11.95	88	72.88	7.68	130	79.23	9.07	115	77.91	5.62
Hardness SD	116	16.13	2.87	88	17.91	1.78	130	18.76	1.59	115	17.96	1.85
Kernel diameter	116	2.19	0.17	88	2.26	0.17	130	2.24	0.12	115	2.3	0.1
Diameter SD	116	0.45	0.06	88	0.45	0.05	130	0.44	0.04	115	0.44	0.04
Peak time ^c	116	6.17	2.29	88	6.81	2.42	130	5.69	3.95	115	5.48	1.45
Stability ^c	116	6.91	3.47	88	10.71	3.35	130	12.13	5.41	115	8.33	2.71
Absorption ^c	116	62.39	3.75	88	61.14	2.98	130	60.65	2.02	115	61.66	2.03

^aObs = number of observations.^bSD = standard deviation.^cPhysical (rheological) dough test used for flour quality from a Farinograph; peak time, stability and absorption = optimum water absorption.

Table 2. Estimated Mixed Models of Wheat Flour Quality for Crop Years 1998, 1999, 2000, and 2001

Independent Variable	Absorption ^a		Peak Time ^a		Stability ^a	
	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value
Intercept	38.27*	9.87	17.91*	3.39	58.16*	7.3
Test weight	0.04	0.65	-0.18*	-2.34	-0.46*	-4.01
Wheat protein	1.78*	19.71	0.73*	5.91	-0.7*	-3.77
Hardness	0.04*	3.24	-0.04*	-2.49	-0.07*	-3.16
Hardness SD ^b	-0.18*	-4.07	-0.07	-1.07	0.05	0.55
Diameter	0.11	0.16	-2.23*	-2.4	-2.26	-1.62
Diameter SD	2.46	1.24	-0.92	-0.34	-7.86	-1.94
Covariance Parameter						
Random effect (v^2)	0.27		0.41		2.94	
Error variance (σ^2)	3.37		6.31		14.08	
Null Model Likelihood Ratio Test						
Chi-square	14.03		10.64		40.55	
Pr > Chi-square	0.0002		<0.0011		<0.0001	

^aPhysical (rheological) dough test used for flour quality using a Farinograph; optimum water absorption, peak time, and stability.^bSD = standard deviation.

* Denotes significance at the 5% level.

Table 3. Estimated Models of Flour Quality by Crop Year

Independent Variable	Absorption ^a		Peak Time ^a		Stability ^a	
	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value
1998						
Intercept	58.56*	6.27	20.16*	2.45	56.04*	4.92
Test weight	-0.28*	-2.1	-0.22	-1.88	-0.49*	-3.01
Wheat protein	1.95*	9.04	0.09	0.5	-1.27*	-4.84
Hardness	0.02	0.53	0.02	0.83	-0.001	-0.03
Hardness SD	-0.16	-1.31	-0.07	-0.62	-0.05	-0.37
Diameter	-0.21	-0.13	-1.33	-0.94	-3.14	-1.61
Diameter SD	0.29	0.07	1.93	0.49	8.21	1.5
R-Squared	0.56	0.54 ^b	0.09	0.04 ^b	0.24	0.2 ^b
1999						
Intercept	24.49*	4.78	22.46*	2.83	70.09*	5.81
Test weight	0.17*	2.19	-0.28*	-2.38	-0.55*	-3.05
Wheat protein	1.98*	16.65	0.83*	4.5	-1.17*	-4.18
Hardness	0.06*	3.22	-0.03	-1.07	-0.06	-1.27
Hardness SD	-0.01	-0.12	-0.07	-0.5	-0.09	-0.43
Diameter	0.6	0.64	-2.28	-1.57	-1.52	-0.69
Diameter SD	-1.39	-0.48	2.22	0.5	-10	-1.47
R-Squared	0.84	0.83 ^b	0.43	0.38 ^b	0.3	0.25 ^b

2000						
Intercept	33.4*	5.12	16.58	1.18	49.79*	2.27
Test weight	0.18	1.84	0.16	0.73	0.22	0.67
Wheat protein	1.22*	8.13	2.11*	6.55	0.94	1.88
Hardness	0.05*	2.52	-0.2*	-4.71	-0.32*	-4.86
Hardness SD	-0.08	-0.89	-0.42*	-2.27	-0.25	-0.86
Diameter	-0.99	-0.82	-6.55*	-2.52	-7.26	-1.79
Diameter SD	5.83	1.55	-11.8	-1.46	-33.38*	-2.65
R-Squared	0.54	0.52 ^b	0.44	0.41 ^b	0.27	0.24 ^b
2001						
Intercept	5.6	0.66	3.3	0.37	45.21*	2.72
Test weight	0.25*	1.99	0.19	1.42	-0.18	-0.75
Wheat protein	1.66*	9.73	0.37	2.04	0.02	0.07
Hardness	0.08*	3.04	-0.03	-1.18	-0.06	-1.23
Hardness SD	-0.11	-1.4	0.07	0.84	0.09	0.58
Diameter	4.84*	3.27	-2.96	-1.91	-5.64	-1.94
Diameter SD	14.88*	4.29	11.89*	-3.26	-22.45*	-3.29
R-Squared	0.62	0.59 ^b	0.17	0.12 ^b	0.16	0.12 ^b

^aPhysical (rheological) dough test for flour quality using a Farinograph; optimum water absorption, peak time, and stability.

^bDenotes adjusted R-Squared.

* Denotes significance at the 5% level.

Table 4. Elasticity between Wheat Kernel Properties and Flour Quality by Crop Year

Wheat Property	Absorption ^a	Peak Time ^a	Stability ^a
1998			
Test weight	-0.274	-2.180	-4.336
Wheat protein	0.366	0.171	-2.154
Hardness	0.025	0.253	-0.011
Hardness SD ^c	-0.041	-0.183	-0.117
Diameter	-0.007	-0.472	-0.995
Diameter SD	0.002	0.141	0.535
1999			
Test weight	0.167	-2.464	-3.077
Wheat protein	0.350	1.318	-1.181
Hardness	0.072	-0.321	-0.408
Hardness SD	-0.003	-0.184	-0.151
Diameter	0.022	-0.757	-0.321
Diameter SD	-0.010	0.147	-0.420
2000			
Test weight	0.176	1.668	1.076
Wheat protein	0.225	4.150	0.867
Hardness	0.065	-0.278	-2.090
Hardness SD	-0.025	-1.385	-0.387
Diameter	-0.037	-2.579	-1.341
Diameter SD	0.042	-0.912	-1.211
2001			
Test weight	0.245	2.095	-1.306
Wheat protein	0.314	0.787	0.028
Hardness	0.101	-0.427	-0.561
Hardness SD	-0.032	0.229	0.194
Diameter	0.181	-1.242	-1.557
Diameter SD	0.106	0.955	-1.186

Note: Elasticities show the percentage change in the dependent variable with a percentage change in the independent variable. For example, the first elasticity of -0.274 means that if test weight goes up 1%, absorption decreases 0.274%.

^aPhysical (rheological) dough test for flour quality using a Farinograph; optimum water absorption, peak time, and stability.

^cSD = standard deviation.