

# Relationships Between Small-Scale Wheat Quality Assays and Commercial Test Bakes<sup>1</sup>

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## ABSTRACT

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Typical commercial bakeries in the United States are highly mechanized, mass-production facilities. U.S. hard wheat breeding programs use small-scale physical dough testing and pup loaf bake procedures to identify and select improved quality genotypes. The accuracy of such approaches in the prediction of commercial-scale quality performance is poorly understood. Samples from six hard red winter wheat cultivars grown in 11 locations over three harvest years were used to correlate grain hardness, small-scale test bakes, mixograph variables, and various measures of flour protein composition with quality assessments from commercial test laboratories. Samples were milled on both pilot- and small-scale mills. Pro-

tein content and 100-g pup loaf volume were more often significantly correlated with commercial test bake variables than all other small-scale variables. Stepwise multiple regression models explained, on average, ≈40% of the variation in commercial test bake procedures. Mixograph properties, pup loaf volumes and absorption, and flour protein content were the most frequent variables identified in model development. Pup loaf bake results on pilot- and small-scale milled flours were highly correlated. Differences in milling technology do not appear to be a significant source of error in relating small-scale test bakes to commercial quality.

Commercial bakers often claim U.S. hard wheat cultivars lack the processing quality necessary for modern bake plants. Most U.S. commercial bakeries use highly mechanized systems, requiring flours that possess a good deal of “tolerance” to both under- and over-mixing, and the ability to withstand the rather rigorous treatment of doughs on the conveyor belt systems used to deliver loaves to and from the ovens. Dough sizes may exceed 600 kg for sponge and dough bake methods. Commercial plants also desire single flours capable of being used in a variety of products, as opposed to multiple flours for multiple uses. The perceived lack of acceptable quality among U.S. cultivars could be due to the use of inaccurate selection procedures on the part of hard wheat breeding programs. Alternatively, the baking industry might be guilty of engineering a system that places demands on wheat flour that exceed its biological capabilities. Finally, the movement toward faster mills, and the lack of mill and bake chemists at milling operations, may have contributed to a system whereby the quality potential inherent in wheat cultivars is not being realized at bakeries.

Commercial quality control test laboratories can not precisely duplicate the typical bakery production line, but many companies have developed test bake methods typically using loaves baked from ≈700 g of flour to evaluate potential flour performance on the bake floor. Identification of wheat cultivars with acceptable end-use quality requires selection procedures capable of forecasting performance in these test bake procedures. Nearly all U.S. hard wheat breeding programs make early-generation quality selections based on: dough strength testing devices such as the mixograph; determination of flour protein content and grain hardness; and, at times, some measure of aggregative protein quality by procedures such as the SDS sedimentation (SDSS) test. In later generations, 100-g

loaves are baked using straight-dough procedures. Many such tests have been used with little change in procedures for more than 50 years. Despite the longevity of breeder or small-scale testing procedures, little is known of the accuracy in forecasting commercial test bake quality. In addition, milling procedures also differ. Breeder-scale test bake samples generally are prepared on small laboratory-scale mills rather than the multistoried systems used to prepare commercial samples. Differences in milling procedures also represent possible sources of error when selections are made for improved quality.

Cereal chemists have been active in the past 50 years investigating the relationships between all components of wheat endosperm and end-use quality. Most studies have correlated measures of flour protein, lipids, or carbohydrates to quality as measured by small-scale tests. In general, flour protein content and protein quality are the two variables most highly correlated with processing quality (MacRitchie et al 1990, Weegels et al 1996). Protein quality may be defined by the amount of insoluble protein measured by the SDSS test or other similar procedures (summarized by Eckert et al 1993), or by the amounts of polymeric glutenin protein (Singh et al 1990a,b; Gupta et al 1993) as determined by size-exclusion HPLC. Higher levels of either total or insoluble glutenin protein generally correlate with stronger doughs and larger loaf volumes, at least when small-scale test bakes are used. The relationships between any of the various measures of protein quality and commercial test bake results from U.S. laboratories have received scant, if any, attention.

Adoption of commercial test bake procedures as selection tools in wheat breeding programs is unlikely. Such an approach would require the typical wheat breeding program to quadruple in size and would require extensive capital investment in new bake laboratory equipment and personnel. Funds for such endeavors are simply unavailable. If wheat breeders are to develop and release cultivars acceptable to the U.S. baking industry, an early-generation test with high predictive value of commercial test bake results is required. The goal of this study was to determine to what extent small-scale bake results, dough strength assays, protein quality, and grain hardness measurements can predict commercial test bake results.

## MATERIALS AND METHODS

Six wheat cultivars, ‘Abilene’, ‘Arapahoe’, ‘Cimarron’, ‘Karl’, ‘Scout66’, and ‘TAM-107’ were used. All are hard red winter wheats adapted to Great Plains environments and represent diverse quality types. At the inception of the study, all except Scout66 were commonly cultivated by wheat producers. Cultivars were sown in two-

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replicate trials; harvested in 1993, 1994, and 1995; and grown in several locations including Beatrice, Clay Center, Lincoln, Hemingford, Mead, McCook, North Platte, Sidney, and Scottsbluff, NE, and Hays and Hutchinson, KS. Plot size was variable, but at each location sufficient area was seeded to provide ≈60 kg of grain per cultivar per plot at harvest. Over the three harvest years, certain locations were lost to excessive winterkill, hail damage, late season rains, etc. A total of 285 samples were successfully harvested.

A 300-seed sample from each harvested plot was analyzed with a single kernel classification system (SKCS 4100, Perten Instruments, Reno, NV) to determine kernel size, weight, and hardness, as well as the standard deviation of hardness within each sample. Samples were tempered to 15.5% moisture and milled in the 55CWT Miag pilot-mill at the USDA-ARS Spring and Durum Wheat Quality Laboratory, Fargo, ND. Pilot-mill settings were described by Shuey and Gilles (1965) and Lillard and Hertsgaard (1983). Sam-

ple size for pilot-milling was ≈41 kg. In addition, a 1.5-kg aliquot of each sample was tempered to 15.2% moisture and milled in a Buhler experimental mill in the University of Nebraska Wheat Quality Laboratory. Flour ash content (%) was determined by Approved Method 08-01 (AACC 1995).

Pilot-milled flour samples from all three years were test baked in the commercial test laboratory at the American Institute of Baking (AIB), Manhattan, KS, using a sponge and dough procedure. The sponge formulation was 490 g of flour, 14 g of compressed yeast (Red Star Yeast, Milwaukee, WI), 3.5 g of nonbromated yeast food (ADM Arkady, Kansas City, MO), and 294 g of water. The sponge was mixed with a Hobart A-120 mixer with a McDuffee bowl and fork agitator, and allowed to ferment for 4 hr at 28.9°C. After fermentation, the sponge was added to a dough produced from 210 g of flour, 49 g of sucrose (C&H Sugar Co., Crockett, CA), 3 g of unemulsified plastic shortening (Vream, hydrogenated

**TABLE I**  
Reproducibility of Performance of Control Flours in Test Bake Procedures

	AIB <sup>a</sup>				UNL <sup>b</sup>			
	Proof Time (min)	Loaf Volume (mL)	Loaf Grain (0–10)	Overall Bake Score (0–10)	Bake Mixtime (min)	Loaf Volume (mL)	Loaf Grain (0–12)	Loaf Texture (0–12)
Mean	55.6	2,674	6.75	5.25	7.00	954	9	10
Standard deviation	4.6	84.2	0.34	0.50	0.25	35.8	1	1
Coefficient of variation	8.3	3.1	5.0	8.6	0.8	3.8	11.1	10.0

<sup>a</sup> American Institute of Baking (*n* = 32).

<sup>b</sup> University of Nebraska (*n* = 21).

**TABLE II**  
Evaluation of AIB<sup>a</sup> Test Bake Variables

Variable	Scale or Units	Mean	Standard Deviation	Minimum	Maximum	Coefficient of Variation (%)
Sponge character (SPNG)	0–6	4.00	0.90	1.00	5.00	16.1
Bake absorption (ABS)	%	58.4	3.1	50.0	66.5	1.8
Bake mixtime (MT)	min	13.5	9.6	2.5	68.0	41.3
Tolerance (MTO)	0–6	3.25	1.40	0.50	5.50	23.1
Proof time (PT)	min	59.8	8.2	42.0	86.0	5.9
Loaf volume (LV)	mL	2,712	160	2,150	3,100	2.4
Out-of-mixer (OOM)	0–6	4.10	1.00	1.00	5.75	18.2
At-make-up (AMU)	0–6	4.50	0.50	2.50	5.25	8.2
Texture (TXT)	0–6	4.75	0.25	3.50	5.25	8.2
Crumb color (CRCO)	0–6	4.20	0.70	2.00	5.50	11.2
Loaf grain (GRN)	0–10	6.25	1.10	2.50	9.00	11.8
Overall bake score (OVER)	1–10	4.0	1.7	0.5	8.0	26.8

<sup>a</sup> American Institute of Baking (*n* = 272).

**TABLE III**  
Evaluation of UNL<sup>a</sup> Test Bake Variables

Variable	Scale or Units	Mean	Standard Deviation	Minimum	Maximum	Coefficient of Variation (%)
Pilot-milled samples ( <i>n</i> = 280)						
Flour protein (PFPO)	%	13.6	1.8	9.1	18.5	4.2
Flour ash (PFLASH)	%	0.42	0.04	0.31	0.56	5.3
Bake absorption (PBABS)	%	60.8	1.5	57.0	64.0	1.1
Bake mixtime (PMT)	min	6.1	1.7	2.6	12.5	7.5
Loaf volume (PLV)	mL	905	81	625	1110	3.5
Loaf exterior (PEXT)	0–12	6	3	0	11	22.9
Loaf grain (PGRN)	0–12	7	2	2	11	17.5
Loaf texture (PTXT)	0–12	6	2	1	11	25.4
Buhler-milled samples ( <i>n</i> = 285)						
Flour protein (PFPO)	%	13.9	1.7	9.1	18.8	4.0
Flour ash (PFLASH)	%	0.42	0.04	0.31	0.56	5.3
Bake absorption (PBABS)	%	60.8	1.5	57.0	64.0	1.1
Bake mixtime (PMT)	min	5.8	1.6	2.3	11.0	7.6
Loaf volume (PLV)	mL	887	97	560	1,090	3.9
Loaf exterior (PEXT)	0–12	6	2	0	10	19.8
Loaf grain (PGRN)	0–12	7	2	0	10	15.4
Loaf texture (PTXT)	0–12	6	2	0	10	21.3

<sup>a</sup> University of Nebraska.

soy and cottonseed, Bunge Foods, Bradley, IL), 14 g of salt (food-grade flour salt, North American Salt Co., Overland Park, KS), 0.8 g of calcium propionate (ADM, Kansas City, MO), plus variable water as necessary to reach peak dough development. The sponge and dough mixture was mixed to a predetermined optimum time and allowed to rest for 20 min at 28.9°C. The dough was divided into two 524-g loaves and run through a straight grain molder. The molder had a head roll gap of 0.87 cm, a sheeter roll gap of 0.67 cm, and a 3.1- × 22.86-cm pressure plate. Molded loaves were placed in pans 7 cm deep and allowed to proof at 43.3°C and 85% rh until they had reached a height of 1.6 cm above the top of the pan. Loaves were baked for 22 min at 215°C.

Optimum water absorption of each flour was determined by mixing a full-formula dough at 65% absorption for 6 min in a Hobart

mixer. A 500-g sample was removed, transferred to the bowl of a Brabender Farinograph, and mixed for 2 min. Test dough absorption was adjusted by 1% per unit difference from an optimum of 480 Brabender units (BU). The position of the fully optimized dough was used as the base from which to measure subsequent test doughs. Once optimum water absorptions were established, doughs were mixed in the Hobart mixer to the point of breakdown. Mixing time of the doughs was established by mixing a series of doughs to at least three different mixing times, all shorter than the time required for overmixing. Loaves were baked at three different bake times. Optimum bake time was established by considering dough-handling conditions during mixing and make-up, and the internal and external characteristics of the loaves after baking. Fully optimized bread dough for each flour was rebaked using two

**TABLE IV**  
Evaluation of Mixograph Variables

Variable	Scale or Units	n	Mean	Standard Deviation	Minimum	Maximum	Coefficient of Variation (%)
Fixed absorption							
Peak time (FXEPT)	min	273	4.4	1.6	1.4	11.8	8.9
Peak height(FXEPTV)	%	273	63.4	10.0	37.1	95.3	4.5
Peak width (FXEPW)	%	273	27.5	7.0	12.2	49.1	11.2
Mix tolerance(FXMLTW)	%	270	17.8	2.8	10.1	25.1	7.4
Slope after peak(FXEAS)	b-value	262	-1.68	1.15	-6.89	0	-25.8
Area (FXEAI)	mm <sup>2</sup>	262	40.3	7.2	25.4	65.8	7.8
Optimized absorption							
Peak time (BAEPT)	min	271	4.07	1.3	1.5	9.4	10.2
Peak height(BAEPV)	%	271	65.2	10.0	41.4	95.2	4.3
Peak width (BAEPW)	%	271	29.4	7.8	14.4	64.5	11.0
Mix tolerance(BAMLTW)	%	270	18.5	3.1	9.2	28.7	8.2
Slope after peak(BAEAS)	b-value	265	-1.64	1.21	-7.62	0.16	-27.9
Area (BAEAI)	mm <sup>2</sup>	265	42.0	7.4	25.4	61.3	7.9

**TABLE V**  
Evaluation of Kernel and Protein Composition

Variable	Scale or Units	n	Mean	Standard Deviation	Minimum	Maximum	Coefficient of Variation (%)
Single kernel classification system							
Hardness, average (HAVG)	hardness units	278	66.7	9.9	38.4	89.7	3.5
Hardness, standard deviation (HSD)	hardness units	278	15.4	1.5	11.6	19.6	5.6
Seed diameter (DAVG)	mm	278	2.25	0.18	1.80	2.70	2.6
Seed weight (WAVG)	g	278	28.8	3.9	17.9	39.2	3.2
Protein quality <sup>a</sup>							
SDSS vol. (SDSS)	mL	280	37.0	5.0	22.0	45.0	4.0
Total glutenin (GLU)	%	190	0.48	0.03	0.37	0.56	4.2
Gliadin (GLI)	%	190	0.45	0.05	0.36	0.58	5.0
Albumins + globulins (ALBGLO)	%	190	0.08	0.05	0.01	0.16	15.4
Insoluble glutenin (INSGLU)	%	190	0.27	0.03	0.14	0.38	8.3

<sup>a</sup> Determined by SDS sedimentation test (SDSS) and size-exclusion HPLC.

**TABLE VI**  
Correlation (r) of Variables for Pilot-Milled Flours in AIB<sup>a</sup> and UNL<sup>b</sup> Test Bakes

AIB	UNL							
	PFPO	PFLASH	PBABS	PMT	PLV	PEXT	PGRN	PTXT
SPNG	0.22**c	-0.09	-0.12	0.03	0.32**	0.38**	0.15	0.15
ABS	0.58**	0.01	0.59**	-0.50**	0.16*	-0.02	-0.06	0.08
MT	0.41**	0.17*	0.11	0.21**	0.48**	0.36**	0.05	0.10*
MTO	0.38**	0.14*	-0.06	0.26**	0.55**	0.46**	0.18*	0.20**
PT	-0.64**	-0.14*	-0.37**	0.31**	-0.41**	-0.25**	-0.17*	-0.18**
LV	0.34**	-0.07	-0.05	0.07	0.63**	0.19**	0.11*	0.02
OOM	-0.03	-0.11	-0.01	-0.25**	-0.13*	0.03	0.07	0.03
AMU	0.22	-0.01	0.19**	-0.36**	-0.06	0.06	0.09	0.01
TXT	0.26**	-0.13*	0.11	-0.16*	0.35**	0.04	0.15*	0.09
CRCO	0.13*	-0.11	-0.17*	0.17*	0.41**	0.26**	0.12*	0.12*
GRN	0.14*	0.07	-0.30**	0.32**	0.49**	0.38**	0.24**	0.20**
OVER	0.29**	0.04	-0.18**	0.16**	0.42**	0.28**	0.26**	0.31**

<sup>a</sup> American Institute of Baking. For abbreviations, see Table II.

<sup>b</sup> University of Nebraska. For abbreviations, see Table III.

c \* =  $P < 0.05$ , \*\* =  $P < 0.01$ .

duplicate loaves. During and after the baking process several variables were measured: sponge character (0–6) absorption (%), bake mix time (min), dough feel out-of-mixer (0–6), dough feel at make-up (0–6), bake tolerance (0–6, a measure of the flours response over three different bake mix times), proof time (min), loaf volume (mL), texture (0–6), crumb color (0–6), loaf grain (0–6), and an overall bake score (1–10). A commercial flour sample was included with each test bake to evaluate consistency of bake procedures.

All pilot-milled samples also were baked in the University of Nebraska (UNL) wheat quality laboratory using a 100-g straight-dough pup loaf procedure (Approved Method 10-09, AACC 1995) with no added oxidants. Buhler-milled samples were baked using the same 100-g procedure. Variables recorded included: bake absorption (%), bake mix time (min), loaf volume (mL), loaf grain (0–12), loaf texture (0–12), and loaf exterior (0–12). Each test bake included a commercial flour sample as a control.

Dough strength parameters were measured at the UNL laboratory using a mixograph (National Manufacturing, Lincoln, NE), and mixograms were interpreted through use of Mixsmart software (National Manufacturing). Mixograph variables obtained included: peak time (time in minutes to peak dough resistance), peak height, peak width (width of mixogram at peak time), tolerance (width of mixogram at 2 min past peak dough development), slope (slope of decline of the mixogram after peak time), and area of the mixogram in the region between peak time and the point at which tolerance was measured. Mixograph tolerance, slope, and area provided measures of the dough's resistance to overmixing. Mixograms were obtained using both fixed absorptions (10 g of flour + 6 mL of H<sub>2</sub>O) and optimal absorptions. Optimal absorptions were estimated using absorption values obtained in the pup loaf bake procedure.

Flour protein content (dwb) was determined by combustion using a nitrogen analyzer (Leco Manufacturing Co., St. Joseph, MO). Protein quality was determined using the SDSS test and SE-HPLC. A 2-g modification of Approved Method 56-60 (AACC 1995) was used to determine SDSS volumes (mL). SE-HPLC methods were those of Gupta et al (1993). Total glutenin, insoluble glutenin, gliadin and albumin + globulin content were measured as percentages of total extracted protein. SDSS volumes were measured on pilot-mill samples from 1993, 1994, and 1995. SE-HPLC analyses were conducted on 1993 and 1994 samples.

Means, standard deviations, and minimum and maximum values were determined for all measured parameters. Coefficients of variation (CV) were determined from analysis of variance (ANOVA). For ANOVA, each location-year combination was treated as a separate environment. Main effects in the ANOVA were environment, cultivar, and cultivar-by-environment. Simple correlations (Steele and Torrie 1980) were used to describe relationships between all small-scale bake tests, mixograph variables, protein quality variables, and commercial test bakes. Each field plot of each cultivar was used as an observation. SAS statistical programs and procedures were used in all computations (SAS Institute, Cary NC).

## RESULTS AND DISCUSSION

Reproducibility of test bake procedures was determined using select variables from AIB and UNL test bakes and examining the range of response of commercial control flours (Table I). Both objective (proof time, loaf volume, and bake mix time) and subjective (loaf grain, loaf texture, and overall bake score) variables were consistent (CV < 10%). Significant variation was

TABLE VII  
Correlation (*r*) of Variables for Pilot-Milled Flours in AIB<sup>a</sup> Test Bakes and Mixograph<sup>b</sup> Variables

AIB	Fixed Absorption						Optimal Absorption					
	FXEPT	FXEPV	FXEPW	FXMLTW	FXEAS	FXEAI	BAEPT	BAEPV	BAEPW	BAMLTW	BAEAS	BAEAI
SPNG	-0.03	0.21** <sup>c</sup>	0.25**	0.19**	0.12*	0.26**	-0.04	0.25**	0.29**	0.17**	-0.11	0.31**
ABS	-0.53**	0.58**	-0.41**	0.21**	-0.44**	0.28**	-0.48**	0.46**	0.31**	0.05	-0.48**	0.09
MT	0.14*	0.50**	0.57**	0.51**	-0.22**	0.62**	0.13*	0.50**	0.58**	0.53**	-0.23**	0.60**
MTO	0.20**	0.38**	0.45**	0.47**	-0.09	0.51**	0.18*	0.40**	0.47**	0.53**	-0.10	0.57**
PT	0.32**	-0.52**	-0.43**	-0.35**	0.32**	-0.38**	0.27**	-0.33**	-0.27**	-0.18**	0.30**	-0.17**
LV	0.08	0.18**	0.15*	0.23**	0.07	0.20**	0.06	0.10	0.11	0.26**	0.08	0.17**
OOM	-0.17**	-0.10	-0.14*	-0.19**	0.01	-0.16**	-0.19**	-0.08	-0.10	-0.22**	-0.05	-0.16*
AMU	-0.29**	0.03	-0.06	-0.18**	-0.18**	-0.17**	-0.27**	-0.07	-0.14*	-0.32**	-0.18**	-0.28**
TXT	-0.15*	0.27**	0.17**	0.08	-0.17**	0.09	-0.18**	0.23**	0.16**	0.12*	-0.11	0.10
CRCO	0.14*	0.17**	0.22**	0.14*	-0.06	0.20**	0.08	0.25**	0.31**	0.25**	-0.04	0.33**
GRN	0.31**	0.09	0.09	0.19**	0.15*	0.16**	0.27**	0.01	0.11	0.29**	0.15*	0.26**
OVER	0.15*	0.13*	0.16**	0.26**	0.08	0.22**	0.12	0.12	0.19**	0.31**	0.05	0.31**

<sup>a</sup> American Institute of Baking. For abbreviations, see Table II.

<sup>b</sup> For abbreviations, see Table IV.

<sup>c</sup> \* = *P* < 0.05, \*\* = *P* < 0.01.

TABLE VIII  
Correlation (*r*) of AIB<sup>a</sup> Test Bake Variables with SDS Sedimentation Volumes (SDSS) and Flour Protein Fractions<sup>b</sup>

AIB	SDSS	GLU	INSOLGLU	GLI	ALBGLO
SPNG	0.21** <sup>c</sup>	0.13	0.09	-0.12	-0.03
ABS	0.16**	0.03	-0.26**	0.34**	-0.39**
MT	0.18**	0.01	0.15*	-0.20**	0.21**
MTO	0.32**	0.19*	0.18**	-0.27**	0.15*
PT	-0.33**	-0.37**	0.25**	-0.25**	0.53**
LV	0.39**	0.15*	0.06	-0.16*	0.06
OOM	0.07	-0.05	-0.13	0.16*	-0.14
AMU	0.03	0.14	-0.29**	0.30**	-0.42**
TXT	0.16*	0.08	-0.02	-0.07	0.02
CRCO	0.22**	-0.08	0.26**	-0.23**	0.30**
GRN	0.38**	0.23**	0.14*	-0.11	-0.04
OVER	0.44**	0.28**	0.07	-0.05	-0.16*

<sup>a</sup> American Institute of Baking. For abbreviations, see Table II.

<sup>b</sup> Flour protein fractions determined by size-exclusion HPLC. For abbreviations, see Table V.

<sup>c</sup> \* = *P* < 0.05, \*\* = *P* < 0.01.

associated with all main effects for all measured variables (ANOVA, results not shown). Even though all samples were derived from released cultivars, a wide range in response was detected for most variables (Tables II–V) and approximated that encountered in early-generation breeding programs. The observed range in variation arose from the selection of cultivars to represent diverse quality types and the large number of sampled environments. For most objectively determined variables generally CV < 15%. Variables with CV > 20% included AIB bake mix time, AIB tolerance, AIB overall bake score, UNL loaf exterior and texture, and mixograph slopes. With the exception of mixograph slopes, all variables with these high CV values are based on subjective ratings by bakery personnel.

Simple correlations between commercial test bake variables (AIB) and 100-g pup loaf bake variables (UNL) for the pilot-milled samples from 1993, 1994, and 1995, are presented in Table VI. Numerous variables were recorded in each bake procedure, and all

**TABLE IX**  
Correlation (*r*) of AIB<sup>a</sup> Test Bake and Single Kernel Characterization System<sup>b</sup> Variables

AIB	HAVG	HSD	DAVG	WAVG
SPNG	-0.16** <sup>c</sup>	-0.03	-0.15*	-0.20**
ABS	0.29**	-0.39**	0.09	0.21**
MT	0.02	-0.11	-0.14*	-0.13*
MTO	-0.05	-0.09	-0.26**	-0.26**
PT	-0.19**	0.28**	0.15*	0.03
LV	-0.26**	0.03	-0.34**	-0.30**
OOM	-0.08	0.12*	-0.01	-0.01
AMU	-0.01	-0.06	-0.03	-0.01
TEXT	0.02	-0.15	0.01	0.05
CRCO	-0.29**	0.06	-0.07	-0.12
GRN	-0.20**	0.14*	-0.28**	-0.33**
OVER	-0.12*	-0.01	-0.29**	-0.30**

<sup>a</sup> American Institute of Baking. For abbreviations, see Table II.

<sup>b</sup> For abbreviations, see Table V.

<sup>c</sup> \* = *P* < 0.05, \*\* = *P* < 0.01.

**TABLE X**  
Correlations (*r*) of Identical Pup Loaf Variables

Variable	Pilot-Milled vs. Buhler-Milled
Flour protein content	0.89** <sup>a</sup>
Flour ash content	0.42**
Bake absorption	0.57**
Bake mix time	0.92**
Loaf volume	0.82**
Loaf exterior	0.68**
Loaf grain	0.50**
Loaf texture	0.55**

<sup>a</sup> \*\* = *P* < 0.01.

**TABLE XI**  
Results (*r*<sup>2</sup>) of Stepwise Regression Analyses

AIB <sup>a</sup>	Stepwise Regression Model <sup>b</sup>	
	Three-Year	Two-Year
SPNG	0.30	0.33
ABS	0.60	0.63
MT	0.54	0.57
MTO	0.57	0.60
PT	0.51	0.47
LV	0.62	0.59
OOM	0.17	0.16
AMU	0.30	0.40
TEXT	0.19	0.21
CRCO	0.30	0.44
GRN	0.43	0.49
OVER	0.40	0.46

<sup>a</sup> American Institute of Baking. For abbreviations, see Table II.

<sup>b</sup> All parameters from small-scale analyses used as independent variables. Two-year analyses include size-exclusion variables; three-year analyses do not.

are of potential commercial importance. Hence, correlations were calculated using the entire matrix, not just between like variables, with the rationale that wheat breeders would be interested in identifying *any* small-scale variable capable of predicting *any* commercial variable. The most useful variables in the small-scale procedures appear to be protein content and loaf volume. UNL loaf volumes showed significant positive correlations above *r* = 0.50 not only with AIB loaf volumes, but with bake mix time, tolerance, crumb color, loaf grain, and overall bake score. Protein content was significantly correlated with AIB absorption and mixing properties, but showed low or nonsignificant correlations with loaf properties. The highest correlation between any variable for UNL and AIB was *r* = 0.63, observed with the intercorrelation of loaf volumes. Loaf grain scores frequently are described as being the most important attribute in commercial baking procedures. Pup loaf grain scores were significantly correlated with commercial grain scores but only at *r* = 0.25. Hence, pup loaf grain scores explain only 6.25% (*r*<sup>2</sup>) of the variation in commercial grain scores. In contrast, pup loaf volumes explained more than 24% of the variation in commercial loaf grain scores.

In standard mixograph procedures, “. . . the majority of workers have favored use of absorptions adjusted to each flour’s bread-baking requirements as giving more generally informative results” (Approved Method 54-40, AACC 1995). To obtain rapid results with large numbers of tested lines, many small-scale laboratories perform mixograph analyses using fixed absorptions adjusted to typical protein contents within a lot of samples. In the present study, mixograph analyses were conducted using both fixed (60%) and optimal absorptions. Correlations of mixograph variables with AIB test bake variables (Table VII) were nearly identical when the two methods were compared. Using fixed absorptions in breeding programs seems a legitimate approach. Numerous significant correlations were obtained between mixograph variables and AIB test bakes, but in general, absolute values were *r* < 0.50. The highest correlations were observed between peak height, peak width, and mixograph tolerance, with the AIB variables bake mix time and bake tolerance. Mixograph peak time was significantly correlated with AIB absorption, bake mix time, and proof time.

SE-HPLC separation of wheat flour proteins has been advocated as a possible early-generation selection tool for improved wheat quality (Singh et al 1990a,b; Gupta et al 1993). Correlations between various protein fractions and AIB test bake variables (Table VIII) often were nonsignificant. Correlation between albumins+globulins and AIB proof time did exceed that observed with nearly all other UNL test bake or mixograph variables. In general, though, all significant correlations were *r* < 0.5. The far less expensive and technically simpler SDSS test was more highly correlated with AIB sponge characteristics, tolerance, loaf volume, loaf grain, and overall bake score. Many programs substitute SDSS tests for pup loaf volumes, especially during early-generation selection. Correlations of pup loaf volume with AIB variables, however, exceeded those of SDSS volumes (Tables VI and VIII).

The single kernel classification system scored 90% of the samples as hard wheats; the remainder were classified as mixed. No samples were classified as soft. Significant correlations between grain hardness, size, weight, and AIB test bake variables were observed. However, all correlations were low, with absolute values of *r* < 0.33 (Table IX).

Milling procedures represent another potential source of variation between small-scale test bake laboratories and commercial test laboratories. Pup loaf test bakes were used to compare laboratory Buhler-milled samples to pilot-milled flour. Bake procedures were identical. Correlations between all variable pairs were highly significant (Table X). High correlations (*r* ≥ 0.8) observed with protein content, bake mixing time, and loaf volumes suggested little variation arose due to milling procedures. Correlations with loaf exterior, loaf grain, and loaf exterior were lower, though still significant. Differences between these variables could arise merely as a result of

random error; these are subjective scores with relatively high CV values assigned by laboratory workers. Correlations between ash contents and absorption, however, were only  $r = 0.42$  and  $0.57$ , respectively. These measures are objective; the lower correlations indicate some physical flour differences. These observed differences in flour composition did not influence protein content, bake mixing times, or loaf volumes, but they may have contributed to differences in loaf properties.

Stepwise multiple regression models (Table XI) explained, on average, 40% ( $r^2 = 0.40$ ) of the variation in any given AIB bake variable. The amount of variation explained ranged from <30% for sponge character, dough properties at make-up and out-of-mixer, loaf texture, and crumb color to > 60% for loaf volume and bake absorption. Numerous independent variables contributed to the models, but only small-scale loaf volumes and mixograph area explained the major portion of the variation in more than one AIB variable. Pup loaf bake absorption most frequently occurred as a significant model factor. SDSS volume and SE-HPLC fractions (when included in the two-year analyses) rarely contributed. This may indicate loaf volume as an assessment of protein quality is more useful than these alternative approaches. SDSS and SE-HPLC may still be valuable if available sample size is small or an assessment of protein quality on numerous breeding lines is desired.

Results of this study suggest small-scale wheat quality tests explain less than one-half the observed variation in commercial-scale test bakes. Wheat breeders may now question the utility of using small-scale tests as selection tools, when such tests still leave a major portion of the variation unexplained. Small-scale tests still have utility, however, in that they can be used to eliminate truly wretched wheat genotypes, especially those characterized by low dough strength. Elimination of otherwise promising lines based on suboptimal pup loaf grain scores, however, is not warranted. Pup loaf grain scores and commercial test bake loaf grain scores showed little agreement.

To some, the solution to the wheat breeders' dilemma may seem obvious. Wheat breeders simply should use commercial test bake procedures as tools in the selection of improved cultivars. Unfortunately, as noted above, use of commercial test bakes would require a fourfold increase in the size of the typical wheat breeding program. Land seeded to breeding trials, number of plots harvested, and field and laboratory crews; all would have to quadruple in size. In addition, massive capital investment in planting and harvesting equipment and in commercial test bake facilities would be required. Funds for such endeavors are wanting, especially when the marketplace offers few incentives for the production of high baking quality wheats.

The only reasonable options available to wheat breeders seem to be those currently used. Cultivars identified as having acceptable or superior quality in commercial settings should be chosen as parents in wheat breeding programs. These parents may be intermated with the goal of selecting progeny with improved quality. Several problems hinder progress with this approach. Cultivars with commercially superior quality can not be identified until after they enter production systems. Hence, 10 years might elapse before such lines, when used as parents, contribute to a new round of cultivars. Secondly, the heritability of bake performance traits has not been well defined. If heritabilities are low, the chances of capturing bake performance of a parental line in progeny lines are low. Finally, without adequate tests to identify lines with commercially superior quality, breeding progress will remain difficult.

Economic constraints will force wheat breeders to continue to rely on current, albeit imperfect, selection tools. Quick, inexpensive early-generation tests such as mixograph analyses to eliminate lines with weak doughs, followed by bake tests in later generations, will likely continue. This article does suggest some changes in interpretation of small-scale bake results are warranted. Loaf grain scores from pup loaves have little utility in predicting commercial test bake performance; thus, there seems to be little to be gained by scoring pup loaves for this trait. Also, for a number of years, the U.S. baking industry has discouraged wheat breeders from selection for higher loaf volumes. This opinion was based on the perception that most U.S. hard wheat cultivars gave adequate loaf volumes in commercial settings, and improvements were not necessary. However, as pup loaf volume was significantly correlated to several commercial bake variables, selection for higher loaf volumes by wheat breeders could lead to improved overall commercial bake quality. High loaf volume in pup loaf tests most likely serves as the best indicator of flour protein quality. Improvements in protein quality likely may lead to improved commercial bake performance.

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