Rapid Assessment and Prediction of Wheat and Gluten Baking Quality With the 2-g Direct Drive Mixograph Using Multivariate Statistical Analysis

B. J. Dobraszczyk[1,2] and J. D. Schofield[1]

ABSTRACT

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A computerized 2-g direct drive mixograph was used to study the mixing characteristics of flours milled from a range of breadmaking cultivars obtained from five separate locations around the UK, providing 54 flour samples. Fifteen parameters were extracted from each mixograph trace using the Mixsmart software program and correlated with baking volume using partial least squares multiple regression statistical analysis to give a prediction of baking volume. Location had a considerable influence on the prediction of baking volume. Excellent predictions of baking volume were obtained from flours from individual locations (R^2 = 0.805–0.995), but predictions based on all cultivars without discriminating locations were poor. When mixograph and baking volume data for each cultivar were averaged over all five locations, a very high correlation was obtained (R^2 = 0.999). Preparation of flour samples using rapid, small-scale milling procedures (Brabender Quadrumat Jr. mill and Perten 3100 hammer mill) did not have any adverse effect on prediction of baking volume. Mixograph parameters obtained from six commercial glutens of varying quality gave good correlations with test baking volumes, based on 6% gluten addition to a control flour.

There is a pressing commercial need among wheat breeders and millers for a rapid and reliable means of predicting the baking quality of commercial wheat samples. The principal requirement for such tests is that they are rapid, technically simple, and that the sample size is small—from one kernel up to a few ears. None of the tests used currently, such as the SDS sedimentation test, Falling Number test, or test for high molecular weight glutenin subunits (HMW-GS) using SDS-PAGE gives reliable results for predicting baking quality of newly derived progeny in the breeding of wheat cultivars; many are too slow and technically difficult to allow them to be used as a rapid quality test.

New wheat crosses and parental candidates for crossing in breeding programs require screening for quality in large numbers before selection, and the most relevant quality attribute is baking performance. The trial baking test conducted on small batches of flour under near-commercial baking conditions is currently the most widely used test for the assessment of differences in baking quality among new breeding lines of wheat. But it has the disadvantage of being slow, labor intensive, requiring relatively large amounts of wheat, and requiring highly trained staff, and specialized facilities and equipment. In many countries, many wheat cultivars are of poor breadmaking quality (feed or biscuit wheats). Although these cultivars have greater agronomic yield, they are unsuitable for breadmaking and are either used as animal feed or have to be supplemented with higher quality breadmaking wheat, often imported from abroad. However, the emphasis on wheat production is increasingly being driven by end-use quality requirements rather than agronomic yield. There is, therefore, a need to breed new, higher quality cultivars suitable for local climatic and agronomic conditions and for breadmaking in medium-to-large automated bakeries. Therefore, it is important to seek tests that relate directly to commercial baking performance rather than to optimized baking tests or indirect flour quality parameters that often have little direct relationship to commercial baking performance.

Both the mixograph and farinograph have been used to predict dough processing properties and baking quality, mainly based on visual assessments of their mixing traces such as mixing tolerance score, or some arbitrary selection of a single parameter derived from the trace such as mixing time to peak or peak height (Dobraszczyk 2001). In the literature, the most widely used mixograph parameter to discriminate quality has been peak mixing time. However, several recent publications have shown that peak time was a poor discriminator of baking quality as measured by loaf volume. Khatkar et al (1996) used the computerized 2-g mixograph to relate mixing characteristics to an optimized microbaking quality test developed by Finney (1984), using a range of flours and glutens obtained from the UK, Canada, and France. They found that peak time did not correlate with loaf volume, but a highly significant correlation was found between peak height and loaf volume for flour (R^2 = 0.82) and gluten samples (R^2 = 0.91). Martinant et al (1998) investigated relationships between various wheat grain quality indices and parameters obtained from an instrumented 10-g mixograph. They also found that peak time was a poor parameter to explain breadmaking quality but found strong relationships between loaf volume and peak height and peak bandwidth. Wikström and Bohlin (1996) found that no single mixograph parameter could successfully predict baking performance in a range of Swedish breadmaking wheat cultivars, and showed that baking volume could be predicted more successfully by statistical selection of several parameters from the mixograph trace using multivariate statistical analysis. Chung et al (2001) used a new multivariate calibration technique, continuum regression (CR), to obtain regression models that predict baking characteristics from computer-analyzed mixograph parameters.

These results suggest that the use of a single parameter in describing the mixing characteristics of a dough does not give a reliable indication of its baking quality. Each different sample set of flours used probably requires a different set of mixing parameters to relate to baking quality, and therefore would require a separate regression model to predict baking performance. The major problem is that current interpretation of mixing curves is highly subjective and is based as much as on the "feel" of the operator as on any objective assessment of the curve. Complete quantification of a complex mixing trace such as that obtained from torque recording mixers is difficult and has not yet been tackled to any satisfaction. Various workers have attempted to take objective measurements by fixing readings at particular points on the curve, taking slopes, bandwidths, and areas under the curve, but these do not amount to a complete quantitative description of the trace, and deciding where these points are fixed is still subjective. The work of Wikström and Bohlin (1996) and Chung et al (2001) has shown that statistical selection of several parameters describing the mixograph trace using multivariate statistical analysis provides a better approach than selecting a single arbitrary fixed point from the mixing trace.

The mixograph (National Mfg. Div., TMCO, Lincoln, NE), first described by Swanson and Working (1926, 1933), was originally designed to simulate the action of high-speed commercial mixers used in the United States. The mixograph is a recording mixer that

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*The *e*-Xtra logo stands for "electronic extra" and indicates the HTML abstract available on-line contains links to supplemental material.

[1] School of Food Biosciences, PO Box 226, Whiteknights, The University of Reading, Reading, RG6 6AP, UK.

[2] Corresponding author. E-mail: b.dobraszczyk@reading.ac.uk.

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uses planetary rotating pins oriented vertically to mix the dough in a bowl with three fixed pins. Torque during mixing is recorded either by a pen on chart paper, or electronically, or in more recent versions by recording electrical output from the motor driving the pins. Mixing traces similar to those recorded by the farinograph are obtained. The detailed mixing traces appear quite different from those obtained from the farinograph because of the nature of the mechanical connections between the dough mixer head and torque recording device and also because of the different nature of mixing action between the two. Gras et al (2000) showed that the mixing action in the mixograph is mainly extensional, and that the changing bandwidth of the mixing trace is a qualitative measure of the changing extensional viscosity occurring in a dough during mixing. In general, the mixograph uses much smaller samples. The latest models require only 5 g (Finney 1989) or 2 g of flour (Rath et al 1990), while older models use 10 g (Finney and Shogren 1972) or 35 g. The 2-g direct drive instrumented mixograph was developed by Rath et al (1990) to study the effects of small quantities of protein fractions on reconstituted flours. The power demand to a constant speed direct drive motor is directly measured to give an indication of the torque variations during mixing of the dough. However, the power demand is affected by other factors in addition to the resistance to mixing of the dough: frictional losses in the drive system vary according to temperature (a problem if a constant laboratory temperature is not maintained), and wear in the drive system after considerable use causes possible drift in the instrument readings. No easily performed user calibration (such as hanging a weight on the farinograph mixer arm) of the instrument is possible. This could be a considerable drawback of the mixograph, especially for use in quality control purposes where calibration is considered essential.

The objectives of this study were to provide an initial evaluation of the computerized 2-g mixograph procedure as a rapid means of assessing the baking quality of UK wheat cultivars, and as a means of assessing the breadmaking quality of commercial wheat glutens.

Abbreviation	Description of Parameter
MPH	Midline peak height
MPT	Midline peak time
MPA	Midline peak area
MPW	Midline peak bandwidth
M30SA	Midline area to 30 sec
M30SW	Bandwidth at 30 sec
M30SS	Slope of the midline to 30 sec
10MH	Midline height at 10min
10MW	Bandwidth at 10 min
10MA	Midline area to 10 min
MLS	Midline left slope
MRS	Midline right slope
EPH	Envelope peak height
E30ST	Envelope height at 30 sec
E30SS	Envelope slope to 30 sec

Fig. 1. Abbreviations and parameter descriptions of preselected data acquisition and trace analysis variables for Mixsmart (v. 3.40) program.

MATERIALS AND METHODS

Wheat and Flour

Samples of wheat and flour were provided by the Campden and Chorleywood Food Research Association (CCFRA) from the 1996 harvest Recommended List (RL) from five separate locations around the UK: Bridgets, Harper Adams, Morley, Rosemaund, and Seale Hayne. The total of 54 samples encompassed all the major commercially used breadmaking and biscuit flour wheats in the UK. The flour samples provided by CCFRA were milled in a Bühler laboratory mill. Some of the wheat samples were test-milled at Reading using 1) a Brabender Quadrumat Jr. mill for white flours of ≈60% extraction, and 2) a Perten 3100 hammer mill for whole meal flours to investigate the effect of rapid, small-scale milling on the mixograph characteristics.

Baking Procedure

The flours had been previously test baked at CCFRA using the Chorleywood Bread Process (CBP). Test baking was performed in duplicate. Water addition level was calculated from 600 BU farinograph water absorption. The formula used standard CBP ingredients, based on % flour weight of 1,000 g: yeast 2.5, salt 2.0, fat (Ambrex) 1.0, ascorbic acid 100 ppm, fungal α-amylase 40 FU). Flours were mixed in a Morton mixer to a fixed work input of 11 Wh/kg at atmospheric pressure to a target temperature of 30 ± 1°C. The dough was scaled by hand into two 454-g pieces and proved at ambient temperature for 10 min before final molding into a single-piece cylinder into a greased unlidded tin. Doughs were proved to constant height (10 cm) at 43°C at high humidity and then baked in a direct gas-fired reel oven at 244°C for 25 min. The loaves were allowed to cool on an open rack at room temperature and then stored overnight in a closed cupboard at 21°C. Loaf volume measurement was by seed displacement.

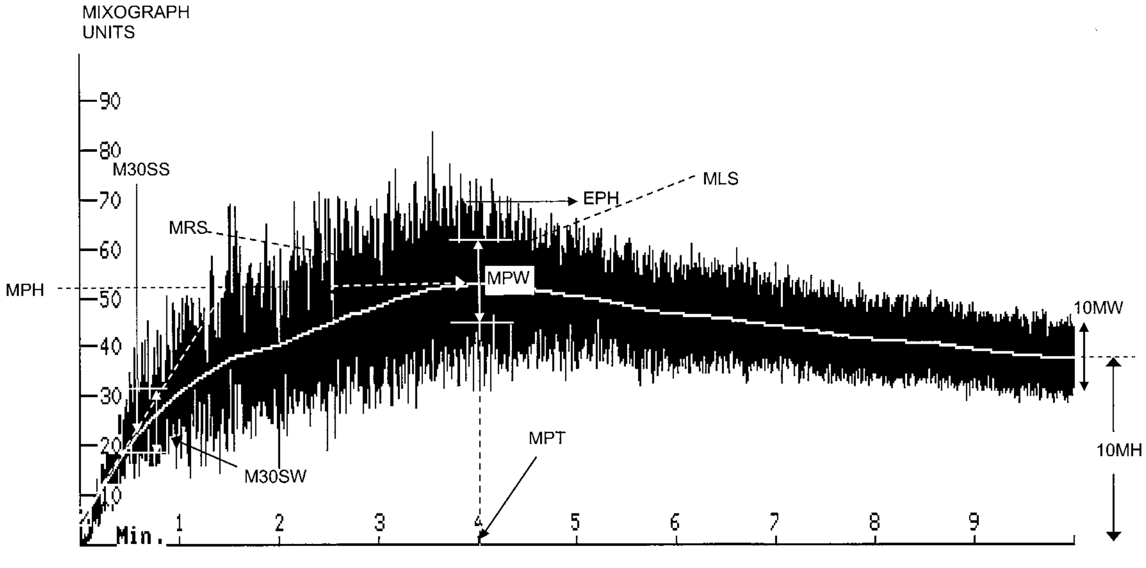

Fig. 2. Typical mixing trace recorded using the 2-g computerized mixograph with parameters as defined in Fig. 1.

Mixograph Measurements

Mixing tests were performed on the 2-g direct drive computerized mixograph. All tests used 2 g flour and water was added according to the water addition figures provided by CCFRA. For the gluten samples, 3.7 g of water was added to 2 g of dried gluten to give 65% water (based on final wet weight), and the gain setting on the mixograph was set fully anticlockwise. All measurements were made in an air-conditioned laboratory (21 ± 1°C, 25% rh).

Before the start of mixing, preselected data acquisition and trace analysis variables can be set in the Mixsmart (v. 3.40) program. The mixer was started with a PC and the mixing trace was displayed in real time on the PC monitor. The mix time was set at 10 min, and data were recorded at 10 points per second (pps) with a mixing head speed of 88 rpm. At the end of mixing, the trace was automatically recorded and analyzed using the Mixsmart software program. Using this software, various pre-selected parameters can be chosen by the user from the mixing trace (Figs. 1 and 2).

The Mixsmart software constructs a midline curve from the recorded mixing trace (Fig. 2) and an upper and lower envelope (not shown). The software can be used to analyze both the upper envelope and midline curves. A number of parameters were derived from the midline trace: peak height (MPH), the maximum height of the midline curve expressed as a percentage of full-scale mixograph units; peak time (MPT), the time in minutes at midline peak height; peak area (MPA), the integral of the area under the midline trace to peak; peak bandwidth (MPW), the height between the upper and lower envelopes at the peak. Ascending and descending slopes about the peak (left and right of peak slopes, MLS and MRS) were also calculated. An arbitrary time of 30 sec was selected at which to calculate area (30SA), slope (30SS) and bandwidth (30SW), mainly to compare results with those described by Wikström and Bohlin (1996). Upper envelope parameters recorded were: peak height (EPH), height at 30 sec (E30S); and slope to 30 sec (E30SS).

Statistical Analysis

Statistical analysis of the data was performed using partial least squares (PLS) multiple regression using Minitab for Windows 95 (v. 11.2) statistical software package. Regression analysis describes the relationship between a response variable (in this case, baking volume) and one or more predictors (mixograph parameters). A number of further options are available in Minitab regression analysis: 1) stepwise regression for selecting predictors from a pool of potential variables; 2) best subsets regression for choosing best subsets of predictors from a pool of potential variables; and 3) % fit line for a polynomial regression and plot of a fitted regression line.

RESULTS AND DISCUSSION

Baking Volumes

CBP (Chorleywood Baking Process) baking volumes for all the Recommended List (RL) breadmaking cultivars and locations are shown in Fig. 3. These suggest no major differences in baking volume between most cultivars when averaged over the five locations. Differences are apparent only between those cultivars at the extremes of baking volume, for example, between Hereward and Charger with high average baking volumes and between Magellan and Soissons with the lowest average baking volumes. Comparison of baking volumes for cultivars grown at individual locations shows greater differences between locations than between cultivars, indicating a considerable effect of growing location on baking performance within a cultivar (Fig. 3). This highlights the danger in assuming that flours from a single cultivar will have similar quality attributes regardless of origin.

Correlation Between Mixograph, Wheat Quality, and Baking Parameters

Baking and wheat quality data were correlated with mixograph parameters. Initially, all 15 recorded mixograph parameters were cor-

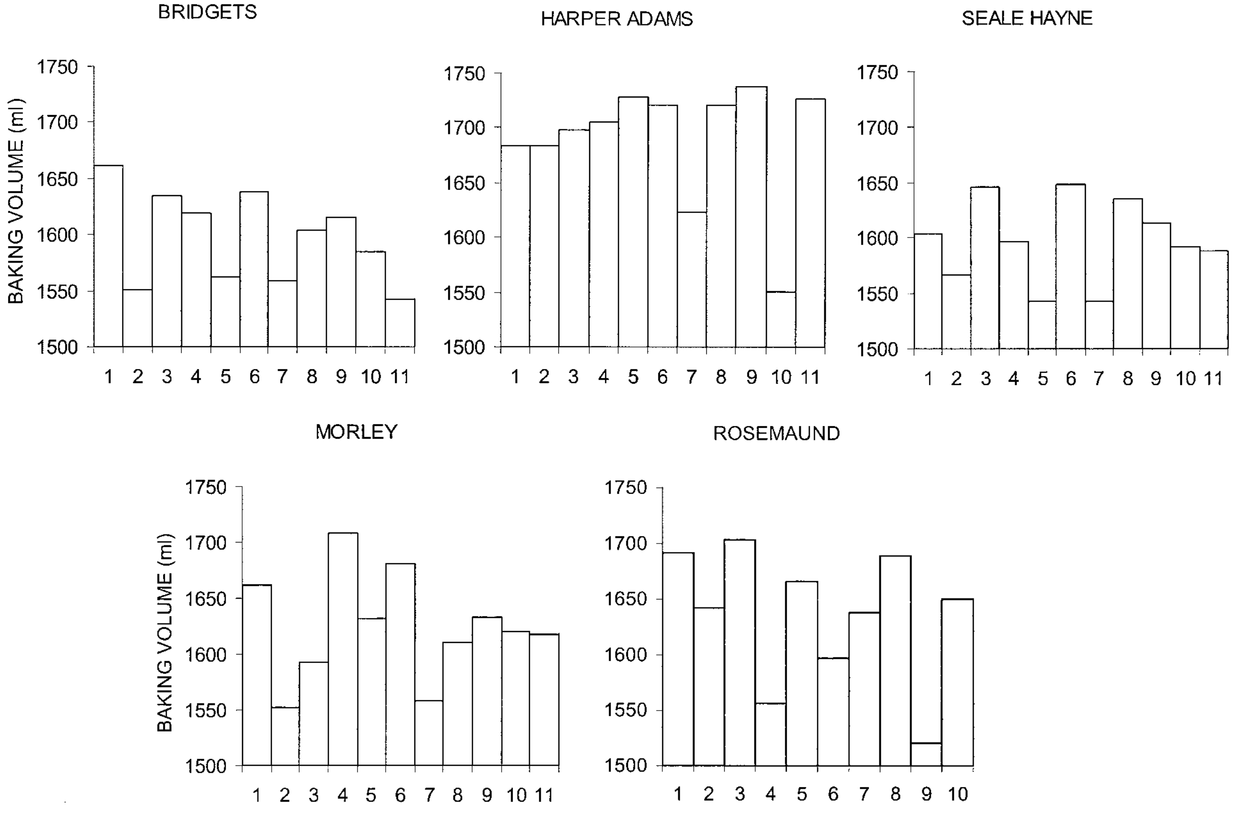

Fig. 3. Baking volumes for UK Recommended List breadmaking cultivars (1, Abbot; 2, Cadenza; 3, Caxton; 4, Charger; 5, Chianti; 6, Hereward; 7, Magellan; 8, Mercia; 9, Rialto; 10, Soissons; 11, Spark) grown at five different locations.

related individually with the quality data to give a series of linear correlation coefficients (*R*), the most significant of which are shown in Table I. Flour protein content had highly significant and relatively high correlations with the mixograph parameters MPH ($R = 0.766$), 10MA ($R = 0.741$), and EPH ($R = 0.711$), supporting the results of Chung et al (2001) and Khatkar et al (1996), who also found good correlations between flour protein (FP) content and MPH. SDS volume had low correlations with flour protein and baking volume, but reasonable correlations with several mixograph parameters. Baking volume had very low and insignificant correlations with protein and SDS volume. The mixograph parameters were then included as predictors in multiple regression analysis, where best subsets regression was used to exclude mixograph parameters that did not contribute significantly to baking volume. Best subsets regression can be used to select the smallest group of parameters (subset) that accounts for the largest amount of variation (R^2) in volume. Best subsets provide three values that can be used for subset selection (R^2, R^2_{ADJ} and *Cp*. R^2) indicating how well the data (baking volume vs. mixograph parameters) are fitted by a straight line, and is often used as an indication of how well the prediction is working. However, caution should be exercised because R^2 always increases with the number of parameters used. A large number of parameters will always give a larger R^2 than a smaller number, and if models contain different numbers of parameters, then R^2_{ADJ} should be used. R^2_{ADJ} is an approximately unbiased estimate of the population R^2 to allow for changes in the number of parameters used. Mallows *Cp* statistic (Gilmour 1996) can also be used to select the optimum number of parameters in multiple linear regression. In general, the *Cp* value should be low and close to *p*, the number of parameters used in the model. A low *Cp* value indicates that the model is relatively precise in predicting future responses, while a high *Cp* value shows a considerable overfitting of the data. The subsets selected for prediction were based on a maximum value of R^2_{ADJ} and a minimum value of *Cp*.

TABLE I
Simple Linear Correlation Coefficients (*R*) Between Mixograph and Flour Quality Parameters

Flour Quality Parameter	Correlation Coefficient (*R*)	*P* Value
Flour Protein[a] (%) vs:		
Midline peak height (MPH)	0.766	0.000
10 min area (10MA)	0.741	0.000
Envelope peak height (EPH)	0.711	0.000
10 min height (10MH)	0.682	0.000
Midline peak bandwidth (MPW)	0.592	0.000
Baking volume	0.136	0.323
SDS volume vs:		
10 min bandwidth (10MW)	0.762	0.000
10 min height (10MH)	0.692	0.000
Midline peak bandwidth (MPW)	0.643	0.000
10 min area (10MA)	0.630	0.000
Midline peak area (MPA)	0.620	0.000
Flour protein	0.327	0.015
Baking volume	0.302	0.054

[a] On a 14% flour moisture basis.

Table II shows multiple regression between baking volume and mixograph parameters for various groups of flour samples and locations. When the baking volumes for the individual cultivars from all locations were used in the regression analysis, a poor correlation was obtained. The regression ($R^2 = 0.177$) indicated a poor fit to the data and suggested that baking volume is poorly predicted by the mxograph parameters alone. The prediction of volume is improved if protein is added to the multiple regression prediction, R^2 increasing to 0.417, although protein by itself is a poor predictor of volume. Best subsets regression was used to show those mixograph parameters that contributed the greatest amount of variation to baking volume.

It is possible that regression predictions of volume are influenced by the markedly different distributions of baking volumes and mixograph parameters between different groups of samples, for example between different locations as shown in Fig. 3. To investigate further, the total sample group was split up into individual locations, and regressions were calculated independently for each group using best subsets regression, with and without protein. The data are shown in Table II, with the optimum number of mixograph parameters selected by best subsets regression. Figure 4 shows the best subsets fitted regression lines for locations Harper Adams, Seale Hayne, Rosemaund, and Morley. Regressions for individual locations are considerably improved, giving R^2 values of 0.805–0.995 with protein included and 0.643–0.978 with protein excluded from the prediction. This shows that growing location has a considerable effect on the prediction of baking volume using mixograph parameters. Inclusion of protein in the regressions for individual locations improves the prediction of volume but the effect is not as large as observed previously for the whole data set. This shows that protein by itself is a poor predictor of baking quality, especially within groups of breadmaking flours where there are no major differences in protein. But, when combined with mixograph parameters in a multiple regression, a good prediction of volume can be obtained.

Another approach to minimizing variation due to location is to calculate the regression between volume and mixograph parameters for each cultivar averaged over all five locations. Best subsets regression on location-averaged cultivar data gives a high correlation with selected mixograph parameters ($R^2 = 0.999$, $R^2_{ADJ} = 0.987$, $Cp = 8.0$) (Table II and Fig. 5). This further underlines the importance of location on mixograph baking correlations. The regression prediction

TABLE II
Predicting Baking Volume and Gluten Quality Using Best Subsets Multiple Regression of Mixograph Parameters

			Best Subsets Regression							
			With Protein				Without Protein			
	n	Selected Mixograph Parameters[a]	R^2	R^2_{ADJ}	*Cp*	*P*	R^2	R^2_{ADJ}	*Cp*	*P*
Breadmaking cultivars	54	All 15 mixograph parameters	0.417	0.331	5.0	0.323	0.177	0.053	14.0	0.936
Breadmaking locations										
Bridgets	11	MPH/MPA/30SS/10MH/10MA/MRS/EPH	0.805	0.396	7.4	0.394	0.776	0.384	8.0	0.426
Harper Adams	11	MPH/MPT/MPA/10MA/MRS	0.899	0.746	7.0	0.054	0.848	0.695	6.0	0.041
Seale Hayne	11	MPH/MPT/MPA/30SS/10MH/10MA/MRS/EPH	0.995	0.948	10.0	0.166	0.978	0.900	9.0	0.086
Morley	11	MPH/MPT/MPA10MH/10MA/MRS/EPH	0.885	0.616	6.3	0.434	0.643	0.287	8.0	0.651
Rosemaund	10	MPH/MPT/MPA/10MH/10MA/MRS/EPH	0.947	0.526	7.0	0.477	0.840	0.520	7.0	0.457
Cultivar data[b]	12	MPH/MPT/MPA/30SA/30SW/30SS/10MA	0.999	0.987	8.0	0.094	0.703	0.543	1.6	0.279
Quadrumat milled	20	MPA/MPW/30SA/30SS/30SW/10MH/10MA/MLS/MRS/EPH	0.895	0.750	10.0	0.008	0.948	0.860	7.3	0.004
Perten milled	12	MPH/MPT/30SS/10MA/EPH	0.917	0.793	6.0	0.037	0.889	0.796	4.4	0.010
Gluten quality	6	MPW/10MH/EPH	0.971	0.854	5.0	0.254	0.969	0.924	3.0	0.045

[a] Definitions as in Fig. 1.
[b] Location-averaged.

successfully distinguishes Magellan and Soissons with the lowest average baking volumes, despite the fact that they have very different mixing traces and protein levels. Chianti, Cadenza, and Spark form an intermediate group. A distinct group of cultivars (Mercia, Caxton, Shango, Rialto, Abbot, Charger, Hereward) is discriminated at the higher end of the baking volume scale.

Effect of Milling Procedure on Mixograph Correlations

The effect of milling procedure on mixograph correlations with baking was investigated. Wheat samples were selected for rapid milling using the Brabender Quadrumat and Perten 3100 Falling Number mills. While Bühler milled flours provide white flour similar to commercially milled flour and are appropriate for many of the currently used quality tests, the procedure takes too long for rapid intake testing, whereas cruder, more rapid and small-scale milling techniques such as Quadrumat and Perten would be more desirable in an intake testing environment. Table II shows the fitted best subsets regression for CBP volume versus selected mixograph parameters for Quadrumat milled samples (Harper Adams samples). The prediction is robust and relatively precise ($R^2 = 0.948$, $R^2_{\text{ADJ}} = 0.860$, $Cp = 7.3$), higher than the equivalent Bühler-milled Harper Adams flours ($R^2 = 0.848$, $\text{R}^2_{\text{ADJ}} = 0.695$, $Cp = 6.0$). Perten-milled samples, which produce a whole meal flour, gave a slightly poorer correlation with best subsets regression ($R^2 = 0.889$, $R^2_{\text{ADJ}} = 0.796$, $Cp = 4.4$), the values are very similar to values for Bühler-milled flours. Therefore, rapid milling does not appear to have an adverse effect on predicting baking volume based on mixograph parameters.

To estimate the robustness of the regression prediction, the model was validated by withdrawing a subset of approximately one-third (6 samples) from the Quadrumat-milled Harper Adams data set (Abbot, Cadenza, Harrier, Mercia, Rialto, Riband); the cultivars covered a wide range in variation of baking volumes. A new prediction was calculated for the remaining two-thirds of the data set (14 samples). The baking volumes of the subset were predicted using the new prediction equation. The R^2 value decreased from 0.948 to 0.892, R^2_{ADJ} increased from 0.860 to 0.886, and Cp decreased from 7.3 to 2, indicating the robustness of the model. Further cross-validation with larger data sets is recommended to establish calibration models within groups of flours.

Characterization of Commercial Wheat Gluten Quality

The potential of the 2-g mixograph as a means of assessing commercial wheat gluten quality was investigated. Six commercial wheat gluten samples of varying quality were provided by Amylum Group, Belgium. Baking volume (6% gluten added to a control flour) was normalized against a 100-g control bake and expressed as % of the control loaf volume. Normalized baking volumes and other analytical data for the glutens are given in Table III. Best subsets regression was used to identify mixograph parameters that gave the best prediction of baking volume. The three parameters that gave the best prediction of volume were midline peak bandwidth (MPW), 10-min height (10MH), and envelope peak height (EPH), giving an R^2 value of 0.969 (Table II). This shows that gluten quality, expressed as baking volume, can be adequately predicted by mixograph parameters alone.

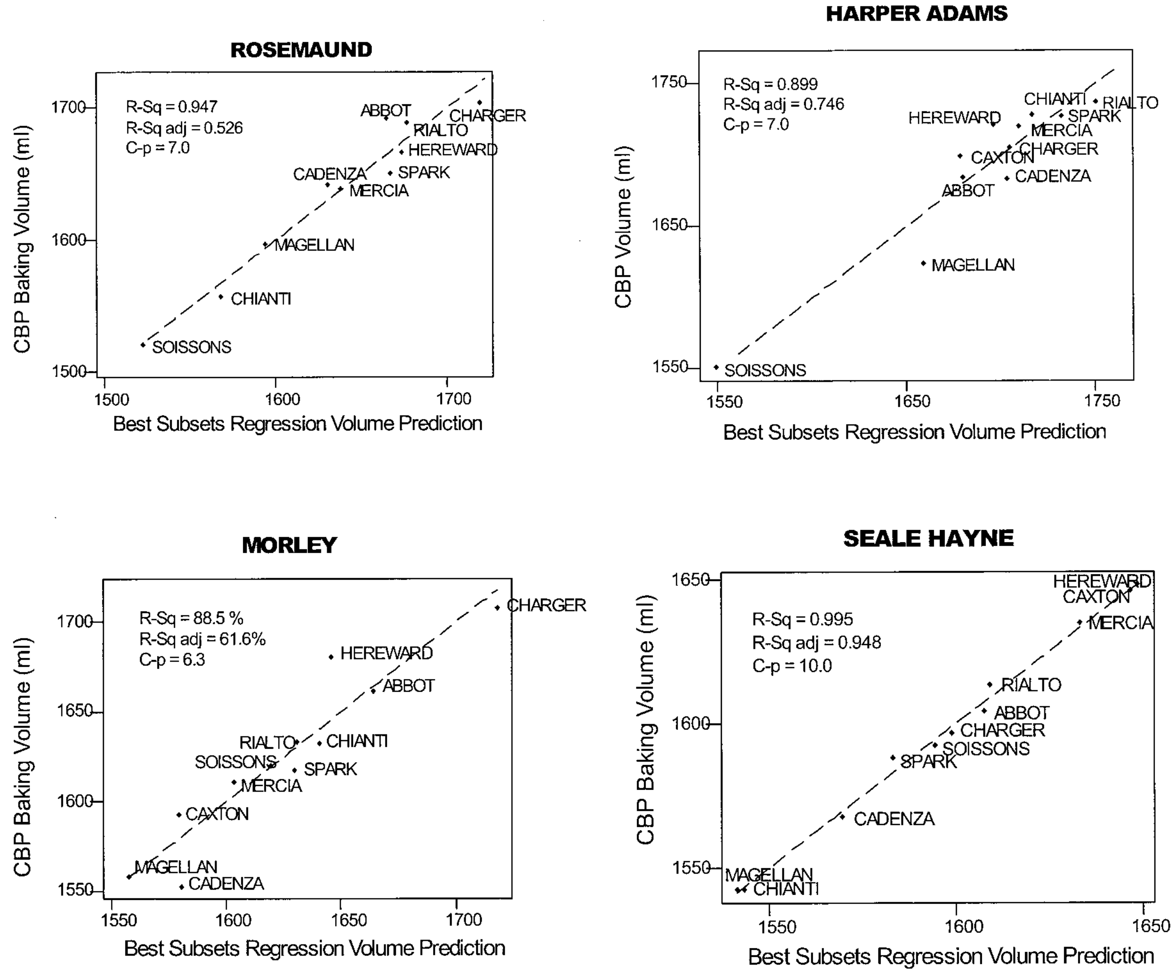

Fig. 4. Prediction of baking volume using best subsets regression of mixograph parameters for flours obtained from individual growing locations within the UK: Rosemaund, Harper Adams, Morley, and Seale Hayne.

TABLE III
Analytical and Quality Data for Commercial Wheat Gluten Samples Used in Mixograph Quality Predictions[a]

	Gluten1	Gluten2	Gluten3	Gluten4	Gluten5	Gluten6
Moisture (%)	4.9 (0.5)	5.7 (0.6)	5.5 (0.6)	5.9 (0.4)	6.0 (1.0)	6.0 (0.7)
Ash (%)	0.94 (0.07)	0.72 (0.04)	0.97 (0.13)	0.86	0.9 (0.1)	0.85 (0.07)
Protein (%)	75 (2)	76 (2)	78 (4)	78 (3)	77 (1)	77 (1)
Alveograph values[b]						
P	77 (9)	67 (7)	53 (11)	35 (9)	50 (13)	60 (9)
L	91 (16)	100 (21)	129 (26)	129 (35)	115 (22)	124 (19)
W	260 (17)	215 (29)	219 (38)	104 (25)	159 (44)	230 (38)
Baking volume (%)[c]	83	94	90	82	90	100
Quality assessment	Poor	Very Good	Good	Poor	Good	Very Good

[a] Numbers in brackets are one standard deviation from the mean.
[b] P = tenacity (mm), L = extensibility (mm), W = dough strength ($\times 10^{-4}$ J).
[c] Normalized against control loaf volume (Gluten6).

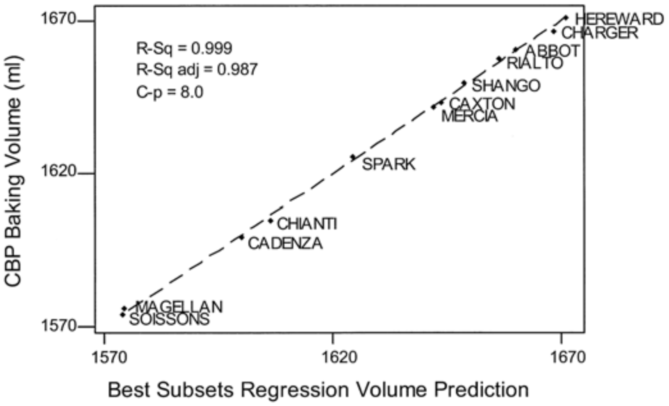

Fig. 5. Prediction of baking volume using best subsets regression of mixograph parameters with baking volume and mixograph parameters for each cultivar averaged over five locations. (Regression equation: Baking volume = 1,830 + 173 flour protein – 79.8 MPH – 753 MPT + 16.6 MPA + 145 30SA + 67.4 30SW + 59.1 30SS – 2.77 10MA).

CONCLUSIONS

Mixograph parameters derived from the computerized 2-g mixograph have demonstrated their potential usefulness as a rapid, small-scale method for the prediction of wheat and gluten baking quality using multivariate statistical analysis. The work has shown substantial effects of growing location on prediction of baking quality using mixograph parameters, even within a relatively homogeneous climatic region such as England. Whole meal flours prepared using rapid, small-scale milling procedures showed similarly good predictions of baking performance using mixograph parameters. Commercial gluten quality, expressed as improvement in baking volume, was well predicted by three mixograph parameters.

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