HGCA

PROJECT REPORT No. 236

RAPID ASSESSMENT OF WHEAT QUALITY, INCLUDING DIFFERENTIATION OF 'EXTRA-STRONG' CULTIVARS, USING THE TWO-GRAM DIRECT DRIVE MIXOGRAPH

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by

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Contents

ABSTRACT

Aims. The objectives of this one year 'pilot study' study were to provide an initial evaluation of the two-gram Mixograph procedure: (i) as a rapid means of assessing the baking quality of UK wheat varieties, (ii) as a means of differentiating 'extra strong' gluten type wheat varieties from those with a more 'normal' gluten strength characteristics, and (iii) as a means of assessing the bread making quality of commercial wheat glutens.

Conclusions. An instrumented two-gram direct drive Mixograph was used to study the mixing characteristics of flours milled from a range of breadmaking varieties from the 1996 harvest Recommended List grown at five different locations around the U.K. Fifteen parameters were extracted from each Mixograph trace using the Mixsmart software programme, and correlated with baking volume using multiple regression statistical analysis to give a prediction of baking volume. Sample site effects were shown to have a considerable influence on the prediction of baking volume. When regressions were calculated independently for each site, excellent predictions of baking volume were obtained, giving R^2 values between 0.805 to 0.995. Similarly, when Mixograph and baking volume data for each variety were averaged over all 5 sites, a very high correlation was obtained ($R^2 = 0.999$). When the baking volumes for individual samples from all sites were used in the regression analysis, much poorer correlations were obtained, indicating substantial effects of growing site on the prediction of baking volume from Mixograph parameters. Preparation of flour samples for Mixograph assessment using rapid, small-scale milling procedures (Brabender Quadrumat Junior mill for white flours of about 60% extraction and Perten 3100 hammer mill for wholemeal flours) did not have any adverse effect on the good predictions of baking volume described above. 'Extra-strong' varieties (Fresco, Torfrida, Classic, Aubaine and Florence Aurore) were differentiated successfully from 'normal' breadmaking varieties using the Mixograph. Mixograph parameters obtained from six commercial glutens of varying quality were correlated with test baking volumes, based on 6% gluten addition to a control flour. Three Mixograph parameters gave a good prediction of baking volume ($R^2 = 0.954$): peak bandwidth, 10 minute height and maximum peak height.

Implications for levy payers. The baking quality of UK wheat varieties can be predicted using a rapid and simple test, the two-gram Mixograph, which should prove particularly valuable for plant breeders where sample quantity is a problem. This technique can also be used to discriminate wheats of different classes, including the 'extra-strong' gluten type wheat varieties and also as a means of assessing the bread making quality of commercial wheat glutens.

SUMMARY

The project aimed to demonstrate the potential of the two-gram Mixograph as a rapid and simple test method for evaluating the baking quality of UK wheat varieties and isolated gluten, and also as a means of differentiating 'extra strong' gluten type wheat varieties from those with a more 'normal' gluten strength characteristics.

Bühler experimental milled white flours from 1996 harvest Recommended List Trial samples grown at five different locations around the U.K were assessed using the two-gram direct drive Mixograph. Fifteen parameters were extracted from each Mixograph trace using the Mixsmart software programme, and correlated with baking volume using multiple regression statistical analysis to give a prediction of baking volume.

Preparation of samples using rapid, small-scale milling procedures (Brabender Quadrumat Junior mill for white flours and Perten 3100 hammer mill for wholemeal flours) did not have any adverse effect on the predictions of baking volume. 'Extra-strong' varieties (Fresco, Torfrida, Classic, Aubaine and Florence Aurore) were differentiated successfully from 'normal' breadmaking varieties. Mixograph parameters obtained from six commercial glutens of varying quality were correlated with test baking volumes, based on 6% gluten addition to a control flour.

Introduction

There is a pressing commercial need for a rapid and reliable means of predicting the baking quality of commercial wheat samples at mill intake and at early stages in selection during plant breeding. None of the currently used rapid intake tests (such as the SDS sedimentation test) are capable of discriminating the baking quality of wheat successfully, and other methods such as HPLC or capillary electrophoresis, which are successful in discriminating varieties, are too slow and technically difficult to allow them to be used as a rapid intake test.

The Mixograph (National Manufacturing Inc., USA), first described by Swanson & 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, which uses planetary rotating pins oriented vertically to mix the dough in a bowl which contains three fixed pins. Torque during mixing is measured and 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 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. 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), whilst older models use 10 g (Finney & Shogren, 1972) or 35 g. The two-gram direct drive instrumented Mixograph was developed by Rath, Gras, Wrigley and Walker (1990) in order 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, mainly due to frictional losses in the drive system which vary according to temperature (a problem if a constant laboratory temperature is not maintained), and also due to wear in the drive system after considerable use, causing possible drift in the instrument readings. Because no easily performed user calibration of the instrument is possible, for example as in hanging a weight on the Farinograph mixer arm, this can be seen to be a considerable drawback of the Mixograph, especially for use in quality control purposes where calibration is considered essential.

Both the Mixograph and Farinograph have been used to predict dough processing properties and baking quality, based on the assessment of their mixing traces. 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 two- gram Mixograph to relate mixing characteristics to the breadmaking quality of a broad 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 ten-gram Mixograph. They also found that peak time was a poor parameter to explain bread making quality, but found strong relationships between loaf volume and peak height and peak bandwidth. Wikström & Bohlin (1996) found that no single Mixograph parameter could successfully predict baking performance in a range of Swedish breadmaking wheat varieties, and showed that baking volume could be predicted more successfully by statistical selection of several parameters from the Mixograph trace using multivariate statistical analysis.

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 quality. Each sample set of flours and/or type of breadmaking procedure used probably requires a different set of optimum mixing parameters to relate to baking quality, and therefore would require a separate regression model to predict baking performance. The major problem is that interpretation of the 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 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 description of the trace and are still subjective in deciding where these points are fixed. The work of Wikström & Bohlin (1996) has shown that statistical selection of several parameters from the Mixograph trace using multivariate statistical analysis provides a better approach than selecting a single arbitrary fixed point.

MATERIALS AND METHODS

Wheat and Flour

Samples of wheat and flour were provided by CCFRA from the 1996 harvest Recommended List (R.L.) samples from 5 separate locations around the U.K. (Bridgets, Harper Adams, Morley, Rosemaund and Seale Hayne), and also some National List samples (Tables 1 & 2). These comprised 95 samples in total, encompassing all the major commercially used breadmaking and biscuit flour wheats. The flour samples provided by CCFRA were milled in a Bühler laboratory mill, and quality data are provided in Tables 1 & 2. Some of the wheat samples were test-milled at Reading using (i) a Brabender Quadrumat Junior mill for white flours of about 60% extraction and (ii) a Perten 3100 hammer mill for wholemeal flours to investigate the effect of rapid, small-scale milling on the Mixograph characteristics.'Extra strong' wheat varieties were provided by Monsanto UK Ltd., Cambridge, and commercial gluten samples were provided by Amylum Group, Belgium.

Baking Procedure

The flours had been previously test baked at CCFRA. Test baking was performed in duplicate. Water addition level was calculated from the 600BU Farinograph water absorption. The ingredients used are shown in Table 3. Flours were mixed in a Morton mixer to a fixed work input of 11Wh/kg at atmospheric pressure to a target temperature of $30\pm1\,^{\circ}C$. The dough was scaled by hand into two 454 g pieces and proved at ambient temperature for 10 minutes before final moulding into a single-piece cylinder into a greased unlidded tin. Doughs were proved to constant height (10cm) at 43 °C at high humidity and then baked in a direct gas-fired reel oven at 244°C for 25 minutes. The loaves were allowed to cool on an open rack at room temperature and then stored overnight in a closed cupboard at 21 °C. Volume measurement was by seed displacement.

Mixograph Measurements

Mixing tests were performed on the two-gram direct drive computerised Mixograph (National Manufacturing Division, TMCO, Lincoln, USA) . All tests used 2 g flour and water was added according to the water addition figures provided by CCFRA, with the exception of the extra strong samples, where a fixed water addition of 60% was used. For the gluten samples, 3.7 g of water was added to 2 g 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 carried out in an air-conditioned laboratory ($21\pm1\,^{\circ}C$, 25% R.H.).

Before the start of mixing, pre-selected data acquisition and trace analysis variables can be set in the Mixsmart® (version 3.40) programme (Table 4). The mixer was started via the P.C. and the mixing trace displayed in real time on the P.C. monitor. The mix time was set at 10 minutes 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 analysed using the Mixsmart® software programme supplied with the two-gram Mixograph by National Manufacturing TMCO. Using this software, various pre-selected parameters can be chosen by the user from the mixing trace, as shown in Figure 1 and Table 5.

The Mixsmart® software constructs a mid-line curve from the recorded mixing trace indicated in Figure 1, and an upper and lower envelope (not shown here). The software can be used to analyse both the upper envelope and mid-line curves. A number of parameters were derived from the mid-line trace shown in Figure 1: peak height, the maximum height of the mid-line curve, expressed as a percentage of full-scale Mixograph Units, peak time, the time in minutes at mid-line peak height, peak area, the integral of the area under the mid-line trace to peak, peak bandwidth, the height between the upper and lower envelopes at the peak. Ascending and descending slopes about the peak (left and right of peak slopes) were also calculated. An arbitrary time of 30 seconds was selected at which to calculate area, slope and bandwidth, mainly to compare results with those described by Wikström & Bohlin (1996). Upper envelope parameters recorded were: Maximum height at peak (TMAX), height at 30 seconds (T30S) and slope to 30 seconds (T30SLOPE).

RESULTS AND DISCUSSION

Baking volumes

CBP (Chorleywood Bread Process) volumes for all the Recommended List (R.L.) breadmaking varieties and sites are shown in Figure 2. The standard deviations of each variety (averaged over the different sites) overlap in most cases, suggesting no significant differences in baking volume between most varieties. Significant differences are apparent only between those varieties at the extremes of baking volume, for example between Hereward and Charger with high average baking volumes and Magellan and Soissons with the lowest average baking volumes (Figure 3). Comparison of baking volumes for varieties grown at individual sites shows greater differences within most varieties than between different varieties, indicating a considerable effect of growing location on baking performance within a given variety (Figure 4). This highlights the danger in assuming that flours from a single variety will have similar quality attributes.

Correlations between Mixograph parameters and baking volumes

Baking volume data were correlated with Mixograph parameters using partial least squares (PLS) multiple regression method using Minitab for Windows® 95 statistical software package, version 11.2, (Minitab Inc. USA). Regression analysis is used to describe the relationship between a response variable (baking volume in this case) and one or more predictors (Mixograph parameters). A number of further options are available in Minitab regression analysis: (i) stepwise regression for selecting predictors from a pool of potential variables, (ii) best subsets regression for choosing best subsets of predictors from a pool of potential variables and (iii) %fitline which does a polynomial regression and plots a fitted regression line.

Initially all 15 recorded Mixograph parameters were included as predictors in the regression and then 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 provides three statistics which can be used for subset selection: R^2, R^2_{ADJ} and Cp. R^2 indicates 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 as 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. The Cp statistic can also be used as an indication of how well the model fits the data: in general the value of Cp should be small and close to p, the number of parameters used in the model. A small value of Cp indicates that the model is relatively precise in predicting future responses, whilst a large value of Cp shows a considerable lack of fit.

Figure 5 shows a multiple regression between baking volume and all the 15 Mixograph parameters for all flour samples and sites. When the baking volumes for the individual varieties from all sites were used in the regression analysis, a poor correlation was obtained , the regression ($R^2 = 0.263$) indicating a poor fit to the data and that baking volume is poorly predicted by the Mixograph parameters only. The prediction of volume is improved if protein is added in to the multiple regression prediction, R^2 increasing to 0.513, although protein by itself is not a good predictor of volume ($R^2 = 0.078$). Best subsets regression was used to show those Mixograph parameters that contributed the greatest amount of variation (R^2) to baking volume.

Table 6 and Figure 6 show the cumulative contribution of Mixograph parameters and protein to the best subsets regression prediction of volume. As more parameters are included the value of R^2 increases, but R^2_{ADJ} and Cp reach an optimum at 9 and 7 parameters respectively. Figure 6 shows R^2 beginning to level off beyond 7 parameters. No individual Mixograph parameter contributed greatly to the overall variation, with the first seven variables in Figure 6 (protein, peak height, 10 minute area, 10 minute height, Tmax, T30S and T30 SLOPE) contributing the most with a combined R^2 value of 0.461.

It is possible that regression predictions of volume are being masked by markedly different distributions of baking volumes and Mixograph parameters between different groups of samples, for example between biscuit and breadmaking flours and also between different sites. To investigate further, the total sample group was split up into breadmaking and biscuit flours and regressions calculated independently for each group.

Looking first at the biscuit flours only (Figure 7), the regression improves considerably ($R^2 = 0.846$), and if the National List flours are also included, the R^2 value increases to 0.948 (Figure 8). The Recommended List breadmaking flours on their own give a poor R^2 value of 0.326, which was not much improved by selectively deleting parameters using best subsets regression. One possible reason why the R^2 value for the R.L. breadmaking flours may be poor is the effect of site. As previously indicated, the R.L. breadmaking data set includes 11 varieties from 5 different sites (Figure 4), and it was noticed that most varieties from Harper Adams gave higher baking volumes than from the other locations. If Harper Adams varieties are deleted from the data set, the R^2 value improves to 0.546, suggesting site variations are important for the R.L. breadmaking varieties.

The R.L. breadmaking data were further split up into separate groups for each site and regressions calculated independently for each group using best subsets regression with and without protein . The data are shown in Table 7, and Figure 9 shows the best subsets fitted regression lines for Rosemaund, Harper Adams, Morley and Seale Hayne. Regressions for individual sites are considerably improved, giving R^2 values between 0.805 and 0.995 with protein included, and between 0.643 and 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 sites gives an improvement in 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 not a good 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 of minimising variation due to site is to calculate the regression between volume and Mixograph parameters for each variety averaged over all 5 sites. The average Mixograph and baking data are shown in Table 8. Best subsets regression on average variety data gives a high correlation with selected Mixograph parameters ($R^2 = 0.999$, $R^2_{ADJ} = 0.987$ Cp = 11), Table 7 and Figure 10. This further underlines the importance of site on the Mixograph baking correlations. The regression prediction 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 and a distinct group of varieties is discriminated at the higher end of the baking volume scale (Mercia, Caxton, Shango, Rialto, Abbot, Charger and Hereward).

Effect of milling procedure on Mixograph correlations

The effect of milling procedure on Mixograph correlations with baking was investigated. A sub-set of the wheat samples was selected for rapid milling using the Brabender Quadrumat and Perten 3100 Falling Number mills. Whilst 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. Figure 11 shows the fitted best subsets regression line for CBP volume vs. selected Mixograph parameters for Quadrumat milled samples (Harper Adams samples only). The prediction is robust and relatively precise ($R^2 = 0.964$, $R^2_{ADJ} = 0.861$ $Cp = 15$, $p = 20$), higher than the equivalent Bühler milled Harper Adams flours ($R^2 = 0.899$ $R^2_{ADJ} = 0.746$ $Cp = 7.0$, $p = 8$). Perten milled samples, which produce a wholemeal flour, gave a slightly poorer correlation with best subsets regression (Figure 12), giving values of $R^2 = 0.899$ $R^2_{ADJ} = 0.774$ $Cp = 7.0$, $p = 12$), which are very similar to values for Bühler milled flours. Therefore, rapid milling does not appear to have an adverse effect on estimating a prediction of baking volume based on Mixograph parameters.

To estimate the robustness of the regression prediction the model was validated by withdrawing a sub-set of approximately one-third of the samples from the Quadrumat milled Harper Adams data set (6 samples: Abbot, Cadenza, Harrier, Mercia, Rialto and Riband), the varieties chosen to cover a wide range in variation of baking volumes. A new prediction was calculated for the remaining two-thirds data set (14 samples). The baking volumes of the sub-set were predicted using the new prediction equation, and are shown plotted in Figure 13. The R^2 value decreased from 0.964 to 0.892, R^2_{ADJ} increased from 0.861 to 0.886 and Cp decreased from 15 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.

Differentiation of 'extra-strong' wheat varieties using Mixograph parameters

The use of the two-gram Mixograph in differentiating wheats of different classes, in particular 'extra-strong' varieties from the normal breadmaking wheat varieties was investigated. Samples of the extra strong wheat varieties Fresco, Torfrida, Classic, Aubaine, Florence Aurore and Glenlea were provided by PBI Cambridge and milled using the Brabender Quadrumat. The flours were mixed in the 2g Mixograph using 60% water addition. The Mixograph parameters for the extra strong samples and comparisons with average breadmaking varieties are shown in Table 8. Figure 14 shows bar charts of comparisons of selected Mixograph parameters (peak height, peak time, peak area and 10 minute area). Peak height values for all the extra strong varieties except Classic are higher than those for the breadmaking varieties, whilst the peak time values for the extra strong varieties are higher than most breadmaking varieties (with the notable exception of Soissons). The peak area and 10 minute area values for the extra strong varieties are higher than most breadmaking varieties.

CBP baking volumes for extra strong varieties were predicted using the best subsets regression equation derived previously for average breadmaking varieties (Figure 10) . The volumes predicted were compared with the breadmaking predicted regression line shown in Figure 15. When compared using the breadmaking prediction, most of the extra strong varieties were clearly differentiated from the breadmaking varieties, with Fresco and Aubaine showing a very strong differentiation, followed by three varieties clearly grouped together (Torfrida, Florence Aurore and Classic). Whilst most of the extra strong varieties are predicted to behave very differently from the average breadmaking varieties, the baking volume of the variety Glenlea is predicted to be close to that of the best of the breadmaking varieties on the basis of its mixing characteristics.

Characterisation of commercial wheat gluten quality

The potential of the two-gram Mixograph as a means of assessing commercial wheat gluten quality was investigated. Six commercial wheat glutens samples of varying quality were provided by Amylum Group, Belgium. Baking volume (6% gluten added to a control flour) was normalised against a 100g control bake and expressed as a percentage of the control loaf volume. Normalised baking volumes and other analytical data for the glutens are given in Table 9. Best subsets regression was used to identify the Mixograph parameters that gave the best prediction of baking volume. Three parameters gave the best prediction of volume: Peak Bandwidth, 10 minute height and Tmax, giving an R^2 value of 0.954 (Figure 16). This shows that gluten quality, expressed as baking volume, can be adequately predicted by Mixograph parameters alone.

Conclusions and further work

The results from this work have demonstrated the potential of the two-gram Mixograph as a rapid and simple test method for evaluating the baking quality of UK wheat varieties and isolated gluten, and also as a means of differentiating 'extra strong' gluten type wheat varieties from those with a more 'normal' gluten strength characteristics. The important effects of growing location shown in this study clearly need to be addressed in future work so that predictions of baking quality applicable across different sites can be generated. The effects of different fertiliser regimes, growth conditions and pre-harvest conditions on Mixograph parameters needs to be investigated, together with their effects on water absorption and mixing properties.

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Figure 1: typical Mixograph mixing trace showing derived parameters used.

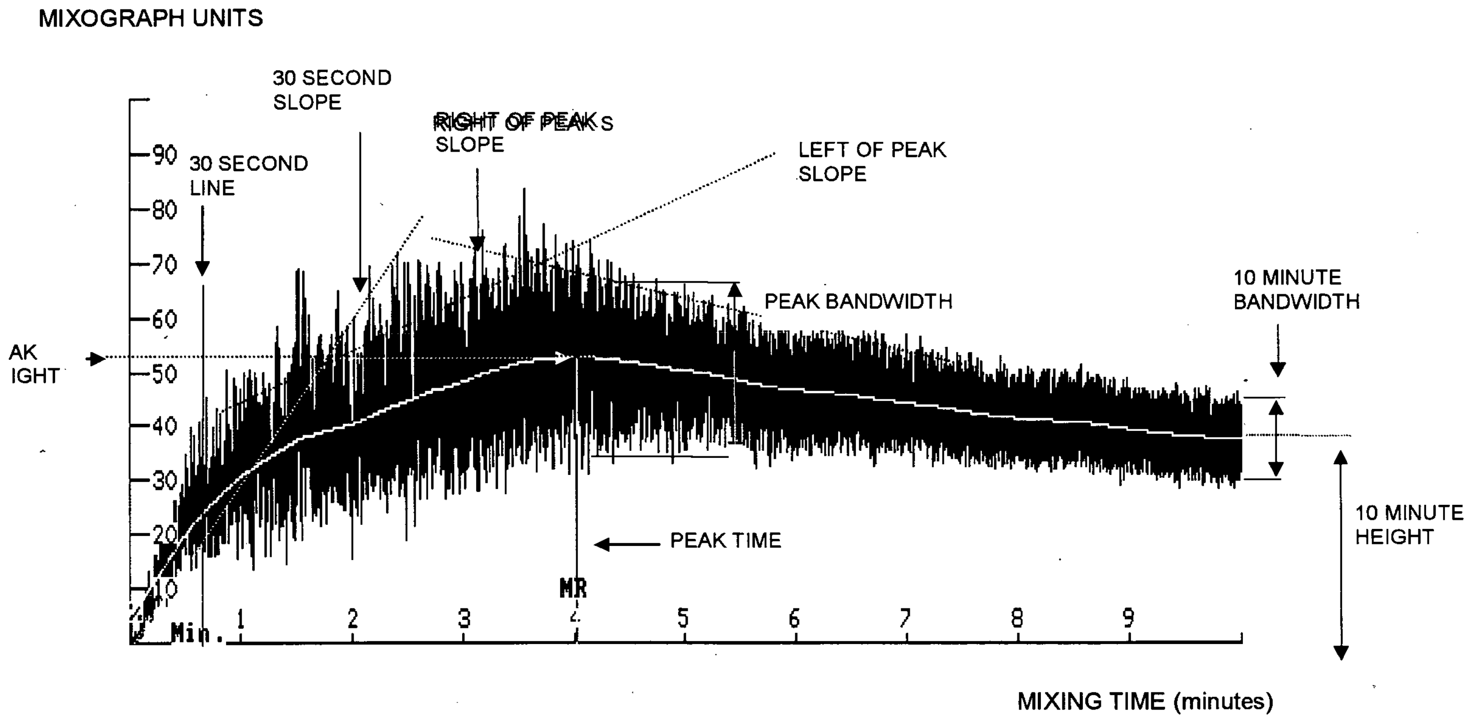

Figure 2. CBP baking volumes for Recommended List breadmaking varieties from different growing sites, showing error bars for each variety (expressed as one standard deviation about the mean).

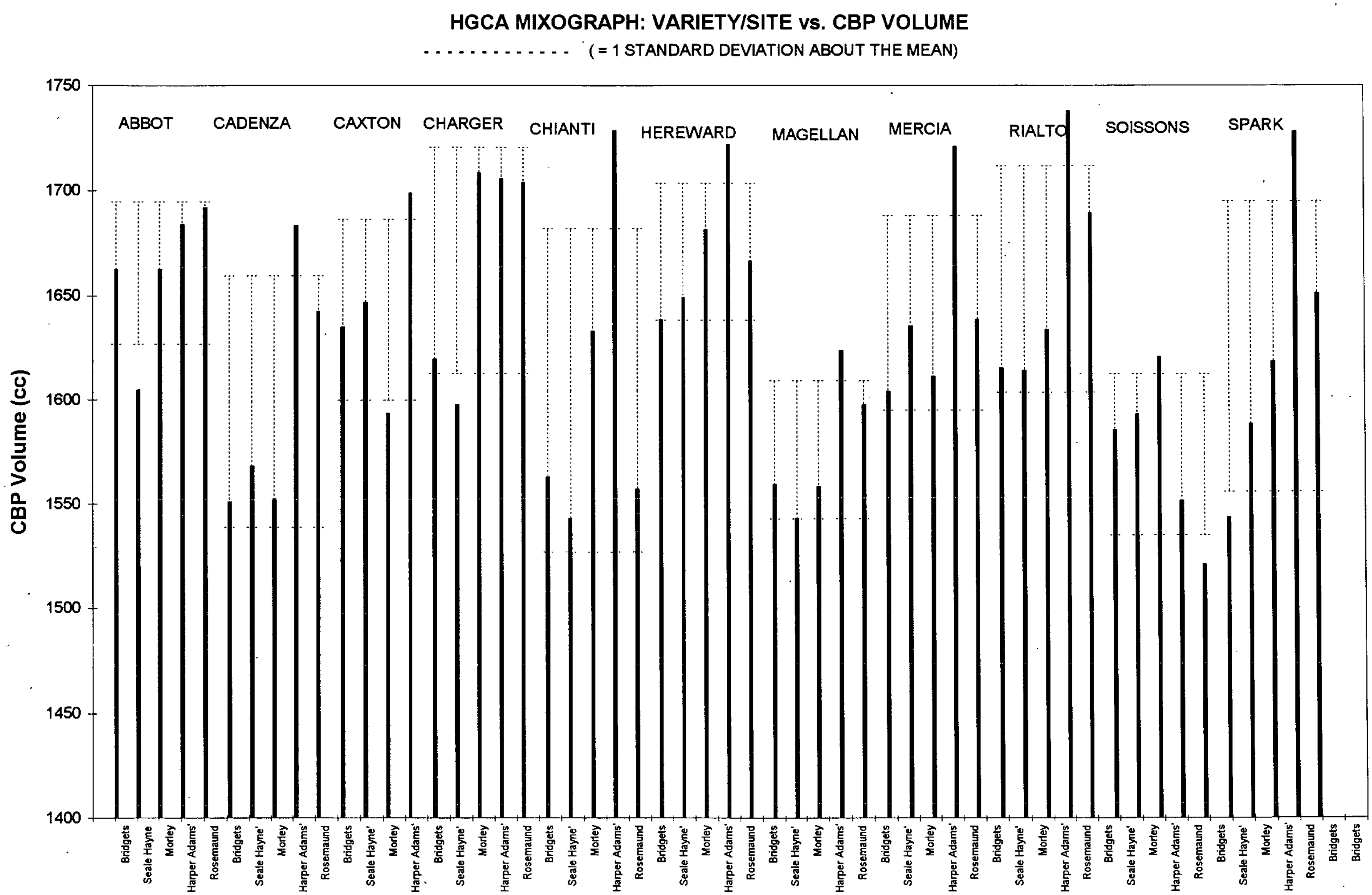

Figure 3. Site averaged CBP baking volumes for R. List breadmaking varieties in ascending order

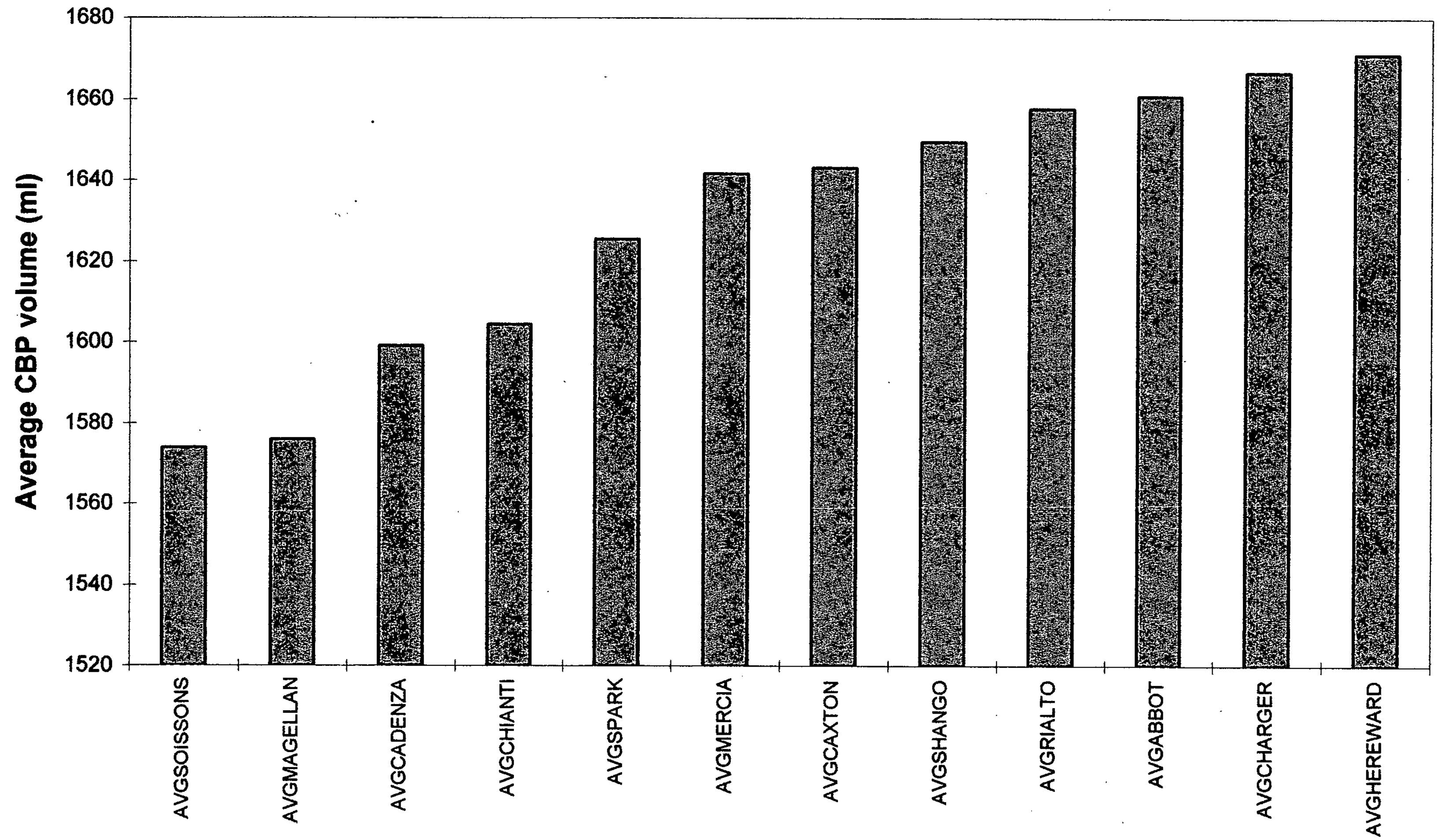

Figure 4. CBP baking volumes for Recommended List breadmaking varieties from different growing sites.

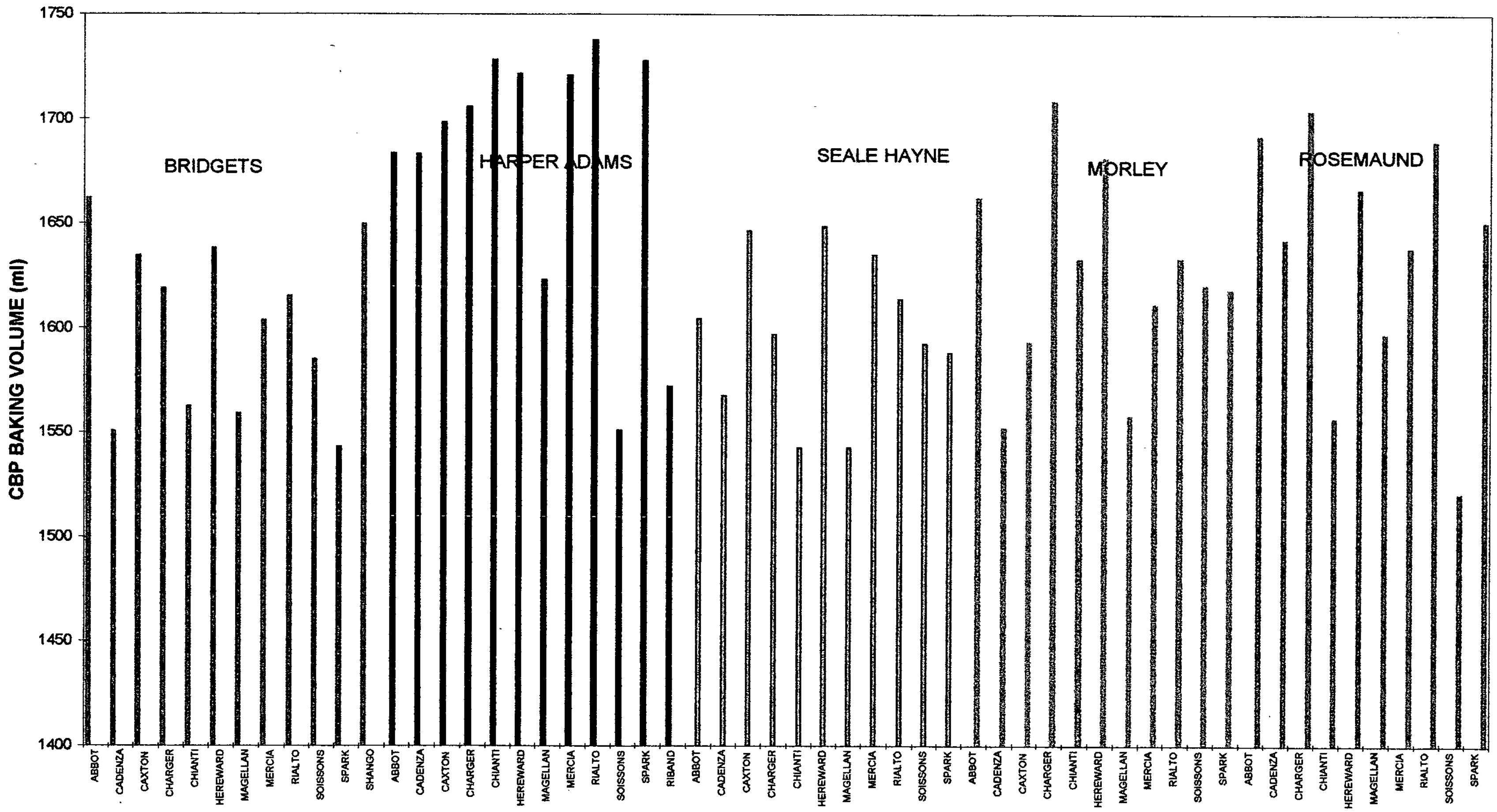

Figure 5. Multiple regression prediction of volume for all Recommended List samples (showing fitted regression line) using all 15 Mixograph parameters.

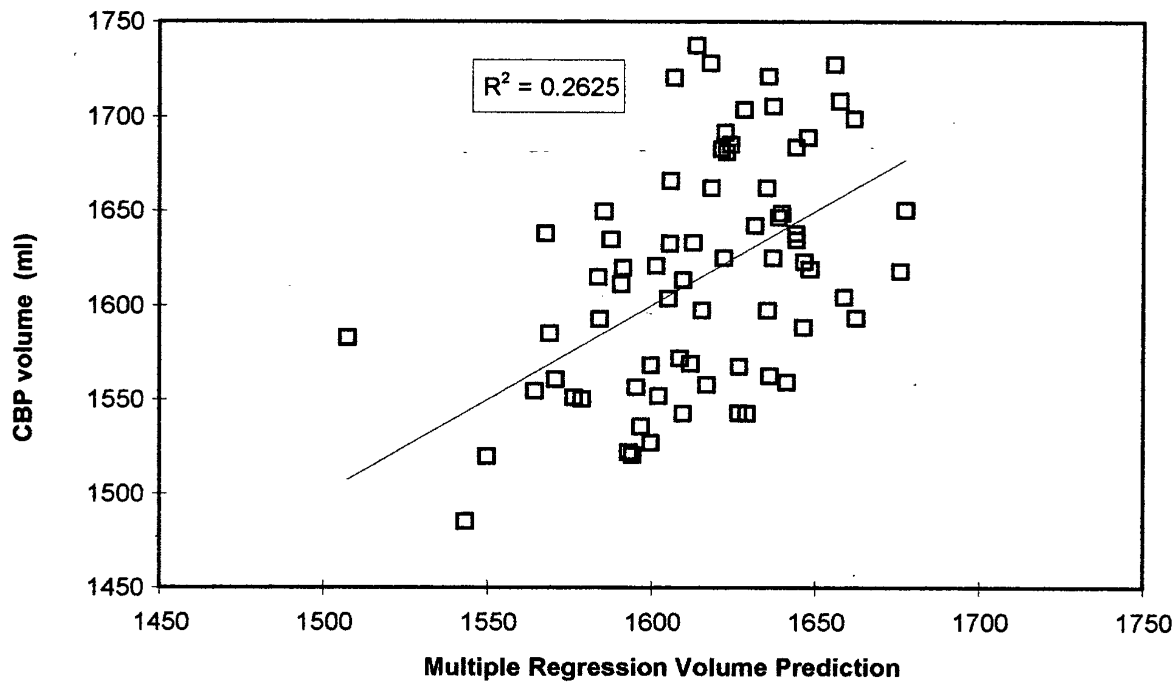

Figure 6. Cumulative contribution of Mixograph parameters and protein to best subsets regression prediction of baking volume (data point numbers refer to the combinations of variables described in Table 6).

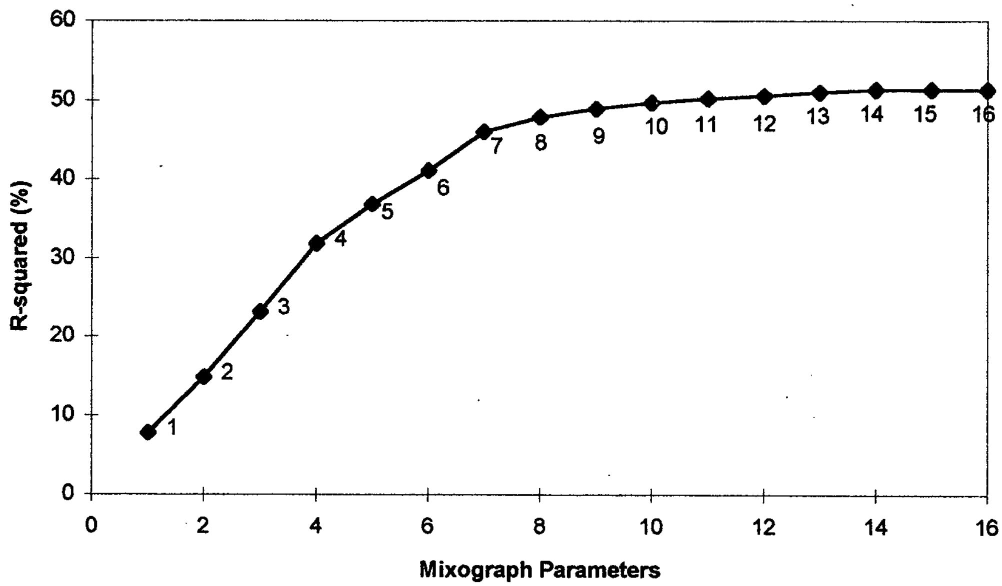

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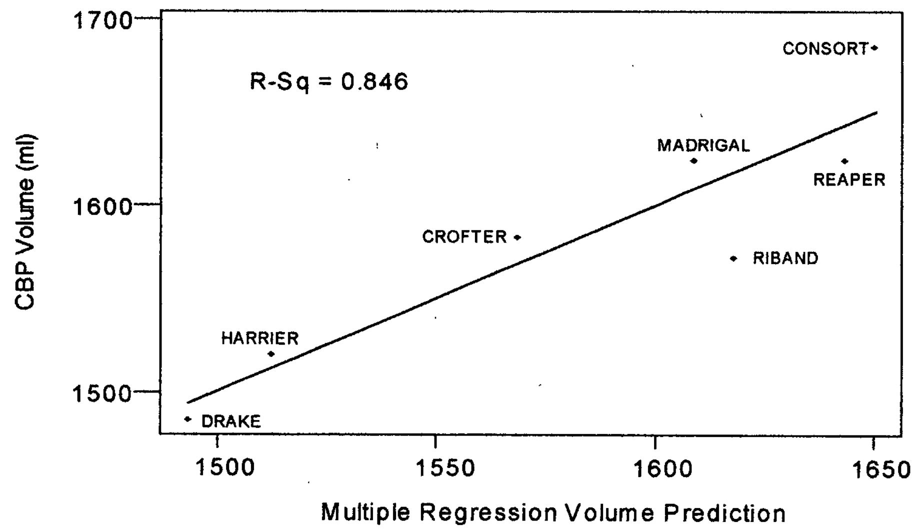
Table 6. Best subsets regression: cumulative contribution of Mixograph parameters and protein to volume prediction.

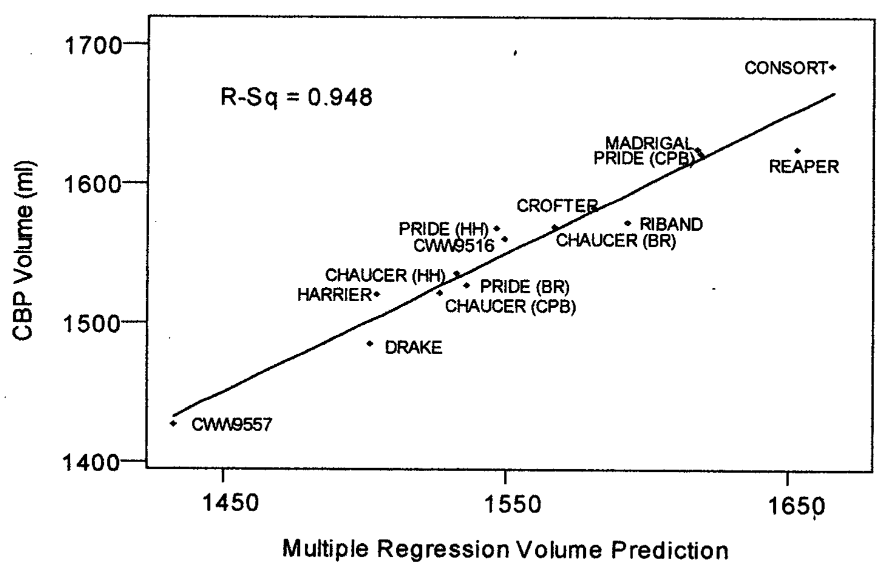
VARIABLES →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
R^2	7.8	14.9	23.1	31.9	36.9	41.1	46.1	47.9	48.9	49.7	50.2	50.6	51.0	51.3	51.3	51.3
R^2_{ADJ}	6.4	12.3	19.5	27.5	31.8	35.3	39.8	40.9	41.0	40.8	40.5	39.8	39.2	38.4	37.2	36.0
C_p	32.5	27.0	20.4	13.3	10.0	7.6	4.4	4.5	5.4	6.6	8.1	9.7	11.2	13.0	15.0	17.0
PROTEIN	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
PKHEIGHT		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PKTIME												X	X	X	X	X
PKAREA										X	X	X	X	X	X	X
PKBWDTH									X	X	X	X	X	X	X	X
30SAREA						X										X
30SWDTH															X	X
30SSLOPE					X	X							X	X	X	X
10MHT				X	X	X	X	X	X	X	X	X	X	X	X	X
10MWDTH								X	X		X			X	X	X
10MAREA		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LEFTSLP										X	X	X	X	X	X	X
RIGHTSLP												X	X	X	X	X
TMAX							X	X	X	X	X	X	X	X	X	X
T30S							X	X	X	X	X	X	X	X	X	X
T30SLOPE							X	X	X	X	X	X	X	X	X	X

Figure 7. CBP volume regression prediction for Recommended List biscuit flours only



HGCA7_2.MGF

Figure 8. CBP volume regression prediction for Recommended List biscuit flours and selected National List flours



HGCA7_1.MGF

Figure 9. Prediction of baking volume using best subsets regression for Rosemaund, Harper Adams, Morley and Seale Hayne.

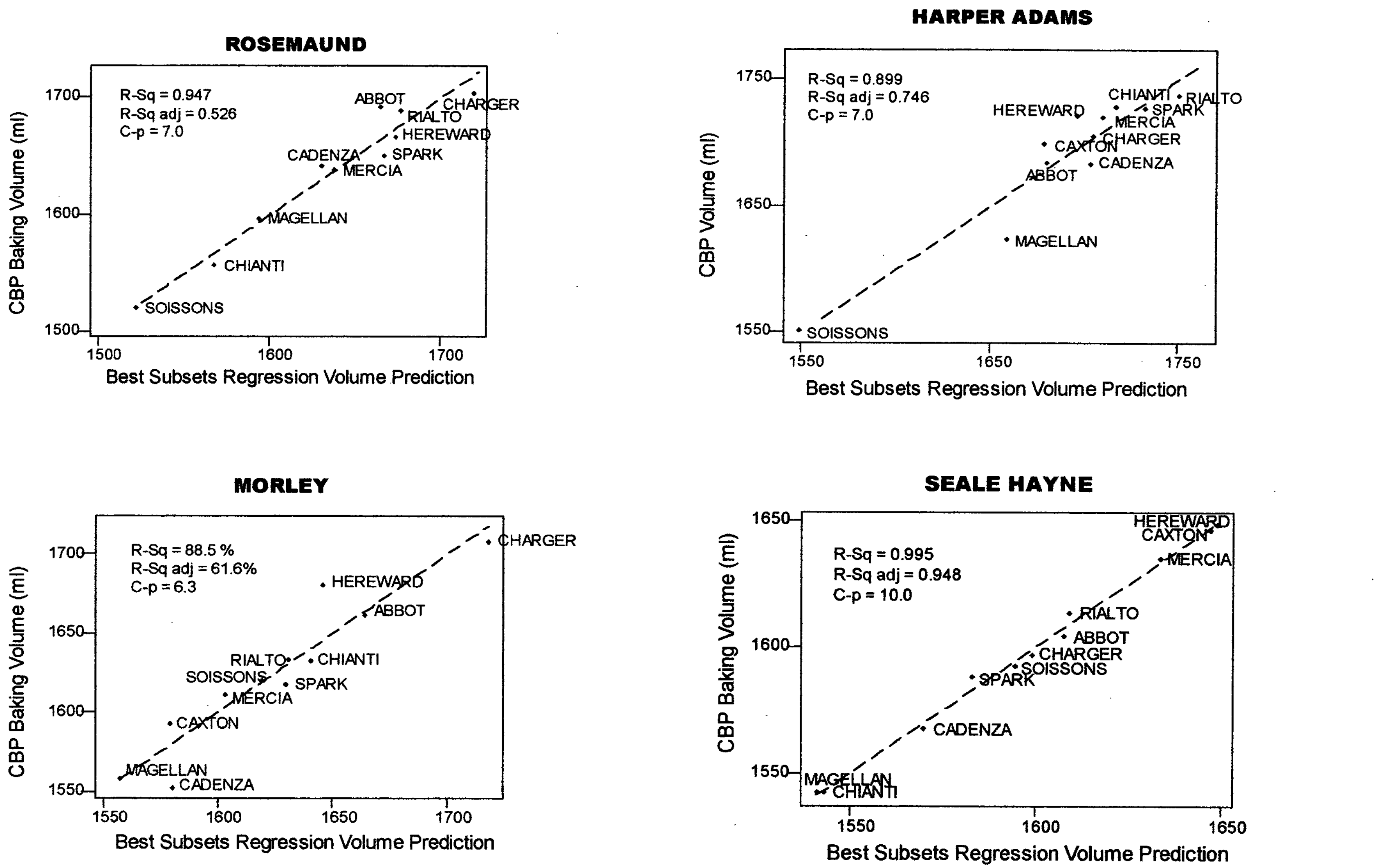


Figure 10. Prediction of baking volume using best subsets regression for Mixograph parameters: baking volume and mixograph parameters for each variety averaged over all 5 sites.

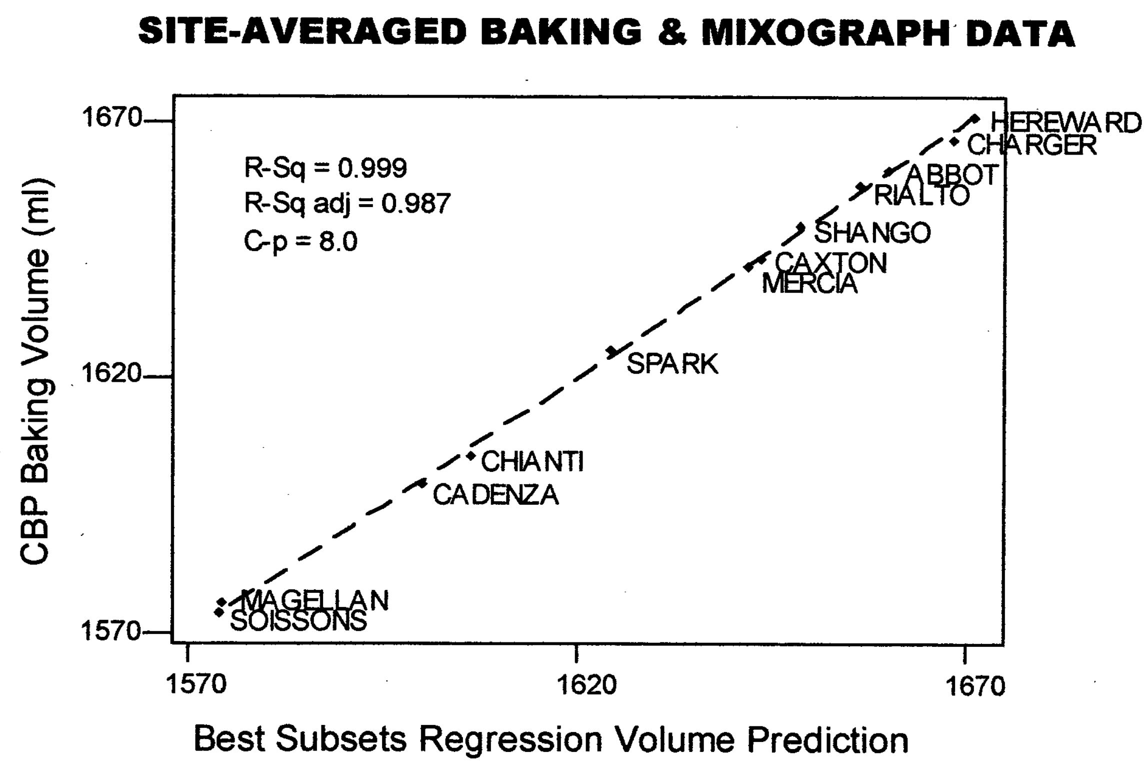
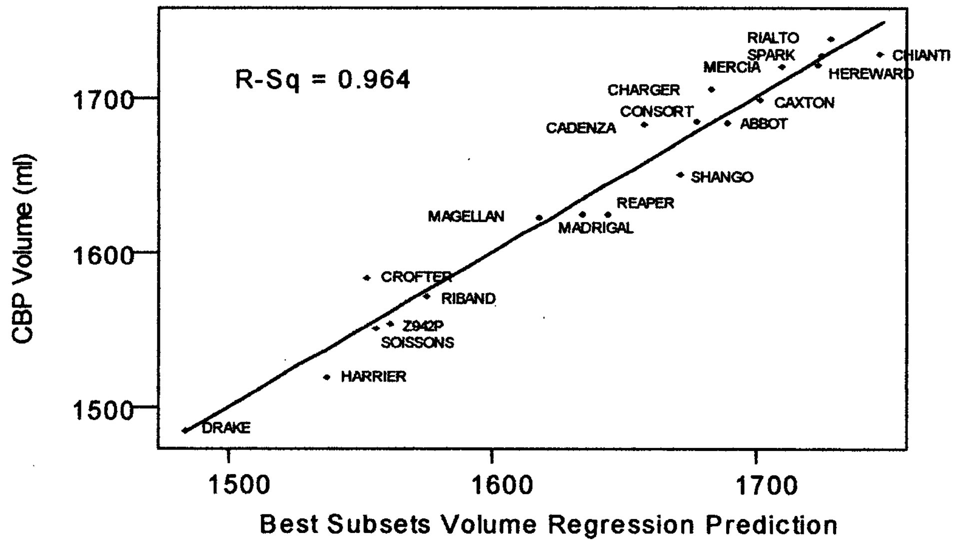
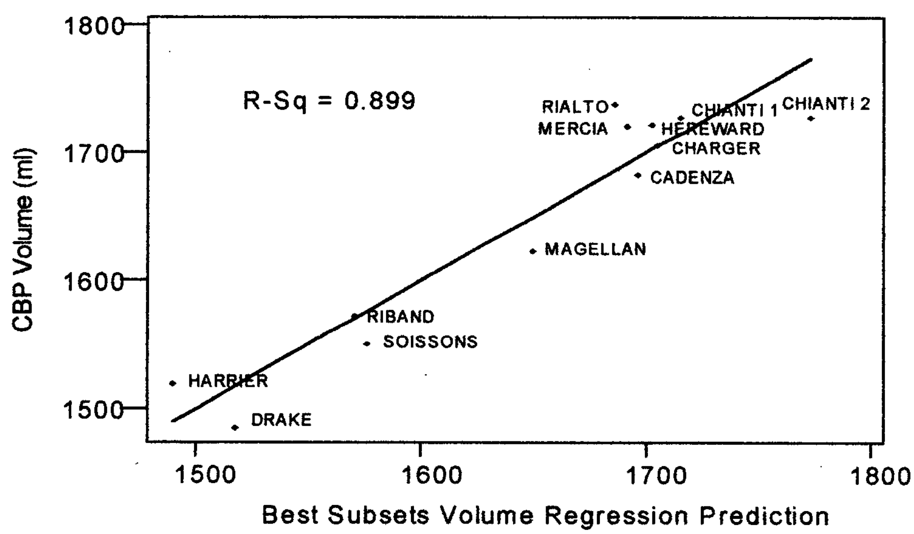


Figure 11. CBP volume best subsets regression prediction for Quadrumat milled Harper Adams flours



HGCA7_9.MGF

Figure 12. CBP volume best subsets regression prediction for Perten milled Harper Adams flours



HGCA7_10.MGF

Figure 13. Validation of regression volume prediction: subset of Harper Adams Quadrumat milled samples compared with main data set prediction

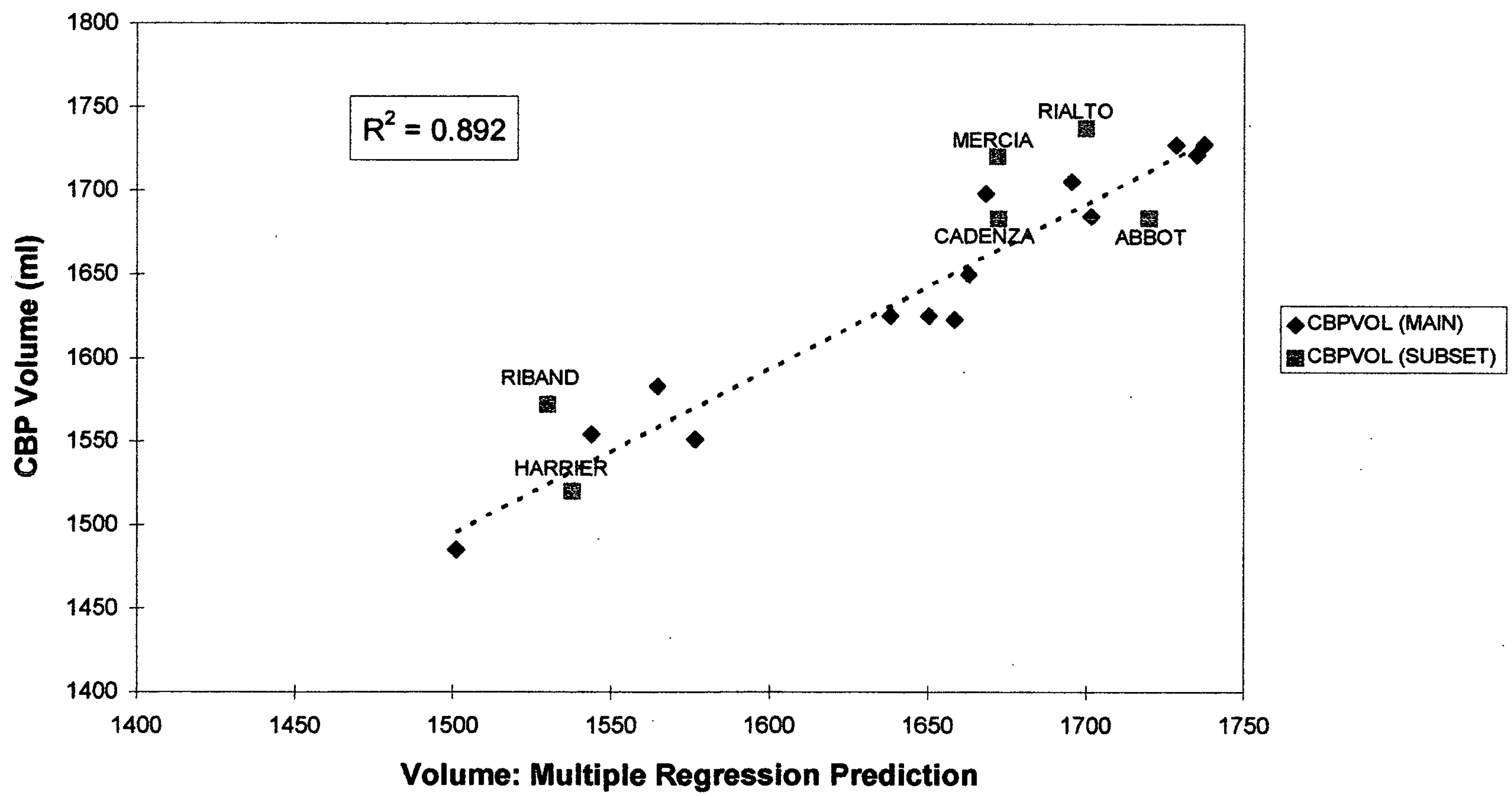


Figure 14. Bar charts showing comparisons between selected Mixograph parameters for site averaged R.List breadmaking varieties and extra-strong varieties

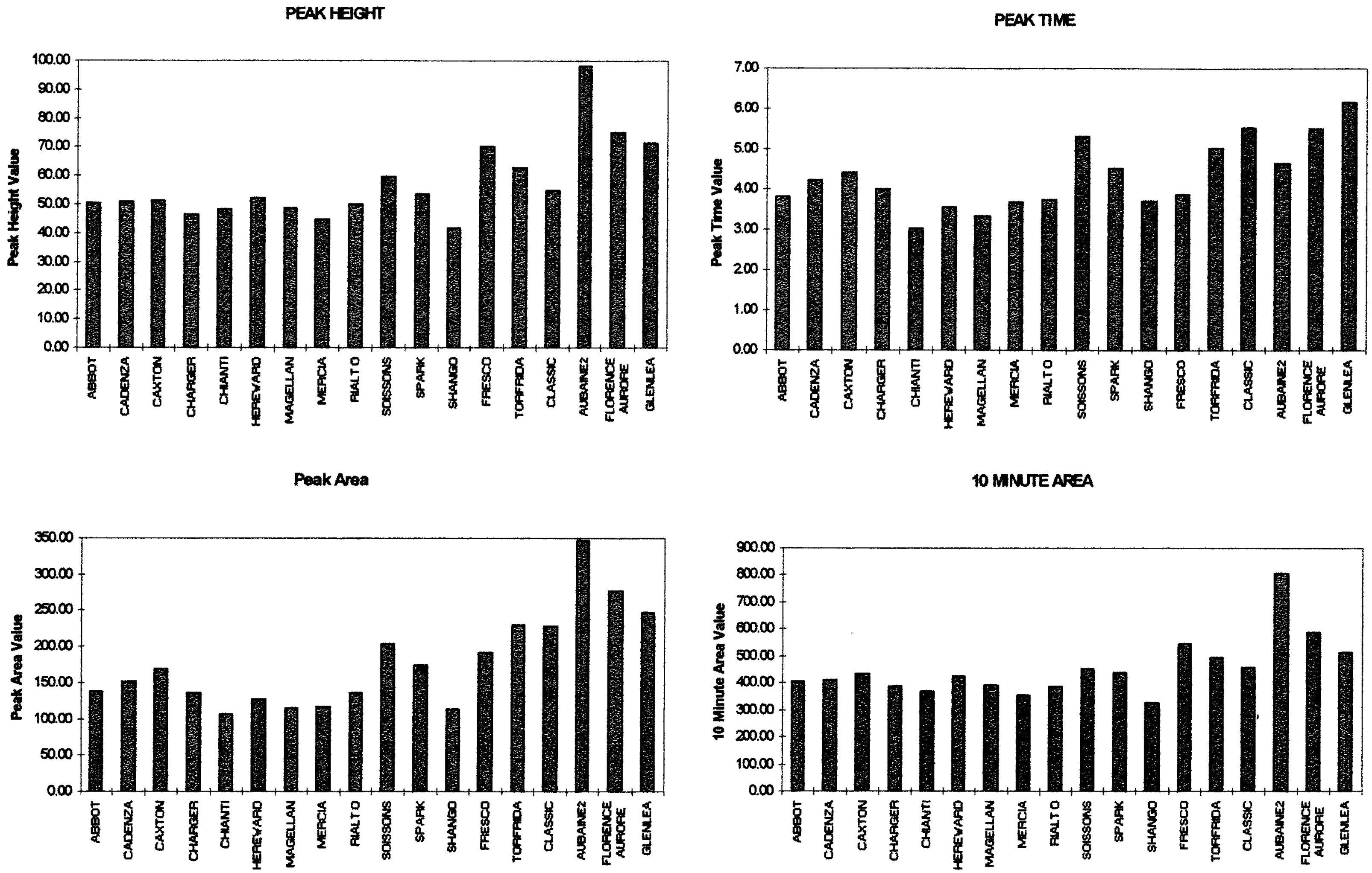


Figure 15. Regression volume predictions for extra strong varieties compared with the volume prediction for site averaged varieties

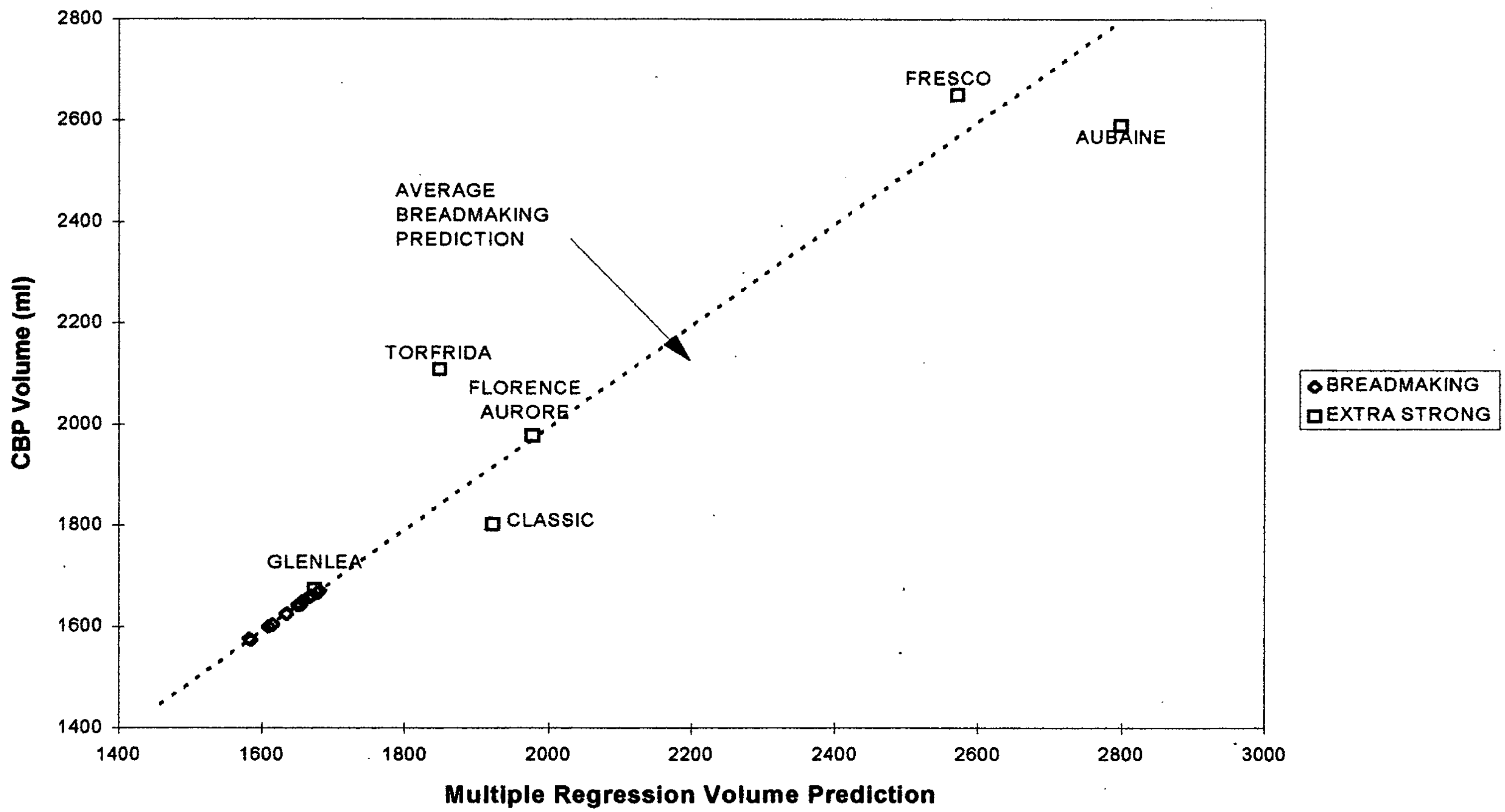


Figure 16. Best subsets regression volume prediction for commercial gluten samples of varying quality based on 6% addition of gluten added to a control flour (numbers refer to gluten samples in Table 9).

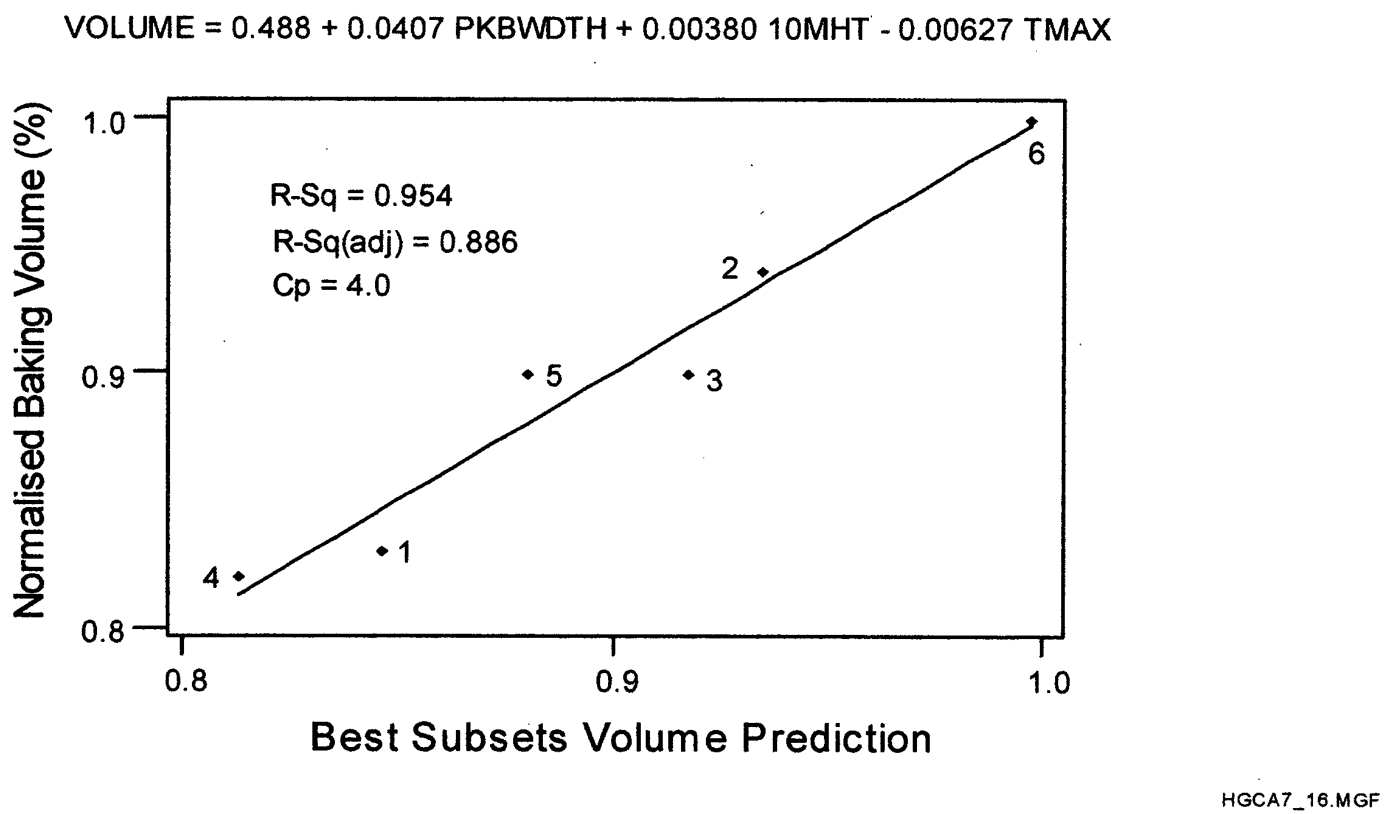


Table 1. Baking and Quality Data for Breadmaking Flours

RECOMMENDED LIST Winter Wheat 1996: Breadmaking Wheats							
		Water	Loaf Volume		Loaf	Flour	Flour
		Abs.	CBP	CBP	Volume	Protein	Protein on
		as is	A	B	Spiral	NIR as is	14% mb
Variety	Site	%	ml	ml	ml	%	%
ABBOT	Bridgets	54.2	1650	1674	1643	8.8	8.9
ABBOT	Seale Hayne	53.7	1591	1618	1596	9.3	9.4
ABBOT	Morley	55.7	1603	1721	1692	9.4	9.4
ABBOT	Harper Adams	51.4	1692	1675	1558	8.9	9.0
ABBOT	Rosemaund	51.2	1717	1666	1689	9.7	9.8
CADENZA	Bridgets	58.6	1550	1551	1581	8.6	8.7
CADENZA	Seale Hayne	58.8	1557	1578	1549	10.5	10.6
CADENZA	Morley	61.7	1535	1569	1600	10.5	10.5
CADENZA	Harper Adams	53.7	1698	1668	1620	10.0	10.1
CADENZA	Rosemaund	56.7	1602	1682	1600	10.4	10.5
CAXTON	Bridgets	57.4	1586	1683	1494	8.5	8.5
CAXTON	Seale Hayne	55.8	1680	1613	1515	9.9	10.0
CAXTON	Morley	59.1	1597	1589	1414	9.4	9.4
CAXTON	Harper Adams	50.5	1697	1700	1742	9.7	9.8
CHARGER	Bridgets	53.0	1601	1637	1614	8.3	8.3
CHARGER	Seale Hayne	53.3	1595	1599	1578	9.6	9.7
CHARGER	Morley	53.0	1664	1752	1576	8.8	8.8
CHARGER	Harper Adams	51.5	1728	1683	1673	8.8	8.9
CHARGER	Rosemaund	50.0	1708	1699	1689	9.3	9.4
CHIANTI	Bridgets	57.8	1555	1570	1558	8.3	8.3
CHIANTI	Seale Hayne	55.8	1509	1576	1560	9.1	9.2
CHIANTI	Morley	56.5	1628	1637	1595	8.8	8.8
CHIANTI	Harper Adams	48.8	1717	1739	1706	8.9	9.0
CHIANTI	Rosemaund	54.6	1567	1546	1551	9.1	9.2
HEREWARD	Bridgets	55.5	1632	1644	1661	9.5	9.6
HEREWARD	Seale Hayne	54.5	1625	1672	1634	10.0	10.1
HEREWARD	Morley	56.0	1668	1694	1723	10.0	10.1
HEREWARD	Harper Adams	50.3	1725	1718	1757	9.9	10.1
HEREWARD	Rosemaund	51.7	1660	1672	1713	10.3	10.4
MAGELLAN	Bridgets	59.5	1573	1545	1560	8.3	8.3
MAGELLAN	Seale Hayne	58.2	1544	1541	1519	9.4	9.4
MAGELLAN	Morley	58.8	1558	1558	1605	8.6	8.6
MAGELLAN	Harper Adams	53.6	1639	1607	1615	9.2	9.3
MAGELLAN	Rosemaund	54.8	1610	1584	1559	9.1	9.2
MERCIA	Bridgets	57.7	1600	1607	1588	8.9	8.9
MERCIA	Seale Hayne	55.4	1621	1649	1569	10.1	10.2
MERCIA	Morley	57.4	1604	1618	1604	9.7	9.7
MERCIA	Harper Adams	50.6	1714	1727	1623	9.8	10.0
MERCIA	Rosemaund	54.5	1634	1642	1631	9.9	10.0
RIALTO	Bridgets	56.7	1615	1615	1540	8.8	8.9
RIALTO	Seale Hayne	54.1	1599	1628	1564	9.6	9.7
RIALTO	Morley	58.0	1648	1618	1592	9.8	9.8
RIALTO	Harper Adams	52.6	1727	1748	1661	9.8	9.9
RIALTO	Rosemaund	52.6	1685	1693	1680	9.9	10.1
SOISSONS	Bridgets	55.6	1576	1594	1437	9.7	9.8
SOISSONS	Seale Hayne	54.0	1618	1567	1344	10.2	10.3
SOISSONS	Morley	58.2	1593	1647	1289	11.6	11.6
SOISSONS	Harper Adams	51.7	1594	1508	1334	9.7	9.8
SOISSONS	Rosemaund	53.4	1549	1492	1363	9.9	10.0
SPARK	Bridgets	59.3	1553	1533	1555	9.3	9.4
SPARK	Seale Hayne	57.8	1563	1613	1446	10.0	10.0
SPARK	Morley	58.5	1615	1621	1564	9.8	9.8
SPARK	Harper Adams	54.1	1716	1739	1676	10.6	10.7
SPARK	Rosemaund	54.6	1672	1629	1620	10.7	10.8
SHANGO	Bridgets	54.9	1654	1645	1602	8.4	8.4
Z94/2P	Bridgets	55.5	1555	1554	1468	8.1	8.2

Table 2. Quality Data for Biscuit Wheats & National List Breadmaking Wheats

RECOMMENDED LIST Winter Wheat 1996: Biscuit Wheats							
		Water Abs. as is	Extensograph			Flour Protein NIR as is	Flour Protein on 14% mb
			Resist.	Extens.			
Variety	Site	%	BU	cm	100E/R	%	%
CONSORT	Harper Adams	48.3	510	18.0	3.5	8.8	8.9
CROFTER	Harper Adams	51.0	180	14.7	8.2	8.8	8.8
DRAKE	Harper Adams	48.0	110	14.2	12.9	9	9.1
HARRIER	Harper Adams	49.8	240	15.3	6.4	8.8	8.9
MADRIGAL	Harper Adams	48.9	335	14.1	4.2	8.6	8.6
RALEIGH	Harper Adams	50.5	270	13.9	5.1	8.7	8.8
REAPER	Harper Adams	52.4	360	17.8	4.9	9.3	9.4
RIBAND	Harper Adams	49.0	270	16.8	6.2	8.4	8.4
CONSORT	Headley Hall	50.3	245	18.5	4.7	8.8	8.8
CROFTER	Headley Hall	52.0	100	13.7	13.7	9.1	9.1
DRAKE	Headley Hall	49.3	185	13.8	7.5	8.9	8.9
HARRIER	Headley Hall	50.2	150	13.4	8.9	8.8	8.8
MADRIGAL	Headley Hall	50.1	215	14.4	6.7	8.8	8.8
RALEIGH	Headley Hall	54.2	150	13.4	8.9	8.6	8.6
REAPER	Headley Hall	57.0	170	17.5	10.3	8.9	8.9
RIBAND	Headley Hall	49.5	200	16.4	8.2	8.6	8.6
CROFTER	Morley	51.3	170	13.4	7.9	8.2	8.2
DRAKE	Morley	48.6	220	13.2	6.0	8.1	8.1
RALEIGH	Morley	52.4	150	12.6	8.4	8.4	8.4
RIBAND	Morley	50.5	275	15.0	5.5	8.3	8.3
CONSORT	Rosemaund	50.2	395	19.4	4.9	8.9	9
CROFTER	Rosemaund	51.8	160	16.0	10.0	9.2	9.2
DRAKE	Rosemaund	50.7	200	14.2	7.1	9.3	9.3
HARRIER	Rosemaund	51.6	190	15.3	8.1	9.1	9.1
MADRIGAL	Rosemaund	50.0	285	14.3	5.0	8.8	8.8
RALEIGH	Rosemaund	53.1	190	16.5	8.7	9.4	9.5
REAPER	Rosemaund	52.7	210	20.8	9.9	9.4	9.5
RIBAND	Rosemaund	50.4	290	17.1	5.9	8.7	8.7
RALEIGH	Seale Hayne	54.4	200	13.9	7.0	9.2	9.2
REAPER	Seale Hayne	54.0	330	17.3	5.2	9.4	9.5

NATIONAL LIST Winter Wheat 1996: Breadmaking Wheats							
		Water Abs. as is	Loaf Volume CBP A	CBP B	Loaf Volume Spiral	Flour Protein NIR as is	Flour Protein 14% mb
Variety	Site	%	ml	ml	ml	%	%
CHAUCER	Bridgets	54.0	1569	1569	1518	8.3	8.4
CHAUCER	Headley	52.2	1529	1542	1515	8.5	8.6
CHAUCER	CPB	53.1	1521	1523	1531	8.3	8.4
PRIDE	Bridgets	59.7	1515	1539	1498	9.8	9.8
PRIDE	Headley	59.0	1563	1573	1559	9.6	9.6
PRIDE	CPB	58.2	1614	1628	1642	9.5	9.6
CWW 95/16	Bridgets	54.6	1578	1543	1440	8.6	8.7
CWW 95/57	Bridgets	56.6	1444	1410	1287	8.3	8.4
CWW 95/57	Headley	56.3	1547	1527	1403	8.9	9.0

Table 3. Ingredients used in test baking

INGREDIENT	% FLOUR WEIGHT	g/ MIX
FLOUR	100	1400
YEAST (COMPRESSED)	2.5	35.0
SALT	2.0	28.0
WATER	-	600 BU FARINOGRAPH
FAT (AMBREX)	1.0	14.0
ASCORBIC ACID (100 ppm)	0.01	0.14
FUNGAL α-AMYLASE	-	40 F.U.

Table 4. Values of variables used in the Mixsmart® software programme

VARIABLE NAME	VALUE	VARIABLE NAME	VALUE
Total Run Time (Min.)	10.00	Frequency (Samples/Sec)	10
Mid Curve Filter	160	Mid Curve No. Stages	1
Delta Left of Peak (Min.)	0	Delta Right of Peak (Min.)	0
Tq. Min. Std. Reading	70	Tq. Max. Std. Reading	700
Analysis Start Time (Min.)	0.00	Delta End Time (Min.)	0
Top Finder Window (Sec.)	0.7	Bottom Finder Window (Sec.)	0.7
Top Curve Filter	160	Top Curve No. Stages	1
Bottom Curve Filter	160	Bottom Curve No. Stages	1
Arbitrary Time 'X' (Min.)	0.50	Tq. Slope Scanning Window	10.0
Use Manual First Mid Peak	No	Mid Peak Fit Window (%)	10.0
Use Manual First Top Peak	No	Top Peak Fit Window (%)	10.0

Table 5. Table of derived Mixograph parameters and abbreviations used

MIXOGRAPH PARAMETER	ABBREVIATION USED
MIDLINE PEAK HEIGHT	PKHEIGHT
MIDLINE PEAK TIME	PKTIME
MIDLINE PEAK AREA	PKAREA
PEAK BANDWIDTH	PKBWDTH
30 SECOND AREA	30SAREA
30 SECOND BANDWIDTH	30SWDTH
30 SECOND SLOPE	30SSLOPE
10 MINUTE HEIGHT	10MHT
10 MINUTE BANDWIDTH	10MWDTH
10 MINUTE AREA	10MAREA
LEFT OF PEAK SLOPE	LEFTSLP
RIGHT OF PEAK SLOPE	RIGHTSLP
MAXIMUM HEIGHT	TMAX
MAXIMUM HEIGHT AT 30 SEC	T30S
MAXIMUM SLOPE TO 30 SEC	T30SLOPE

Table 7. Best subsets multiple regression volume prediction values with and without protein for Recommended List breadmaking varieties grouped according to growing site or averaged over all 5 growing sites.

SITE	SELECTED MIXOGRAPH PARAMETERS	BEST SUBSETS REGRESSION	
		WITH PROTEIN	WITHOUT PROTEIN
BRIDGETS	PROTEIN/PK.HEIGHT/PK.AREA/30S SLOPE/10MIN HT/10MIN AREA/RT.SLOPE/Tmax	$R^2 = 0.805$ $R^2_{ADJ} = 0.396$ Cp = 7.4	$R^2 = 0.776$ $R^2_{ADJ} = 0.384$ Cp = 8.0
HARPER ADAMS	PROTEIN/PK.HEIGHT/PK.TIME/PK.AREA/10 MINAREA/RT.SLOPE	$R^2 = 0.899$ $R^2_{ADJ} = 0.746$ Cp = 7.0	$R^2 = 0.848$ $R^2_{ADJ} = 0.695$ Cp = 6.0
SEALE HAYNE	PROTEIN/PK.HEIGHT/PK.TIME/PK.AREA/30 S SLOPE/10MIN HT/10MIN AREA/RT.SLOPE/Tmax	$R^2 = 0.995$ $R^2_{ADJ} = 0.948$ Cp = 10.0	$R^2 = 0.978$ $R^2_{ADJ} = 0.900$ Cp = 9.0
MORLEY	PROTEIN/PK.HEIGHT/PK.TIME/PK.AREA/10 MIN HT/10MIN AREA/RT.SLOPE/Tmax	$R^2 = 0.885$ $R^2_{ADJ} = 0.616$ Cp = 6.3	$R^2 = 0.643$ $R^2_{ADJ} = 0.287$ Cp = 8.0
ROSEMAUND	PROTEIN/PK.HEIGHT/PK.TIME/PK.AREA/10 MIN HT/10MIN AREA/RT.SLOPE/Tmax	$R^2 = 0.947$ $R^2_{ADJ} = 0.526$ Cp = 7.0	$R^2 = 0.840$ $R^2_{ADJ} = 0.520$ Cp = 8.0
SITE-AVERAGED VARIETY DATA	PROTEIN/PK.HEIGHT/PK.TIME/PK.AREA/30 S AREA/30S WIDTH/ 30S SLOPE/10MIN AREA/T30SLOPE/Tmax-T30S	$R^2 = 0.999$ $R^2_{ADJ} = 0.987$ Cp = 8.0	

TABLE 8. Baking and Mixograph data for site-averaged Recommended List breadmaking and 'extra-strong' varieties

VARIETY	CBP VOLUME	PROTEIN	PKHEIGHT	PKTIME	PKAREA	PKBWDTH	30SAREA	30SWDTH	30SSLOPE	10MHT	10MWDTH	10MAREA	LEFTSLP	RIGHTSLP	TMAX	T30S	T30SLOPE	TMAX-T30S
ABBOT	1660.70	9.22	50.34	3.80	137.10	30.09	5.66	11.69	26.55	37.27	14.19	405.30	8.54	-2.35	65.86	24.27	35.07	41.59
CADENZA	1599.00	10	50.83	4.21	151.74	28.53	4.76	10.04	26.97	38.26	13.67	410.80	5.89	-2.93	65.65	22.08	36.81	43.57
CAXTON	1643.13	9.375	51.45	4.41	168.10	30.94	6.34	12.96	27.11	42.76	17.04	432.13	4.42	-1.43	66.65	25.64	34.05	41.01
CHARGER	1666.60	8.96	46.37	3.99	135.61	28.43	5.84	12.44	24.73	37.17	14.01	388.90	5.26	-1.80	61.44	25.27	33.87	36.17
CHIANTI	1604.40	8.84	48.33	3.03	105.43	26.89	6.09	11.98	27.74	29.14	10.37	367.60	9.15	-4.23	61.98	26.23	34.38	35.75
HEREWARD	1671.00	9.94	52.21	3.55	127.49	32.50	4.92	10.62	26.51	39.51	14.77	422.25	9.72	-2.58	68.72	22.05	34.89	46.68
MAGELLAN	1575.90	8.92	48.80	3.34	115.20	28.83	5.68	11.42	26.12	34.90	12.51	393.10	8.58	-2.76	63.49	24.19	33.81	39.30
MERCIA	1641.60	9.68	44.76	3.69	117.16	26.49	4.54	10.98	25.83	30.92	10.73	353.57	7.02	-3.29	58.41	21.30	34.13	37.11
RIALT O	1657.60	9.58	49.87	3.77	136.56	24.98	6.23	12.05	27.32	33.52	11.50	388.00	6.72	-3.51	62.74	26.06	35.20	36.68
SOISSONS	1573.80	10.22	59.52	5.31	204.09	37.17	4.84	11.67	25.31	46.02	16.10	454.13	10.46	-3.66	78.71	22.24	34.47	56.47
SPARK	1625.40	10.08	53.36	4.53	173.51	30.83	5.49	11.03	25.64	43.44	15.98	438.13	5.34	-1.89	69.62	23.39	33.07	46.23
SHANGO	1649.50	8.4	41.50	3.73	113.87	24.77	5.20	13.10	26.60	27.47	9.53	328.00	6.09	-2.98	54.13	24.00	36.37	30.13
FRESCO		11.4	70.35	3.88	192.10	38.35	8.30	17.30	31.15	46.60	13.35	546.75	13.53	-6.57	90.60	34.60	45.25	56.00
TORFRIDA		10.5	62.60	5.05	229.40	35.70	5.30	11.60	29.35	46.40	15.20	496.10	6.11	-4.85	81.85	24.10	40.55	57.75
CLASSIC		11.2	54.70	5.52	227.30	31.60	4.50	8.70	24.40	45.95	19.50	455.70	3.50	-1.56	71.25	19.65	32.15	51.60
AUBAINE2		11.7	98.30	4.66	346.80	41.40	9.70	13.70	43.85	75.70	20.40	806.40	-0.30	-0.30	122.00	37.40	54.00	84.60
FLORENCE AURORE		11.4	75.1	5.51	277.3	41.00	7.80	10.50	32.60	59.00	16.60	586.60	-0.41	-0.41	96.60	29.60	41.00	66.00
GLENLEA		15.7	71.60	6.17	246.70	41.10	3.70	6.20	18.90	65.20	16.50	513.80	-0.70	-0.70	92.60	15.30	23.00	77.30

TABLE 9. Analytical and quality data for commercial wheat gluten samples used in Mixograph quality predictions
(numbers in brackets are one standard deviation about the mean)

ANALYSIS	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)
ALVEO P	77 (9)	67 (7)	53 (11)	35 (9)	50 (13)	60 (9)
ALVEO L	91 (16)	100 (21)	129 (26)	129 (35)	115 (22)	124 (19)
ALVEO W	260 (17)	215 (29)	219 (38)	104 (25)	159 (44)	230 (38)
TOTAL FAT	6.6 (0.3)	4.6 (0.5)	5.5 (0.6)	5.3 (0.2)	5.2 (0.4)	7.0 (0.7)
STARCH	6 (2)	7 (1)	6 (1)	3.9 (0.2)	6 (1)	5 (1)
NORMALISED BAKING VOLUME	83	94	90	82	90	100
QUALITY ASSESSMENT	POOR	VERY GOOD	GOOD	POOR	GOOD	VERY GOOD