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THE VARIABLE BAKING QUALITY OF GLUTEN SUPPLEMENTED FLOURS

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The variable baking quality of gluten supplemented flours

by

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Final report of a three year project at the Flour Milling and Baking Research Association, Chorleywood, Hertfordshire WD3 5SH. The work commenced in May 1987 and was supported by a grant of £147,000 from the Home-Grown Cereals Authority (Project No. 0036/3/87).

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THE VARIABLE BAKING QUALITY OF GLUTEN SUPPLEMENTED FLOURS

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ABSTRACT

Gluten fortification of white and wholemeal flours from five varieties (Avalon, Brock, Galahad, Mercia and Slejpner) for harvest years 1986, 1987 and 1988 has shown that the better breadmaking varieties (Avalon and Mercia) responded less well to added gluten in the Chorleywood Bread Process (CBP) than did the other (poorer quality) varieties. Similar results were obtained for the varieties baked by the Bulk Fermentation Process (BFP) in harvest years 1987 and 1988.

Fundamental rheological parameters such as elastic and viscous moduli (G' and G'') measured on the Bohlin rheometer correlated well with baking performance of gluten, when a wide range of quality was available through the inclusion of heat-damaged samples. However, the uniformly good quality of the commercial gluten samples available, made prediction of baking quality from other quality measurements impossible.

The lactic acid sedimentation test was again shown to be a good screening test for gluten quality and equivalent to the rheological parameters in statistical terms. A new instrument, the Glutograph was shown to have potential as a quality tool, but sample preparation is critical for consistent results.

In fortification systems, gluten may be heated to 70°C without deleterious effect. The loss of vitality that occurs at higher temperatures is associated with the loss of solubility of the gliadin fraction and suggests that the viscous component is important

in the functionality of wheat gluten when used to fortify low protein base flour.

Long term (16 week) storage of gluten fortified wholemeal flour showed that despite increases in lipid hydrolysis and oxidative products, there were no differences in the baking performance between stored gluten fortified wholemeal and stored wholemeal with gluten addition fresh at the mixer. Changes that did occur were considered to be due to changes in fat requirement of the flour rather than to loss of gluten functionality.

Fortification of individual wheat variety base-flours with individual variety glutens washed out in the laboratory show that in general, there is no advantage in fortifying a base-flour with its own gluten. However, one flour variety, Haven, had a poor baking performance and did not respond to its own gluten. Haven gluten did not perform well with the other base-flours. With the exception of Haven gluten, the glutens were of a generally uniform standard.

OBJECTIVES

The overall aims of this three year study were:

1. to determine the reasons for the variable breadmaking quality of gluten supplemented flours, and to define how such variability can be minimised.

2. to investigate methods of accurately predicting the baking performance of gluten.

3. to study in greater detail the effectiveness of gluten supplemented wholemeal flours, potentially the most important area of gluten usage, and to determine the storage stability of such flours.

1. BACKGROUND

The widespread and increasing use of gluten in the UK breadmaking industry during the 1980's resulted in a number of studies into various aspects of this practice. In particular, work carried out at the Flour Milling and Baking Research Association (FMBRA) at Chorleywood concerned the response of flour made from home grown wheat to gluten and to the establishment of quality assessment methods for gluten.

Collins and Evans (1986) indicated that the characteristics of the base flour influenced the loaf volume and crumb improvements obtained when they were fortified with gluten. In that work, eight commercially milled flours with protein contents from 8.1 to 11.1% (as-is) were fortified with gluten to increase their total protein by 1 and 2 percentage points. Volume improvement from 1% gluten protein addition ranged from 4.1 to 10.7% and for 2% addition from 5.1 to 13.5%. The volume improvement from gluten addition varied between flours, but there was no obvious correlation with flour characteristics. The difference in response of the above flours was thought to be due to different wheat varieties used in the grist and a possible dissimilar response of different varieties to gluten fortification. It therefore became apparent that information was required on the response of such flours (white and wholemeal) to gluten.

Increased usage of home-grown wheat for milling and the predominance of just a few recommended varieties has made it more likely that breadmaking flours will be produced from grists dominated by single wheat varieties.

Earlier studies (McDermott 1986, McDermott and Chamberlain 1985) suggested that the varietal source of the gluten was relatively unimportant in determining the baking quality of the gluten, but with the emphasis on single variety base-flour, a more detailed study was considered necessary.

Over a number of years McDermott and Chamberlain (1984, 1985, 1986) studied gluten quality and methods of measuring it in an attempt to find a simple test that could predict baking performance. The Chorleywood Bread Process (CBP) method was used for most of the baking quality assessment in fortification of a low protein English flour with 2% additional protein as gluten. A number of assessment methods were shown to correlate with test baking quality, but no direct predictive ability was observed with any single test.

With further funding available from the Home-Grown Cereals Authority (HGCA) for work on gluten, studies have continued at Chorleywood on the baking quality of gluten. Rheological techniques such as the Bohlin Rheometer and Glutograph, that were not available to McDermott have been added to the quality assessment, and the test baking has been extended to include a number of base flours and baking processes.

The increasing popularity of wholemeal bread, with its requirement for gluten fortification made a more detailed study of gluten fortified wholemeal flour desirable. Previous studies, into the effects of particle size distribution, gluten fortification (Hook and Collins, 1987 and 1988) and differing levels of starch damage (Bent, Collins and Sang, 1990) were reported earlier. The known susceptibility of wholemeal flours to hydrolytic and oxidative degradation of lipids through enzymic action (Galliard 1986), made a study of the storage stability of gluten fortified wholemeal desirable.

The three year project 0036/1/87 was therefore divided into four subject areas:-

- The variation in the response of single variety base-flours to added gluten. (Section 2)

- The variable quantity of commercial gluten. (Section 3)

- Breadmaking performance and storage stability of gluten supplemented wholemeal flours. (Section 4)

- The interaction between single variety glutens and single variety base-flours. (Section 5)

For the convenience of the reader, this report is presented as four separate "chapters" linked by this introduction and by a general discussion. A number of appendices containing additional information are also attached.

2. VARIATION IN THE RESPONSE OF SINGLE VARIETY BASE FLOURS TO ADDED GLUTEN

2.1 Objective

To determine whether varietal effects contribute to variability in the breadmaking performance of gluten supplemented flours.

2.2 Introduction

Previous work at FMBRA into gluten-fortified flours (Collins and Evans, 1986) indicated that the characteristics of the base flour influenced loaf volume and crumb improvements obtained when they were fortified with gluten. One of the reasons for the difference in response of these flours to gluten addition was considered to be the wheat variety used in the grist.

In this more detailed study we compared the response of five single wheat varieties obtained from three harvest years, 1986, 87 and 88, to gluten fortification. The five wheats investigated were Avalon, Brock, Galahad, Mercia and Slejpner. The improvement from added gluten protein in white and wholemeal bread, made by the Chorleywood Bread Process (CBP) was compared for all three harvest years, and by a 1 hour Bulk Fermentation Process (BFP) for the harvest years 1987 and 1988. For 1988 harvest, samples of the same varieties grown at five sites were also obtained and the response to gluten fortification investigated in bread made by the CBP.

2.3 Materials and methods.

Wheat samples.

Commercial samples of the five wheat varieties were purchased from Merchants and farmers in Berkshire, Bedfordshire and Southampton for the harvest years 1986 and 1987. Samples from the 1988 harvest were obtained from five ADAS trial sites, as follows:

March, Cambridgeshire.
Reading, Berkshire.
Owstwick, Humberside.
Terrington, N. Yorkshire.
West Rudham, Norfolk.

Varietal composition of wheats were identified by electrophoresis (Salmon and

Burbridge, 1985) to determine the level of purity. Table 2.1 lists the varieties of wheats identified in each commercial sample. Milling was carried out under the conditions described in Appendix 1.

Flour analysis

White and wholemeal flours were analysed for moisture, protein, Falling Number, damaged starch and *alpha*-amylase. For white flours the Grade Colour Figure was also measured and for wholemeals particle size by seive analysis with ash value determined for the fraction below 180 microns. Table 2.2 gives the flour characteristics and water absorptions as determined by the Simon Extrusion Meter (Dodds, 1972).

Throughout, baking tests on the wholemeal flour took place within one week of milling. The rapid deterioration reported for wholemeal flour (Kent, 1984) during storage at ambient temperature was thus avoided. This aspect of the use of wholemeal flour is disclosed in greater detail in section 4, page 48.

Gluten

A single source of dried gluten, obtained from Europe, was used. Analysis of the two consignments obtained for this work are given in Table 2.3. To compensate for the increase in dough water when gluten was added, the absorption determined by the Simon Extrusion Meter was increased by a factor of 1.5 times the weight of gluten added.

Breadmaking

White and wholemeal CBP and 1 hour BFP recipes and dough processing methods used throughout this work are given in Appendices 2 and 3. Breadmaking was carried out with flours and wholemeals as milled and with added gluten protein to increase the base flour protein six percentage points in one or two percent increments. The amount of gluten needed to increase the flour protein was calculated using a published equation (Collins and Evans, 1986). The calculation is based on the normal commercial practice of adjusting flour protein content by gluten addition at the mill. When gluten was used to increase the protein content of a flour, it was added to the base of the mixer followed by the flour, other ingredients and then water.

All baking tests were carried out in random order. The 1986, 87 and 88 CBP tests were duplicated and gluten protein was added in one percent increments. 1987 and 88 BFP tests were duplicated and gluten protein was added in 2% increments. For wheats grown on five sites, single mixings were carried out with gluten protein increases of 2%. The breadmaking procedure used in this report measured the time for a dough piece to reach 10cm height in the prover. Typically this would be of the order of 45 min. In certain cases, especially for some wholemeal test variations, when this height was not achieved within one hour the loaves were placed into the oven.

Loaf quality assessment

Loaf volume was measured by seed displacement (Cornford, 1969) and crumb score by expert examination of the cell size, uniformity and wall thickness, scoring up to a maximum of 10 points. High scores were given for close, even structure of cells with thin walls.

2.4 Results and Discussion

Effect of wheat variety and gluten supplementation on loaf volume and crumb score.

Tables 2.4 and 2.5 give the average CBP loaf volume and crumb score of duplicate white and wholemeal for the harvest years 1986, 87 and 88. Tables 2.6 and 2.7 give the results for 1 hour BFP for harvest years 1987 and 88. Tables 2.8 and 2.9 give the CBP white, and Tables 2.10 and 2.11 wholemeal, loaf volume and crumb scores for the wheat samples grown on five different sites for the 1988 harvest. Loaf volume results are also presented in graphical form, (Fig. 2.1 to 2.5) for Avalon, Brock, Galahad, Mercia and Slejpner respectively. For each variety there are three charts showing:-

(a) CBP white and wholemeal loaf volume for harvest years 1986, 87 and 88 with gluten protein increasing in 1% increments. The top three curves are for white flour and the bottom for wholemeal.

(b) Loaf volume from 1 hour BFP with gluten protein increasing in 2% increments.

(c) "Site to Site Variations" the average loaf volume for each variety. In this third chart the maximum and minimum volumes obtained from the five sites are illustrated by lines above and below the appropriate average.

Statistical analysis of loaf volume results.

For the purpose of the analysis, it was assumed that the response to gluten addition was linear. Figures 2.1 to 2.5 indicate that this may not be accurate in certain cases, especially for the BFP results. However, in some instances there were insufficient levels of addition to assess the non-linearity and analysis of a quadratic term would have complicated interpretation of the model unduly. The analysis concentrated on assessing the response in terms of the rate of increase of loaf volume with added gluten. Three factors affected the response: variety, whether wholemeal or white flour and the year of harvest (in the case of three year comparison) or site.

In view of the number and variability of results, it was thought to be of little value to quote any values for response slopes or variability statistics. Instead, the results are presented graphically (Figure 2.1 to 2.5)

CBP: Harvest years 1986, 87 and 88.

The individual response of Avalon, Galahad, Mercia and Slepjner was similar for the three years tested. The year to year response of Brock was different with a significance of 0.1%.

Avalon and Mercia showed significantly less response to gluten supplementation than Brock and Galahad. The response for Slejpner was ambiguous. The white and wholemeal results for Slejpner were similar in 1986, to the responses for Brock and Galahad, as were the Slejpner white results for 1988 but in other cases, the Slejpner response was similar to Avalon and Mercia.

BFP: Harvest years 1987 and 1988.

Neither the year to year nor the white versus wholemeal effects were significant, possibly due to higher variability of results. The varieties responded in two ways with Avalon and Mercia giving lower volume increases to gluten supplementation than Brock or Galahad. The response of Slepjner was somewhere between the two groups.

CBP: Harvest year 1988, five sites.

There were no significant differences in loaf volume response to gluten between the different sites. However, there were differences between white and wholemeal in some instances. Brock gave a greater response for white, whereas Mercia gave a greater response for wholemeal. The varietal differences for white were as before, with Slejpner being similar to Brock and Galahad. For wholemeal there were no significant differences between varieties at all.

Discussion.

In the absence of gluten protein addition, loaf volume and crumb structure differed between varieties. Throughout the tests two trends were apparent, Avalon and Mercia gave relatively high volume and high crumb scores for both white and wholemeal, whereas Brock, Galahad and Slejpner gave low volumes and crumb scores. This can be seen by comparing results in the appropriate Tables and charts. Avalon and Mercia which gave high loaf volume and crumb scores without gluten addition showed a gradual rate of improvement in loaf properties as gluten addition increased. Conversely varieties which gave low loaf volumes and low crumb scores without gluten addition, Brock, Galahad and Slejpner, gave substantial increases as the level of added gluten was increased.

These results can be seen for CBP in the 3 year average figures, the 2 year average for BFP in white and wholemeal and for varieties from the five sites in white bread. The above trend was not found in the wholemeal loaf volumes from varieties grown at five different sites although crumb scores did follow the trend. There were no apparent reasons in the characteristics of the wholemeal flours from the sites why the trend in volume improvement from gluten addition was not found. There were fewer samples available in this section of the work.

Table 2.1

Wheat variety identification by polyacrylamide gel electrophoresis of gliadin protein bands

Harvest year	Named variety	Varieties present	No. of grains	Observed %	95% confidence limits for composition of the bulk sample
1986	Avalon	Avalon	28	100	87 - 100
	Brock	Brock	13	46	26 - 67
		Stetson	7	25	11 - 45
		Armada	4	14	4 - 33
		Moulin	2	7	1 - 24
		Avalon	1	4	0 - 18
		Brimstone	1	4	0 - 18
	Galahad	Galahad	15	54	33 - 73
		Norman	11	39	22 - 60
		Avalon	2	7	1 - 24
	Mercia	Mercia	28	100	87 - 100
	Slejpner	Slejpner	28	100	87 - 100
1987	Avalon	Avalon	26	93	76 - 99
		Brock	1	4	0 - 18
		Galahad	1	4	0 - 18
	Brock	Brock	28	100	87 - 100
	Galahad	Galahad	24	86	67 - 96
		Brock	3	11	2 - 29
		Slejpner	1	4	0 - 18
	Mercia	Mercia	27	95	82 - 100
		Avalon	1	4	0 - 18
	Slejpner	Slejpner	26	93	76 - 99
		Mission	1	4	0 - 18
		Rapier	1	4	1 - 18

Table 2.1 cont/d

Harvest year	Growing site	Named variety	Varieties present	No of grains	Observed %	95% confidence limits for composition of the bulk sample
1988	March					
		Avalon	Avalon	13	93	66 - 100
			Ambassador	1	7	0 - 34
		Brock	Brock	12	86	57 - 98
			Brimstone	1	7	0 - 34
			Galahad	1	7	0 - 34
		Galahad	Galahad	14	100	76 - 100
		Mercia	Mercia	14	100	76 - 100
		Sjejpner	Slejpner	13	93	66 - 100
			Broom	1	7	0 - 34
1988	Owstwick					
		Avalon	Avalon	23	85	67 - 96
			Mercia	2	7	1 - 24
			Boxer	1	4	0 - 18
			Slejpner	1	4	0 - 18
		Brock	Brock	22	92	74 - 99
			Flanders	1	4	0 - 20
			Slejpner	1	4	0 - 20
		Galahad	Galahad	26	93	76 - 99
			Apollo	1	4	0 - 18
			Hornet	1	4	0 - 18
		Mercia	Mercia	20	71	51 - 87
			Brock	4	15	4 - 33
			Slejpner	3	11	2 - 29
			Parade	1	4	0 - 18
		Slejpner	Slejpner	21	84	64 - 95
			Avalon	2	8	1 - 26
			Norman	2	8	1 - 26
1988	Reading					
		Avalon	Avalon	14	100	76 - 100
		Brock	Brock	11	85	54 - 98
			Galahad	2	15	2 - 46
		Galahad	Galahad	28	100	87 - 100
		Mercia	Mercia	14	100	76 - 100
		Slejpner	Slejpner	14	100	76 - 100

Table 2.1 cont/d

Harvest year	Growing site	Named variety	Varieties present	No of grains	Observed %	95% confidence limits for composition of the bulk sample
1988	Terrington					
		Avalon	Avalon	26	93	76 - 99
			Slejpner	2	7	1 - 24
		Brock	Brock	24	86	67 - 96
			Slejpner	4	14	4 - 33
		Galahad	Galahad	28	100	87 - 100
		Mercia	Mercia	27	96	82 - 100
			Slejpner	1	4	0 - 18
		Slejpner	Slejpner	28	100	87 - 100
1988	West Rudham					

As there was insufficient grain sample of some varieties for tests, electrophoresis was carried out on a wholemeal flour sample.

Galahad	Galahad	27	96	82 - 100
	Aquila	1	4	0 - 18

Avalon - probably all or nearly all Avalon
Brock - probably all or nearly all Brock
Mercia - probably all or nearly all Mercia
Slejpner - probably all or nearly all Slejpner

Table 2.2

1986 Flour Characteristics

	Wholemeal					White Flour				
Variety	Avalon	Brock	Galahad	Mercia	Slejpner	Avalon	Brock	Galahad	Mercia	Slejpner
FMBRA Laboratory No.	E1374	E1377	E1378	E1375	E1376	E504	E507	E506	E505	E508
Moisture (130^{o}C for 1.5h) %	12.9	11.8	13.7	14.5	12.9	14.2	13.8	14.0	14.5	14.2
Protein (N x 5.7, as is) %	11.0	10.7	10.0	9.3	10.5	9.7	9.0	8.4	8.1	9.0
Grade Colour Figure (Kent-Jones & Martin)	-	-	-	-	-	0.6	0.5	-0.7	-0.3	1.2
Falling No. (7g) s	386	244	283	373	350	414*	310*	304*	384*	333*
Damaged starch (Farrand Units)	14	13	18	22	19	18	15	9	27	25
Alpha-amylase (Farrand Units)	8	13	15	8	12	7	6	5	3	5
Water Absorption % (Simon Extrusion Meter, 10min)	63.6	57.5	57.9	62.5	61.4	55.4	50.4	50.0	55.0	51.8

* Calculated from 5g result 7g = (1.5) 5g result + 43

Table 2.2 (continued)

1987 Flour Characteristics

Variety	Wholemeal Avalon	Wholemeal Brock	Wholemeal Galahad	Wholemeal Mercia	Wholemeal Slejpner	White Flour Avalon	White Flour Brock	White Flour Galahad	White Flour Mercia	White Flour Slejpner
FMBRA Laboratory No.	E904	E901	E1373	E905	E903	E909	E906	E1358	E910	E908
Moisture (130^{o}C for 1.5h) %	13.2	12.9	13.6	13.9	13.2	14.0	13.5	14.0	14.2	13.3
Protein (N x 5.7, as is) %	11.6	11.1	11.8	11.0	10.9	10.2	9.7	9.9	9.8	9.7
Grade Colour Figure (Kent-Jones & Martin)	-	-	-	-	-	1.5	1.7	3.0	1.2	2.3
Falling No. (7g) s	244	244	342	213	249	269	242	341	235	260
Damaged starch (Farrand Units)	25	12	7	27	21	21	10	6	26	18
Alpha-amylase (Farrand Units)	18	13	10	22	15	10	12	6	16	11
Water Absorption %										
(Simon Extrusion Meter, 10min)	63.2	61.8	62.1	62.5	60.4	56.1	52.5	51.4	55.7	55.4
(" " " , 1 hour)	62.8	61.4	61.4	60.0	62.1	55.7	49.6	51.4	55.7	55.0

Sieve analyses of wholemeal

Sieve size (microns)	Avalon	Brock	Galahad	Mercia	Slejpner
> 1000	1.8	1.9	NA	1.4	2.2
> 850	2.6	2.7	-	2.7	3.7
> 500	10.1	10.2	-	11.2	10.6
> 300	5.4	5.0	-	6.4	6.3
> 180	4.4	8.2	-	4.8	7.4
< 180	75.8	72.0	-	73.5	69.8

Table 2.2 (continued)

1988 Flour Characteristics
March site

Variety	Wholemeal Avalon	Wholemeal Brock	Wholemeal Galahad	Wholemeal Mercia	Wholemeal Slejpner	White Flour Avalon	White Flour Brock	White Flour Galahad	White Flour Mercia	White Flour Slejpner
FMBRA Laboratory No.	E396	E397	E398	E399	E400	E391	E392	E393	E394	E395
Moisture (130°C for 1.5h) %	14.8	14.1	14.3	13.9	14.3	15.2	14.5	14.5	14.2	14.6
Protein (N x 5.7, as is) %	10.5	10.1	10.2	10.9	9.8	9.4	8.3	8.5	9.5	8.3
Grade Colour Figure (Kent-Jones & Martin)	-	-	-	-	-	0.7	1.7	1.2	1.3	1.4
Falling No. (7g) s	246	124	277	288	335	230	125	281	301	340
Damaged starch (Farrand Units)	12	10	6	17	15	10	7	4	19	15
Alpha-amylase (Farrand Units)	21	86	9	9	4	19	80	5	5	3
Water Absorption % (Simon Extrusion Meter, 10min)	56.1	53.2	55.0	62.1	57.9	50.4	46.1	50.0	54.6	51.1

Sieve analyses of wholemeal

Sieve size (microns)	Avalon	Brock	Galahad	Mercia	Slejpner
> 850	2.8	-	4.2	2.3	2.8
> 500	7.2	-	6.2	7.2	7.3
> 300	4.9	-	5.2	5.3	5.1
> 180	7.0	-	8.4	5.1	7.3
< 180	73.2	-	70.5	77.4	74.3

Table 2.2 (continued)

1988 Flour Characteristics
Owstwick site

Variety	Wholemeal Avalon	Brock	Galahad	Mercia	Slejpner	White Flour Avalon	Brock	Galahad	Mercia	Slejpner
FMBRA Laboratory No.	E295	E296	E297	E298	E299	E225	E226	E227	E228	E229
Moisture (130^{o}C for 1.5h) %	13.6	13.6	13.8	13.5	13.9	13.8	13.9	14.2	13.8	14.2
Protein (N x 5.7, as is) %	11.3	10.6	10.7	10.7	10.5	10.1	8.8	8.8	9.4	9.1
Grade Colour Figure (Kent-Jones & Martin)	-	-	-	-	-	2.5	2.2	2.1	1.2	2.2
Falling No. (7g) s	398	266	311	343	356	368	248	298	319	321
Damaged starch (Farrand Units)	16	6	8	15	13	14	5	6	16	13
Alpha-amylase (Farrand Units)	5	19	7	5	4	2	8	3	2	2
Water Absorption % (Simon Extrusion Meter, 10min)	60.7	58.6	59.3	60.0	57.5	56.7	49.6	50.4	54.6	50.7

Sieve analyses of wholemeal

Sieve size (microns)	Avalon	Brock	Galahad	Mercia	Slejpner
> 1000	2.8	3.8	4.3	2.7	3.7
> 850	2.6	3.5	3.2	2.6	2.7
> 500	7.2	7.9	8.0	7.3	8.1
> 300	5.0	5.2	5.2	4.7	5.0
> 180	6.3	8.1	7.4	6.5	10.0
< 180	76.1	71.5	71.9	76.2	70.5

Table 2.2 (continued)

1988 Flour Characteristics
Reading site

Variety	Wholemeal Avalon	Wholemeal Brock	Wholemeal Galahad	Wholemeal Mercia	Wholemeal Slejpner	White Flour Avalon	White Flour Brock	White Flour Galahad	White Flour Mercia	White Flour Slejpner
FMBRA Laboratory No.	E325	E326	E327	E328	E329	E320	E321	E322	E323	E324
Moisture (130^{o}C for 1.5h) %	14.3	13.9	14.0	14.2	14.7	14.7	14.3	14.3	15.1	14.6
Protein (N x 5.7, as is) %	11.9	10.5	11.5	10.6	11.4	10.7	8.8	9.7	10.0	9.0
Grade Colour Figure (Kent-Jones & Martin)	-	-	-	-	-	3.3	2.0	3.5	1.9	2.9
Falling No. (7g) s	213	159	155	243	290	239	166	178	252	299
Damaged starch (Farrand Units)	19	13	14	20	20	17	6	10	21	17
Alpha-amylase (Farrand Units)	28	44	44	8	14	12	35	28	9	6
Water Absorption % (Simon Extrusion Meter, 10min)	61.4	53.9	56.1	57.5	57.9	54.3	47.5	47.1	55.4	50.4

Sieve analyses of wholemeal

Sieve size (microns)	Avalon	Brock	Galahad	Mercia	Slejpner
> 1000	3.2	3.7	3.8	3.1	3.4
> 850	2.9	3.2	2.9	2.8	3.0
> 500	7.1	7.6	8.1	7.1	7.2
> 300	4.7	5.0	5.3	4.9	5.4
> 180	6.8	6.2	2.0	6.4	9.0
< 180	75.3	74.3	77.9	75.7	72.0

Table 2.2 (continued)

1988 Flour Characteristics

Terrington site

Variety	Wholemeal Avalon	Wholemeal Brock	Wholemeal Galahad	Wholemeal Mercia	Wholemeal Slejpner	White Flour Avalon	White Flour Brock	White Flour Galahad	White Flour Mercia	White Flour Slejpner
FMBRA Laboratory No.	E2311	E2312	E2313	E2314	E2315	E2306	E2307	E2308	E2309	E2310
Moisture (130°C for 1.5h) %	13.3	12.8	13.3	12.9	13.0	13.5	13.1	13.8	13.4	13.3
Protein (N x 5.7, as is) %	9.9	9.7	10.0	10.0	8.9	8.9	8.3	8.5	8.9	7.6
Grade Colour Figure (Kent-Jones & Martin)	-	-	-	-	-	2.0	0.8	2.3	1.0	1.1
Falling No. (7g) s	213	169	278	300	292	191	164	266	317	294
Damaged starch (Farrand Units)	27	12	10	26	26	28	11	9	28	27
Alpha-amylase (Farrand Units)	29	35	10	10	9	29	38	9	7	7
Water Absorption %										
(Simon Extrusion Meter, 10min)	61.8	57.9	59.6	63.6	58.9	55.4	48.2	49.3	55.7	52.1
(" " " , 1 hour)	64.8	57.9	59.6	63.6	61.1	55.0	48.9	49.6	57.1	53.2

Sieve analyses of wholemeal

Sieve size (microns)	Avalon	Brock	Galahad	Mercia	Slejpner
> 1000	2.2	3.6	3.8	2.0	2.2
> 850	2.7	3.1	3.0	2.3	2.4
> 500	7.5	7.0	7.0	8.3	7.1
> 300	5.3	4.3	4.3	5.3	4.9
> 180	6.0	4.7	5.3	5.0	5.1
< 180	76.3	77.3	76.6	77.1	78.3

Table 2.2 (continued)

1988 Flour Characteristics

West Rudham site

Variety	Wholemeal Avalon	Wholemeal Brock	Wholemeal Galahad	Wholemeal Mercia	Wholemeal Slejpner	White Flour Avalon	White Flour Brock	White Flour Galahad	White Flour Mercia	White Flour Slejpner
FMBRA Laboratory No.	E285	E286	E287	E288	E299	E290	E291	E292	E293	E294
Moisture (130^{o}C for 1.5h) %	13.9	13.8	13.8	13.6	13.9	14.3	14.2	14.2	13.9	14.2
Protein (N x 5.7, as is) %	10.2	9.9	9.9	10.1	9.4	9.1	8.2	8.2	8.7	8.0
Grade Colour Figure (Kent-Jones & Martin)	-	-	-	-	-	1.1	0.3	1.1	0.4	1.2
Falling No. (7g) s	321	172	316	351	358	329	180	331	358	352
Damaged starch (Farrand Units)	15	8	7	16	15	15	8	5	17	15
Alpha-amylase (Farrand Units)	11	48	6	4	4	4	30	2	2	1
Water Absorption % (Simon Extrusion Meter, 10 min)	58.9	53.9	56.1	59.6	56.8	52.9	46.8	48.9	54.3	50.0

Sieve analyses of wholemeal

Sieve size (microns) %	Avalon	Brock	Galahad	Mercia	Slejpner
> 1000	2.9	3.3	3.6	2.3	3.4
> 850	2.6	2.8	3.2	2.3	2.8
> 500	7.0	7.5	8.1	7.5	7.3
> 300	4.9	4.6	5.6	5.2	4.7
> 180	5.7	6.7	7.9	6.3	7.2
< 180	76.9	75.1	71.6	76.4	74.6

Table 2.3

Gluten characteristics

Throughout the three years of the project two samples of commercial gluten were used, both were obtained from the same supplier.

Protein (% dry basis)	83.4	82.2
Protein (% as is)	77.1	75.5
Moisture (%)	7.6	8.1
Hydration rate (s)	20	30
Water absorption (ml/g protein)	2.22	2.12
SDS sedimentation volume (ml/g protein)	93	108
Lactic acid sedimentation (%)	28.0	19.4
Particle size % less than 160µm	88.5	81.3

Table 2.4

Loaf volume (ml) of gluten fortified white and wholemeal flours milled from five wheat varieties

CBP: Harvest years 1986 '87 and 1988

Variety	Gluten protein added (%)	WHITE VOLUME 1986	1987	1988	Average volume for the 3 years	WHOLEMEAL VOLUME 1986	1987	1988	Average volume for the 3 years
Avalon									
	0	1508	1501	1482	1497	1248	1110	938	1099
	1	1542	1561	1451	1518	1317	1227	996	1180
	2	1604	1591	1544	1580	1362	1240	1163	1255
	3	1628	1652	1547	1609	1355	1261	1230	1282
	4	1654	1680	1648	1661	1391	1342	1261	1331
	5	1651	1740	1672	1688	1433	1360	1337	1376
	6	1642	1742	1617	1667	1409	1403	1389	1401
Brock									
	0	1277	1275	1080	1211	956	979	938	958
	1	1365	1396	1143	1301	1109	1033	918	1020
	2	1474	1496	1273	1414	1196	1081	999	1092
	3	1565	1585	1370	1507	1214	1179	1086	1160
	4	1645	1632	1433	1570	1250	1209	1177	1212
	5	1675	1751	1557	1661	1261	1248	1234	1248
	6	1730	1742	1589	1687	1321	1347	1283	1317
Galahad									
	0	1373	1315	1127	1272	-	1027	932	980
	1	1468	1402	1203	1358	-	1112	984	1048
	2	1593	1514	1287	1464	-	1193	1100	1147
	3	1625	1620	1381	1542	-	1264	1166	1215
	4	1660	1655	1483	1599	-	1309	1222	1260
	5	1728	1682	1520	1643	-	1374	1269	1322
	6	1733	1725	1587	1682	-	1384	1288	1336
Mercia									
	0	1437	1631	1396	1488	1142	1084	1132	1119
	1	1484	1668	1465	1539	1191	1158	1194	1181
	2	1554	1687	1486	1576	1291	1136	1274	1234
	3	1585	1708	1528	1607	1251	1308	1318	1292
	4	1611	1710	1605	1642	1327	1377	1322	1342
	5	1636	1851	1545	1677	1314	1348	1390	1351
	6	1640	1787	1642	1690	1403	1430	1403	1412
Slejpner									
	0	1287	1432	1166	1295	985	999	995	993
	1	1356	1559	1241	1385	1024	1083	1053	1053
	2	1450	1644	1332	1475	1125	1176	1184	1162
	3	1538	1696	1434	1556	1205	1239	1226	1223
	4	1596	1665	1509	1590	1254	1276	1302	1277
	5	1675	1705	1565	1648	1309	1352	1331	1331
	6	1716	1737	1620	1691	1350	1404	1370	1375

Table 2.5

Crumb score (max 10) of gluten fortified white and wholemeal flours milled from five wheat varieties.

CBP: Harvest years 1986 '87 and 1988

Variety	Gluten protein added (%)	White 1986	White 1987	White 1988	Average crumb score for the 3 years	Wholemeal 1986	Wholemeal 1987	Wholemeal 1988	Average crumb score for the 3 years
Avalon	0	6.5	5.5	5	5.6	5	2.5	1	2.8
	1	7.5	7.5	8	7.6	5	3.5	2	3.5
	2	8	8	8	8.0	6.5	4.5	3	4.7
	3	8	8	9	8.3	5.5	5	7	5.8
	4	7.5	8	9	8.2	7	6.5	7	6.8
	5	7.5	8	9	8.2	8	7.5	8	7.8
	6	7.5	8	9	8.2	7.5	8	9	8.2
Brock	0	4	1	1	2.0	1	2.5	1	1.5
	1	5	3	2	3.3	1.5	2.5	1	1.7
	2	6.5	5.5	3	5.0	2.5	2.5	2	2.3
	3	7	7	4	6.0	3.5	3.5	3	3.3
	4	7.5	8	7	7.5	4.5	4	5	4.5
	5	8.5	8	9	8.5	5.5	5	6	5.5
	6	8	8	9	8.3	6	6.5	6	6.2
Galahad	0	5	4	1	3.3	1	1	1	1
	1	6	5	3	4.7	2	3	1	2
	2	7	6	3	6.3	2.5	5	2	3.2
	3	8	7	6	7.0	5.5	6	4	5.2
	4	7.5	7	7	7.2	6.5	7	6	6.5
	5	8.5	8	8	8.2	6	8	6	6.7
	6	8	8	9	8.3	7	9.5	6	7.5
Mercia									
	0	6	7	7	6.6	3	2.5	4	3.2
	1	6.5	7.5	9	7.7	4.5	3.5	5	4.3
	2	6.5	8	8	7.5	4	3	7	4.7
	3	7	8	9	8.0	5.5	5	8	6.2
	4	7.5	7	9	7.8	6	6	8	6.7
	5	7.5	8	9	8.2	7	5.5	9	7.2
	6	8	7.5	9	8.2	5.5	7.5	9	7.3
Slejpner	0	4	4	1	3	1	1	1	1.0
	1	5	6.5	3	4.8	1	3	2	3.0
	2	6	7.5	4	5.8	3	3.5	4	3.5
	3	6.5	8	5	6.5	4	5.5	7	5.5
	4	8	8	8	8.0	6.5	6	7	6.5
	5	7.5	8	8	7.8	6.5	6	8	6.8
	6	9	7.5	8	8.2	6	8	9	7.7

Table 2.6

Loaf volume (ml) of gluten fortified white and wholemeal flours milled from five wheat varieties

BFP: Harvest years 1987 '88

Variety	Gluten protein added (%)	White 1987	White 1988	Average	Wholemeal 1987	Wholemeal 1988	Average
Avalon	0	1501	1432	1467	1177	1197	1187
	2	1525	1498	1510	1249	1225	1237
	4	1598	1566	1582	1319	1272	1296
	6	1623	1514	1569	1333	1278	1306
Brock	0	1327	1137	1232	991	847	913
	2	1585	1136	1480	1200	1083	1142
	4	1672	1471	1572	1311	1174	1243
	6	1682	1504	1593	1349	1266	1308
Galahad	0	1340	1160	1250	1105	961	1033
	2	1486	1354	1420	1288	1154	1221
	4	1500	1455	1478	1360	1245	1303
	6	1526	1531	1529	1380	1250	1315
Mercia	0	1578	1336	1457	1145	1109	1127
	2	1641	1382	1512	1276	1197	1237
	4	1673	1421	1547	1342	1188	1265
	6	1682	1444	1563	1391	1287	1339
Slejpner	0	1530	1188	1359	1111	1037	1018
	2	1608	1333	1471	1267	1202	1235
	4	1642	1453	1548	1313	1221	1267
	6	1657	1443	1550	1395	1261	1328

Table 2.7

Crumb score (max 10) of gluten fortified white and wholemeal flours milled from five wheat varieties

BFP: Harvest years 1987 '88

Variety	Gluten protein added (%)	Crumb score White 1987	White 1988	White Average	Wholemeal 1987	Wholemeal 1988	Wholemeal Average
Avalon	0	5.5	8	6.8	2.5	5	3.8
	2	6.5	8	7.3	5.5	7	6.3
	4	6	8	7.0	8	6	7.0
	6	6	8	7.0	7.5	8	7.8
Brock	0	3	1	2.0	1.5	1	1.3
	2	6	5	5.5	4	3	3.5
	4	6.5	8	7.3	7	5	6.0
	6	6.5	5	5.8	8	8	8.0
Galahad	0	4	2	3.0	1	1	1.0
	2	7.5	6	6.8	4	5	4.5
	4	7	5	6.0	7	6	6.5
	6	7	8	7.5	7	8	7.5
Mercia	0	9	7	8.0	3.5	5	4.3
	2	8	7	7.5	6	6	6.0
	4	6	8	7.0	7	8	7.5
	6	7	7	7.0	7.5	9	8.3
Slejpner	0	6	2	4.0	2	2	2.0
	2	7	7	7.0	5	7	6.0
	4	6	8	7.0	8	8	8.0
	6	6.5	5	5.8	7.5	8	7.8

Table 2.8

Loaf volume (ml) of gluten fortified white flours milled from 5 wheat varieties

CBP: Harvest year 1988, five growing sites

Variety	Gluten protein added (%)	March site	Owstwick site	Reading site	Terrington site	West Rudham site	Average
Avalon	0	1320	1301	1283	1482	1249	1327
	2	1463	1405	1391	1544	1401	1441
	4	1644	1459	1543	1608	1485	1548
	6	1647	1581	1632	1617	1488	1593
Brock	0	1218	1182	1184	1080	1069	1147
	2	1387	1355	1311	1273	1302	1326
	4	1546	1485	1492	1433	1410	1473
	6	1659	1586	1682	1589	1615	1626
Galahad	0	1263	1293	1189	1127	1151	1205
	2	-	1448	1290	1287	1351	1344
	4	1533	1516	1491	1483	1491	1503
	6	1618	1662	1650	1587	1529	1609
Mercia	0	1397	1474	1450	1369	1362	1410
	2	1524	1459	1429	1486	1469	1473
	4	1580	1570	1663	1605	1582	1600
	6	1622	1519	1561	1642	1465	1562
Slejpner	0	1203	1229	1150	1166	1165	1183
	2	1300	1402	1262	1332	1270	1313
	4	1458	1465	1460	1509	1469	1472
	6	1555	1605	1482	1620	1593	1571

Table 2.9

Crumb score (max 10) of gluten fortified white flours milled from five wheat varieties

CBP: Harvest year 1988, five growing sides

Variety	Gluten protein added (%)	March site	Owstwick site	Reading site	Terrington site	West Rudham site	Average
Avalon	0	5	6	3	5	4	4.6
	2	7	7	5	8	8	7.0
	4	8	8	8	9	8	8.2
	6	8	9	8	9	9	8.6
Brock	0	1	1	1	1	1	1.0
	2	6	7	4	3	5	5.0
	4	7	8	8	7	7	7.4
	6	6	9	8	9	9	8.2
Galahad	0	2	4	1	1	2	2.0
	2	-	8	4	3	6	5.3
	4	7	8	8	7	7	7.4
	6	8	9	8	9	6	8.0
Mercia	0	6	8	7	7	8	7.2
	2	8	9	7	8	8	8.0
	4	9	9	8	9	9	8.8
	6	6	9	7	9	6	7.4
Slejpner	0	2	2	1	1	2	1.6
	2	4	7	4	4	4	4.6
	4	6	7	6	8	8	7.0
	6	7	8	7	8	8	7.6

Table 2.10

Loaf volume (ml) of gluten fortified wholemeal flours milled from five wheat varieties

CBP: Harvest year 1988, five growing sites

Variety	Gluten protein added (%)	March site	Owstwick site	Reading site	Terrington site	West Rudham site	Average
Avalon	0	982	1078	1044	938	987	1006
	2	1219	1188	1224	1163	1133	1185
	4	1256	1298	1277	1261	1222	1263
	6	1237	1359	1328	1389	1337	1330
Brock	0	940	924	960	938	916	936
	2	1045	961	978	999	955	988
	4	1195	1171	1132	1177	1151	1165
	6	1235	1262	1278	1283	1243	1260
Galahad	0	970	925	956	932	905	1013
	2	-	1140	1020	1100	965	1056
	4	1232	1266	1183	1222	1148	1210
	6	1307	1316	1227	1288	1298	1287
Mercia	0	1069	1093	1119	1132	1070	1097
	2	1206	1227	1203	1274	1208	1224
	4	1233	1320	1315	1322	1301	1298
	6	1382	1398	1394	1403	1386	1393
Slejpner	0	995	962	919	995	971	968
	2	1075	1120	954	1184	987	1064
	4	1228	1242	1167	1302	1120	1212
	6	1312	1323	1216	1370	1267	1298

Table 2.11

Crumb score (max 10) of gluten fortified wholemeal flours milled from five wheat varieties

CBP: Harvest year 1988, five growing sites

Variety	Gluten protein added (%)	March site	Owstwick site	Reading site	Terrington site	West Rudham site	Average
Avalon	0	2	5	2	1	3	2.6
	2	7	6	5	3	5	5.2
	4	8	8	8	7	6	7.4
	6	8	8	8	9	7	8.0
Brock	0	1	1	1	1	2	1.2
	2	3	2	2	2	2	2.2
	4	5	6	6	5	4	5.2
	6	7	7	8	6	7	7.0
Galahad	0	1	4	1	1	1	1.6
	2	-	4	2	2	2	2.0
	4	7	7	5	6	5	6.0
	6	8	8	7	6	7	7.2
Mercia	0	3	5	6	4	5	4.6
	2	7	7	7	7	7	7.0
	4	8	8	8	8	8	8.0
	6	8	9	9	9	9	8.8
Slejpner	0	1	3	1	1	2	1.6
	2	4	6	2	4	2	3.6
	4	7	7	5	7	6	6.4
	6	7	8	7	9	7	7.6

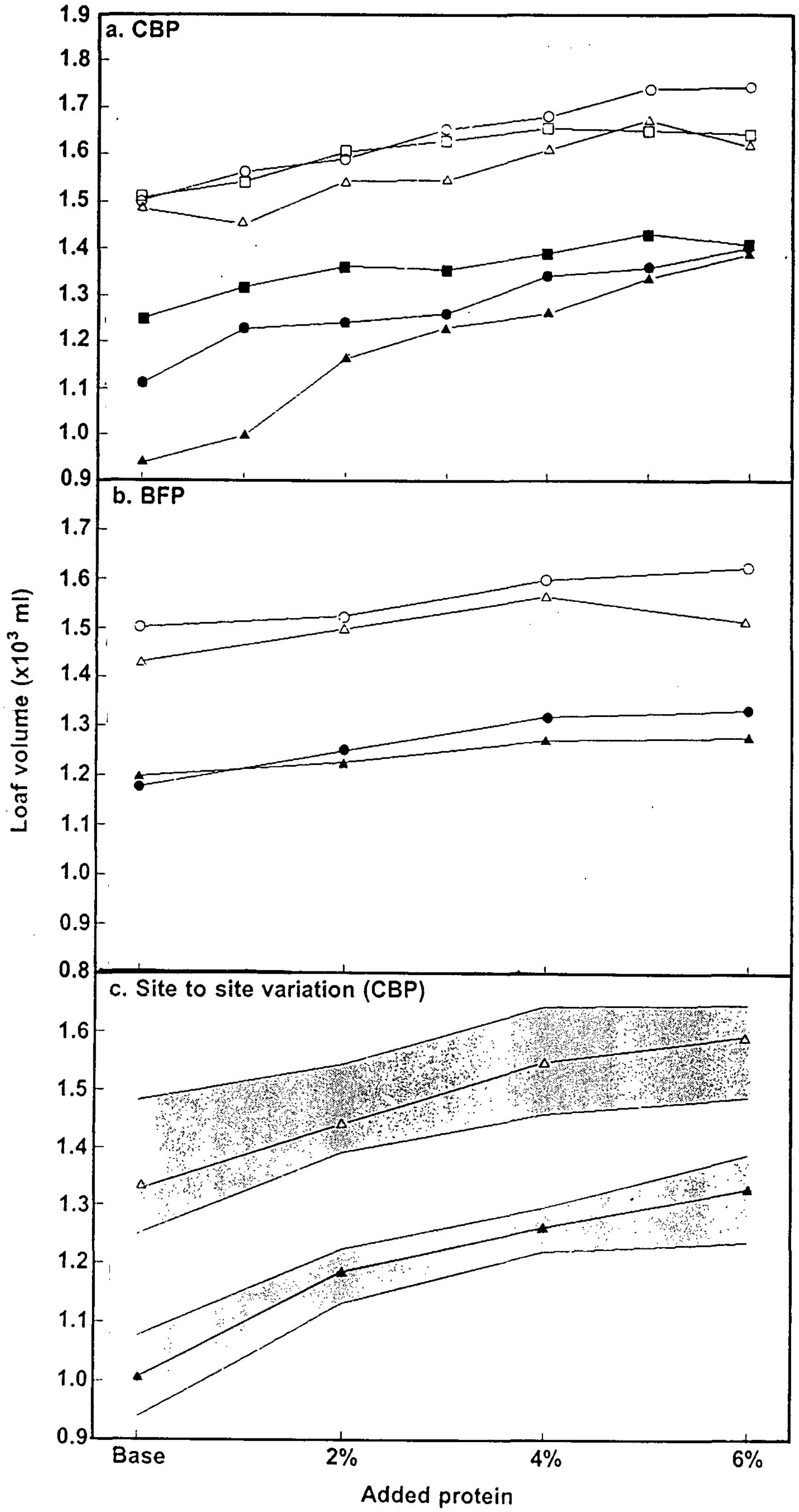

Fig. 2.1 The effect on loaf volume of gluten fortification of white and wholemeal flours: Avalon variety (□) white flour 1986, (○) white flour 1987, (△) white flour 1988, (■) wholemeal flour 1986, (●) wholemeal flour 1987, (▲) wholemeal flour 1988.

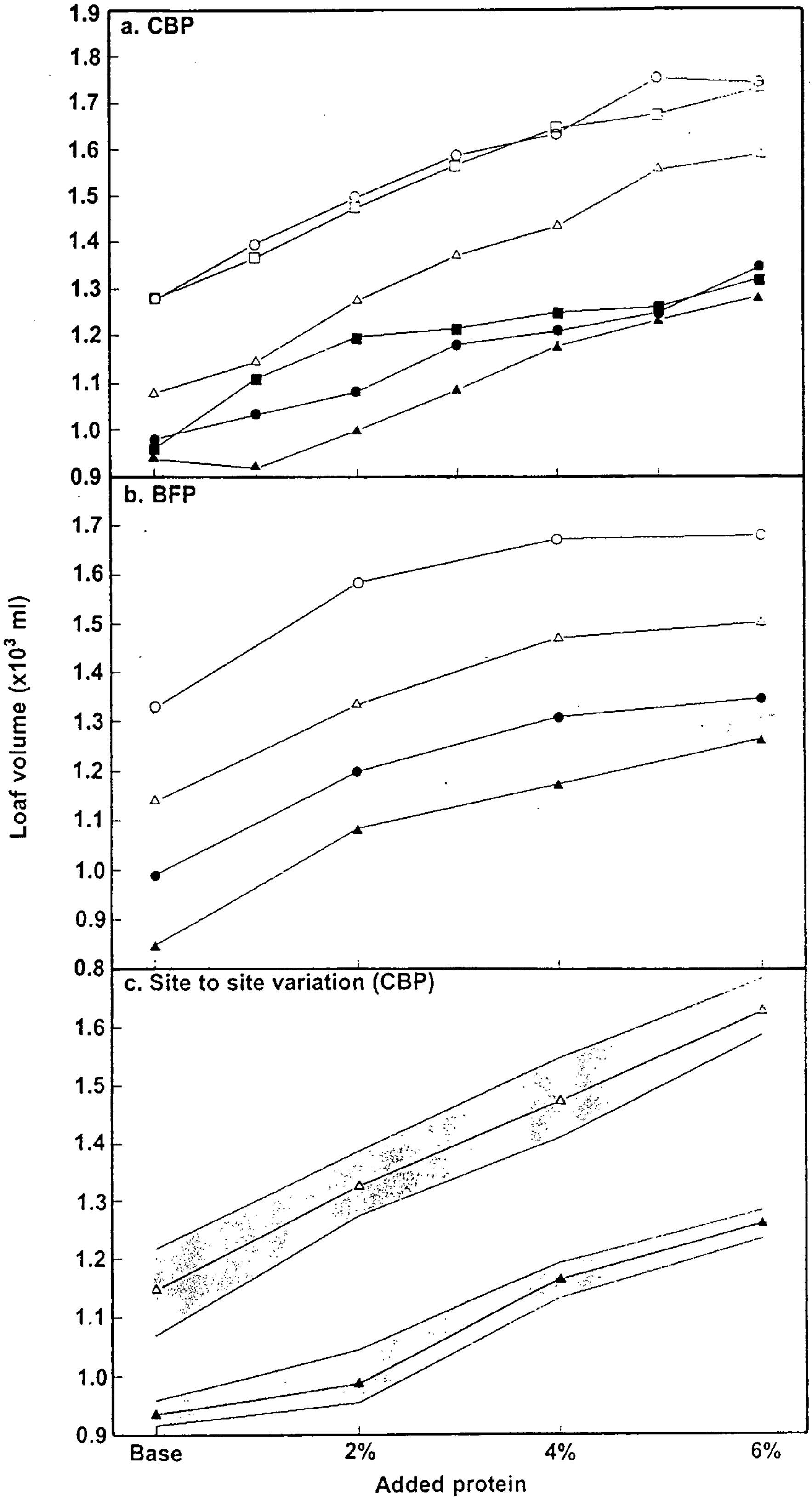

Fig. 2.2 The effect on loaf volume of gluten fortification of white and wholemeal flours: Brock variety (□) white flour 1986, (○) white flour 1987, (△) white flour 1988, (■) wholemeal flour 1986, (●) wholemeal flour 1987, (▲) wholemeal flour 1988.

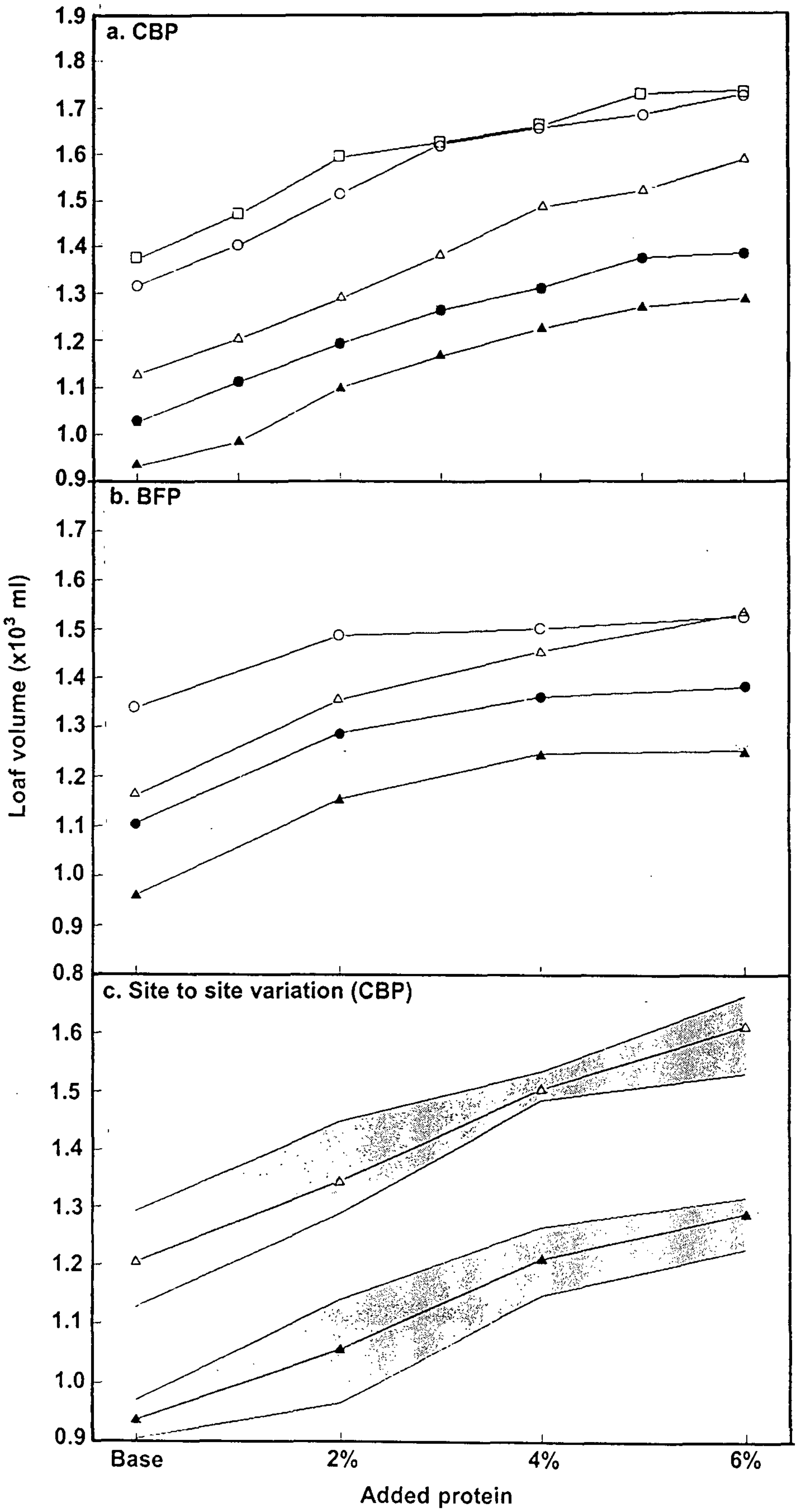

Fig. 2.3 The effect on loaf volume of gluten fortification of white and wholemeal flours: Galahad variety (□) white flour 1986, (○) white flour 1987, (△) white flour 1988, (■) wholemeal flour 1986, (●) wholemeal flour 1987, (▲) wholemeal flour 1988.

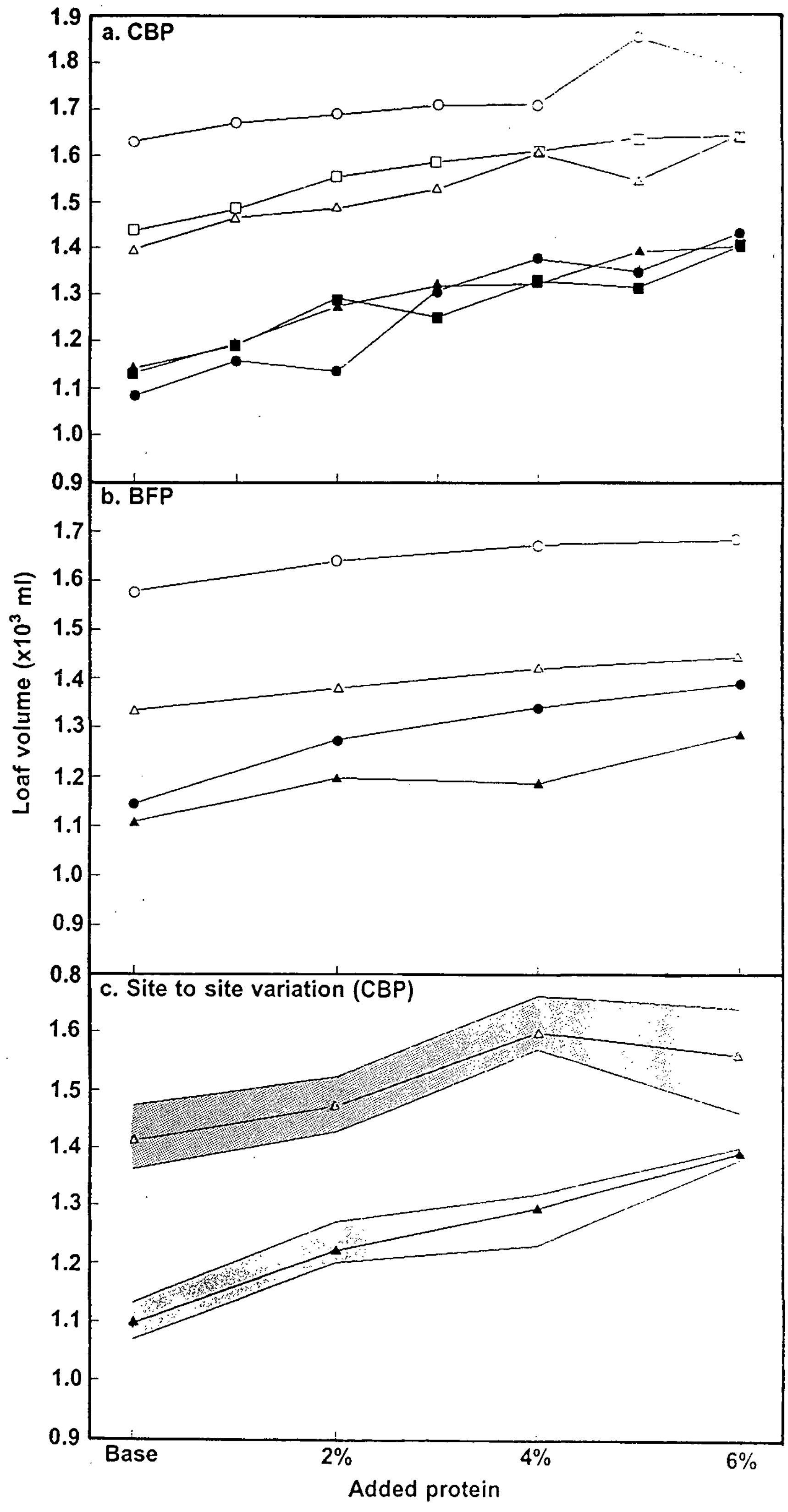

Fig. 2.4 The effect on loaf volume of gluten fortification of white and wholemeal flours: Mercia variety (□) white flour 1986, (○) white flour 1987, (△) white flour 1988, (■) wholemeal flour 1986, (●) wholemeal flour 1987, (▲) wholemeal flour 1988.

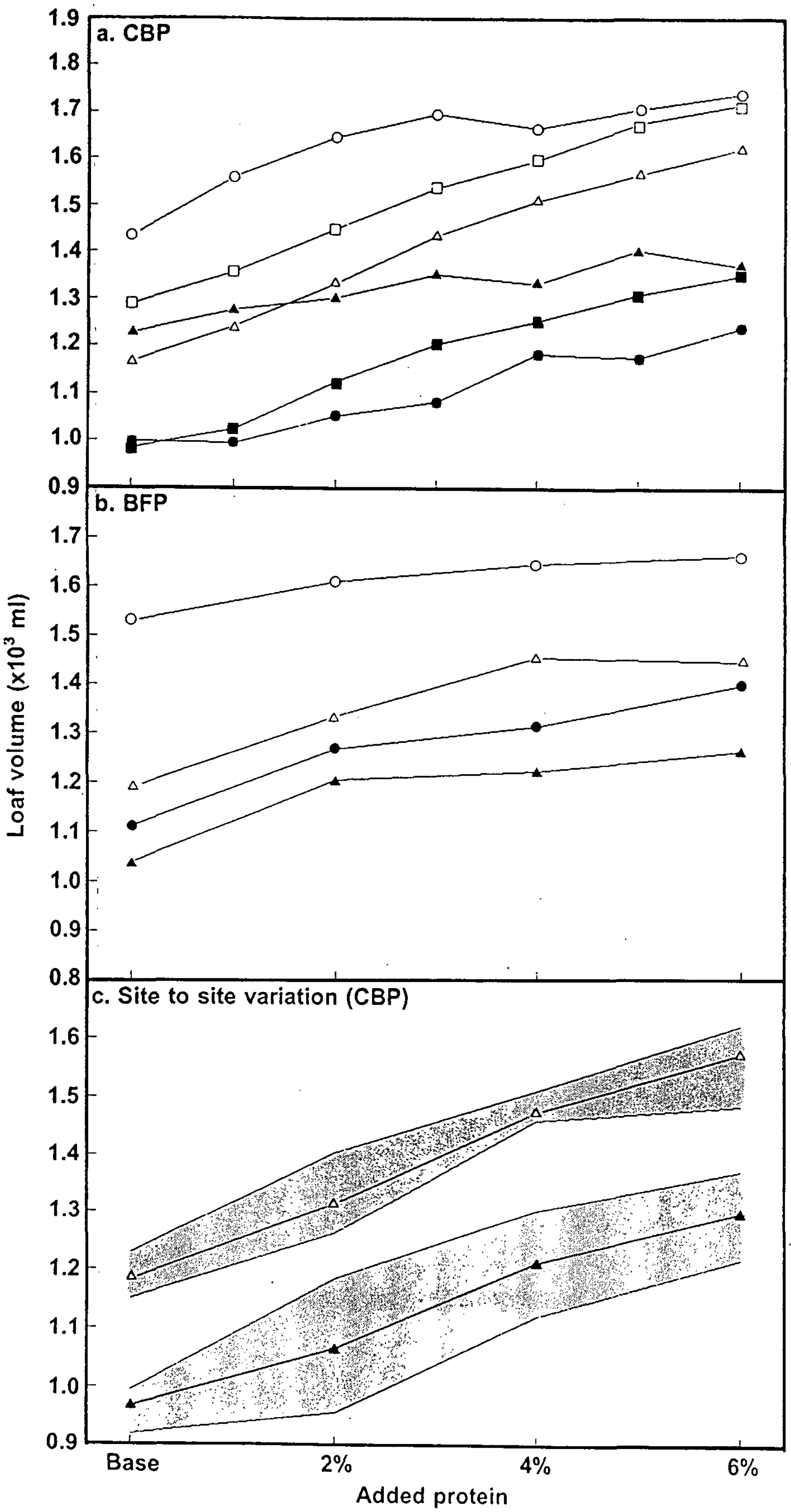

Fig. 2.5 The effect on loaf volume of gluten fortification of white and wholemeal flours: Slejpner variety (□) white flour 1986, (○) white flour 1987, (△) white flour 1988, (■) wholemeal flour 1986, (●) wholemeal flour 1987, (▲) wholemeal flour 1988.

3. THE QUALITY OF COMMERCIAL GLUTEN

3.1 Objective

To evaluate new methods of assessing gluten quality as a predictive test of the baking quality of commercial gluten.

3.2 Introduction

Previous work at Chorleywood has suggested that no single test of gluten could accurately predict the baking quality of commercial gluten. The availability of new rheological instruments, together with a need to evaluate the influence of base flour and baking process on the baking quality of gluten, led to this more detailed study of the quality of commercial gluten.

3.3 Materials and Methods

Gluten samples

A series of 17 commercial gluten samples were obtained from a number of sources and assessed for baking quality in protein supplementation studies involving a number of base flours and test baking methods. The glutens belonged to two sets.

1. A series of ten obtained from a number of manufacturers that included several countries of origin. (Nine European and one Japanese).

2. A series of 7 glutens, 6 of which were selected from a larger sample supplied on the basis of test baking data that suggested that the 6 covered a wide range of baking quality. The remaining gluten was of Dutch origin, and used as the standard gluten for other work at the RA and known to be of a consistently high baking quality. (See table 2.3, page 21)

In addition, a series of heated glutens produced from Avalon variety flour in the laboratory were studied to investigate the effect of heat on gluten. This set of samples also represented a wide range of quality for calibration of the various assessment procedures.

Base flours

The baking quality of the glutens was assessed by fortification of low protein base flours. White flours were fortified by 1% and 2% protein addition and wholemeal by 2% and 6%. The base flours used were:

Set 1 Glutens

a) A UK milled mixed grist french bread flour of 9.1% protein content.

b) Laboratory milled Galahad variety white flour of 9.9% protein.

c) Laboratory milled Galahad variety wholemeal flour of 11.8% protein.

Set 2 Glutens

a) A commercially produced white flour of Mercia variety of 8.8% protein.

b) A laboratory milled Galahad variety white flour of 8.2% protein.

Heated Glutens were test baked with the UK milled mixed grist french bread flour.

Test Baking

Two test baking processes were used in our studies. All the gluten-base flour combinations were baked by the CBP, based upon 1400g flour or flour plus gluten. We used 400g single piece loaves, four loaves per batch. The sequence of the test bakes was randomised and the results were statistically analysed. Bread was asessed by loaf volume, subjective assessment of crumb structure on a 0 to 10 scale and by crumb colour on the Hunterlab Colorimeter.

The second set of glutens were also test baked in a one-hour long bulk fermentation (BFP) procedure using both base flours. Except for the 1% protein fortification by these glutens, all combinations were tested in duplicate. Standard Chorleywood test baking methods were used throughout. See Appendices 2 and 3.

Water addition for the CBP was based upon the 10 minute Simon method and for the BFP, on the 1 hour unyeasted method water absorption of the base flour. With gluten fortification water was added at the rate of 1½ times the weight of gluten, the flour water being adjusted in proportion to the lower weight of flour in the recipe.

Laboratory preparation of heated freeze-dried gluten

Heated gluten samples were prepared by a batter system (1400g flour + 2100 g water) at 40°C. After mixing the batter was centrifuged at 2000rpm for 30 minutes. The gluten layer was recovered and washed out to a visco-elastic mass. Approximately 20g pieces were placed in polyethylene bags, clamped between metal sheets 3mm apart and heated in a water-bath for 20 minutes at temperatures ranging from 40 to 90°C. Including an unheated control, 10 gluten samples were prepared. The heated glutens were freeze dried and hammer-milled using an 0.8mm screen and then collected through a 160μm sieve. Average protein content of the laboratory-prepared samples was 75.5% on dry mass basis (dmb) (range 72.1 to 78.7) and moisture content ranged from 6.1 to 8.0%.

Gluten quality assessment

Gluten Rheology

Two instruments were used in our studies of gluten rheology:-

1. Bohlin Rheometer (Bohlin Reologi AB, Lund, Sweden)
2. Brabender Glutograph (Brabender OHG, D4100 Duisburg West Germany)

1. Bohlin Rheometer

Gluten is a visco-elastic material and therefore its rheological character plays an important part in its observed functionality. Hibberd and Wallace (1966) showed that dough (and therefore gluten) behaves linearly only at very small deformations i.e. strain is proportional to stress. Rheological properties of the gluten samples were assessed on the Bohlin Rheometer by oscillation and stress relaxation tests. Small shear strains were used to ensure we were operating in the linear visco-elastic region, where the dynamic moduli are independent of the strain amptitude (Le Grys *et al* 1981).

General method for Bohlin Rheometer

Gluten (10g) was reconstituted with distilled water to 65% moisture content in a minorpin mixer for 150 secs and rested in a plastic container for 10 mins. A small piece was cut off and transferred to the base plate of the rheometer. The upper plate was lowered for a gap size of 2mm. Surplus gluten expelled from the gap was gently trimmed off and gluten at the exposed outer edge was coated with silicone oil to prevent moisture loss and, therefore, creation of 'artificial' stresses. The torque reading was zeroed before the sample was allowed to 'rest' for a further 10 min before commencing the test. All measurements were made at 25°C and freshly prepared samples were used for each test.

Further details of the principles and theory of the Bohlin rheological tests are described in Appendix 4.

2. Brabender Glutograph

The Glutograph is based upon a 'creep' test. A constant force, independent of gluten quality, is applied to the sample clamped between a lower (moveable) and an upper (fixed) plate and the resulting deformation is recorded as a function of time where the time taken to reach a preset shear angle is recorded.

Gluten (5g) was reconstituted with 16ml of 2.5% sodium chloride solution. The gluten ball was 'rested' under saline water for 20min and then transferred to a Simon gluten washer and washed for 5 min in tap water. The sample was cut into 2 equal pieces and rested under tap water for 20 min.

Other Quality Parameters

Glutens were also analysed for protein (Kjeldahl N x 5.7) and moisture content (5 hours at 100°C). SDS sedimentation vol, lactic acid sedimentation (% loss of turbidity), hydration rate, water absorption and particle size were all carried out as described by McDermott and Chamberlain (1985). Stretch characteristics were measured by the method of Kaminski and Halton (1964).

3.4 Results and discussion

The range and mean gluten quality data for the 17 glutens is listed in Table 3.1. Although the glutens were handled as two sets, there was little difference in the range and mean value for each set and so for convenience they have been combined. Quality data for the heated gluten samples is listed in Table 3.2.

Set 1 glutens

All ten (set 1) glutens increased loaf volume with all three flours, at both of the two levels of protein fortification (1% and 2% for the white flours, and 2% and 6% for the wholemeal) (Table 3.3). On average, the loaf volume improvement was linear for the white flour, but for the wholemeal 6% protein addition approximately doubled the effect with 2% fortification.

The average percentage loaf volume improvement is clearly very dependent upon the quality (as judged by loaf volume) of the base flour. An inverse linear relationship is apparent, although with only three data points a statistical appraisal was not appropriate. The importance of base flour selection for the routine test baking of commercial gluten samples is therefore apparent. Statistical analysis showed that for the French white flour, and the Galahad variety white flour, there was no significant differences between the glutens ($P<0.05$). With the Galahad wholemeal flour differences between the gluten was just significant (P.0.05). However, it is apparent that gluten 5 was consistently inferior to the others.

McDermott and Chamberlain (1985), in a study of the baking quality of gluten, set criteria for judging gluten quality in a baking test. All ten glutens when baked with the Galahad white flour (the nearest equivalent to that used in the earlier study), exceeded 10.5% loaf volume improvement at 2% protein fortification, and would therefore be classed as of good quality. The uniform quality of the glutens which were obtained from a wide variety of countries, is an encouraging reminder that gluten quality is now of a consistently high standard, with the occasional poor sample being very hard to find.

Despite the uniform but good baking quality of the glutens studied, there was a wide spread of values for the individual quality parameters (Table 3.4) i.e. there is a range of parameter values within which baking quality is acceptable, for instance, the hydration rate varied from 10 to 282 seconds.

Regression analysis of the gluten quality data against baking test data showed only limited correlations over the flours as a whole. Where heat damaged gluten samples were also included in the test baking with the French white flour more meaningful correlations were achieved. (Table 3.4). Multiple regression analysis of the data indicated that no addition of parameters bettered the individual correlations with the white flour. However a multiple regression equation was obtained for Galahad wholemeal. At 2% protein fortification:-

$$\text{Loaf vol} = 1377^{1} - 39.94M + 301.9S + 9.611G^{*} - 8.568\,G' - 85.39\,G'' + 101.2V$$

1 at 6% fortification the constant is 1569

where	M	=	moisture content
	S	=	SDS sedimentation volume
	G*	=	)
	G'	=	) rheological parameters
	G"	=	)
	V	=	viscosity

This equation with a correlation coefficient r of 0.99, residual error 3% is at first sight a good predictor of baking performance. Its true value would have to be tested against other gluten samples.

The data show that the fundamental rheological characteristics (G*, G' and G" etc) correlate well with baking performance. For a simple test, the lactic acid % drop in turbidity has correlation coefficient and residual error of similar magnitude to the Bohlin data. It remains a good screening method for gluten quality.

The Glutograph

Correlation coefficients between Glutograph times and other quality parameters are listed in Table 3.5 together with similar data for the stretch test (Kaminski and Halton 1964). Parameters not listed were not correlated with either of the simple rheological tests. However, our initial experiments indicated that sample preparation for the Glutograph is critical and that glutens prepared under different conditions resulted in very different properties. There could be problems with reproducibility if test method protocols are not strictly adhered to.

The Glutograph data correlated well with the Bohlin fundamental rheological parameters, suggesting that it may well prove to be a useful, simple instrument for the assessment of the rheological quality of gluten.

Set 2 glutens

Table 3.6 lists the percent increase in loaf volume for the seven glutens at 2% protein fortification of two base flours (A and B) in two baking processes (CBP and 1 hour BFP). There was no consistent pattern; the effect of a particular gluten depended on the base flour and process, and the rank order of the glutens varied. Loaf volume improvements following gluten addition were significantly better with base flour B, the Galahad variety, normally considered poor for breadmaking, compared to flour A considered a good breadmaking flour, in both bread processes. This again emphasises the importance of base flour selection in breadmaking where flours considered to be of poor quality for breadmaking are seen to respond extremely well to gluten addition. (See section 2).

The greatest increases in loaf volume were generally obtained in the CBP against both flours, although some glutens gave similar increases e.g. Nos. 3 and 6 against flour A. Statistical analysis showed that the glutens were significantly different ($P<0.05$) in the CBP method for flour B, and for both flours with the BFP method ($P<0.01$). This would suggest that the more gentle mixing, followed by a bulk fermentation stage might be a more effective method of differentiating between glutens. Nevertheless, the more uniform performance of the glutens in the CBP, which is of course the predominant process used in the UK, indicates that gluten quality is generally of a consistent nature in the UK baking industry context.

No statistical correlation was found relating gluten quality to baking performance. Again the relatively uniform quality of the glutens made statistical analysis difficult. Our results do not confirm the original wide quality variation claims for these samples. However, the original data were obtained over a number of months and glutens were not all baked against the same base flour. Under standard conditions the glutens were clearly of much more uniform quality.

The functionality of heated gluten

Most of the biochemical and rheological parameters detect a change in gluten properties when gluten is heated to 70°C or greater (Table 3.2). This is consistent with observations previously reported (McDermott 1986) and confirmed here that the baking performance of gluten in base-flour protein fortification systems is unaffected until the temperature of heating exceeds 70°C. (Table 3.7). However, the elastic modulus (G'), which appears to change at a lower temperature of around 60°C may predict more accurately the baking performance of heated gluten in reconstitution test baking, where the gluten is the sole source of protein in the system, and loss of baking performance occurs progressively from 55°C (Schofield *et al* 1983). When the bulk of the protein is supplied by the base flour, elasticity may be less important than viscosity in predicting baking performance.

The functional roles of glutenin and gliadin have been demonstrated by fractionation and reconstitution studies (Finney 1985), where gliadin and glutenin components of good and poor quality flours were interchanged and reconstituted into flours containing starch and water solubles. Subsequent baking indicated that loaf volume potential and crumb grain quality were a function of the gliadin fractions, whilst the mixing requirement of dough was controlled by the glutenin fraction. Further evidence of the importance of the gliadin fraction is seen with size-exclusion HPLC (Bietz 1984) fractionation of heated gluten proteins (Fig. 3.1). Progressively from 50°C, the glutenin fraction is rendered insoluble in SDS-phosphate buffer, while the gliadin fraction is unaffected. Only above 70°C, the point at which baking performance is lost, do the gliadins begin to be affected, consistent with the observed changes in the viscosity modulus (G") and viscosity data (Table 3.2).

The Glutograph as supplied has a built in cut-off at 132 seconds, which was exceeded by glutens heated at 75 and 80°C. Gluten heated to 90°C does not form a coherent gluten ball, and therefore cannot be tested on this kind of instrument.

Table 3.1

Properties of commercial glutens

	Range		Mean
Moisture %	4.9 -	8.3	6.7
Protein (N x 5.7) as is %	66.6 -	77.0	71.5
dmb %	72.5 -	81.9	76.6
SDS sed. vol/g protein ml	48	197	115
Lactic acid sed. (loss of turbidity) %	2 -	30	7.9
Hydration Rate s	5 -	300+	51
Water absorption /g protein ml	1.87 -	2.63	2.29
Particle size <160µm %	63.7 -	99.8	92.5
Stretch units/min	0.3 -	9.5	3.9
Glutograph time s	9.2 -	78.8	23.2
Fundamental rheological parameters Measured at 65% moisture basis on Bohlin Rheometer			
Complex modulus G* Pa	685 -	2070	1437
Elastic modulus G' Pa	563 -	1920	1302
Viscous modulus G" Pa	360 -	908	618
Viscosity Pas	57.3 -	145	98.3
Delta G"/G'	21.6 -	31.7	25.9

Table 3.2

Biochemical and rheological properties of heated gluten

Sample	SDS Sed.vol (ml)	Lactic Acid (%)	Hyd rate (sec)	Water Abs (ml/g)	Rheological data G' (Pa)	G" (Pa)	Viscosity (Pas)	Glutograph time (sec)
Unheated	197	2	9	3.11	1420	677	108	5.6
40°C	197	3	6	2.91	1570	748	119	8.3
50	194	5	9	2.66	1300	721	115	8.0
55	189	33	9	2.91	1480	582	93	5.5
60	206	25	8	2.99	1530	593	94	4.1
65	203	19	13	2.68	1960	699	111	11.0
70	189	16	44	2.34	2020	850	135	85.4
75	89	24	462	2.02	3160	1050	169	NA
80	53	37	00	1.92	4190	1180	187	NA
90	15	47	00	NA	14700	2610	416	NA

Table 3.3

% Loaf volume improvement by 10 commercial glutens

	Flour: French bread wheat White		Galahad Variety White		Galahad Variety Wholemeal	
Protein content %	9.1		9.9		11.8	
Base flour LV/ml	1585		1346		981	
% protein added	1%	2%	1%	2%	2%	6%
Gluten						
1	2.8	5.8	8.5	13.5	22.6	41.3
2	2.9	4.3	6.4	11.6	21.4	40.1
3	1.1	3.3	4.6	15.0	21.5	42.9
4	2.0	6.3	6.1	14.4	22.6	42.4
5	0.6	2.8	3.3	10.7	18.7	35.4
6	3.2	4.0	7.9	11.2	21.0	36.3
7	2.1	4.5	8.5	14.3	24.8	45.9
8	1.7	4.5	7.1	12.0	20.5	39.9
9	1.0	6.9	6.9	12.9	22.4	48.0
10	0.9	4.4	6.2	11.6	19.4	38.8
Mean	1.8	4.7	6.6	12.7	21.5	41.1
LSD	5.07		4.44		8.86	

Table 3.4

Correlation of quality data with loaf volume data (French white flour)

	Correlation coefficient	P	Residual error
Protein		NS	
Moisture		NS	
SDS sed. vol.	0.74	<0.001	46
Lactic acid sed.	0.78	<0.001	38
Hydration rate		NS	
Water absorption	0.61	<0.001	62
Particle size		NA	
Stretch		NA	
Glutograph		NA	
Bohlin G*	-0.80	<0.001	36
G'	-0.80	<0.001	36
G"	-0.77	<0.001	41
Viscosity	-0.77	<0.001	41
delta	0.81	<0.001	34

Table 3.5

Correlation between Glutograph time, and stretch test data against other gluten quality parameters

	Glutograph	Stretch Test
SDS Sedimentation	NS	0.50^{x}
Lactic acid sedimentation	0.78^{xxx}	-0.52^{x}
Water absorption	-0.42	0.77^{xxx}
Bohlin, G* at 1 Hz	0.83^{xxx}	-0.50^{x}
G'	0.86^{xxx}	-0.56^{x}
G"	0.77^{xxx}	-0.30
Viscosity	0.76^{xxx}	-0.29
delta	-0.49^{x}	0.89^{xxx}
Glutograph times	-	0.58^{x}

xxx significant at 0.1% (p<0.001)
xx significant at 1% (p<0.01)
x significant at 5% (p<0.05)

Table 3.6

Loaf volume improvement with set 2 glutens at 2% protein fortification against 2 flours and 2 processes

Gluten	Flour A Mercia Variety		Flour B Galahad Variety	
	CBP	BFP	CBP	BFB
1	6.8	3.1	23.2	14.2
2	8.5	9.5	19.3	18.0
3	10.1	10.2	20.7	19.6
4	7.2	6.1	16.2	17.4
5	10.2	7.4	21.4	19.9
6	7.8	7.2	21.4	16.0
7	8.6	10.0	14.3	11.8
Mean...	8.5	7.6	19.5	16.7
LSD ($P<0.05$)	6.48	4.15	5.35	3.17

Table 3.7

The effect of temperature on the baking performance of heated gluten

Temp/^{o}C	Protein supplementation % 1%	2%
25	5.3	6.8
40	2.6	5.9
50	3.8	8.0
55	3.1	3.3
60	4.8	1.4
65	4.9	4.2
70	3.5	5.2
75	2.9	2.0
80	0.8	0.0
90	- 4.7	- 5.9
LSD ($P<0.05$)	4.70	

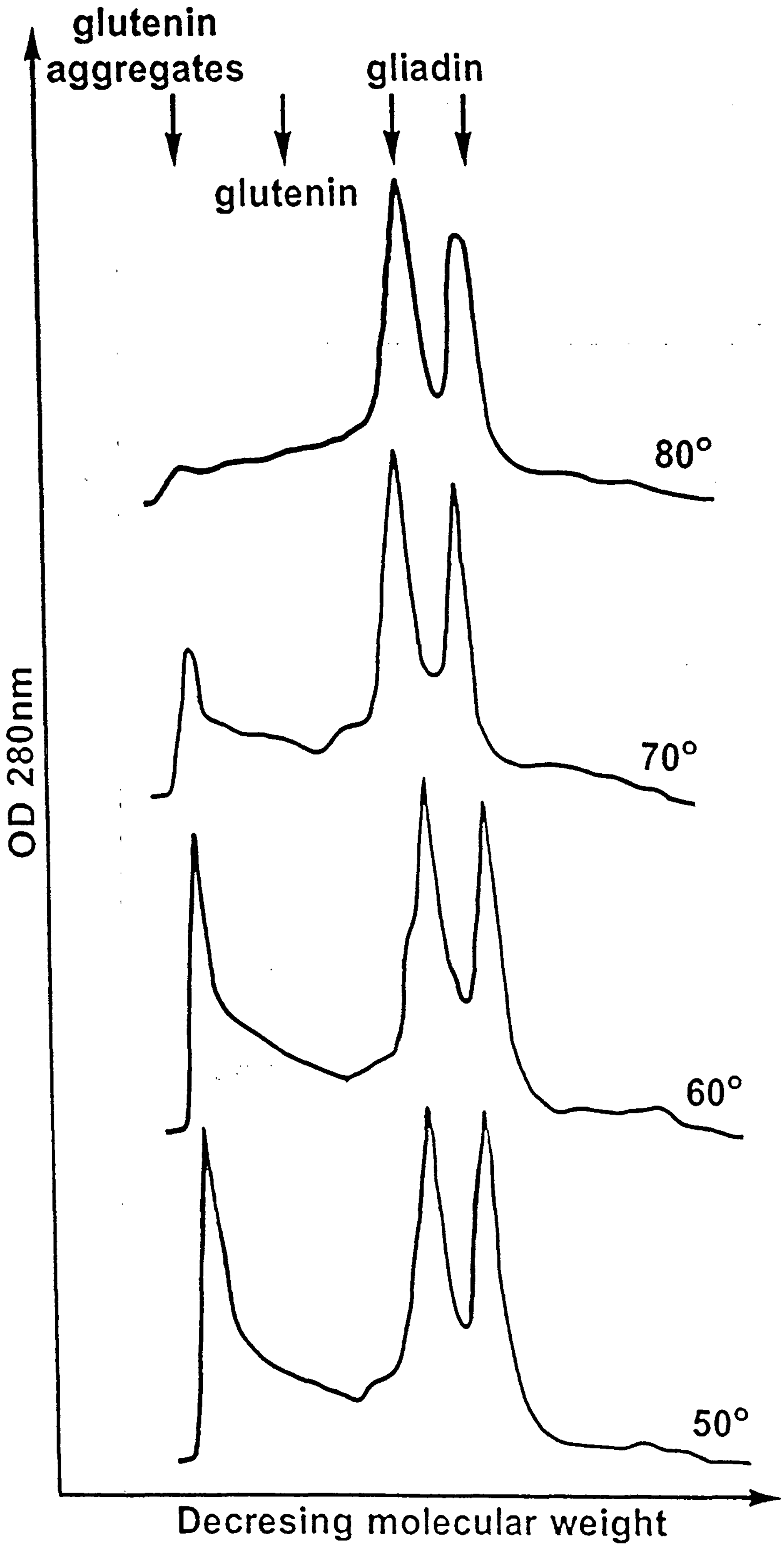

Fig. 3.1 Size exclusion HPLC of heated gluten

4. BREADMAKING PERFORMANCE AND STORAGE STABILITY OF GLUTEN SUPPLEMENTED WHOLEMEAL FLOURS.

4.1 Objectives

To compare the storage stability of wholemeals from Canadian Western Red Springs (CWRS) wheats with that from European wheat, gluten fortified to the same protein level.

To investigate the effects of adding gluten blended and stored in flour compared with addition fresh at dough mixing.

4.2 Introduction

The work reported here is a continuation of investigations into the breadmaking performance of wholemeal flour, and is concerned with storage stability of gluten fortified wholemeals, compared with meal from CWRS, over a sixteen week period. As storage of a flour proceeds, the fatty acid content increases which raises fat requirement in breadmaking (Bell, Chamberlain, Daniels and Fisher, 1976 and 1980). Fat requirement differs naturally and tests (Chamberlain, Collins and Elton, 1965) have shown that white flours from CWRS wheats may have a higher fat requirement than European. Determining the precise level of fat required for each flour in breadmaking is time consuming and difficult.

To allow for differences in fat requirement, an overall or 'blanket' level is usually used which is satisfactory in most cases. The level chosen may be slightly higher than necessary which causes no problem in normal circumstances and may even be beneficial because as storage time goes by the excess fat will meet the increased requirement, thus maintaining loaf quality. However, in this work if fat of a higher level than required when the meal was fresh were used, deterioration as a result of increased fat requirement would be 'masked' and therefore could go unnoticed. To eliminate that problem, tests were carried out with and without fat addition and no emulsifier was used. Baking 800g loaves, as in previous work, would be unsuccessful without these additions, resulting in poor dough stability in proof so a 400g loaf procedure was chosen.

4.3 Materials and methods

Grists and wholemeal flour milling

Wheats were obtained from a commercial miller.

Two roller-milled wholemeals were produced from two grists: 100% CWRS and 100%

all-European, using a laboratory Buhler mill (MLU 202). To ensure uniformity, each wholemeal was thoroughly blended in a ribbon blender before entry into the test programme.

Analysis

Wheats in the grists were identified by electrophoresis and the wholemeal flours analysed. Meals were sieved on a mechanical shaker, having a Plansifter type action, using a set of Endecott 200mm diameter woven wire sieves of apertures : 1000, 850, 500, 300 and 180 microns. The water absorptions of the wholemeals were determined by the Simon Research Extrusion meter, 10 minute method (Dodds, 1972).

Gluten

A single consignment of dried gluten was used throughout the tests. Addition of the gluten was made as soon as possible after milling to half of the all-European meal to raise the protein content to equal that of the CWRS meal. Blending took place for 60 minutes using a ribbon blender. Sufficient of the meal without gluten was retained for gluten addition just before the dough-mixing stage. Blending in this case took place using a vertical Hobart bench mixer for 3 minutes on 1st speed. Gluten added at dough-mixing was stored throughout the tests at -18^{o}C.

Wholemeal blending, storage, coding, analysis and baking

Half of the European wholemeal blended with gluten was stored double wrapped in polyethylene bags at -18^{o}C and the other half in polyethylene bags at a temperature of 21^{o}C. The European and CWRS meals without added gluten were sub-divided and stored in the same way.

Coding of the meals were as follows;

CWRS -18^{o}C	=	CWRS meal stored at -18^{o}C.
Euro/mill gluten -18^{o}C	=	European meal blended with gluten immediately after milling and stored at -18^{o}C.

Euro/bky gluten -18°C = European meal without gluten until doughmixing and stored at -18°C.

CWRS 21°C = CWRS meal stored at 21°C.

Euro/mill gluten 21°C = European meal blended with gluten immediately after milling and stored at 21°C.

Euro/bky gluten 21°C = European meal without gluten until doughmixing and stored at 21°C.

Samples of CWRS, Euro/mill gluten and Euro/bky gluten meals (before gluten was added at dough mixing) from both storage temperatures were analysed for moisture, lipid content, free fatty acid % and peroxide value and baked during the first week after milling and thereafter during weeks 2, 4, 6, 9, 12 and 16. The total storage period selected is more than double the usual time in commercial bakeries.

Loaves were produced using the Chorleywood Bread Process (CBP). Recipe and processing details are given in Appendix 2. Dough mixings were based on 1400g wholemeal. Each wholemeal was baked with and without fat in the recipe. All baking tests were carried out in duplicate and the order of mixing randomised. Variations without fat were produced first. All traces of grease were removed from the mixer by cleaning with absolute alcohol prior to mixings taking place.

Assessment

Loaves were cooled before storage overnight at 21°C and assessed using the techniques given in Appendix 2.

4.4 Results and Discussion

Grist composition and flour properties

Table 4.1 gives details of grist composition, wheat and wholemeal flour analyses, particle size distribution and analysis of the endosperm fractions below 180 microns.

Wholemeal analysis during storage

Table 4.2 gives results for moisture, lipid, free fatty acids and peroxide value on wholemeal samples taken at the beginning of each week in which baking tests were carried out.

Lipid (acid hydrolysis), %: These values were consistent throughout the period of storage, there was no change in fat content.

free fatty acid (oleic acid) %: Free fatty acid (FFA) values of flours stored at 21^{O}C were substantially higher at 6 weeks of storage than at 0-1 week. Changes in FFA were similar for both the Euro without gluten and the Euro/mill gluten.

ffa: values of meals stored at -18^{O}C were consistent over the storage period and were similar in value to meals stored at 21^{O}C for 2 weeks.

peroxide value, per kg of fat: Peroxide values of the stored meals were higher at 0-1 week and at week 9 than at the other sampling periods, particularly for those meals stored at 21 C.

Gluten analysis

Table 4.3 shows the results of the dried gluten analysis.

Breadmaking

Dough consistency

Subjective assessments prior to first moulding showed that doughs tended to be soft, sticky and fairly extensible. Difficulty was experienced in the processing of many doughs through the final moulder and this resulted in some poorly moulded shapes. There did not seem to be any constant pattern of stickiness or extensibility for any test variation and storage period.

Loaf volume

Table 4.4 gives the mean loaf volumes of the eight loaves produced from duplicate mixing for each storage period with no fat addition and with fat at 2% on flour weight. Graphs 4.1a to 4.1d show the effects of storage time on changes in loaf volume.

With all meals there was a general tendency for loaf volume to increase before decreasing with storage time.

-18^{O}C Temperature (Fig 4.1a and 4.1b)

1. With all meals stored at $-18^{O}C$, loaf volume was maintained throughout the storage trial when compared to week 0-1.

2. The effect of storage time on loaf volume was similar for the European and CWRS meals, as shown by the pattern of the response curves. When no fat was added, the CWRS meals gave a significantly lower loaf volume than the European meals. There was no significant difference in volume between the European and CWRS meals when 2% fat was used.

3. Irrespective of fat addition, loaves produced from all meals stored for approximately 9-12 weeks had a significantly higher loaf volume than those produced at 0-1 week.

4. Euro/mill gluten and Euro/bky gluten wholemeals gave similar performances at both 0 and 2% fat additions.

$21^{O}C$ Temperature (Fig 4.1c and 4.1d)

1. With the CWRS meals, loaf volume at both 0 and 2% fat, decreased after approximately 9 weeks of storage. Loaf volume was significantly lower at 16 weeks than at 0-1 week of storage.

2. Loaves produced from CWRS meals were significantly lower in volume at both 0 and 2% fat than those produced from the European meals.

3. The general trend for the Euro/mill gluten and Euro/bky gluten wholemeals was for loaf volume to decrease after approximately 12 weeks of storage, even though at both 0 and 2% fat, loaf volume from Euro/bky gluten meals was maintained relative to week 0-1.

4. At 0% fat, the performance of Euro/mill gluten and Euro/bky gluten wholemeals was similar throughout the trials.

At 2% fat, the Euro/mill gluten and Euro/bky gluten meals gave a similar performance up to approximately 12 weeks of storage. On increasing the time to 16 weeks, loaf volume for the Euro/mill gluten was significantly lower than at 0-1 week and also significantly lower than volumes from the Euro/bky gluten wholemeals.

Crumb scores

Table 4.5 gives the mean crumb scores of the loaves from the duplicate mixings and it shows the effects of storage time on loaf crumb score. Fig 4.2a-d With all meals, crumb scores over the whole storage period were fairly consistent with those at 0-1 week. An exception was the CWRS meal, stored at 21°C and baked with fat in the recipe. These loaves had lower crumb scores after the first week of storage. Both Euro/mill gluten and Euro/bky gluten meals gave loaves with similar scores to each other.

Discussion

The fat requirement of wholemeal has not been investigated as thoroughly as that of white flours. It was recognised in this work that changes in fat requirement during storage might affect the interpretation of any changes in gluten performance during storage. There appears to be one instance where fat requirement may have affected the comparison between Euro/mill gluten and Euro/bky gluten (See graph 4.1d).

At a storage temperature of -18°C, changes in fat requirement occur much more slowly than at higher temperatures. It would therefore be expected that the storage of gluten at -18°C added fresh at doughmixing would avoid deterioration and increased fat requirement, thus when added to the meal it would enable any fat in the recipe to be satisfactory for longer as storage time increased. We believe that the changes in week 16 at 2% fat between the Euro/mill gluten and Euro/bky gluten wholemeals stored at 21°C, are due to a difference in fat requirement and not to deterioration of the functional properties of the gluten stored in the meal.

With one exception, throughout the tests loaf volumes for CWRS meals were lower than those from Euro/mill gluten and Euro/bky gluten wholemeals. That suggested fat requirement of the CWRS meals was not fully met from the start which seemed to be confirmed during subjective assessment when 'hard cores' in the crumb of CWRS loaves were found, an indication of inadequate fat addition. The exception to this was at -18°C storage temperature when 2% fat was added. Loaf volume in this case was not significantly lower than from European meals and at -18°C, with 2% fat, would not have been expected to follow the same pattern as the other CWRS results, simply because of the combination of fat addition and the slower rate of increased requirement at this temperature.

Normal commercial practice is to use wholemeal within a period of approximately six weeks. Our results showed that even when storing at 21^{o}C, loaf volume increased beyond this period and loaf crumb scores remained constant. That result suggested that in terms of loaf physical properties, wholemeal has good tolerance to storage. However, results for free fatty acids (FFA) and peroxide values showed more adverse patterns. Both of the analyses are indicators of rancidity, table 4.2 shows the FFA content of the stored meals at 21^{o}C steadily increased up to week 16. Although formal taste panel assessments were not carried out, some tasting of samples during assessment of loaf physical characteristics did not reveal any undesirable flavours or odours. Peroxide values are indicators of oxidative changes in the meal. The steady pattern and then the increase in these values at week 9 may be linked to the natural oxidation which occurs during the earlier stages of storage and which is known to result in increases in loaf volume.

Table 4.1

Characteristics of CWRS and all-European grists and the wholemeal flours prepared from them

WHEATS	**CWRS**		**All-European**
Grist composition	CWRS 100%		English 100%
Wheat variety	Katepwa/Neepawa	9	Mercia 14
Electropheresis (14 grains)	Columbus	2	
	Other	3	
Wheat analyses			
Protein (N x 5.7 on 14% m.b), %	15.4		11.5
Falling No (7g) s	455		377
SDS sedimentation volume, ml	68		68
Moisture (130°C for 1.5h), %	11.8		12.2
WHOLEMEALS			
Wholemeal analyses			
Protein (N x 5.7, as is), %	15.4		11.5
Moisture (130°C for 1.5h), %	13.7		13.1
Free fatty acid % Oleic	6.04		9.57
Alpha-amylase, Farrand Units	2		2
Water absorption (10 min. method), %	65.0		61.7
Particle size distributions			
Sieve size (microns)			
		% material	
>1000	3.0		3.8
>850	2.7		2.1
>500	8.9		10.0
>300	5.2		5.1
>180	5.6		5.2
<180	74.6		73.8
Total	100.0		100.0
Endosperm analyses (fractions below 180 microns)			
Protein content (N x 5.7, as is), %	15.2		10.6
Moisture (130°C for 1.5h), %	13.6		13.2
Damage starch, Farrand Units	14		24
Ash value (d.b), %	0.61		0.55

Table 4.2

Wholemeal analysis during storage

Week	0-1	2	4	6	9	12	16
MOISTURE % ICC oven method							
CWRS -18°C	NA	13.9	14.0	13.9	13.9	13.6	13.7
Euro/mill gluten -18°C	NA	13.2	13.1	13.1	13.0	12.7	13.0
Euro without gluten -18°C	NA	13.3	13.3	13.3	13.3	13.3	13.2
CWRS 21°C	14.0	14.0	13.8	13.7	13.5	13.3	13.7
Euro/mill gluten 21°C	13.2	13.2	13.0	13.0	12.8	12.7	13.1
Euro without gluten 21°C	13.4	13.4	13.3	13.3	13.3	12.9	13.2
LIPID % Acid Hydrolysis							
CWRS -18°C	NA	2.21	1.88	2.12	1.98	2.02	2.10
Euro/mill gluten -18°C	NA	2.13	2.22	2.22	2.34	1.99	1.80
Euro without gluten -18°C	NA	2.02	1.61	1.98	2.06	1.82	1.70
CWRS 21°C	2.69	2.23	1.89	2.17	2.16	1.83	2.20
Euro/mill gluten 21°C	2.61	2.08	2.03	2.07	2.37	2.11	1.80
Euro without gluten 21°C	2.37	2.02	1.56	1.95	1.67	1.87	2.00
FREE FATTY ACID % Oleic acid							
CWRS -18°C	NA	7.44	6.96	9.04	8.18	7.90	7.93
Euro/mill gluten -18°C	NA	7.35	5.22	8.68	6.73	6.70	7.23
Euro without gluten -18°C	NA	5.78	5.43	6.82	7.12	6.60	6.56
CWRS 21°C	6.76	9.03	10.53	15.09	17.05	22.90	22.89
Euro/mill gluten 21°C	5.12	7.70	11.82	16.79	20.79	24.60	25.36
Euro without gluten 21°C	5.14	8.59	10.88	16.99	20.21	23.80	25.62
PEROXIDE VALUE/kg fat							
CWRS -18°C	NA	2.57	8.50	6.50	14.52	11.40	3.52
Euro/mill gluten -18°C	NA	3.86	0.86	7.36	14.91	5.10	1.83
Euro without gluten -18°C	NA	3.12	2.60	0.53	9.49	7.30	2.54
CWRS 21°C	12.0	2.31	11.16	6.79	18.49	11.10	4.73
Euro/mill gluten 21°C	16.0	4.55	7.42	2.19	24.32	6.00	2.14
Euro without gluten 21°C	11.0	5.24	1.61	1.56	21.05	2.90	1.91

NA = Not applicable

Table 4.3

Dried gluten analysis

Protein (N x 5.7) as is, %	:	73.6
Protein (d.m.b), %	:	81.5
Moisture, %	:	9.7
Particle size < 160um, %	:	94
Water absorption, ml/g protein	:	2.02
SDS sedimentation, ml/g protein	:	99.6
Lactic acid sedimentation value, % (loss in turbidity)	:	9.1
Hydration rate, s	:	30

Table 4.4

Average loaf volume (ml.)

WITHOUT FAT

Week	0-1	2	4	6	9	12	16
CWRS -18^{o}C	1226	1222	1178	1242	1330	1323	1208
Euro/mill gluten -18^{o}C	1374	1355	1344	1406	1432	1444	1386
Euro/bky gluten -18^{o}C	1382	1335	1402	1396	1455	1497	1409
CWRS 21^{o}C	1216	1193	1193	1200	1277	1226	1147
Euro/mill gluten 21^{o}C	1375	1341	1320	1398	1394	1400	1339
Euro/bky gluten 21^{o}C	1414	1343	1345	1345	1357	1439	1349

Standard deviation of a single replicate = 23.09 ml
Least significant difference (LSD) at 5% of 2 means = 46.6 ml

WITH 2% FAT

CWRS -18^{o}C	1437	1408	1391	1344	1498	1510	1434
Euro/mill gluten -18^{o}C	1490	1462	1473	1471	1502	1538	1437
Euro/bky gluten -18^{o}C	1452	1432	1437	1440	1509	1566	1422
CWRS 21^{o}C	1419	1390	1386	1357	1438	1401	1308
Euro/mill gluten 21^{o}C	1484	1410	1427	1406	1501	1531	1386
Euro/bky gluten 21^{o}C	1486	1415	1445	1397	1508	1526	1446

Standard deviation of a single replicate = 27.26 ml
LSD at 5% of 2 means = 55.0 ml

Table 4.5

Average crumb score (max. 10)

WITHOUT FAT

Week	0-1	2	4	6	9	12	16
CWRS -18°C	4.5	4.0	3.0	4.0	2.0	4.0	3.5
Euro/mill gluten -18°C	6.0	5.0	4.0	5.5	6.0	6.0	6.0
Euro/bky gluten -18°C	6.0	5.0	5.5	6.0	5.0	7.0	6.0
CWRS 21°C	4.0	4.0	3.0	4.0	2.0	3.0	3.5
Euro/mill gluten 21°C	5.0	5.0	4.0	6.0	3.5	6.0	6.0
Euro/bky gluten 21°C	7.0	5.0	4.5	6.0	3.5	6.0	5.5

Standard deviation of a single replicate = 0.4
Least significant difference (LSD) at 5% of two means = 0.8

WITH 2% FAT

CWRS -18°C	7.0	6.0	5.0	5.5	6.0	7.0	7.0
Euro/mill gluten -18°C	7.5	7.5	7.0	8.0	7.5	7.5	7.5
Euro/bky gluten -18°C	8.5	7.0	7.5	7.0	8.0	7.5	8.0
CWRS 21°C	8.0	6.0	5.5	5.0	5.0	5.0	5.5
Euro/mill gluten 21°C	7.5	7.5	6.5	7.0	8.0	7.5	8.5
Euro/bky gluten 21°C	8.5	7.5	7.0	6.5	8.0	8.0	7.5

Standard deviation of a single replicate = 0.7
LSD at 5% of two means = 1.5

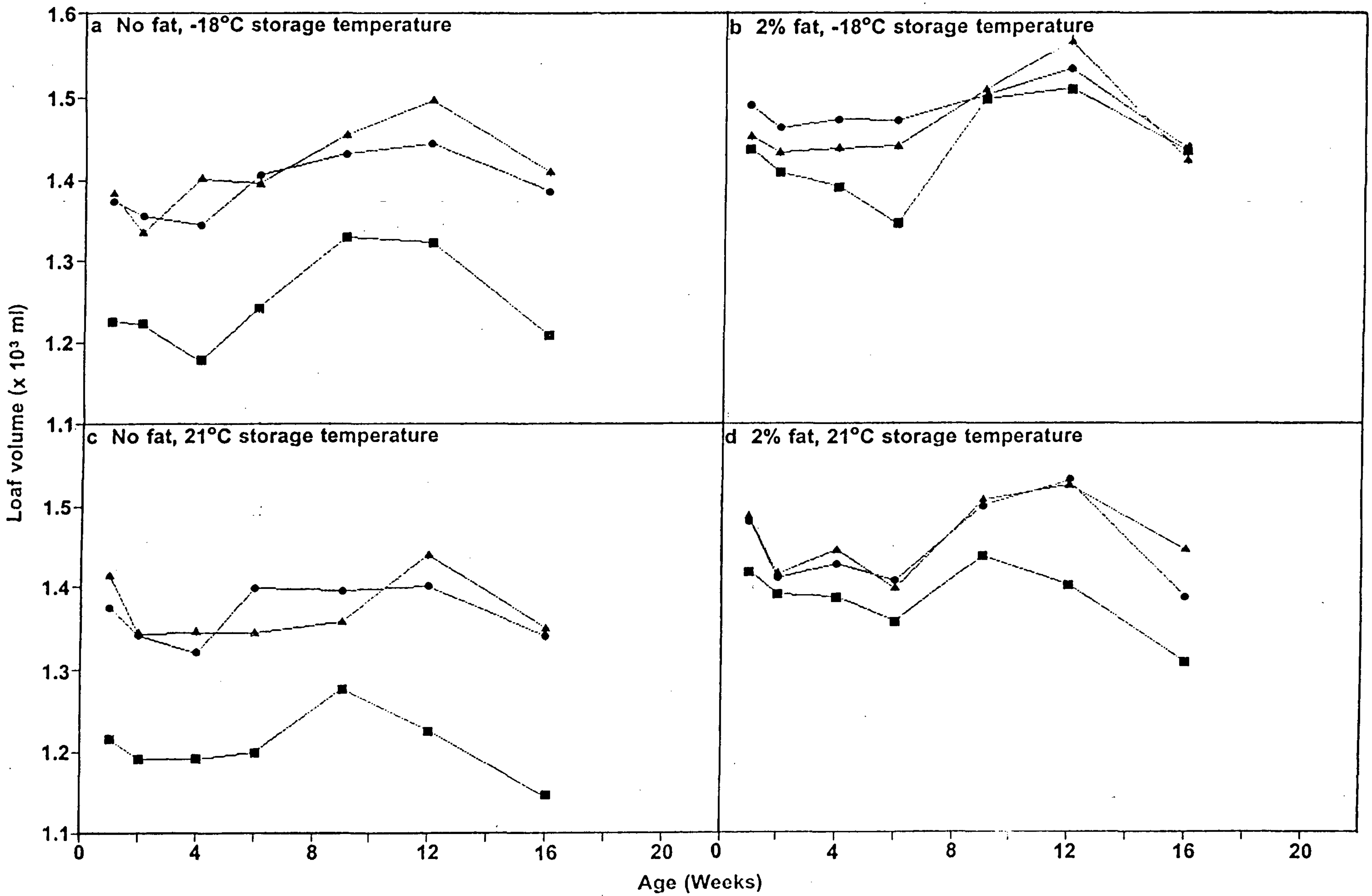

Fig 4.1 The effect of storage time on the loaf volume of the gluten fortified wholemeal flours. (■) unfortified CWRS control. (●) European flour + mill gluten. (▲) European flour + bakery gluten.

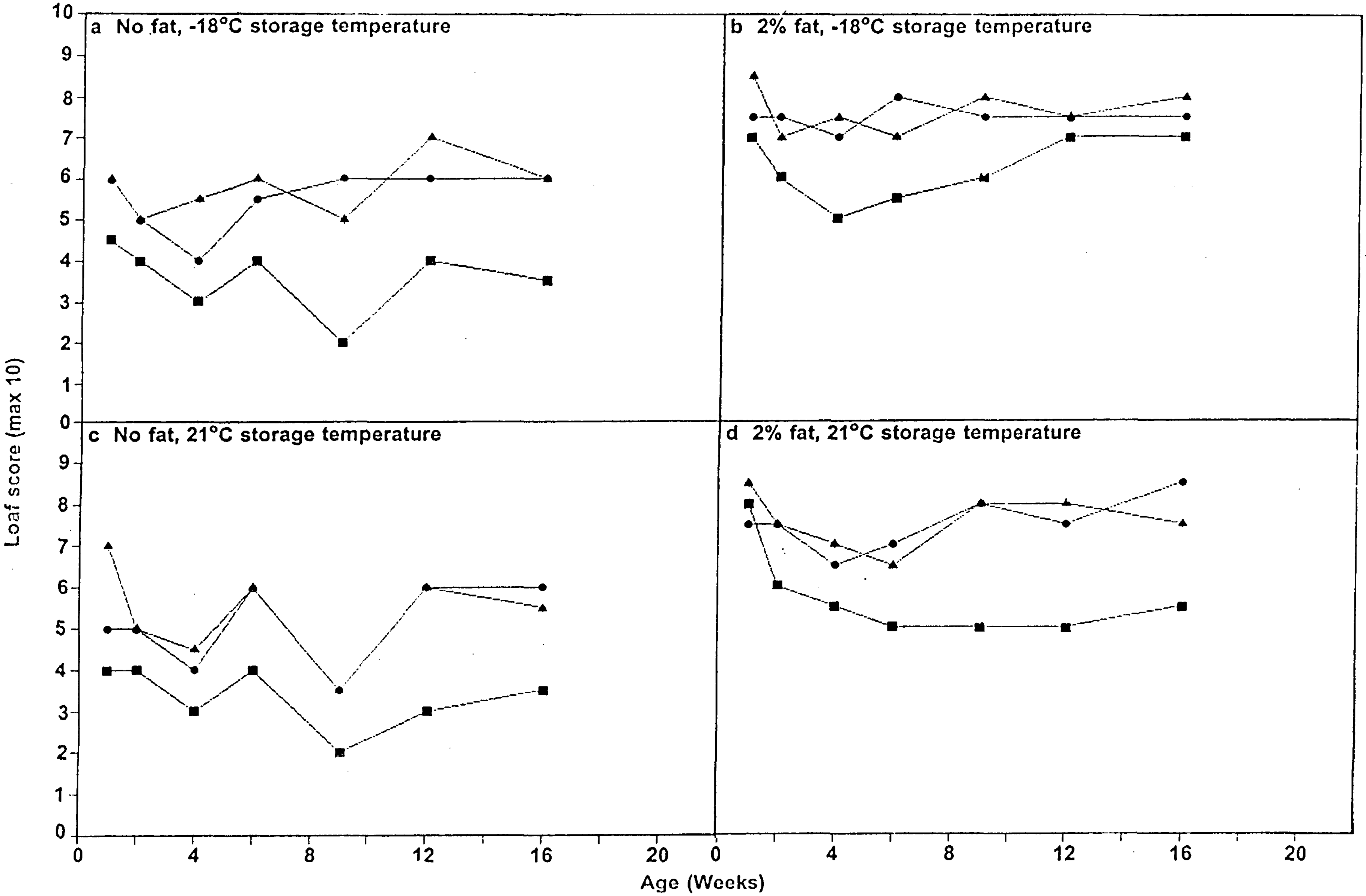

Fig 4.2 The effect of storage time on the crumb scores of gluten fortified wholemeal flours.
(■) unfortified CWRS control, (●) European flour + mill gluten, (▲) European flour + bakery gluten.

5. THE INTERACTION BETWEEN SINGLE VARIETY GLUTENS AND SINGLE VARIETY BASE-FLOUR

5.1 Objective

To prepare gluten from six single wheat variety flours covering a range of baking quality and test bake these glutens in protein fortification of their own and the other five base-flours in the CBP.

5.2 Introduction

The variable response of different wheat varieties to gluten addition in breadmaking has already been discussed, (Section 2, page 9). In general, poor breadmaking varieties, e.g. Galahad, respond better to gluten addition in terms of loaf volume increase and improvements in crumb structure than do strong breadmaking varieties such as Avalon and Mercia. It seems, however, that the variable quality of different wheat varieties is lost during gluten production. Developments that have taken place in gluten processing, particularly in the drying stage, enable gluten to be of a consistent quality, independent of varietal origin. This has been verified by several test bake studies which have shown little apparent difference between the baking quality of commercial gluten from different countries of origin (section 3, page 38). However, the increasing use of flours derived from single wheat varieties, together with the regular changes in the popular wheat varieties grown in the UK, and therefore available for both baking and gluten manufacture, made a more detailed study necessary.

5.3 Materials and Methods

Flour and gluten samples

Flours

Six laboratory, Buhler-milled single wheat varieties were used. Five of the flours covered a range of quality according to the FMBRA Classification of Home-Grown Wheats, 1989 (Table 5.1). Additionally a control flour (E2247) of 8.8% protein was test baked with a control gluten of protein 73.6% to indicate any changes in the process within and between days.

Gluten

Gluten samples were prepared from the six single wheat varieties using a process based on making a batter from flour and water in the ratio 2:3 respectively, as described previously (page 35). The gluten was freeze-dried and powdered on a hammer mill with a 0.8 mm screen and finally collected through a 160μm sieve.

Gluten characteristics and yield from the different varieties was recorded (Table 5.2). All the glutens were assessed by standard tests (Table 5.3).

Methods

Test Baking

Gluten addition was tested at 2% increase in base flour fortification by the CBP (see Appendix 2). Each variation was replicated. The test variations were spread over four baking days and each day was divided into 3 blocks of 8 experiments. Each block represents a flour variety and all its gluten variations including controls, so there was a total of 8 variations for each flour. In this statistical design, we were looking at both variations between the gluten samples and the interaction of the glutens with different base flours. The experimental design was less concerned with variations between the flour varieties.

Gel Protein

The effect of gluten addition on flour gel protein levels was determined. Three flours representing a wide range in baking quality, namely CWRS, Avalon and Haven, were fortified by 6% gluten protein. The flour and gluten samples were defatted using 60ml petroleum ether (40-60^{o}C boiling range) per 20g flour or gluten. The flour and gluten components were combined through a 250μm sieve. 5g samples were subsequently taken for gel protein determinations. Gel protein levels of the unfortified flours were also measured (Graveland *et al* 1978).

Gluten Rheology

Rheological properties of the gluten samples were assessed on the Bohlin Rheometer by the oscillation test. (Appendix 4). Values of the different rheological parameters were taken at 1.0Hz for any comparisons.

Other Quality Parameters

Glutens were assessed by standard tests as described by McDermott and Chamberlain (1984).

5.4 Results and Discussion

Loaf Volume

The effect of gluten variety on loaf volume and crumb colour are tabulated with least significant differences (LSD) in Tables 5.4 and 5.5 respectively. A simple visual comparison of the effect of the different glutens relative to a flour foritfied with its own variety gluten is shown in Fig. 5.1. Any gluten outside the probability bar is significantly different at the 5% level compared to the base flour fortified with its own variety gluten.

Generally, the glutens were fairly uniform in quality except when test baked against Haven flour. With Avalon, Mercia, Galahad and Riband flours, all the glutens produced similar average loaf volumes relative to the base flours fortified with their own glutens. With CWRS flour, all varieties of gluten, apart from Haven, produced similar effects. Haven gluten with CWRS flour gave significantly lower volumes compared to CWRS gluten at the 5% level.

Overall, the greatest increases in loaf volume were obtained with the CWRS flour with all the glutens. It was only with the poor quality Haven flour that we could detect clear differences between the gluten varieties. Glutens from good baking varieties (Mercia, CWRS and Avalon) produced loaves which had significantly higher average values than those produced from Haven gluten. Here, differences were significant at the 1% level. Galahad and Riband glutens gave similar values to the Haven gluten. This distinction between glutens from good and poor quality breadmaking varieties is also apparent in the SDS sedimentation test (Tables 5.3). The overall poor quality of Haven flour and its corresponding gluten was also demonstrated during gluten production when problems were encountered during the separation and handling of the freshly prepared gluten (Table 5.2).

Crumb Colour

The effect of gluten on crumb colour varied with the different flour varieties. All varieties of gluten gave similar average crumb colour as the respective base flours for Avalon, Mercia and Riband (Fig. 5.2). Glutens from Avalon and Haven consistently gave lower crumb colour values. With Galahad flour, glutens from Avalon, Riband, Haven and Galahad gave significantly lower average crumb colour than the base flour. These differences were significant at the 1% level (Table 5.5). For Haven flour, glutens from Haven, Avalon and Galahad gave significantly lower crumb colour than the base at the 1% level, as did Galahad and Haven glutens for CWRS flour.

Clearly, crumb colour is dependent on the flour variety fortified, although Haven gluten generally gave lower Hunter-lab crumb colour values whilst CWRS gluten generally gave increased crumb colour. This is consistent with gluten colour obtained as Whiteness Index (WI) values from The Dr. Lange Microcolor tristimulus instrument

(Table 5.3). Here, CWRS gluten registered a high WI value whereas Haven gluten showed a significantly lower value. However, interpretation may be difficult since improved loaf volume and crumb structure from gluten addition may itself lead to a perceived lighter crumb colour.

Gluten Quality Assesments

All 6 glutens were assessed by standard quality tests (Table 5.3). The results obtained were within ranges found acceptable for baking performance in previous work. However, there appeared to be two distinct groups in terms of protein quality as judged by the SDS sedimentation test. Here, glutens from good baking varieties of Avalon, Mercia and CWRS gave SDS values of greater than 170ml/g protein, whereas Galahad, Haven and Riband glutens gave distinctly lower SDS values in the region of 84ml/g protein.

Gel Protein

Investigation of the properties of the various proteins in wheat flour has shown that the visco-elastic properties of a dough reside mainly in the gluten proteins, i.e. the glutenins (elastic properties) and the gliadins (viscous properties). Using an extraction and fractionation method described by Graveland *et al* (1979), the amount of gel fraction (sodium dodecyl sulphate (SDS) - insoluble, high molecular weight (HMW) glutenins) was determined for base flour and gluten combinations. The quantity of these high molecular weight aggregates is a wheat varietal characteristic and is strongly related to breadmaking potential. A relationship between the HMW subunits and breadmaking quality has been previoulsy reported (Payne *et al* 1987).

Gel protein measurements against corresponding loaf volume are shown in Fig. 5.3. For Haven flour, the relationship between gel weight and loaf volume is highly significant. Due to the poor quality of the flour, there is a good response to gluten addition resulting in improved loaf volume and crumb structure. Glutens from CWRS, Avalon and Mercia gave higher gel protein values compared to those of Galahad, Riband and Haven. This distinction in quality between the gluten varieties is observed in the loaf volume data for Haven flour (Fig. 5.1).

Increasing gluten protein levels for CWRS and Avalon flours increased loaf volume and gel protein, but there was no significant trend between loaf volume and gel protein. This is consistent with previous observations whereby very strong flours or strong flours with gluten added cannot be used to their full potential efficiently in the standard baking tests. It appears that above a gel protein level of 13 and 14g, there are no linear increases between gel protein levels and loaf volume within a flour variety. Instead, the results suggest similar average loaf volume increases for CWRS flour and all its gluten combinations, and similarly for Avalon flour and all its gluten variations. The source of the gluten, therefore, is unimportant here. There are differences, however, between Avalon and CWRS flours in terms of loaf volume but with similar gel protein levels, hence, maximum loaf volume is variety dependent. The maximum volumes for CWRS and Avalon were 1642ml and 1528ml respectively. The maximum volume for Haven was 1510ml but further tests would be required to check that the maximum has been achieved.

Gluten Rheology

Only Riband and Haven glutens show any statistical correlations between rheological parameters and average loaf volume (Table 5.6). Once again, Haven appears to be set apart from the other glutens giving significantly lower values for the different rheological parameters. (Table 5.3).

Table 5.1

Milling and baking quality of wheat varieties
Categories:

Flour Variety	Bread	Biscuit	Texture	Season
Avalon	B	D	Hard B	Winter
Mercia	B	D	Hard B	Winter
Galahad	D	C	Soft C	Winter
Riband	D	B	Soft C	Winter
Haven	D	C	Hard B	Winter
* CWRS	A	D	Hard A	Spring

* Canadian Western Red Spring

Table 5.2
Comparison of gluten characteristics prepared from 6 single wheat varieties

Flour Variety	Flour Protein %	Flour Moisture %	Mean wt. of gluten recovery g/1400g flour	Gluten yield %	Comments
Avalon	77.1	6.9	110	7.9	
Mercia	78.4	6.4	126	9.0	1
Galahad	72.7	6.7	105	7.5	
Riband	67.1	5.9	139	9.9	2
Haven	79.5	5.8	107	7.6	3
CWRS	77.6	5.9	187	13.4	4

1. Gluten quite tough
2. Gluten difficult to clean from starch
3. Poor separation of gluten and starch following centrifugation. Gluten very sticky in consistency and significantly yellow in appearance.
4. Strong, elastic gluten

Table 5.3

Properties of 6 Laboratory prepared glutens

Quality parameter	**Avalon**	**CWRS**	**Galahad**	**Haven**	**Mercia**	**Riband**
			Gluten Samples			
Moisture, %	6.9	5.9	6.7	5.8	6.4	5.9
Protein, as is, %	77.1	77.6	72.7	79.5	78.4	67.1
SDS, ml/g protein	178	176.9	86.2	83.9	175.2	83.2
Lactic Acid, % (drop in turbidity)	4.4	6.3	2.9	14.0	9.4	1.2
Hydration time, s	5	5	5	4	4	5
Colour, (WI)	37.9	39.3	35.3	20.0	28.0	35.5
Water absorption, ml/g protein	2.58	2.56	2.52	3.01	2.42	3.01

Fundamental Rheological Parameters. Measured at 65% moisture basis on Bohlin Rheometer

Complex modulus, G*, Pa	1570	1920	1420	736	1710	1050
Elastic Modulus, G', Pa	1440	1780	1270	650	1580	962
Viscous Modulus, G", Pa	624	743	625	346	661	417
Viscosity, Pas	250	306	226	117	272	167
Delta, G"/G'	23.4	22.7	26.1	28.0	22.8	23.4

Table 5.4

Loaf Volume

Variety	Base	G1	G2	G3	G4	G5	G6	Variety Means
Avalon	1458.5	1524.0	1553.5	1502.0	1532.5	1521.5	1533.5	1517.9
Mercia	1456.0	1566.5	1531.0	1512.5	1529.5	1559.5	1570.5	1532.2
Galahad	1411.0	1491.0	1529.0	1494.0	1463.5	1496.0	1497.5	1483.1
Riband	1418.0	1499.5	1519.5	1498.0	1507.5	1468.5	1521.5	1490.4
Haven	1381.5	1507.0	1512.0	1463.0	1452.5	1425.5	1510.0	1464.5
CWRS	1578.5	1643.5	1633.0	1666.0	1634.0	1610.0	1663.5	1632.6
Gluten means	1450.6	1538.5	1546.3	1522.6	1519.9	1513.5	1549.5	1520.1

Least Significant Differences

For comparing

Two variety means	43.45 (5%)	68.14 (1%)
Two gluten means	18.52 (5%)	24.82 (1%)
Two gluten means for one variety	45.37 (5%)	60.82 (1%)

Key:

G1	-	Avalon Gluten
G2	-	Mercia "
G3	-	Galahad "
G4	-	Riband "
G5	-	Haven "
G6	-	CWRS "

Table 5.5

Colour, Hunterlab Y-value

Variety	Base	G1	G2	G3	G4	G5	G6	Variety Means
Avalon	58.675	57.580	58.240	58.860	58.610	57.830	59.480	58.468
Mercia	59.820	58.820	59.960	59.260	59.800	58.895	59.530	59.441
Galahad	58.110	56.465	57.105	55.980	56.320	56.180	58.395	56.936
Riband	58.045	57.170	57.765	57.220	57.855	56.905	58.445	57.629
Haven	57.065	55.550	56.450	55.500	56.065	55.710	56.995	56.191
CWRS	62.255	61.480	62.140	60.490	61.170	60.065	61.920	61.360
Gluten means	58.995	57.844	58.610	57.885	58.303	57.599	59.128	58.338

Least Significant Differences

For comparing

Two variety means	1.011 (5%)	1.585 (1%)
Two gluten means	0.407 (5%)	0.546 (1%)
Two gluten means for one variety	0.997 (5%)	1.337 (1%)

Table 5.6

Relationship between rheological properties of the glutens and average loaf volume

Rheological parameter	Flour Variety Avalon	Mercia	Galahad	Riband	Haven	CWRS
G*	0.33	0.15	0.47	0.84*	0.95**	0.72
G'	0.36	0.16	0.47	0.85*	0.95**	0.70
G"	0.18	0.09	0.49	0.76	0.89*	0.79
Viscosity	0.33	0.15	0.47	0.84*	0.95**	0.72
Phase	0.65	0.12	0.09	0.92**	0.83*	0.40

* significant at 5% probability level
** significant at 1% probability level

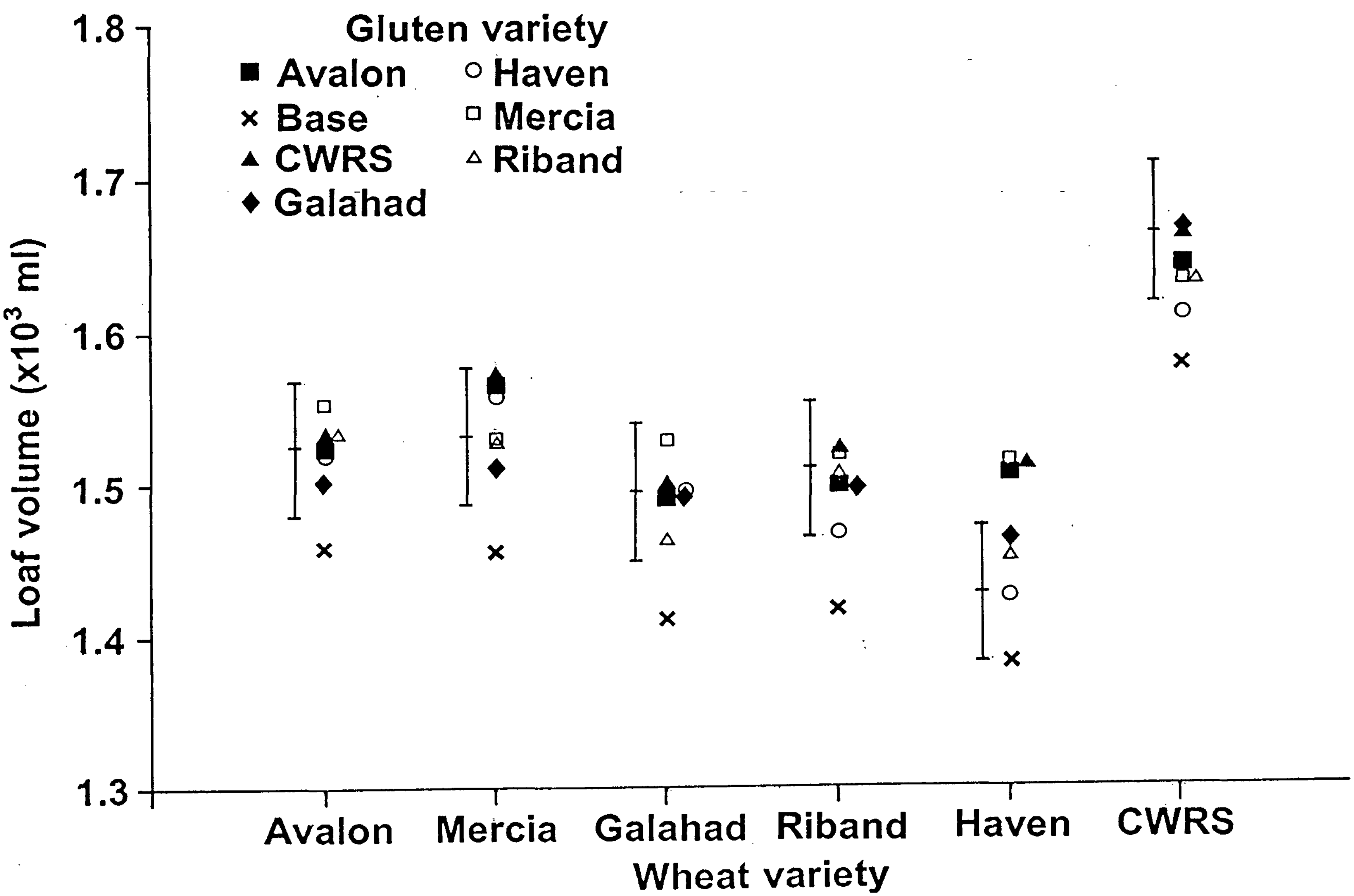

Fig. 5.1: Assessment of six glutens against six flours by loaf volume in the CBP

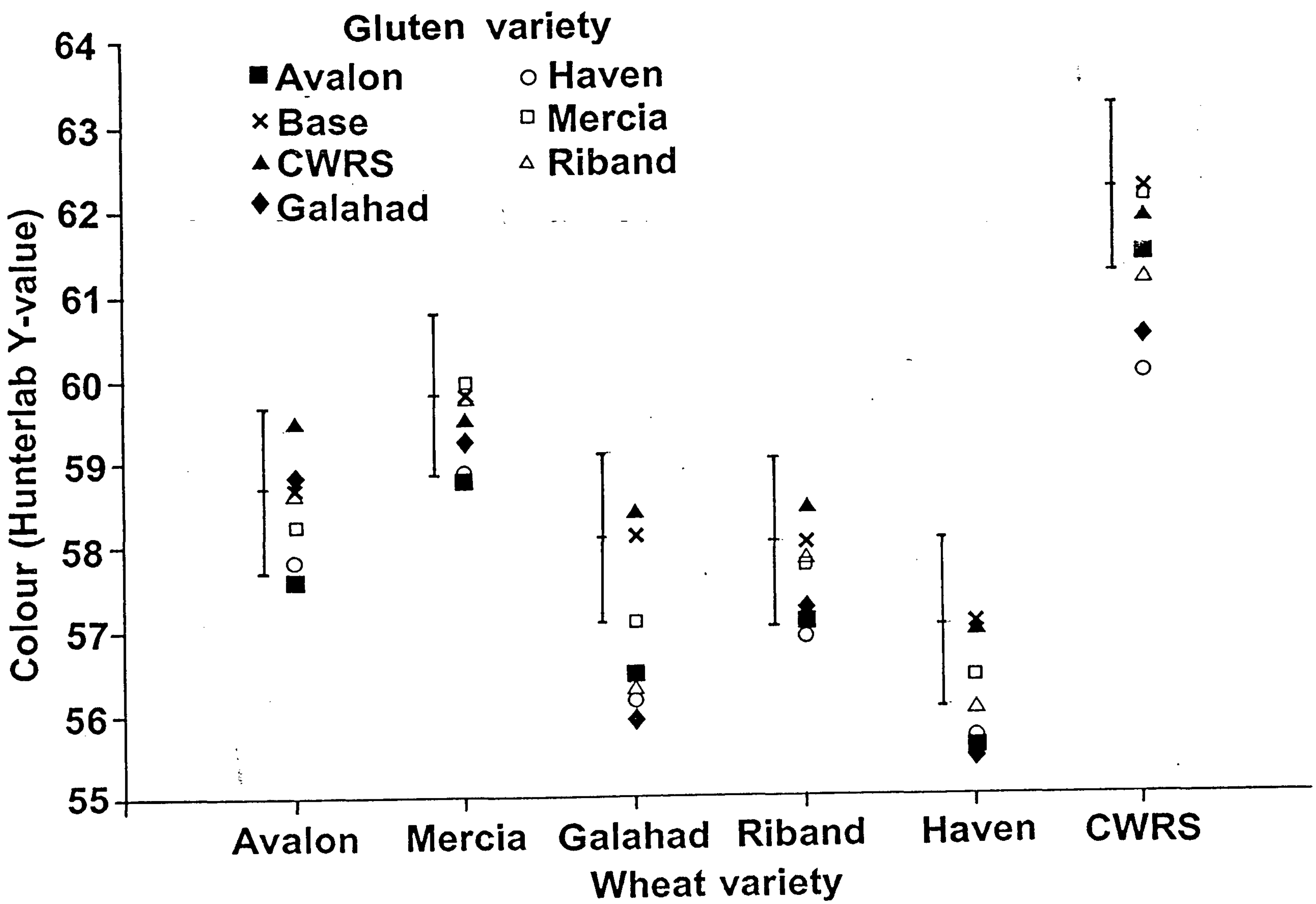

Fig. 5.2: Effect of gluten addition on crumb colour

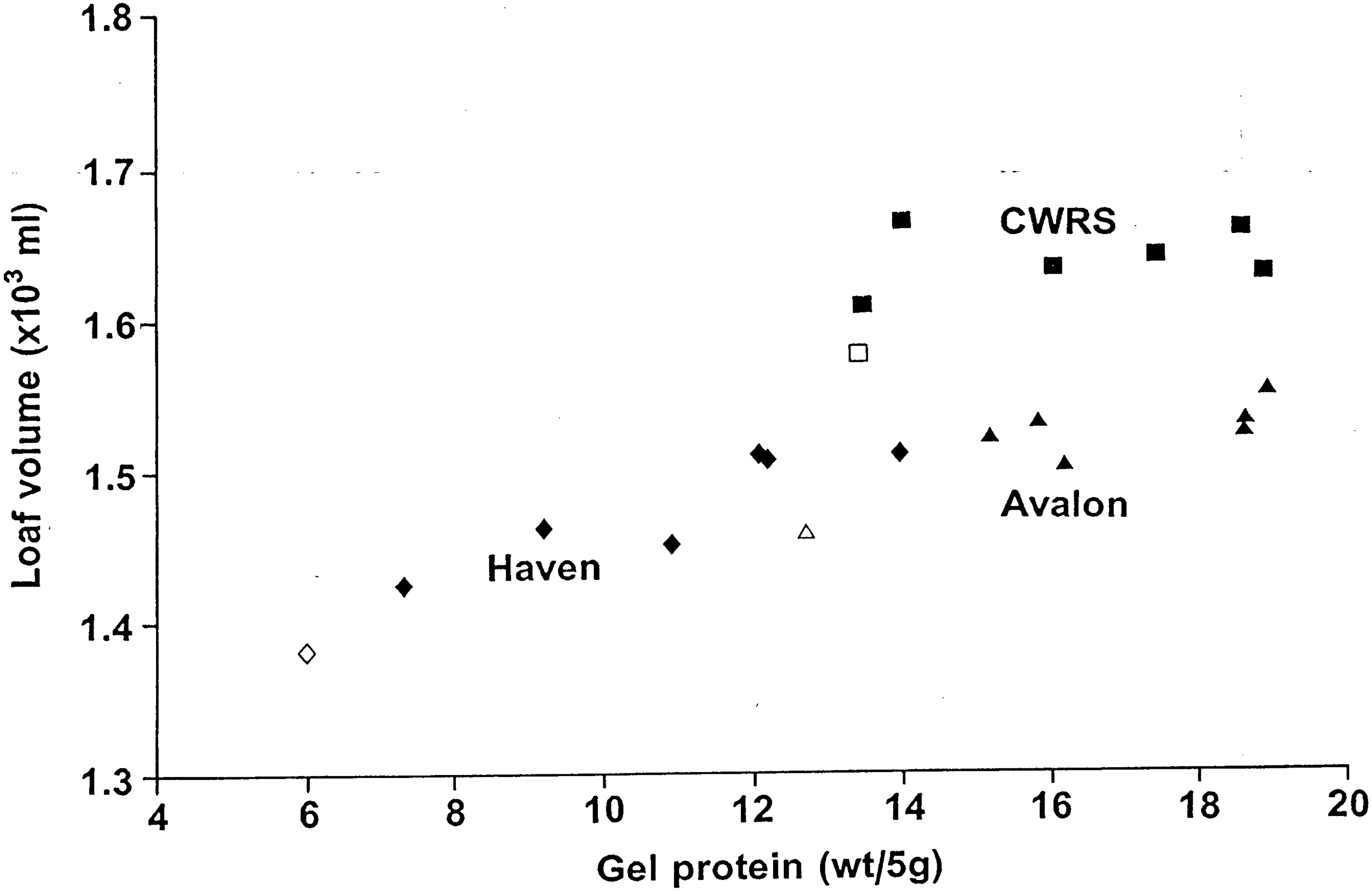

Fig. 5.3: Relationship between loaf volume and gel protein levels of gluten fortified flours. Open shape shows base control value.

6. GENERAL DISCUSSION AND CONCLUSION

The studies discussed in this report cover a number of aspects of the use of gluten in the UK during the later 1980's. The response of single variety base-flours to added gluten clearly show that good breadmaking varieties such as Avalon and Mercia respond less well to gluten than do poorer varieties such as Brock, Galahad and Slejpner. There is some evidence (Pritchard, unpublished results) that interactions between the glutenin fractions of the flour and gluten play an important role in the performance of gluten fortified flours. It is probable that the combination of a strong variety and added gluten has an increased mixing requirement, that is not fully met by a standard process such as the CBP, and therefore the dough is not sufficiently developed for optimal baking performance. This phenomenon needs to be studied in more detail and could form the basis of future project proposals.

With the increased use of home-grown wheat, and the trend towards single variety grists for the milling and baking industries, there is clearly a requirement for new varieties to be assessed for response to added gluten at an early stage. Also, the individual glutens, although generally of an acceptable quality, did show that it is possible to find a variety (Haven) where the poor baking quality of the flour is carried over into the gluten. Our studies, of course, used laboratory prepared glutens; problems were experienced in the preparation of Haven gluten which may serve as a screening system before selection of a variety for gluten production.

Good correlations between the lactic acid sedimentation test and baking data have again shown this test to be a good screening method for detecting poor quality gluten. Fundamental rheological parameters, as determined with the Bohlin Rheometer also correlated well with baking data when low quality (heated) glutens were included in the sample range. Despite some problems with reproducibility, the Glutograph showed good correlations with the Bohlin data and may be a useful 'poor man's' rheometer. The deleterious effects of heating were again shown to occur only after heating above 70^{O}C, a temperature at which the gliadins were beginning to be affected with consequent influences on the dough.

Our studies have shown that commercial gluten is of a consistently high quality when tested under standardised baking conditions against single variety base-flours and that loaf volume improvement is inversely related to the quality of the base flour. The goal of finding a small scale laboratory test to predict gluten quality, has again proved elusive. The increasing world-wide importance of gluten has meant that we are not alone on searching for a predictive test.

Using other techniques Czuchajowska and Pomeranz (1990) have come to a similar conclusion that:

> "the quest for a single, simple universal test to evaluate end-use functional properties of commercial vital dry gluten originating from many manufacturers around the world can be satisfied only partially at this time".

Wadhawan and Bushuk (1989a, 1989b) have also evaluated various quality parameters of gluten but they concluded that parameters such as the ratio of free to bound lipid and the sodium chloride content were either too complicated or not applicable to gluten from a number of sources, i.e. some manufacturers use sodium chloride, others do not and therefore such a measure could only be used as a quality control tool in individual plants.

A fluoresence test was shown to correlate with heat damage, but in some preliminary assessments (not reported) we could not distinguish between commercial samples of different baking quality, although heat damage was detectable.

It is clear that the performance of a gluten is critically dependent upon the base flour being fortified, the baking method employed and in all probability the product being made. It seems unlikely that any one test will accurately predict each and every combination used within the industry.

The storage stability studies on gluten fortification of wholemeal flour led to a number of conclusions:

1. Changes in free fatty acids and peroxide values were similar between gluten fortified and non-fortified wholemeals during storage, i.e. the presence of gluten with its high lipid content did not increase the susceptibility of the wholemeal to hydrolytic or oxidative attack.

2. The functional properties of gluten added immediately after milling to wholemeal of European origin were maintained at least equal to the natural protein of CWRS meals throughout a 16 week period at 21^{o}C.

3. No differences in breadmaking performance were identified between loaves produced from European meal with gluten added at the milling stage and European with gluten added at the dough-mixing stage until week 16 when stored at 21^{o}C, using 2% fat in the recipe. At that storage point, the European wholemeal with gluten added at doughmixing was considered to have a lower fat requirement. This was due to the gluten added at that stage having been prevented from increasing in fat requirement by storage at -18^{o}C. Thus, differences are not due to deterioration of the functional properties of the gluten but to changes in fat requirement.

4. Increases in loaf volume over the storage period are thought to be due to oxidation, possibly linked to peroxide values.

5. CWRS meals showed early signs of having a greater fat requirement than the European wholemeals.

With an industry norm of about six weeks storage for wholemeal flour, it can be concluded from this study that gluten fortification at the mill is a practical possibility and will not lead to losses of gluten functionality, or to unacceptable deterioration of the meal.

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Appendix 1

Procedure for Buhler milling

Samples of wheat with a moisture content greater than 15% on arrival were dried (in a Mitchell hot air oven on trays) to less than 15% and stored at ambient temperature in a RH of 53%.

18-24 hours prior to milling samples were conditioned to adjust moisture content. To optimize milling, soft varieties were adjusted to 15% mositure and hard 15.5%.

Samples were then milled in a laboratory Buhler mill (Model MLU 202) set to give commercial levels of damaged starch, i.e. the first and third break roll with a gap 0.7 and 0.3mm, the first and third reduction roll gap 0.25 and 0.2mm. The feed rate was set at 6kg/h.

Milling was carried out under controlled temperature and humidity of 20^{o}C with a RH of 65%, in accordance with the recommendations given by Hook *et al* (1984). Extraction rates for the white flours were 73-76% (this figure is based on the straight run flour from the Buhler plus the flour recovered from the passing of the bran and offal through a laboratory Buhler bran finisher). Wholemeals were produced using the Roller Milled/Ground method (RM/G) described by Hook and Collins (1987).

The RM/G method gives maximum release of endosperm from the bran, the efficiency of the separation is monitored by measurement of the ash content of the endosperm/flour part of the wholemeal (i.e. the fraction less than 180 microns). RM/G consists of re-grinding the bran fraction in a Christy and Norris hammer mill fitted with a 1.6mm mesh. Blending of the components of the wholemeal was carried out in a ribbon blender for 30min.

Appendix 2

CBP recipe and method for 400g white and wholemeal bread

Recipe

	Single variety gluten quality		Storage stability
	White	Wholemeal	Wholemeal
	% of flour weight		
Flour	100	100	100
Yeast (compressed)	2.1	2.1	2.5
Salt	1.8	1.8	2.0
Water (as determined by Simon Extrusion Meter, 10 min method)			
Fat (Ambrex, slip point c. 45^{o}C)	0.7	2.0	see text
Ascorbic acid	0.003	0.01	0.01
Potassium bromate	0.0045	Nil	-
Gluten	see text variations		
fungal *alpha*-amylase			80FU

Dough processing:

Mixing machine	:	Morton
Beater speed	:	300 rev/min
Work input	:	11Wh/kg
Pressure	:	Atmospheric
Dough temperature	:	30.5 +/- 1^{o}C
Scaling	:	By hand to 454g
First moulding	:	Cylinder using Mono moulder
First proof	:	10 min at ambient temperature
Final moulding	:	Single-piece cylinder (R7 W5.5 P1.25)
Pan size	:	Top 160mm x 98mm, 83mm deep
Shape	:	Unlidded
Porving conditions	:	43^{o}C, humidity to prevent skinning
Proving height	:	10cm
Baking temperature	:	230^{o}C
Oven type	:	Electric direct-fired reel
Baking time	:	25 min
Baking humidity	:	No steam injected
Cooling	:	Open rack at room temperature
Storage	:	Closed cupboard overnight at 21^{o}C

Loaf quality assessment

Loaf volume was measured by seed displacement (Cornford, 1969) and crumb score by expert examination of the cell size, uniformity and wall thickness, scoring up to a maximum of 10 points.

Appendix 3

1 hour Bulk Fermentation process for 400g white and wholemeal bread

Recipe	White	Wholemeal
	% of flour weight	
Flour	100	100
Yeast (compressed)	2.5	2.5
Salt	1.8	1.8
Water (as determined by Simon Extrusion Meter, 1h yeasted method)		
Fat (Ambrex, slip point c. 45°C)	0.7	2.0
Ascorbic acid	Nil	0.002
Potassium bromate	0.002	Nil

Dough Processing:

Mixing machine	:	Twin armed Artofex
Mixing time	:	10 min
Dough temperature	:	27 +/- 1°C
Bulk fermentation	:	1 hour at 27°C
Scaling	:	By hand to 454g
First moulding	:	Cylinder using Mono moulder
First proof	:	10 min at ambient temperature
Final moulding	:	Single-piece cylinder
Pan size	:	Top 160mm x 98mm, 83mm deep
Shape	:	Unlidded
Proving conditions	:	43°C humidity to prevent skinning
Proving height	:	10cm
Baking temperature	:	230°C
Oven type	:	Electric-fired reel
Baking time	:	25 min
Baking humidity	:	No steam injected
Cooling	:	Open rack at room temperature
Storage	:	Closed cupboard overnight at 21°C

Loaf quality assessment

As for CBP (Appendix 2).

APPENDIX 4

Operating conditions for the Bohlin Rheometer

Rheological properties of the gluten samples were assessed on the Bohlin Rheometer by oscillation and stress relaxation tests. Small shear strains were used to ensure we were operating in the linear visco-elastic region, where the dynamic moduli are independent of the strain amplitude (Le Grys *et al* 1981). The operating conditions for the oscillation and stress relaxation tests are listed in Table 1.

Table 1: 'Operating conditions for the oscillation (OT) and stress relaxation tests (SRT)'

Parallel Plate System	PP25H
Torque Element	18.8gcm
Filter	5
Gap Size	2mm
Sensitivity	1 x
Start Temperature	$25^{o}C$
Strain Rise Time (SRT)	0.02s
Measurement Time (SRT)	10800s
Amplitude (OT)	0.5%
Measurement Time (OT)	45s
Frequency Range (OT)	0.1 - 10Hz
Frequency Sweep	Down - no measurement interval

(a) Oscillation Test
A sinusoidally varying strain, at a defined amplitude and frequency, is applied to the sample, which is clamped between an oscillating lower head and a fixed upper surface. By comparing the stress generated and the strain applied, the Bohlin is able to evaluate the complex shear modulus, G*, from which we can determine the dynamic storage or elastic modulus, G', which is in phase with the applied strain and the dynamic loss or viscosity modulus, G", which is out of phase with the applied strain. A typical gluten oscillation test result is shown in Fig. A4.1. Values of the different components were usually taken at 1.0Hz for comparisons and statistical analysis.

Previous work has indicated a relationship between storage and loss moduli with loaf volume (Le Grys *et al* 1981). Due to the similarity in the 10 commercial glutens, no correlations were obtained between rheological parameters and baking data. However, when the heat-damaged laboratory-prepared glutens were included in the study, correlations between fundamental rheological characteristics (G*, G' and G" etc) and the baking data were observed.

(b) Stress Relaxation Test
The sample is subjected to a sudden shear strain which is then kept constant. The shear stress that is produced in the sample is monitored as a function of time. In visco-elastic materials like gluten, the stress decays gradually. (Bohlin 1984).

A typical stress relaxation curve is shown in Fig. A4.2

The different variables in Fig. A4.2 can be represented as following:-

Relaxation Modulus, G $= \frac{To}{\gamma o}$

To = initial stress

γo = shear strain (constant)

$$\text{Relaxation Spectrum} = \frac{dG}{d \ln t} = \frac{-d\,(T/\gamma o)}{d \ln t}$$

The relaxation spectrum usually produced a 2nd and/or 3rd peak. The height of the last peak is claimed to be directly related to protein quality in terms of gluten baking performance (Bohlin 1984). However, we were not able to verify this correlation in our work. Only very badly heat-damaged gluten, i.e. heated to 90^{o}C, showed any marked difference from the other glutens. Here, the relaxation spectrum showed abnormally large peaks where the last peak was over 14 times greater than that for any other gluten sample. This indicated a very slow elastic recovery which points to the complete disruption of the visco-elastic nature of the material. In consequence, results for this assessment of gluten quality are not quoted.

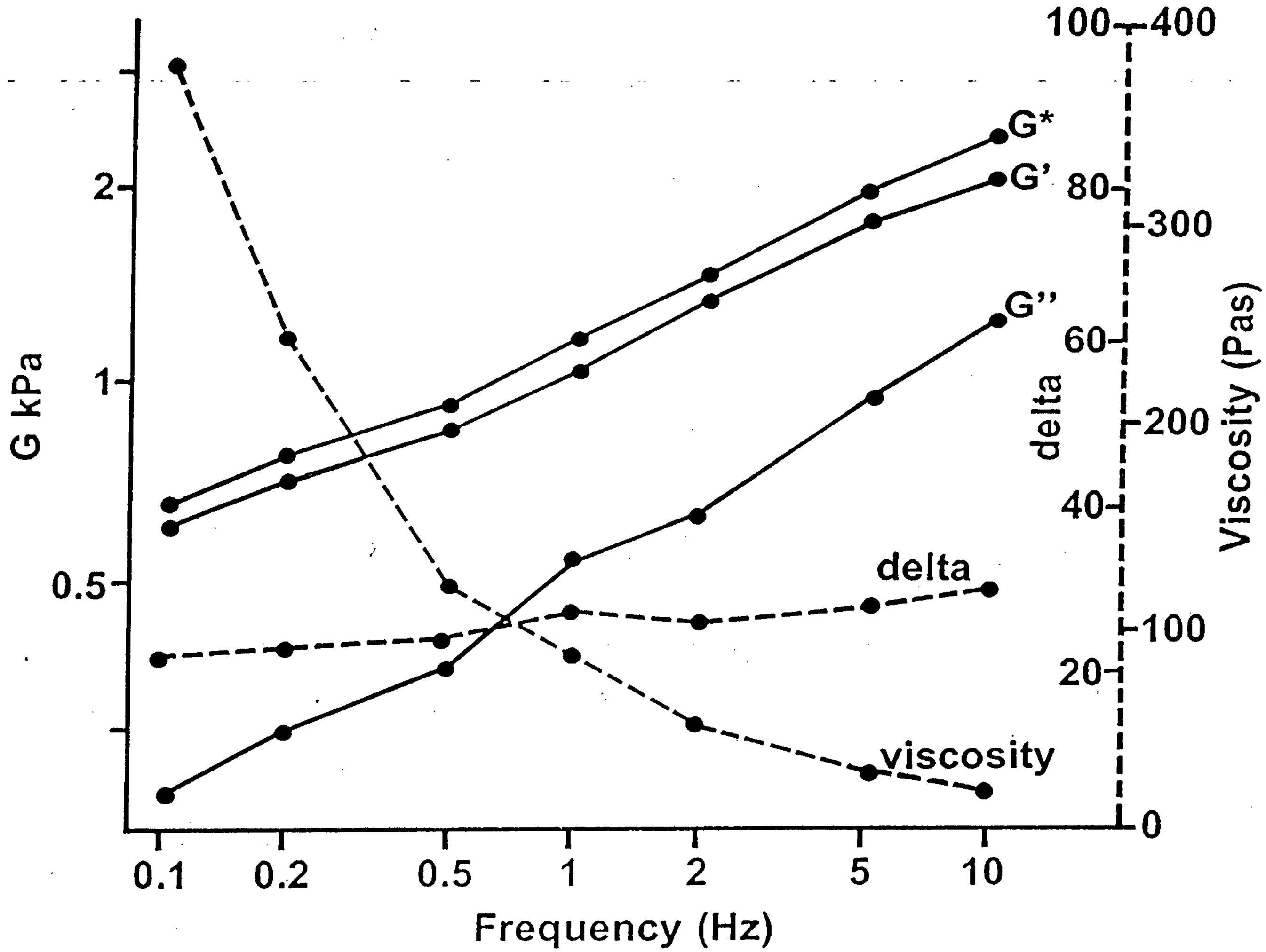

Fig. A4-1: Bohlin Rheometer System oscillation test

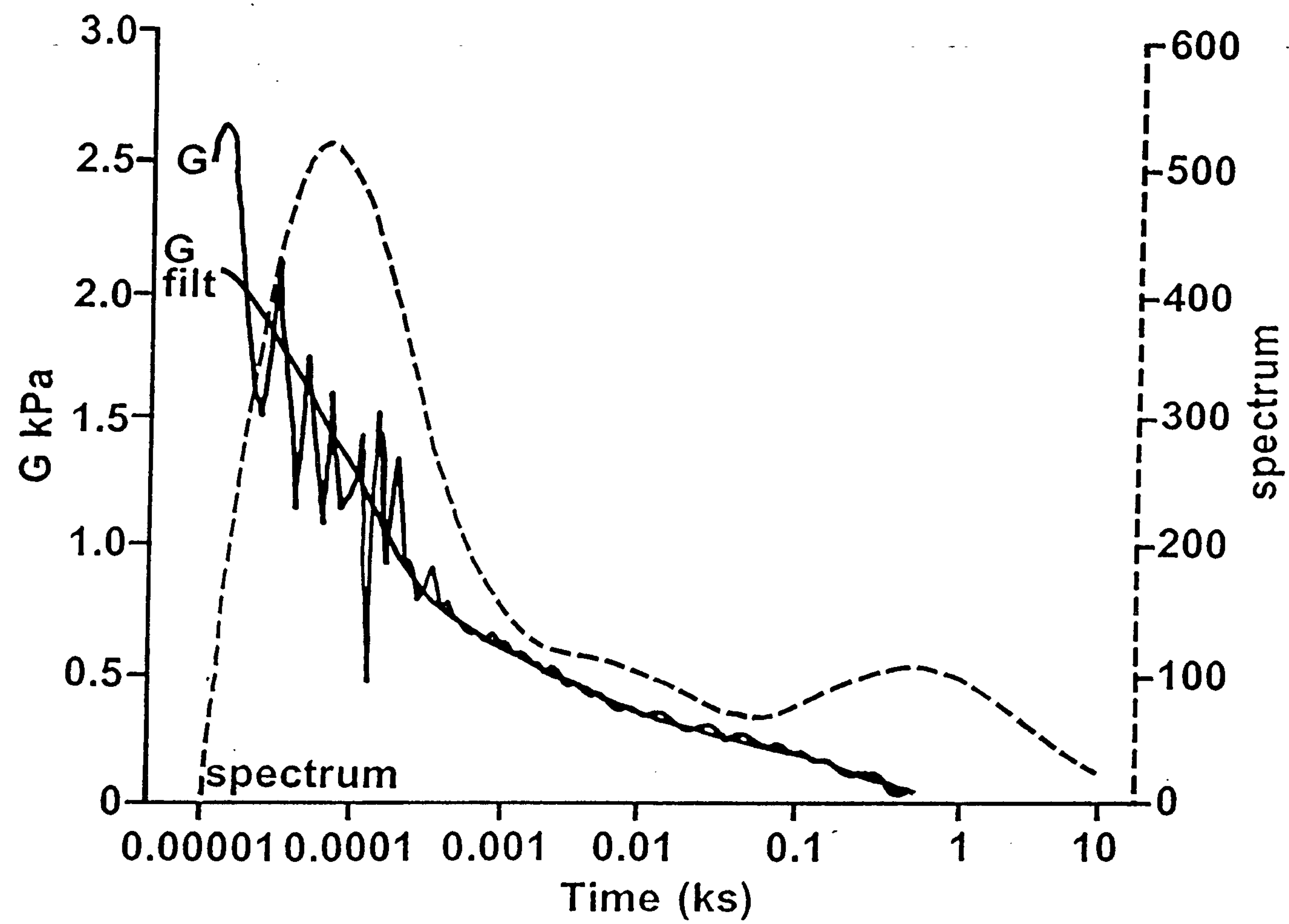

Fig. A4-2: Bohlin Rheometer System relaxation test