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THE BREADMAKING QUALITY OF PASTICHE

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by

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Final report of a five month project which commenced in November 1990. The work was carried out by the Flour Milling and Baking Research Association and was supported by a grant of £23,600 from the Home-Grown Cereals Authority (Project No: 0014/1/90).

CONTENTS

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Final report on a project of duration 0.4 year commencing 1 November 1990

ABSTRACT

Pastiche was provisionally recommended by the Cereal Trials Advisory Committee as a hard milling, breadmaking wheat in 1989 and became available in commercial quantities in 1990. By September 1990, the major UK milling companies had rejected Pastiche for breadmaking purposes on the basis of their assessments of commercially-grown samples. An investigation was therefore carried out to discover why a variety which had been provisionally recommended as a breadmaking wheat was found to be unsuitable for that purpose when grown in commercial quantities.

During the first three years of trialling, the performance of Pastiche was assessed against Avalon as the control variety. From the 1989 harvest, Mercia was adopted as the new control for winter breadmaking wheat and was therefore the variety against which Pastiche was judged on commercially-grown wheat.

The results obtained in this project with commercially-grown wheats supported the assessments made on trial assessments using the same testing procedures. Based on the use of potassium bromate as a flour treatment agent, on average Pastiche performed better than Mercia in a three hour Bulk Fermentation Process (BFP) and similar to Mercia in the Chorleywood Bread Process (CBP). Using the CBP with ascorbic acid as the sole flour treatment agent, which was adopted following the withdrawal of clearance for use of potassium bromate as a flour treatment agent in the UK in April 1990, commercially-grown samples of Pastiche were found on average to be poorer than those of Mercia but, in contrast, there was no difference in the average breadmaking performance of Pastiche and Mercia with the 1990 RL samples. Accordingly, the difference in the comparative assessment of Pastiche and Mercia would appear to be due to differences in the properties of commercial

and trial samples.

The commercial samples in this study were selected to cover as wide a range of protein contents as possible in order to examine the relationship between loaf volume and flour protein content. Irrespective of the milling and baking procedure used, when individual loaf volumes of the Pastiche samples were plotted against protein content, there was no significant response of loaf volume to increasing protein content and the variation in loaf volume appeared to be greater at higher levels of protein. With Mercia, on the other hand, there is a consistent increase in loaf volume with additional protein content. Since the samples of Avalon, Mercia and Pastiche grown in National and Recommended List trials from 1986 to 1990 were generally of much lower protein content than would be considered by millers to be suitable for inclusion in breadmaking grists, extrapolation of the trial assessments to commercial practice was misleading. This finding would account for the reported difference in the breadmaking performance of Pastiche as assessed on trial and on commercially-grown samples. It is therefore imperative for successful evaluation of breadmaking quality of new wheat varieties that trialling procedures are designed and carried out to reflect, as far as possible, commercial husbandry practice for the production of breadmaking wheat with a minimum protein content of 11% at 14% moisture content and that samples of potential breadmaking varieties which are unsuitable in this respect are not assessed.

Overall, the results of this study confirm the milling industry's reservations about the breadmaking quality of Pastiche and demonstrate that the different assessments obtained between trialling and commercial practice were due to the generally low protein contents of the trial samples which did not enable the lack of response of breadmaking performance to additional protein content in this variety to be identified. These findings are unaffected by the testing procedures used.

Further work is needed to explain the lack of response of breadmaking performance of wheat varieties to additional protein content using Pastiche as an example and to establish the relationships between loaf volume and flour protein content for new breadmaking varieties.

OBJECTIVE

Establish the cause of reported variation in the breadmaking performance of Pastiche as assessed in Recommended List trials and by the milling industry on commercially-grown samples.

INTRODUCTION

The UK has a well established trialling system for the evaluation of new varieties of wheat (Fiddian, 1979). The Plant Varieties and Seeds Act 1964 as amended by the European Communities Act 1972 and its subordinate legislation provides for the official testing of new plant varieties, the National List (NL) trials in which wheat varieties spend two years on trial (NL1 and NL2), to ensure that basic levels of achievement can be met before varieties can be marketed. However, NL trials do not provide a comprehensive assessment of the performance of a variety but rather function as a first sift of the large number of varieties entering the official testing system. Therefore, a voluntary, non-statutory Recommended List operates alongside the NL in order to identify through more extensive trials, usually three years before a variety is fully recommended, those varieties with outstanding performance across regions. Varieties are not considered for inclusion in RL trials until both NL1 and NL2 assessments are available. Each variety then undergoes one year of RL trials before consideration for provisional recommendation and a further two years before consideration for full recommendation. Together, the NL and RL trials form an integrated system which provides the information needed to compare the relative merits of different varieties in terms of value for cultivation and use.

As part of the assessment of value for cultivation and use in both the NL and RL trials, samples of wheat grown in the trials by the National Institute of Agricultural Botany (NIAB) are tested at FMBRA for milling and baking quality. Greatest emphasis is given to breadmaking quality since this represents the most important end-use requirement for flour. The work forms the basis for the official assessment considered by the NIAB's Cereal Trials Advisory Committee.

Pastiche was provisionally recommended by the Cereal Trials Advisory Committee as a hard milling, breadmaking wheat in 1989 and become available in commercial quantities in 1990. By September 1990, the major UK milling companies had rejected Pastiche for breadmaking purposes (Anon., 1990) on the basis of their assessments of commercially-grown samples and it was subsequently transferred to the "becoming outclassed" category for the 1991 Recommended List (it should be noted, however, that Pastiche was becoming outclassed in terms of its agronomic performance, specifically its disappointing yield in the 1990 trials). An investigation was therefore carried out to discover why a variety which had been provisionally recommended as a breadmaking wheat was found to be unsuitable for that purpose when grown in commercial quantities.

MATERIALS AND METHODS

Samples

Commercially-grown samples of Pastiche and Mercia (as a control) from the 1990 harvest covering as wide a range of growing areas and protein contents as possible were obtained from merchants and millers. One sample of Mercia was obtained from the ADAS secondary trial at Reading since it did not prove possible to find a commercially-grown sample with the required protein content of c. 14%.

The varietal purity of each sample was confirmed by polyacrylamide gel electrophoresis of 25 grains (Salmon, 1985; Salmon and Burbridge, 1985) and the level of heat damage estimated from the gliadin electrophoretic patterns produced. Protein content was determined by NIR using an Oxford QN 1000 (Osborne and Barrett, 1989) and Falling Number (ICC Standard No. 107) and SDS sedimentation volume (BS 4317 part 19) were measured.

A total of thirteen samples of Pastiche and six of Mercia were subjected to quality assessment.

Laboratory milling

Wheat samples were milled to provide white flour for quality testing. Samples were checked to ensure that moisture contents were below 14.5% then stored at ambient temperature and humidity prior to cleaning. Cleaning was carried out using a Carter-Day Dockage Tester then cleaned wheat was conditioned to 15.5% moisture content. Water was added to aliquots of the samples in plastic pots and dispersed throughout the sample by shaking. Conditioning was carried out in the late afternoon before milling so that samples received a lying time of between 16 and

23 hours.

Cleaned, conditioned wheat was milled in a Buhler MLU 202 laboratory mill at a feed rate of approximately 7 kg/hr and a Buhler MLU 302 laboratory impact finisher was used to re-treat the bran and offals twice (Robinson and Stewart, 1980). The straight run and finisher flours were blended for 15 min in a KEK-Gardner double cone mixer (8LD C/2) and passed through a Russell-Finex 14550 redresser fitted with 300μm screen. Milling was carried out at a controlled temperature of 20^{O}C and a relative humidity of 60% (Hook et al, 1984). Extraction rate was calculated on a total product basis, with the requirement that 98.5% of the feed was recovered from the mill. Prior to milling, the roll gap settings were calibrated by use of a feeler gauge. Two sets of milling conditions were employed on different mills:

1. The mill settings for the first and third break rolls were 1.0 and 0.7 mm respectively while the first and third reduction roll gaps were 0.7 and 0.3 mm respectively. These roll gap settings and the sifter cloth sizes employed are such that the flour produced meets the requirements of EC Regulation No 1628/77 (Gundelach, 1977).

2. The mill settings for the first and third break rolls were 0.6 and 0.4 mm respectively while the first and third reduction roll gaps were 0.3 and 0.2 mm respectively. The scalpers from the first and second reduction roll sifters were removed. These conditions were chosen so that extraction rates in excess of 79% and starch damage values of 35-40 Farrand units could be achieved when milling commercially-grown Mercia samples.

One control sample of a given protein content was milled with a number of Pastiche samples of protein contents as close as possible to that of the control. Millings were performed in batches of four or five over five days and where possible each control and its corresponding Pastiche samples were milled on the same day. Both millings (1 and 2) were carried out on the same day and with the same order of samples.

Measurement of flour properties

The flour obtained from laboratory milling 1 was assessed using the methods described by Draper and Stewart (1980) for Grade Colour, water absorption, dough extensibility and resistance as well as starch damage content (Farrand, 1964), Falling Number (ICC Standard No. 107) and protein and moisture contents by NIR using an Oxford QN 1000 (Osborne and Barrett, 1989).

For laboratory milling 2, in place of the Simon Research extrusion meter and Extensometer, water absorption, development time, degree of softening and stability were measured using a Brabender Farinograph (ICC Standard No. 115 but measured to the 600 BU line) and dough extensibility and resistance measured using a Brabender Extensograph (ICC Standard No. 114).

All flours were tested for gel protein content according to the following procedure (Graveland et al, 1979): 10g of flour was de-fatted with 25ml petroleum ether (b.p. 40-60°C) for 1 hour, filtered and dried. 5g defatted flour was stirred with 90ml of 1.5% sodium dodecyl sulphate (SDS) for 10 min at 10°C then centrifuged at 25000 rpm for 40 min. The gel protein was then weighed.

Response of the gel protein to mixing was assessed as follows: 50g flour was mixed with 0.9g sodium chloride and water (in accordance with water absorption determined previously) for 3 min. Aliquots were removed at 1, 2 and 3 min and frozen immediately after removal. Flour aliquots were freeze-dried and ground to a powder so that samples passed through a 250μm sieve, then defatted and gel protein determined as described above. The logarithm of gel protein weight was plotted against mixing time to obtain the rate of breakdown of gel protein during mixing.

All flours were examined for glutenin subunit composition by SDS gradient polyacrylamide gel electrophoresis (Laemmli, 1970).

Laboratory baking tests

A. 3 hour Bulk Fermentation Process (BFP) 400g loaves

Recipe

	% on flour weight	g/mix
Flour	100	280
Yeast	2.0	5.6
Salt	2.0	5.6
Sucrose	2.0	5.6
Water	As determined by Simon Extrusion Meter (1 hour method)	
Potassium bromate	variable	

Potassium bromate levels were varied according to the extensibility recorded during the Extensometer testing of the dough (Draper and Stewart, 1980).

Dough Processing

Mixing machine	:	Hobart peg mixer, 2 min
Dough temperature	:	27 ± 1°C
First moulding	:	Mono bench moulder (settings 18,2) after 2hr fermentation to knock back
Final moulding	:	Mono bench moulder (settings 18,2) after 2h 55min fermentation, rest 5 min and remould at same settings
Proving conditions	:	50 min at 32°C, 85% RH
Tin size	:	Top 150mm x 100mm x 68mm deep
Baking temperature	:	218°C
Baking time	:	32 min, with added steam
Oven type	:	Simon Reel (Electric)
Cooling	:	On wire racks at room temperature and stored in a cupboard overnight

The loaves were assessed on the day after baking for the following properties:

(a) **Volume:** Measurements were made by displacement of rape seed (Cornford, 1969) and the measured volume in ml was converted to a numerical score by means of a scale:

≤ 1050ml	-	0
1051 - 1100	-	1
1101 - 1150	-	2
		etc.

(b) **External appearance:** Observations were made of general appearance and crust colour. A good loaf should have an attractive golden brown crust, a smooth oven-break, a matt surface to the sides of the loaf and rounded corners. The loaf was marked down for sharp corners, a glassy surface to the sides, and a "slatey" torn crust. A score was awarded out of ten.

(c) **Crumb texture:** The crumb texture of the surface exposed by cutting the loaf was assessed with the fingers. The surface should be silky and refrain from crumbling. The texture should be such that "buttering" the crumb would cause no problems. A score was given out of ten.

(d) **Crumb cell structure:** The crumb cell structure should be fine and even. The crumb should be fully aerated; solid areas of bread are undesirable. The individual cells should be thin-walled and elliptical in shape rather than honey-combed. Again a score out of ten was given.

(e) **Crumb resilience:** This was assessed by pressing the cut surface of the loaf with the fingers. Ideally the crumb should be soft, but resilient. Solid, dense crumbs and soft crumbs lacking resilience were down-graded. A score out of ten was awarded.

The loaf score is the sum of the scores awarded for (a) - (e) inclusive.

B. Chorleywood Bread Process (CBP) 400g loaves

Recipe

	% on flour weight	g/mix
Flour	100	300
Yeast	2.1	6.2
Salt	1.8	5.4
Fat (Ambrex, slip point c. 45°C)	0.7	2.1
Water	As determined by Simon Extrusion Meter, 10 min method	
Potassium bromate	0.0045	0.0135
Ascorbic acid	0.0030	0.009

Both ascorbic acid and potassium bromate were added separately as solutions (5ml of aqueous solutions containing 0.675g potassium bromate and 0.45g ascorbic acid respectively)

Dough processing

Mixing machine	:	Speeded-up Farinograph operating at 140 rpm
Work input	:	11 Wh/kg
Dough temperature	:	30 ± 1°C
Scaling	:	By hand to 454g
First moulding	:	Mono bench moulder, settings (18, 2)
First proof	:	10 min under cover at 27°C
Final moulding	:	Mono bench moulder, settings (18,2)
Tin size	:	Top 160mm x 98mm x 83mm deep
Proving conditions	:	43°C with humidity to prevent skinning
Proving height	:	10cm
Baking temperature	:	230°C with added steam
Baking time	:	25 min
Oven type	:	Simon Reel (electric)
Cooling	:	On wire racks and stored in a cupboard overnight

C. Chorleywood Bread Process (CBP) 400g loaves

Recipe

	% of flour weight	g/mix
Flour	100	300
Yeast	2.5	7.5
Salt	2.0	6.0
Fat (Ambrex, slip point c. 45°C)	1.0	3.0
Ascorbic acid (100ppm)	0.01	0.03
Water	As determined by Simon Extrusion Meter, 10 min method	

Ascorbic acid was added as a solution (10ml of an aqueous solution containing 0.75g/250ml of water)

Dough Processing:

Mixing machine	:	Speeded-up Farinograph operating at 140rpm
Work input	:	11Wh/kg
Dough temperature	:	30 +/- 1°C
Scaling	:	by hand to 454g
First moulding	:	Mono bench moulder, settings (18, 2)
First proof	:	10 min under cover at 27°C
Final moulding	:	Mono bench moulder, settings (18,2)
Tin size	:	Top 160 x 98 x 83 mm deep
Proving conditions	:	43°C with humidity to prevent skinning
Proving height	:	10cm
Baking temperature	:	230°C with added steam
Baking time	:	25 min
Oven type	:	Simon reel (electric)
Cooling	:	on wire racks and stored in a cupboard overnight

D. Chorleywood Bread Process (CBP) 400g loaves

Recipe

	% of flour weight	g/mix
Flour	100	840
Yeast	2.5	21
Salt	2.0	16.8
Fat (Ambrex, slip point c. 45°C)	1.0	8.4
Ascorbic acid (100ppm)	0.01	0.084
Water	As determined by Farinograph	

Ascorbic acid was added as a solution (10ml of an aqueous solution containing 2.1g/250ml of water).

The level of cereal *alpha*-amylase activity in the flour was estimated from the flour Falling Number value then the *alpha*-amylase activity of the flour was adjusted to 80 Farrand units by the addition of fungal *alpha*-amylase.

Dough Processing:

Mixing machine	:	Morton mixer, 30 sec slow speed, scrape down then remainder fast speed
Work input	:	11Wh/kg
Dough temperature	:	30 +/- 1^{o}C
Scaling	:	by hand to 454g
First moulding	:	Mono bench moulder, settings (18, 2)
First proof	:	10 min under cover at 27^{o}C
Final moulding	:	Mono bench moulder, settings (18, 2)
Tin size	:	Top 160 x 98 x 83 mm deep
Proving conditions	:	43^{o}C with humidity to prevent skinning
Proving height	:	10cm
Baking temperature	:	230^{o}C with added steam
Baking time	:	25 min
Oven type	:	Simon reel (electric)
Cooling	:	on wire racks and stored in a cupboard overnight

Loaves from each of the CBP baking tests were assessed on the day after baking for volume by the displacement of seed (Cornford, 1969) and ranked for outside appearance and crumb structure.

Flours from milling 1 were baked according to procedure A, B and C; flours from milling 2 were baked according to procedures C and D.

RESULTS

The results of assessments of the breadmaking quality of commercially-grown Pastiche and Mercia samples (1990 harvest) are given in Tables A1-A9, Appendix A. The means and standard deviations (in brackets) of the results averaged over all samples within each variety are given in Tables 1-4. For Pastiche, sample 2 was found to be severely affected by heat damage and has been omitted from the analysis of the results. Least significant differences (LSD) are also given to assess the statistical significance of the differences between means. Any pair of means is significantly different ($p<0.05$) if they differ by more than this figure.

Table 1. Summary of wheat characteristics

Variable	Pastiche	Mercia	LSD
SDS Volume (ml)	75.75 (9.14)	60.33 (2.87)	8.22
Falling No. (sec)	464.58 (23.50)	407.68 (14.05)	44.54

Table 2. Summary of the results of laboratory milling

Variable	Milling 1			Milling 2		
	Pastiche	Mercia	LSD	Pastiche	Mercia	LSD
Extraction rate (%)	76.47 (1.101)	76.38 (1.508)	1.32	79.77 (0.728)	79.67 (1.229)	0.97
GCF	-1.71 (0.376)	-0.90 (0.501)	0.44	-0.05 (0.614)	0.59 (0.656)	0.66
Starch Damage (FU)	22.5 (2.11)	26.0 (2.53)	2.4	30.4 (2.27)	36.7 (3.14)	2.7
Water Abs. % as is	57.52 (1.105)	56.68 (1.434)	1.29	62.11 (1.840)	59.83 (1.972)	1.99

Table 3. Mean and range data for gel protein determinations

	g per 5g flour or freeze-dried dough			
	Pastiche		Mercia	
	Mean	Range	Mean	Range
Flour	12.00	8.28 - 14.85	8.57	7.33 - 9.95
After mixing for:				
1 min	3.42	1.90 - 6.18	5.29	4.02 - 6.97
2 min	0.77	0.42 - 1.24	2.27	1.08 - 4.13
3 min	0.48	0.20 - 0.83	1.25	0.39 - 2.21

Table 4. Summary of the results of laboratory baking expressed as loaf volumes (ml)

Baking Process	Milling 1 Pastiche	Milling 1 Mercia	LSD	Milling 2 Pastiche	Milling 2 Mercia	LSD
A	1380.8 (67.38)	1292.5 (68.03)	71.6			
B	1359.2 (69.47)	1408.3 (58.54)	70.2			
C	1357.9 (41.53)	1469.2 (33.83)	41.6	1306.7 (33.93)	1382.5 (31.42)	35.2
D				1471.7 (42.18)	1500.0 (55.50)	49.5

N.B. The volumes cannot be directly compared between baking processes because of differences in scaling weights.

Characteristics of samples received

10kg samples of Pastiche were collected from a number of merchants and millers. The varietal purity, indication of heat damage, protein content, Falling Number and SDS sedimentation volume of the 13 samples used for quality assessment are given in Table A1. Since Mercia is the current control winter wheat breadmaking variety in RL trials, samples of this were also collected and the characteristics of these are given in Table A2. A summary of the Falling Number and SDS sedimentation volumes is given in Table 1. A further four samples of Pastiche and two of Mercia were received but not used because of varietal impurity since it was imperative for the success of this project that only pure samples were assessed for breadmaking quality.

Laboratory milling

The extraction rate, Grade Colour (GCF), flour protein and starch damage content from both millings are given in Table A3 in order of increasing flour protein content under milling regime 1. A summary of the extraction rate, GCF, starch damage and water absorption results is given in Table 2.

Flour properties

The measured flour properties from millings 1 and 2 are given in Tables A4 and A5. The gel protein contents of the flour, and the amounts remaining after 1, 2 and 3 min mixing are listed in Tables A4 and A5. The product of flour quantity and amount remaining after 1 min mixing is also presented as a measure of both the quantity and quality of the glutenin fraction of the protein in these flour samples. Mean and range data (Table 3) show the different responses of the two wheat varieties and the semi-log plots of gel protein against mixing time (Fig. 1) demonstrate the rates of breakdown of gel protein of the two varieties during mixing.

Laemmli gels were scanned using a Joyce Loebl Chromoscan 3 scanning densitometer. A scan for each of the two varieties is shown in Figure 2. The HMW glutenin subunits are marked, and the relative percentages of them are listed for each flour sample in Tables A6 and A7.

Laboratory baking tests

The assessments of loaves produced from laboratory baking tests are given in tables A8 and A9. A summary of the results for volume is given in Table 4.

DISCUSSION

The trialling system is designed to compare the relative merits of different varieties across growing sites and seasons. Varieties are only added to the NIAB Recommended List if their performance is as good as, or better than that of the best comparable variety already listed. Pastiche was considered for provisional recommendation in November 1988 following the standard three years of trialling in which it was compared with the then winter breadmaking wheat control, Avalon. Since there was no significant difference between Avalon and Pastiche in either BFP score or CBP volume averaged over the three years 1986-88, Pastiche was awarded the same breadmaking score as Avalon and given provisional recommendation in January 1989. The basis for comparison was changed from the 1989 harvest when Mercia was adopted as the control winter breadmaking wheat variety. Mercia was therefore the variety against which Pastiche was judged when it was grown in commercial quantities.

A re-examination of the trial data for the years 1988-90 when Pastiche and Mercia were grown in the same trials (Appendix B) was carried out to compare the breadmaking performance of these two varieties. Pastiche gave a significantly higher average BFP score compared to Mercia but the comparison of CBP volumes depended upon the harvest year. The volumes for Pastiche were fairly consistent from year to year while those for Mercia were considerably more variable. This would appear to be due to the protein contents of the Mercia samples which were particularly low in 1988 and 1990. In both these years, the average volumes for Mercia were not significantly higher than those for Pastiche. In 1989, on the other hand, where flour protein contents greater than 10.5% were generally attained, the average loaf volume was significantly greater for Mercia than for Pastiche. This was apparently due to a lack of response of loaf volume to additional protein content in the case of Pastiche samples grown at the two sites (Bridgets and Seale Hayne) with the highest average protein contents; the comparison of the breadmaking quality of Pastiche and Mercia is therefore dependent upon the protein contents of the samples.

In order to determine whether the test methods for laboratory milling and baking employed by FMBRA for the evaluation of trial samples and by milling company laboratories for the assessment of commercially-grown wheat samples may have affected the assessments of varieties, two milling regimes and four baking procedures were carried out on the commercially-grown Pastiche and Mercia samples examined in this project. Milling regime 1 is that used for assessment of trial samples since 1980 and meets the requirements of testing wheat offered into Intervention. However, company laboratories prefer to employ conditions, as in milling regime 2, which result in the production of flour with properties closer to those of commercially-milled CBP bread flour. It must be stressed, however, that the Buhler laboratory mill MLU 202 used by FMBRA and by company laboratories is a fixed milling system designed to compare the milling performance of wheat samples and that a laboratory mill and a commercial mill cannot be expected to produce identical flour from the same grist.

For many years, trial assessments have been based on a 3 hour BFP baking test (procedure A) in which the level of potassium bromate in the recipe was adjusted according to the measured dough extensibility and resistance so as to counteract the wide range of protein contents and qualities encountered in the examination of trial samples (Draper and Stewart, 1980). The sucrose was added to overcome the deficiency of sugar arising from low damaged starch levels in flours from variety trials as compared to commercial flours. The view that the BFP test afforded better discrimination between varieties than CBP is generally supported by trialling data up to 1989. However, since most commercial bread in the UK is baked by the CBP, a CBP baking test (procedure B) has also been carried out as part of the assessment of trial samples. Due to the lack of discrimination, CBP loaves were not scored in the same way as BFP loaves and a ranking on outside appearance and crumb structure was carried out instead. In response to the withdrawal in April 1990 of clearance for use in the UK of potassium bromate as a flour treatment agent, the recipe for the CBP baking test was changed in that year to one based on the use of ascorbic acid as the sole flour treatment agent (procedure C). For this project, the CBP baking test was also scaled up to enable a mixing machine more similar to those found in commercial bakeries to be used (procedure D).

Thirteen samples of commercially-grown Pastiche and six of Mercia were compared using the two different milling regimes and four different baking procedures but due to restricted amounts of samples, not all baking procedures were applied to flours from both milling regimes. To allow a comparison to be made with historical trial data, milling regime 1 was used in conjunction with those baking procedures which had been used in the assessment of trial samples, i.e., A, B and C. Milling regime 2 was only applied to the two alternative CBP procedures based on ascorbic acid as the sole flour treatment agent since those employing potassium bromate are no longer applicable. Assessments were based on loaf volume (the only objective measure of breadmaking quality made).

The Pastiche samples had a significantly higher average SDS sedimentation volume than the Mercia samples (Table 1). The inference that the breadmaking quality of Pastiche is better than that of Mercia is borne out with flours from milling regime 1, including potassium bromate, where Pastiche gave a significantly higher average loaf volume than Mercia in a 3 hour BFP (procedure A). On the other hand, in the CBP with added potassium bromate and ascorbic acid (procedure B) there was no significant difference in the average loaf volume between the two varieties. These results with commercially-grown wheats therefore support the assessments made on trial samples using the same test methods. However, Pastiche was found to give a significantly lower average loaf volume than Mercia using the CBP with ascorbic acid as the sole flour treatment agent (procedure C) but there was no significant difference in the average loaf volume obtained from the Pastiche and Mercia samples in the CBP when a different mixing machine was used and the levels of alpha-amylase in the flours were raised to a constant level by the addition of fungal alpha-amylase (procedure D). The relevant findings also hold with flours from milling regime 2. In contrast to the present results, there was no significant difference in the average loaf volume produced using baking procedure C between Pastiche and Mercia samples in the 1990 RL trial (Appendix B). Accordingly, the difference in the comparative assessment of Pastiche and Mercia would appear to be due to differences in the properties of commercial and trial samples.

The commercial samples in the present study were selected to cover as wide a range of protein contents as possible in order to examine the relationship between loaf volume and flour protein content. Irrespective of the milling and baking procedure used, when individual loaf volumes of the Pastiche samples are plotted against flour protein content no significant response of loaf volume to increasing protein content is found (Figs 3-5), although there appears to be a slight non-linear relationship between the two variables. This is in contrast to the significant relationship observed for Mercia between loaf volume and flour protein content (Salmon et al, 1990) and significant linear increases with increasing protein content in overall breadmaking quality (as judged by a combination of volume, outside appearance, crumb texture, crumb cell structure and crumb resilience) of other varieties reported by Kent (1983). Non-linear relationships between flour protein content and breadmaking performance have, however, been observed with some French breadmaking wheats (Fischer, 1988). Since the samples of Avalon, Mercia and Pastiche grown in National and Recommended List trials from 1986 to 1990 were generally of much lower protein content than would be considered by millers to be suitable for inclusion in breadmaking grists, extrapolation of the trial assessments samples to commercial practice was misleading. This finding accounts for the difference in the breadmaking performance of Pastiche as assessed on trial and on commercially-grown samples. It is therefore imperative for successful evaluation of breadmaking quality of new wheat varieties that trialling procedures are designed and carried out to reflect as far as possible commercial husbandry practice for the production of breadmaking wheat with a minimum protein content of 11.0% (leading to a minimum flour protein content of 10.5%) and that samples of potential breadmaking varieties which are unsuitable in this respect are not assessed.

In addition to the lack of response of loaf volume to protein content, the variation in loaf volume for Pastiche samples appeared to be greater at higher levels of protein particularly with baking procedures A and B (Figs 4 and 5). It must be pointed out, however, that as in the assessment of trial samples only a single loaf per baking procedure was baked from each sample. This was because of limited quantities of samples. It is not therefore possible to determine how much of the observed variation is due to sampling and measurement error. Nevertheless, these results would suggest that account should be taken of variability in addition to average performance of varieties undergoing trialling. This would require the testing of replicate samples leading to increased costs.

A detailed study of the flour and dough properties of Pastiche and Mercia was carried out in an attempt to find an explanation for the observed differences in breadmaking performance between the two varieties. With both milling regimes, there was no significant difference in the average extraction rate for Pastiche and Mercia but the Pastiche samples had lower GCF values than the Mercia samples (Table 2). Milling regime 2 resulted in higher extraction rates and flour starch damage contents than milling regime 1 and this was reflected in a lower average CBP loaf volume for both varieties using baking procedure C (the only procedure common to both millings). Pastiche had a lower average loaf volume than Mercia in baking procedure C but the Falling Number results (Table 1) reveal that Pastiche samples were deficient in alpha-amylase so might have been at a disadvantage in a recipe with no added sucrose or fungal alpha-amylase. For this series of tests, when fungal alpha-amylase is added in procedure D, the Pastiche samples responded more strongly on average to this than the Mercia samples and there was then no significant difference in the average loaf volume compared with Mercia. Individual Pastiche samples with similar Falling Number values (e.g. 8 and 10), however, varied in their response to the fungal alpha-amylase while those with the lowest and highest Falling Number (4 and 9) responded equally.

If the Farinograph water absorption values are compared with those calculated by the Farrand equation (Farrand, 1969), the results are very similar for Pastiche (average difference between observed and calculated 0.15%) while for Mercia the observed increase in starch damage under identical milling conditions did not lead to the expected increase in water absorption (average difference between observed and calculated 3.9%). This means that higher levels of starch damage could be imparted during the milling of Mercia compared to Pastiche without causing a deleterious effect on breadmaking performance. Other features of the Farinograph curves do not identify any difference between or within the Pastiche and Mercia samples. The differences in results between samples for development time, stability and degree of softening are all within experimental error.

Both the Simon Extensometer and the Brabender Extensograph show that Pastiche samples tend to be more extensible and less resistant than Mercia samples. Furthermore, contrary to expectations, the extensibility of the Pastiche samples generally increases with increasing protein content although no consistent relationship between high extensibility and low loaf volume is apparent.

The unique ability of wheat flour to form a visco-elastic dough when mixed with water is that character of wheat that has allowed its exploitation for breadmaking. The wheat protein called gluten is principally composed of two components gliadin and glutenin, of which the glutenin fraction is the elastic component. The nature of the glutenin is therefore very important in the development of bread doughs and in the assessment of baking quality. The glutenin fraction of wheat protein consists of a number of sub-units, including the so-called high molecular weight (HMW) subunits. When flour or dried dough are extracted in the cold with SDS and centrifuged, a gel layer is observed. This layer, named gel protein or glutenin I by Graveland et al (1979), is variety dependent in terms of both quantity and quality (as judged by the rate of depolymerisation during mixing). The variety influence is strongly related to the HMW glutenin subunit composition (Payne et al 1987), and recent studies at Chorleywood (Brock and Pritchard, unpublished) have shown that the rate of depolymerisation of glutenin is influenced by the subunit composition. In particular the presence of subunit 5 + 10 in Mercia imparts a resistance to depolymerisation that is clearly demonstrated in Figure 1. However,with the exception of three Pastiche samples, the actual level of glutenins as measured by gel protein content in Pastiche is higher than in Mercia, which would imply improved baking quality, were it not for the weaker nature of the glutenin aggregates made up from subunits 7 + 8 and 4 + 12. It must be concluded, that in mixing regimes, where energy is supplied at a rapid rate, as in the CBP, there is a risk that for varieties such as Pastiche, the glutenin is unable to withstand the rate of energy input. In a less rigorous mixing regime, such as in the BFP, the glutenin fraction is allowed to achieve its full potential with improved baking quality.

The Laemmli SDS-PAGE assessment of the varieties (Figure 2) was carried out to investigate if any inconsistencies were apparent between Pastiche samples to account for the alleged variability of the variety. Proteins are made soluble in an SDS solution which also gives the proteins an overall strong negative charge. With reduction by dithiothreitol all the inter and intra-molecular disulphide bonds are cleaved. This straight chained form of the protein is then made to pass through the pores in the polyacrylamide gel by applying an external potential difference. The pore size which is dependent on the acrylamide concentration thus dictates the rate of flow of any given sized protein through the gel and so the proteins in the sample are resolved into their sizes with the smallest travelling the furthest distance through the gel. This then enables the different glutenin subunit composition to be clearly observed, giving not only the type(s) of subunit(s) present but with the aid of a scanning densitometer a measure of the quantity can also be obtained.

The data in Tables A6 and A7 in general show little difference between the samples with the exception of subunit 7 in samples milled from Pastiche sample number 2. Other evidence, including that of low gel protein figures, and low CBP loaf volumes confirms heat damage. The relative percentage of subunits 7 and 12 were clearly higher in these two samples than in other samples. The importance of this observation is as yet unknown and could be an artefact of the form or origin of the heat damage.

Further work on the protein biochemistry of Pastiche will be needed in order to arrive at a more complete explanation of its variable breadmaking quality.

CONCLUSIONS

1. The breadmaking performance of Pastiche samples does not increase significantly with increasing flour protein content and the variation in performance appears to be greater at higher levels of protein. On this basis Pastiche is of inferior breadmaking quality to Mercia at wheat protein contents at or above those which would be considered by millers to be suitable for inclusion in breadmaking grists. Since the samples of Pastiche, Avalon and Mercia grown in NL and RL trials from 1986 to 1990 were generally of much lower protein content, this effect was not detected.

2. The findings given in 1 above are unaffected by the testing procedures used.

3. The glutenin content is higher in Pastiche than in Mercia, which would imply that the breadmaking quality of Pastiche is superior to that of Mercia. However, the composition of the glutenin in Pastiche suggests that its glutenin aggregates are weaker and this is borne out by the more rapid depolymerisation during dough mixing in Pastiche flours compared to Mercia.

RECOMMENDATIONS

1. Trialling procedures for wheat must reflect, as far as possible, commercial husbandry practice for the production of breadmaking wheat with a minimum protein content of 11.0%.

2. It would be desirable to test replicate samples in order to assess variability in quality.

3. Further work is needed to explain the lack of response of breadmaking

performance of wheat varieties to additional protein content using Pastiche as an example of this behaviour and to establish the relationships between loaf volume and flour protein content for new breadmaking varieties.

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Appendix A

Assessments of the breadmaking quality of commercially-grown Pastiche and Mercia samples, 1990 harvest.

Table A1. Characteristics of Pastiche wheat samples

Lab No.	Varieties Present (no. of grains)	Heat Damage	Protein Content % @ 14%mb	Falling No. (sec)	SDS Volume (ml)
Past/1	Pastiche (25)	Yes, Slight in 1/25	12.6	492	71
Past/2	Pastiche (25)	Yes, Slight in 11/25	12.5	557	56
Past/4	Pastiche (25)	Yes, Slight in 2/25	13.4	450	69
Past/5	Pastiche (25)	Yes, Slight in 2/25	10.6	450	73
Past/6	Pastiche (25)	Yes, Slight in 2/25	12.0	494	73
Past/7	Pastiche (25)	No	10.3	448	64
Past/8	Pastiche (25)	No	12.6	480	71
Past/9	Pastiche (25)	No	11.3	458	73
Past/10	Pastiche (25)	No	13.0	429	71
Past/11	Pastiche (25)	Yes, Slight in 1/25	12.5	444	90
Past/12	Pastiche (24) Mercia (1)	No	13.0	471	73
Past/13	Pastiche (25)	No	13.8	505	90
Past/15	Pastiche (25)	No	12.3	454	91

Table A2. Characteristics of Mercia wheat samples

Lab No.	Varieties Present (no. of grains)	Heat Damage	Protein Content % @ 14%mb	Falling No. (sec)	SDS Volume (ml)
Merc/1	Mercia (24) Avalon (1)	No	11.9	415	58
Merc/4	Mercia (25)	No	10.7	425	60
Merc/9	Mercia (25)	No	11.2	386	60
Merc/10	Mercia (25)	No	10.4	401	65
Merc/11	Mercia (25)	No	11.2	402	57
Merc/12*	Mercia (24) Hornet (1)	Yes, Slight in 1/24	13.9	417	62

* ADAS secondary trial sample

Table A3. Results of laboratory milling

Sample	Milling 1				Milling 2			
	Protein % on 14% mb	Extraction rate %	GCF	Starch damage (FU)	Protein % on 14% mb	Extraction rate %	GCF	Starch damage (FU)
Past/5	9.3	74.7	- 1.85	20	9.5	78.9	- 0.3	28
Past/7	9.5	76.4	- 1.8	25	9.7	79.3	- 0.3	32
Past/9	10.0	77.7	- 2.1	20	10.3	80.5	- 0.2	27
Past/1	10.5	74.8	- 1.75	26	10.7	78.4	- 0.3	33
Past/6	10.6	75.9	- 2.0	21	10.8	79.5	- 0.7	29
Past/8	10.8	75.7	- 1.8	24	11.0	79.1	- 0.05	33
Past/2	10.8	74.0	- 0.4	33	11.0	77.7	0.85	44
Past/10	11.4	76.0	- 1.15	24	11.6	80.2	0.95	34
Past/11	11.4	77.1	- 1.9	24	11.6	80.2	- 0.3	32
Past/15	11.5	77.9	- 2.3	21	11.5	80.4	- 1.0	29
Past/12	11.8	76.4	- 1.1	22	12.1	79.7	1.1	30
Past/4	12.2	77.8	- 1.3	23	12.4	80.7	0.35	29
Past/13	12.4	77.2	- 1.5	20	12.5	80.3	0.2	29
Merc/10	9.2	77.8	- 1.6	21	9.3	79.8	- 0.3	31
Merc/4	9.6	77.1	- 1.25	28	9.7	80.0	0.1	38
Merc/11	9.7	77.0	- 0.6	27	9.9	80.5	1.05	39
Merc/9	9.8	75.8	- 0.7	27	10.1	79.4	0.8	38
Merc/1	10.4	77.0	- 1.05	26	10.7	80.9	0.4	39
Merc/12	12.0	73.6	- 0.2	27	12.2	77.4	1.5	35

Table A4. Properties of flours produced from milling regime 1

Sample Ref.	Falling Number	Simon Water Abs (1hr) % on 14% m.b.	Simon Water Abs (10 min) % on 14% m.b.	Simon Extensometer Resistance	Simon Extensometer Extensibility	Gel Protein g/5gflour	Gel Protein after mixing for 1 min (g/5g freeze dried dough)	2 min	3 min
Past/5	448	57.9	57.1	635	15.9	10.84	2.61	1.06	0.42
Past/7	450	58.9	58.9	565	19.9	11.56	2.90	0.68	0.60
Past/9	440	60.0	57.5	515	20.5	11.73	3.43	0.58	0.20
Past/1	440	61.8	58.6	580	19.9	11.51	3.19	0.53	0.43
Past/6	441	59.3	57.1	555	21.5	12.30	3.56	0.67	0.51
Past/8	477	61.4	59.3	410	22.0	12.09	2.30	0.64	0.70
Past/2	509	63.2	61.1	615	16.1	9.14	2.48	1.05	0.44
Past/10	451	58.6	58.6	560	19.0	12.91	3.49	0.79	0.35
Past/11	434	60.4	59.6	570	20.0	12.94	5.91	1.24	0.46
Past/15	420	58.9	58.2	665	17.5	13.95	4.08	0.78	0.42
Past/12	441	59.6	58.9	550	23.8	14.48	4.35	1.09	0.38
Past/4	437	56.8	57.9	530	24.7	14.13	2.80	0.58	0.61
Past/13	458	59.3	58.2	510	23.8	14.85	5.51	0.83	0.59
Merc/10	311	58.9	55.7	785	15.0	7.89	4.77	2.84	1.88
Merc/4	362	57.5	57.5	710	18.2	8.56	5.00	1.69	1.16
Merc/11	387	59.3	57.5	640	14.2	8.49	5.32	1.72	0.88
Merc/9	402	59.3	56.8	780	16.3	8.89	6.75	3.13	1.75
Merc/1	402	56.4	56.4	820	15.7	8.49	4.46	1.59	1.29
Merc/12	462	60.0	60.4	610	16.2	9.95	6.64	4.01	2.21

Table A5. Properties of flours produced from milling regime 2

Sample Ref.	Falling Number	FARINOGRAPH (600 line) Water Abs. % as is	Develop. Time (min)	Stability (min)	Degree of Softening (BU)	EXTENSOGRAPH Resistance (BU) at 45 min	Extensibility (cm) at 45 min	Gel Protein (g/5g flour)	Gel Protein after mixing for 1 min (g/5g freeze dried dough)	2 min	3 min
Past/5	430	58.5	2.0	3.0	135	240	16.7	10.98	1.90	0.46	0.45
Past/7	428	61.2	2.5	2.0	150	110	19.8	10.06	3.26	0.76	0.54
Past/9	460	59.9	3.0	2.0	130	195	20.0	10.66	2.10	0.42	0.31
Past/1	449	62.2	3.0	2.5	140	150	20.3	9.15	2.00	0.69	0.52
Past/6	416	60.3	3.0	2.5	140	320	19.4	11.45	2.97	0.59	0.47
Past/8	432	63.0	3.0	2.5	135	145	19.6	11.94	2.90	0.73	0.55
Past/2	472	66.8	3.0	2.5	105	180	14.7	8.28	3.20	1.23	0.83
Past/10	431	64.5	3.0	2.0	145	160	22.1	12.97	2.53	0.67	0.31
Past/11	410	64.3	3.5	2.5	130	170	22.4	12.67	4.72	0.74	0.47
Past/15	414	62.1	4.0	3.0	130	-	-	13.3	6.18	1.04	0.32
Past/12	457	63.4	3.0	2.5	135	-	-	12.82	3.40	0.83	0.55
Past/4	405	62.3	2.5	2.0	145	100	22.6	12.25	2.29	0.48	0.57
Past/13	454	63.6	3.5	2.5	135	130	24.0	12.36	4.74	0.93	0.39
Merc/10	395	57.2	1.5	3.5	145	375	15.5	7.54	6.23	4.13	1.82
Merc/4	356	59.3	3.0	3.0	145	165	15.9	8.66	4.88	1.71	1.18
Merc/11	389	60.2	2.5	3.0	155	240	16.9	7.33	4.02	1.29	0.41
Merc/9	403	59.0	2.5	3.0	145	270	16.3	8.80	5.39	2.45	1.32
Merc/1	388	60.1	3.0	2.5	155	200	15.9	8.40	4.32	1.08	0.39
Merc/12	447	63.2	3.5	3.5	120	250	14.6	9.75	5.64	1.60	0.75

Table A6. HMW glutenin subunit composition of Pastiche samples

Sample	Subunit (relative %)			
	4	7	8	12
Past/5	1.25	1.75	1.46	2.27
Past/7	0.80	1.64	1.29	2.09
Past/9	1.12	1.89	1.43	2.33
Past/1	1.25	2.03	1.54	2.69
Past/6	1.14	1.93	1.41	2.53
Past/8	1.25	1.85	1.43	2.53
Past/2	1.53	2.42	1.50	3.55
Past/10	1.25	1.74	1.41	2.49
Past/11	1.08	1.57	1.21	2.41
Past/15	1.20	1.73	1.48	2.31
Past/12	1.15	1.78	1.19	2.41
Past/4	1.16	1.65	1.32	2.30
Past/13	1.34	1.86	1.46	2.40

Table A7. HMW glutenin subunit composition of Mercia samples

Sample	Subunit (relative %)			
	5	6	8	10
Merc/10	1.45	1.03	1.58	2.24
Merc/4	1.20	1.05	1.60	2.55
Merc/11	1.26	1.12	1.80	2.70
Merc/9	1.54	1.18	1.90	2.63
Merc/1	1.30	1.16	1.85	2.26
Merc/12	1.54	1.11	1.55	3.13

Table A8. Properties of loaves baked using flour from milling regime 1

Sample Ref	A: Loaf Volume (ml)	A: Loaf Score	B: Loaf Volume (ml)	B: Ranking Outside Appearance	B: Ranking Crumb Structure	C: Loaf Volume (ml)	C: Ranking Outside Appearance	C: Ranking Crumb Structure
Past/5	1340	20	1315	7	4	1325	3	2
Past/7	1290	19	1315	8	5	1320	4	3
Past/9	1400	29	1325	8	5	1330	3	3
Past/1	1385	27	1285	8	5	1305	3	3
Past/6	1365	25	1335	7	4	1350	4	3
Past/8	1425	24	1355	8	5	1365	3	3
Past/2	1475	17	1115	9	6	1145	4	5
Past/10	1330	25	1305	8	5	1325	4	4
Past/11	1480	28	1415	5	2	1425	3	2
Past/15	1320	22	1465	1	1	1425	1	2
Past/12	1395	23	1295	7	5	1345	4	4
Past/4	1515	28	1495	7	4	1375	4	4
Past/13	1325	19	1405	8	4	1405	3	2
Merc/10	1195	14	1395	2	2	1515	1	1
Merc/4	1310	18	1395	1	2	1455	3	2
Merc/11	1280	20	1315	7	2	1430	2	2
Merc/9	1295	19	1405	6	2	1445	2	1
Merc/1	1270	17	1455	3	2	1465	1	2
Merc/12	1405	25	1485	4	3	1505	2	1

Table A9. Properties of loaves baked using flour from milling regime 2

	Test baking procedure					
	C			D		
		Ranking			Ranking	
Sample ref.	Loaf volume (ml)	outside appearance	crumb structure	Loaf volume (ml)	outside appearance	crumb structure
Past/5	1320	2	2	1505	3	2
Past/7	1240	4	4	1415	4	1
Past/9	1275	4	3	1450	4	2
Past/1	1290	3	4	1435	4	3
Past/6	1310	3	3	1530	2	2
Past/8	1345	4	4	1420	4	4
Past/2	1135	4	6	1340	5	7
Past/10	1280	4	5	1510	4	5
Past/11	1325	4	2	1460	3	2
Past/15	1350	1	2	1540	3	1
Past/12	1350	4	5	1455	4	3
Past/4	1285	4	5	1450	5	6
Past/13	1310	2	3	1490	4	1
Merc/10	1360	1	1	1455	2	3
Merc/4	1385	2	1	1555	2	1
Merc/11	1335	2	3	1425	2	3
Merc/9	1410	2	1	1550	1	2
Merc/1	1420	2	2	1540	2	1
Merc/12	1385	1	1	1475	2	3

Appendix B

Assessments of the breadmaking quality of Pastiche, Avalon and Mercia in National and Recommended List trials 1986-1990.

Year	Trial	Site	Pastiche				Avalon				Mercia			
			Flour Prot. %	Flour Fall. No.	BFP Score	CBP Vol. ml	Flour Prot. %	Flour Fall. No.	BFP Score	CBP Vol. ml	Flour Prot. %	Flour Fall. No.	BFP Score	CBP Vol. ml.
1986	NL1	Cambridge	12.6	244	22	1470	11.2	242	30	1340				
		Sutton Bonnington	11.5	239	35	1395	11.5	226	34	1395				
		Bridgets	10.7	212	29	1222	10.8	224	35	1217				
		Terrington	10.2	215	31	1405	9.6	220	29	1445				
		Headley Hall	9.7	164	33	1155	9.6	203	30	1145				
		Mean			28.0	1329			31.6	1308				
1987	NL2	Cambridge	11.2	99	*	1363	10.3	64	*	1163				
		Bridgets	9.4	206	*	1300	9.1	125	*	1175				
		Harper Adams	11.2	190	*	1297	10.9	91	*	1075				
		Sutton Bonnington	11.1	201	*	1375	11.8	161	*	1345				
		East of Scotland	8.2	228	*	1160	7.7	108	*	1187				
		Mean				1299				1189				
1988	RL	Bridgets	10.8	214	23	1230	10.7	166	23	1165	9.7	216	22	1287
		Cambridge	10.1	104	31	1425	10.0	130	25	1325	9.1	139	26	1400
		Harper Adams	11.4	175	18	1235	10.3	103	23	1345	9.6	143	16	1220
		Headley Hall	8.7	232	16	1210	9.5	135	24	1175	7.5	158	16	1225
		Seale Hayne	9.2	219	20		7.6	85	14		7.1	178	17	
		Mean			21.6	1275			21.8	1252			19.4	1283

Year	Trial	Site	Pastiche				Avalon				Mercia			
			Flour Prot. %	Flour Fall. No.	BFP Score	CBP Vol. ml	Flour Prot. %	Flour Fall. No.	BFP Score	CBP Vol. ml	Flour Prot. %	Flour Fall. No.	BFP Score	CBP Vol. ml.
1989	RL	Bridgets	12.3	237	38	1305	11.8	243	38	1305	11.4	222	30	1405
		Cambridge	11.5	243	38	1395	11.6	261	32	1345	11.4	221	32	1415
		Harper Adams	11.4	295	33	1405	10.1	290	36	1325	9.7	243	20	1455
		Seale Hayne	13.6	278	31	1225	12.7	267	36	1275	13.3	266	35	1425
		Wye	9.1	287	24	1350	9.6	265	29	1315	9.1	266	17	1335
		Mean			32.8	1336			34.2	1313			26.8	1407
1990	RL	Bridgets	10.0	421	21	1265	9.3	411	21	1025	9.1	384	17	1305
		Headley Hall	11.7	421	21	1395	11.1	400	21	1345	9.8	349	13	1395
		Morley	10.9	384	23	1315	10.4	405	20	1275	10.0	357	19	1345
		Rosemaund	9.0	402	19	1247	8.8	394	16	1262	8.5	394	13	1284
		Wye	11.4	412	33	1290	10.2	397	32	1230	10.0	322	22	1390
		Mean			23.4	1302			22.0	1228			16.8	1345

* BFP loaves were not scored in 1987 due to excessive stickiness.

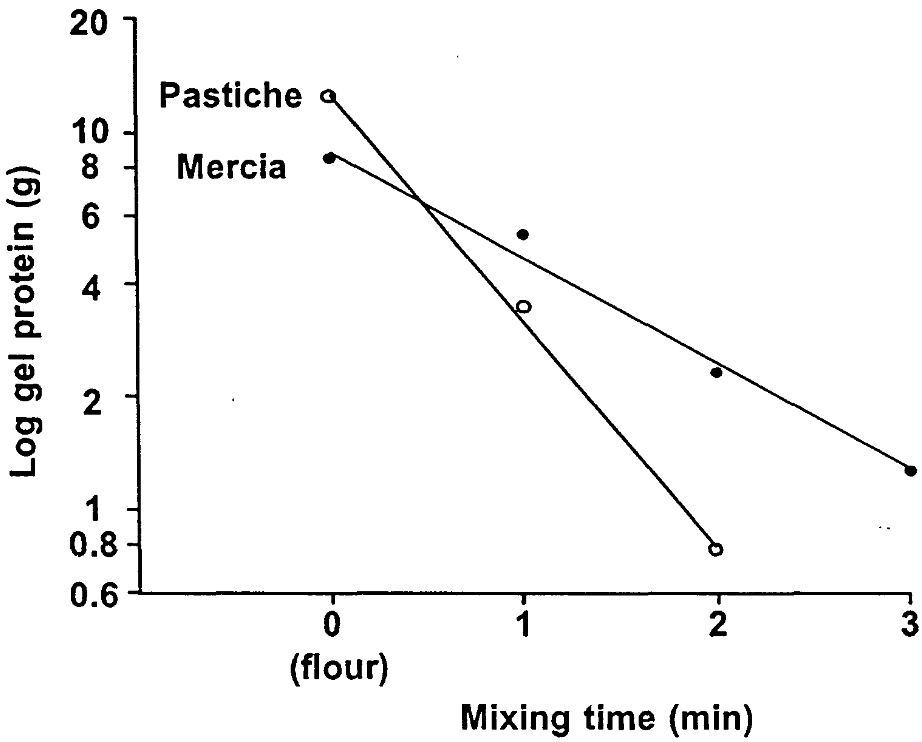
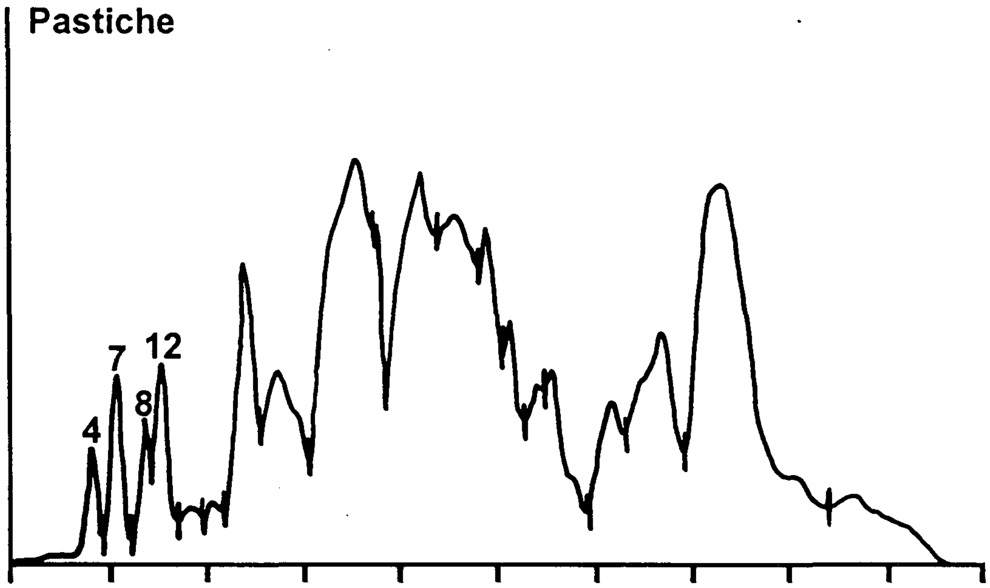


Fig 1. Breakdown rate of glutenin fraction from Mercia and Pastiche



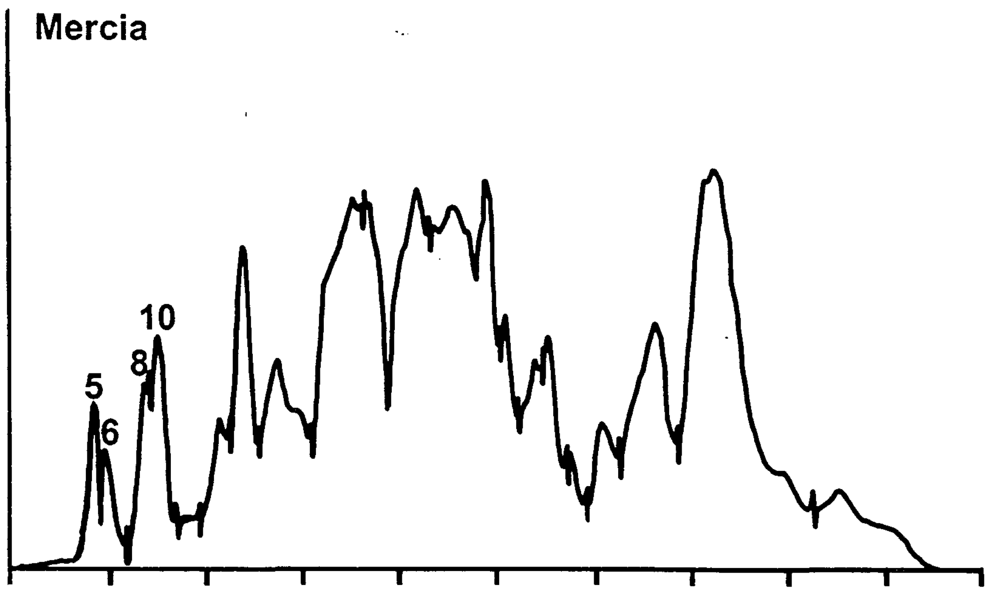


Fig. 2 Densitometer scans of Laemmli gels for Pastiche and Mercia showing subunit patterns

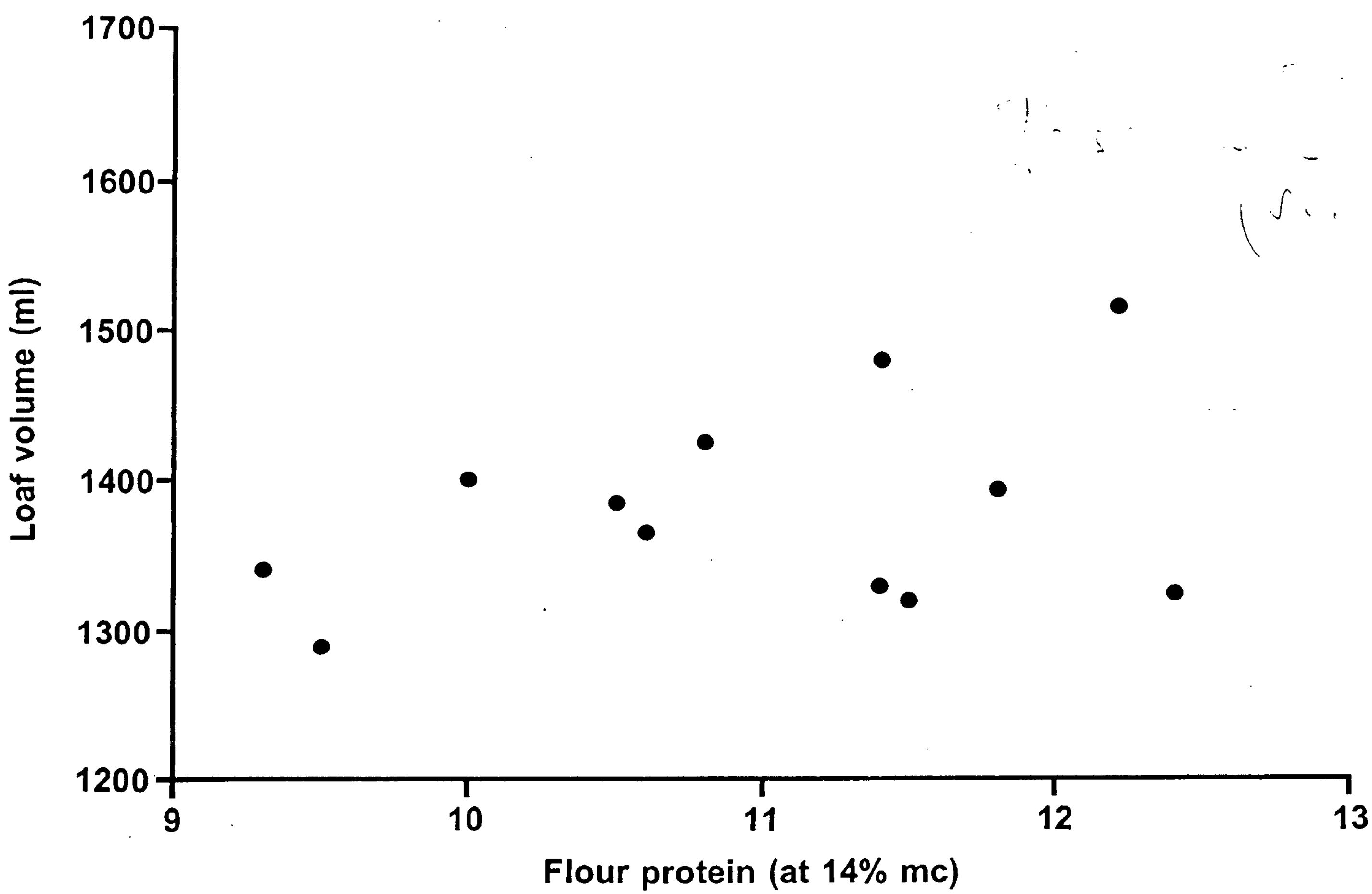


Fig. 4 Plot of loaf volume versus flour protein content for baking procedure A

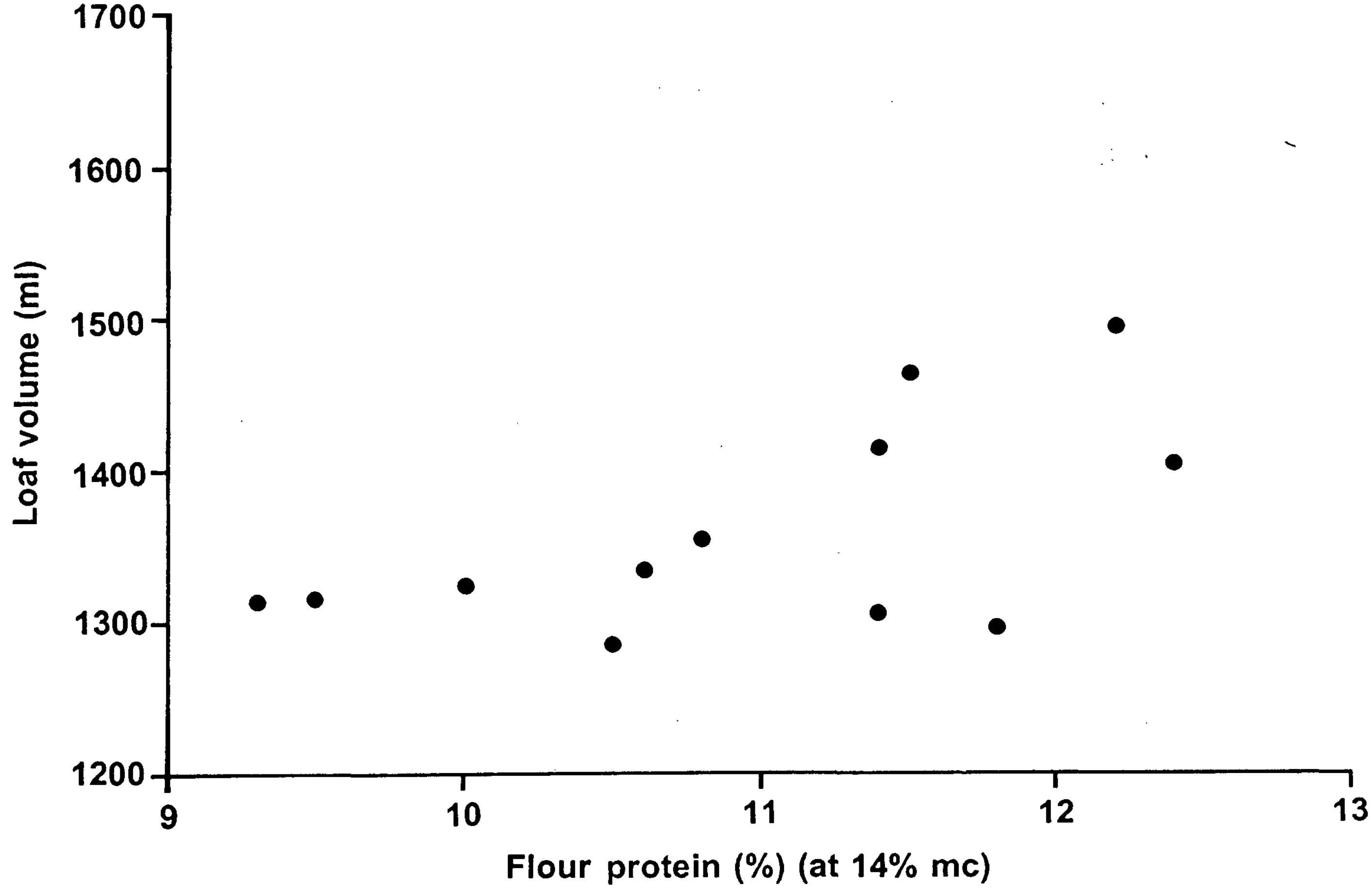


Fig. 5 Plot of loaf volume versus flour protein content for baking procedure B

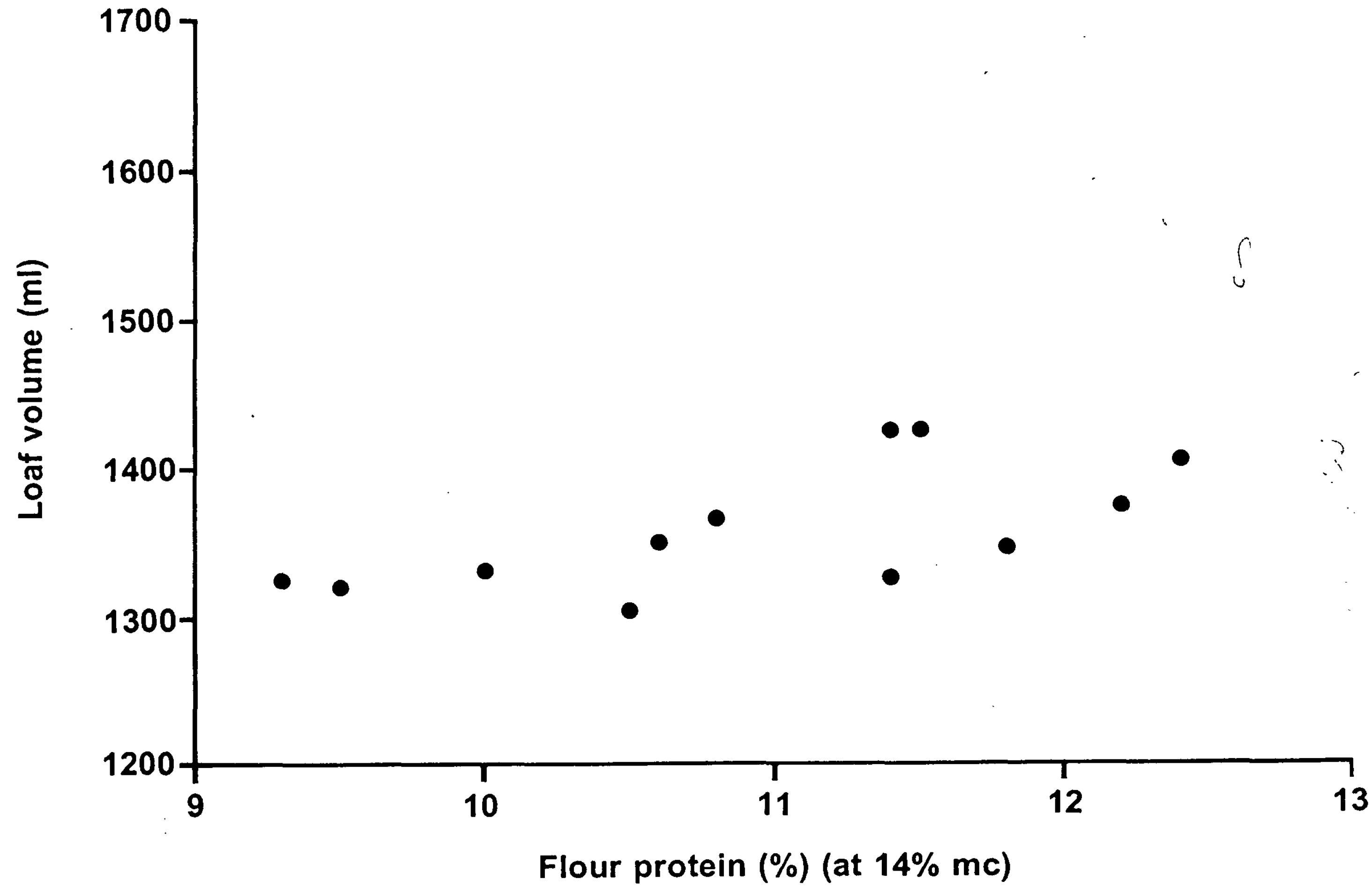


Fig. 3 Plot of loaf volume versus flour protein content for baking procedure C