HGCA

PROJECT REPORT No. 60

THE CHARACTERISTICS AND PROCESSING REQUIREMENTS OF WHEAT FOR BREADMAKING

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THE CHARACTERISTICS AND PROCESSING REQUIREMENTS OF WHEAT FOR BREADMAKING

by

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Final report of work carried out by the Flour Milling and Baking Research Association, Chorleywood, Hertfordshire WD3 5SH. The work commenced in April 1988 when it was 75% funded by the Ministry of Agriculture, Fisheries and Food, and 25% by the Home-Grown Cereals Authority under HGCA project numbers 0019/3/88 (white bread) and 0020/3/88 (wholemeal bread). After April 1990, work continued on the project, with 26% funding by the Home-Grown Cereals Authority and 24% funding by the Ministry of Agriculture, Fisheries and Food as part of an ECLAIR (European Co-operative Linkage in Agro-Industrial Research) programme (project AGRE 0052), which is continuing to 1995. The grants from the Authority between April 1988 and June 1992 have been £86,075 and £79,675 for project numbers 0019/3/88 and 0020/3/88 respectively.

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ABSTRACT

The increasing proportion of the UK breadmaking wheat grist that is of UK origin (up to 88%), and the dominance of single wheat varieties has made the baking performance of these varieties very important.

Work carried out under this project has shown that the work-input requirement in the CBP can vary from 5Wh/kg for Riband up to 20 Wh/kg for "extra-strong" types such as Fresco. Clear differences were observed between varieties in their tolerance to high work-input levels and rates of work input. Fresco performed best at high work-input/mixer speed combinations, and performed poorly in mixing regimes equivalent to current commercial practice.

Hereward and Mercia performed well at low work-input levels. In particular Hereward performed well in all mixing conditions. Riband was surprisingly tolerant of high-work input levels, although lower loaf volumes and crumb scores reflected its lower quality.

In a traditional breadmaking process, the fermentation tolerance of CWRS, Hereward, Mercia and Haven showed that for all varieties, increased fermentation time was not beneficial probably due to a lack of fermentable sugars for the yeast.

The varieties Fresco and Hereward are capable of carrying weaker varieties such as Galahad, Riband and Haven, the work-input requirement and baking performance of the blends approximating to the arithmetic means of the base flours.

In wholemeal, the high work-input requirement of "extra-strong" varieties such as Fresco was lost, and gluten fortification had no effect on the work-input requirement of wholemeal flours. The importance of protein content in wholemeal was demonstrated.

Wholemeal flours were shown to be more tolerant to increased cereal *alpha*-amylase levels (up to 100 FU). The deleterious effects observed in white bread on crumb stickiness, resilience and density were not apparent. Dextrin formation was much lower than in white bread possibly due to binding of calcium by phytic acid present in bran restricting enzyme activity.

A survey of several UK and continental European wheats showed that wholemeal loaf volumes could not be predicted from those of white. Soft milling varieties of breadmaking quality, and "extra-strong" varieties appeared to have advantages in wholemeal.

Rheological and biochemical tests highlighted a number of quality assessment methods that have potential in prediction of baking quality. In particular, the stress relaxation properties of yeasted doughs gave correlations with loaf volume in a relation that included white, wholemeal, and gluten fortification of wholemeal.

The glutenin fraction of wheat protein measured as gel-protein indicated that the elastic modulus (G') or the breakdown rate during mixing are quality attributes that may be used to predict the performance of varieties in the CBP. Such tests, had they been in use, would have demonstrated the "extra-strong" character of Fresco and the weak quality of Pastiche at an early stage in the trialling system. These tests are now included in the assessment of potential breadmaking varieties in Recommended List Trials.

1. INTRODUCTION

About 5M tonnes of wheat per annum are milled into flour for human food. Over the last 20 years or so there has been a continuing trend for an ever increasing proportion of the wheat used in milling to be UK grown. In seasons when the crop was of appropriate quality up to 88% has, in fact, been of UK origin. The only significant use of non-EC wheat is in milling certain types of bread flour, particularly wholemeal, which require especially high levels of protein for producing bread of satisfactory quality. Even with bread flours, however, more than 70% of the 'average' national bread grist may be wheat grown in the UK, and for standard white bread, which still accounts for over 50% of all bread consumed, virtually all the grist can be UK-grown wheat.

This reliance on UK-grown wheat has made it much more likely that breadmaking and other flours will be produced from grists dominated by single wheat varieties rather than mixtures of wheats. Under these circumstances the quality characteristics of the particular varieties that dominate the grists become of considerable importance.

During the period covered by this study, the UK breadmaking industry was faced with the loss of the oxidative improver potassium bromate. This oxidant acts in the absence of oxygen and is therefore unaffected by changes in air occlusion during mixing. The principal remaining oxidant, ascorbic acid, is dependent upon oxygen for conversion to the active form dehydro-ascorbic acid and is therefore affected by mixer action[1]. The performance of a variety in the mixer may therefore also affect the efficiency of oxidative improvement. Although this study was not intended to address the problem of oxidative improvement in breadmaking, it was nevertheless the first detailed study of breadmaking without bromate.

Studies on the breadmaking quality of single wheat varieties has also been addressed in two short-term projects funded by the HGCA. Both were in response to problems experienced by the baking industry.

The variety Pastiche, which had passed successfully through the trialling system with good loaf volume and SDS volumes was found not to perform well in the CBP when grown commercially to acceptable protein contents (c.10.5%). HGCA project No. 0014/1/90 addressed this problem.

Results showed that at high protein contents, the variety did not achieve its full potential. It was observed that the glutenin fraction, as measured by gel-protein[2] had weak mixing characteristics. This study was fully reported in HGCA Project Report No. 31[3].

The "extra-strong" character of Fresco was known at the time of the project proposal. There was industry resistance to its use in white bread because of suspected high work-input requirement. It had not been considered for special purposes such as wholemeal and it was perceived that its rejection may have been premature.

It was therefore decided to subject the variety Torfrida, also of "extra-strong" character to detailed study. HGCA project 003/1/91, fully reported in HGCA Project Report No. 36[4] showed that there were problems with consistency with the variety and no definite conclusion could be drawn as to the value or otherwise of "extra-strong" wheats in wholemeal or blending.

This project of a longer term nature was intended to investigate the breadmaking performance of existing UK and some continental European varieties in both white and wholemeal, and to understand how that performance might be improved by blending of strong with weak varieties, and the effect of gluten fortification.

The principal objectives of the research were to:

in white bread

1. Establish the exact processing requirements of "extra-strong" varieties of wheat now emerging from breeding programmes in terms of work-input during mixing and fermentation tolerance, and assess the extent to which these requirements are compatible with contemporary bakery equipment and breadmaking processes.

2. Establish the ability of these new varieties to 'carry' inferior, weaker varieties, even feed wheats, in mixed grists.

3. Determine the rheological characteristics of doughs and gluten from bread wheats to identify the physical factors related to the quality differences.

4. Determine the biochemical features that account for the physical and functional differences among bread wheats.

5. Develop rapid and simple small-scale tests suitable for use in plant breeding or in grain trading that are capable of differentiating wheats with different breadmaking properties.

and in wholemeal to

1. Determine the sensitivity of wholemeal bread characteristics, particularly those such as loaf volume and crumb density distribution that may be related to slicing ability, to increasing levels of *alpha*-amylase activity.

2. Determine the effect of wheat variety on wholemeal breadmaking performance and to compare breadmaking performance of wholemeals with that of white flour from the same varieties.

3. Define the underlying causes of variation in breadmaking quality among different wheat varieties if found and discrepancies between wholemeal breadmaking performance and white breadmaking performance by analysis of brans and germs from different wheats.

4. Devise rapid, simple and preferably small scale tests of wholemeal breadmaking potential of different wheats.

Initially conceived as two projects 0019 white bread and 0020 wholemeal these two projects were combined into one, in the light of initial experimental results.

2. MATERIALS AND METHODS

2.1. White bread

2.1.1. Work-input requirements and fermentation tolerance of UK and continental European wheat varieties

A. Performance of UK varieties in the CBP

Wheat varieties and purity Avalon, Fresco, Galahad, Haven, Hereward, Mercia, Pastiche and Riband wheats were secured from the 1989 harvest and tested for purity of variety by electrophoresis.

Milling and flour analysis Avalon, Fresco and Riband were Buhler-milled and a CBP-type commercial, untreated, unbleached breadmaking flour purchased. The flours were analysed for moisture, protein, Grade Colour Figure, damaged starch, Falling Number and *alpha*-amylase activity. Water absorption was determined with the Simon Research Extrusion Meter by the 10 minute method (Dodds)[5].

Dough recipe and processing Recipe and dough processing details for CBP white bread are given in Appendix 1.

Mixing The new mixing machine, designed and built at FMBRA to allow more accurate determination of work-input requirements of flours (see Figure 1 p30), was used to determine the CBP mixing requirements of doughs made from white flours of the Buhler-milled varieties and a CBP-type commercial flour. Each flour was used at dough work- inputs of 5, 8, 11, 14 and 17 Wh/kg to determine the approximate requirement, and then with one Wh/kg increments about the approximate work level to determine the optimum.

Loaf quality assessment Loaf volume was measured by seed displacement and crumb colour by Hunterlab Tristimulus Colorimeter using Y value as a measure of whiteness. Crumb structure was assessed by expert examination of the cell size, uniformity and wall thickness and scored up to a maximum of 10 points. High points were given for structure which was of mainly small cells with thin walls. Faults, such as non-uniformity or streaks (s), or random larger than average holes of openness (o), in an otherwise close structure, were noted by the appropriate suffix alongside scores. Colour photographs of crumb surfaces were taken to record differences in structures. Whole-loaf scores were given to identify differences between loaves with similar crumb structure but different whole-loaf characteristics. High points were awarded for uniform shape and"neat" oven spring break, showing a smooth expansion of the dough during rapid rise in the oven. Crumb and loaf scores were assessed on randomised duplicate loaves.

B. Detailed study of selected varieties. (Also studied on wholemeal bread) in the CBP

Wheat varieties

Fresco, Hereward, Mercia and Riband from the 1990 harvest in the UK and Festival and Gala from France in the 1991 harvest.

Milling and flour analysis

As for the survey of UK varieties (A).

Mixing

Each variety was mixed to five work-inputs at each of five mixing speeds ranging from 250 to 600 rev/min. Each variety was mixed in a total of 25 mixing regimes.

The work-input ranges chosen were 8 to 20 Wh/kg for Fresco and Hereward, 5 to 17 for Mercia and 3 to 14 for Riband. These ranges were based on the white bread optimum found previously for these varieties.

The French varieties were mixed in a simplified system. Each variety was mixed at 250 rev/min at five work input levels (5 to 17 Wh/kg) and at 5 Wh/kg at five mixing speeds (250 to 600) and selected combinations, giving 13 mixing variations for each variety.

Loaf quality assessment was as for the survey of UK Varieties.

C. Fermentation tolerance in traditional processes

Using traditional breadmaking processes three single varieties, Hereward and Mercia and Haven were compared with each other and with a Canadian Western Red Springs wheat

(CWRS). Doughs were mixed for 10 minutes using a twin-arm, low-speed machine. Immediately after mixing they were transferred to temperature controlled storage for bulk fermentation time of between 1 and 3.5 hours with adjusted yeast level. Full details of the recipe and dough processing are given in Appendix 2.

Varieties, flour milling and coding

Three single wheat varieties and one CWRS wheat were obtained from commercial millers, each from the 1989 harvest year and chosen with their optimum work-input capacity in mind. The following list shows the varieties chosen plus their determined optimum work input capacity.

CWRS	(high-work input type)
Hereward	(high-work input type)
Mercia	(medium-work input type)
Haven	(low-work input type)

Flours were roller-milled in the laboratory using a Buhler mill (MLU 202) set to give a white flour.

Each flour produced was coded according to wheat type and harvest.

Test variations

All doughs were processed using a bulk fermentation process (BFP) with fermentation times of 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5 hours. Each dough produced was divided into two with one half left to ferment for the hourly time chosen and the other section for the half hourly time directly following. Doughs were placed into "aluminium" tins with lids and left to ferment in a temperature controlled cabinet maintained at 21°C.

2.1.2. Blending

Wheat varieties Blends were made in the ratios 25/75, 50/50, and 75/25 of flours from varieties with high and low work-input requirement. Blends examined were: Hereward with Galahad (89), Mercia (89) and Haven (90); and Fresco with Riband (89), Galahad (90) and

Haven (90). Figures in brackets indicate harvest year.

Milling as above.

Mixing The work-input of the blends was determined using the same techniques as applied to individual varieties.

Loaf quality assessment as above.

2.1.3. Rheological characteristics

Dough mixed in the detailed study of selected varieties (2.1.1B) were assessed for rheological quality using the Bohlin VOR rheometer[6]. A stress relaxation test, where a small strain is applied to the dough and the resulting stress in the dough monitored over time was employed. Five doughs from each variety, representing increases in both work-input and mixer speed were analysed.

Stress relaxation tests were carried out at strains between 0.00249 and 0.00311 with a strain rise time of 0.05s. The initial equilibrium time was zero and the autozero was in the off position. Amplitude was set to 1.2% and the filter used was 4. Manual temperature control was employed and the maximum measurement time was 2000s.

For each dough (white or wholemeal) a straight line was fitted to the data corresponding to the initial rapid decrease in stress. A second gradient was plotted representing longer term stress relaxation in the dough. The two gradients (M1 and M2 respectively) gave a measure of the viscoelasticity of the dough and its ability to store energy.

2.1.4. Biochemical factors accounting for varietal differences

The principal assessment method of biochemical quality was a measure of the glutenin fraction of wheat protein first observed by Graveland known as gel-protein[2]. Gel-protein separates as an insoluble gel-like layer when flour is extracted at 10°C in 1.5% sodium dodecylsulphate (SDS) and centrifuged at 63,000 x g.

Wheat varieties - Samples from the detailed work-input study on selected varieties.

Gel-protein was measured on flour, and on doughs sampled immediately after CBP mixing, after first proof, and 20 minutes into and after final proof. (approx. 60 minutes after end of mixing). Doughs were flash frozen in liquid nitrogen.

Gel-protein method

10g flour was defatted with 25ml petroleum ether (b.p. 40-60°C) for 1 hour, filtered and dried. 5g of defatted flour was stirred with 90ml of 1.5% sodium dodecyl sulphate for 10 min at 10°C then centrifuged at 63,000 x g for 40 mins. The gel protein weight was recorded.

Some laboratory mixing tests were carried out using Minorpin or Majorpin mixers. The following method was adopted:

50g flour was mixed with 0.9g sodium chloride and water as determined by FTP method 0004 for 5 min. Equal aliquots were removed at 1,2,3 and 5 min and frozen immediately after removal. After freeze-drying the samples were ground up to pass through a 250 micron sieve. Gel-protein was determined as for flour.

Gel-protein rheology

In the later stages of the project the rheological quality of the gel-protein layer was measured using an oscillatory frequency sweep test on the Bohlin VOR. In this test a fixed strain amplitude is applied sinusoidally in the linear viscoelastic region (strain is proportional to stress).

Results are quoted at 1 Hz frequency and are expressed as elastic modulus (G') viscosity modulus (G") phase angle (tan δ) and viscosity. Elastic modulus figures are usually quoted.

2.2. Wholemeal

2.2.1 Sensitivity of wholemeal to *alpha*-amylase

Grists, wholemeal flour milling and coding

European and CWRS wheats were obtained from grists in use by a commercial miller. Wholemeals were roller-milled in the laboratory using a Buhler mill (MLU 202) set to give a white flour. The bran was ground using a Cristy Norris 8 inch laboratory hammer-mill, fitted with 1.6mm round hole screen, before blending with the flour, germ and offals to produce wholemeal.

Two wholemeals from European wheats and one from CWRS were produced and coded according to the wheat type and harvest year. Roller-milled CWRS wheat from 1989 harvest was coded RM-C89 and the European meals RM-E89 and RM-E90. Each meal from the Buhler was thoroughly blended in a ribbon blender before entry into the test programme.

Wheat variety identification, grist and wholemeal analysis

Wheats in the grist were identified by electrophoresis, the wholemeal flour properties analysed and particle size distributed determined using a mechanical shaker, with a plansifter type action, using a set of Endecott 200mm diameter woven wire sieves of apertures: 1000, 850, 500, 300 and 180 microns.

***Alpha*-amylase activity**

A standard level of 80 Farrand units of fungal *alpha*-amylase was added to all meals at doughmixing, in accordance with common commercial practice. Small differences in natural cereal *alpha*-amylase were ignored.

The effects of increasing cereal *alpha*-amylase were studied by making additions of enzyme-active wholemeal wheat malt flour. A single consignment of malt flour was added in increasing amounts to produce meals with a range of cereal *alpha*-amylase levels. The *alpha*-amylase activity of the malt used was 34 SKB units, equivalent to approximately 4692 Farrand units.

Gluten fortification

The protein contents of the wholemeals from European grists, RM-E89 and RM-E90 were increased to the same as that of the CWRS by the addition of dried gluten. A single consignment of dried gluten was blended into the meals, for 3 minutes using a beater attachment on a vertical bench model Hobart, prior to doughmixing. The gluten used had a moisture content of 8.05% and protein of 74.5%.

Water absorption

Water absorptions of the wholemeals with malt flour additions were determined using the Simon Extrusion Meter 10 minute method[5]. The water absorption determined in that way was increased for meals with dried gluten addition by 1.5 times the weight of gluten added.

Baking

800g wholemeal loaves were produced by two methods, the Chorleywood Bread Process (CBP) and a low-speed mixing method (LSM) using an Artofex mixing machine and the same recipe. Doughs based on 1680g wholemeal were mixed and processed using the recipe and processing methods outlined in Appendix 3.

Test variations

Wholemeal loaves were made from RM-C89 and gluten-fortified RM-E89 and RM-E90 with levels of malt to increase cereal *alpha*-amylase activity in the meal by 0,5,10,20,30,50,75 and 100 FU.

Baking tests were carried out in duplicate and the order of mixing randomised. A "blank" dough was mixed between test doughs in the CBP to avoid contamination of one test by another. That precaution was not required when using LSM because the simpler machine design made thorough removal of all dough easy to achieve.

Loaves were cooled before storage overnight at 21°C and assessed the following day.

Assessment

Loaf characteristics of volume, and crumb density were measured and crumb structure and resilience scored by expert assessment. Crumb samples were analysed for reducing sugars, amylose and dextrins.

Carbohydrate analysis of amylose, dextrins and reducing sugars

Reducing sugars (mg/g d.w.b.)	:	By the Bernfeld DNS method[7]
Amylose (mg/g c.w.b.)	:	By the Blue value method[8] p31-32
Dextrins (units/g d.w.b.)	:	By the Blue value method[8] p31-32
Crumb stickiness (/10 NMM)	:	By Instron[9]

Eight top cores and eight bottom cores were taken from the same loaf to establish an average measurement of crumb stickiness.

2.2.2. The effect of wheat variety on wholemeal breadmaking performance in relation to that of white

A. Performance of UK and continental European wheats

Wheat varieties

Fourteen wheats (4 French, 5 German and 5 UK) were milled as above into white and wholemeal flours and also into blended wholemeals where the bran and offals for thirteen of the varieties were interchanged with those of the fourteenth (the variety Mercia). A sample of this variety was milled each week alongside the selected other variety such that the time between milling and baking was kept constant.

Wheats in the grists were identified by electrophoresis, the wholemeal flour properties analysed and particle size distribution determined using a mechanical shaker, with a plansifter type action, using a set of Endercott 200mm diameter woven wire sieves of operatures: 1000, 850, 500 and 180 microns.

Baking and loaf assessment. By CBP and as described previously.

Biochemical characteristics

Gel-protein content of all base flours and interchanged bran and offal blends were determined as described previously.

B. Detailed study of selected varieties in the CBP (see page 7)

Wheat varieties. As listed under white bread.

Mixing, rheology and biochemical characteristics.

By techniques described previously under white bread.

2.2.3. Underlying causes of variation

Bran and offal from a number of varieties were analysed for reducing glycosides, (hydroquinone compounds) using a method of Graveland[10].

3. RESULTS AND DISCUSSION

3.1 White bread

3.1.1. Work-input requirement and fermentation tolerance of UK and continental European wheat varieties

A. Performance of UK varieties in the CBP

Wheat and flour analyses of the varieties are listed in Table 1, and the optimum work-input levels of the flours, and the loaf volumes and loaf quality scores are listed in Table 2.

The results for two harvest years show large differences between varieties. In particular the high work-input requirement of Fresco (17 to 18 Wh/kg) was established. The newer variety Hereward was also shown to perform better at work input levels greater than the 11 Wh/kg of the CBP. Haven, Riband and Galahad typically had low optimum work-inputs, but even at the optimum did not perform well in baking performance terms. Optimum work-input was not affected by harvest year.

All the flours were milled by a laboratory Buhler mill (RA Standard laboratory method), which may not produce damaged starch levels representative of those generated in industrial flour milling. To establish if milling method had any influence on work-input requirement and therefore baking quality, Riband, Galahad and Pastiche were also milled in a commercial mill and by an adjusted laboratory Buhler method, to give higher extraction rate and increased damaged starch, which we called "RA Commercial". The two laboratory milling methods are summarised in Appendix 4.

Optimum work-inputs and loaf characteristics are listed in Table 3.

For any variety, work input was not seriously affected by the milling method.

Full details of the flour analysis and particle-size distribution of flours produced by the three milling methods were reported previously[11].

B. Detailed study of selected UK and French varieties

When mixing to high work-input levels, mixing times are increased such that the original requirement of the CBP, that the input of energy should take place within 3 to 5 minutes and preferably in less than 4 minutes are no longer met. For this reason increases in mixer blade speed were an appropriate means to keeping mixing times within that constraint.

Flour properties are listed in Table 4.

Mixing times, loaf volumes, crumb and loaf scores and gel-protein quantity after mixing (A) and after final proof (B) are listed in Table 5A (Fresco) 5B (Hereward) 5C (Mercia) and 5D (Riband). Initial stress relaxation slope for selected mixer speed/work input combination are also included.

Data for the French varieties Gala and Festival are listed in Table 5E and 5F respectively. Gel-protein determinations were not included in the study, but data for the W value from the Alveograph is listed for those samples examined by stress relaxation properties using the Bohlin VOR.

Each table is supported by copies of photographs of the crumb structure of bread baked from doughs mixed by the extremes of the mixing conditions: i.e. for Fresco, work-input/mixer speed combinations of 8/250, 8/600, 20/250 and 20/600 are illustrated. The varieties are represented in Figures 2A (Fresco), 2B (Hereward), 2C (Mercia), 2D (Riband), 2E (Gala) and 2F (Festival).

The results clearly demonstrate the characteristics of the so-called "extra-strong" variety Fresco. At low work input the variety performs poorly. Increase of mixer speed, or work input level both improve baking performance. Increase of both results in the best loaf quality such that at 20 Wh/kg and 600 rpm the variety achieves its full potential - unfortunately these conditions are not likely to be commercially acceptable. Similar characteristics were observed in Torfrida, studied under an HGCA contract and reported in 1991[4].

The varieties Mercia and Hereward performed better than Fresco at low work-input levels, but did not perform best under the most vigorous mixing regimes. Hereward showed a wide tolerance to mixing conditions, producing good loaf volumes and high crumb scores from 8 Wh/kg to 20 Wh/kg, at all mixer speeds.

Mercia, the predominant breadmaking variety in the crop years studied achieves its optimum at 11 Wh/kg, and did not deteriorate at higher work-input levels.

Riband, produced bread of a lower quality than the other varieties at all work-input/mixer speed combinations but surprisingly was not adversely affected by high work-input. This resilience would be beneficial if used in blending with so-called stronger varieties.

Of the two French varieties, Gala had the better baking performance. Only at high work-input levels did Festival achieve its best and it is concluded that this variety has "extra-strong" characteristics similar to, but not as extreme as those of Fresco.

C. Fermentation tolerance in traditional processes

Optimum bulk fermentation requirement was surprisingly short for all varieties and CWRS at one and two hours. Tolerance to extending fermentation time for an extra thirty minutes was generally poor, limited by available fermentable sugars for the yeast.

CWRS

Good loaf characteristics decreased with fermentation length, suggesting poor fermentation tolerance. Best performance at 1.0 - 1.5 hours.

Hereward

Consistent loaf characteristics were obtained with all hourly fermented doughs. The extended half hour after a 2 hour length caused a decrease in quality of all characteristics. Fairly good fermentation tolerance. Best performance at 1.0 - 2.0 hours.

Mercia

Very consistent loaf volumes maintained throughout. Crumb structure and whiteness decreased slightly after two hours of fermentation. Good fermentation tolerance. Best performance at 1.0 - 2.0 hours.

Haven

Good loaf characteristics decreased slightly after two hours of fermentation. Good fermentation tolerance. Best performance at 1.0 - 2.0 hours.

In all cases, proof time was within 34-39 minutes up to two and a half hours of fermentation. Thereafter proof time was at least fifty-five minutes and in most cases over one hour.

The results suggest that all varieties including CWRS did not hold up to long fermentations. A possible explanation would be lack of substrate, i.e. insufficient yeast food to sustain fermentation. Haven performed particularly and surprisingly well. It is interesting to note that for this variety the natural *alpha*-amylase level was 4 FU, whereas the later varieties had lower levels of 1 to 2 FU. The cereal *alpha*-amylase content of the flour is important in fermentation tolerance.

3.1.2. Blending

Optimum work- input requirement, and baking performance data are listed in Table 7, for blends of Fresco with Riband, Galahad and Haven, and for Hereward with Galahad, Mercia and Haven.

In general terms, these blends of varieties with high and low work input had mixing requirements and loaf quality of approximately the arithmetical average for the blend.

Fresco, which gave good loaf quality, had an optimum mixing requirement of more than three times that of Riband, which gave poor loaf quality. Blends of Fresco and Riband gave loaves which exhibited more of the characteristics of Fresco than Riband. 25 Fresco/75 Riband gave acceptable loaf quality, though not of the standard of 100% Fresco, and illustrated the potential ability of Fresco to "carry" and improve the breadmaking quality of the non-breadmaking varieties such as Riband.

Fresco, on its own, as the equal or dominant variety in a blend gave loaves with streaks in the crumb structure. The streaks followed the pattern created by the sheeting and curling used to mould the dough pieces into a cylinder immediately prior to placing it into the baking pan. The streaks were reminiscent of the swirls seen in a Swiss roll, with light and dull colour, uniform close cells and more open structure showing in a concentric pattern.

It is unlikely that more than 50% of Fresco in a grist would be commercially acceptable no matter which weaker diluent was used. Such a problem does not occur if Hereward is the strong variety.

3.1.3. Rheological characteristics

The initial relaxation rate in the stain relaxation test on the Bohlin VOR was found to be a good predictor of loaf volume. A plot of initial relaxation rate M1 on loaf volume for the varieties examined in this study is shown in Figure 3, p.48.

The equation of the relationship is:

Loaf volume = 0.24 x M1 + 1907

Correlation coefficient 0.82

A similar relationship exists for M2 the longer term stress relaxation characteristic of bread dough (r = 0.81). Combining M1 and M2 leads to a correlation coefficient of 0.90. The relationship includes white, wholemeal, and gluten-fortified wholemeal flour doughs. The results suggest that this quality aspect of wheat dough is a useful predictor of baking quality. It may be possible to develop it for small-scale use in the future.

3.1.4. Biochemical factors

The gel-protein data, listed in Table 5 demonstrate two aspects.

- In Fresco doughs the gel-protein was not completely solubilised after mixing, whereas it was in the other UK varieties
- during proof, the gel-protein reaggregated in Fresco doughs, but not to any significant extent with other varieties.

The study of gel-protein has been carried out under other projects at FMBRA[12]. The results for Fresco are in keeping with the "extra-strong" character of the variety. Supporting data from laboratory mixing trials is listed in Table 8.

The role of "extra-strong" varieties has been reported to the HGCA[4] for the variety Torfrida and the quality of the gel-protein of Pastiche was a contributory factor in the failure of that variety to perform in the CBP[3].

3.2. WHOLEMEAL

3.2.1 Sensitivity of wholemeal to *alpha*-amylase

Grist composition and wholemeal flour properties

Table 9 gives the grist compositions, wheat variety identification by electrophoresis, wheat, wholemeal flour and endosperm analyses and particle size distribution. The European grists both consisted of mainly Pastiche wheat.

Baking

Dough consistency

All of the doughs handled fairly well thoughout, though some differences were noticed between the two mixing methods used. Doughs from CBP tended to be slightly sticky compared with a drier feel and stronger extensibility of doughs from low-speed mixing. No progressive effect of malt addition on consistency was found.

Loaf characteristics

Table 10 (average loaf volume), Table 11 (average crumb structure scores) and Table 12 (dry density of bread-crumb) list the results of the physical assessment of the loaves. Table 13 (average crumb resilience scores) and Table 14 (crumb stickiness) link textural qualities of the crumb, and Tables 15 (dextrin), Table 16 (amylose) and Table 17 (reducing sugars) list the soluble carbohydrate composition of the *alpha*-amylase fortified bread-crumb.

In the CBP there was little overall effect on the physical characteristics of the loaves from increasing levels of cereal *alpha*-amylase activity. CWRS and European grists behaved similarly in this respect. However, throughout the range of cereal *alpha*-amylase additions, the crumb density of RM-E90 loaves was lower than both RM-C89 and RM-E89 which were similar to each other.

For all grists, the tendency was for crumb resilience to decrease with increasing levels of cereal *alpha*-amylase. Loaves from RM-C89 and RM-E89 had similar crumb resilience scores throughout, whereas loaves from RM-E90 had higher scores at additions of cereal *alpha*-amylase up to 30 FU.

For the LSM the effect of cereal *alpha*-amylase on loaf volume, crumb score and crumb densities was similar for the CWRS and European grists. For each grist, the baking properties when no cereal *alpha*-amylase was used were maintained up to 100 FU addition. Irrespective of the level of amylase added, RM-C89 produced loaves which were consistently higher in volume than those for either of the European grists. This was due to low response to the dried gluten component of the RM-E89 and RM-E90 when using LSM. This also explains the even lower volume of loaves from RM-E90, as more dried gluten was required to bridge the gap in protein for this grist.

Crumb scores varied considerably for the three grists over the whole range of amylase activities; there was no consistent pattern in the scores with increasing amylase addition.

Crumb density did not change with increasing levels of cereal *alpha*-amylase addition with any grist. RM-E89 and RM-E90 gave loaves with denser crumb, particularly at the bottom of the loaf, compared with loaves from RM-C89. Crumb density near to the top of the loaves from RM-E89 and RM-E90 were similar to loaves from RM-C89. These density differences between grists reflect both the overall loaf volumes and a tendency for the loaves from RM-E89 and RM-E90 to be more open and weaker towards the top crust.

Crumb resilience gradually decreased with increasing levels of cereal *alpha*-amylase.

Soluble carbohydrate analysis

Amylose, dextrin and reducing sugar values increased as the level of cereal *alpha*-amylase was increased. The rate of increase was generally similar for the three grists. The increase in soluble carbohydrate was as expected, and the relatively greater increase in the higher molecular weight amylose and dextrins was typical of that seen with high levels of cereal *alpha*-amylase. The increase was not, however, as great as seen in earlier studies with white bread (Chamberlain et al 1981)[13], and together with the crumb density data suggests that wholemeal flours are more resilient to higher levels of cereal *alpha*-amylase. Since the earlier study, loaf shape has changed such that heat transfer during baking would be quicker thus reducng the time when the dough was passing through the critical 60-80°C zone, where still active *alpha*-amylase is able to attack gelatinising starch. The presence of phytic acid in the bran may also help in ameliorating the *alpha*-amylase activity through its binding of calcium, essential for the activity of the enzyme.

This study of the influence of *alpha*-amylase activity on wholemeal led to the following points:

- Loaf volume and crumb structure were not affected by increasing levels of cereal *alpha*-amylase activity but there was a gradual decrease in crumb resilience.
- Amylose, dextrin and reducing sugars increased as the level of cereal *alpha*-amylase was increased.
- Crumb stickiness increased with increasing levels of dextrins.
- Responses to increasing levels of cereal *alpha*-amylase were similar using both CBP and LSM processes. Differences in loaf properties between the processes were caused by lower performance of added dried gluten when using low-speed mixing.

3.2.2 The effect of wheat variety on wholemeal breadmaking performance in relation to white

A. Performance of UK and continental European wheats

The loaf volumes of white and wholemeal bread baked from 14 UK and continental European varieties are listed in Table 18. Each week a control sample (Mercia) was test baked. These data are included together with loaf volumes of bread baked with bran and offal interchanged between the test variety and the control Mercia.

Single variety assessment of wholemeal baking quality

The data presented in Table 18 show that the wholemeal loaf volume as a percentage of the equivalent white volume varies with variety. In particular the two soft varieties, Festival and Minaret, produce relatively better wholemeal loaf volumes than do other varieties (with the exception of Fresco). The soft varieties when milled under standardised conditions yield lower damaged starch levels (c.8 FU) compared with the hard varieties (c.30 FU). Farrand proposed a formula that for optimum performance starch damage should not exceed $P^2/_6$ where P is the protein content. Thus, comparing flours with damaged starch levels of 8 and 30 would imply an effectively greater protein content in the soft varieties, for the purpose of carrying the inert dead weight of the bran particles, thus allowing greater loaf volume.

B. More detailed study of UK and French varieties

The study conducted under section 3.2.2A highlighted a problem that white-bread baking performance is influenced by the work-input requirement of the variety (Section 3.1.1A and 3.1.1B). Thus comparisons between white and wholemeal may have been influenced by the fixed work-input level used (CBP at 11 Wh/kg). It was therefore decided to subject the wholemeal flour to the same matrix system as used for white bread.

Flour properties are listed in Table 19. Mixing times, loaf volumes, crumb and loaf scores and gel protein quantity after mixing (A) and after final proof (B) are listed in Table 20A (Fresco) 20B (Hereward) 20C (Mercia) and 20D (Riband). Gel-protein data for Fresco represent after moulding and 20 mins into final proof. Initial stress relaxation slopes for selected mixer speed/work-input combinations are also included. Data for the French varieties Gala and Festival are listed in Tables 20E and 20F respectively. Gel-protein data were not obtained, but W values on the Alveograph were included.

Each table is again supported by copies of photographs of the crumb structure of bread baked from doughs mixed by the extremes of the mixing conditions. The varieites are represented by figures 4A to 4F respectively for Fresco, Hereward, Mercia, Riband, Gala and Festival.

The results show that the high work input requirement of Fresco in white bread is not apparent in wholemeal. The data also show that in the presence of bran and offal, the gel-protein is broken down more rapidly, and furthermore re-aggregation does not occur during proof. In this respect Fresco becomes similar to other varieties such as Hereward, Mercia or Riband. Hereward was clearly the best variety for wholemeal bread production, but no clear trend with work-input or mixer speed was observed. Both Mercia and Riband showed a tendency to deteriorate at high work-input levels; both had low gel-protein contents which may have adversely affected their performance.

The French varieties Gala and Festival were selected because they are soft, but of breadmaking quality. Gala was the better of the two, but the relative performance in white and wholemeal confirms the initial suggestion that soft varieties, probably because of the lower damaged starch, and therefore lower water absorption, would perform better in wholemeal than hard varieties.

The performance of Fresco suggested that "extra-strong" varieties do perform better in wholemeal than do normal bread-making varieties, whatever the work-input level used in the comparison. Results obtained in the Torfrida project reported in HGCA Project Report No. 36[4] were inconclusive on the value of "extra-strong" varieties in wholemeal. This more detailed study has given a more positive appraisal of their value.

Gluten fortification

The comparison between the baking performance in white and wholemeal was discussed in the HGCA Report[9] on "extra-strong" varieties such as Torfrida and highlighted the discrepancy between the protein content of the CWRS control ($\simeq$ 14%) and that of the UK grown Torfrida ($\simeq$ 10%). Likewise in this study wholemeal bread was made with unfortified wholemeal flour. One of the possible uses of "extra-strong" varieties may be in wholemeal bread. A limited study of the effect of gluten fortification of Mercia and Fresco at 3% and 6% additional protein as gluten was included. The results are listed in Table 21A (Mercia + 3%) 21B (Mercia + 6%), 21C (Fresco + 3%) and 21D (Fresco + 6%)

Each table is again supported by copies of photographs of the crumb structure of bread baked from doughs mixed by the extremes of the mixing condition. Figures 5A (Mercia +3%), 5B (Mercia +6%), 5C (Fresco +3%) and 5D (Fresco + 6%) illustrate the influence of added gluten on baking performance.

Gluten addition improved breadmaking performance consistently and did not raise the optimum work-input requirements or even increase them to those of the white equivalent.

Gluten fortified wholemeals gave gel-protein levels which increased with protein content. There was a varietal effect, 3% added gluten gave 1g extra gel-protein for Mercia and 2g for Fresco. The loaf volume from Mercia improved more with gluten addition than it did with Fresco. This suggested that interactions between added gluten protein and native flour protein were more effective in Mercia. The lack of effect of added gluten on work input requirement in breadmaking was consistent with unchanged gel-protein breakdown rate. Addition of gluten gave a reduction in elastic modulus of the glutenin fraction which was unexpected and requires further investigation.

3.2.3 Underlying causes of variation in wholemeal baking performance

The effect of interchanging bran and offal from the test variety with that of the control (Mercia) on loaf volume is shown in Table 18.

Interchange of bran and offal led to mixed results, confused by the unexpectedly high variability of the Mercia control from week to week. Despite the use of a single sample of grain, and weekly millings alongside those of the selected test variety, variability over fourteen weeks on the Mercia data were:

Mean white loaf volume	1595 $\pm$ 49 mls
Wholemeal loaf volume	1228 $\pm$ 62 mls

Nevertheless this study of white, wholemeal and blended wholemeal has highlighted a number of features. The white loaf volumes have given an indication of the endosperm quality of each variety relative to Mercia. Likewise, interchanging test variety bran and offal with that of Mercia, in Mercia wholemeal has given a value for the bran and offal. It is possible therefore to predict the wholemeal volume of the test variety from that of the Mercia control. Such a prediction results in a correlation coefficient of 0.77 significant at 1%.

The base flours and the interchanged bran and offal samples were assessed for gel protein, known to correlate with loaf volume in the CBP when a wide range of quality is studied. This test is related to the SDS sedimentation volume.

Gel protein levels are listed in Table 22.

Thus only Florida, Pernel, Hereward and Future bran and offal reduced the gel-protein content of Mercia, and Kanzler increased it. Mercia bran and offal improved gel-protein contents of Florida, and Hereward wholemeal, and Festival, Fresco and Maris Widgeon were adversely affected.

This aspect of the study is worthy of more detailed investigation. It remains an objective of the final years of the ECLAIR project of which the work described here is a part.

Measurement of reducing glycosides on the bran and offal of selected varieties showed no difference in amount between varieties of different baking quality and so was not pursued during the time period covered by this report.

A major objective of the study of wholemeal baking performance is to answer the question, can you predict wholemeal baking quality from that of white? The answer, on the basis of the work reported here, is probably not, although wholemeal loaf volume could be predicted from the individual influences of endosperm and bran and offal. More complex statistical treatment of the data may provide more precise predictive ability.

4. GENERAL DISCUSSION

This project has highlighted the importance of the work-input requirement of wheat varieties in establishing their baking performance. The goal of finding new quality tests has been partially achieved. The study of gel-protein has shown that the "extra-strong" character of Fresco can be predicted from measurements of the breakdown rate or elastic modulus of that fraction of wheat protein. Indeed these methods have now become part of the testing programme for Recommended List trial samples (starting in the 1991 harvest).

HGCA project number 0018/1/91, "Improvement of methods for measuring the quality of breadmaking wheat" has as one of its objectives the determination of optimum work-input requirements of wheat varieties on a small scale. The methods described in this report require large quantities (approx. 40kg wheat for white and wholemeal).

The influence of bran and offal in removing the "extra-strong" characteristic of Fresco, is as yet unexplained. It is probable that reducing power is involved. Future work (up to Dec 1994) under the ECLAIR programme will attempt to address this aspect.

The use of "extra-strong" varieties in the manufacture of wholemeal, is restricted by the protein content achieved in the UK environment of high yields and temperate wet summers.

With gluten fortification Fresco achieved reasonable loaf quality, but did not show any clear advantage over Mercia. It is therefore doubtful if such varieties have any special role in the UK breadmaking industry, and it is to be hoped that this trait in the breeding stock will be replaced by more adaptable characteristics.

Interchanging bran and offal in wholemeal was inconclusive in establishing the cause of the variability in breadmaking performance. That a correlation could be achieved by predicting the loaf volume from a wholemeal flour on the basis of the endosperm and bran and offal quality relative to that of Mercia indicates that some underlying quality aspects are influential, but it is clear that grain hardness and wheat quality are important factors that confuse the prediction of wholemeal loaf volume from that of white.

The evidence that soft varieties are beneficial was confirmed in the two French varieties Gala and Festival, but the lower water absorption would lower yield of dough, with an economic disadvantage. They might still have a role, since lower protein contents might be useable, i.e. reducing the levels of gluten fortification may have a cost benefit.

This study has introduced three new tests of wheat quality, gel-protein breakdown rate, gel-protein elastic modulus (G') and stress relaxation of freshly mixed yeasted bread doughs.

The two gel-protein tests would have predicted the problems with Pastiche and Fresco and are increasingly being used for quality assessment. The stress relaxation test has enabled doughs containing yeast, oxidants and emulsifiers to be assessed with good prediction of loaf volume. Predictive ability appears to include white, wholemeal and gluten fortified wholemeals. An initial study of the use of the Alveograph, already widely used in relation to export quality[14], would be a more practical alternative to the Bohlin VOR, a sophisticated rheometer. Further work with the Alveograph will be carried out under HGCA Project No. 0018/1/91.

5. CONCLUSIONS

- Wheat varieties vary in their optimum work-input requirement in the CBP from 5 Wh/kg to 20 Wh/kg in white bread.
- "Extra-strong" varieties such as Fresco are suitable for blending with weaker varieties in white bread, and may be superior to other varieties in wholemeal.
- In a traditional baking process several varieties, spanning a wide baking quality range showed a common lack of tolerance to increased fermentation time probably due to a lack of fermentable sugars for the yeast.
- In wholemeal, "extra-strong" varieties lose their high work-input requirement, and baking performance is more influenced by protein content than is white bread.
- Gluten fortification of wholemeal did not change the work-input requirement of Fresco and Mercia.
- High levels of cereal *alpha*-amylase (up to 100 FU) have a smaller influence on crumb properties such as density, resilience and stickiness in wholemeal than they do in white bread.

- It was not possible to predict wholemeal loaf volume from that of white without making allowance for wheat quality attributes such as hard versus soft milling or "extra-strong" character.
- Wholemeal loaf volume of a test variety could be predicted from that of wholemeal from a Mercia control using estimates of the relative quality of the endosperm and bran and offal fractions of the two varieties.
- A number of new wheat quality assessment methods have evolved from this study, of which the elastic modulus of the glutenin fraction (gel-protein) and the stress relaxation of yeasted doughs show promise. These methods have already been adopted as part of the assessment of varieties in Recommended List Trials.

6. ACKNOWLEDGEMENTS

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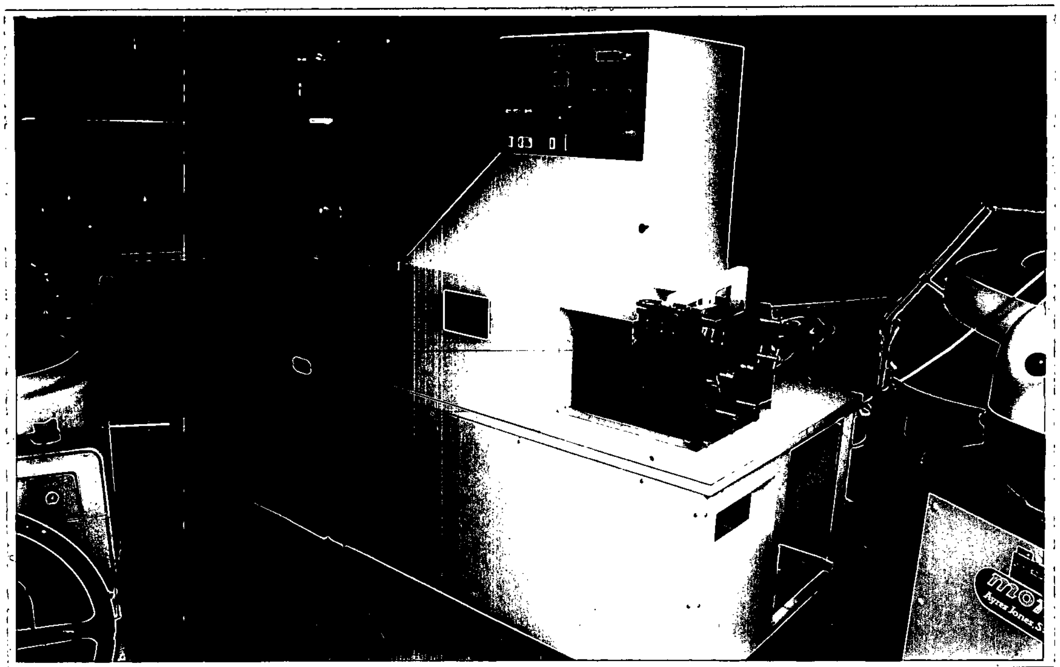
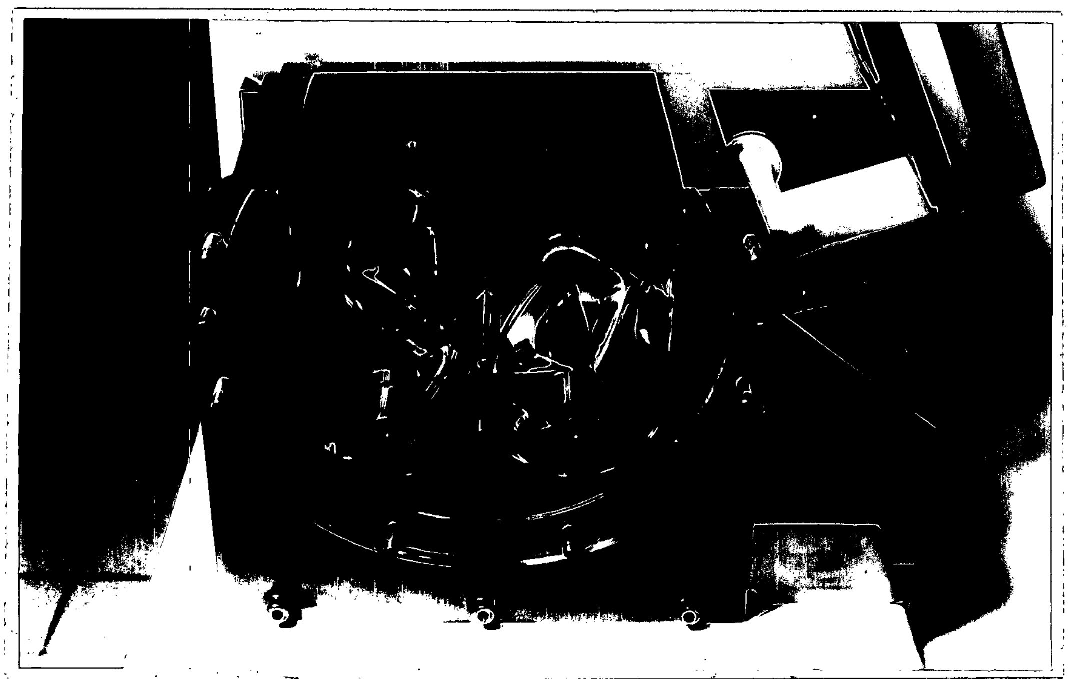
FIG 1

The new pilot-scale bread mixer at FMBRA



The mixer



The mixing head

TABLE 1

Wheat and flour analysis for varieties used from both 1989 and 1990 harvests

WHEAT

		Moisture %	Protein %	Falling No. (7g) s
Fresco	89	14.0	10.6	413
	90	15.7	10.7	419
Galahad	89	13.5	11.8	314
	90	13.1	10.5	349
Hereward	89	13.0	13.0	435
	90	13.9	11.4	408
Haven	89	13.2	11.3	336
	90	12.5	10.2	294
Pastiche	89	13.2	12.8	432
	90	15.5	11.4	348
Riband	89	14.0	10.6	267
	90	13.4	10.5	349

FLOUR

		Moist %	Prot %	Fall. No. (7g) s	GCF	Damaged starch FU	Alpha-amylase FU	Water abs %
Fresco	89	14.2	9.3	388	-1.8	20	1	51.4
	90	14.8	9.9	391	-3.1	29	1	53.6
Galahad	89	14.1	10.2	376	-1.1	8	2	51.0
	90	13.4	9.2	357	-0.4	10	3	53.2
Hereward	89	13.6	11.8	460	-0.5	23	1	55.4
	90	14.1	10.4	379	-2.5	24	1	55.4
Haven	89	14.0	9.7	354	-0.4	16	4	50.7
	90	13.5	9.2	331	0.5	25	4	55.7
Pastiche	89	14.5	11.2	387	-2.1	15	1	54.6
	90	13.7	10.5	462	-2.2	25	1	55.7
Riband	89	14.2	9.7	244	-1.3	9	7	50.7
	90	14.2	9.1	314	-1.8	11	1	49.6

TABLE 2

Work-input requirements, loaf volume and crumb structure score of white flours from both 1989 amd 1990 harvests

		Optimum Work-input Wh/kg	Loaf volume ml	Crumb score Max 10	Whole Loaf score Max 10
Fresco	89	17	1642	8	9
	90	18	1613	7	8
Galahad	89	8	1453	6	4
	90	9	1429	3	6
Haven	89	5	1557	4	7
	90	5	1557	4	7
Hereward	89	14	1627	8	9
	90	13	1763	9	9
Pastiche	89	10	1503	9	7
	90	12	1563	8	8
Riband	89	5	1401	6	4
	90	5	1387	6	4

TABLE 3

Optimum work-input requirements from three milling methods 1990 harvest

	Optimum Work-input Wh/kg	Loaf volume ml	Crumb score Max 10	Whole Loaf score Max 10
Galahad 90				
Standard	7	1435	5	5
RA Commercial	9	1417	4	4
Commercial	8	1272	4	3
Pastiche 90				
Standard	12	1563	8	8
RA Commercial	11	1547	8	8
Commercial	12	1477	6	7
Riband 90				
Standard	5	1387	6	4
RA Commercial	5	1348	4	3
Commercial	5	1236	4	3

TABLE 4

Wheat and flour analysis of UK and French varieties

Harvest year	Fresco 1990	Hereward 1990	Mercia 1990	Riband 1990	Gala 1991	Festival 1991
14 grain electrophoresis	Pure	Pure	Pure	Pure	Pure	13/14
Flour						
Moisture %	14.5	1.42	14.3	13.7	13.7	13.9
Protein N x 5.7 %	10.2	10.8	8.4	7.4	9.6	10.3
Grade Colour Figure	-1.2	19.9	-1.9	-2.7	-1.8	-0.6
Falling No. (7g) s	426	420	403	352	345	356
Damaged starch FU	34	21	29	14	12	12
Alpha-amylase FU	1	1	1	2	1	2
Water absorption (10 min)	57.5	55.4	54.3	48.2	51.4	53.9
Gel-protein g/5g	10.32	10.79	6.82	6.98	9.75	11.08

TABLE 5

The influence of work-input and mixer speed on the baking performance of wheat varieties

A. FRESCO

Work-input, Wh/kg		8	11	14	17	20
600 RPM						
Mixing time, s		56	77	108	116	125
Loaf volume, ml		1478	1637	1634	1734	1723
Crumb score, max 10		6	8	9	8	9
Loaf score, max 10		7	8	8	8	9
Gel protein, 5g dough	A	6.18	1.59	1.11	0.46	0.40
	B	10.11	9.17	7.53	6.54	6.25
ISR (1/s)	M1	-4400	-6386	-3372	-6610	-6682
	M2	-70	-61	-61	-89	-72
500 RPM						
Mixing time, s		73	104	120	145	167
Loaf volume, ml		1503	1621	1632	1626	1659
Crumb score, max 10		5	7	8	7	7
Loaf score, max 10		8	8	6	7	7
Gel protein, 5g dough	A	3.61	1.02	0.31	0.45	0.15
	B	8.93	7.45	6.48	4.85	4.83
ISR (1/s)	M1	-3661	-3702	-5061	-8823	-4728
	M2	-58	-56	-73	-86	-84
400 RPM						
Mixing time, s		100	136	167	201	240
Loaf volume, ml		1471	1531	1635	1637	1613
Crumb score, max 10		5	7	7	7	6
Loaf score, max 10		8	8	6	8	8
Gel protein, 5g dough	A	4.06	1.65	0.27	0.18	0.19
	B	9.98	10.26	7.17	7.21	4.81
ISR (1/s)	M1	-5390	-4040	-4251	-5443	
	M2	-50	-73	-84	-57	
300 RPM						
Mixing time, s		170	224	280	330	398
Loaf volume, ml		1453	1563	1559	1598	1598
Crumb score, max 10		5	6	6	6	7
Loaf score, max 10		7	7	5	7	7
Gel protein, 5g dough	A	2.37	0.66	0.24	0.40	0.21
	B	10.73	7.83	7.75	5.76	5.45
ISR (1/s)	M1	-7038	-8172	-6646	-12598	-7656
	M2	-106	-146	-114	-75	-136
250 RPM						
Mixing time, s		202	292	353	451	574
Loaf volume, ml		1368	1447	1500	1539	1565
Crumb score, max 10		4	5	6	8	7
Loaf score, max 10		4	7	7	7	7
Gel protein, 5g dough	A	4.54	1.42	0.39	0.22	0.54
	B	10.51	9.33	4.80	4.46	3.18
ISR (1/s)	M1	-5087		-3370	-6232	-4185
	M2	-65		-65	-104	-63

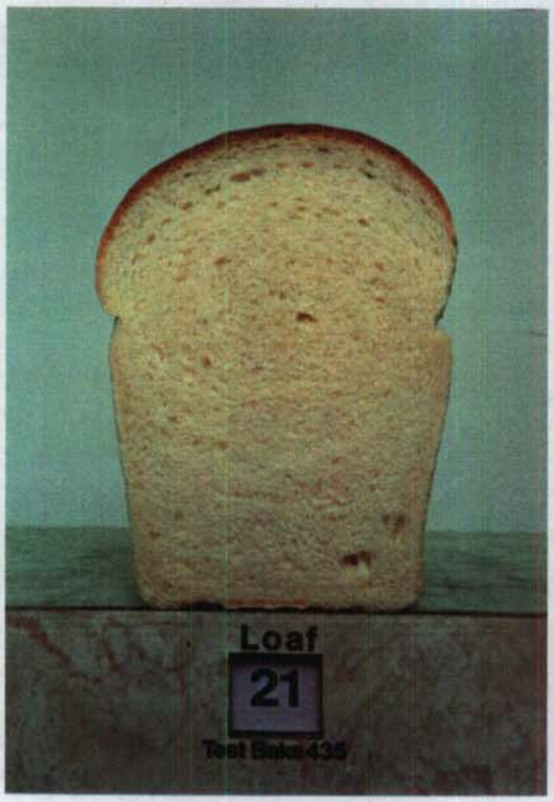
ISR = Stress relaxation on Bohlin VOR

FIG 2A

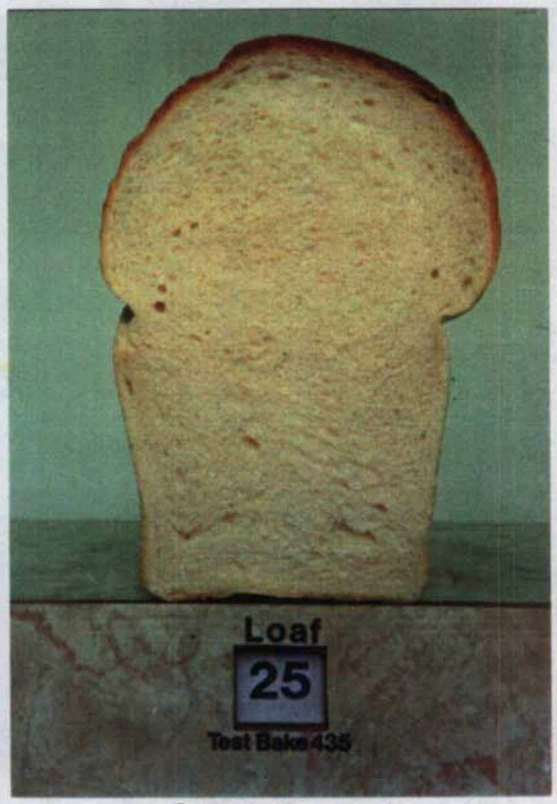
FRESCO
White

8Wh/kg | 20Wh/kg

600 rev/min

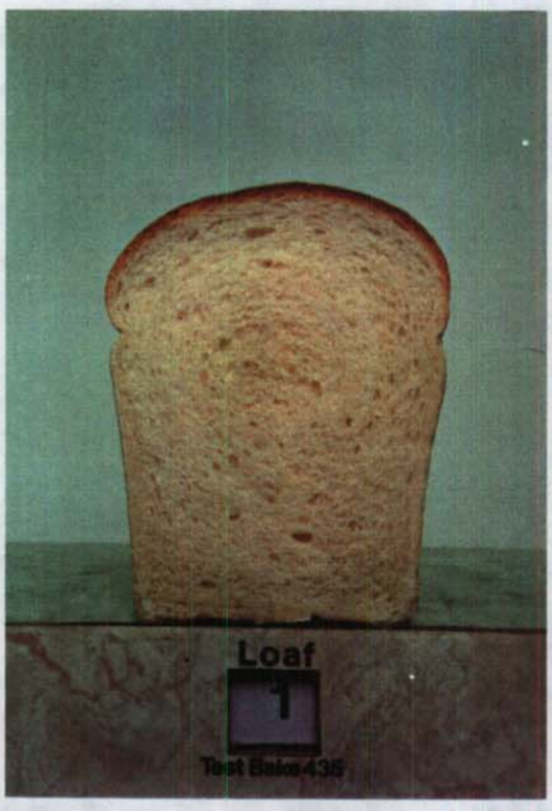


1478 ml



1723 ml

250 rev/min



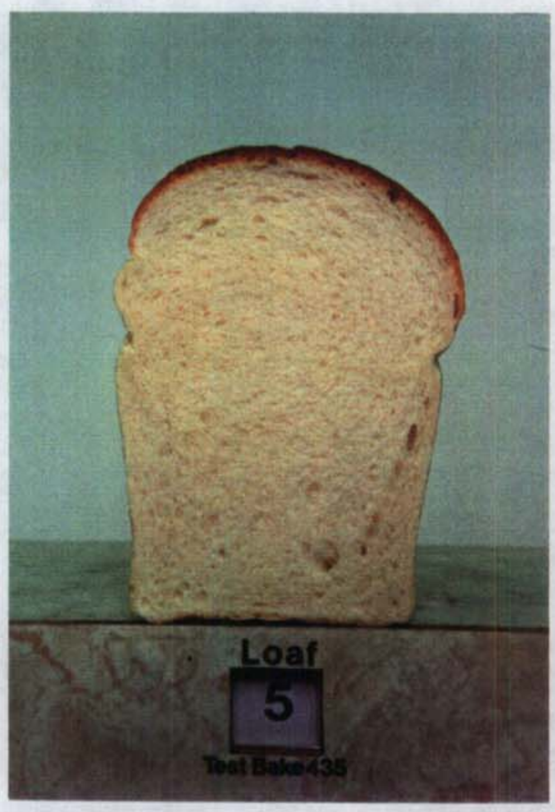


TABLE 5 cont/d

B. HEREWARD

Work-input, Wh/kg		8	11	14	17	20
600 RPM						
Mixing time, s		47	62	73	88	108
Loaf volume, ml		1656	1658	1821	1809	1793
Crumb score max 10		6	7	8	8	7
Loaf score, max 10		7	8	9	8	8
Gel protein, 5g dough	A	0.73	1.07	0.70	0.51	0.35
	B	1.41	1.30	1.21	1.34	1.30
ISR (1/s)	M1	-1424	-1013	-946	-756	-798
	M2	-12	-10	-9	-10	-10
500 RPM						
Mixing time, s		70	95	111	106	123
Loaf volume, ml		1678	1700	1684	1856	1935
Crumb score, max 10		7	8	7	8	7
Loaf score, max 10		7	8	7	8	9
Gel protein, 5g dough	A	0.57	0.40	0.37	0.41	0.65
	B	1.10	1.37	1.55	1.52	1.28
ISR (1/s)	M1	-1435	-1090	-954	-1209	
	M2	-12	-17	-13	-9	
400 RPM						
Mixing time, s		99	135	159	179	206
Loaf volume, ml		1716	1802	1847	1772	1809
Crumb score, max 10		7	8	7	6	6
Loaf score, max 10		10	10	9	9	9
Gel protein, 5g dough	A	0.74	0.48	0.41	0.38	0.50
	B	1.20	1.51	1.38	1.27	1.34
ISR (1/s)	M1	-1154	-1079	-1246	-2197	-1576
	M2	-10	-8	-16	-15	-11
300 RPM						
Mixing time, s		139	174	231	280	331
Loaf volume, ml		1688	1759	1770	1825	1790
Crumb score, max 10		7	7	6	6	6
Loaf score, max 10		8	9	9	9	9
Gel protein, 5g dough	A	0.52	0.77	0.58	0.76	0.62
	B	1.73	1.81	1.64	1.62	1.38
ISR (1/s)	M1	-662	-713	-1517		-1859
	M2	-12	-13	-20		-14
250 RPM						
Mixing time, s		182	246	300	368	440
Loaf volume, ml		1646	1756	1714	1781	1707
Crumb score, max 10		6	8	7	6	6
Loaf score, max 10		7	8	7	8	8
Gel protein, 5g dough	A	0.56	0.59	1.31	0.72	0.62
	B	1.42	1.38	1.26	1.11	1.31
ISR (1/s)	M1	-1212	-806		-696	-702
	M2	-15	-14		-12	-14

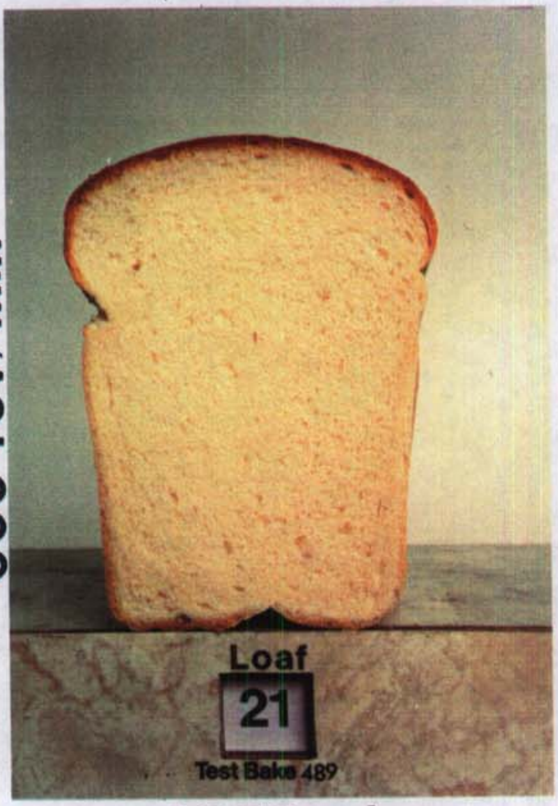
FIG 2B

HEREWARD

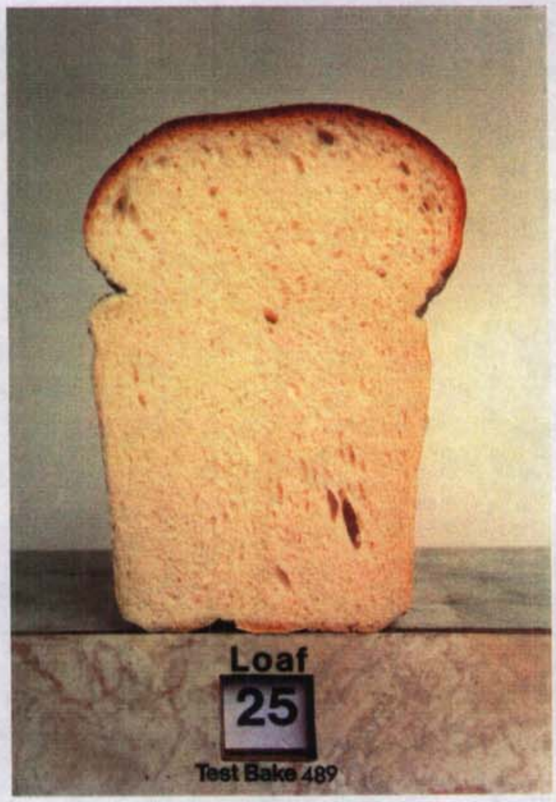
White

	8 Wh/kg	20 Wh/kg

600 rev/min

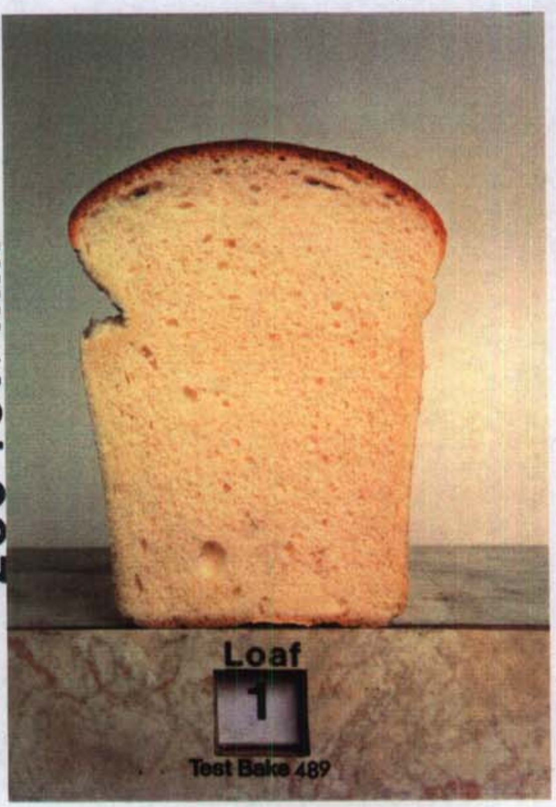


1656 ml

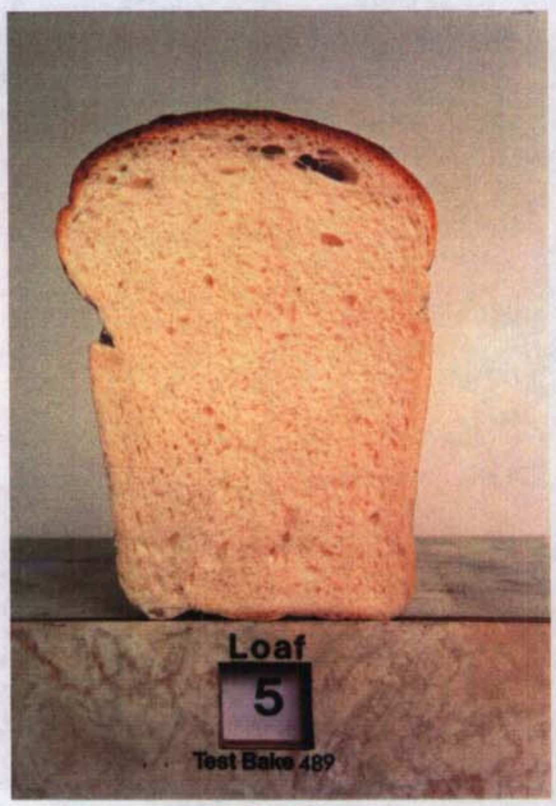


1793 ml

250 rev/min



1646 ml



1707ml

Table 5 cont/d

C. MERCIA

Work-input, Wh/kg		5	8	11	14	17
600 RPM						
Mixing time, s		41	72	90	104	116
Loaf volume, ml		1499	1623	1573	1645	1629
Crumb score max 10		5	8	9	8	7
Loaf score, max 10		7	8	9	8	8
Gel protein, 5g dough	A	1.78	0.61	0.41	0.92	0.32
	B	1.80	1.52	1.50	1.28	1.39
ISR (1/s)	M1					-3078
	M2					-11
500 RPM						
Mixing time, s		60	74	111	115	142
Loaf volume, ml		1516	1609	1607	1644	1635
Crumb score, max 10		5	7	7	7	7
Loaf score, max 10		7	7	8	8	8
Gel protein, 5g dough	A	1.64	0.58	0.26	0.30	0.30
	B	2.08	1.71	1.79	1.23	1.11
ISR (1/s)	M1				-2091	
	M2				-23	
400 RPM						
Mixing time, s		63	90	118	141	160
Loaf volume, ml		1510	1616	1610	1624	1614
Crumb score, max 10		5	7	8	7	7
Loaf score, max 10		6	9	8	8	8
Gel protein, 5g dough	A	1.78	0.66	0.39	0.44	0.32
	B	2.32	1.86	1.89	1.83	1.76
ISR (1/s)	M1			-3161		
	M2			-26		
300 RPM						
Mixing time, s		98	160	197	234	280
Loaf volume, ml		1537	1575	1631	1621	1649
Crumb score, max 10		5	8	8	6	6
Loaf score, max 10		6	8	8	8	8
Gel protein, 5g dough	A	0.89	0.32	0.42	0.31	0.47
	B	1.63	1.60	1.20	1.45	1.20
ISR (1/s)	M1		-3405			
	M2		-20			
250 RPM						
Mixing time, s		142	210	280	296	363
Loaf volume, ml		1526	1552	1544	1571	1591
Crumb score, max 10		6	8	8	7	7
Loaf score, max 10		7	8	7	8	8
Gel protein, 5g dough	A	0.68	1.17	1.02	0.48	0.46
	B	3.00	1.52	1.34	1.37	1.12
ISR (1/s)	M1	-4786				
	M2	-41				

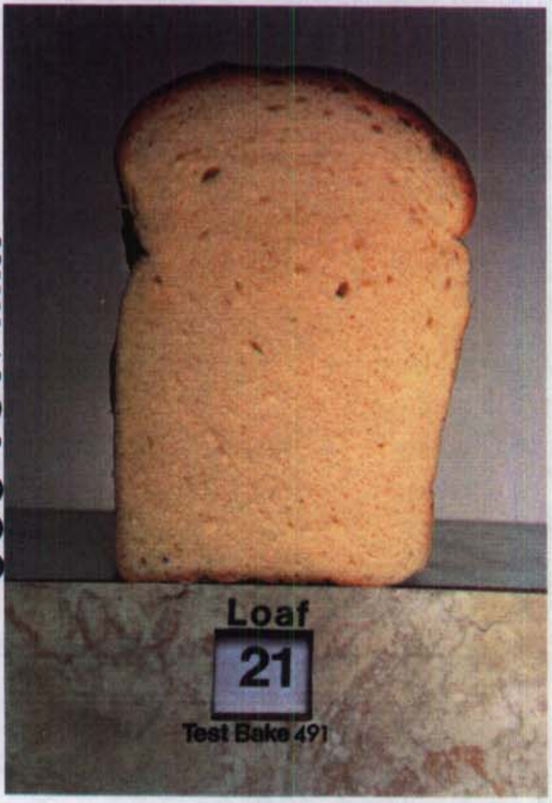
FIG 2C

MERCIA

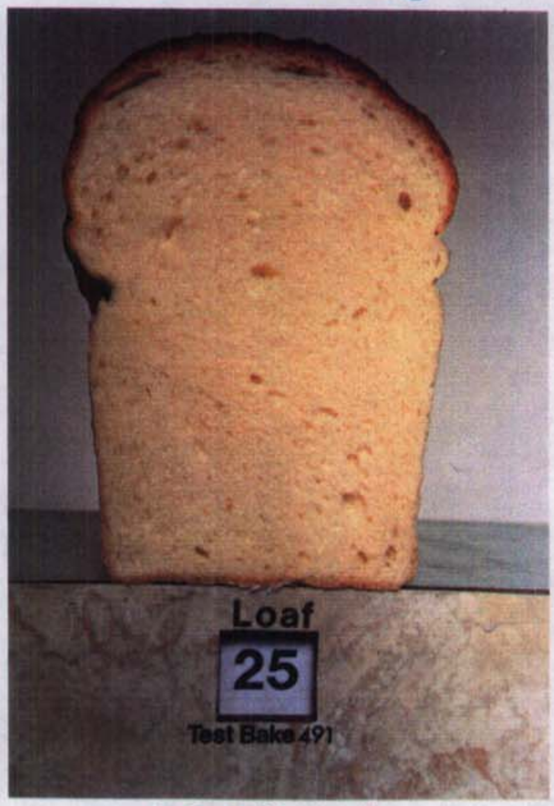
White

	5 Wh/kg	17 Wh/kg

600 rev/min

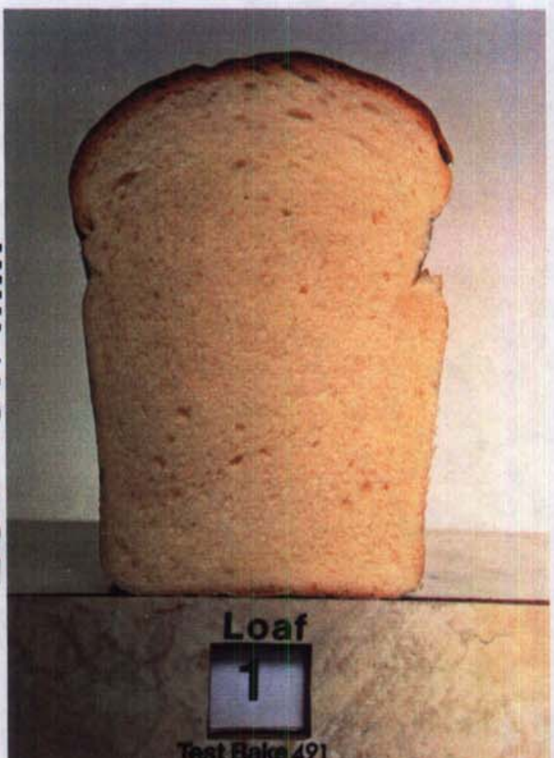


1499 ml

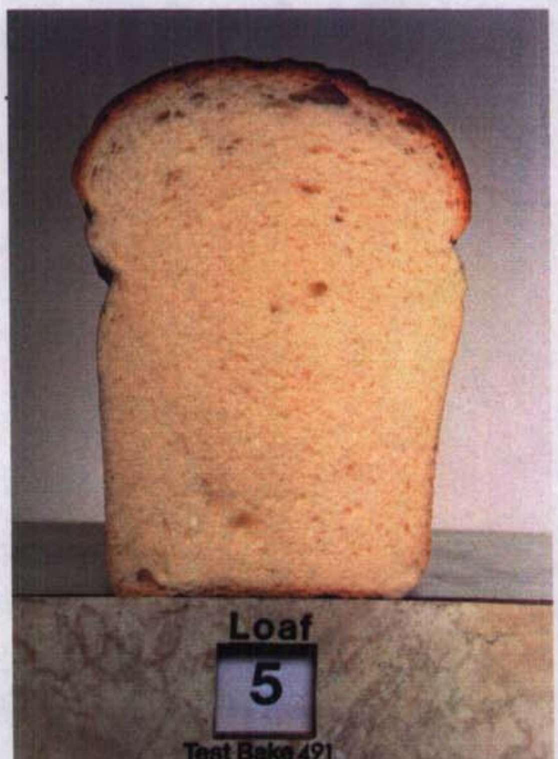


1629 ml

250 rev/min



1526 ml



1591 ml

Table 5 cont/d

D. RIBAND

Work-input, Wh/kg		3	5	8	11	14
600 RPM						
Mixing time, s		29	46	64	80	88
Loaf volume, ml		1371	1401	1438	1440	1459
Crumb score max 10		5	6	5	5	5
Loaf score, max 10		5	6	6	6	6
Gel protein, 5g dough	A	0.74	0.41	0.38	0.25	0.28
	B	0.51	0.49	0.40	0.63	0.50
ISR (1/s)	M1					-4411
	M2					-39
500 RPM						
Mixing time, s		37	61	71	93	106
Loaf volume, ml		1370	1402	1433	1452	1449
Crumb score, max 10		5	6	5	5	5
Loaf score, max 10		6	6	6	6	6
Gel protein, 5g dough	A	0.44	0.44	0.35	0.25	0.17
	B	0.81	0.48	0.36	0.43	0.67
ISR (1/s)	M1				-6163	
	M2				-43	
400 RPM						
Mixing time, s		42	66	85	111	136
Loaf volume, ml		1409	1414	1451	1456	1456
Crumb score, max 10		5	5	6	6	6
Loaf score, max 10		6	6	6	5	6
Gel protein, 5g dough	A	0.92	0.42	0.34	0.42	0.33
	B	0.47	0.56	0.52	0.52	0.47
ISR (1/s)	M1			-5185		
	M2			-56		
300 RPM						
Mixing time, s		48	78	113	162	198
Loaf volume, ml		1428	1398	1430	1477	1433
Crumb score, max 10		5	6	7	7	6
Loaf score, max 10		5	6	6	5	6
Gel protein, 5g dough	A	0.44	0.38	0.34	0.42	0.42
	B	0.86	0.61	0.52	0.43	0.34
ISR (1/s)	M1		-4338			
	M2		-40			
250 RPM						
Mixing time, s		56	103	154	216	260
Loaf volume, ml		1366	1392	1427	1453	1455
Crumb score, max 10		5	6	7	7	7
Loaf score, max 10		5	5	6	6	5
Gel protein, 5g dough	A	0.34	0.26	0.36	0.63	0.36
	B	0.70	0.75	0.41	0.43	0.41
ISR (1/s)	M1	-19754				
	M2	-69				

FIG 2D

RIBAND
White

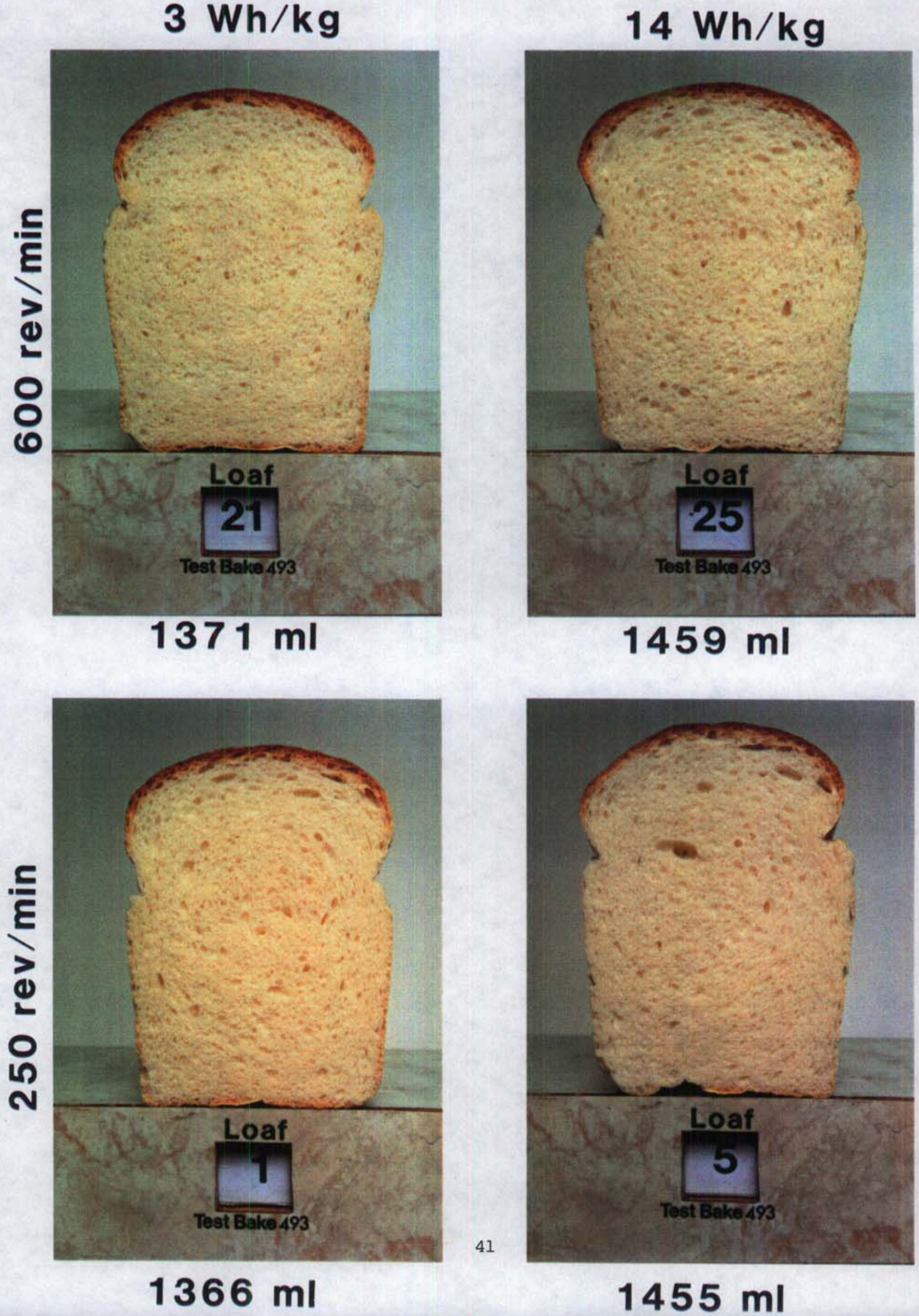


Table 5 cont/d

E. GALA

Work-input, Wh/kg		5	8	11	14	17
600 RPM						
Mixing time, s		41				118
Loaf volume, ml		1489				1674
Crumb score max 10		6				7
W (x 10 Joules)						88.7
ISR (1/s)	M1					-1759.6
	M2					-17.2
500 RPM						
Mixing time		44			155	
Loaf volume, ml		1476			1668	
Crumb score, max 10		6			7	
W (x 10 Joules)					99.24	
ISR (1/s)	M1				-1579.6	
	M2				-17.9	
400 RPM						
Mixing time, s		63		115		
Loaf volume, ml		1534		1672		
Crumb score, max 10		6		8		
W (x 10 Joules)				91.02		
ISR (1/s)	M1			-1593.2		
	M2			-16.2		
300 RPM						
Mixing time, s		78	131			
Loaf volume, ml		1512	1633			
Crumb score, max 10		6	7			
W (x 10 Joules)			118.4			
ISR (1/s)	M1		-1378.5			
	M2		-12.7			
250 RPM						
Mixing time, s		109	175	208	257	285
Loaf volume, ml		1524	1609	1691	1683	1689
Crumb score, max 10		7	7	8	6	8
W (x 10 Joules)		111.9				
ISR (1/s)	M1	-1783.2				
	M2	-19.4				

Stress relaxation on Bohlin VOR
W (x 10 Joules). The area under the curve ISR (proportional to the energy required to unflate the bubble until it bursts and therefore related to the strength of the dough)

FIG 2E

GALA
White

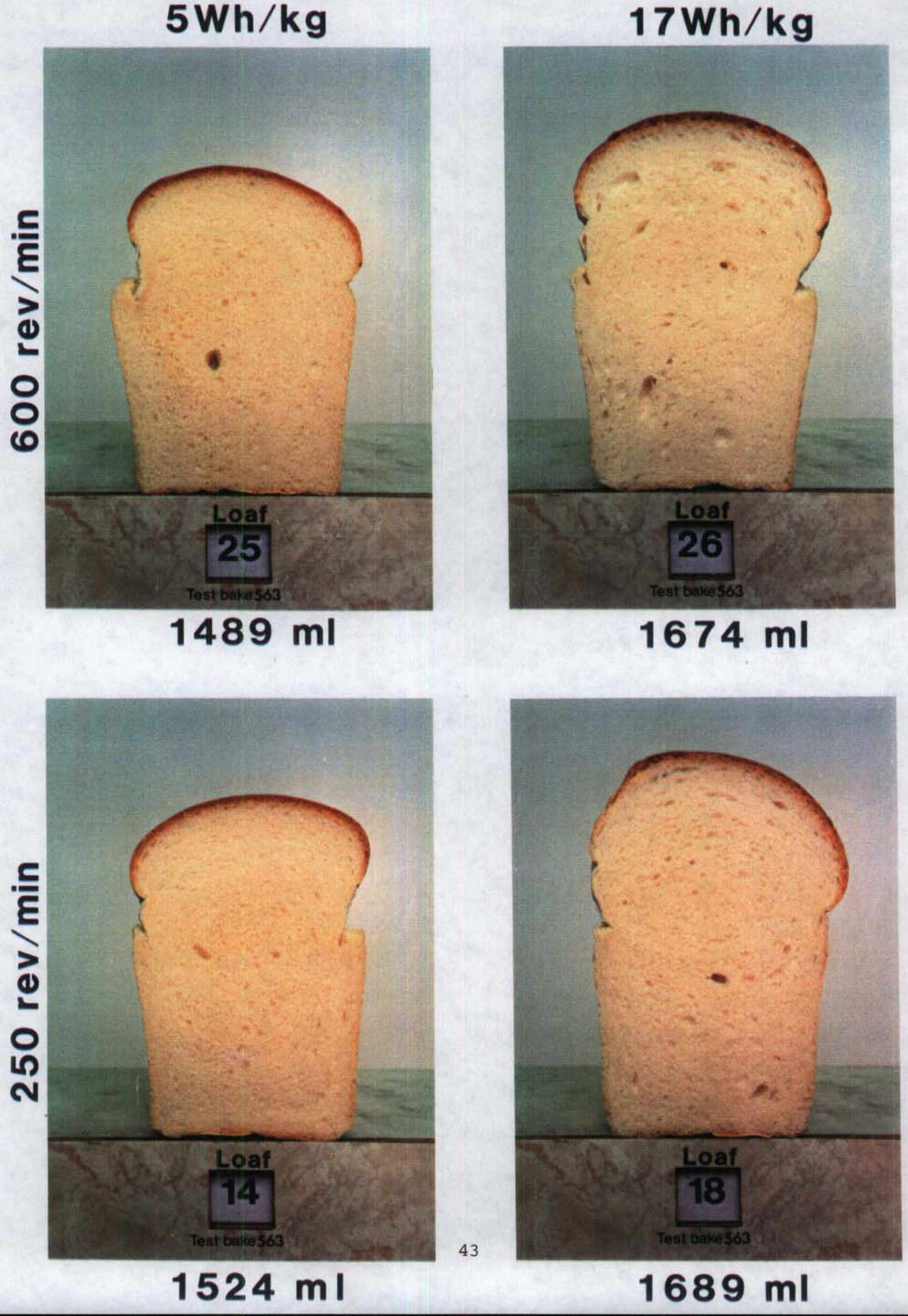


Table 5 cont/d

F. FESTIVAL

Work-input, Wh/kg		5	8	11	14	17
600 RPM						
Mixing time, s		46				107
Loaf volume, ml		1438				1650
Crumb score, max 10		5				6
W (x 10 Joules)						106.8
ISR (1/s)	M1					-1403.6
	M2					-20.6
500 RPM						
Mixing time, s		51			110	
Loaf volume, ml		1450			1605	
Crumb score, max 10		5			7	
W (x 10 Joules)					112.7	
ISR (1/s)	M1				-1241.1	
	M2				-18.3	
400 RPM						
Mixing time, s		62		128		
Loaf volume, ml		1455		1603		
Crumb score, max 10		4		8		
W (x 10 Joules)				115.0		
ISR (1/s)	M1			-1711.4		
	M2			-19.5		
300 RPM						
Mixing time, s		91	146			
Loaf volume, ml		1493	1567			
Crumb score, max 10		4	6			
W (x 10 Joules)			104.2			
ISR (1/s)	M1		-1448.5			
	M2		-17.2			
250 RPM						
Mixing time, s		129	187	253	298	325
Loaf volume, ml		1404	1535	1554	1603	1609
Crumb score, max 10		5	7	7	6	7
W (x 10 Joules)		137.5				
ISR (1/s)	M1	-1904.4				
	M2	-19.6				

ISR: Stress Relaxation on Bohlin VOR
W (x 10 Joules): The area under the curve (proportional to the energy required to inflate the bubble until it bursts and therefore related to the strength of the dough)

FIG 2F

FESTIVAL

White

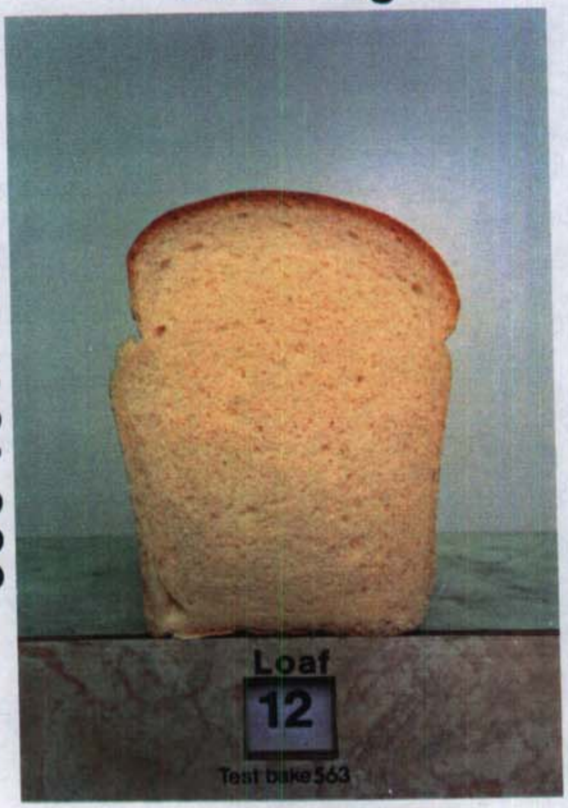
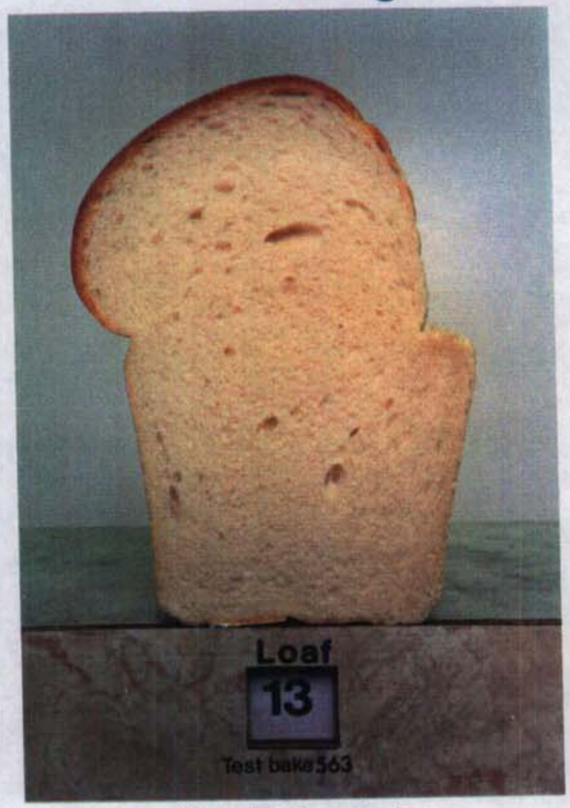
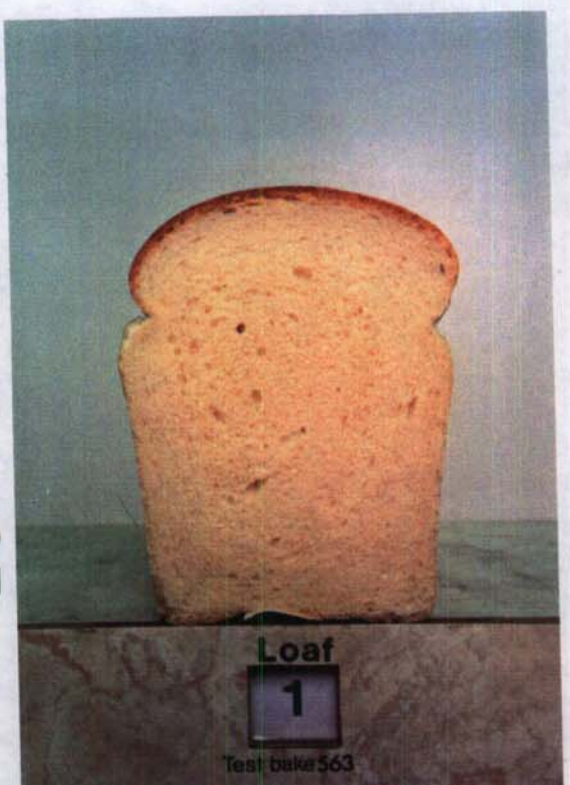
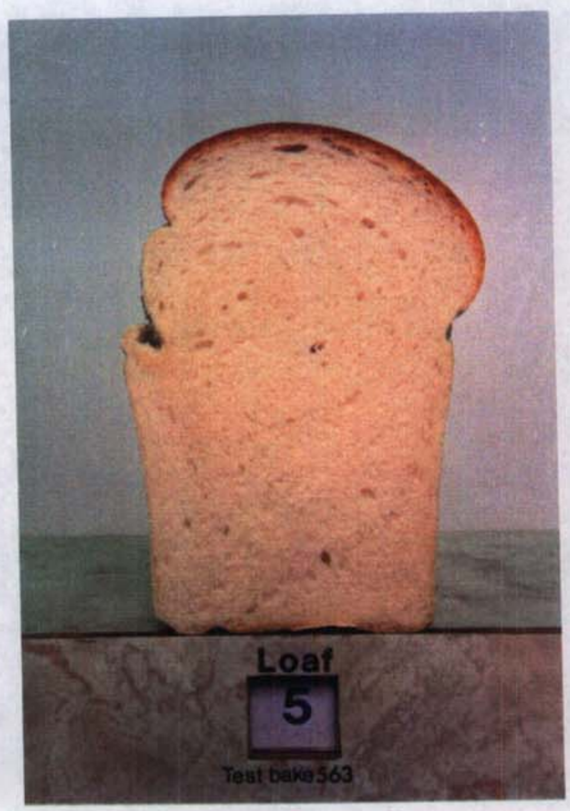
	5Wh/kg	17Wh/kg
600 rev/min	 1438 ml	 1650 ml
250 rev/min	 1404 ml	 1609 ml

TABLE 6

Fermentation tolerance tests - loaf characteristics

A. Average loaf volumes (ml)

Bulk fermentation time (hrs)	1.0	1.5	2.0	2.5	3.0	3.5
CWRS/89	1728	1715	1696	1522	1619	1368
Hereward/89	1461	1467	1459	1375	1402	1331
Mercia/89	1490	1466	1465	1374	1442	1428
Haven/89	1514	1579	1519	1405	1467	1334

B. Average crumb structure scores (max 10)

CWRS/89	8.0	8.0	7.5	5.5	7.5	2.0
Hereward/89	7.5	8.0	8.0	4.5	7.0	3.5
Mercia/89	7.0	7.0	8.0	5.0	6.5	4.0
Haven/89	7.0	7.5	8.0	7.0	7.5	5.0

C. Average whiteness values (Hunterlab "Y" value)

CWRS/89	58.53	59.06	59.03	56.54	57.20	52.18
Hereward/89	59.02	59.73	59.61	55.87	58.00	52.63
Mercia/89	58.66	57.58	57.43	55.74	56.53	52.65
Haven/89	56.56	57.67	56.89	54.38	55.72	52.14

TABLE 7

Optimum work-input requirements, loaf volume and crumb structure score of flours from blends of strong and weak varieties

Blend	Optimum Work-input Wh/kg	Loaf volume ml	Crumb score Max 10	Whole Loaf score Max 10
Fresco/Riband 89 harvest				
Fresco 25%-Riband 75%	11	1508	8	6
Fresco 50%-Riband 50%	10	1652	9	9
Fresco 75%-Riband 25%	13	1708	9	8
Fresco/Galahad 90 harvest				
Fresco 25%-Galahad 75%	11	1548	7	6
Fresco 50%-Galahad 50%	13	1640	8	9
Fresco 75%-Galahad 25%	15	1677	8	8
Fresco/Haven 90 harvest				
Fresco 25%-Haven 75%	8	1604	6	7
Fresco 50%-Haven 50%	10	1668	8	8
Fresco 75%-Haven 25%	15	1654	8	9
Hereward/Galahad 89 harvest				
Hereward 25%-Galahad 75%	8	1437	6	2
Hereward 50%-Galahad 50%	12	1481	8	6
Hereward 75%-Galahad 25%	11	1566	8	8
Hereward/Mercia 89 harvest				
Hereward 25%-Mercia 75%	9	1526	8	8
Hereward 50%-Mercia 50%	11	1563	9	6
Hereward 75%-Mercia 25%	12	1566	8	7
Hereward/Haven 90 harvest				
Hereward 25%-Haven 75%	7	1593	5	7
Hereward 50%-Haven 50%	10	1615	6	7
Hereward 75%-Haven 25%	11	1638	8	8

Fig 3. Initial Stress Relaxation Rate of Yeasted Bread Doughs

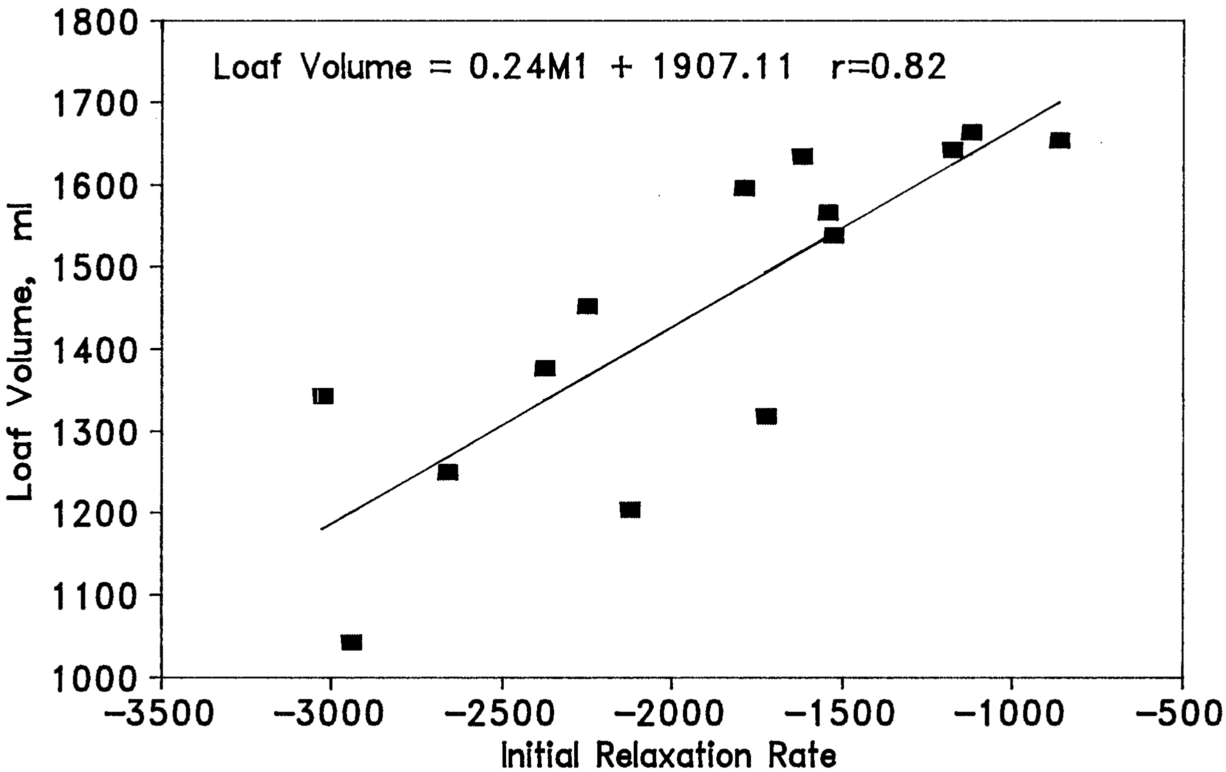


TABLE 8

Gel-protein weight, breakdown rate and elastic modulus (G') of selected UK and French varieties

	Weight g/5g	Breakdown rate 1/min	G' Pa
White			
Fresco	10.32	<0.03	NA
Hereward	10.77	0.31	NA
Mercia	6.77	0.10	NA
Riband	6.98	0.36	NA
Gala	9.47	0.39	24.9
Festival	11.05	0.09	36.2
Wholemeal			
Fresco	7.70	<0.03	NA
Hereward	9.68	0.29	NA
Mercia	4.98	0.11	NA
Riband	5.57	NA	NA
Gala	8.34	0.30	17.1
Festival	10.62	0.10	14.0

NA: Measurement not made

TABLE 9

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

	WHEATS		
	CWRS	**European-89**	**European-90**
Grist composition	CWRS 100%	All-European 100%	All-European 100%
Wheat variety			
Electrophoresis (based on 14 or 28 grains)	Katepwa/Neepawa 21 Columbus 6 Pattern A 1	Pastiche 27 Slejpner 1	Pastiche 13 Avalon 1
Wheat analysis			
Protein (N x 5.7 on 14% m.b.), %	15.2	12.5	12.5
Falling No. (7g) s	454	432	420
SDS sedimentation volume, ml	72	NA	8.3
Moisture (130°C for 1.5h), %	13.7	15.0	15.0
Alpha-amylase, Farrand Units	3	1	1
Wholemeal flour analysis			
Protein (N x 5.7 on 14% m.b.), %	15.4	12.8	11.0
Moisture (130°C for 1.5h), %	13.5	13.6	13.6
Alpha-amylase, Farrand Units	3	2	2
Water absorption (10 min method), %	66.1	62.9	60.7
Particle size distribution			
Sieve size (microns)		**% Material**	
>1000	1.8	1.4	1.7
>850	2.6	2.2	2.7
>500	9.0	9.0	9.8
>300	5.6	5.8	5.3
>180	4.6	4.8	4.7
<180	76.4	76.8	75.8

TABLE 10

Sensitity of wholemeal to *alpha*-amylase

Average loaf volume (ml)

Cereal *alpha*-amylase content (FU)	0	5	10	20	30	50	75	100
CBP								
RM-C89	3116	3126	3150	3129	3109	3071	3100	3060
RM-E89	3077	3168	3132	3119	3158	3141	3142	3139
RM-E90	3119	3122	3173	3150	3221	3159	3106	3089

Standard deviation of a single replicate = 42.02
Least significant differnece (LSD) at 5% of two means = 87

LSM								
RM-C89	3043	3088	3067	3128	3096	3122	3097	3136
RM-E89	2987	2980	2976	3002	3028	3087	2988	3057
RM-E90	2912	2931	2891	2882	2888	3016	2953	2915

Standard deviation of a single replicate = 42.36
Least significant difference (LSD) at 5% of two means = 88

TABLE 11

Sensitity of wholemeal to *alpha*-amylase

Average crumb structure socres (max 10)

Cereal *alpha*-amylase content (FU)	0	5	10	20	30	50	75	100
CBP								
RM-C89	6.5	7.5	7.0	6.5	6.0	6.5	6.0	6.5
RM-E89	6.5	7.5	6.5	6.5	5.5	6.5	5.5	6.0
RM-E90	6.0	6.0	7.0	6.5	7.0	4.5	5.5	5.0

Standard deviation of a single replicate = 1.07
Least significant difference (LSD) at 5% of two means = 2

LSM								
RM-C89	7.0	6.5	6.5	6.5	7.5	6.0	5.5	5.5
RM-E89	5.5	6.0	5.5	4.0	5.5	6.0	4.5	6.5
RM-E90	6.0	5.5	5.0	6.5	4.0	5.0	7.0	6.0

Standard deviation of a single replicate = 1.06
Least significant difference (LSD) at 5% of two means = 2

TABLE 12

Sensitivity of wholemeal to *alpha*-amylase

Dry density of bread-crumb (g/ml)

Cereal *alpha*-amylase content (FU)	Core position	0	5	10	20	30	50	75	100
CBP									
RM-C89	top	0.117	0.111	0.115	0.115	0.111	0.106	0.115	0.113
RM-C89	bottom	0.106	0.108	0.110	0.114	0.114	0.105	0.109	0.113
RM-E89	top	0.118	0.113	0.107	0.120	0.104	0.107	0.113	0.113
RM-E89	bottom	0.109	0.113	0.100	0.120	0.107	0.105	0.109	0.105
RM-E90	top	0.093	0.098	0.097	0.096	0.099	0.100	0.115	0.091
RM-E90	bottom	0.091	0.102	0.097	0.101	0.095	0.100	0.094	0.099

Top
Standard deviation of a single replicate = 0.0066
Least significant difference (LSD) at 5% of two means = 0.014

Bottom
Standard deviation of single replicate = 0.0071
Lest significant difference (LSD) at 5% of two means = 0.015

Cereal *alpha*-amylase content (FU)	Core position	0	5	10	20	30	50	75	100
LSM									
RM-C89	top	0.099	0.105	0.108	0.100	0.104	0.112	0.099	0.106
RM-C89	bottom	0.101	0.105	0.110	0.096	0.099	0.093	0.107	0.106
RM-E89	top	0.121	0.122	0.118	0.107	0.112	0.113	0.114	0.104
RM-E89	bottom	0.108	0.120	0.126	0.119	0.112	0.124	0.118	0.126
RM-E90	top	0.119	0.131	0.113	0.126	0.102	0.113	0.091	0.110
RM-E90	bottom	0.123	0.114	0.115	0.128	0.119	0.111	0.119	0.114

Top
Standard deviation of a single replicate = 0.0086
Least significant difference (LSD) at 5% of two means = 0.018

Bottom
Standard deviation of a single replicate = 0.0079
Least significant difference (LSD) at 5% of two means = 0.016

TABLE 13

Sensitivity of wholemeal to *alpha*-amylase

Average crumb resilience scores (max 5)

Cereal *alpha*-amylase content (FU)	0	5	10	20	30	50	75	100
CBP								
RM-C89	3.0	3.0	3.0	3.0	3.0	2.5	2.0	1.0
RM-E89	4.0	3.0	3.5	2.5	3.0	2.0	1.5	1.0
RM-E90	5.0	5.0	4.0	3.5	3.5	2.0	1.5	2.0

Standard deviation of a single replicate = 0.707

LSM								
RM-C89	5.0	5.0	4.0	3.0	3.5	2.5	3.5	2.5
RM-E89	5.0	4.5	4.0	4.0	3.5	3.5	2.0	3.5
RM-E90	5.0	4.5	4.5	5.0	5.0	4.0	3.0	3.5

Standard deviation of a single replicate = 0.612

TABLE 14

Sensitivity of wholemeal to *alpha*-amylase

Crumb stickiness by Instron (/10 N/m^2)

Cereal *alpha*-amylase content (FU)	Core position	0	20	50	100
CBP					
RM-C89	top	NA	NA	NA	NA
RM-C89	bottom	NA	NA	NA	NA
RM-E89	top	41.50	66.72	68.22	118.30
RM-E89	bottom	29.30	35.49	93.19	80.10
RM-E90	top	35.70	39.46	45.52	76.89
RM-E90	bottom	34.43	38.41	61.73	90.18

Top
Standard deviation of a single replicate = 17.11
Least significant difference (LSD) at 5% of two means = 39

Bottom
Standard deviation of a single replicate = 18.08
Least significant difference (LSD) at 5% of two means = 42

Cereal *alpha*-amylase content (FU)	Core position	0	20	50	100
LSM					
RM-C89	top	44.50	77.49	63.03	99.99
RM-C89	bottom	95.79	87.16	51.90	83.00
RM-E89	top	47.96	64.15	41.85	87.35
RM-E89	bottom	49.94	109.49	80.65	135.85
RM-E90	top	38.18	119.77	89.98	147.15
RM-E90	bottom	42.56	84.98	73.06	135.84

Top
Standard deviation of a single replicate = 35.01
Least significant difference (LSD) at 5% of two means = 76

Bottom
Standard deviation of a single replicate = 35.93
Least significant difference (LSD) at 5% of two means = 73

NA = Not Available

TABLE 15

Sensitivity of wholemeal to *alpha*-amylase

Dextrin measurements (units/g d.w.b.)

Cereal *alpha*-amylase content (FU)	0	5	10	20	30	50	75	100
CBP								
RM-C89	79	58	118	209	244	365	422	393
RM-E89	96	144	167	205	288	343	466	587
RM-E90	44	78	121	186	264	389	467	608

Standard deviation of a single replicate = 36.94
Least significant difference (LSD) at 5% of two means = 76

Cereal *alpha*-amylase content (FU)	0	5	10	20	30	50	75	100
LSM								
RM-C89	75	88	115	174	197	287	367	378
RM-E89	67	58	118	175	236	318	408	455
RM-E90	167	196	270	355	406	536	663	807

Standard deviation of a single replicate = 25.43
Least significant difference (LSD) at 5% of two means = 53

TABLE 16

Sensitivity of wholemeal to *alpha*-amylase

Amylose measurement (mg/g d.w.b.)

Cereal *alpha*-amylase content (FU)	0	5	10	20	30	50	75	100
CBP								
RM-C89	1.48	1.55	2.34	2.79	3.19	4.62	5.07	5.24
RM-E89	1.87	2.16	2.30	3.08	3.56	4.53	4.96	5.14
RM-E90	2.28	2.56	2.78	3.89	4.47	5.19	6.43	6.86

Standard deviation of a single replicate = 0.30
Least significant difference (LSD) at 5% of two means = 0.61

Cereal *alpha*-amylase content (FU)	0	5	10	20	30	50	75	100
LSM								
RM-C89	1.37	1.52	2.01	2.39	3.09	3.63	4.34	4.89
RM-E89	1.88	2.09	2.43	3.12	3.62	4.75	5.45	6.08
RM-E90	1.60	1.92	2.32	3.21	3.65	4.68	5.57	6.67

Standard deviation of a single replicate = 0.235
Least significant difference (LSD) at 5% of two means = 0.49

TABLE 17

Sensitivity of wholemeal to *alpha*-amylase

Reducing sugar measurement (mg/g d.w.b.)

Cereal *alpha*-amylase content (FU)	0	5	10	20	30	50	75	100
CBP								
RM-C89	44.7	47.9	54.4	52.7	61.8	88.0	74.2	80.5
RM-E89	46.3	47.3	36.0	52.3	55.3	62.7	55.6	62.9
RM-E90	46.5	63.6	63.5	66.2	72.9	78.5	86.7	91.3

Standard deviation of a single replicate = 6.61
Least significant difference (LSD) at 5% of two means = 14

	0	5	10	20	30	50	75	100
LSM								
RM-C89	43.6	47.6	44.7	49.5	49.9	56.6	64.5	66.7
RM-E89	47.5	49.5	52.2	51.4	59.8	63.6	74.6	70.8
RM-E90	53.6	58.3	58.8	65.6	64.1	66.2	80.4	79.2

Standard deviation of a single replicate = 4.00
Least significant difference (LSD) at 5% of two means = 8

TABLE 18

Loaf volumes of individual wheat varieties (white, wholemeal and interchanged Bran and offal test)

Test Variety	(1)	Mercia Control White	Mercia Control Wholemeal	% (2)	Test Variety White	Test Variety Wholemeal	%	Mercia + Test B + 0	± (3)	Test Mercia	±
Pernel	F	1619	1263	78	1591	1197	75	1234	-	1275	+
Festival	F	1630	1310	80	1561	1353	87	1334	+	1358	+
Thesee	F	1598	1355	84	1543	1178	76	1296	-	1247	+
Camp Remy	F	1641	1340	82	1659	1347	81	1328	-	1341	-
Minaret	UK	1523	1288	85	1460	1305	89	1264	-	1239	-
Hereward	UK	1529	1247	82	1538	1284	83	1248	0	1277	-
Sperber	G	1497	1173	78	1572	1258	80	1134	-	1265	+
Futur	G	1530	1163	76	1536	1266	82	1211	+	1252	-
Florida	G	1595	1249	78	1525	1101	72	1142	-	1167	+
Kanzler	G	1528	1197	78	1614	1272	79	1248	+	1290	+
Rektor	G	1605	1262	79	1670	1362	82	1223	-	1395	+
Maris Widgeon	UK	1553	1249	80	1684	1250	74	1191	-	1210	-
Fresco	UK	1593	1216	76	1453	1306	90	1231	+	1296	-

Notes:

1. Country of origin. F = France G = Germany
2. Wholemeal volume as percentage of white
3. Effect of interchanged bran and offal relative to natural wholemeal

TABLE 19

Flour properties of wholemeal flours

	Fresco	Hereward	Mercia	Riband	Gala	Festival
Harvest year	1990	1990	1990	1990	1990	1990
Purity	Pure	Pure	Pure	Pure	Pure	13/14
Moisture %	14.1	13.9	13.8	13.0	13.4	13.5
Protein %	11.0	11.5	9.5	8.8	10.7	11.3
Falling No. 7g s	409	388	384	326	389	307
Damaged starch FU	24	22	31	12	12	12
Alpha-amylase FU	0	0	1	2	2	5
Water absorption (10 min)	61.1	60.4	62.1	55.4	57.5	61.8
Gel-protein g/5g	7.70	9.68	4.97	3.90	8.34	10.62
Particle size % Sieve size (microns)						
>1000	2	1	1.6	NA	0.6	1.2
850	3	2	2.1	NA	1.4	1.6
500	8	7	8.0	NA	6.2	6.2
300	5	5	4.4	NA	4.0	4.4
180	4	4	4.2	NA	3.8	3.6
>180	78	81	79.7	NA	84.0	83.0
Ash	0.57	0.53	NA	0.57	1.55	0.68

TABLE 20

Baking performance in wholemeal of selected UK and French varieties

A. FRESCO

Work-input, Wh/kg		8	11	14	17	20
600 RPM						
Mixing time, s		68	100	113	135	164
Loaf volume, ml		1257	1355	1365	1371	1307
Crumb score, max 10		6	8	8	7	7
Loaf score, max 10		7	7	7	7	7
Gel protein, 5g dough	A	2.51	1.22	1.02	0.62	0.43
	B	1.64	1.15	1.03	0.91	0.51
500 RPM						
Mixing time, s		93	120	144	164	201
Loaf volume, ml		1310	1339	1336	1337	1352
Crumb score, max 10		8	7	8	7	7
Loaf score, max 10		6	7	7	7	7
Gel protein, 5g dough	A	1.28	0.84	0.68	0.49	0.42
	B	0.94	0.64	0.63	0.51	0.34
400RPM						
Mixing time, s		140	162	196	240	464
Loaf volume, ml		1308	1332	1361	1341	1319
Crumb score, max 10		8	8	7	7	6
Loaf score, max 10		6	7	7	7	6
Gel protein, 5g dough	A	1.31	0.70	0.24	0.40	0.36
	B	1.29	1.13	1.08	0.92	0.72
300 RPM						
Mixing time, s		179	242	297	350	389
Loaf volume, ml		1317	1304	1328	1358	1309
Crumb score, max 10		8	8	7	7	6
Loaf score, max 10		8	8	7	7	6
Gel protein, 5g dough	A	0.63	0.59	0.54	0.54	0.60
	B	0.47	0.43	0.14	0.14	0.13
250 RPM						
Mixing time, s		220	306	374	441	493
Loaf volume, ml		1320	1312	1303	1321	1307
Crumb score, max 10		8	7	6	6	6
Loaf score, max 10		8	8	7	6	6
Gel protein, 5g dough	A	0.87	0.48	0.35	0.42	0.24
	B	1.38	0.36	0.47	0.38	0.15

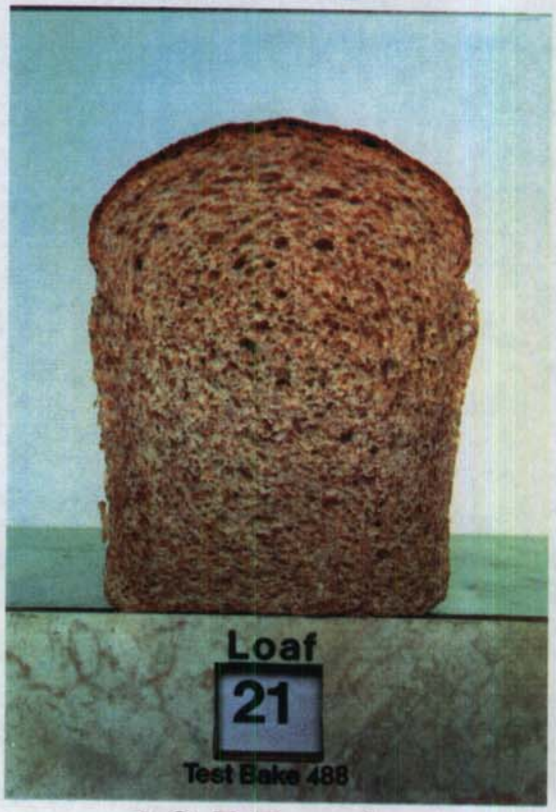
Key: A. After mixing
B. 20 min into final proof

FIG 4A

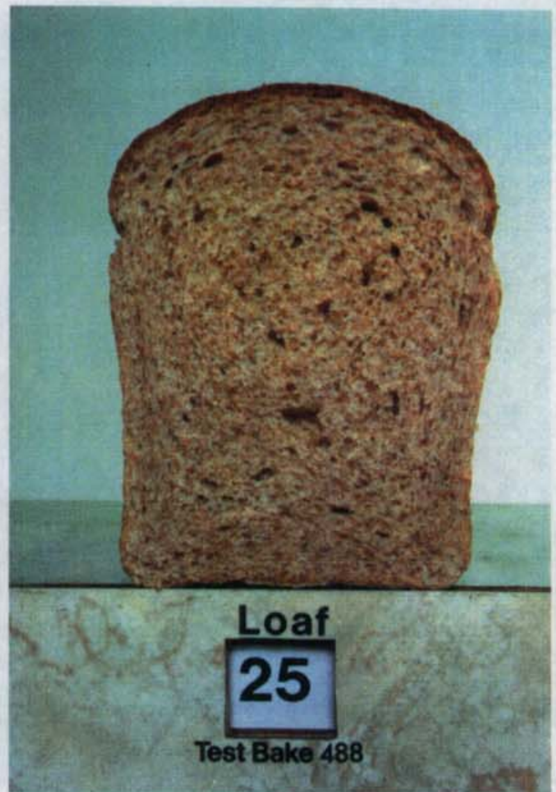
FRESCO
Wholemeal

8Wh/kg | 20Wh/kg

600 rev/min

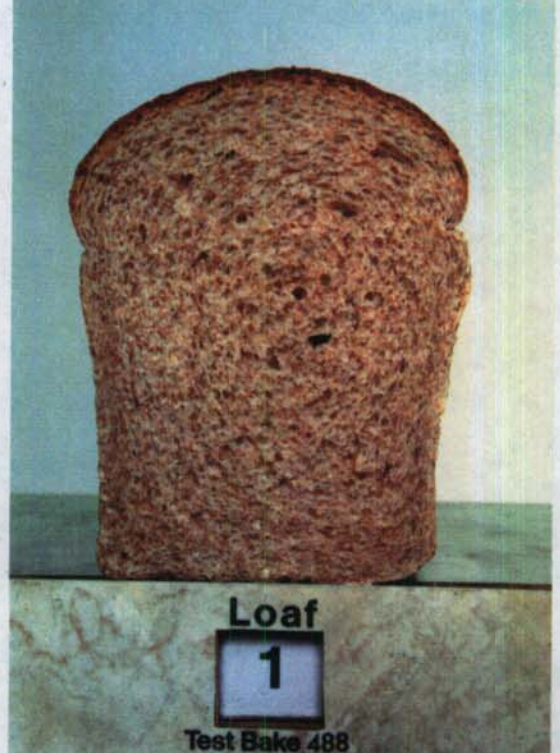


1257 ml

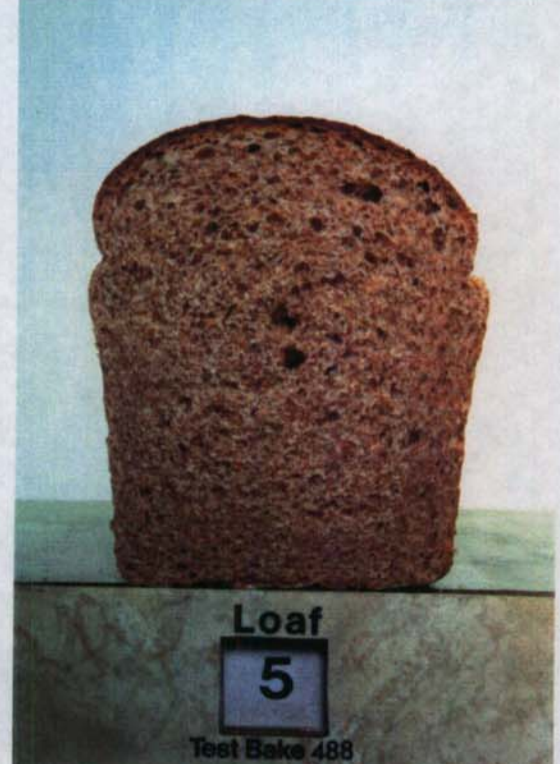


1307 ml

250 rev/min



1320 ml



1307 ml

Table 20 cont/d

B. HEREWARD

Work-input, Wh/kg		8	11	14	17	20
600 RPM						
Mixing time, s		65	79	114	118	131
Loaf volume, ml		1339	1352	1346	1363	1344
Crumb score, max 10		7	7	7	6	6
Loaf score, max 10		5	5	5	5	4
Gel protein, 5g dough	A	0.56	0.32	0.44	0.33	0.59
	B	0.60	0.48	0.58	0.41	0.33
500 RPM						
Mixing time, s		71	105	117	132	153
Loaf volume, ml		1374	1362	1365	1349	1309
Crumb score, max 10		7	7	6	7	6
Loaf score, max 10		6	5	5	5	4
Gel protein, 5g dough	A	0.34	0.45	0.38	0.16	0.25
	B	0.37	0.57	0.50	0.59	0.27
400 RPM						
Mixing time, s		120	125	138	149	180
Loaf volume, ml		1414	1385	1367	1367	1341
Crumb score, max 10		7	7	7	5	6
Loaf score, max 10		5	5	5	4	4
Gel protein, 5g dough	A	0.41	0.50	0.25	0.34	0.61
	B	0.45	0.47	0.46	0.50	0.54
300 RPM						
Mixing time, s		129	147	181	218	265
Loaf volume, ml		1396	1367	1389	1373	1333
Crumb score, max 10		7	6	6	6	6
Loaf score, max 10		5	5	5	5	4
Gel protein, 5g dough	A	0.39	0.50	0.41	0.46	0.33
	B	0.55	0.51	0.49	0.50	0.45
250 RPM						
Mixing time, s		169	196	247	323	358
Loaf volume, ml		1345	1356	1353	1343	1330
Crumb score, max 10		6	7	6	6	5
Loaf score, max 10		6	6	5	6	4
Gel protein, 5g dough	A	0.43	0.37	0.22	0.22	0.32
	B	0.44	0.50	0.36	0.37	0.60

Key: A. After mixing
B. End of final proof

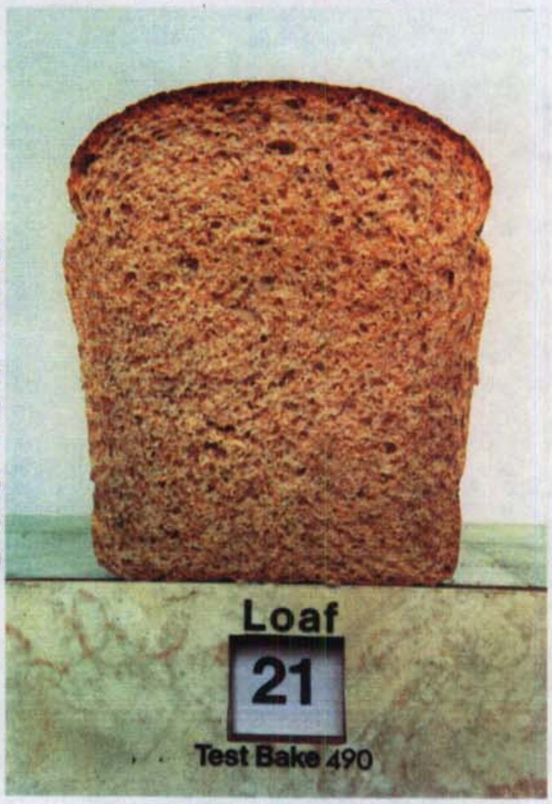
FIG 4B

HEREWARD

Wholemeal

8 Wh/kg | 20 Wh/kg

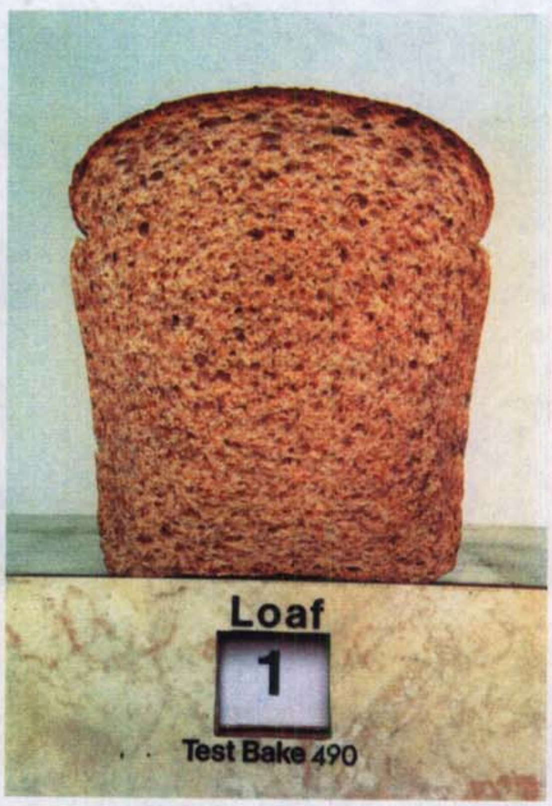
600 rev/min



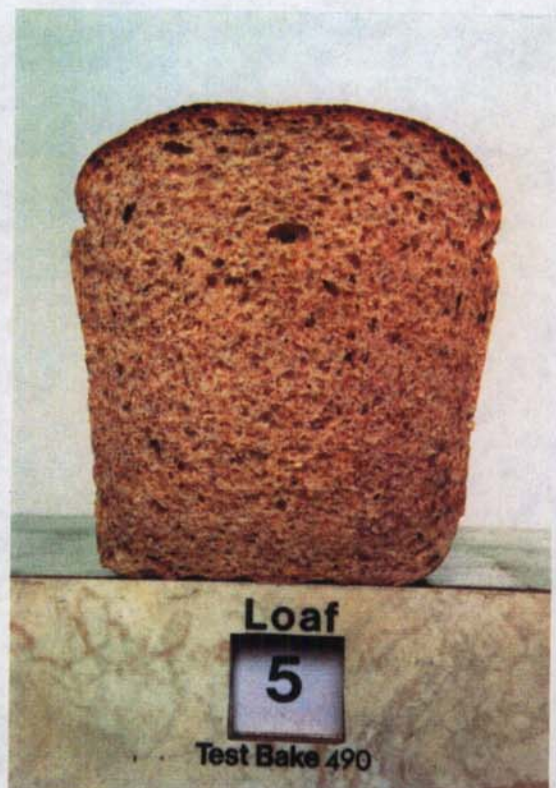
1339 ml

1344 ml

250 rev/min



1345 ml



1330 ml

Table 20 cont/d

C. MERCIA

Work-input, Wh/kg		5	8	11	14	17
600 RPM						
Mixing time, s		65	86	116	144	153
Loaf volume, ml		1205	1214	1234	1201	1189
Crumb score, max 10		7	6	6	5	4
Loaf score, max 10		5	4	4	3	2
Gel protein, 5g dough	A	0.61	0.30	0.32	0.29	0.23
	B	0.38	0.43	0.10	0.37	0.20
IRS (1/s)	M1					-8382
	M2					-43
500 RPM						
Mixing time, s		64	118	137	160	191
Loaf volume, ml		1204	1225	1225	1153	1192
Crumb score, max 10		7	7	6	7	6
Loaf score, max 10		5	7	6	4	2
Gel protein, 5g dough	A	0.73	0.88	0.89	0.97	0.96
	B	0.69	0.36	0.39	0.32	0.26
ISR (1/s)	M1				-5377	
	M2				-46	
400 RPM						
Mixing time, s		95	131	163	206	237
Loaf volume, ml		1238	1269	1197	1208	1129
Crumb score, max 10		7	7	7	6	4
Loaf score, max 10		6	6	5	4	2
Gel protein, 5g dough	A	0.71	0.88	0.58	1.05	0.84
	B	0.75	0.27	0.28	0.34	0.41
ISR (1/s)	M1			-4602		
	M2			-36		
300 RPM						
Mixing time, s		146	172	228	288	330
Loaf volume, ml		1144	1241	1212	1191	1151
Crumb score, max 10		6	7	6	5	4
Loaf score, max 10		5	6	5	4	2
Gel protein, 5g dough	A	0.36	0.40	0.37	0.36	0.30
	B	0.35	0.35	0.21	0.27	0.36
ISR (1/s)	M1		-7660			
	M2		-53			
250 RPM						
Mixing time, s		172	243	300	337	359
Loaf volume, ml		1242	1222	1205	1164	1175
Crumb score, max 10		8	7	6	5	4
Loaf score, max 10		6	5	4	3	2
Gel protein, 5g dough	A	0.38	0.55	0.40	0.30	0.45
	B	0.44	0.30	0.28	0.35	0.17
ISR (1/s)	M1	-5988				
	M2	-13				

Key: A. After mixing
B. End of final proof
ISR: Stress relaxation on the Bohlin VOR

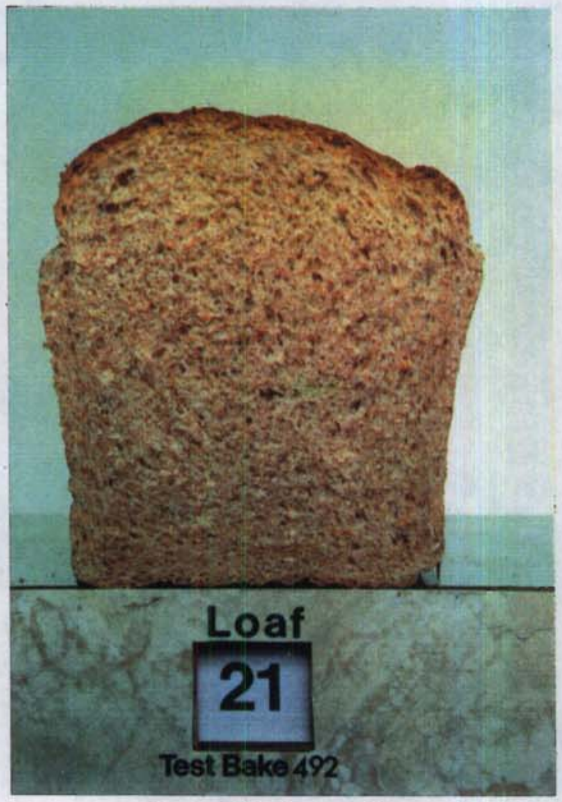
FIG 4C

MERCIA

Wholemeal

5 Wh/kg | **17 Wh/kg**

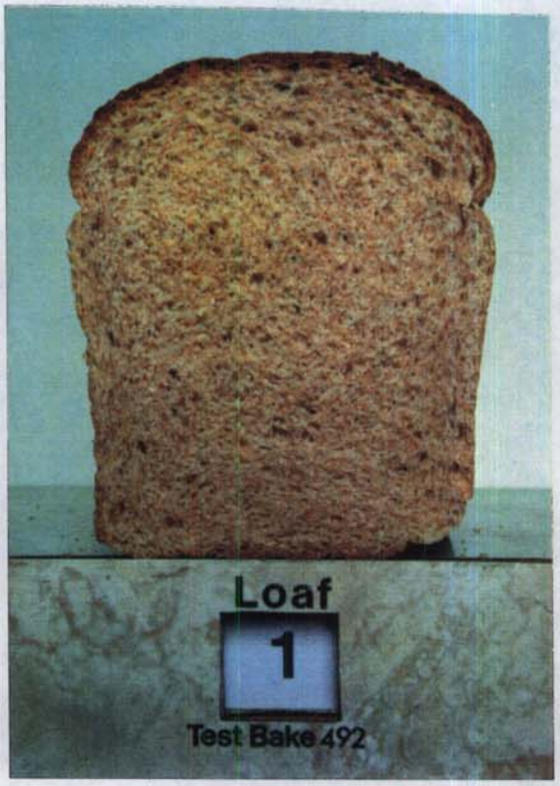
600 rev/min



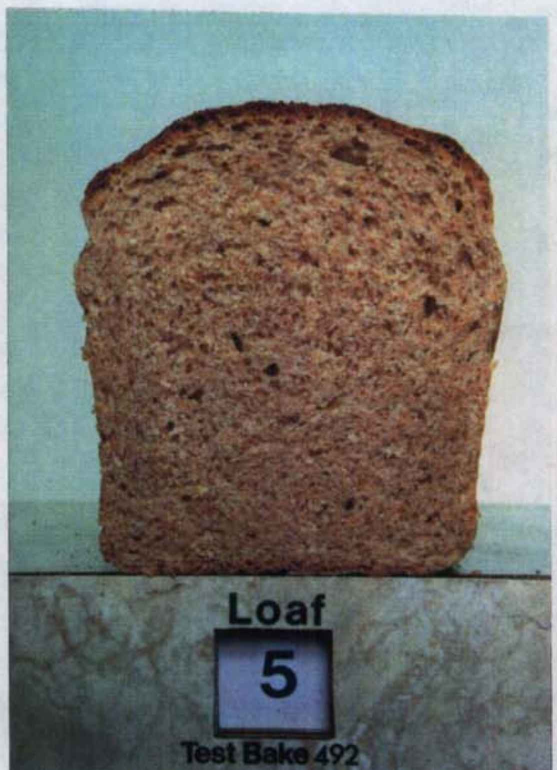
1205 ml

1189 ml

250 rev/min



1242 ml



1175 ml

Table 20 cont/d

D. RIBAND

Work-input, Wh/kg		3	5	8	11	14
600 RPM						
Mixing time, s		40	60	83	105	128
Loaf volume, ml		1041	1033	1071	1072	976
Crumb score, max 10		2	2	3	3	2
Loaf score, max 10		2	2	3	3	2
Gel protein, 5g dough	A	0.39	0.24	0.35	0.18	0.19
	B	0.22	0.16	0.10	0.14	0.22
ISR (1/s)	M1					-8798
	M2					-94
500 RPM						
Mixing time, s		53	65	98	118	145
Loaf volume, ml		1071	1070	1042	1023	993
Crumb score, max 10		3	2	2	2	2
Loaf score, max 10		3	3	3	3	2
Gel protein, 5g dough	A	0.26	0.31	0.24	0.17	0.39
	B	0.38	0.16	0.16	0.11	0.20
ISR (1/s)	M1			-4711	-5268	
	M2			-91	-89	
400 RPM						
Mixing time, s		59	80	117	140	167
Loaf volume, ml		1107	1079	1036	1026	997
Crumb score, max 10		4	3	3	3	2
Loaf score, max 10		4	2	3	2	2
Gel protein, 5g dough	A	0.42	0.27	0.23	0.28	0.31
	B	0.24	0.33	0.21	0.22	0.23
300 RPM						
Mixing time, s		84	109	167	219	273
Loaf volume, ml		1070	1088	1023	994	967
Crumb score, max 10		3	3	2	2	2
Loaf score, max 10		2	2	2	2	2
Gel protein, 5g dough	A	0.35	0.29	0.21	0.43	0.15
	B	0.44	0.24	0.23	0.26	0.22
ISR (1/s)	M1		-5374			
	M2		-102			
250 RPM						
Mixing time, s		99	150	221	284	358
Loaf volume, ml		1084	1078	1024	981	973
Crumb score, max 10		3	3	2	2	2
Loaf score, max 10		3	3	2	2	2
Gel protein, 5g dough	A	0.28	0.20	0.30	0.33	0.21
	B	0.17	0.22	0.14		0.21
ISR (1/s)	M1	-13916				
	M2	-101				

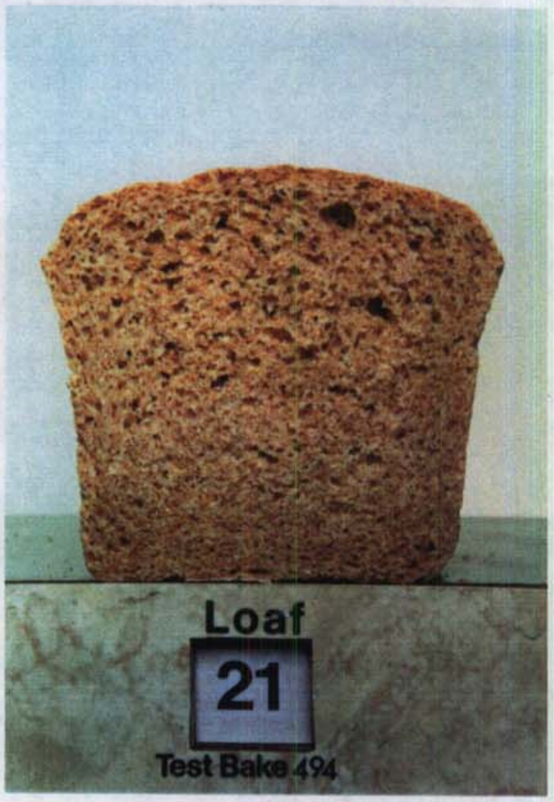
Key: A. After mixing
B. End of final proof
ISR: Stress relaxation on Bohlin VOR

FIG 4D

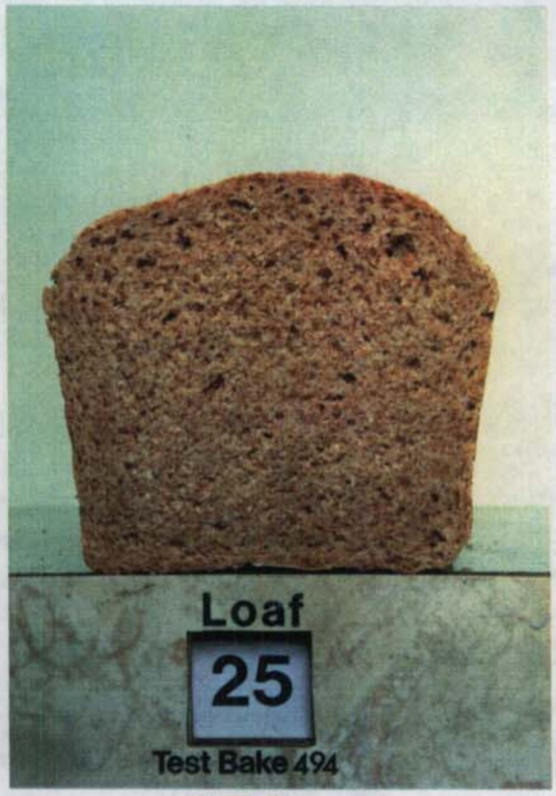
RIBAND
Wholemeal

3 Wh/kg | 14 Wh/kg

600 rev/min

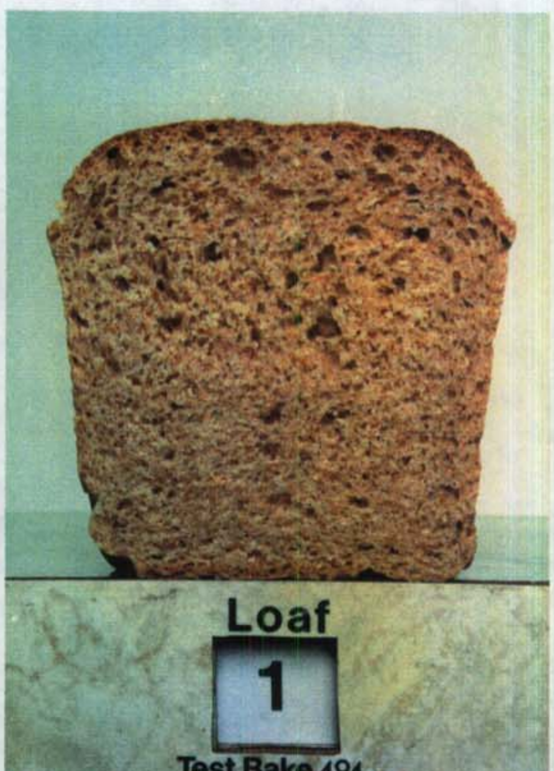


1041 ml



976 ml

250 rev/min



1084 ml

973 ml

Table 20 cont/d

E. GALA

Work-input, Wh/kg		5	8	11	14	17
600 RPM						
Mixing time, s		50				122
Loaf volume, ml		1279				1339
Crumb score, max 10		8				8
W (x 10 Joules)						NA
ISR (1/s)	M1					-2246.7
	M2					-21.0
500 RPM						
Mixing time, s		60			130	
Loaf volume, ml		1294			1336	
Crumb score, max 10		5			7	
W (x 10 Joules)					NA	
ISR (1/s)	M1				-3051.3	
	M2				-17.1	
400 RPM						
Mixing time, s		75		137		
Loaf volume, ml		1293		1342		
Crumb score, max 10		5		7		
W (x 10 Joules)				73.11		
ISR (1/s)	M1			-2970.7		
	M2			-26.2		
300 RPM						
Mixing time, s		106	154			
Loaf volume, ml		1348	1364			
Crumb score, max 10		5	6			
W (x 10 Joules)			71.05			
ISR (1/s)	M1		-3093.2			
	M2		-22.9			
250 RPM						
Mixing time, s		129	180	205	265	312
Loaf volume, ml		1333	1352	1341	1367	1366
Crumb score, max 10		7	7	6	5	5
W (x 10 Joules)		77.95				
ISR (1/s)	M1	-3789.7				
	M2	-26.1				

ISR: Initial Stress Relaxation
W (x 10 Joules): The area under the curve (proportional to the energy required to inflate the bubble until it bursts and therefore related to the strength of the dough).
NA Data not available, bran interfered with bubble growth.

FIG 4E

GALA

Wholemeal

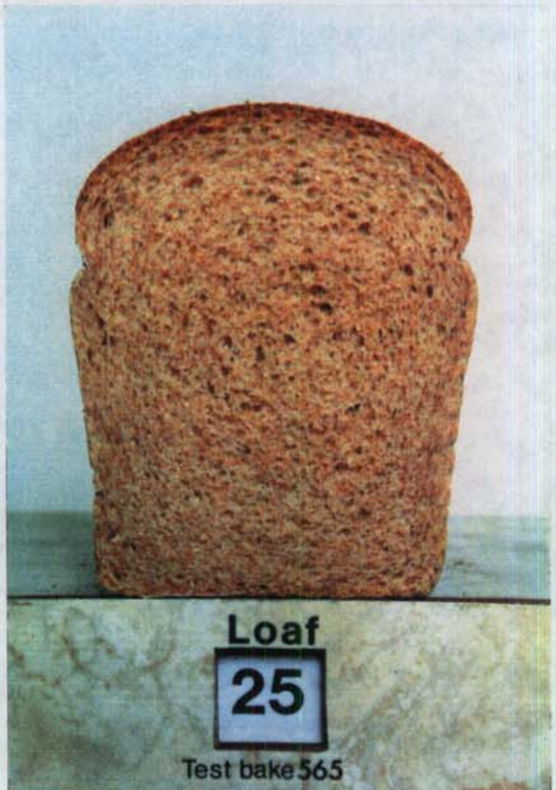
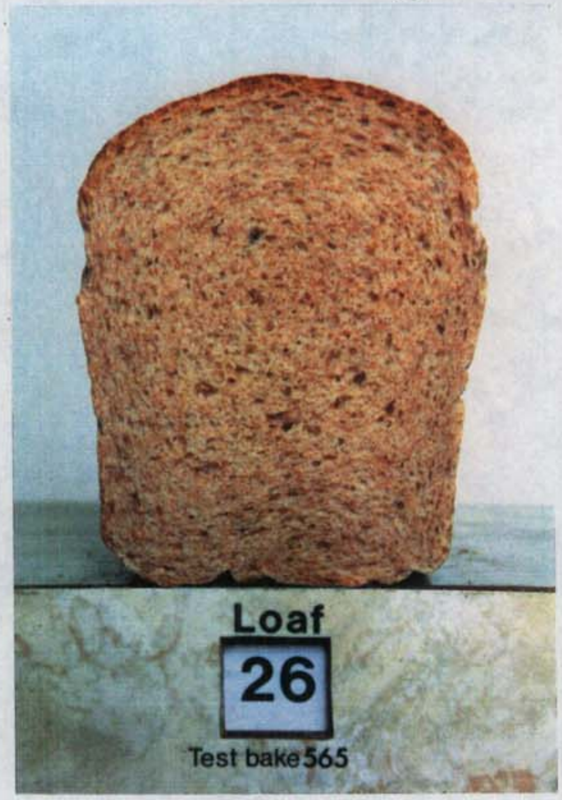
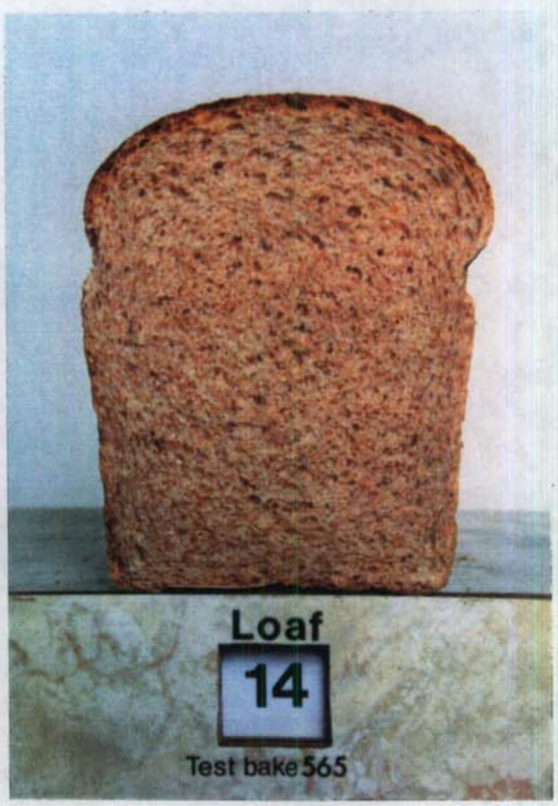
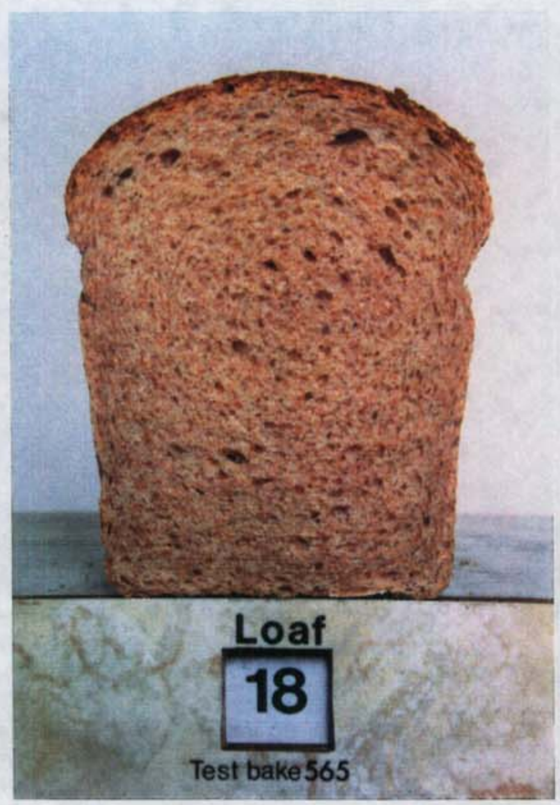
	5Wh/kg	17Wh/kg
600 rev/min	 1279 ml	 1339 ml
250 rev/min	 1333 ml	 1366 ml

Table 20 cont/d

F. FESTIVAL

Work iput, Wh/kg		5	8	11	14	17
600 RPM						
Mixing time, s		59				134
Loaf volume, ml		1221				1253
Crumb score, max 10		6				6
W (x 10 Joulres)						NA
ISR (1/s)	M1					-2426.1
	M2					-27.2
500 RPM						
Mixing time, s		67			124	
Loaf volume, ml		1238			1220	
Crumb score, max 10		6			7	
W (x 10 Joules)					62.88	
ISR (1/s)	M1				-2845.8	
	M2				-29.2	
400 RPM						
Mixing time, s		82		149		
Loaf volume, ml		1200		1264		
Crumb score, max 10		5		5		
W (x 10 Joules)				57.66		
ISR (1/s)	M1			-2794.6		
	M2			-26.6		
300 RPM						
Mixing time, s		122	174			
Loaf volume, ml		1246	1263			
Crumb score, max 10		6	7			
W (x 10 Joules)			NA			
ISR (1/s)	M1		-2577.1			
	M2		-26.1			
250 RPM						
Mixing time, s		140	259	309	357	410
Loaf volume, ml		1226	1266	1261	1185	1155
Crumb score, max 10		8	7	6	5	5
W (x 10 Joules)		77.01				
ISR (1/s)	M1	-8084.8				
	M2	-74.2				

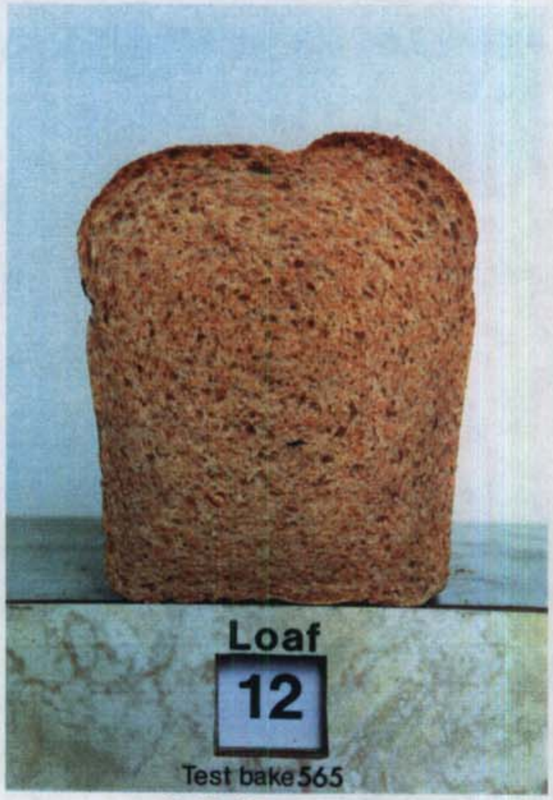
ISR: Initial Stress Relaxation
W (x 10 Joules): The area under the curve (proportional to the energy required to inflate the bubble until it bursts and therefore related to the strength of the dough).
NA No data available, bran interfered with bubble growth.

FIG 4F

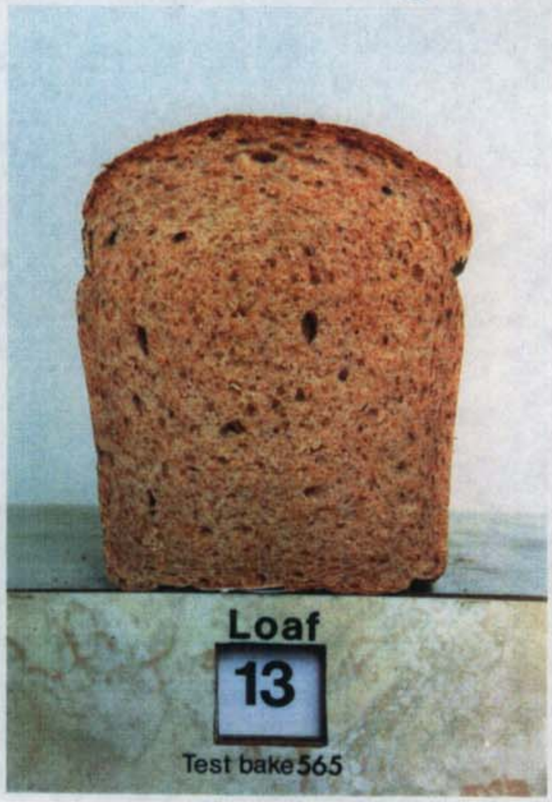
FESTIVAL
Wholemeal

5Wh/kg | **17Wh/kg**

600 rev/min

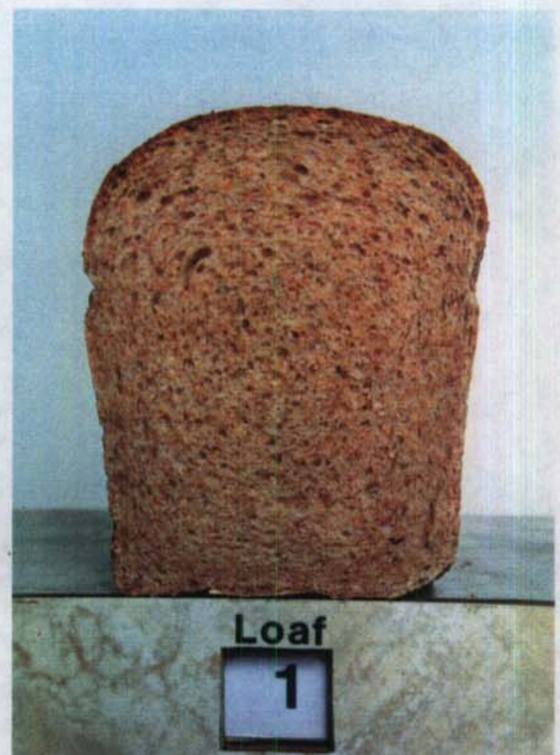


1221 ml



1253 ml

250 rev/min



1226 ml

1155 ml

TABLE 21

Breadmaking performance of gluten fortification of wholemeal flours

A. MERCIA 3% protein increase

Work-input, Wh/kg		5	8	11	14	17
600 RPM						
Mixing time, s		48				114
Loaf volume, ml		1360				1346
Crumb score, max 10		8				5
ISR (1/s)	M1					-2001.7
	M2					-17.7
500 RPM						
Mixing time, s		70			127	
Loaf volume, ml		1397			1370	
Crumb score, max 10		8			6	
ISR (1/s)	M1				-2053.9	
	M2				-14.3	
400 RPM						
Mixing time, s		84		130		
Loaf volume, ml		1404		1398		
Crumb score, max 10		7		7		
ISR (1/s)	M1			-2248.9		
	M2			-15.0		
300 RPM						
Mixing time, s		109	159			
Loaf volume, ml		1417	1398			
Crumb score, max 10		7	6			
ISR (1/s)	M1		-2394.3			
	M2		-9.7			
250 RPM						
Mixing time, s		150	206	271	336	388
Loaf volume, ml		1376	1407	1332	1340	1304
Crumb score, max 10		9	7	6	6	5
ISR (1/s)	M1	-3185.7				
	M2	-3.7				

ISR: Initial Stress Relaxation

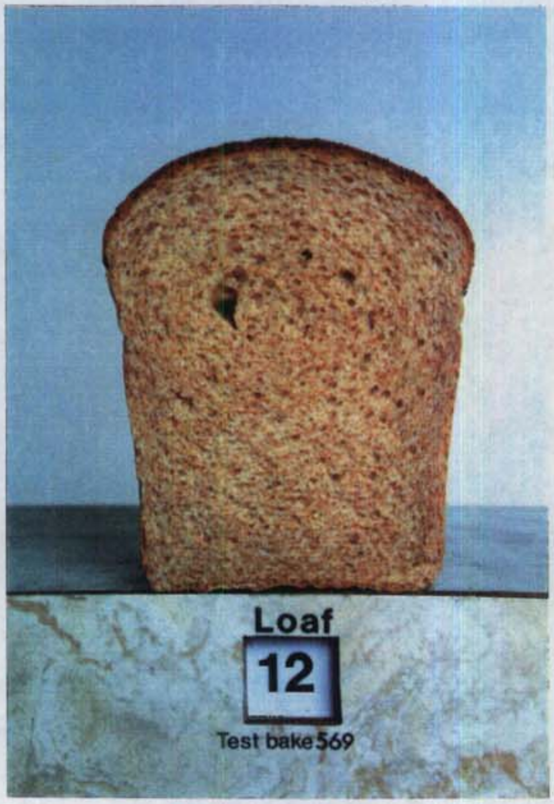
FIG 5A

MERCIA

3% Protein Increase

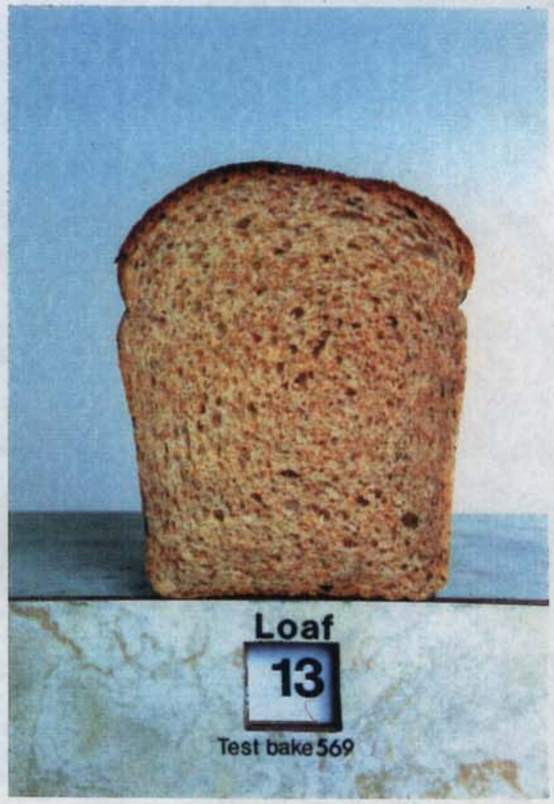
600 rev/min

5Wh/kg



1360 ml

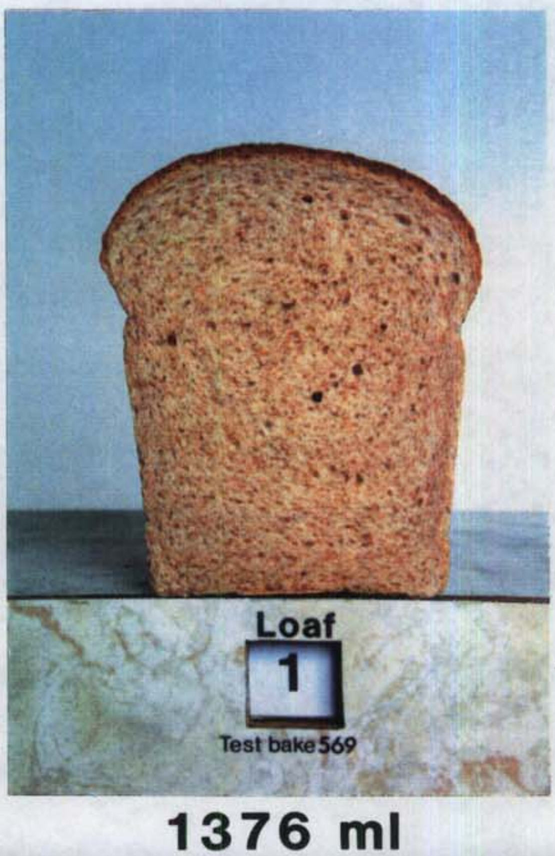
17Wh/kg



1346 ml

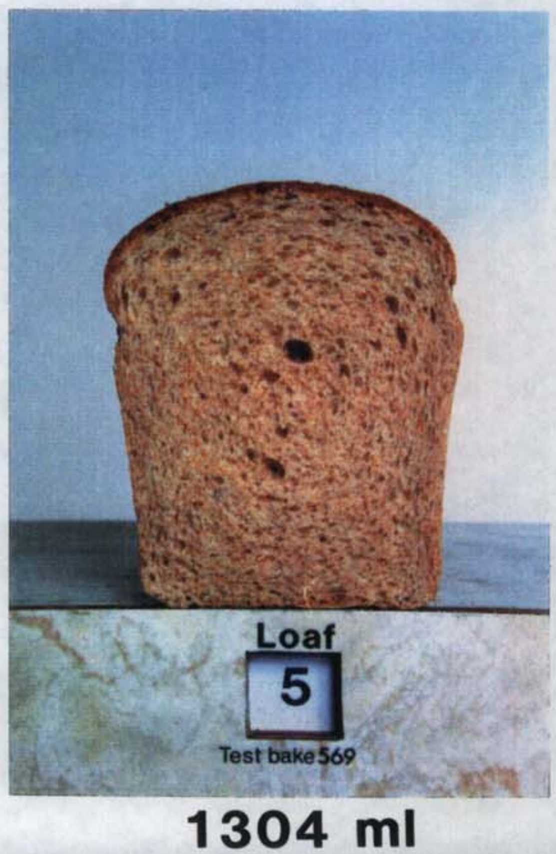
250 rev/min

5Wh/kg



1376 ml

17Wh/kg



1304 ml

Table 21 cont/d

B. MERCIA 6% protein increase

Work-input, Wh/kg		5	8	11	14	17
600 RPM						
Mixing time, s		50				117
Loaf volume, ml		1550				1562
Crumb score, max 10		7				5
ISR (1/s)	M1					-1349.1
	M2					-11.4
500 RPM						
Mixing time, s		59			128	
Loaf volume, ml		1528			1580	
Crumb score, max 10		7			6	
ISR (1/s)	M1				-1637.5	
	M2				-16.2	
400 RPM						
Mixing time, s		80		134		
Loaf volume, ml		1602		1583		
Crumb score, max 10		7		6		
ISR (1/s)	M1			-1848.0		
	M2			-18.8		
300 RPM						
Mixing time, s		105	152			
Loaf volume, ml		1548	1624			
Crumb score, max 10		8	7			
ISR (1/s)	M1		-1843.2			
	M2		-15.1			
250 RPM						
Mixing time, s		138	191	242	298	319
Loaf volume, ml		1630	1589	1544	1490	1472
Crumb score, max 10		8	7	6	6	6
ISR (1/s)	M1	-2266.6				
	M2	-11.0				

ISR: Initial Stress Relaxation

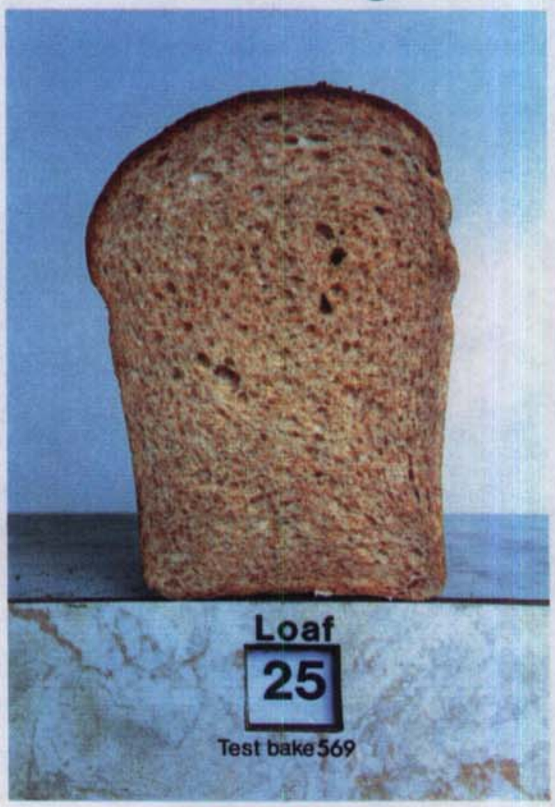
FIG 5B

MERCIA

6% Protein Increase

5Wh/kg | 17Wh/kg

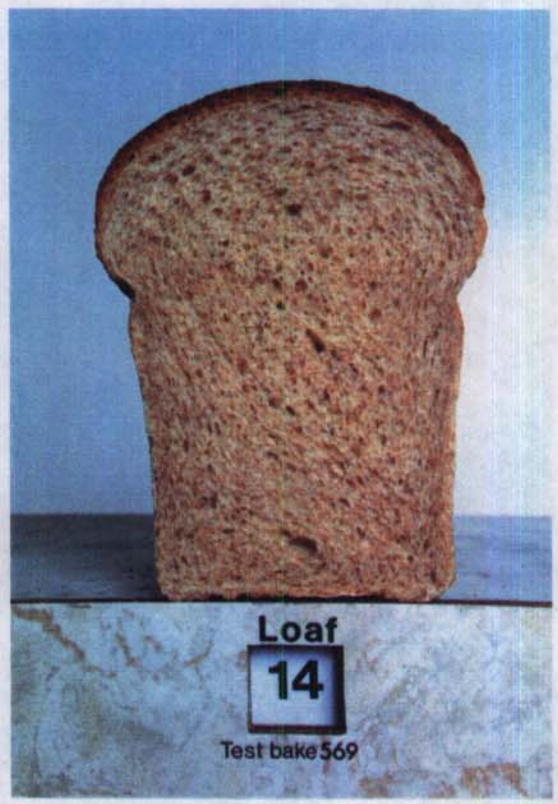
600 rev/min



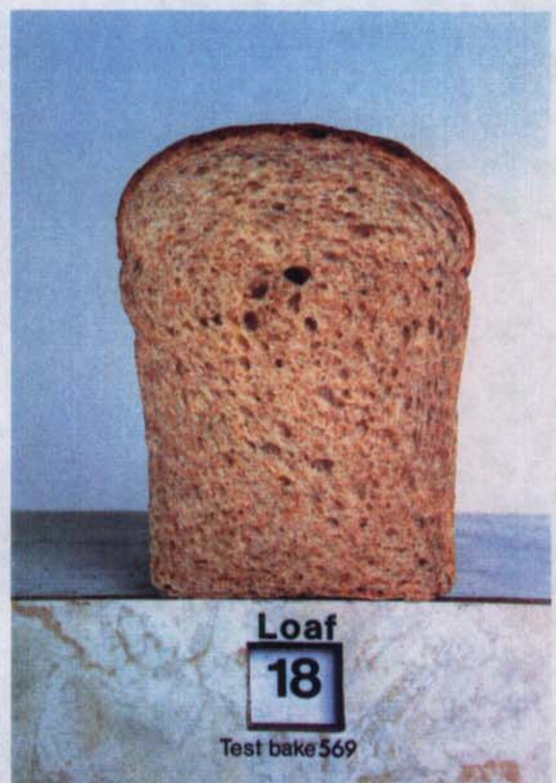
1550 ml

1562 ml

250 rev/min



1630 ml



1472 ml

Table 21 cont/d

C. FRESCO 3% protein increase

Work-input, Wh/kg		8	11	14	17	20
600 RPM						
Mixing time, s		72				150
Loaf volume, ml		1463				1442
Crumb score, max 10		6				7
ISR (1/s)	M1					-1926.3
	M2					-13.9
500 RPM						
Mixing time, s		84			153	
Loaf volume, ml		1416			1477	
Crumb score, max 10		7			8	
ISR (1/s)	M1				-2175.6	
	M2				-14.5	
400 RPM						
Mixing time, s		109		177		
Loaf volume, ml		1413		1495		
Crumb score, max 10		7		6		
ISR (1/s)	M1			-2143.6		
	M2			-8.8		
300 RPM						
Mixing time, s		171	230			
Loaf volume, ml		1401	1440			
Crumb score, max 10		7	7			
ISR (1/s)	M1		-2040.3			
	M2		-9.5			
250 RPM						
Mixing time, s		228	310	380	414	441
Loaf volume, ml		1410	1415	1402	1425	1395
Crumb score, max 10		8	6	6	5	4
ISR (1/s)	M1	-2970.9				
	M2	-6.1				

ISR: Initial Stress Relaxation

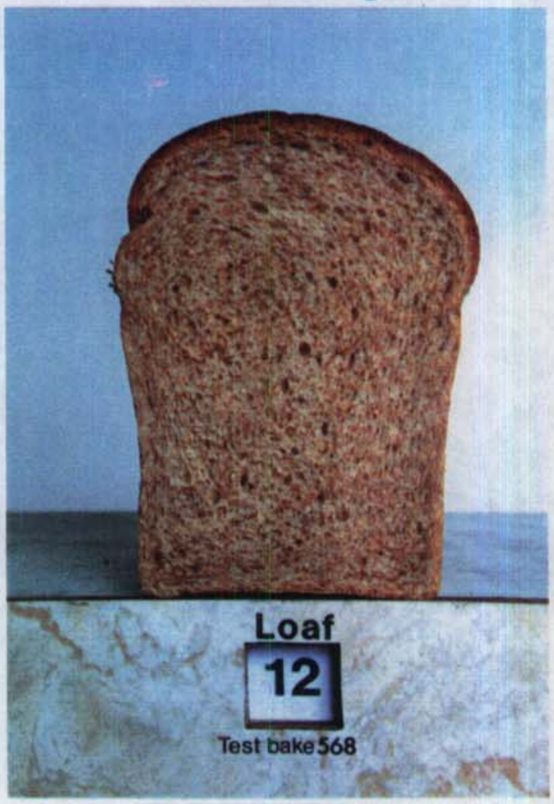
FIG 5C

FRESCO

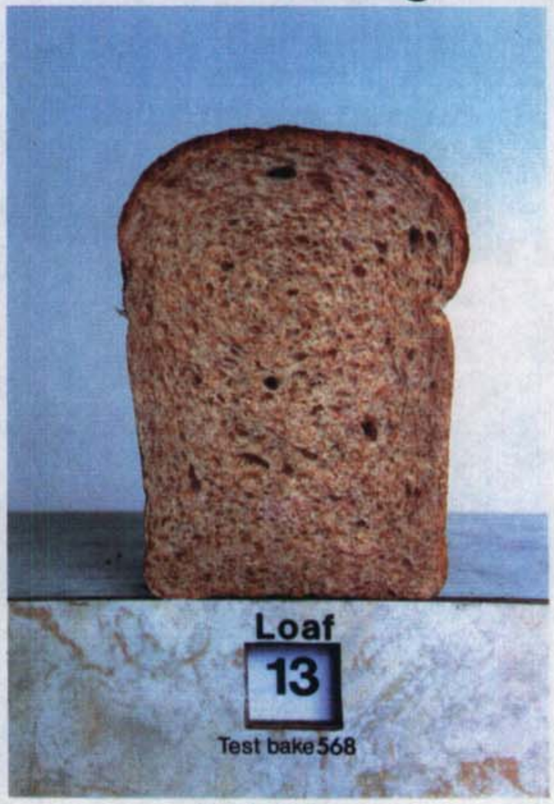
3% Protein Increase

8Wh/kg | 20Wh/kg

600 rev/min

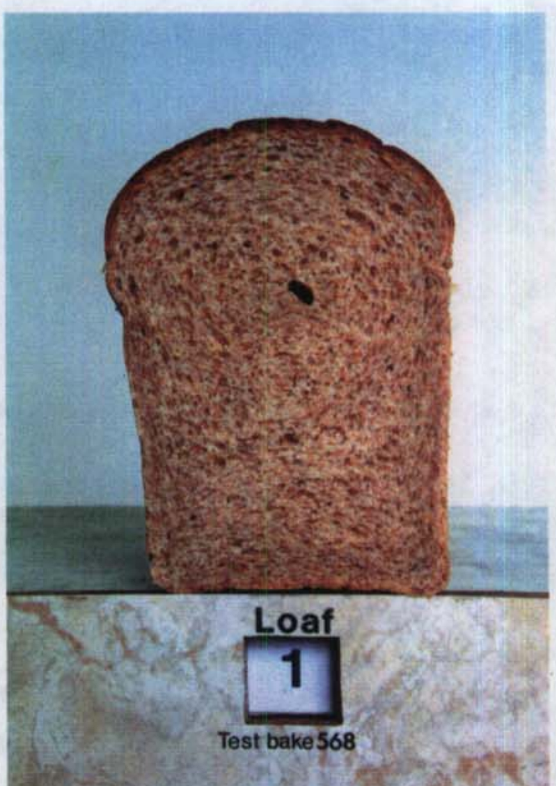


1463 ml

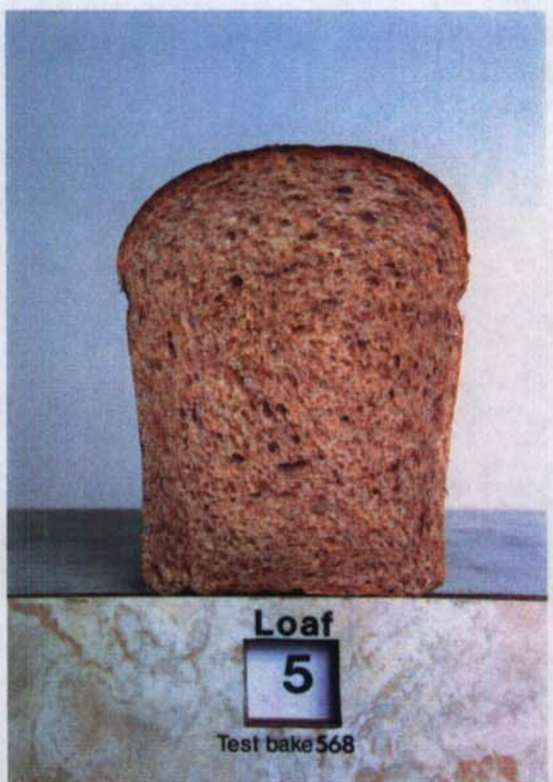


1442 ml

250 rev/min



1410 ml



1395 ml

Table 21 cont/d

D. FRESCO 6% protein increase

Work-input, Wh/kg		8	11	14	17	20
600 RPM						
Mixing time, s		73				158
Loaf volume, ml		1511				1549
Crumb score, max 10		8				5
ISR (1/s)	M1					-1285.4
	M2					-9.6
500 RPM						
Mixing time, s		99			157	
Loaf volume, ml		1503			1544	
Crumb score, max 10		7			5	
ISR (1/s)	M1				-1493.5	
	M2				-12.5	
400 RPM						
Mixing time, s		119		180		
Loaf volume, ml		1448		1522		
Crumb score, max 10		6		5		
ISR (1/s)	M1			-1695.9		
	M2			-12.2		
300 RPM						
Mixing time, s		170	239			
Loaf volume, ml		1460	1575			
Crumb score, max 10		6	5			
ISR (1/s)	M1		-1570.4			
	M2		-9.2			
250 RPM						
Mixing time, s		244	277	293	365	380
Loaf volume, ml		1503	1526	1502	1512	1470
Crumb score, max 10		7	6	6	6	5
ISR (1/s)	M1	-1589.8				
	M2	-11.5				

ISR: Initial Stress Relaxation

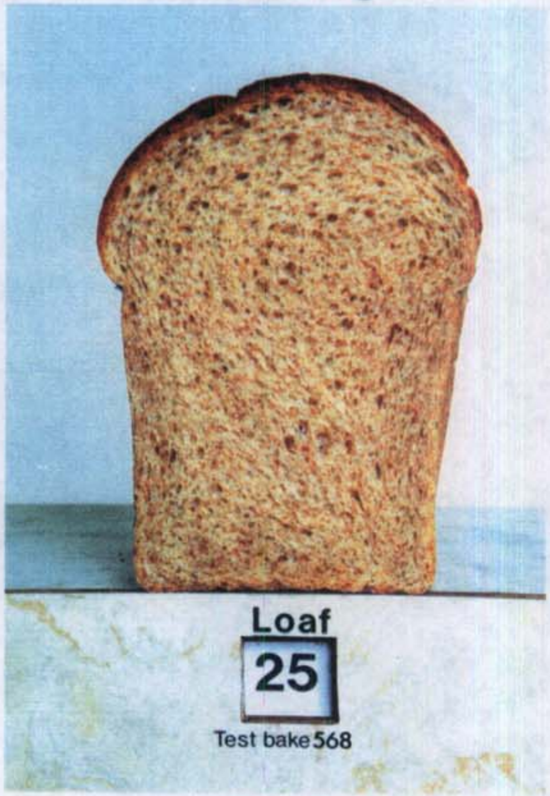
FIG 5D

FRESCO

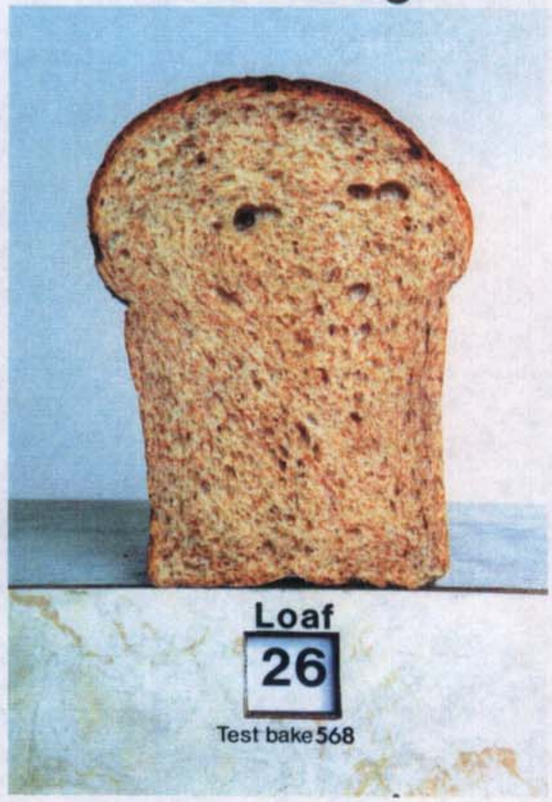
6% Protein Increase

8Wh/kg | 20Wh/kg

600 rev/min

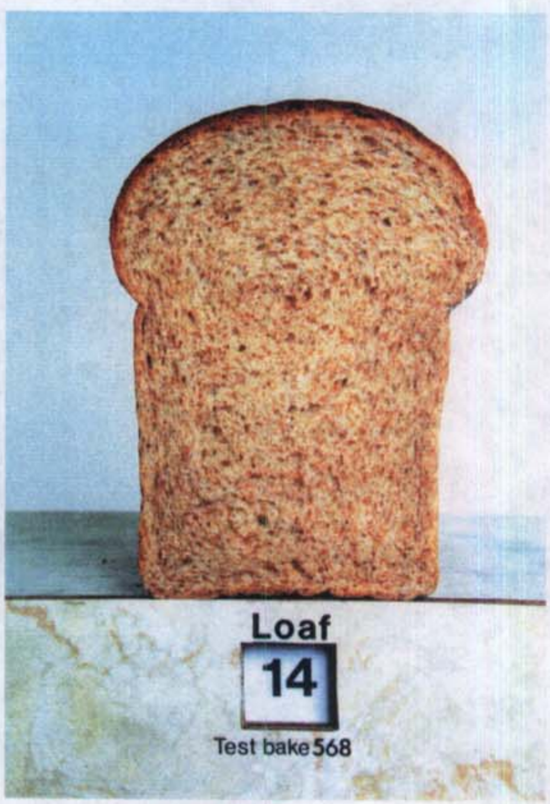


1511 ml

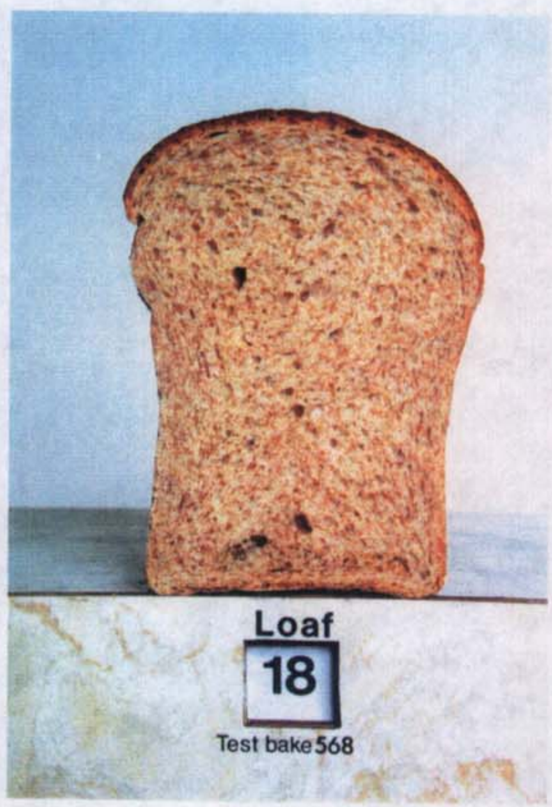


1549 ml

250 rev/min



1503 ml



1470 ml

TABLE 22

Gel-protein content of white, wholemeal and interchanged bran and offal flours

Base flour	White	%	Wholemeal	+ Donor b + o	Donor B + o
Mercia	11.67	80	9.33	8.56	Pernel
Mercia	11.87	83	9.90	9.86	Festival
Mercia	12.15	83	10.04	9.98	Thesee
Mercia	11.88	84	9.98	9.93	Camp Remy
Mercia	9.20	89	8.21	8.08	Minaret
Mercia	9.05	85	7.66	7.21	Fresco
Mercia	8.36	89	7.45	6.18	Hereward
Mercia	9.08	75	6.82	6.84	Sperber
Mercia	9.03	76	6.85	7.51	Kanzler
Mercia	8.96	68	6.12	5.19	Future
Mercia	8.89	85	7.57	7.14	Rektor
Mercia	8.40	85	7.14	4.55	Florida
Mercia	9.42	80	7.57	7.22	M. Widgeon
Pernel	11.30	74	8.37	8.69	Mercia
Festival	11.72	91	10.67	10.06	Mercia
Thesee	12.55	79	9.88	9.39	Mercia
Camp Remy	14.85	78	11.58	12.06	Mercia
Minaret	15.71	78	12.29	12.37	Mercia
Fresco	11.59	83	9.60	8.56	Mercia
Hereward	10.84	69	7.48	9.37	Mercia
Sperber	9.50	85	8.03	8.39	Mercia
Kanzler	12.04	86	10.32	10.13	Mercia
Future	10.74	67	7.22	6.74	Mercia
Rektor	12.64	76	9.64	9.74	Mercia
Florida	3.24	87	2.81	3.47	Mercia
M. Widgeon	11.44	81	9.29	7.68	Mercia

APPENDIX 1

CBP recipe and dough processing methods for white bread

Test baking procedure No. 1AA

Breadmaking process: CBP

Bread type: 400g, white

Mixing machine: Morton

Control recipe:

	% of flour weight	g/mix
Flour	100	1400
Yeast (compressed)	2.5	35
Salt	2.0	28
Water	As determined by Simon Extrusion Meter 10 min method	
Fat (Ambrex, slip point c.45°C)	1.0	14
Ascorbic acid (100 ppm AA)	0.01	0.14

The *alpha*-amylase activity of the flour is adjusted to 80 FU by the addition of fungal *alpha*-amylase.

Dough processing:

Mixing machine	:	Morton
Beater speed	:	Variable
Work input	:	Variable
Pressure	:	Atmospheric
Dough temperature	:	30.5 +/- 1°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
Proving conditions	:	43°C humidity to prevent skinning
Proving height	:	10cm
Baking temperature	:	244°C
Oven type	:	Direct gas-fired Reel
Baking time	:	25 min
Baking humidity	:	No steam injected
Cooling	:	Open rack at room temperature
Storage	:	Closed cupboard overnight at 21°C

APPENDIX 2

BFP recipe and dough processing methods for white bread

Breadmaking process: Bulk Fermentation Process (BFP)

Bread type: 400g, white

Mixing machine: Laboratory scale, twin armed Artofex

Control recipe:

		% of flour weight	g/mix
Flour		100	2800
Yeast (compressed)	1hr	2.5	70
	2hr	2.0	56
	3hr	1.5	42
Salt		2.0	56
Water	As determined by Simon Extrusion Meter 10 min method (1 and 3hr method)		
Fat (Ambrex, slip point c.45°C)		1.0	28
Fungal *alpha*-amylase		Adjusted to 15 FU	

Dough processing:

Mixing machine	:	Twin armed Artofex
Mixing time	:	10 minutes
Dough temperature	:	27°C +/- 1°C
Bulk fermentation	:	1.0, 1.5, 2.0, 2.5, 3.0 and 3.5hrs 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, (R5, W5.5, P1.25)
Pan size	:	Top 160mm x 98mm, 83mm deep
Shape	:	Unlidded
Proving conditions	:	43°C humidity to prevent skinning
Proving height	:	10cm
Baking temperature	:	244°C
Oven type	:	Direct gas-fired Reel
Baking time	:	25 min
Baking humidity	:	No steam injected
Cooling	:	Open rack at room temperature
Storage	:	Closed cupboard overnight at 21°C

APPENDIX 3

CBP recipe and dough processing methods for wholemeal

Test baking procedure No. 7AA

Breadmaking process:	CBP
Bread type:	400g, wholemeal
Mixing machine:	Morton

Control recipe:

	% of flour weight	g/mix
Flour	100	1400
Yeast (compressed)	2.5	35
Salt	2.0	28
Water	As determined by Simon Extrusion Meter 10 min method	
Fat (Ambrex, slip point c.45°C)	2.0	28
Ascorbic acid (100 ppm AA)	0.01	0.14

The *alpha*-amylase activity of the flour is adjusted to 80 FU by the addition of fungal *alpha*-amylase.

Dough processing:

Mixing machine	:	Morton
Beater speed	:	Variable
Work input	:	Variable
Pressure	:	Atmospheric
Dough temperature	:	30.5 +/- 1°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
Proving conditions	:	43°C humidity to prevent skinning
Proving height	:	10cm
Baking temperature	:	244°C
Oven type	:	Direct gas-fired Reel
Baking time	:	25 min
Baking humidity	:	No steam injected
Cooling	:	Open rack at room temperature
Storage	:	Closed cupboard overnight at 21°C

APPENDIX 4

Wheat storage and procedures for laboratory milling

Wheat samples were checked to ensure moisture content was below 14.5% before storage at ambient temperature and humidity of 53% before cleaning.

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

A laboratory Buhler mill model 202 was used to mill flours using two sets of conditions.

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

RA Commercial. The Buhler mill settings for the first and third break rolls were 0.6 and 0.4 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.

The feed for milling was approximately 6kg/h.

Bran and offal was retreated on Buhler 302 laboratory impact finisher, passing through once for the Standard and twice for the RA Commercial settings.

Milling was carried out at a controlled temperature of 20°C and a relative humidity of 65%.

Extraction rate was calculated on a total product basis, with the requirement that 98.5% of the feed was recovered from the mill.

All flour samples were blended for 30 minutes before entry into the baking test programme.