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THE CHARACTERISTICS AND PROCESSING REQUIREMENTS OF WHEAT FOR BISCUIT MAKING

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by

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ABSTRACT

The aims of this project were to identify soft wheat varieties giving good biscuits without sodium metabisulphite (SMS, a source of sulphur dioxide) and to define the molecular basis for variations in performance. This information would be of potential benefit to plant breeders.

This programme of work has identified which of the modern varieties give good biscuits without SMS, using a standard test baking procedure. This test revealed that modern wheats are in two groups, those in which biscuit hardness is not affected by SMS in the recipe and those which give harder biscuits without SMS.

No biochemical or rheological tests examined in this work clearly discriminated wheat varieties on the basis of their biscuit making potential. However, useful linear relationships were found between dough viscosity and biscuit eccentricity and between dough elasticity and biscuit softness.

Measurement of rheological characteristics of wafer batters gives information on the strength of protein to protein interactions, a major factor in the tendency for gluten aggregation in these systems.

Further work is suggested to assess the impact of rectifying sulphur deficiency in UK soils on the performance in biscuits and wafers of new wheat varieties. Annual testing of current and new wheat varieties for biscuit and wafer making potential is also recommended.

Extension of this study into the manufacture of snack crackers is recommended.

OBJECTIVES

To identify soft wheat varieties giving good biscuits in the absence of gluten modifying additives such as sodium metabisulphite (SMS), and ultimately establish the molecular basis for variation in behaviour.

1. PROCESSING REQUIREMENTS OF WHEATS FOR BISCUIT MAKING

Seventeen soft and four hard milling wheats were tested in a small scale test baking procedure for semi-sweet biscuits. The forty one samples tested covered three harvests, 1990-1992, and two samples from commercial sources. When a variety was tested from more than one site, it is labelled A,B or C to denote the growing site.

Most of the test wheats and a further seven samples from the 1988 harvest were tested for their suitability for wafer batter making.

A preliminary study was made of the use of L-Cysteine (as the hydrochloride) as an alternative to SMS in modifying the gluten characteristics of flours in semi-sweet biscuits.

MATERIALS AND METHODS

Materials

Table 1 lists the wheat varieties tested, the year they were recommended by the National Institute of Agricultural Botany, Cambridge and their flour characteristics and endosperm texture.

Methods

A published method (Barron, 1979) was used as the test baking procedure for semi-sweet biscuits, both with and without SMS. The test recipe and process details are summarized in Appendix 1.

Biscuit softness (hardness) was assessed with the Baker Perkins Texture Meter, in which the time taken to saw through a standard stack of biscuits is measured, harder biscuits taking longer. The criterion of acceptability for biscuit texture was set at a maximum of 33s with the Texture Meter. This was based on a survey of the properties of commercial semi-sweet biscuits (Turrell, 1983).

Biscuit thickness and eccentricity (length/width) were measured with gauges. The surface finish of the biscuits was assessed visually.

The wafer batter test procedure is summarized in Appendix 2. The definitions of terms used in the batter test are given below, together with alternative terms, in parentheses, sometimes used in the industry:-

- Gluten hydration time ("knock-out time") is the time for hydrated gluten to form, which corresponds with the maximum on the power/time curve measured in this test.
- Gluten dispersion time ("knock-in time") is the time to disperse the hydrated gluten into a smooth batter.

It is desirable to have both these factors as short as possible for wafer batters and to avoid aggregation of developed gluten in the batter.

L-Cysteine hydrochloride was used at a level of 300 parts per million (ppm) in place of SMS using both the water level for the sulphited dough and that for a dough with the standard extrusion time (50s).

RESULTS

1a) Semi-sweet biscuits

(i) Doughs containing SMS

Table 2 gives data for varieties which met the criteria of acceptability for biscuit texture, a maximum of 33s with the Texture Meter, for biscuits made without SMS, and Table 3 lists data for varieties failing this test.
Table 4 gives data for biscuit thickness and eccentricity (length/width) both with and without SMS.

(ii) Doughs containing L-Cysteine hydrochloride

Three soft wheat varieties, Beaver, Galahad and Riband were examined using the test procedure for semi-sweet biscuits containing L-Cysteine hydrochloride in place of SMS. The results for biscuit softness, thickness and eccentricity may be found in Tables 5, 6 and 7. The levels of water used in the doughs are given in Table 8.

(iii) Wafer batter test

The results of wafer batter tests are shown in Table 9 for those varieties giving harder biscuits without SMS and in Table 10 for those not giving significantly harder biscuits without SMS.

DISCUSSION

1a) Semi-sweet biscuits

(i) Doughs containing SMS

Seven of the 17 wheat varieties tested, (see Table 2) gave biscuits which met the target softness without SMS. It is known (Wainwright et al. 1985) that hard milling wheats give harder biscuits than soft wheats. By far the most important factor affecting the hardness of a wheat cultivar is its genetic constitution and to a lesser extent its growing conditions (Pomeranz and Williams 1988). However, the dependence of biscuit hardness on SMS in the dough for some varieties but not others is less well understood. In studies conducted in Australia (Randall and Wrigley, 1986), sulphur deficiency consistently produced harder grain and cookies produced from such wheats were smaller in diameter. A current HGCA funded Project (0051/1/91) has shown that many soils in the U.K. are deficient in sulphur. It remains to be discovered whether correcting this will have a good or bad impact on the performance of wheats in semi-sweet biscuits.

The biscuits were significantly thicker, with the exception of Tara (1992 harvest, but not 1991 harvest), when made without SMS compared with biscuits made from the same flour with SMS (see Table 4). It is interesting to note that the very old variety Bersee gave much thicker biscuits than the newer varieties, although the reason for this is unknown.

This study has shown that the growing conditions can influence the performance of a variety in this baking test: Galahad grown in 1990 and 1991 produced biscuits which had similar hardness both with and without SMS, although the higher protein content sample from 1991 gave biscuits outside the acceptable limit of hardness. Galahad grown in 1992 gave sulphited biscuits of acceptable hardness with SMS but gave very hard biscuits without. The flour from the 1992 sample had a much higher SDS value than the other samples, indicating that it had a higher quality of protein.

Before this study, all wheats tested at the FMBRA gave harder biscuits without SMS and this was found for the old varieties Bersee, Cappelle-Desprez and Little Joss and the modern varieties Axial, Apollo (one sample), Camp Remy, Galahad (one sample) Riband (one sample), Thesee and Wasp (Table 3). However, for the other varieties tested, sulphited and unsulphited biscuits were of similar hardness.

(ii) Doughs containing L-Cysteine

Replacing SMS with L-Cysteine at the same water level had no significant effect on the softness of semi-sweet biscuits but produced thicker products (see Tables 5 and 6). The doughs containing L-Cysteine had higher extrusion times than those containing SMS. However, increasing the water level to give doughs of the same extrusion time gave a further increase in thickness. The biscuits containing L-Cysteine were all of good flavour and appearance. Further work on this aspect of flour performance will be undertaken at FMBRA under the Co-operative Research Programme.

(iii) Wafer batter test

Most of the varieties tested gave low gluten hydration times (see Tables 9 and 10) and none gave a flocculated gluten during mixing. Five samples, Axial, Bersee, Cappelle-Desprez, Festival and Pernel, gave long gluten hydration times. Those flours which gave harder biscuits without SMS gave longer times for hydration and dispersion of gluten than most of the other varieties. However, samples of Galahad from the 1991 and 1992 harvests gave different performance in biscuit making but similar performance in the wafer batter test, suggesting that there is little or no direct relationship between the two methods of assessment. Galahad 7 and Galahad 77 gave the lowest dispersion times, consistent with low levels of poor quality gluten as judged by the SDS test (see Table 1).

2. CHARACTERISTICS OF WHEAT PROTEINS, DOUGHS AND WAFER BATTERS

Examination of dough and protein characteristics and their sensitivity to SMS may yield diagnostic methods for identifying wheats suitable for biscuit making without the need for gluten modifying agents. Similarly measurements of wafer batter rheology may yield information of diagnostic value in relation to the recurring problem of gluten aggregation in batter systems.

2a) Gel protein level and strength

Gel protein level and strength were measured as described in Appendix 3. The data (Table 11) shows differences in the level of flour gel protein but it was not possible to relate these differences to biscuit quality parameters. The quantity of gel protein which is the high molecular weight (HMW) glutenins insoluble in SDS solution is a wheat varietal characteristic which is strongly related to breadmaking potential.

The amount of gel left after mixing the flour, water and salt dough for 2 minutes and allowing it to rest for 30 minutes is taken as a measure of gel protein strength. Table 11 shows the data for samples from the 1992 harvest and the lowest levels were found for Galahad 7 and Galahad 77, although this test did not discriminate between the performance of the varieties. It was not possible to relate the biscuit making qualities of the flours to the rate of breakdown of the gel proteins during mixing. Table 12 shows the time taken to reduce the gel protein weight to the same level for the wheat varieties from the 1988 harvest.

Table 13 shows the level of gel protein after 1 minute mixing and after 30 minutes recovery for doughs with and without SMS, as described in Appendix 3, for the wheat varieties from the 1988 harvest. A wide range of gel protein levels was found after 1 minute mixing without SMS, however only Little Joss showed a significant increase in gel protein after 30 minutes recovery. Table 14 shows these results expressed as a percentage of the original gel weight. Thus the varieties Riband and Sniper are clearly different from Little Joss and the other varieties. A weak linear relationship appears to exist between biscuit hardness (Texture) and the recovery in gel protein expressed as a percentage of the original protein. However, the results in Table 13 show that the use of SMS in the dough reduces the gel protein to a low level and that there is little change after the 30 minute recovery period. This is consistent with the known ability of SMS to reduce the variability in performance of wheat varieties in biscuit making.

An inverse relationship was found between gel protein level and the elastic modules (G^1) measured at 28°C of a flour water dough but there was no relationship between G^1 and biscuit characteristics.(see Table 15)

The rheology of flour water doughs was measured using a Bohlin Rheometer fitted with an oven unit to simulate the rates of heating used in biscuit baking. The dough samples were prepared with water added at the level determined by the Simon Research Water Absorption equipment (10 minute method) and mixed in a Minorpin mixer for 150s. The samples were 'rested' in a plastic container for 10 minutes before a small piece was transferred to the measuring head of the rheometer, 'rested' again for 10 minutes and tested. The operating conditions for the Bohlin Rheometer are given in Appendix 4.

2b) Friabilin content and endosperm texture of wheat varieties

Friabilin, a protein associated with soft endosperm texture, occurs on the surface of water-washed starch granules. The level of friabilin was quantified in starch isolated from flours from the 1988 harvest using a published procedure (Schofield and Greenwell, 1987) and endosperm texture was confirmed by reference to the particle size index (PSI) - see Appendix 5.

Table 16 shows the results for friabilin content and PSI of the flours. The PSI values clearly distinguish Little Joss from the other six varieties as being a hard-milling wheat, although the values for Riband, Cappelle-Desprez and Bersee are a little lower than expected for soft varieties (PSI generally ≫5.0).

The friabilin data, which are averages of triplicate measurements (with average standard deviation of ±14% of the figure given) also clearly distinguish Little Joss as a hard wheat. The other six samples all had friabilin at the level expected for soft wheats. However, there was no relationship between the level of friabilin and biscuit hardness.

2c) Level of sulphydryl compounds in flours

Differences in the naturally occurring compounds that reduce glutenins in wheat flour doughs could be contributing factors to differences in performance of these flours in semi-sweet biscuit doughs. Their effect should be larger, in principle, in unsulphited doughs because sulphur dioxide would swamp effects due to such reducing compounds. Typical reducing agents in flour contain free sulphydryl groups and these were estimated using the Ellman protocol. This has been described in the HGCA-funded Project 0020/1/91. Investigation of the causes of seasonable variation and short-term changes during storage in breadmaking performance of home-grown wheat. Final report available in Autumn 1994. This consists of the following steps:

- replicate sub-samples (150mg) of flour are defatted with petroleum ether and acetone to remove pigments and lipids.

- the flour is reacted with Ellman's reagents in the presence of sodium dodecyl sulphate and a clear supernatant solution obtained by centrifugation.

- the sulphydryl content is calculated from the yellow colour measured at 412nm after correction for light scattering.

Table 17 shows the results of sulphydryl determination for 6 wheat varieties from the 1990 harvest. The range of levels found was low, expected values being in the range 0.6 to 1.8 μmoles/g flour, and fell in two groups. The first with relatively high sulphydryl levels being Axial, Brock and Haven; the second with relatively low levels being Beaver, Festival and Wasp. This test did not clearly discriminate between the performance of the varieties in either semi-sweet biscuits or wafer batters.

2d) Dough rheology

Rheological measurements on semi-sweet biscuit doughs were carried out with the Bohlin Rheometer as previously described in Appendix 4, at a fixed temperature of 35°C. The dough extrusion time was measured (Barron, 1979). The results of the measurements may be found in Table 18.

Three recipe variations were produced for each variety in duplicate. Recipe formulations were as follows:

1. With SMS at a water level optimised to give a standard extrusion time.
2. Without SMS at a water level optimised to give a standard extrusion time for doughs containing SMS.
3. Without SMS at a water level optimised to give a standard extrusion time.

The viscous and elastic moduli of doughs containing SMS were generally lower than corresponding doughs with no SMS. This indicates that SMS is reducing the extent of cross-linking in the dough. However, varieties Beaver and Galahad 7 saw little change or a slight increase in rheological parameters when SMS was included in the recipe. This suggests that for these varieties SMS is not reducing the degree of cross-linking and may possibly promote extra cross-links in the dough.

For doughs containing no SMS increasing dough recipe water decreased rheological values to a greater extent than SMS inclusion. Only doughs from Galahad 7 failed to show a change in rheology with increasing water. This variety produced doughs which behaved quite differently to those made from other varieties. Doughs from Galahad 7 had a phase angle ($\tan^{-1}$ viscous modulus/elastic modulus) of ~50° whereas all other doughs gave values in the region 24°-30°. A phase angle of 50° indicates that the factors contributing to the the viscous nature of the dough are dominant in Galahad 7 whereas the elastic properties dominate rheological behaviour in the other varieties studied.

2e) Comparison of rheological parameters and biscuit properties

Dough rheological properties showed a weak relationship with biscuit texture. Generally biscuit texture increased with increasing extrusion time. The inclusion of SMS in the recipe produced doughs with a very narrow range of extrusion times and SMS had little effect on biscuit texture. This suggests that texture is primarily determined by variety although level of water addition to the dough may affect texture. The dough elastic modulus gave better discrimination of doughs containing SMS, although there is still only a weak trend with biscuit texture. However, doughs from Galahad 7 comprise a separate group and if these results are ignored the correlation improves (r=0.7).

Rheological parameters showed a better relationship with biscuit eccentricity. This is a measure of biscuit length/biscuit width, dough pieces are cut to an eccentricity of 1.0625 so deviation from this can be determined and used as a measure of the doughs ability to relax. Doughs that gave long extrusion times gave the lowest values of eccentricity suggesting that they underwent greater relaxation of residual elasticity in the dough. Linear regression of this data produced a correlation coefficient of 0.74, although visual comparison suggest that there are two separate populations, one comprising doughs with SMS and the second consisting of doughs without SMS.

The viscosity measured with the Bohlin gave better correlations (0.65 for doughs with SMS, 0.83 for doughs without SMS) with eccentricity than the extrusion time.

The rheological data are useful in assessing the performance of doughs in biscuit making, but do not give a clear discrimination between varieties that give biscuits of target softness for doughs made without SMS.

2f) Wafer batter rheology

Wafer batters were produced according to the standard procedure from flours from Beaver, Galahad, Galahad 7, Galahad 77, Hunter, Riband and Tara and three commercial wafer flours (one good quality, one intermediate quality and one poor quality). The flours were studied in random order in duplicate. Details of the test methods may be found in Appendix 6. The bulk rheological data may be found in Table 19.

The highest elastic modulus (145.8 Pa) was obtained from Galahad batter. Beaver displayed an intermediate value (119.0 Pa) and batters from the remaining flours gave values in the range 79-90 Pa. The lowest elastic modulus value was obtained with Galahad 7. Galahad (79.6 Pa) and Beaver (74.9 Pa) gave the highest batter viscous moduli. Galahad 7 Galahad 77, Tara and Riband gave lower viscous moduli values in the region ~47 - 54 Pa.

The relative importance of the elastic and viscous properties in determining batter rheology can be seen by observing the values of phase angle, (=$\tan^{-1}$ viscous modulus/elastic modulus). The batters produced phase angles ranging from 27° for Riband to 33° for Galahad 7 indicating that in all cases the elastic properties were very important in determining overall rheological behaviour. If the batters have been made to a standard viscosity rather than a constant solids value then Riband may have produced a comparatively high elastic modulus potentially resulting in production difficulties.

Results show that the strongest molecular interactions and aggregation were found in batters prepared from Galahad and Beaver. Processing of batters of this type may cause problems through aggregation leading to blockages of pipes during pumping. Batters from the remaining flours had low elastic modulus and viscosity, indicating weak interactions and little aggregation, factors favourable for wafer production. The utility of Riband, however, may depend upon the precise processing conditions.

These results may be compared with the wafer batter mixing tests.

Thus gluten development and breakdown, as recorded by hydration and dispersion times, were measured by monitoring power changes during high speed mixing in a blender. All batters produced gluten hydration times of 1.2 seconds. Gluten dispersion times varied for the flours and can be related to rheological values (see Tables 10 and 19).

Batter dispersion times were found to generally increase with increasing batter viscosity and elastic modulus. This is not surprising as batters with strong glutens would be expected to have high rheological values. An exception to this was Riband which gave a longer dispersion time than was expected from its rheology. This anomalous behaviour may be due to the strong role the elastic properties play in governing the rheological behaviour of the batter. There is a weak relationship between the phase angle of the batter and gluten breakdown time, with batters giving long dispersion times having lower phase angles.

The batters were also examined by surface rheological tests (see Appendix 2).

Wafer batters were centrifuged to isolate batter liquor for surface studies. Surface rheology measurements separated the variety of flours studied into two groups; those which produced surface films of high elasticity and those which produced low elasticity (see Table 20). High elasticity was produced by flours which gave batters with weak bulk rheological properties in the current system (Galahad 77, Galahad 7, Riband). Those flours giving batters with strong bulk rheology produced films with poor elasticity (Galahad and Beaver). This difference may originate from the strength of the interactions between gluten forming proteins. Strong protein-protein interactions would lead to gluten formation and less protein solubilised in the batter liquor phase resulting in films of poor rheology. Weak protein-protein interactions between gluten forming proteins would result in more protein being solubilised in the batter liquor resulting in films of greater elasticity.

Surface tension measurements on the batter liquor extracts fell in the range 41.4-43.2mN/m. These values are typical of extracts containing both water-soluble lipids and proteins. The presence of lipids is also likely to influence the rheology of surface films. Broadly speaking lipids tend to reduce the interactions between proteins and can displace proteins from an interface resulting in films of poor rheology.

The wafer batter rheology measurements have thus shown that Galahad and Beaver produced wafer batters with the strongest bulk rheology. These batters also produced long gluten dispersion times, Riband also produced a long dispersion time despite having low rheological values. This discrepancy is possibly due to it producing batters with a lower phase angle than the other varieties. A low phase angle indicates that the elastic properties in the batter dominate the overall rheology and it has been observed that the batters with high elastic moduli produce long gluten dispersion times. In Riband the strong dominance of the elastic properties may be the cause of the long dispersion time. Galahad 7, Galahad 77 and Tara all produce batters with weak rheological properties indicating their suitability for processing. Batters with weak bulk rheological properties appear to produce films of strong surface elasticity from batter liquor material.

CONCLUSIONS

1. Wheat varieties have been identified which give good biscuits without SMS using a standard test baking procedure.

2. Modern wheat varieties are in two groups, those in which hardness is affected by addition of SMS and those in which hardness is not affected.

3. No biochemical or rheological tests examined in this work clearly discriminated between wheat varieties on the basis of their biscuit making potential.

4. Linear relationships were found between dough viscosity and biscuit eccentricity and between dough elasticity and biscuit softness.

5. The measurement rheological properties of wafer batters can be used to assess the strength of protein to protein interactions and hence the tendency for gluten development.

RECOMMENDATIONS FOR FUTURE WORK

1. Agronomic studies to assess the impact of rectifying sulphur deficiency in UK soils on the performance in biscuits and wafers of new wheat varieties.

2. Annual testing of current and new wheat varieties for biscuit and wafer making potential (to include further rheological studies of wafer batters).

3. Extension of the study of new wheat varieties into production of snack crackers.

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TABLE 1

Wheat varieties tested, the year they were recommended and their flour characteristics

Variety	Year Recommended	Protein %	SDS* volume ml	Simon Extensometer (1h method)		100E/R
				R^+	E^{++}	
1991 Test Programme						
1988 Harvest						
Beaver	1990	7.7	20	355	17.8	5.0
Bersee	1940's	10.8	57	500	20.0	4.0
Capelle Desprez	1953	11.0	62	498	20.3	4.1
Galahad	1983	9.6	42	325	25.4	7.8
Little Joss	1930's	11.2	70	815	19.6	2.4
Riband	1989	7.8	31	-	-	-
Squareheads Master	1930's	15.1	64	494	23.8	4.8
Sniper	-	8.7	41	405	17.7	4.4
1990 Harvest						
Apollo A	1988	9.0	39			
Apollo B	1988	9.3	44			
Apollo C	1988	8.8	34	483	15.4	3.1
Bersee	1940's	11.9				
Cappelle Desprez	1953	10.6				
Galahad A	1983	8.1	35	376	22.1	5.9
Galahad B	1983	8.2	35	414	20.9	5.0
Little Joss	1930's	12.3				
Riband A	1989	7.8	39	409	17.9	4.4
Riband B	1989	8.3	42	394	19.7	5.0
Riband C	1989	7.9	33	465	16.3	3.5
Slejpner A**	1986	8.2	42	626	14.4	2.3
Slejpner B**	1986	9.3	53	469	18.6	4.0

TABLE 1
(cont.)

Variety	Year Recommended	Protein %	SDS* volume ml	Simon Extensometer (1h method) R^{+}	E^{++}	100E/R
1992 Test Programme						
1990 Harvest						
Axial		8.7	51	561	16.7	3.0
Beaver	1990	8.0	30	292	15.1	5.2
Brock	1985	8.7	37	384	17.8	4.6
Camp Remy**		10.3	90	606	16.0	2.6
Festival		10.1	80	556	22.2	4.0
Galahad 7		12.1	22	-	-	-
Haven**	1990	7.9	32	365	12.9	3.5
Pernel**		9.4	86	590	14.0	2.4
Tara		8.7	23	435	14.7	3.4
Thesee**		9.0	78	705	15.4	2.2
Wasp		8.3	46	500	14.7	2.9
1991 Harvest						
Admiral		11.9	29	386	14.9	3.9
Apollo	1988	10.2	44	335	20.4	6.1
Axial		12.0	53	516	20.1	3.9
Beaver	1990	12.8	29	365	17.6	4.8
Galahad	1983	11.5	37	469	19.2	4.1
Haven**	1990	14.2	38	375	17.4	4.6
Riband	1989	9.6	44	464	16.7	3.6
Tara		9.3	23	284	16.6	5.8
1990 Harvest Commercial Flours						
Galahad	1983	8.4	16			
Riband	1989	9.6	18			
1993 Test Programme						
1992 Harvest						
Beaver	1990	9.5	37	89	15.3	17.2
Galahad	1983	9.1	50	374	20.1	5.4
Galahad 7		10.3	10	-	-	-
Galahad 77		9.7	9	255	9.5	3.7
Hunter		8.8	41	294	19.1	6.5
Riband	1989	9.6	52	274	23.5	8.6
Tara		8.8	21	204	14.8	7.3

* Sodium dodecyl sulphate
** Hard milling varieties
$^{+}$ Resistance
$^{++}$ Extensibility

TABLE 2

Wheat varieties that gave semi-sweet biscuits of target softness without SMS

Variety	Recipe water % of flour	With SMS texture S	Without SMS texture S
1990 Harvest (Year 1)			
Apollo C	19.5	33	33
Galahad A	21	30.5	33
Galahad B	21	29	32
1990 Harvest (Year 2)			
Beaver	17.5	31	31.5
Festival	20	30.5	32
Galahad*	20	28.5	30
Riband*	20.5	34	31.5
1992 Harvest (Year 3)			
Galahad 77	17.5	36	32.5
Tara	18.5	34.5	32.5

* Commercially milled samples

TABLE 3

Wheat varieties that did not give biscuits of target softness without SMS

Variety	Recipe water % of flour	With SMS texture S	Without SMS texture S	
1990 Harvest (Year 1)				
Apollo A	20.5	31	36	
Apollo B	20.5	29.5	34.5	
Bersee	21.5	30.5	53	++
Cappelle Desprez	22	31.5	43	++
Little Joss	25	70	62	++
Riband A	22.5	32	34.5	
Riband B	20	36.5	35	
Riband C	19	30.5	33.5	
Slejpner A	21.5	52.5	49	
Slejpner B	22	58.5	62	
1990 Harvest (Year 2)				
Axial	21.5	51	32.5	++
Brock	20.5	42	39.5	
Camp Remy	21	73	60	++
Galahad 7	20	54.5	57	
Haven	20	50	54	
Pernel	22.5	81	51	++
Tara	18.5	48.5	52.5	
Thesee	22.5	75	48.5	++
Wasp	21	51.5	38	++
1991 Harvest (Year 3)				
Admiral	22.5	52	47	
Apollo	20.5	47	32	++
Axial	23.5	57	37.5	++
Beaver	20	34.5	34	
Galahad	22.5	43.5	37	
Haven	20	56.5	54.5	
Riband	22.5	47	39	
Tara	20.5	45	43.5	

TABLE 3
(contd)

Variety	Recipe water % of flour	With SMS texture s	Without SMS texture s	
1992 Harvest (Year 3)				
Beaver	18	39.3	43	
Galahad	19	32.5	51	++
Galahad 7	18.5	49.5	50	
Hunter	18.5	33	39	
Riband	18	29	42	++

++ Differences between biscuits made with and without SMS, significant at 5%

TABLE 4

Effect of removing SMS on semi-sweet biscuit thickness and eccentricity

Variety	With SMS +Thickness mm	With SMS Eccentricity	Without SMS Thickness mm	Without SMS Eccentricity
1990 Harvest (Year 1)				
Apollo A	54.0	1.05	65.5	1.01
Apollo B	53.5	1.045	66.0	1.00
Apollo C	52.0	1.055*	64.0	1.03*
Bersee	65.0	0.975	78.0	1.01
Cappelle Desprez	57.0	0.95	70.5	1.03
Galahad A	50.5	1.05	68.0	0.99
Galahad B	51.5	1.04	61.5	0.975
Little Joss	57.0	0.97	69.5	1.01
Riband A	48.5	1.04	65.0	0.985
Riband B	52.5	1.045	65.0	0.975
Riband C	52.0	1.045	67.0	1.00
Slejpner A	45.0	1.045	63.0	0.99
Slejpner B	47.0	1.04	61.0	0.985
1990 Harvest (Year 2)				
Axial	51.5	1.045	63.5	0.975
Beaver	51.0	1.06	57.0	1.02
Brock	48.5	1.05	65.0	0.975
Camp Remy	55.5	1.025	67.5	0.93
Festival	59.5	1.045	83.0	0.925
Galahad 7	53.0	1.04	60.0	0.99
Haven	46.5	1.05	55.0	1.005
Pernel	55.0	1.02	62.0	0.945
Tara	49.5	1.05	55.5	1.03
Thesee	47.0	1.035	47.0	0.955
Wasp	51.5	1.035	59.0	0.985
1991 Harvest (Year 2)				
Admiral	47.5	1.05	53.0	1.025
Apollo	54.5	1.04	64.0	1.00
Axial	52.0	1.025	67.5	1.00
Beaver	54.5	1.035	65.0	1.00
Galahad	49.0	1.03	59.0	0.99
Haven	49.5	1.04	57.0	0.995
Riband	47.5	1.05	60.0	1.005
Tara	50.5	1.04	59.0	1.02

TABLE 4
(contd)

Variety	With SMS +Thickness mm	With SMS Eccentricity	Without SMS Thickness mm	Without SMS Eccentricity
Commercial Flours				
Galahad	48.5	1.045	57.5	1.00
Riband	46.0	1.055	63.5	0.995
1992 Harvest (Year 3)				
Beaver	51.3	1.038	58.5	0.998
Galahad	46.5	1.045	57.5	0.955
Galahad 7	44.0	1.045	59.0	0.985
Galahad 77	49.0	1.050	59.0	0.990
Hunter	50.5	1.035	61.0	0.970
Riband	54.0	1.045	66.0	0.965
Tara	45.0*	1.060	49.0*	1.035

Differences between biscuits with and without SMS

* Not significant, others at least 1%

\+ Thickness of 10 biscuits

TABLE 5

Effect of L-Cysteine on semi-sweet biscuit softness

Variety	With SMS	Texture with L-Cysteine	With L-Cysteine & extra water
1992 Harvest	**S**	**S**	**S**
Beaver	41.0	36.5	34.5
Galahad	31.5	33.5	28.0**
Riband	31.0	26.5	27.0

** Differences between biscuits with SMS and L-Cysteine or L-Cysteine and extra water, significant at 1%

TABLE 6

Effect of L-Cysteine on semi-sweet biscuit thickness

Variety	With SMS mm	Thickness+ with L-Cysteine mm	With L-Cysteine & extra water mm
1992 Harvest			
Beaver	49.3	53.8*	53.5*
Galahad	46.3	51.0	52.8**
Riband	48.0	53.5*	54.5**

* Differences between biscuits with SMS and L-Cysteine or L-Cysteine and extra water, significant at 5% (*) or 1% (**)

\+ Thickness of 10 biscuits

TABLE 7

Effect of L-Cysteine on semi-sweet biscuit eccentricity

Variety	**With SMS**	**Eccentricity with L-Cysteine**	**With L-Cysteine & extra water**
1992 Harvest			
Beaver	1.025	1.015	1.020
Galahad	1.045	1.025*	1.035
Riband	1.035	1.005**	1.015*

* Differences between biscuits with SMS and L-Cysteine or L-Cysteine and extra water, significant at 5% (*) or 1% (**)

TABLE 8

Recipe water levels used in sulphited and unsulphited doughs and doughs containing L-Cysteine

Variety 1992 Harvest	**With SMS**	**Recipe water level** **Without SMS**	**With L-Cysteine**	**With L-Cysteine & extra water**
	% of flour	% of flour	% of flour	% of flour
Beaver	19	22.0	19	20.5
Galahad	19	23.5	19	20.0
Riband	18	22.0	18	20.5

TABLE 9

Wafer batter tests for single wheat varieties giving significantly harder biscuits without SMS

Variety	Gluten hydration time (HT) s	Gluten dispersion time (DT) s	HT + DT s
1988 Harvest (Year 1)			
Bersee	48.0	19.8	67.8
Cappelle-Desprez	22.8	22.8	45.6
Little Joss	1.2	39.6	40.8
1990 Harvest (Year 2)			
Axial	24.0	22.0	46.0
Pernel	83.0	43.0	12.6
Thesee	1.2	38.0	39.2
Wasp	3.6	33.6	37.2
1991 Harvest (Year 3)			
Apollo	1.2	19.2	20.4
Axial	1.2	19.2	20.4
1992 Harvest			
Galahad	1.2	25.5	26.7
Riband	1.2	26.0	27.2

TABLE 10

Wafer batter tests for single wheat varieties not giving significantly harder biscuits without SMS

Variety	Gluten hydration time (HT)	Gluten dispersion time (DT)	H + T
1988 Harvest (Year 1)			
Beaver	1.2	30.0	31.2
Galahad	1.2	25.2	26.4
Riband	1.2	50.4	51.6
Squareheads Master	1.2	40.2	41.4
1990 Harvest (Year 1)			
Apollo A	2.4	19.8	22.2
Apollo B	1.2	22.8	24.0
Apollo C	1.2	22.2	23.4
Galahad A	1.2	36.0	37.2
Galahad B	1.2	31.2	32.4
Riband A	1.8	31.2	33.0
Riband B	1.2	24.0	25.2
Riband C	2.4	31.8	34.2
Slejpner A	1.2	27.6	28.8
Slejpner B	1.2	21.0	22.2
1990 Harvest (Year 2)			
Beaver	1.2	30.0	31.2
Festival	48.4	51.0	99.4
Galahad 7	3.0	3.8	6.8
Galahad	1.2	31.0	32.2
Haven	1.2	17.0	18.2
Tara	1.2	16.0	17.2
1991 Harvest (Year 3)			
Admiral	1.2	11.7	12.9
Beaver	1.2	11.4	12.6
Galahad	2.4	22.2	24.6
Haven	2.9	8.4	11.3
Riband	1.2	18.6	19.8
Tara	1.2	10.8	12.0
1992 Harvest(Year 3)			
Beaver	1.2	18.9	20.1
Galahad 7	1.2	8.8	10.0
Galahad 77	1.2	9.9	11.1
Hunter	1.2	27.3	28.5
Tara	1.2	10.2	11.4

TABLE 11

Gel protein level and weight recovered after mixing and resting (gel strength) for single wheat varieties

Variety	**Gel protein weight** **g**	**Gel protein weight after mixing and resting** **g**
1988 Harvest		
Beaver	3.7	-
Bersee	10.8	-
Cappelle-Desprez	12.9	-
Little Joss	9.3	-
Riband	9.6	-
Sniper	5.6	-
1992 Harvest		
Beaver	3.6	0.05
Galahad	7.1	0.4
Galahad 7	1.7	0.0
Galahad 77	1.4	0.1
Hunter	4.8	0.2
Riband	8.3	0.3
Tara	2.5	0.2

TABLE 12

Time taken to reduce gel protein weight to the same level for wheat varieties from the 1988 harvest

Variety	**Mixing time/s** **(2.0g)**	**(0.5g)**
Beaver	33	84
Bersee	48	84
Cappelle-Desprez	66	126
Little Joss	105	153
Riband	66	150
Sniper	30	90
Squareheads Master	90	179

TABLE 13

Evaluating the reducing power of SMS by gel protein breakdown and recovery

Variety		Gel protein wt/g With SMS	Change	Without SMS	Change
Beaver	1 min mix	0.39		1.28	
	30 min recovery	0.40	-0.01	0.93	-0.35
Bersee	1 min mix	0.35		3.55	
	30 min recovery	0.25	-0.10	3.23	-0.32
Cappelle	1 min mix	0.50		5.20	
Desprez	30 min recovery	0.28	-0.22	5.28	+0.08
Little Joss	1 min mix	0.81		5.07	
	30 min recovery	0.96	+0.15	5.90	+0.83
Riband	1 min mix	0.95		4.66	
	30 min recovery	0.47	-0.48	3.36	-1.30
Sniper	1 min mix	0.35		2.10	
	30 min recovery	0.17	-0.18	1.40	-0.70
Squareheads	1 min mix	0.80		7.47	
Master	30 min recovery	0.66	-0.14	7.10	-0.37

TABLE 14

The change in flour gel protein levels following 1 minute mixing and 30 minute recovery period

Variety	Change as a % of original gel weight	Biscuit texture*
Beaver	-9.31	28
Bersee	-3.0	37
Cappelle Desprez	-0.62	39
Little Joss	+8.91	57
Riband	-13.51	24
Sniper	-12.57	44
Squareheads Master	-2.38	41

TABLE 15

Gel protein level and dough elastic modules (at 28°C) for wheat flours

Variety	Gel weight g	G^1 Pa
Beaver	3.7	5.9×10^4
Bersee	10.1	3.6×10^4
Cappelle Desprez	12.9	2.8×10^4
Little Joss	9.3	2.3×10^4
Riband	9.6	4.2×10^4
Squareheads Master	15.6	2.5×10^4
Sniper	5.6	6.8×10^4

TABLE 16

Particle size index (PSI) and friabilin content

Variety	PSI (g)	Friabilin staining intensity (Arbitrary units)
Beaver	7.1	380
Bersee	4.5	280
Cappelle Desprez	4.7	290
Little Joss	3.0	110
Riband	4.8	320
Sniper	5.7	360
Squareheads Master	5.5	280

TABLE 17

Level of sulphydryl compounds in flours (1990 harvest)

Variety	Sulphydryl groups μmole/g
Axial	0.402
Beaver	0.332
Brock	0.365
Festival	0.330
Haven	0.395
Wasp	0.331

TABLE 18 Rheological data for semi-sweet biscuit doughs made from single variety wheat flours

Variety 1992 Harvest	Treatment	Water on flour weight %	Phase angle degrees	Viscosity $X10^3$ Pas	Elastic Modulus $X10^4$ Pa	Viscosity Modulus $X10^4$ Pa	Extrusion time s
Beaver	1	18.0	20	7	12.0	4.4	51.0
	2	18.0	24	7	9.8	4.4	149.0
	3	21.0	22	5	8.0	3.3	61.0
Galahad	1	19.0	28	10	12.0	6.5	64.5
	2	19.0	27	19	23.0	12.0	387.0
	3	23.5	25	7	10.0	4.4	75.0
Galahad 7	1	18.5	52	9	4.0	5.6	44.0
	2	18.5	51	6	3.0	4.0	175.0
	3	22.5	49	6	3.5	4.0	56.0
Galahad 77	1	17.5	25	6	8.0	3.8	52.0
	2	17.5	23	8	12.0	5.2	211.0
	3	21.0	26	5	6.5	3.2	62.0
Hunter	1	18.5	25	9	12.0	5.7	55.0
	2	18.5	26	12	16.0	7.8	224.0
	3	23.0	25	5	7.0	3.3	40.0
Riband	1	18.0	30	10	12.0	6.6	47.0
	2	18.0	28	13	15.0	8.0	328.0
	3	23.0	27	6	7.0	3.6	40.0
Tara	1	18.5	24	4	6.0	2.8	52.0
	2	18.5	24	6	8.0	3.	140.0
	3	22.0	27	3	3.5	1.8	41.5

TABLE 19

Wafer batter bulk rheological measurements

Variety 1992 Harvest	**Phase Angle Degrees**	**Viscosity Pa s**	**Elastic Modulus Pa**	**Viscous Modulus Pa**
Beaver	32.3	11.9	119.0	74.9
Galahad	28.8	12.7	146.0	79.6
Galahad 7	33.4	8.3	79.5	51.8
Galahad 77	29.9	7.5	82.4	47.4
Hunter	31.9	11.2	115.0	70.5
Riband	26.8	7.7	87.8	48.2
Tara	30.8	8.6	90.3	53.9
Commercial flours:				
Moderate	22.1	5.2	80.0	32.4
Good	26.1	5.0	65.0	31.3
Poor	21.1	10.5	172.0	65.9

TABLE 20

Wafer batter liquor surface rheological measurements

Variety 1992 Harvest	**Batter yield %**	**Surface tension mNm^{-1}**	**Surface elasticity mNm^{-1}**	**Surface viscosity $mNsm^{-1}$**
Beaver	35.2	42.7	2.1	0.104
Galahad	32.3	42.1	2.2	0.094
Galahad 7	29.5	42.8	9.5	0.051
Galahad 77	32.0	43.2	10.6	0.196
Hunter	33.8	41.4	1.6	0.125
Riband	33.5	42.2	7.8	0.196
Tara	35.4	41.7	1.2	0.104

APPENDIX 1

Test baking procedure

Test recipe

Ingredient	Weight (g)
Flour	200
Pulverised sugar	42
Shortening	32
Skimmed milk powder	5.0
Salt	0.7
Cream powder	0.7
Sodium bicarbonate	1.1
Ammonium bicarbonate	1.1
Sodium metabisulphite	0.045 (if required)
Water	As determined

Processing details

Water level: as determined by Simon Extensometer, with an extrusion time of 50s in the 1h procedure (Barron, 1979)

Dough sheet thickness: 1.5mm

Baking time: 6.5min

Dough sheet braking procedure:

Pass	Roll gap setting (mm)
1st	16
2nd	12
3rd	8
4th	4
5th	2
6th	1.5

APPENDIX 2

Wafer batter mixing test

Test recipe

Ingredient	Weight (g)
Flour	395
Water (approx 43°C)	475

Processing details

Batters were initially whisked in a Hobart mixer (30s at speed 1, 120s at speed 2)

Batter viscocity was measured with a viscometer cup (time taken for 200g of batter to pass through a 7.75mm diameter hole).

200g of batter was placed in the liquidizer attachment of a Kenwood Major and mixed at speed 3. During this time a trace from a chart recorder examined the power input via a power meter placed between the mixer and the mains.

APPENDIX 3

Measurements on gel proteins from single wheat variety flours

Gel protein level

This method is based on that published by Graveland, Bongers and Bosveld, 1979.

Defatted flour (5g) was dispersed in 1.5% sodium dodecyl sulphate solution (SDS, 90ml) and mixed at 10°C for 10 minutes. The flour suspension was centrifuged for 40 minutes at 25,000 rpm in an MSE Europa 55M ultra-centrifuge to give a layer of gel protein on a starch layer. The gel protein fraction was removed and weighed.

Gel protein strength

Flour (28g), salt (0.5g) and water (to satisfy the flour water absorption as determined by the Simon Water Absorption 10 minute procedure) were mixed in a Minorpin mixer. Dough samples were removed after 1, 2 and 3 minutes mixing, frozen, freeze-dried and milled to less than 250μm. The gel protein level was determined on these samples after defatting.

Effect of SMS on gel protein level and recovery

Doughs were prepared by the procedure described for determining gel protein strength without SMS and with SMS (at 200 ppm sulphur dioxide on a flour basis). Doughs were mixed for 1 minute and sampled for estimation of the level of gel protein. The remainder of the doughs were left for 30 minutes to allow for protein "recovery" and sampled for analysis.

APPENDIX 4

Operating conditions for the Bohlin Rheometer

Rheological measurements of the dough samples were measured under heating conditions which simulated the rate of heating used in biscuit baking as shown below:

Measuring system	Parallel plate PP25H
Torque element, gcm	18.08
Filter	5
Gap size, mm	2
Sensitivity	1X
Temperature:	
gradient, °C/min	25
range, °C	25 - 120
Holding time at 120°C,s	312
Amplitude, %	5
Frequency, Hz	1
Measurement interval,s	30

The measurements involve applying a sinusoidaly varying strain, at a defined amplitude and frequency, to the sample which is clamped between an oscillating lower head and a fixed upper surface. Comparison of the strain applied with the stress generated in the samples yields the dynamic storage or elastic modulus (G^1) and the dynamic loss or viscosity modulus (G^{11}).

APPENDIX 5

Estimation of friabilin in flours and measurement of wheat endosperm texture

Friabilin content of isolated starches

Starch was extracted from flour (200mg) by a microscale procedure. The defatted flour was dispersed in water and the starch separated from the slurry by selective centrifugation into a density cushion of caesium chloride solution. The small amount of protein remaining on the starch granules was then extracted with the detergent sodium dodecyl sulphate (SDS) and analysed (after reduction of the disulphide bonds) by SDS-PAGE electrophoresis. The friabilin protein was then quantified by staining and scanning densitometry of the band of apparent molecular weight 15,000.

Particle Size Index

The flours were prepared using fixed settings on the FMBRA's pilot-scale Buhler mills and a standard sieving test used to assess endosperm hardness. Flour (10g) was screened on a 75 micron metal sieve in an Alpine Air-Jet Sieve. The weight of flour in grammes passing through the sieve is defined as the Particle Size Index. Generally, on this scale, Hard endosperm ⟨5.0 ⟨Soft endosperm.

APPENDIX 6

Rheological examination of wafer batters using a Bohlin VOR Rheometer

All measurements were carried out using a concentric cylinder (25mm internal diameter) with an 87g cm torque bar. The measurement temperature was 33°C, the temperature of the batters at the end of mixing. Strain sweep tests showed a linear viscoelastic region centred around a strain of 0.0018; this was the strain therefore applied for oscillatory measurements 5 minutes after batter preparation.

The mixed batter was centrifuged in the Europa 55M centrifuge for 30 minutes at 33°C, 62,500 g force. The batter liquor was a straw-coloured water-like liquid. It was collected by inverting the centrifuge tubes for 60 seconds. The contents of all the tubes were combined and stirred vigorously for 10 minutes before measurements of surface tension and rheology were carried out.

Surface tension measurements of wafer batter extracts

Surface tension measurements were made at 30°C using a Kruss Interfacial Tensiometer K8. The measuring method used was the Ring Method, whereby a platinum ring connected to a balance beam is immersed into the solution and afterwards slowly withdrawn. The force necessary to withdraw the ring against the interfacial tension was measured.

Surface rheology measurements

Surface rheology measurements were made with a normalised resonance oscillating ring surface shear rheometer at the air-wafer batter liquor interface. The measuring head of the instrument consists of a platinum du Nouy ring attached to a moving coil galvanometer. The plane of the ring is located in the interface, ensuring that it is completely wetted by the solution and then forced to oscillate at resonance. The oscillation is produced by passing an input sine-wave voltage through the galvanometer head and the resultant movement recorded as an output voltage using a proximity probe and displacement transducer unit. Automatic analysis of the signal produced gives the surface shear elasticity and shear viscosity simultaneously.

The starting frequency in this work was 3.3 Hz and the maximum strain employed was 1%. The oscillatory method of measurement used is on the whole non-destructive and may be used to study fragile systems such as adsorbed interfacial films.