HGCA

PROJECT REPORT No. 152

ASSESSMENT OF THE IMPACT OF CHANGES IN CROP GROWTH AND DEVELOPMENT ON THE GRAIN QUALITY OF WHEAT, WITH PARTICULAR REFERENCE TO CHOPIN ALVEOGRAPH

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ASSESSMENT OF THE IMPACT OF CHANGES IN CROP GROWTH AND DEVELOPMENT ON THE GRAIN QUALITY OF WHEAT, WITH PARTICULAR REFERENCE TO CHOPIN ALVEOGRAPH

by

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Summary

Wheat samples were obtained from a number of ADAS experiments in which a range of agronomic and environmental factors were examined, including variety, site, rotational position, nitrogen, sowing date, seed-rate, application of plant growth regulator, water availability and shading. Grain samples were analysed for total protein, Hagberg Falling Number (HFN), sodium dodecyl sulphate (SDS) and Zeleny sedimentation volumes, and Alveograph characteristics (configuration ratio, P/L and deformation energy, W). Yield, thousand grain weight (TGW) and specific weight (SpWt) were obtained from existing data.

Data were analysed statistically to identify agronomic and environmental factors influencing grain quality. Yield, TGW and SpWt responded to the experimental treatments as expected based on previous agronomic experience. Alveograph characteristics were influenced by variety, site, nitrogen and water availability. Nitrogen application resulted in higher W values and lower P/L ratios at lower levels, suggesting an improvement in bread-making quality, but with little effect at application rates in excess of optimal nitrogen rates for yield. Drought resulted in increases in both P/L and W in all varieties, although there was some evidence of varietal differences in response. Changes in P/L ratio due to drought and nitrogen were different, nitrogen mainly affecting dough extensibility (L) whereas drought mainly affected dough strength (P). It was evident from these results that Alveograph characteristics were affected by changes in both amount and composition of grain protein, as affected by agonomic treatment and crop environment. Variety, site, nitrogen and water availability were also the main factors affecting HFN, SDS and Zeleny volumes, with drought and higher applied nitrogen rates suggesting improvements in bread-making quality. A summary of the magnitude of the effects of the various factors on Alveograph characteristics is shown in Figures 1 and 2.

Examination of the results for grain quality in relation to the physiology of the crop indicated that apparent improvements in bread-making potential appeared to be related to lower photosynthetic capacity combined with greater nitrogen uptake. These factors may help to explain both inter- and intra-site differences in quality, as noted in BCE Alveograph tests. It is recommended that further more detailed studies be carried out, examining in more detail the effects of site, nitrogen and water availability on grain quality. **Grain from 1997 harvest may prove valuable in this respect since greater climatic variability was found in this harvest year.** Further studies should also include the effects of strobilurin-based fungicides which have been shown to influence grain-filling via changes in Green Area Index (HGCA project 0043/01/96). A wider range of wheat varieties should be examined, including bread, biscuit and feed quality wheats. In addition, more detailed analysis of differences in flour quality should be undertaken in order to help explain the observed effects.

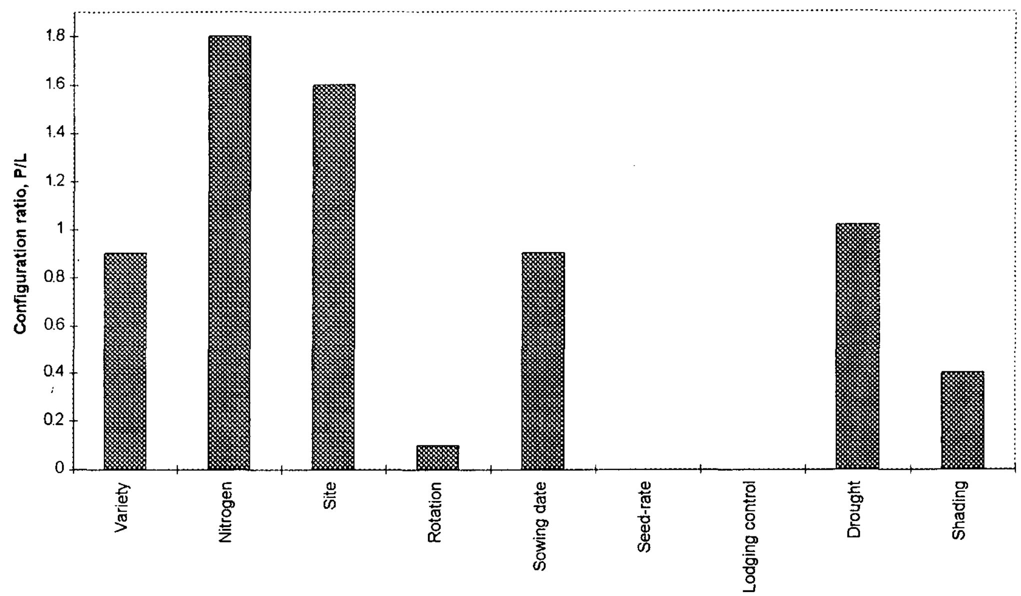

Figure 1. Magnitude of the effects (absolute values) of agronomic and environmental factors on configuration ratio, P/L

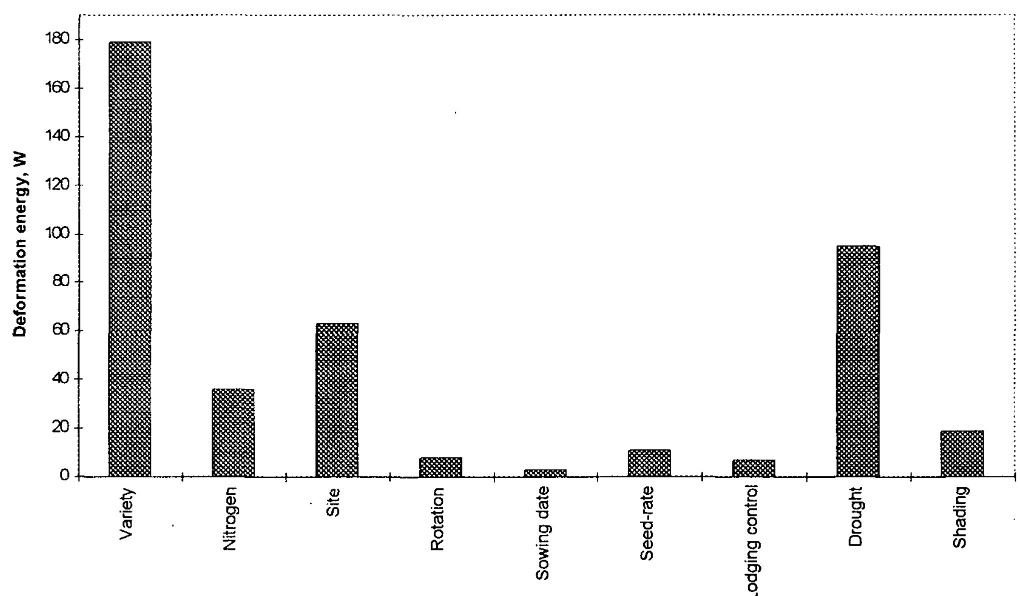

Figure 2. Magnitude of the effects (absolute values) of agronomic and environmental factors on deformation energy, W

Introduction

Britain produces around 16 million tonnes of wheat per annum, of which approximately 25% is exported, with the most important destinations being Spain, Italy and Portugal. The maintenance of wheat export markets is thus of vital importance to the UK grower, a point emphasised by BCE at an export forum in 1995 where it was stated that: “The whole UK market for cereals is strongly influenced by the success of exports”.

The quality of the wheat grain is crucial in maintaining these export markets. A number of quality parameters are quoted for export, with selling specifications being specific weight (SpWt), Hagberg Falling Number (HFN) and protein content. Further tests on arrival at export destinations include the Chopin Alveograph and these additional specifications are seen as vital to maintain these markets. To emphasise this, it was stated in a BCE press release in 1995: “Measuring wheat protein quality with the Chopin Alveograph features strongly in export trade to many important destinations such as Italy, Spain and North Africa”.

It is thus important to understand the effects of agronomy and environment on wheat quality, with particular reference to Alveograph tests, in order to aid the sourcing of grain for export and ensure that the reputation of UK wheat in export markets is maintained and where possible enhanced. This is the principal aim of the current project.

The Chopin Alveograph test

The Alveograph is a rheological instrument which measures the air pressure required for biaxial extension of a sample of dough. It was initially proposed in the 1920’s by Marcel Chopin and has been developed into a precise modern instrument. The test was originally intended to simulate as closely as possible the process that dough undergoes in bread-making, and measures the resistance of a dough to stretching and its extensibility, under closely controlled test conditions, up to the point at which the dough ruptures.

Testing of a sample using the Alveograph relies on the following steps:

1. Wheat is milled using a standardised procedure
2. A dough is prepared consisting of fixed proportions of flour, salt and water
3. Strips of dough are extruded, from which discs are cut
4. The test discs are allowed to rest for a fixed period of time at a standard temperature
5. The test discs are inflated up to the point of rupture, with properties of the dough being monitored during inflation

Each sample is analysed using five test discs prepared from the original flour, with the graphic recordings being averaged to produce the measured parameters.

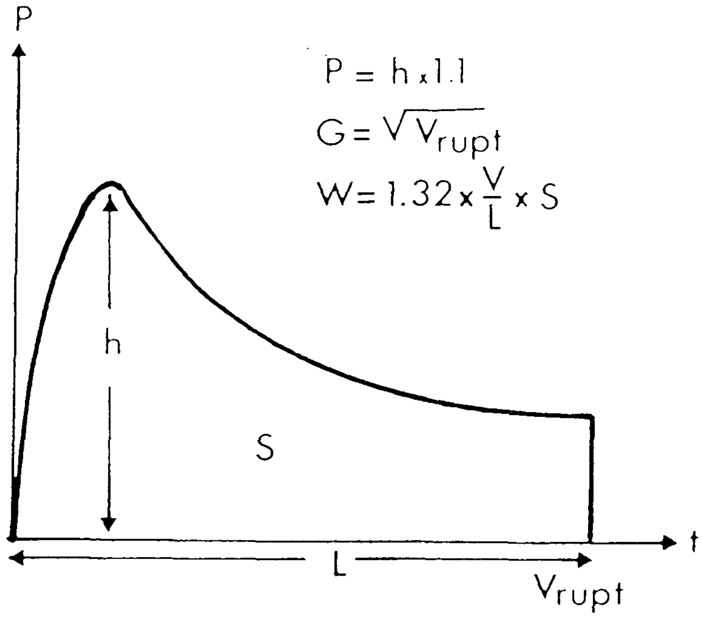

Figure 3. Diagram showing a typical alveogram. P = overpressure (mm), L = abscissa at rupture (mm), G = swelling index (ml), V = volume of air (ml), W = deformation energy (10^{-4} x J), h = maximum height (mm), and S = area under the curve (cm^2). (Faridi and Rasper, 1987)

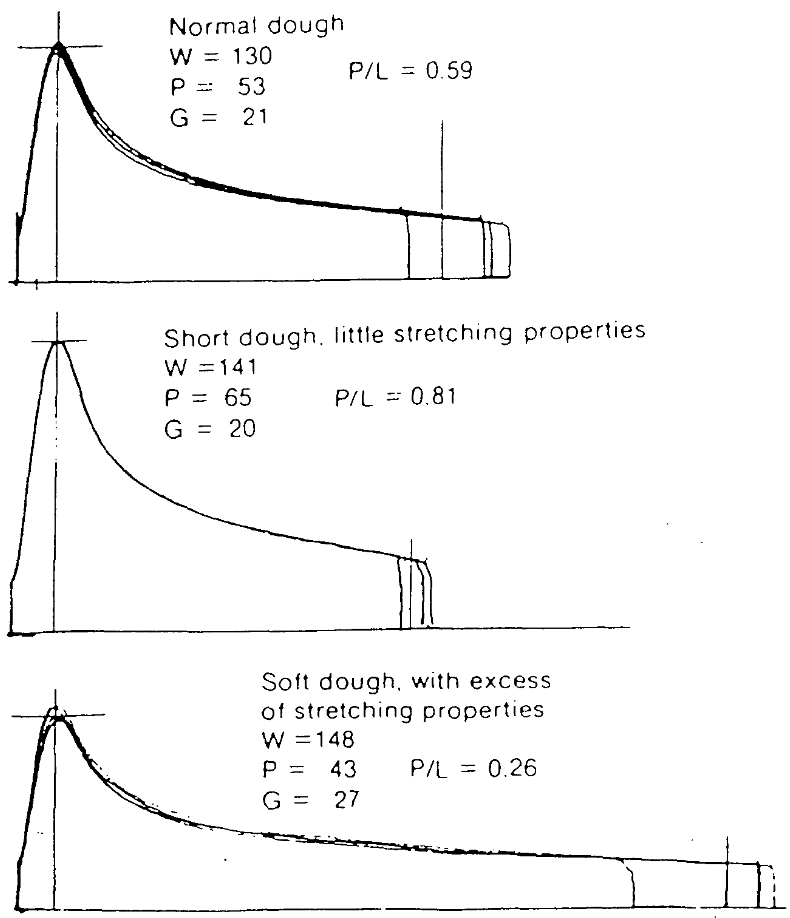

Figure 4. Alveograms of flours with distinctly different dough-forming and baking qualities (Faridi and Rasper, 1987).

The characteristics of the dough in the Alveograph test are assessed using four parameters, as shown in the example in Figure 3. These parameters are defined as follows:

P Maximum Overpressure. This is the maximum pressure required for deformation of the sample, representing the strength of the test dough.

L Average Abscissa at Rupture. This is the length of the curve, representing the extensibility of the test dough.

G Index of Swelling. This is the measurement of the volume of air in the bubble at the point of rupture, representing the tolerance of the dough.

W Deformation Energy. This is the surface of the recording curve and is linked to the energy required to inflate the bubble until it ruptures.

The P/L value, known as the 'configuration ratio' is calculated and used in combination with the deformation energy (W) to specify the quality of flour for particular end-uses. Potential export markets usually specify a minimum W and a maximum P/L ratio, in addition to other quality parameters. The current preferred overseas buyers specifications are shown in Table 1.

Table 1. Preferred overseas buyers specifications

Market	Minimum specific weight kg/hl	Minimum HFN s	Minimum protein % at 14% moisture	Alveograph P/L ratio	Alveograph W J x 10^{-4}
Strong bread flour	76	240	12.0	≤0.8	≥240
Bread flour	76	225	10.0	≤0.6	≥170
Blended flour	76	225	10.0	≤0.6	-
Biscuit flour	76	225	10.0	≤0.5	≤110
Animal feed	72-76	-	-	-	-

(BCE Growers' Guide, 1997/8)

Practical relevance of Alveograph values

There has been much debate over the relevance of the parameters measured by the Alveograph, particularly the Maximum Overpressure, P and several researchers have tried to relate this measure to empirical aspects of dough rheology. Chopin (1927) originally claimed that this value was an indicator of the tensile strength of the dough in its initial state of expansion and whereas Scott-Blair and Potel (1937) stated that it correlated with dough viscosity which varied as a result of the water-absorbing capacity of the tested flour. Hlynka and Barth (1955) found that the maximum height of the alveogram depends on the thickness the the dough bubble wall at the time the maximum height is reached as well as the viscosity. Bloksma (1957a, 1958) acknowledged this finding and placed significance on the sharpness of the curve peak. He suggested the use of a second measure, the ratio of height of the curve at the bubble volume of 100 ml to the height of the maximum. It was found that this ratio correlated well with loaf volume data in baking experiments (Bloksma, 1957b). Despite the numerous criticisms, the P value is now widely accepted as an indicator of dough resistance to deformation, representing the strength of the dough at fixed water levels..

Unlike the P value, the L value has not received as much debate and is widely accepted as a measure of dough extensibility. The configuration ratio, P/L is thus an approximate indication of the shape of the alveogram, with a low P/L ratio given by a dough which is easy to inflate and is highly extensible, whereas a high P/L ratio is given by a dough which is hard to inflate and collapses quickly because of poor extensibility. However, some workers have reported that the P/L ratio is a poor indicator of flour quality (Weipert, 1981).

The swelling index, G, is also regarded as a measure of dough extensibility (Kent-Jones and Amos, 1967) and is recorded in this study, though it does not feature in export specifications for UK wheats.

The W value is considered to relate closely to the flour strength. Whether W can be used to predict loaf volume is more debatable, with some workers reporting highly significant correlations between W and loaf volume of flours of different types (Aitken *et al.*, 1944; Marcelle, 1955) whereas others found poor correlations (Bloksma, 1957b). Attempts have also been made to correlate W values with dough hydration capacity and protein content (Rasper *et al.*, 1986).

Differences seen in alveograms of some flours with different dough-forming properties are shown in Figure 4. Essentially, flours for bread-making must exhibit low P/L ratios and high W values, whereas for biscuit making they must have low P/L ratios and low W values.

BCE Alveograph testing

Since 1990, BCE have been funding Alveograph tests of all the main UK wheat varieties. The results have shown that although the absolute values recorded in the tests vary, within a site the ranking remains fairly constant. Results have shown that although the variety rankings tend to remain constant there is significant variation within each variety, both between sites and also within a site. In some cases the variation within a site can be as large as that between sites and can be large enough to move a variety from within the export quality criteria to well outside. It is likely that this variation is due to differences in the growth and development of individual crops and it is this field to field variation with which this project is interested.

Factors affecting Alveograph characteristics

It is essential for the grower to understand the effects of agronomic and environmental factors which within a variety may affect wheat quality in order that husbandry can be adopted which will maintain and improve quality. Some information is available concerning the effects of individual flour components on Alveograph characteristics and indicates that although protein is of most significance, other factors may also be important (Faridi and Rasper, 1987). Hence agronomic factors known to influence all these factors have been included in the present study.

In addition to the Alveograph, other quality tests are included in this study so that an overall picture of wheat quality can be obtained. This project is intended as a preliminary study, sourcing grain from experiments in which a range of agronomic and environmental factors have been examined. In addition to providing recommendations as to which factors are likely to have most influence on wheat quality parameters the results will also provide guidelines for more detailed studies on wheat quality.

Objectives

1. To establish if changes in crop growth as affected by site, variety, agronomic inputs and environmental factors have significant effects on grain quality, with particular reference to Alveograph tests.

2. To provide recommendations for future more detailed research on the effects of agronomy in relation to crop growth and development and grain quality.

Materials and Methods

Grain samples for use in this study were sourced from the 1996 harvest of a number of experiments within ADAS. These experiments were chosen to represent those which contained treatments considered most likely to influence grain quality. A wide range of agronomic and environmental factors were examined, as shown in Table 2. These experiments contained a wide range of crop growth assessments, details of which are given in the results section.

Experimental designs and treatments

Nitrogen

Plots of Riband were sown as fully randomised nitrogen treatments with three replicates arranged in blocks. Seven nitrogen treatments were applied by hand as prilled ammonium nitrate with a split application consisting of 40 kg/ha on

28 February to encourage tillering and the main dressing on 22 April to promote tiller survival. The final nitrogen levels applied were in the range 0 to 420 kg/ha as shown in Table 3. The economic optimum rate of nitrogen on yield terms was estimated to be 243 kg/ha.

Site

Crops were grown to a rigidly applied standard protocol with inputs at a level aimed to exclude all other factors except those directly attributable to site. Variety Mercia was used throughout the experiment.

Rotational position

Experimental design was a randomised split plot with first and third cereals as the main plots with five varieties (Brigadier, Rialto, Riband, Soissons, and Spark) randomised within each main plot. There were three replicates arranged in blocks. All agrochemical and fertiliser treatments were applied according to standard crop management. Differences in residual nitrogen levels were minimised by targeting nitrogen inputs to the break crops preceding each first wheat to leave a similar residue in the wheat crop and all crop residues were baled and removed in an attempt to minimise any differential mineralisation of nitrogen in the spring or summer of the test crop.

Sowing date, seed-rate and lodging control

Mercia was sown in a split split plot experimental design. Main plots were sowing date with seed rate as a sub-plot, randomised on the main plots and lodging control (PGR) as a further sub-plot. There were three replicates arranged in blocks with the main plots for sowing date. Sowing dates were mid September and early November, seed rates were 500/m2 and 250/m2, and PGR applied was New 5C Cycocel (chlormequat [1612.5 g a.i./ha] + choline chloride [80 g a.i./ha]) + Terpal (2-chloroethylphosphonic acid [232.5 g a.i./ha] + mepiquat chloride [457.5 g a.i./ha]) applied at GS 30/31.

Water availability

The experiment was carried out at ADAS Gleadthorpe, which regularly experiences drought conditions due to light sandy soils and being located on the eastern side of the country. Irrigation treatments were used in order to investigate the response to drought in terms of grain quality. Design was as a split-plot experiment with three replicate blocks with two main irrigation treatments randomised on main plots with five varieties randomised on sub-plots. The irrigation treatment consisted of water applied using a linear move irrigator to maintain a fixed soil moisture deficit, using the ADAS Irriguide model (Bailey and Spackman, 1996), of below 60 mm up to GS61+ 4weeks and below 75 mm thereafter. The irrigated plots can thus be considered to be undroughted and the non-irrigated plots the response to drought.

Table 2. Source of grain for use in the study

Experiment	Code	Funding	Site(s)	Soil type	Factors examined	Varieties
Winter wheat lodging prediction	0050/1/92A	HGCA	ADAS Rosemaund, Herefordshire	Silty clay loam	Sowing date, seed-rate, lodging control (pgr)	Mercia
Exploitation of varieties: Rotational position	0037/1/91	HGCA	ADAS Rosemaund, Herefordshire	Silty clay loam	Rotation position, variety	Brigadier, Rialto, Riband, Soissons, Spark
Exploitation of varieties: Moisture availability	0037/1/91	HGCA	ADAS Gleadthorpe, Nottinghamshire	Sandy loam	Water availability, variety	Riband, Rialto, Spark, Mercia, Haven
Integrated disease risk	CE0512	MAFF	ADAS Terrington	Silty clay loam	Incident radiation	Slejpner
Growth and nitrogen recovery	NT 1207	MAFF	ADAS Stetchworth	Clay loam	Applied soil nitrogen	Riband
Crop intelligence - reference crops	0023/1/95	HGCA	ADAS Rosemaund	Silty clay loam	Site	Mercia
			ADAS Boxworth	Chalky boulder clay		
			Sutton Bonnington	Medium stony loam		

Shading

Experimental design was as fully randomised shading treatments with two replicates arranged in blocks. The equipment used to shade the plots consisted of a galvanised steel framework covered with a black, knitted, high density polyethylene net cloth, designed to occlude 73% of light. The shades were moved into position as required using motors fitted to each shade. Shades were moved into 'active' shading positions under conditions of full sun, assessed visually. Following cloudy periods in excess of 15 minutes the shades were moved to the 'park' area. The shading treatments were applied to the plots to reduce the amount of radiation intercepted during the growth stages as defined in Table 6. The shades were used 15, 14, 6, 14 and 26 times in each of shading treatments at GS 31-39, 39-55, 55-61, 61-71 and 71-87 respectively during the course of the study. Measurements of microclimate within the plots showed that the shades effectively reduced the incident radiation on sunny days to that of a cloudy day while rainfall was not affected.

Grain analysis

Grain samples from three separate field plots were collected and analysed separately; hence means calculated from the results were true means of field replicates and not simply means of three analyses on a single grain sample.

Basic grain quality parameters yield, thousand grain weight (TGW), specific weight (SpWt), moisture content, protein content (Dumas method, results expressed as N x 5.7 at 15% moisture), Hagberg falling number (HFN) and sodium dodecyl sulphate sedimentation (SDS) volume were measured using in-house ADAS procedures. Yield, TGW, SpWt and moisture were measured on-site following harvest but protein content, HFN and SDS volume were measured at ADAS Wolverhampton laboratories.

Samples from the original stored grain were analysed by the Zeleny sedimentation test and Chopin Alveograph tests at Campden and Chorleywood Food Research Association, Chipping Campden. All samples within the study were analysed for these parameters using ICC Standard Methods Nos. 116/1, 121 (Chopin Alveograph) and 118 (Zeleny sedimentation test).

Data analysis

Following compilation of data, statistical analysis was carried out using Genstat software. Means and standard errors of differences (SED) were calculated and were then compared using analysis of variance.

Results

Results of analysis of grain are shown in Tables 3 to 7. No statistical identification of outliers was undertaken but the results were examined manually for obvious erroneous values and these were removed where found. Each result is represented as a mean value, calculated from individual analyses of three separate field plots. Variation between these mean analyses is represented both as SED's and coefficients of variation (CV, %). Results of comparison of means using analysis of variance are shown as F values; results with F values less than 0.100 are tabulated but those greater than this are designated 'not significant' (ns). An F value of 0.050 or lower is considered to indicate a significant difference between means. Histograms of the data and plots of 'residuals' (not shown) revealed that in all cases the data points were normally distributed and that analysis of variance the data in this way was valid. Where results are missing from the tables, this is because data were not available. Moisture content of samples is included in the tables so that it can be seen whether any anomalous results relate to unusually high moistures at harvest. Since this is merely to aid interpretation of the results, no analysis of variance was carried out on these values. Results did in fact show that all samples were harvested within the normally accepted range of moisture content.

The results are discussed factor by factor, with the discussion considering the overall effects of agronomy and physiology.

Nitrogen

Samples from a very wide range of nitrogen levels were available since the original experiment was aimed at examining the effects of super-optimal levels of nitrogen application. Nitrogen offtake increased with applied nitrogen, as a result of higher biomass and nitrogen content in whole plant material. The rate of increase slowed as nitrogen levels increased and reached a maximum at 300 kg/ha.

Crop growth was assessed as GAI, photosynthetically active radiation intercepted, and total biomass, all of which increased with applied nitrogen up to 180 kg/ha, beyond which there was little or no further change. Green area index showed a large increase with nitrogen up to 180 kg/ha both in terms of canopy expansion and also duration. Nitrogen levels 40 and 80 kg/ha produced markedly lower GAI than the higher nitrogen levels, particularly during senescence. In summary, at sub-optimal nitrogen levels (<240 kg/ha) increased applied nitrogen resulted in positive effects on all growth processes, giving increased yield, whereas above optimal nitrogen (>240 kg/ha) most growth processes were limited and any further small increases were not translated into higher yield.

Effects of applied nitrogen on grain yield and quality are shown in Table 3. All quality parameters measured showed significant effects due to nitrogen application. The strong response of yield at sub-optimal nitrogen levels was as expected, due to increased GAI and nitrogen uptake. There was a concurrent decrease in TGW due to increased tillering resulting in production of smaller grains and a progressive increase in grain protein content.

Table 3. Effects of applied nitrogen on wheat quality parameters (var. Riband).

Nitrogen	Yield	TGW	Sp. Wt.	Moisture	Protein	HFN	SDS	Zeleny	P	L	P/L	G	W
kg/ha	t/ha	g	kg/hl	%	%	s	ml	ml	mm	mm		ml	J x 10^{-4}
0	5.34	47.2	nm	12.3	6.0	264	34	10	35	18	2.0	9	27
40	7.08	47.3	nm	12.3	6.3	222	34	10	38	18	2.1	9	30
90	7.94	43.8	nm	12.1	7.1	258	36	10	33	33	1.0	13	42
135	8.69	42.6	nm	12.0	8.3	256	38	10	30	56	0.5	17	50
180	9.32	42.1	nm	11.7	9.0	276	36	11	28	63	0.5	18	50
240	9.43	40.3	nm	11.7	9.8	307	41	11	27	87	0.3	21	56
300	9.34	38.9	nm	11.6	10.7	335	48	16	27	96	0.3	22	58
360	9.62	39.6	nm	11.5	10.6	351	47	18	28	94	0.3	22	60
420	9.50	38.1	nm	11.6	11.3	322	48	17	28	105	0.3	23	63
Mean	8.47	42.2	-	11.9	8.8	288	40	12	31	63	0.8	17	48
SED	0.315	0.87	-	-	0.33	25.9	3.0	1.8	1.5	6.1	0.15	0.8	4.0
CV (%)	4.6	2.5	-	-	4.6	11.0	9.2	17.5	6.1	11.9	22.3	5.8	10.1
Significance of effects (F)													
Nitrogen	<0.001	<0.001	-	-	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

nm, not measured

HFN increased with applied nitrogen and most samples met the minimum value of 225 s for export. The lower HFN values at low applied nitrogen levels may have been due to harvesting all field samples on the same date. This could be avoided in future studies by sequential harvesting based on actual maturation times. In general, grain quality increased with applied nitrogen up to 300 kg/ha with additional nitrogen giving little further change. Up to 180 kg/ha nitrogen, P/L decreased and W increased, but at higher nitrogen application rates there was no further change in P/L but a gradual further increase in W. These changes are shown in Figures 5 and 6.

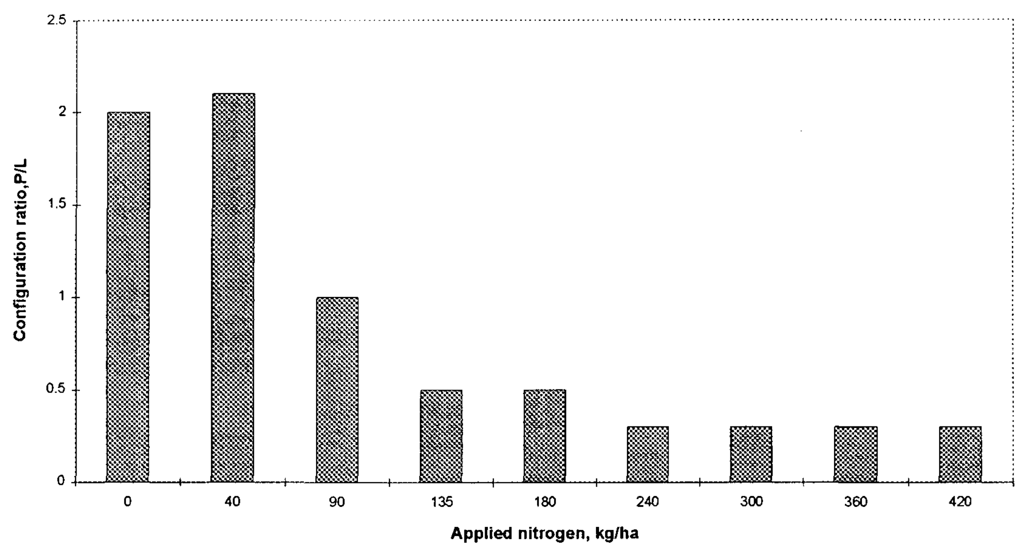

Figure 5. Effects of applied nitrogen on configuration ratio, P/L

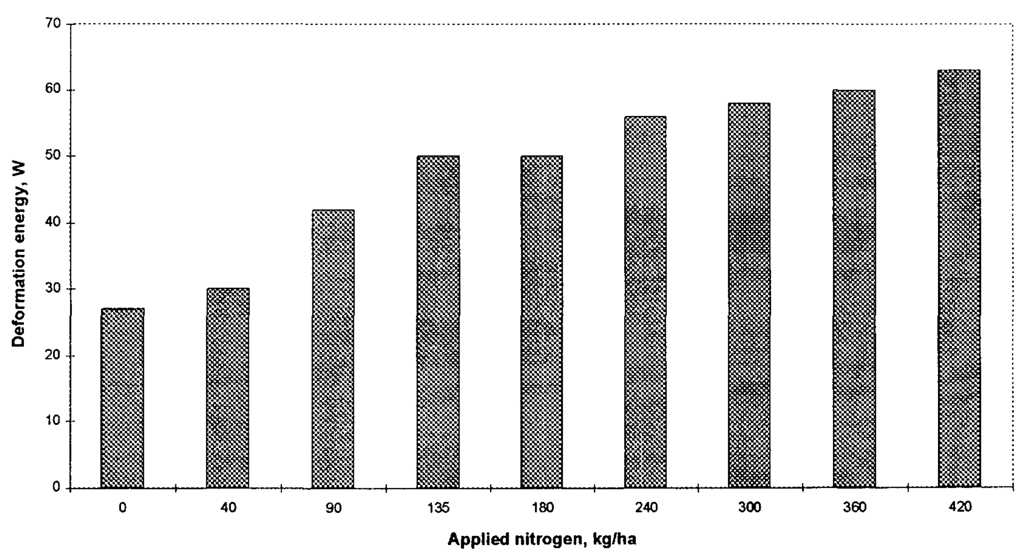

Figure 6. Effects of applied nitrogen on deformation energy, W.

The decreased P/L ratio was largely a result of a large increase in the L value, showing that dough extensibility increased with applied nitrogen. However, with sub-optimal grain nitrogen content, samples would have failed all export criteria, with 60 kg ha nitrogen required in excess of the optimum for grain yield being required to meet export quality. Despite the changes in P/L and W values, the samples did not reach a bread-making flour Alveograph specification, as expected since the variety Riband is known to be suitable mainly for biscuit flour or blending.

Site

The effects of site were most closely examined in the 'reference crops' shown in Table 4. Significant differences were noted in all analyses except SDS. Improved quality was seen in terms of higher HFN, Zeleny volumes, and W values and lower P/L ratios in the samples grown on the lighter soil at Sutton Bonnington. However, none of the samples met any of the current specifications for export in terms of P/L or W and differences in grain quality may simply reflect the large differences in grain protein content seen across the three sites.

Rotational position

Assessments of disease showed that the third wheats were significantly more affected by take-all than first wheats (23.0 vs. 9.9 take-all index). However, 1996 was generally classed as a low take-all season, due to unseasonally cold conditions for much of spring and early summer hampering development of the disease. Comparison of take-all levels across all samples showed that there was no effect of variety on the level of take-all infection.

Other crop growth parameters were assessed in order to explain any differences in yield due to rotational position. As expected, rate of development varied between varieties. Canopy size and senescence, measured as GAI, varied between varieties but there was no effect of rotational position. There was also no interaction between rotational position and variety on canopy size. Effects of rotational position on biomass were generally small, although significant. First wheats produced greater biomass than third wheats, reflecting lower overall severity of take-all in the first wheats. There was a large effect of variety on biomass, largely a reflection of rate of development, but there was no evidence that the varieties responded differently in terms of biomass to rotational position. Nitrogen offtake by the crop, both at GS 31 and at harvest, varied due to both rotational position and variety. Slightly lower uptake at GS 31 by third wheats may be due to higher levels of take-all impairing root function, and differences between varieties may be due to different rates of development. There was no interaction effect between variety and rotational position in nitrogen uptake. There was no effect of rotational position on tillering although differences between varieties were evident, later developing wheats displaying higher maximum shoot numbers. Finally, levels of water soluble carbohydrate reserves stored in the crops showed no differences between rotational positions, although, as expected from previous studies differed between varieties.

Table 4. Effect of site on wheat quality parameters (var. Mercia)

Site	Yield	TGW	Sp. Wt.	Moisture	Protein	HFN	SDS	Zeleny	P	L	P/L	G	W
	t/ha	g	kg/hl	%	%	s	ml	ml	mm	mm		ml	J x 10^{-4}
Rosemaund	9.87	43.3	81.8	13.9	10.4	346	55	27	62	49	1.3	16	114
Boxworth	9.43	43.8	84.4	16.0	9.2	374	61	30	86	36	2.4	13	134
Sutton Bonnington	**8.22**	**39.6**	**nm**	**15.1**	**13.3**	**390**	**61**	**45**	**63**	**85**	**0.8**	**20**	**177**
Mean	9.17	42.3	83.1	15.0	11.0	370	59	34	70	57	1.5	16	142
SED	0.38	0.66	0.64	-	0.78	11.7	5.8	3.4	8.3	6.9	0.23	0.9	13.5
CV (%)	5.1	1.9	0.9	-	8.7	3.9	12.1	12.1	14.4	14.8	19.2	6.5	11.7
Significance of effects (F)													
Site	0.028	0.005	0.056	-	0.014	0.045	ns	0.012	0.075	0.005	0.005	0.003	0.022

nm, not measured; ns, not significant

The effects of rotational position on grain quality are shown in Table 5. The yield ranking of the first wheats was not as expected from the performance in the recommended list trials, with Rialto clearly yielding highest followed by Soissons, Brigadier, Riband and Spark. Ranking as third wheats was similar to first wheats but yield of all varieties was, as expected, reduced. No effects of crop rotational position were noted in any of the analytical parameters examined. There was no interactive effect between variety and rotational position in any parameter except HFN, possibly due to more rapid maturation of grain of third wheats due to canopy senescence. Alveograph analyses are shown in Figures 7 and 8.

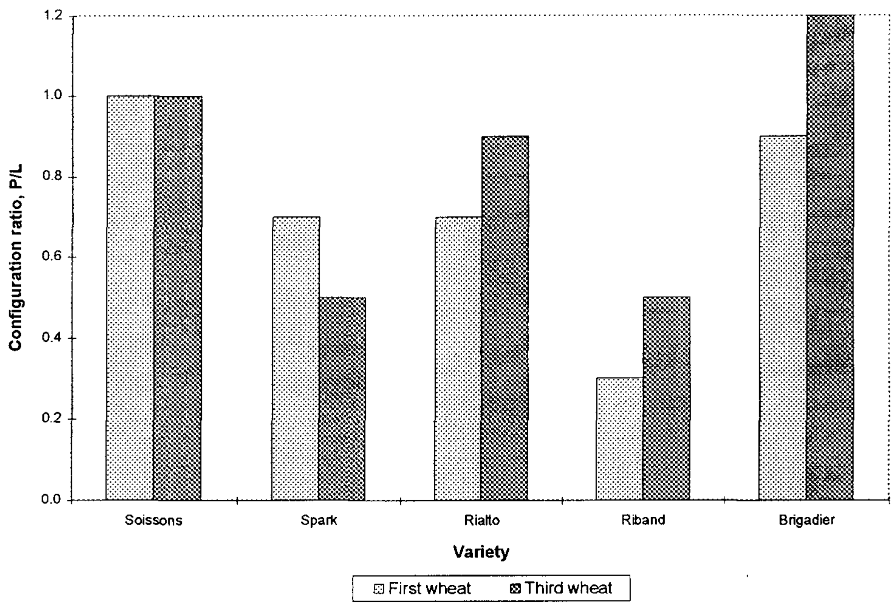

Figure 7. Effects of rotational position and variety on configuration ratio, P/L.

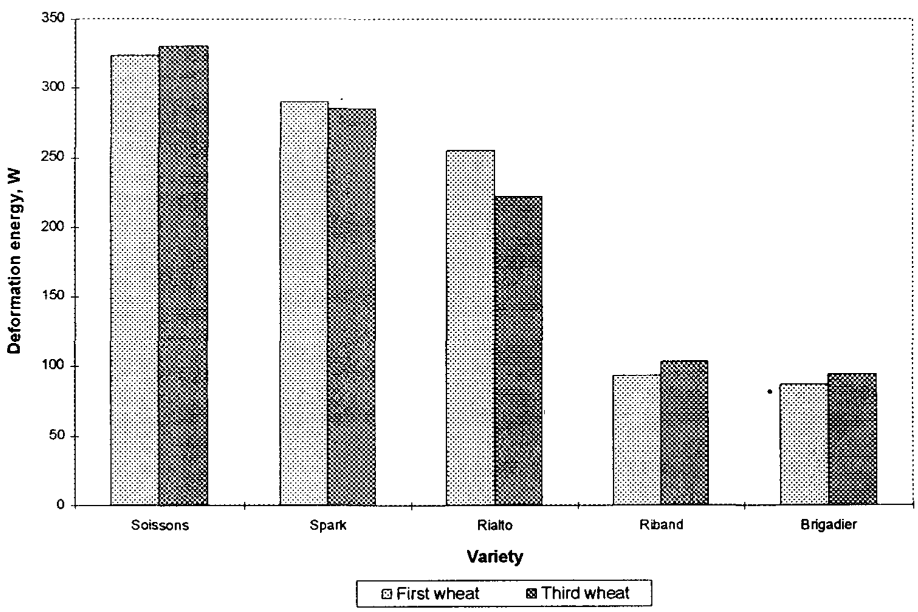

Figure 8. Effects of rotational position and variety on deformation energy, W

Table 5. Effects of rotational position and variety on wheat quality parameters

Rotational position	Variety	Yield t/ha	TGW g	Sp. Wt. kg/hl	Moisture %	Protein %	HFN s	SDS ml	Zeleny ml	P mm	L mm	P/L	G ml	W J x 10^{-4}
First	Brigadier	9.52	42.9	75.3	16.1	10.4	336	62	26	48	53	0.9	16	87
	Rialto	10.83	44.4	77.1	16.2	11.5	368	87	55	66	102	0.7	22	255
	Riband	9.20	42.7	74.1	16.0	10.9	265	58	25	31	90	0.3	21	93
	Soissons	9.92	40.4	78.3	16.2	11.5	324	97	60	74	87	1.0	21	324
	Spark	9.02	33.6	78.9	16.1	11.7	330	100	70	69	108	0.7	43	290
Third	Brigadier	8.81	41.9	74.9	16.3	10.6	368	58	27	55	46	1.2	15	94
	Rialto	9.62	42.8	75.8	16.0	11.4	335	81	55	71	85	0.9	20	222
	Riband	8.32	40.6	74.2	15.9	11.2	313	65	25	36	82	0.5	20	103
	Soissons	9.00	40.0	78.4	16.1	11.5	323	91	55	84	88	1.0	21	331
	Spark	8.36	30.9	77.8	16.0	12.2	381	89	71	64	122	0.5	24	285
Mean		9.26	40.0	76.5	16.1	11.3	334	79	48	60	86	0.8	22	208
SED (RP)		1.030	2.63	1.11	-	0.44	27.4	3.7	2.4	5.7	9.6	0.14	3.4	21.2
SED (V)		0.200	0.91	0.36	-	0.15	12.5	5.6	1.2	4.2	7.1	0.09	5.9	17.5
SED (RP x V)		1.063	2.87	1.20	-	0.48	31.6	8.0	2.8	7.7	13.1	0.18	8.2	30.6
CV (%)		3.7	3.9	0.8	-	2.4	6.5	12.3	4.3	12.0	14.2	20.6	45.4	14.5
Significance of effects (F)														
Rotational position (RP)		ns	ns	ns	-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Variety (V)		<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.073	<0.001
RP x V		ns	ns	ns	-	ns	0.017	ns	ns	ns	ns	ns	ns	ns

ns, not significant

Differences in grain quality analyses between varieties was as expected, with the bread-making varieties Rialto, Soissons and Spark showing reasonable quality contrasting with the poor quality of Brigadier and Riband. The Alveograph results did suggest that Rialto would make export quality as a first wheat but would fail as a third wheat, due to high P/L values. However, this parameter showed a poor degree of precision in this experiment.

Sowing date, seed-rate and lodging control

Effects of sowing date, seed-rate and lodging control were examined in a split-split plot experiment with sowing date as the main blocks. Thus, in addition to the separate effects it was possible to examine interactive effects of the three factors. Sowing date and seed rate treatments generated large differences in crop growth, such that above ground biomass, shoot number and GAI were increased by early sowing and high seed rate. The differences were maintained until harvest for the sowing date treatments but the seed rate differences had disappeared. Statistically different effects were found between the percentage area lodged for all the main treatments, the application of PGR reducing crop growth over the controls and resulting in a reduced above ground biomass. Large variations were evident in the percentage area lodged at harvest, with 93% lodged in the high lodging risk combination (early sowing date, high seed rate, no PGR) compared to 8% lodged in the low risk combination (late sowing date, low seed rate, PGR).

Despite differences in crop growth, the agronomic treatments had only minor effects on grain quality (Table 6). Grain protein, HFN, P/L, G and W showed no significant effects due to any of the three factors or their interactions. Later sowing resulted in increased yield, higher TGW, but lower SDS. Although P and L values were affected by sowing date, with a reduction in dough strength (P) but an increase in dough extensibility (L), the effects were small and did not produce a significant change in the P/L ratio. Since there was no effect on the W value due to sowing date, this parameter failed to affect the ability of Mercia wheat to meet a bread-making quality specification.

Increased seed-rate resulted in lower TGW and SpWt but had no effect on yield. This would be expected to produce a larger number of shoots/m^2, resulting in a greater number of small grains. However, no effects of seed-rate were noted in any of the wheat quality parameters. The only effects due to application of PGR were a small reduction in SpWt, and slight increases in SDS and Zeleny values. No explanation for the small effects on sedimentation volumes can be offered.

Water availability

The total amount of water applied to the irrigated treatment was 262 mm. This was sufficient that the irrigated crop can be considered to be undroughted. Conversely, the non-irrigated crop experienced drought conditions both pre-anthesis and throughout grain-filling within the study.

Table 6. Effects of sowing date, seed-rate and lodging control on wheat quality parameters (var. Mercia).

Sowing date	Seed-rate	Lodging control	Yield t/ha	TGW g	Sp. Wt. kg/hl	Moisture %	Protein %	HFN s	SDS ml	Zeleny ml	P mm	L mm	P/L	G ml	W J x 10^{-4}
Mid September	500/m^2	Nil	8.12	37.5	81.9	13.1	10.8	312	59	30	52	76	0.7	19	124
		PGR	9.45	38.7	82.2	13.4	10.8	362	66	31	56	72	0.8	19	132
	250/m^2	Nil	9.42	38.9	83.1	13.2	11.0	352	61	34	51	92	0.6	21	146
		PGR	9.70	38.9	82.9	13.1	11.1	343	65	36	47	97	0.5	22	147
Early November	500/m^2	Nil	10.05	42.5	83.5	13.5	10.7	334	52	30	44	102	0.4	22	133
		PGR	9.87	39.6	82.3	13.3	10.8	342	57	35	44	110	0.4	23	143
	250/m^2	Nil	10.07	44.8	83.5	13.6	10.7	352	54	36	45	111	0.4	23	138
		PGR	9.53	43.0	82.8	14.3	11.3	340	65	40	49	99	0.5	22	146
Mean			9.53	40.5	82.8	13.4	10.9	342	60	34	48	95	0.5	22	138
SED (SD)			0.150	0.23	0.18	-	0.22	27.2	1.1	2.2	0.8	6.5	0.03	0.7	6.2
SED (SR)			0.196	0.47	0.21	-	0.23	19.4	2.9	2.5	2.2	5.3	0.04	0.6	9.4
SED (LC)			0.168	0.49	0.16	-	0.08	19.2	1.3	0.7	2.0	4.3	0.03	0.5	7.1
SED (SD x SR)			0.247	0.52	0.28	-	0.32	33.4	3.1	3.3	2.3	8.4	0.05	0.9	11.2
SED (SD x LC)			0.225	0.54	0.24	-	0.23	33.3	1.7	2.3	2.2	7.8	0.05	0.8	9.4
SED (SR x LC)			0.258	0.68	0.26	-	0.24	27.3	3.2	2.6	3.0	6.8	0.05	0.8	11.8
SED (SD x SR x LC)			0.342	0.87	0.36	-	0.34	43.0	3.6	3.4	3.7	10.4	0.07	1.2	15.0
CV (%)			4.3	2.9	0.5	-	1.8	13.7	5.3	4.6	10.1	11.1	15.5	5.3	12.5
<u>Significance of effects (F)</u>															
Sowing date (SD)			0.042	0.003	ns	-	ns	ns	0.035	ns	0.018	0.026	0.072	ns	ns
Seedrate (SR)			ns	0.018	0.050	-	ns	ns	ns	ns	ns	ns	ns	ns	ns
Lodging control (LC)			ns	0.094	0.022	-	0.072	ns	<0.001	0.002	ns	ns	ns	ns	ns
SD x SR			0.074	0.093	ns	-	ns	ns	ns	ns	ns	0.046	ns	ns	ns
SD x LC			0.008	0.017	0.011	-	0.074	ns	ns	ns	ns	ns	ns	ns	ns
SR x LC			0.068	ns	ns	-	0.086	ns	ns	ns	ns	ns	ns	ns	ns
SD x SR x LC			ns	ns	ns	-	ns	ns	0.075	ns	ns	0.059	ns	ns	ns

ns, not significant

Drought had large effects on growth and development of the crop, with changes in shoot density, GAI, date of anthesis, accumulation of stem carbohydrate reserves, and harvest dry mass. There were also varietal differences in response to drought. Effects of drought are summarised in Table 7.

Table 7. Physiology assessments in irrigated and droughted crops

Parameter	Irrigated mean	Droughted mean
Shoot density at GS 61, no./m^2	510	440
GAI at GS 61	4.8	2.8
Date of anthesis in June	18	16
Stem WSC at GS 61 + 75°Cd, g/m^2	273	251
Harvest dry mass	1672	1278

Effects of drought on grain quality are shown in Table 8. Differences in moisture content between droughted and irrigated samples were due to the fact that the droughted samples were harvested four days earlier than the irrigated samples. This was a result of the availability of farm machinery at harvest. A large yield reduction was noted in response to drought with an average decrease of 4.4 t/ha. TGW was also affected by drought, decreasing by a mean of 4.4 g. Drought resulted in a significant increase in various measures of bread-making quality with higher SDS, Zeleny, and W values. However, this could have been a result of higher grain protein content, which would have affected a number of components in the milled white flour, rather than changes in the quality of the protein per se. In the irrigated samples this was sufficient to reduce the protein content to a borderline specification for export. The effects of drought were noted in all varieties in the experiment and were particularly noticeable in Alveograph characteristics. Changes in Alveograph characteristics due to drought are shown in Figures 9 and 10.

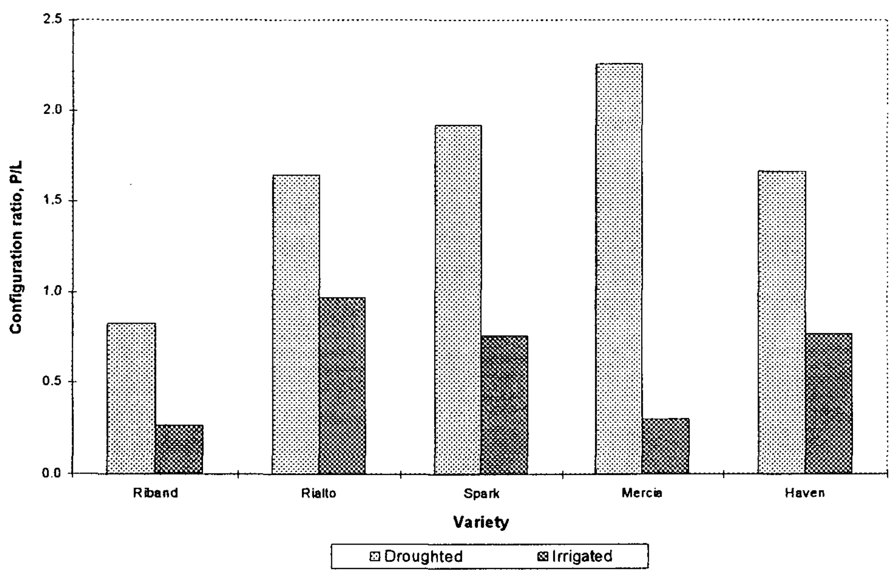

Figure 9. Effects of drought on configuration ratio (P/L)

Table 8. Effects of water availability and variety on wheat quality parameters

Water availability	Variety	Yield t/ha	TGW g	Sp. Wt. kg/hl	Moisture %	Protein %	HFN s	SDS ml	Zeleny ml	P mm	L mm	P/L	G ml	W J x 10^{-4}
Droughted	Riband	6.76	48.7	nm	16.6	11.8	336	59	24	44	55	0.8	16	77
	Rialto	6.06	45.2	nm	16.4	12.9	279	69	37	96	59	1.6	17	224
	Spark	6.11	33.7	nm	16.7	13.2	373	83	44	103	58	1.9	17	222
	Mercia	5.22	39.0	nm	16.6	13.8	383	65	37	102	47	2.3	15	191
	Haven	6.30	47.5	nm	16.1	12.2	369	54	25	58	36	1.7	13	75
Non-droughted	Riband	10.42	50.4	nm	11.0	10.0	238	36	10	18	67	0.3	18	26
(irrigated)	Rialto	10.88	49.0	nm	10.7	10.0	298	46	27	48	50	1.0	16	76
	Spark	10.07	40.0	nm	10.8	10.0	273	60	38	53	71	0.8	19	118
	Mercia	9.80	46.1	nm	11.0	11.0	296	52	23	28	95	0.3	22	67
	Haven	11.47	50.7	nm	10.5	9.6	248	36	13	27	34	0.8	13	29
Mean		8.31	45.0	-	13.6	11.5	309	56	27	58	58	1.1	17	112
SED		0.322	0.18	-	-	0.42	11.3	1.6	0.6	8.5	3.7	0.28	0.5	12.5
SED (V)		0.339	0.67	-	-	0.18	21.2	3.6	1.3	3.8	4.8	0.13	0.7	12.5
SED (W x V)		0.536	0.87	-	-	0.48	29.1	4.9	1.8	9.7	7.2	0.32	1.0	20.1
CV (%)		7.5	2.5	-	-	2.7	11.9	11.2	8.4	11.3	14.7	19.3	7.1	19.6
Significance of effects (F)														
Water availability (W)		0.005	0.002	-	-	0.024	0.021	0.006	0.003	0.033	0.080	0.063	0.093	0.017
Variety (V)		0.009	<0.001	-	-	<0.001	ns	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
W x V		ns	0.005	-	-	0.016	0.035	ns	0.063	<0.001	<0.001	<0.001	<0.001	0.003

nm not measured; ns, not significant

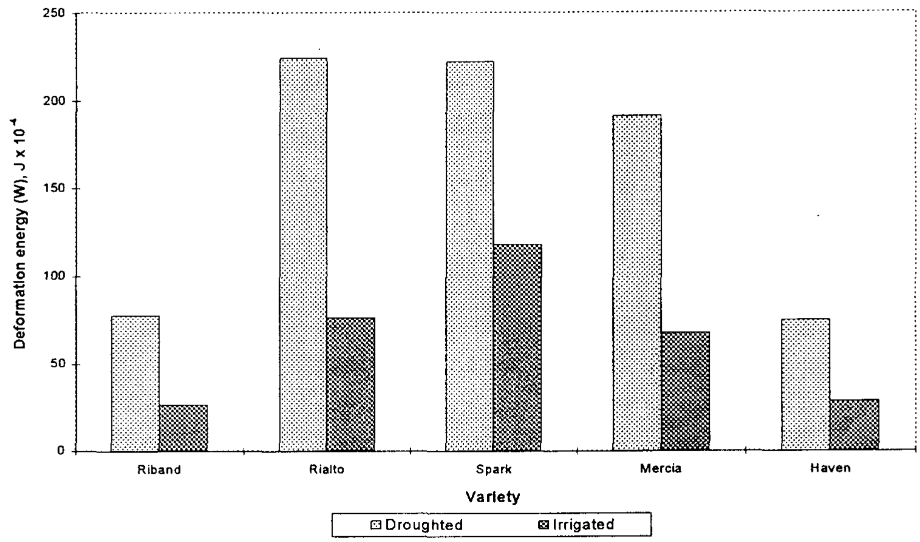

Figure 10. Effects of drought on deformation energy (W)

Large increases in both P/L and W were evident in response to drought, giving a large change in flour quality. All droughted wheats were outside the quality specification for export with regard to P/L (P/L ≤0.6 for bread and ≤0.5 for biscuit flour) and only Riband and Mercia were within specification where plots were irrigated. Although differences in P/L were sufficient to move the wheat from 'in specification' to 'out of specification', due to large variations between replicate samples, the effects of irrigation were not significant ($p = 0.063$). Large and statistically significant increases in W were noted in droughted samples, whereas all wheats from irrigated plots were outside the export specification for bread flour (W ≥170). No samples were within specification for strong bread flour (W ≥240). With the possible exception of Spark, all irrigated wheats were suitable for biscuit flour in terms of W, whereas following drought only Riband and Haven were within specification. The influence of drought on grain quality was also evident from interactive effects between drought and variety, with a larger response in some varieties than others. Large differences in Alveograph results were noted between varieties and were in accord with known varietal differences, with the bread wheats Rialto, Spark and Mercia being significantly different to the feed and biscuit wheats Haven and Riband.

Shading

Shading had no effect on plant development (GS), since this is mainly controlled by temperature and daylength and shading reduced air temperature by an average of only 2%. Shoot numbers were not affected by any of the shading treatments and were similar in all shading treatments at harvest. Differences in GAI between treatments were small and not statistically significant , due to large variations between replicates. There was some evidence that GAI was higher at GS 87, when shaded at GS 71-87, which may have been due to delayed senescence. There were similarly no differences in green leaf area index, green stem area index or green ear area index due to shading treatments. There were significant effects on water soluble carbohydrates (WSC) due to shading, despite large variations between replicates. Accumulation of WSC was directly linked to solar radiation, although following shading prior to grain-filling (GS 31-39, 39-55, 55-61, 61-71) the rate of accumulation of stem sugar increased to levels above that found in unshaded plots. The results suggested that stem reserves acted as a buffer of surplus photosynthate which could be distributed elsewhere in the plant when required. Total dry matter (TDM) was significantly affected by shading, with most assessments showing lower TDM in plants that had just been shaded. Nitrogen uptake was not affected by shading, showing that the assimilation of protein was not affected by the availability of newly assimilated carbohydrate reserves.

The effects of shading the crop at specific periods on grain quality is shown in Table 9. A reduction in yield was noted in all shaded samples compared to the control (unshaded). This was most noticeable when the crop was shaded during the grain-filling phase (GS 71-87). Increases in TGW were found when the crop was shaded during early growth stages (GS 31-39 and GS 39-59) but as expected, a large decrease was found on shading during grain-filling (GS 71-87). The effect of shading on SpWt was similar to TGW.

No effect was noted in grain protein, HFN or Alveograph analysis, but changes were found in SDS and Zeleny values. A decrease was noted in SDS when the crop was shaded at GS 61-71 and increases found when it was shaded at GS 31-39 or GS 71-87. An increase in Zeleny value was found only when the crop was shaded at GS 71-87. However, all effects of shading were relatively small, except for shading during the later growth stages when maximum radiation is required for photosynthesis to support grain-filling.

Table 9. Effects of shading on wheat quality parameters (var. Slejpner).

Shading	Yield	TGW	Sp. Wt.	Moisture	Protein	HFN	SDS	Zeleny	P	L	P/L	G	W
	t/ha	g	kg/hl	%	%	s	ml	ml	mm	mm		ml	J x 10-4
Control	12.43	47.1	80.7	16.8	12.2	343	53	28	50	62	0.9	17	91
GS 31-39	10.40	50.8	81.6	16.7	12.5	341	58	30	49	64	0.8	18	96
GS 39-59	11.62	52.7	81.5	16.5	12.1	364	55	29	48	71	0.7	19	100
GS 59-61	12.07	46.6	80.7	16.1	11.7	349	55	28	42	70	0.6	19	89
GS 61-71	11.00	48.1	80.4	16.6	12.0	372	48	29	52	55	1.0	16	93
GS 71-87	9.78	35.2	76.1	16.9	13.3	365	60	34	49	87	0.6	21	108
Mean	11.22	46.8	80.2	16.6	12.3	355	55	30	48	68	0.8	18	96
SED	0.608	1.7	0.42	-	0.64	18.1	2.6	1.3	7.2	13.5	0.23	1.8	10.8
CV (%)	6.6	4.5	0.6	-	6.3	6.2	5.8	5.6	18.2	24.3	36.0	11.9	13.7
Significance of effects (F)													
Shading	0.010	<0.001	<0.001	-	ns	ns	0.017	0.010	ns	ns	ns	ns	ns

ns, not significant

Discussion

The effects of the various experimental treatments on measured wheat quality parameters are summarised in Table 10. Yield was principally affected by variety, nitrogen, site, sowing date, drought and shading. These factors also affected TGW but not in the same manner as yield. Although the highest yielding varieties and later sowing also gave the largest TGW's, high applied nitrogen was inversely correlated with TGW, due to increased shoot numbers and hence more grain sites. Seed-rate did not influence yield but lower seed-rates gave higher TGW. Although a number of statistically significant effects of the treatments were noted in SpWt the differences were minor. Although there are obviously a number of interesting effects on yield, TGW and SpWt which require further investigation these are not considered a primary objective for further work which should mainly concentrate on grain quality aspects.

HFN provides an estimate of α-amylase activity, but is known to be an extremely variable measure of grain quality, both in terms of its variation between field samples, time of harvesting and the precision of its analysis. Statistically significant effects were discernible only due to variety, nitrogen, site and drought. Since lodging is known to influence HFN by promoting damp harvesting conditions, giving rise to pre-harvest sprouting, it would be expected that higher nitrogen and absence of PGR would lead to lower HFN values due to increased lodging. However, there was no correlation between the observed instances of lodging and HFN, since the harvest period in 1996 was dry and sprouting did not occur even in lodged crops. Lower HFN values at low applied nitrogen were likely to be due to differences in time of maturation since the field samples were harvested at the same time rather than on sequential dates.

SDS and Zeleny volumes provide a similar measure of protein quality, with higher values suggesting bread-making potential. Both volumes were strongly influenced by variety, reflecting varietal differences in bread-making quality of the wheats examined. Effects were also noted due to site (Zeleny only), sowing date (SDS only), nitrogen, PGR, drought and shading. Applied nitrogen had little effect within the normal range of application, differences only being noted at 300 kg/ha and above. Drought had a relatively large positive effect on protein quality in some varieties, but all differences due to agronomic and environmental treatments were relatively small compared to differences between varieties.

Alveograph parameters, P/L ratio and W, were influenced primarily by variety, nitrogen, site and drought. Large varietal differences were found in both P/L and W, with similar values, particularly W, within varieties when compared in both rotational position and water availability experiments. P/L values were generally more variable than W and did not show as much similarity within varieties. Both values were generally in line with the accepted bread or biscuit making quality of the particular varieties.

Table 10. Significance of effects of agronomic and environmental factors on grain quality

Source of variation	Yield	TGW	SpWt	Protein	HFN	SDS	Zeleny	P/L	W
Sowing date	*	**	ns	ns	ns	*	ns	ns	ns
Seed-rate	ns	*	ns	ns	ns	ns	ns	ns	ns
PGR	ns	ns	*	ns	ns	***	**	ns	ns
Sowing date x seed-rate	ns	ns	ns	ns	ns	ns	ns	ns	ns
Sowing date x PGR	**	*	**	ns	ns	ns	ns	ns	ns
Seed-rate x PGR	ns	ns	ns	ns	ns	ns	ns	ns	ns
Sowing date x seed-rate x PGR	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rotation position	ns	ns	ns	ns	ns	ns	ns	ns	ns
Variety	***	***	***	***	***	***	***	***	***
Rotation position x variety	ns	ns	ns	ns	**	ns	ns	ns	ns
Water availability	**	**	-	*	*	**	**	ns	*
Variety	**	***	-	***	ns	***	***	***	***
Water availability x variety	ns	**	-	*	*	ns	ns	***	**
Shading	*	***	***	ns	ns	*	*	ns	ns
Nitrogen	***	***	-	***	**	***	***	***	***
Site	*	**	ns	*	*	ns	*	**	*

*, P<0.05; **, P<0.01; ***, P<0.001; ns, not significant; -, data not available

Increases in applied nitrogen resulted in lower P/L and higher W, improving ability to meet a bread-making quality specification, with most effect seen at lower nitrogen levels. Decrease in P/L was mainly due to increased dough extensibility (L) with only a minor decrease in dough strength (P). It is likely that the changes in Alveograph characteristics were due to increased protein content of the grain. P/L decreased with increasing nitrogen to within export specification but although there were concurrent increase in W, this parameter always remained low, reflecting the poor bread-making quality (though good biscuit quality) of the variety examined, Riband. Although there was an increase in GAI with increased nitrogen, particularly at lower nitrogen levels, giving greater photosynthetic potential, the effects of increased shoot number, giving increased grain number, and hence smaller grains, in combination with greater uptake of nitrogen, outweighed increases in starch deposition. This resulted in more grains, smaller grains, and with higher grain protein content as a percentage of total grain mass.

Drought resulted in increases in both P/L and W in all varieties and in combination with increases in SDS and Zeleny volumes resulted in a large improvement in grain quality. Increased yield and TGW in non-droughted crops indicated that irrigation had resulted in a relatively greater increase in deposition of starch than of protein in the grain. A significant increase in GAI was noted in the irrigated crops (Table 8) and in combination with increased transpiration due to adequate soil moisture in these samples would have resulted in greater potential for photosynthesis and hence starch synthesis. This was supported by the results which showed increased harvest biomass in the irrigated samples (Table 8). Although much of the effect of drought on grain quality may be attributable to increased grain protein content, it is possible that the quality of the protein was also affected; this was evidenced by the increases in the dough strength (P) but not extensibility (L) in the Alveograph test, contrasting with changes in mainly dough extensibility (L) in the nitrogen experiment. The results thus suggest that grain quality in terms of Alveograph characteristics may be affected by both dilution of grain protein and changes in the composition and hence functionality of grain protein. However, the effect of increased protein on the level of starch damage during milling must also be. considered, since increased starch damage would be likely to result in a less extensible dough in the fixed water conditions used in the Alveograph test. There was also evidence of an interaction between drought and variety, with some varieties responding more than others in terms of grain quality, though not yield.

The results indicated that differences due to site might be explained in terms of the effects of both nitrogen and water availability, which would be determined by soil type, nitrogen management, and environment. The effects of drought and its interactions with the effects of variety and applied nitrogen warrant further investigation since there were such large effects of these factors on grain quality. The effect of these inputs is in part due to increased grain number and duration of grain-filling and similar effects could be expected through other agronomic inputs not included in this study. These inputs may include ear fungicides (prolonging canopy through disease control), late applied nitrogen (solid or foliar to supply nitrogen directly to the grain), and control of grain aphids (increasing the rate of grain-filling). Strobilurin based fungicides may be of particular interest and the potential of these chemicals to increase GAI and hence grain-filling has already been seen in HGCA project 0043/01/96.

Additional studies using grain from the 1997 harvest may reveal further information about environmental effects on grain quality since this season was considerably more variable climatically than that in 1996. A wider range of varieties should be examined, including bread, biscuit and feed quality wheats. In addition, more detailed analysis of the wheat and flour tested should be carried out in order to explain the observed effects in terms of protein composition as well as quantity. In any further work it will be necessary to confirm that any effects are due to differences in protein composition rather than differences in flour constituents resulting from milling grains with altered milling properties. This would be accomplished by assessment of grain hardness, standard flour analysis and gel protein measurements.

Conclusions

1. Grain quality in terms of Alveograph characteristics was affected by variety, site, nitrogen, and water availability. No other factors were shown to influence Alveograph characteristics in the current study.

2. Deformation energy (W) showed a moderate increase with nitrogen application within the range 0 - 135 kg/ha, with additional nitrogen giving only minor further increases in W. Concurrent with this was decrease in configuration ratio (P/L), mainly as a result of increased dough extensibility (L).

3. The largest effect on Alveograph characteristics, after varietal differences, was due to water availability, with decreases in both P/L (due mainly to lower P) and W as a response to drought. This was seen in all varieties, although there was evidence of different varietal responses. The combined effects of drought and nitrogen could not be assessed from the current data.

Recommendations

1. Further studies should be carried out using grain sourced from the 1997 harvest, since considerably more variability was noted in harvest conditions than in 1996. This may reveal further factors of importance in addition to confirming results of the first study.

2. The studies should be extended to include the effects of fungicide treatments in relation to the duration of grain-filling. It is expected that the effects may be similar in this respect to those of water availability, and hence may have a significant impact on Alveograph characteristics. In particular, the effects of strobilurin based fungicides should be examined since the potential of

these chemicals for prolonging grain-filling has already been demonstrated in HGCA project 0043/01/96.

3. Further studies are necessary to examine in more detail the effects of water availability and nitrogen and the extent to which the impact of these variables on grain quality can be explained by differences in crop growth. Timing of drought may be important to see if early drought would have the same effect as late drought. The significance of these variables in explaining differences observed in BCE Alveograph tests should form an integral part of any further study, with attempts made to identify reasons for variation in grain quality through measurements of the key parameters of crop growth. These further studies will provide a basis from which a Geographical Information System can be developed, able to predict areas of the country most suitable for producing grain of specific export quality. A wider range of varieties should be examined in any further study, with bread, biscuit and feed quality wheats included in all treatments.

5. A more detailed analysis of the composition of flour and grain components should be carried out in order to explain the observed effects on Alveograph characteristics.

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