Proceedings Agronomy Society
of New Zealand. 17 1987

THE RELATIONSHIP BETWEEN BAKING QUALITY AND PROTEIN CONTENT: SOME CULTIVAR AND ENVIRONMENTAL EFFECTS

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ABSTRACT

An anlysis of historical data for bake score and flour protein was undertaken to identify the response of bake score to a number of parameters. Cultivar, season and district were all seen to affect the mean bake score observed at any one protein content. There was a curved response relating bake score to protein content which plateaued at about 12% white flour protein content. The effect of season and district on baking quality were correlated with the mean temperature over December and January.

Key Words: wheat, baking quality, protein, cultivar, season, district, temperature.

INTRODUCTION

Various studies have shown either a weak positive relationship between grain protein content and bake score for New Zealand cultivars of wheat (Wilson, 1983; Mitchell and Casutt, 1983; Guy, 1985; Drewitt, 1985), or no relationship at all (Hanson and Wilson, 1985). Recent agronomic research work on wheat has centred on the response of grain nitrogen to rate and timing of nitrogen applications, and the differences among cultivars in how changes in grain nitrogen affect protein composition and subsequent MDD bake score (Stevenson, 1987, Grama *et al*, 1987, Cressey *et al*, 1987).

Recent deregulation of the wheat industry has emphasised the need to produce wheat of a consistent high quality that will compete with imported wheat in quality and price. Quality has been assessed at the Wheat Research institute by bake testing, and in 1981 the Mechanical Dough Development (MDD) bake test was introduced as the measure of quality. In 1985 the New Zealand Wheat Board introduced the wheat quality index system, which recognised a number of features which were believed to be significant in affecting overall grain 'quality'. This system awarded index points for both cultivar and bake score, as well as a number of other variables (Laughland, 1985), indicating that neither of these features alone is a sole indicator of quality. The index has been adopted and revised by all mills, and now also often includes a parameter for grain protein.

The objectives of the present study were:

1. To identify the shape of the response curve relating MDD bake score to grain protein.
2. To identify the potential to increase the grain protein content of a cultivar and hence increase its mean MDD bake score.
3. To attempt to relate some environmental parameters to observed differences in baking quality.

MATERIALS AND METHODS

Information about the flour protein concentration, estimated by near-infrared reflectance (NIR), and bake score determined by MDD, for crops of Rongotea and Oroua grown throughout New Zealand in the 1982 and 1983 harvest seasons was provided by the Wheat Research Institute. Similar information for the 1986 harvest season was obtained from New Zealand Cereal Foods, except that data was only available for crops with more than 9% protein and a bake score higher than MDD 22. The district where the wheat was grown was also provided. Various methods, described in the results section, were used to examine the relationship between protein content and bake score.

RESULTS

Analysis of grain protein within a cultivar and season showed that the pattern of distribution was non-normal, and was skewed in a Chi-square type of distribution, (Tables 1 and 2). Regression analysis was conducted on protein data transformed using Log_e to determine the strength of the correlation between MDD bake score and protein content. Subsequent correlation coefficients were low ($r = 0.19$ to $r = 0.66$) for each of the cultivars in the three seasons studies. The Log_e transformation identified some curvature in the response of bake score to increases in grain protein, but this was not large. However, calculated values of bake score at high and low protein contents were obviously incorrect. Protein contents were concentrated within a relatively narrow range of 8 to 12% (Tables 1 & 2) and there were few samples which had high or low concentrations of grain protein which could be used to define the shape of the response curve accurately at these extremes.

Further analysis was conducted by dividing the data from cultivars grown in each season into groups where one group represented a one percent increase in flour protein, eg 9.0 – 9.99; 10.0 – 10.99, etc. The mean and standard deviations for MDD bake score, kernal weight and the mean protein concentration were calculated for each protein group. Thus the mean response of bake score to increases in the mean protein content for each cultivar in each season could be plotted. (Figure 1).

This approach gave a much greater curvature in the response of bake score to increasing protein content, bake score reaching a plateau at about 12% protein. (Figure 1).

Season and cultivar had a considerable effect on the shape of the response curve. In 1983 there was only a small difference between Rongotea and Oroua, and the response curve of bake score to protein was much flatter than in 1982 and 1986. In 1982 and 1986 bake score increased more quickly when protein concentration increased and the differences between Oroua and Rongotea were much greater. (Figure 1).

At comparable protein concentrations above about 9%, Oroua had a higher bake score than Rongotea and the more flour

Table 1. The proportion of lines within a district falling within specified protein groups for 1982.

Oroua 1982					DISTRICT					
Protein Group	NI	N/M	N/C	CHCH	ASHB	TIM	OAM	DUN	INV	NAT.
7.0 – 7.9	0	8	2	7	2	9	2	-	0	3
8.0 – 8.9	3	11	4	15	21	32	29	-	0	3
9.0 – 9.9	16	24	23	28	25	28	36	-	16	26
10.0 – 10.9	36	21	23	24	21	15	24	-	33	23
11.0 – 11.9	28	21	21	14	15	12	8	-	31	17
12.0 – 12.9	11	16	13	14	10	1	1	-	2	8
13.0 – 13.9	5	0	13	9	4	0	0	-	0	3
14.0 – 18.0	0	0	2	2	3	0	0	-	0	1
No of Lines	61	38	56	235	346	211	66	6	49	968
% Total Lines	6	4	5	14	36	22	7	1	5	
Mean Protein %	10.9	10.3	11.0	11.1	10.3	9.4	9.6	10.9	10.3	10.1
mean MDD	22.4	23.0	24.0	24.3	22.4	19.7	21.5	15.8	20.7	21.8
Rongotea 1982					DISTRICT					
Protein Group	NI	N/M	N/C	CHCH	ASHB	TIM	OAM	DUN	INV	NAT.
7.9 – 7.9	4	15	7	3	4	4	2	5	0	4
8.0 – 8.9	14	25	18	16	26	28	24	24	50	24
9.0 – 9.9	26	32	28	25	24	38	39	36	25	31
10.0 – 10.9	31	21	22	25	20	21	26	33	17	22
11.0 – 11.9	14	6	14	14	15	7	8	0	8	12
12.0 – 12.9	9	1	8	12	6	1	2	0	0	2
13.0 – 13.9	2	0	3	4	3	0	0	0	0	2
14.0 – 18.0	0	0	0	1	1	0	0	0	0	0
No of Lines	395	68	258	341	785	688	184	37	12	2768
% Total Lines	14	2	9	13	28	25	7	1	-	
Mean Protein %	10.2	9.3	9.9	10.3	10.0	9.5	9.6	9.5	9.4	9.8
mean MDD	185	19.2	19.7	20.6	19.8	18.8	19.0	16.2	18.4	19.5

KEY: 1. North Island, 2. Marlborough, 3. North Canterbury, 4. Christchurch, 5. Ashburton, 6. Timaru, 7. Omaru, 8. Dunedin, 9. Invercargill

protein concentrations increased above 9%, the larger were the differences in bake score. However in 1982 when the protein concentration of white flour was less than 9% (14% mb), Rongotea had a higher bake score than Oroua. Data for the 1986 season was incomplete, and the changes in bake score at low protein concentrations could not be measured. It was apparent that in Rongotea mean bake score fell less rapidly when the concentration of protein decreased than in Oroua. Conversely. mean bake score increased more rapidly in Oroua when protein concentration was increased in both cultivars. (Figure 1)

In 1986 the response curve for bake score in Rongotea appeared to be similar to that of Oroua. (Figure 1). The selection criteria imposed by Cereal Foods meant that lines with low bake score were omitted, which increased the mean bake score. Interestingly this policy did not alter mean bake scores in Oroua when compared with 1982 when all lines were included. The implication is that an insignificant proportion of lines of Oroua which had a protein concentration above 9% had a MDD bake score below 22 points.

DISTRICT EFFECTS

In 1981 and 1982 the data for each cultivar was further subdivided into groups based upon district of production to determine whether this parameter had any effect on the response of mean bake score to increases in protein content. Data was partitioned into nine groups. For each group mean and standard deviations of bake score were calculated, and the results are given in Figures 2, 3, 4 and 5.

It can be seen from these figures that the lowest bake score at a given protein content ocurred in wheat grown in Invercargill, Dunedin and the North Island, while Blenheim had the highest score. The mean bake scores within a protein group were comparable for all wheat grown in Canterbury. However, there was also a considerable seasonal effect. In both cultivars in 1982 there was little effect of district on the relationship between protein content and bake score, while in 1983 there were pronounced differences between districts. (Figures 2 – 5).

The high standard errors associated with Figures 1 – 5 indicate that it is the trends that are of interest, and not too much emphasis should be placed on minor deviations from these trends. The large standard errors also confirms the conclusion by Wilson (1983) and Mitchell and Casutt (1983) that protein content alone cannot be used as a determinator of baking quality.

Figures 1 to 5 indicate a positive, but diminishing rate of increase in mean MDD score with increasing protein content. Above protein concentrations of about 12% there was a much smaller increase in mean bake score when grain protein was increased. The bake score observed at any protein content was affected by cultivar, season and district of production. While the effect of cultivar and season on mean bake score have been well documented (Mitchell, 1985), the effect of environmental influences on bake score in a cultivar at a given protein concentration (ie protein quality) was further investigated.

TEMERATURE AND BAKING

One environmental variable that was considered to vary among seasons and districts was the mean temperature which ocurred over the grain filling period, which, for the majority of wheat crops grown in New Zealand can be taken to be December and January.

A somewhat subjective look was taken at mean monthly temperature over the December and January period. Fluctuation in mean temperature was considered to be a potential cause of the variation in bake scores within a cultivar observed at comparable concentrations of grain protein, *ie* the fluctuations in protein quality. As can be seen in Figures 2 - 5 the trend is for the more northerly regions of the South Island to produce wheat which has higher bake scores at any given protein content.

Mean temperatures in December and January were plotted for each season against the mean bake score for that season, irrespective of district of production, cultivar or grain protein concentration. These values show that in 1976 and 1977, bulk fermentation bake scores were, on average, low (Figure 6). In 1983 and 1984 MDD bake scores were also low, and it is known that grain protein concentration in these two years was 10.1%, which is not abnormally low, (Wheat Research Institute, 1985 Annual Report).

These low mean bake scores corresponded with a reduction in the mean daily temperature over the December and January period (Figure 6). Regressions of mean bake score against mean temperature were calculated, but proved inconclusive (R^2 = 0.44 (NS) for bulk fermentation data and R^2 = 0.56 (P = 0.05) for MDD data.) These calculations did not take into consideration the variation in mean bake score that may be attributed to cultivar mix or mean protein content (Figure 1)

In the 1982 and 1983 seasons (for Oroua and Rongotea) the mean bake score and protein content in each district was known (Tables 1 & 2) as was the mean temperature in December and January. To remove any effect of variation in grain protein concentration on mean bake score (Figure 1), the MDD bake score was divided by grain protein concentration. Thus the quality of the grain protein for each cultivar and season was regressed against the mean temperature occurring over grain filling period for each district and the results are given in Figure 7. These

Table 2. The proportion of wheat lines within a district and nationally falling within specified protein groups. Mean bake score and protein content by district for 1983.

Oroua 1983					DISTRICT*					
Protein Group	NI	N/M	N/C	CHCH	ASHB	TIM	OAM	DUN	INV	NAT.
7.0 – 7.9	0	0	4	5	4	3	0	0	1	3
8.0 – 8.9	5	15	5	15	10	8	1	19	13	11
9.0 – 9.9	14	5	9	21	20	12	4	17	35	19
10.0 – 10.9	10	25	8	22	20	18	26	39	30	21
11.0 – 11.9	44	35	30	18	21	19	26	25	14	20
12.0 – 12.9	21	15	23	12	15	17	18	0	5	14
13.0 – 13.9	7	5	6	4	5	14	13	0	2	7
14.0 – 18.0	0	0	14	1	3	9	11	0	0	5
No of Lines	73	20	77	131	531	435	38	36	318	1659
% Total Lines	4	1	4	8	32	26	2	2	19	
Mean Protein %	11.2	10.9	11.7	10.4	10.7	11.4	11.8	10.1	10.1	10.8
mean MDD	17.3	23.3	21.2	20.3	20.4	19.6	20.1	13.5	13.7	19.2

Rongotea 1983					DISTRICT					
Protein Group	NI	N/M	N/C	CHCH	ASHB	TIM	OAM	DUN	INV	NAT.
7.9 – 7.9	0	8	4	10	6	7	3	0	0	6
8.0 – 8.9	6	23	8	26	14	13	3	13	11	15
9.0 – 9.9	22	31	13	20	27	19	8	29	56	22
10.0 – 10.9	25	23	19	21	22	21	11	42	22	21
11.0 – 11.9	29	15	18	10	16	19	26	13	11	17
12.0 – 12.9	10	0	12	3	3	4	19	0	0	5
13.0 – 13.9	5	0	12	3	3	4	19	0	0	5
14.0 – 18.0	2	0	8	1	1	2	13	0	0	3
No of Lines	79	13	241	306	581	351	74	31	9	1685
% Total Lines	5	1	14	18	34	21	4	2	-	
Mean Protein %	10.8	9.7	11.2	9.8	10.2	10.4	11.9	10.7	10.0	10.4
mean MDD	17.2	20.2	19.0	18.5	18.9	17.9	18.2	11.0	13.3	18.6

* Key to districts given in Figure 2.

regressions were significant at P = 0.01, R^2 = 0.74 for Oroua and R^2 = 0.64 for Rongotea.

The values plotted in Figure 7 suggested a non linear response curve with a reduction in the response of MDD bake score per protein percentage point above about 16°C. To assess whether there was any curvature a squared function was fitted, but subsequent values for R^2 did not show any marked improvement, (R^2 increased to 0.75 for Oroua and 0.67 in Rongotea).

Thus, with the limited data available, it was not possible to conclusively identify the response curve as being linear or quadratic. A positive increase in bake score per unit flour protein as temerature was increased was apparent however (Figure 7). The 1982 season was generally warmer than 1983 with less variation between districts which may account for at least some of the consistency observed in 1982, but not 1983, between districts (Figures 4 and 5.)

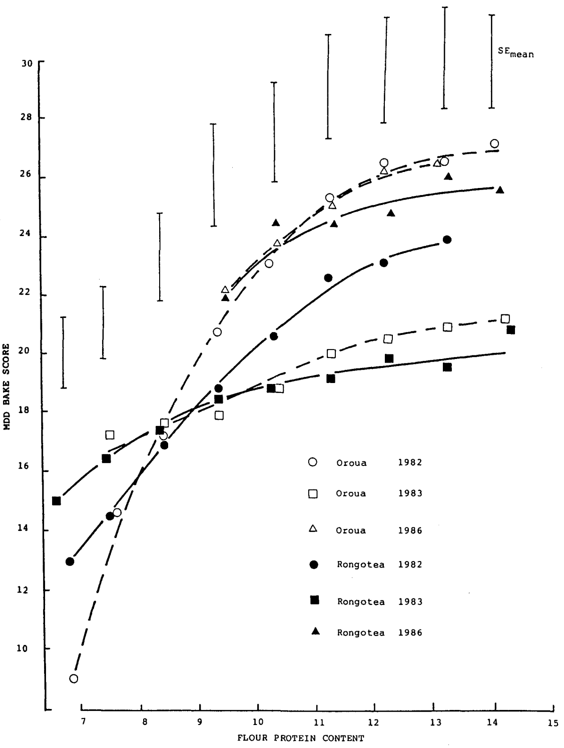

Figure 1: The relationship between MDD bake score and white flour protein concentration : Oroua and Rongotea.

GRAIN PROTEIN CONTENT, KERNEL WEIGHT AND TEMPERATURE OVER GRAIN FILLING

Drewitt (1979) reported a negative correlation (r = -0.88) between kernel weight and grain protein concentration and this was further investigated in this study. Similarly, Vos (1981) concluded that temperature occurring over the grain filling period reduced the average kernel weight, the relationship between kernel weight and mean temperature over December/January was also

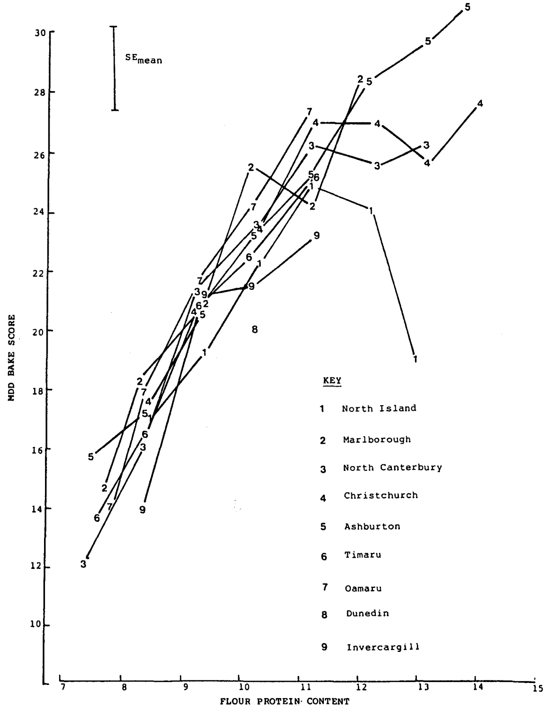

Figure 2: The relationship between MDD bake score and flour protein concentration for Oroua grown in 9 districts in 1982.

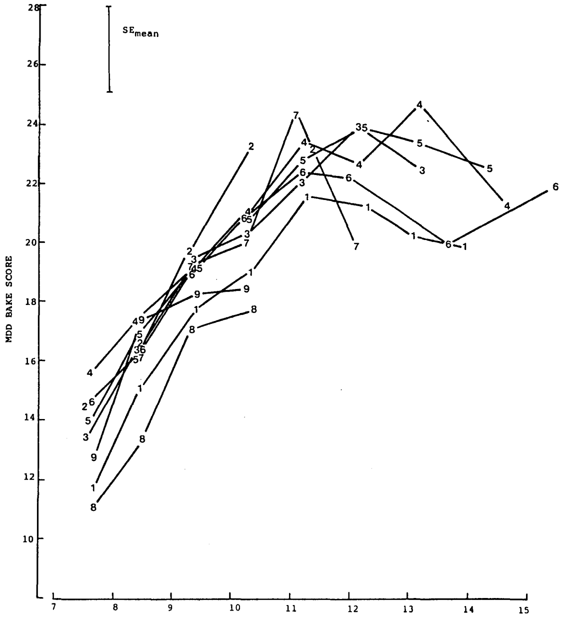

Figure 3: The relationship between MDD bake score and flour protein concentration for Rongotea grown in 9 districts in 1982.

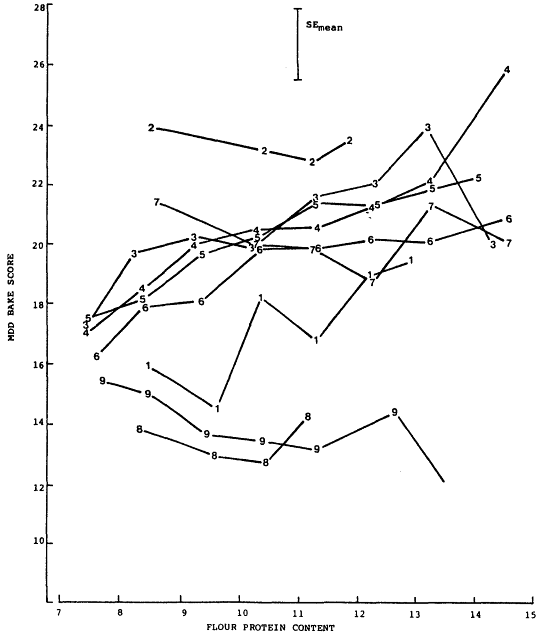

Figure 4: The relationship between MDD bake score and flour protein concentration for Oroua grown in 9 districts in 1983.

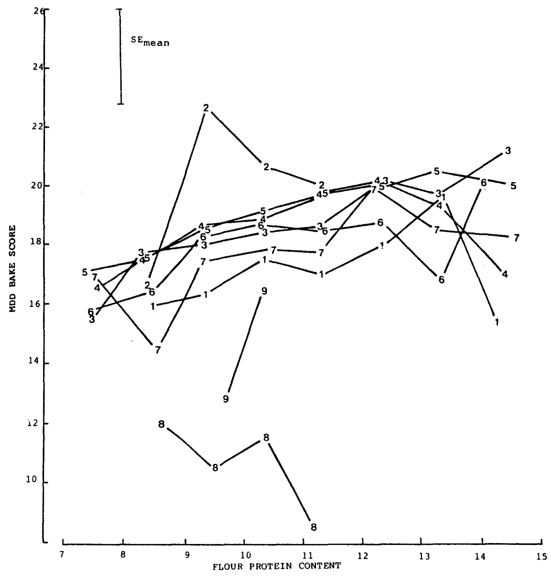

Figure 5: The relationship between MDD bake score and flour protein concentration for Rongotea grown in 9 districts in 1983.

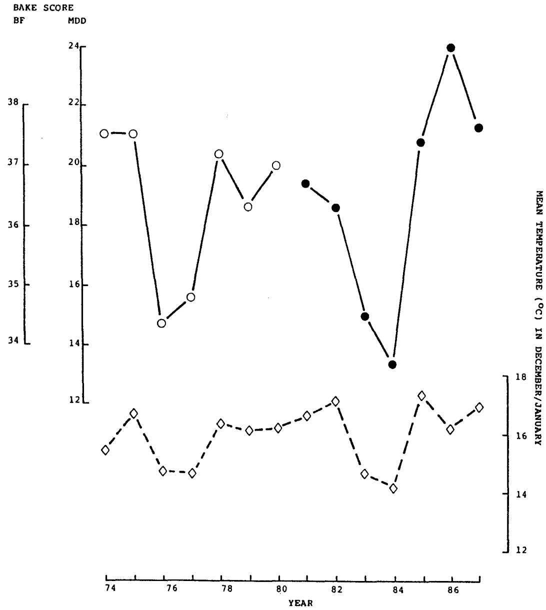

Figure 6: Changes in mean bake score, bulk fermentation for 1974 - 80 and MDD for 1981 - 87, and the change in mean temperature for December and January at Lincoln.

Temp vs BF: $R^2 = 0.44$ NS

Temp vs MDD: $R^2 = 0.56$*

◇ **Mean Temp.**
○ **BTT Bake Score**
● **MDD Bake Score**

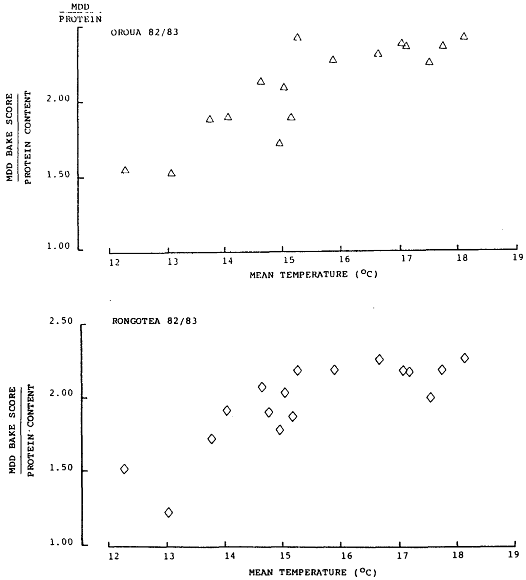

Figure 7: The change in mean MDD bake score points per 1% protein with increasing mean temperature in December and January.

Oroua : $Y = -0.42 + 0.15 x$ $R^2 = 74$ **

Rongotea : $Y = -0.29 + 0.13 x$ $R^2 = 64$ **

investigated. There were no significant correlations identified between any of the parameters suggesting that large grains which have high protein concentration and baking quality are not mutually exclusive parameters.

DISCUSSION

The non-normal distribution of protein concentration in which virtually no samples below 7% and few less than 8% were found (Tables 1 and 2), suggests that some mechanism may be operating within the plant to minimise the level to which protein content can fall. Remobilisation of vegatative nitrogen to the grain is well documented (Ellen and Spiertz, 1975; Austin *et al*, 1977; Quin & Drewitt, 1979), and the lack of lines with very low protein concentration indicates that this mechanism may determine a minimum grain protein concentration. This non-normal distribution meant that significantly more than half of the crop failed to reach the mean protein content, although precise distributions and mean protein content varied according to season and cultivar (Tables 1 and 2).

The curves given in Figure 1, indicated that the responses of bake score to increasing protein content differed between cultivar and season. Cultivar and season (Mitchell, 1985) and mean protein content (Scott, 1981) have long been recognised as affecting bake score. While differences in the responses of bake score to increasing grain protein content are known (Cawley, 1981; Wilson, 1983), the fact that at low concentrations of grain protein Rongotea baked comparably to Oroua was not so well documented. However the bake scores which resulted from these low protein contents are not commercially acceptable (Figure 1).

Differences in peak mean bake score and the rate of decline in bake score as protein content decreased are believed to be associated with the protein balance in the grain (Doekes & Wennekes 1982). A build up of non-protein nitrogen and short chain polypeptides has been measured in American wheats at very high concentrations of grain nitrogen (Finney *et al*, 1957), thus the standard calculation of protein content (N% x 5.7) may not be correct at all concentrations of grain nitrogen.

Increases in nitrogen concentration of the grain alters the proportion of glutenin to gliadin proteins within the grain which is believed to affect the baking characteristics (Doekes & Wennekes, 1982; Wall, 1979; Khan and Bushuk, 1979). Differences in the balance of glutenin to gliadin at changing grain nitrogen concentration among New Zealand cultivars (Stevenson, 1987) may be partly responsible for the differences in the rate of change of mean bake score observed in Figure 1. However, Cressey *et al*, (1987) and Grama *et al*, (1987), were not able to identify any variation in the partitioning of nitrogen between glutenin and gliadin protein groups in the cultivars they studied.

Oroua, which increased bake score more quickly when grain protein increased, (Figure 1) has been found to synthesise gliadin protein in response to applications of nitrogen (Stevenson, 1987), and thus increasing the gliadin:glutenin ratio. An increase in this ratio has been observed to be associated with increases in loaf volume (Wall, 1979; Khan & Bushuk, 1979; Doekes & Wennekes, 1982).

While district and season influenced mean grain protein concentration (Tables 1 and 2) through environmental and crop management practices, there was an apparent effect of district and season on protein quality within a cultivar (Figures 1 - 5). Mean temperature over the grain filling period was significantly correlated with protein quality (Figure 7). Tatham *et al*, (1985) found that the temperature at which gliadin proteins were analysed affected their three dimensional structure and subsequent photochemical properties. Chamberlain (1969) and Kasarda, Nimmo and Kohler (1971) concluded that the three dimensional structure of the protein chain, as well as the order and frequency of sulphur rich amino acids, determined how well a protein cross-linked with other proteins to form a continuous matrix. It is the visco-elastic properties of this matrix, in conjunction with entire starch granules (Kent, 1969; Wall, 1979), that gives a dough the ability to rise when baked.

Thus the supposition is that the mean temperature over the grain filling period has affected protein quality, possibly by affecting the structure of the protein molecules and hence the way that proteins interact during baking. This preliminary analysis has been brief due to the information currently available and further investigation is clearly warranted, possibly including other variables, such as variation in diurnal temperature and solar radiation, as these factors may affect the rate of protein deposition in the grain. It would seem unlikely that only one factor, such as mean temperature during grain filling, could be the only environmental factor affecting the baking characteristics of grain protein.

However, temperature during the grain filling period may have a significant effect on baking quality by affecting protein content (Vos, 1981), and the apparent baking quality per unit of flour protein (Figure 7).

CONCLUSIONS

In 1982 and 1983, the only seasons for which we have complete data, some 41% of Oroua and 51% of Rongotea wheat failed to produce flour having a protein content of 10% (14% m.b.). In these season mean protein content was around 10.3% but was affected by cultivar, season and district of production.

Mean MDD bake score has a positive, but flattening response to increasing protein content, but protein concentration alone cannot be used to assess MDD baking characterisitics. The increase in mean bake score to increasing protein concentration appears to cease around 12%.

There are differences in observed mean bake score at a given protein content due to cultivar, season and district of productions.

Mean temperature during December and January influenced the apparent protein quality of the flour. Further clarification is required and the regions of New Zealand most suitable for the production of grain with high protein quality identified. Grain protein quantity (grain nitrogen percent) can be manipulated agronomically

There was no relationship identified between protein content and kernel weight, nor between temperature during grain filling and kernel weight.

ACKNOWLEDGEMENTS

I would like to thank D Baruch and A Wilson of the Wheat Research Insititute, DSIR, for their help in retrieving the data from the 1982 and 1983 harvests and in the computer analysis of results. I would also like to thank J South of New Zealand Cereal Foods in making data available.

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