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THE EFFECT OF VARIOUS FERTILISERS AND THE ELEMENTAL COMPONENTS OF WHEAT AND FLOUR ON BAKING QUALITY

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ABSTRACT

Investigations on the effect of fertilisers on bakescore of wheat carried out over a 10 year period from the early 1970's, are summarised and discussed. Nitrogen fertilisers generally increase bakescore by one or two units with little difference in effect by varying the time of application. The underlying location differences remain the major cause of large differences in bakescore. Trials with P, S, K, and Mo fertilisers failed to influence bakescore. Nutrient analysis of high and low bakescore samples from the cultivar Karamu found N the major element related to bakescore, with minor positive effects from S and Ca levels. Wheat and flour samples from the cultivars Oroua, Rongotea, Kopara, Takahe and Karamu, which covered the bakescore range, were analysed for nutrient concentrations of major and minor elements. Highly significant correlations of nutrient levels and bakescore only occurred within cultivars and Oroua, Rongotea and Takahe showed no strong correlation between bakescore and any flour nutrients including N and S. Karamu was the only cultivar to give a relationship between N concentrations and bakescore, but with Kopara, bakescore was related to Mg, K and Fe flour concentrations. This research has provided no answers to the large location variation seen in bakescore of wheat and it is suggested further research on the effect of fertilisers on grain quality is unwarranted until there is a greater understanding of the environmental effects on grain N biochemistry in New Zealand wheat.

INTRODUCTION

Baking quality of wheat flour is a function of both the quantity and quality of grain protein and loaf volume is a linear function of protein content in the range of 8-20% protein in optimised baking tests (MacRitchie, 1984). Understandably, this relationship has directed considerable attention into improving baking quality by using nitrogen (N) fertiliser to improve the quantity of protein (Fajersson, 1961; Wright, 1969; Pushman and Bingham, 1976; Timms *et al.*, 1981) and sulphur (S) fertiliser to improve the quality of the protein (Wrigley *et al.*, 1980, Moss *et al.*, 1981).

In New Zealand the relationship between protein content of wheat and baking quality was demonstrated in early experimentation (West, 1931). Nevertheless the large number of N trials conducted on wheat since that time have only given a small improvement in bakescore (Wright, 1969; Sheath and Galletley, 1980). A recent analysis of bake samples taken by the wheat industry showed bakescore could not be predicted from grain protein (Dengate 1983, Wilson 1983).

In N trials on wheat it has been obvious that the trial location has had a much greater influence on bakescore than the N treatments. Little research has investigated the reasons for these effects. Malcolm (1977) found the proceeding crop rotation influenced the baking quality of the cultivar Karamu and Wright (1967, 1969) found that the proceeding crops affected bakescore more than N applications to the wheat crop. Whereas wheat sown after grass gave three bakescore points higher quality (bulk fermentation method) than wheat sown after cereals, N fertiliser only improved bakescore by less than half this amount. However, these crop rotation effects were still only a small portion of site to site bakescore differences and clearly the underlying differences were caused by factors other than crop rotation or N content.

Bakescore also varies among cultivars and within individual cultivars among regions (Simmons, 1983) but again the differences in bakescore do not explain the large differences caused by crop location.

Soil fertility factors outside the traditional fertiliser practices may have influenced baking quality. A preliminary investigation of the relationship between the concentration of nutrients in grain of low and high bakescore indicated that N and S were positively related to bakescore and potassium (K) and molybdenum (Mo) were negatively related (Douglas and Dyson, 1985). Phosphorus (P) and magnesium (Mg) gave weak negative relationships with bakescore. A field study later showed that very high rates of superphosphate markedly depressed the bakescore of Karamu wheat (Douglas *et al.*, 1988). These studies provided an impetus to continue research in this area and this paper summarises the results of a series of trials relating bakescore and grain nutrients conducted over the period from 1973 to 1983.

TRIALS AND RESULTS

Trial 1 Series:

The lack of any effect of N fertiliser on bakescore (Wright 1969) raised questions about whether the timing of the N application was important. In seven trials three rates of nitrolime (0, 25, 75 kg/ha N) were applied to Kopara and Karamu wheat at crop emergence (Feeke 1) late tillering (Feeke 5) and ear emergence (Feeke 10.1). The trials were conducted in Hawkes Bay, Marlborough, South Canterbury, South Otago and Southland in the 1973 and 1974 seasons. Paddock histories are summarised in Table 1. Grain samples were kept and bakescore determinations were made by the Wheat Research Institute and grain N determinations at Ruakura Research Centre by standard methods (Sutton 1984).

The grain N concentrations of Kopara was higher than Karamu except on one site in South Canterbury where bird damage to Karamu may have influenced the result (Table 1). The N concentrations in Kopara was changed by 3% (range 0-10%) when 25 kg/ha was applied and by 10% (range 5-16%) when 75 kg/ha N was applied. In Karamu 25 kg/ha N changed the grain

Table 1. The effects of three rates of nitrogen (kg/ha) applied at three stages of crop growth (Feeke scale) on the nitrogen concentration of the grain and the bakescore (MDD).

District	Blenheim		Sth Cant		Sth Cant		Hawkes Bay		Sth Otago		Sth Otago		Southland		Average	
Soil	Waimakariri		Morven		Temuka		Takapau		Tokomairiro		Warepa		Otapiri			
Paddock History*	P-C-C		W-R-W		G		G-B		G-W-W		B-W-W		G-B-W-			
Response to N	NS		23%		11%		5%		10%		5%		5%			
Kopara	BS	%N	BS	%N	BS	%N	BS	%N	BS	%N	BS	%N	BS	%N	BS	%N
0 N	21	2.86	18	2.08	17	2.12	19	2.24	20	2.08	26	2.11	14	2.60	19.5	2.30
25 N	21	2.87	18	2.07	16	2.15	19	2.46	19	2.13	24	2.17	16	2.68	19.1	2.36
75 N	20	3.08	18	2.22	17	2.23	18	2.58	21	2.33	27	2.46	17	2.76	19.7	2.52
N at F1	21	2.93	18	2.11	17	2.16	20	2.51	21	2.21	25	2.29	15	2.62	19.6	2.40
N at F5	20	2.96	18	2.08	17	2.20	18	2.50	22	2.21	25	2.27	16	2.71	19.6	2.42
N at F10.1	19	3.03	18	2.24	15	2.20	17	2.55	16	2.25	27	2.37	20	2.83	19.1	2.49
Karamu																
0 N	17	2.72	14	2.37	7	1.93	15	2.07	13	1.92	22	2.01	10	2.31	14.1	2.19
25 N	14	2.52	13	2.38	13	2.01	16	2.24	15	2.00	20	2.04	10	2.37	14.4	2.22
75 N	14	2.46	14	2.54	15	2.12	16	2.32	15	2.14	23	2.29	13	2.48	15.7	2.33
N at F1	14	2.51	14	2.43	15	1.99	15	2.34	14	2.05	21	2.12	12	2.37	15.3	2.26
N at F5	15	2.48	13	2.47	14	2.05	17	2.28	16	2.07	21	2.12	10	2.50	15.2	2.28
N at F10.1	13	2.48	13	2.47	13	2.15	15	2.22	13	2.07	22	2.25	13	2.41	14.7	2.29

*B = brassica C = clover G = grass P = peas R = ryegrass W = wheat

N% by 1% (range -7 to 8%) and by 11% (range -11 to 14%) when 75 kg/ha N was applied. Later applications of N increased the N% in the grain more than when the N was applied at crop emergence but the effect was small. In Kopara the %N in the grain was raised by 4% (range 2-8%) when the N was applied at flowering instead of crop emergence but there was little effect of this treatment on Karamu (1% difference, range -5 to 8%).

The bakescore of Kopara was five points higher than for Karamu but in both cultivars it was not related to the N concentration of the grain. Overall, the rate of N applied at each time of application had little influence on bakescore, although there were large differences apparent in some trials.

The greatest differences in grain concentration and in bakescore were associated with the trial sites rather than the imposed treatments.

These trials did not resolve the question of the large site variation in bakescore and application of N fertiliser had little effect no matter when it was applied. The large variation in the baking quality of Karamu in this trial series was also of concern and to follow this up a large number of Karamu samples were analysed in an attempt to understand this problem.

Trial 2 Series:

Two hundred and eighty-eight wholegrain samples of Karamu with high and low bakescores (below 25 and above 35, using the bulk fermentation method) were obtained from commercial crops in 1976 from the Wheat Research Institute and analysed for macro elements (N, S, P, Mg, Ca, K) using standardised methods (Sutton, 1984). The relationships between bakescore and the nutrient concentrations of the grain were investigated.

An analysis of variance conducted on the sampled showed that N, S, and Ca levels were significantly higher in the grain with high bakescore while there was no difference in the amount of P, Mg and K in both groups (Table 2). A regression analysis showed

Table 2. The grain concentration of N, S, P, Mg, Ca and K in Karamu wheat of low and high bakescore.

	mean	(range)	Low Bakescore	High Bakescore	Difference
Bakescore	31.4	(10-45)	-	-	-
% N	2.07	(1.38-2.99)	1.77	2.29	0.52± 0.04***
% S	0.16	(0.07-0.27)	0.147	0.164	0.017± 0.003***
% P	0.38	(0.26-0.59)	0.38	0.38	- NS
% Mg	0.11	(0.07-0.19)	0.11	0.11	- NS
% Ca	0.06	(0.02-0.12)	0.058	0.066	0.008± 0.002**
% K	0.46	(0.31-0.70)	0.46	0.46	- NS

the concentration of N, S and Ca was significantly related to bakescore but the variance accounted for by the N relationship (R^2 = 48%) was considerably higher than for S (R^2 = 7%) and Ca (R^2 = 8%). The regression equation for the relationship between bakescore and N concentration in the grain was:

$$Y\ (\text{Bakescore}) = -33.54 + 49.3\,N - 8.35\,N^2 \qquad R^2 = 48.3$$
$$\pm 9.3 \quad \pm 2.2$$

The variation in this relationship is highlighted in Figure 1.

The grain concentrations of P, Mg and K had no significant individual relationship with bakescore but when these factors were considered collectively, after the contribution of N had been taken into account, they were significantly negatively related to bakescore. Nevertheless, they only accounted for a further 2% of the total explained variance. The concentration of S and Ca had no effect after the N relationship was taken into account. Overall the regression of bakescore on the nutrients showed that if the concentrations of N, S and Ca were high relative to P, K and Mg then the bakescore was more likely to be high.

This research along with the results from other studies (Douglas and Dyson 1985, Douglas *et al.*, 1988), suggested that a number of nutrients other than N were implicated in bake quality, and to study this in the field a trial with single nutrient fertilisers was undertaken.

Trial 3 Series:

In 1976 four trials were conducted to assess the effects of N, P, S, Mo and K fertilisers on the baking quality of Karamu wheat. Nitrolime (23% N), triple superphosphate (20% P) and gypsum (17% S) were each drilled at 250 kg/ha with seed and compared in a 2^3 factorial design with four replicates. In addition to this design were 12 plots comprising of two replicates of the N x S plots which received triple superphosphate which had 250 kg/ha muriate of potash (50% K) and 200 g/ha sodium molybdate (39% Mo) added in factorial combination. The four trials were all spring sown;

Trial 1, sown after linseed out of pasture in South Canterbury on a Claremont silt loam.

Trial 2, sown after 10 previous grain crops in South Canterbury on a Timaru silt loam.

Trial 3, sown after two wheat crops in South Otago on a Tokomairiro soil.

Trial 4, sown after swedes out of pasture in Southland on an Otapiri soil.

Grain samples were collected for MDD baking tests and nutrient analyses. In Trial 1 and 4 individual plot samples were baked but in Trials 2 and 3 plot samples were bulked over replicates for baking.

Yield increases (5%) occurred with triple superphosphate treatments in all trials but there was little or no effect on the P concentration in the grain and no effect on bakescore (Table 3). Gypsum slightly increased the S concentration in the grain in three of the four trials and although grain yield increased in Trial 3 (7%) there was no effect on bakescore. The N treatment gave a large yield response in Trial 3 (33%) a yield depression (15%) in Trial 1 and no effect in the other two. The N in the grain increased in only two trials and then by only 3% – 7%. N fertiliser increased the bakescore by 1-2 units in two trials but there was no effect in the other two.

It is noteworthy that although there were large differences in bakescore among sites the N, P and S fertilisers had little effect on the nutrient concentration in the grain and on the bakescore.

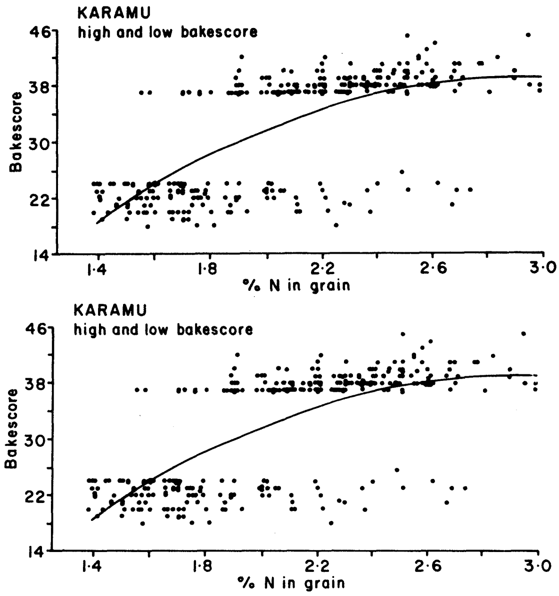

Figure 1. The relationships between bakescore and %N in the wholegrain of high and low bakescore Karamu samples

Table 3. The effect of N, P and S fertilisers on grain yield, nutrient concentration and bakescore in four trials

	No N	N	No P	P	No S	S	SED*
Trial 1							
Yield (t/ha)	3.61	3.06	3.24	3.43	3.36	3.31	0.09
Bakescore	12.4	14.5	13.5	13.4	13.5	13.4	0.46
% Nutrient	%N 2.03	2.18	%P 0.39	0.38	%S 0.14	0.16	NA
Trial 2							
Yield (t/ha)	3.49	3.50	3.40	3.59	3.47	3.52	0.10
Bakescore	22.0	22.2	21.7	22.5	22.5	21.7	NA**
% Nutrient	%N 2.42	2.44	%P 0.38	0.40	%S 0.14	0.15	NA
Trial 3							
Yield (t/ha)	3.52	4.69	3.99	4.22	3.97	4.24	0.11
Bakescore	3.5	3.0	-	-	-	-	NA
% Nutrient	%N 1.92	1.98	%P 0.44	0.44	%S 0.12	0.13	NA
Trial 4							
Yield (t/ha)	7.44	7.59	7.41	7.62	7.54	7.49	0.07
Bakescore	13.5	14.5	14.0	14.0	14.1	13.9	0.35
% Nutrient	%N 2.43	2.44	%P 0.40	0.40	%S 0.16	0.16	NA

* SED standard error of difference between levels within a nutrient.

** Not analysed

Table 4. The mean nutrient level and range of levels of major and minor elements in wheat and flour samples of five wheats.

Wheat Samples	Oroua	Rongotea	Takahe	Kopara	Karamu
Grain Weight	39.8 (31.6-50.0)	41.9 (33.3-51.8)	41.1 (31.0-48.0)	37.9 (26.4-46.1)	36.6 (22.1-47.1)
% N	2.47 (2.0-2.95)	2.43 (1.84-2.87)	2.40 (1.96-2.82)	2.50 (1.97-3.37)	2.23 (1.65-2.77)
% S	0.19 (0.14-0.23)	0.17 (0.13-0.21)	0.16 (0.11-0.21)	0.18 (0.14-0.22)	0.15 (0.09-0.21)
% P	0.45 (0.37-0.54)	0.46 (0.32-0.57)	0.47 (0.38-0.57)	0.44 (0.32-0.57)	0.41 (0.23-0.53)
% Mg	0.16 (0.13-0.22)	0.16 (0.13-0.26)	0.15 (0.11-0.19)	0.15 (0.12-0.19)	0.14 (0.10-0.17)
% Ca	0.06 (0.04-0.10)	0.05 (0.03-0.08)	0.06 (0.04-0.11)	0.06 (0.04-0.09)	0.07 (0.03-0.14)
% K	0.51 (0.34-0.84)	0.60 (0.44-0.93)	0.44 (0.34-0.56)	0.56 (0.35-0.93)	0.55 (0.31-0.76)
ppm Mn	62 (21-120)	65 (21-132)	72 (39-119)	57 (18-100)	53 (24-99)
ppm Zn	46 (30-80)	44 (32-81)	51 (28-83)	43 (26-69)	43 (27-68)
ppm Cu	7 (3-11)	8 (5-11)	8 (5-11)	6 (3-8)	7 (5-10)
ppm Fe	84 (37-598)	98 (41-572)	58 (33-91)	62 (36-114)	81 (33-507)
ppm Mo	0.36 (0.1-1.75)	0.45 (0.11-1.76)	0.14 (0.06-0.26)	0.22 (0.7-0.64)	0.45 (0.06-2.1)
Bakescore	22 (9-27)	18 (6-29)	16 (2-23)	18 (9-25)	16 (2-27)
% N	2.20 (1.65-2.73)	2.04 (1.28-2.5)	2.01 (1.68-2.36)	2.12 (1.6-2.64)	1.85 (1.37-2.51)
% S	0.15 (0.12-0.18)	0.14 (0.07-0.16)	0.14 (0.11-0.18)	0.13 (0.09-0.17)	0.12 (0.09-0.14)
% P	0.12 (0.09-0.15)	0.12 (0.08-0.15)	0.11 (0.07-0.13)	0.10 (0.08-0.13)	0.11 (0.08-0.14)
% Mg	0.04 (0.03-0.06)	0.03 (0.2-0.05)	0.03 (0.02-0.04)	0.2 (0-0.07)	0.02 (0.01-0.05)
% Ca	0.02 (0.01-0.5)	0.03 (0.01-0.5)	0.02 (0-0.05)	0.03 (0.01-0.05)	0.03 (0-0.06)
% K	0.14 (0.1-0.21)	0.17 (0.13-0.21)	0.12 (0.08-0.18)	0.12 (0.08-0.18)	0.14 (0.1-0.17)
ppm Mn	7 (2-12)	8 (3-17)	7 (4-13)	7 (4-12)	8 (4-13)
ppm Zn	13 (9-18)	11 (8-15)	9 (5-14)	9 (6-11)	11 (7-16)
ppm Cu	2 (1-3)	2 (1-3)	3 (2-3)	2 (1-3)	2 (2-3)
ppm Fe	25 (10-133)	19 (11-86)	13 (4-29)	13 (8-19)	26 (8-147)
ppm Mo	0.11 (0.02-0.46)	0.13 (0.02-0.57)	0.04 (0.01-0.08)	0.10 (0.03-0.41)	0.1 (0.02-0.42)

In the investigation of the effects of K and Mo fertilisers on bakescore, an increase in yield to Mo occurred in Trial 1 (12.4%) but there was no effect of either element on bakescore in the three trials in which they were compared.

These series of trials provided some additional information on the effects of nutrient in relationship to small shifts in bakescore but provided no explanation of the large site differences in bakescore. To more clearly examine the relationships between grain nutrient concentrations and bakescore a larger data set was analysed than had been done previously by Douglas and Dyson, (1985).

Trial 4 Series:

In 1982 150 samples taken from commercial samples of wholegrain wheat and flour of Oroua, Rongotea, Takahe, Kopara and Karamu were supplied by the Wheat Research Institute. The samples were chosen to cover the MDD bakescore range and were rechecked by a second baking. There were fewer high scoring samples of Kopara, Karamu and Takahe and fewer low scoring samples of Oroua and Rongotea to choose from. About 40% of the Takahe and Kopara samples had low levels of sprouting (S_1 – S_3) but this should have had little effect on the bakescore (R.W. Cawley, *pers comm*). All samples were weighed to measure grain weight and analysed for macro and micro element concentrations using standard techniques (Sutton 1984).

Oroua and Kopara had the highest mean concentrations of N and S in the flour and Karamu the lowest but overall the nutrient concentrations of all cultivars covered a similar range for both wheat and flour (Table 4). The flour had over 80% of the N and S found in the wholegrain but only 25-33% of all other elements except manganese which was only 11% of the whole grain.

Highly significant correlations between concentrations of grain nutrients, bakescore and grain weight were only achieved within individual cultivars and for ease of comparison the R^2 values are presented rather than the correlations coefficients (Table 5). Karamu was the only cultivar which showed a strong positive relationship between flour N concentration and bakescore. It also had a highly significant negative relationship with the Ca concentration in the flour. No cultivars showed a highly significant relationship between S concentration and bakescore. Takahe and Rongotea showed no strong relationship between any nutrient in the flour and bakescore and Oroua showed a relationship with P.. For Karamu the best prediction of bakescore came from a regression with N levels in the flour as a positive factor and grain weight as a negative factor ($R^2 = 73\%$) but when this combination was applied to Kopara it accounted for only 26% of the variance. The best prediction of bakescore in Kopara flour was a regression equation which included positive K and Mg factors and negative Mn and Mo factors ($R^2 = 84\%$) but the K and Mg factors were the dominant part of this regression ($R^2 = 76\%$).

No nutrient in the wholegrain had a strong relationship with bakescore although some moderate and low R^2 values were statistically highly significant. The N concentration in Karamu and the Mo and K concentrations in Kopara showed moderate positive relationships to bakescore and the Cu, Mo and Mg concentrations in Oroua, Rongotea and Takahe respectively showed moderate negative relationships. Although the positive relationship between bakescore and K in Karamu and Oroua, the Mn and Zn in Karamu, and the negative relationship with Zn in Oroua were highly significant, the R^2 values were low.

In Karamu, and to a lesser extent in Oroua, grain weight was strongly negatively related to bakescore but this did not occur in the other cultivars (Table 5). Grain weight was negatively related to N concentration ($R^2 = 41\%$) in Karamu and K concentration ($R^2 = 57\%$) in Kopara and positively related to the Cu concentration ($R^2 = 48\%$) in Oroua.

This set of data highlights the lack of consistency between cultivars and the lack of any clearcut relationships between nutrient concentrations and bakescore. Overall, all the R^2 values

Table 5. R^2 values (%) for bakescore against flour and wheat nutrient concentrations and grain weight.[1]

	Oroua	Rongotea	Takahe	Kopara	Karamu	All cults
Wheat Samples						
Grain wght	(-)48	-	7	(-)24	(-)63	8
%N	1	4	(-)17	(-)2	42	4
%S	1	2	(-)16	-	-	1
%P	(-)10	(-)3	(-)16	4	5	0
%Mg	(-)17	(-)2	(-)39	1	3	0
Ca	-	10	(-)1	(-)3	3	0
%K	23	-	(-)10	34	27	7
ppm Mn	(-)13	(-)2	(-)7	(-)3	28	0
ppm Zn	(-)23	(-)5	(-)14	(-)12	24	(-)2
ppm Cu	(-)35	(-)8	(-)13	(-)15	(-)4	(-)10
ppm Fe	6	(-)18	(-)5	43	16	4
ppm Mo	8	(-)32	(-)10	43	3	0
Flour Samples						
%N	9	14	(-)3	(-)6	63	11
%S	4	8	(-)4	(-)11	16	2
%P	29	(-)9	(-)5	25	-	3
%Mg	16	-	-	67	19	13
%Ca	6	-	(-)1	(-)33	(-)38	(-)10
%K	17	-	(-)1	66	-	5
ppm Mn	2	-	-	1	20	1
ppm Zn	9	(-)6	(-)3	25	20	6
ppm Cu	(-)4	-	(-)8	(-)5	11	(-)1
ppm Fe	1	(-)15	-	60	8	2
ppm Mo	4	(-)14	-	-	(-)6	0

(-) Negative relationships
1 The 10%, 5% and 1% critical points for the R^2 values are approximately 8%, 12% and 20% respectively.

from the composite analysis were low with the Mg concentration in flour giving a higher R^2 relationship to bakescore than the N concentrations in the flour.

DISCUSSION

Baking quality is a function of both protein quantity and quality (MacRitchie, 1984). The analysis of samples with high and low bakescore in this study and earlier work (Douglas and Dyson, 1985) showed the expected relationship between N concentration and baking quality but in both studies the relationship had a quadratic component which indicated that at higher levels of N concentration there was little change in baking quality with increasing N concentration. This has previously been reported by Bushuk *et al.*, (1978). More confusing is that, with the exception of Karamu, the analyses of the nutrient concentration of the wheat cultivars did not show any predictive relationship between the N concentration in the grain or flour and bakescore. This highlights the difficulties in understanding the large variation in bakescore in New Zealand wheat and confirms the finding of Dengate (1983) and Wilson (1983) that protein levels cannot be used to predict the baking quality of New Zealand wheat.

The results of field trials in this present work also clearly illustrate the lack of relationship between N concentration in grain and baking quality. The N treatments in these field trials gave only small changes in protein concentration and baking quality which is similar to other work in New Zealand (Wright, 1969; Sheath and Galletley, 1980) and they have had little influence on the underlying large site to site variation. Considerable research on N and baking quality has shown that increasing the total protein levies in wheat do not always lead to an increase in baking quality because protein quality may have declined (Finney *et al.*, 1957; Pushman and Bingham, 1976; MacRitchie, 1984). Our results have shown that total grain protein content does not explain the large site differences in bakescore and we need to look toward differences in protein quality for possible explanations. Research on protein composition and protein characterisation in relation to the large site to site differences in bakescore is long overdue in New Zealand and it is pleasing to see some research on this topic has begun (Campbell and Cressey, 1983).

The relationship between adequate S levels in flour and baking quality has been well established from experiments which have manipulated N and S levels where S levels have been limiting (Wrigley *et al.*, 1980; Moss *et al.*, 1981; Timms *et al.*, 1981). However, once S levels are adequate there is little evidence to support a relationship between baking quality and variation in the flour contents of S containing amino acids (MacRitchie, 1984). The present results from the high and low bakescore samples of Karamu support the relationship between S concentrations and bakescore shown in the preliminary study of Douglas and Dyson (1985) but essentially the S effect was minor and not significant once the N effect had been taken into account. In the cultivar comparison there was no correlation between the S concentration in the grain and flour and bakescore and no effect on bakescore due to the use of gypsum in the field. These field trials and earlier work (Douglas *et al.*, 1988) have shown the difficulty of increasing grain S by applying fertiliser with the major variation being caused by the background soil levels. This research suggests that sulphur does not have a major influence on the large site to site variation in bakescore in New Zealand.

The major interest in investigating the concentration of elements other than N and S in wheat and flour is the effect many of these elements have on protein formation and protein composition. However our results have not identified any single factor which relates to the wide variation in bakescore. No element, including N and S, showed any strong relationship to bakescore other than for individual cultivars. However, the fact that the N concentration itself was not related to bakescore is an indication that the relationship achieved with other elements and bakescore may have some importance even though their role is not yet understood.

Grain P levels have been negatively related to baking quality (Bequette *et al.*, 1963; Watson *et al.*, 1963; Douglas and Dyson, 1985) but in our present studies only weak relationships between grain and flour P concentrations and bakescore have been found (Table 5). Phosphatic fertilisers can depress N levels in the grain (Nutall *et al.*, 1979; Douglas *et al.*, 1983) and at times can depress bakescore (Douglas *et al.*, 1988) but in the field studies reported here no effect of phosphatic fertiliser on bakescore was found and no evidence found to suggest P levels were a major influence in the large site to site variation in bakescore.

The positive relationships between Mg, K and Fe concentration in the flour and the bakescore of Kopara need to be treated with caution since they have only ocurred in this cultivar. Added caution is needed since the earlier results (Douglas and Dyson, 1985) found K and Mg concentrations in the wholegrain were related negatively to bakescore rather than the positive relationship shown in the results from the flour analyses (Table 5). Nevertheless, the influence of K and Mg on protein synthesis and composition is well known (Hewitt, 1983) and consequently the effects on bakescore should not be discounted. The negative factors of Mn and Mo concentration in the flour in predicting the bakescore of Kopara did not occur on their own but only after K and Mg were accounted for. In the field studies K and Mo showed no effect on bakescore even though the trials gave wide variation in bakescore and consequently these elements do not appear to have a close association with the large site to site variations in bakescore.

At times in this work, grain weight has been highly negatively related with bakescore, confirming early results (Cressey, 1983; Douglas and Dyson, 1985). In the cultivar comparison only Karamu and Oroua had negative relationships between bakescore and grain weight. The positive correlation of grain weight with Cu concentration in Oroua has been reported before (Douglas and Dyson, 1985) and the effect of N fertiliser in decreasing grain weight is well known (Sheath and Galletley, 1980, Douglas *et al.*, 1983).

This research has provided no explanation for the large location variation in bakescore. There is no indication that bakescore is simply related to the concentration of nutrients in grain or flour and in a number of cases grain weight has provided the most accurate prediction of baking quality. Large differences in bakescore cannot be related to the nutrient status of the flour and consequently the large location differences in the field must remain an intriguing but unanswered question. There is a need for a better understanding of the biochemistry of grain N in New Zealand wheat and the variation due to location before further research on the effects of fertiliser on grain quality is undertaken.

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