Grain yield and quality of two durum wheat cultivars grown in Canterbury

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Abstract

High yields of high quality durum wheat are required to improve New Zealand's durum flour and pasta industries. In this study the effect of the application of nitrogen (N) fertiliser on grain yield and quality of the two cultivars, CRDW17 and Waitohi, was investigated in a field experiment in Canterbury. Fertiliser was applied at tillering (0 or 175 kg N/ha) and at flag leaf emergence (0, 40 or 80 kg N/ha). The grain yield with no N applied was 4.5 t/ha compared with 7.5 t/ha for both the early N treatment and the early plus late N treatment. Late N increased yields by 0.5 t/ha when no N had been applied at tillering. Rainfall just before harvest caused sprout damage that was more severe in cv. CRDW17 than in cv. Waitohi. Mean grain and flour protein percentage was higher for cv. Waitohi (12.4%) than for cv. CRDW17 (11.7%). The late application of 80 kg N/ha increased flour protein content in both cultivars, with average values increasing from 11.2% to 12.8%. Grain colour was measured with a chroma meter. Higher values of the parameter (b*) indicated a more yellow colour which is preferred for pasta production. The mean value of b* over all treatments was greater for cv. Waitohi (24.4) than cv. CRDW17 (23.8). However, b* values for flour were higher in cv. CRDW17 (18.9) than cv. Waitohi (17.5). Grain b* value decreased from 24.7 to 23.5 as a result of early N application, but flour b* values increased from 17.7 to 18.7. Late N application reduced the yellowness of grain from 25.3 to 23.9 after 40 kg N/ha and to 23.0 following 80 kg N/ha. Flour b* values were increased from 17.9 to 18.3 for both rates of late application. Fortuitously, N applications that produced the highest grain yield and flour protein content also gave the most preferred flour colour.

Additional keywords: *falling number, flour, L*a*b* colour space, pasta, protein*

Introduction

At present New Zealand grown durum wheat (*Triticum durum* Desf.) supplies the grain for about 60% of the pasta sold in New Zealand. The remainder is imported. An industry goal is to increase domestic durum wheat production to accommodate 80% of this market. To achieve this the crop must be profitable for growers and processors. Therefore, consistently high yield and quality are required.

High protein content (>11.5%) is a quality requirement to ensure superior cooking quality of pasta (Matsuo *et al.*, 1972). In addition, an industry survey overwhelmingly highlighted that consumers preferred a 'golden colour' because they associate it with high quality (Clarke *et al.*, 1998). Visual perception of colour is a qualitative assessment that can be ambiguous and varies among consumers. The L*a*b* colour space numerically quantifies any colour based on the difference between three elementary colour pairs, L* (black/white), a* (red/green) and b* (yellow/blue) (Gonnet, 1995). Johnson *et al.* (1997) showed that colour preference of oat grain samples could be quantified using the L*a*b* colour space with preference for samples moving from a red to yellow dominance in colour. A minimum flour b* value of 18 is an industry standard. Higher b* values indicate preferred golden colour. Johnson *et al.* (1997) found that agronomic factors (sowing rate, nitrogen and growth regulator) did not affect the b* value of oat cv. Drummond. The importance of L* and a* colour parameters on flour quality are unknown as are the physical changes in flour that cause variation in them. Neither is utilised as flour quality indicators by industry.

To obtain maximum wheat yields nitrogen is applied during tillering (Stephen *et al.*, 1985) while grain protein can be increased by an additional application at about flag leaf emergence (Scott *et al.*, 1992). Thus, the objective of this study was to determine the effect of nitrogen application on the yield and quality of durum wheat. Ideally treatments that maximise grain yields would also produce grain and flour with high protein and preferred golden colour characteristics. This paper is a preliminary report. It presents the results from one of a series of three similar field experiments conducted in contrasting environmental and soil fertility conditions. Two current commercial cultivars were tested.

Materials and Methods

Experimental design

The experiment was established on 27 August 1999 at Crop & Food Research at Lincoln, Canterbury (43°39'S, 172°28'E) on a Templeton silt loam soil. It was sown as a randomised complete block factorial design with three replicates of 12 treatments comprising two cultivars (CRDW17 and Waitohi) and six N application treatments in the form of calcium ammonium nitrate. The plot size was 12 m x 1.35 m. The N treatments were decided on the basis of initial soil N content. These were estimated by the total available soil N prior to sowing from a bulked sample of 10 soil cores taken from depths of 0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm as recommended by Stephen *et al.* (1997). The cores were analysed using anaerobic incubation, followed by ammonium-N extraction using 2M potassium chloride (Keeney and Bremner, 1967). The soil test results (Table 1) suggested an available N content which would support a grain yield potential of about 4-5 t/ha. Therefore, early applications of 0 or 175 kg N/ha were applied at tillering (GS23). Late applications of 0, 40 or 80 kg N/ha were applied at flag leaf emergence (GS39) to produce differences in grain and flour protein content. Total amounts of N applied ranged from 0 to 255 kg N/ha.

Table 1. Available nitrogen in the soil profile before the nitrogen treatments were applied

Depth (cm)	Available nitrogen (kg/ha)
0-15	65
15-30	45
30-45	23
45-60	16
Total 0-60	149

Crop husbandry

A previous crop of potatoes was harvested and the site was then sprayed with Roundup (1.9 kg /ha glyphosate) and Dicamba (100 g /ha dicamba) on the 3 March 1999. This was followed by whole column ploughing on 12 May and deep grubbing on 16 July. Seedbed preparation involved the site being roto-crumbled, harrowed and rolled on 26 August before sowing at 200 kg/ha to achieve a mean plant population of 300 plants/m^2 on the 27 August 1999.

During the season, normal crop husbandry practices were applied to ensure the crop was not water stressed and was free of weeds, pests and diseases. This included the application of 160 mm of water over the growing season to maintain a soil moisture deficit of less than 100 mm in the top 1m of soil. Glean (15 g octanoate/-chlosulfuron/ ha) was applied pre-emergence on 3 September, and Cougar (100 g diflufenican/ha and 500 g isoproturan/ha) was applied post-emergence on 8 October to control weeds. Pirimor 50 was applied at 125 g pirimicarb/ha on 12 October to control aphids. Folicur (190 g terbuconazole/ha) was also applied on 12 October and Cereous (125 ml tridimenol/ha) on 17 November to control fungal diseases.

Measurements

Durum wheat is very susceptible to sprouting and the weather was dull and moist in the period leading up to harvest maturity. Therefore, to ensure that some unsprouted grain would be available for quality tests, a 1m^2 sample was harvested by hand from each plot seven days before they were ready for combine harvesting. The rest of the plots were machine harvested on 21 February. The weight and moisture content of the grain from each plot were measured and yield adjusted to 0% moisture content. Falling number, thousand-grain weight (TGW), percentage screenings, protein content and colour assessment were measured for each of the grain samples. A grain falling number of 250 or above is acceptable for the milling industry.

Grain for milling was tempered to 16% moisture content and then milled using a Brabender® Test Mill Quadrumat® Junior with an average extraction rate of about 40%. Flour quality testing included protein content, colour assessment and falling number.

Grain and flour protein content was measured using near infrared reflectance (NIR). A Minolta CR-210 chroma meter calibrated to a standard white tile (L* =

98.07, a* = -6.23, b* = 1.88) was used for grain colour assessment. Grain readings were taken using a deep glass petrie dish filled with grain and placed on black paper. Flour samples were placed in a standard cell and readings taken using a Minolta CR-300 calibrated to a reference white tile (L* = 97.14, a* = 0.31, b* = 1.74). All colour assessment was carried out under standard fluorescent light conditions.

Statistical Analyses

The full factorial design was used for all analysis of variance (ANOVA) using Minitab (Minitab, 1989) and mean separation was based on Fisher's protected least significant difference at $p < 0.05$.

Results

Yield

Grain yield was increased by N applications and there was a significant interaction ($p < 0.05$) between the effects of early and late applications (Fig.1). Early application increased yield from about 4.5 to 7.5 t/ha for both cultivars. Late N application also increased yield by about 0.5 t/ha where there was no early N applied, but had no effect when early N had been applied. There was no significant difference between the cultivars.

Grain and flour quality

Falling number . The average falling number value was considerably lower in the header-harvested samples than in the hand harvested ($1m^2$) samples (Fig.2). Rainfall of 14 mm that occurred during the seven days before combine harvesting caused sprout damage in all plots. Hand harvested samples were collected before the rain and were considered to be more representative of a 'typical' season. These samples were therefore used for grain and flour quality tests. When falling numbers were averaged over all treatments the value for cv. Waitohi (281s) was higher ($p<0.05$) than for cv. CRDW17 (193s).

Grain. The TGW for cv. CRDW17 (68.0 g) was greater than for cv. Waitohi (57.4 g) over all treatments, and the percentage screenings was also higher for cv. CRDW17 (0.34%) than cv. Waitohi (0.14%).

Early N increased grain protein from 11.2 to 12.8% for both cultivars while late N increased it from 11.2 to 12.0% when 40 kg N/ha was applied and to 12.8% when 80 kg N/ha was applied. The mean grain protein content of cv. Waitohi (12.8%) was greater ($p < 0.05$) than that of cv. CRDW17 (11.7%) over all treatments.

Early and late N applications had interacting ($p < 0.001$) effects on grain b* values (Fig.3). Averaged over the two cultivars early N decreased mean values from

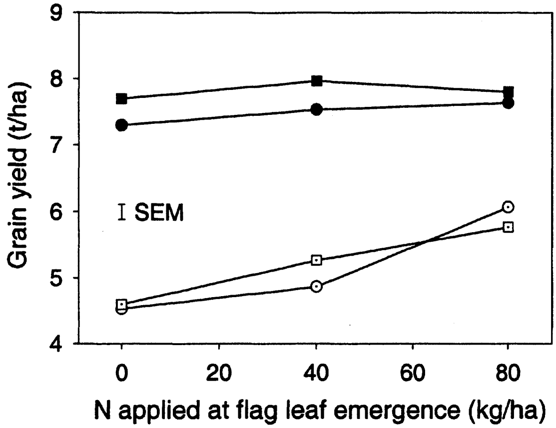

Figure 1. Grain yield responses to late N application to durum wheat cv. Waitohi (●) and cv. CRDW17 (■). Open symbols are for no early N applied and closed symbols are for 175 kg N/ha applied early (at tillering).

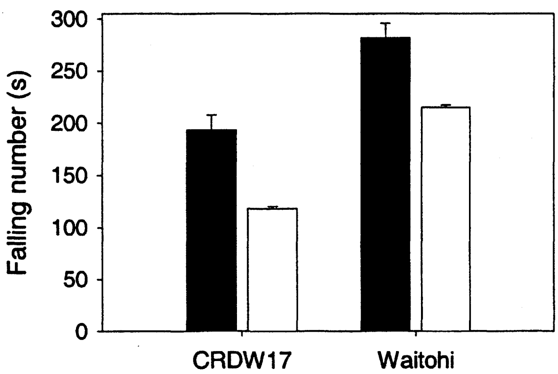

Figure 2. Falling number values for grain of the two durum wheat cultivars harvested before (solid bars) and after (open bars) rainfall during the week before combine harvesting.

24.7 to 23.5. Late N also decreased b* values from 25.3 to 23.0 after 80 kg N/ha was applied. Cv. Waitohi (24.4) had a greater ($p < 0.001$) grain b* value than cv. CRDW17 (23.8) averaged over all treatments.

Grain a* values were only influenced ($p < 0.001$) by the application of early N (175 kgN/ha), being increased from 8.3 to 8.7 for both cultivars. The mean a* value of cv. Waitohi (8.9) was higher ($p < 0.001$) than cv. CRDW17 (8.1).

Early and late N applications had interacting ($p < 0.001$) effects on the L* colour parameter of the grain. Early N decreased the mean L* value from 54.4 to 52.6 in both cultivars. The L* value decreased from 55.0 to 53.0 after 40 kg N/ha was applied late and to 52.6 after 80 kg N/ha was applied.

Flour. Flour protein content increased with N application and there was a significant ($p < 0.001$) interaction between the effects of the early and late applications (Fig.4). On average, an early application of 175 kg N/ha increased flour protein content from about 8 to 11%. A late N application of 40 kg increased it from 9.6 to 10.0% and 80 kg/ha increased it to 12.4%. Cv. Waitohi (11.7%) had a higher ($p < 0.001$) flour protein content than cv. CRDW17 (10.2%) averaged over all treatments.

Flour b* values increased with N application for flour and there was an interaction ($p < 0.05$) between the

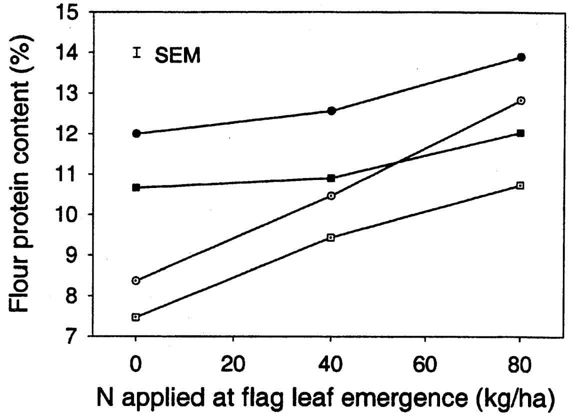

Figure 4. Flour protein content responses to late N application to durum wheat cv. Waitohi (●)and cv. CRDW17 (■). Open symbols are for no early N applied and closed symbols are for 175 kg N/ha applied early (at tillering).

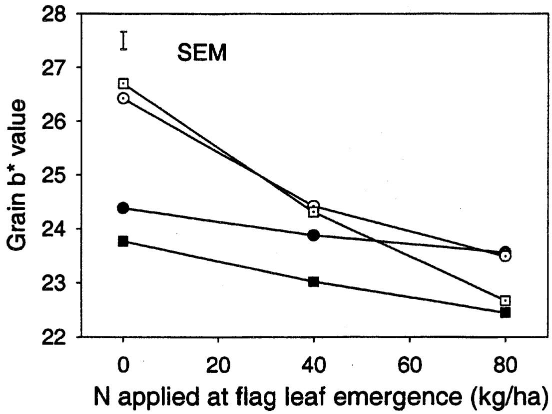

Figure 3. Responses of grain b* values to late N application of Waitohi (●) and CRDW17 (■) durum wheats. Open symbols are for no early N applied and closed symbols are for 175 kg N/ha applied early (at tillering).

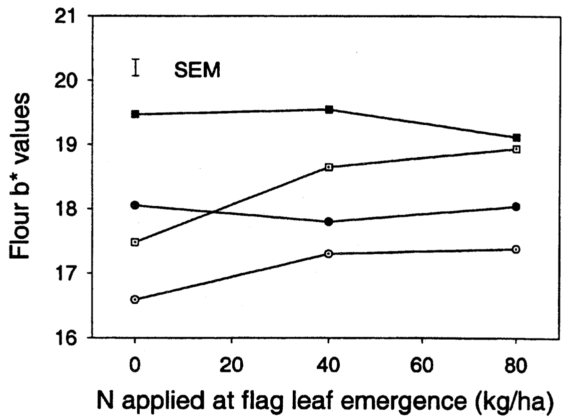

Figure 5. Responses of flour b* values to late N application to durum wheat cv. Waitohi (●)and cv. CRDW17 (■). Open symbols are for no early N applied and closed symbols are for 175 kg N/ha applied early (at tillering).

effects of early and late applications (Fig. 5). Early N increased the b* value from 17.7 to 18.7, while it increased from 17.9 to 18.3 for both application rates of the late N. Over all treatments CRDW17 (18.9) had a greater ($p<0.001$) b* value than Waitohi (17.5).

Flour a* values were only influenced ($p<0.001$) by late N application and cultivar. The value of a* increased when late N was applied and was higher for cv. Waitohi (-1.01) than for cv. CRDW17 (-1.37) (Table 2).

Table 2. Flour a* values from two cultivars of durum wheat after the application of nitrogen (N) at flag leaf emergence (late N) $SE_{cultivar} = 0.019$, $SE_{late\ N} = 0.024$.

Late N (kg/ha)	Cultivar CRDW17	Waitohi	$Mean_{late\ N}$
0	-1.45	-1.14	-1.29
40	-1.40	-1.02	-1.21
80	-1.27	-0.87	-1.07
$Mean_{cultivar}$	-1.37	-1.01	

For both cultivars the L* value when no N was applied was 88.9 (Table 3). The addition of 175 kg N/ha of early N alone or with late N decreased L* by one unit.

Table 3. Flour L* values from two cultivars of durum wheat after nitrogen (N) applications at tillering (early N) and flag leaf emergence (late N) $SE_{early\ N*late\ N} = 0.11$.

Cultivar	Early N	Late N (kg/ha) 0	40	80
CRDW17	0	88.8	87.9	87.7
	175	88.1	88.0	87.8
Waitohi	0	88.9	87.9	87.5
	175	87.8	87.7	87.3

Discussion

The combination of maximum grain yield (Fig.1) and maximum grain and flour protein content (Fig. 4) was achieved from the application of 175 kg N/ha at tillering followed by 80 kg N/ha at flag leaf emergence. This was consistent with previous reports which highlighted early applications as the key to maximising grain yield (Martin, 1987; Stephen *et al.*, 1997) with additional late N to increase the grain protein content (Kosmolak and Crowle, 1980; Dexter *et al.*, 1982). Without early N, the late N applications increased yield but not to the levels achieved with early N.

However, N application had no effect on TGW and screenings. Significantly, flour protein content exceeded industry specifications (>11.5%) for cv. Waitohi with the addition of early N or when only 80 kg N/ha was applied late. In contrast, only the addition of early N plus 80 kg N/ha applied late gave a protein percentage above 11.5% for cv. CRDW17. This implies that cv. Waitohi was more efficient at partitioning available N to flour protein than cv. CRDW17. This result remains to be confirmed from the concurrent experiments.

Grain yellowness was higher in cv. Waitohi than cv. CRDW17. However high grain yellowness did not necessarily imply the high flour b* values (18+) which are preferred by industry. For cv. CRDW17 all treatments achieved a flour b* value of (18+) except the control. In contrast, for cv. Waitohi only the addition of early N gave an acceptable flour b* value. It is likely that cv. CRDW17 had a higher proportion of β-carotene in the endosperm than cv. Waitohi. An increase in yellowness has been associated with increased β-carotene content (Borelli *et al.*, 1999). Furthermore, increased β-carotene content has also been associated with increased flour protein content (Dexter and Matsuo, 1977). A similar trend was apparent in this study particularly for the treatments that received only late N. Differences between cultivars in the relationship between β-carotene and protein contents have also been reported (Dexter and Matsuo, 1977) although these were not apparent in this experiment.

The red-green colour parameter a* was increased with the addition of late N for both cultivars (Table 2). However cv. Waitohi had higher a* values than cv. CRDW17. Although a* is not considered an important parameter in the pasta industry, Johnson *et al.* (1997) found oat samples of preferred colour had low a* values. The importance of the L* parameter is also unknown, but its value was decreased by early and late N (Table 3). Cv. CRDW17 had a higher L* value than cv. Waitohi over all treatments. In contrast, it was cv. Waitohi that had a higher falling number value in both combine and hand harvested samples (Fig. 2). This may be due to cv. Waitohi maturing earlier than cv. CRDW17 and as a result it was susceptible to sprouting during the wet period in this season.

Conclusion

High yields of durum wheat were obtained by applying adequate N at tillering. A further application of N at flag leaf emergence improved quality by increasing grain and flour protein values. Yellowness of the flour was improved by early N application, particularly for cv. CRDW17. Thus, current management practices to maximise yield and protein content were also associated with improved flour colour.

References

Borrelli, G.M., Troccoli, A., Di Fonzo, N. and Fares, C. 1999. Durum wheat lipoxygenase activity and other quality parameters that affect pasta colour. *Cereal Chemistry **76(3)***, 335-340.

Clarke, J.M., Marchhylo, B.A., Kovacs, M.I.P., Noll, J.S., McCaig, T.N and Howes, N.K. 1998. Breeding durum wheat for pasta quality in Canada. *In* Wheat: Prospects for Global Improvement. (ed. H.J Braun). p229-236. Kluwer Academic Publishers. Netherlands.

Dexter, J.E., Crowle, W.L., Matsuo, R.R and Kosmolak, F.G. 1982. Effect of nitrogen fertiliser on the quality characteristics of five North American amber durum wheat cultivars. *Canadian Journal of Plant Science **62**,* 901-912

Dexter, J.E and Matsuo, R.R. 1977. Influence of protein content on some durum wheat quality parameters. *Canadian Journal of Plant Science **57**,* 717-727.

Gonnet, J.F. 1995. A colorimetric look at the RHS chart-perspectives for an instrumental determination of colour codes. *Journal of Horticultural Science **70(2)***, 191-206.

Keeney, R.P. and Bremner, J.M. 1967. Comparison and evaluation of laboratory methods of obtaining an index of soil nitrogen availability. *Agronomy Journal **58***, 493-503.

Kosmolak, F.G and Crowle, W.L. 1980. An effect of nitrogen fertiliser on the agronomic traits and dough mixing strength of five Canadian hard red spring wheat cultivars. *Canadian Journal of Plant Science **60***, 1071-1076.

Johnson, N.J., Moot, D.J. and Lindley, T.N. 1997. Oat groat colour-a quality factor. *Proceedings Agronomy Society of New Zealand **27***, 79-82.

Martin, R.J. 1987. The effect of time of nitrogen application on the yield and quality of contrasting cultivars of autumn sown wheat. *Proceedings Agronomy Society of New Zealand **17***, 103-108.

Matsuo, R.R., Bradley, J. W. and Irvine, G.N. 1972. Effect of protein content on the cooking quality of spaghetti. *Cereal Chemistry **49***, 707-711.

Minitab, 1989. Minitab reference manual: Release 7. Data Tech. Industries, Inc., Valley Forage, PA, USA.

Scott, W.R., Martin, R.J. and Stevenson, K.R. 1992. Soil fertility limitations to wheat yield and quality. *In* Wheat Symposium: Limits to Production and Quality. Agronomy Society of New Zealand, Special publication No. 8. p 47-56.

Stephen, R.C., Saville, D.J and Drewitt, E.G 1997. Relationship between wheat grain yield and plant available soil N and monthly rainfall and potential evapotranspiration. *Proceedings Agronomy Society of New Zealand **27***, 145-150.

Stephen, R.C., Saville, D.J and Kemp, T.N. 1985. Responses of grain yield components of winter-sown wheat to nitrogen fertiliser applied at four growth stages. *Proceedings Agronomy Society of New Zealand **15***, 59-63.