Improving Grain Yield by Selection for Greater Early Vigour in Wheat

T.L. Botwright[1], A.G. Condon[2] , G.J. Rebetzke[2], and R.A. Richards[2]

[1]CSIRO Plant Industry, Wembley WA.
[2]CSIRO Plant Industry, Canberra ACT.

Abstract

Improved early vigour has been proposed as an important trait for increasing water-use efficiency and thereby grain yield in rainfed environments. Field trials were undertaken in WA at two sites with low and medium rainfall over two years to examine the influence of increased early vigour on crop growth and yield. Vigour treatments included (i) breeding lines generated by backcrossing high-vigour into the cultivar Amery, and (ii) increased seed size. Increased leaf area development at 50 DAS at the medium rainfall site was maintained throughout crop growth and contributed to an increase in yield in some lines. Vigour was initially high at the low rainfall site, but differences in biomass production between high vigour lines and the control were minimal by the grain-filling stage. This may have been due to earlier onset of terminal drought at this site. There was no difference in yield between treatments at the lower rainfall site. Combining early vigour with other traits such as earlier flowering and/or improved transpiration efficiency would potentially benefit wheat production in drier environments.

Key words

Seed size, terminal drought, crop growth, leaf area development.

Introduction

Greater early vigour has been identified as one of several physiological traits that have potential for improving wheat water-use efficiency in the drier regions of Australia, especially in the southern and western wheatbelt that have a Mediterranean climate (5). Wheat with greater early vigour, ie. high LAI during early growth, should reduce evaporative water loss from the soil surface (1). The crop can instead transpire this water while the vapour pressure deficit is low and use it in productive growth to increase yield. Additional benefits of greater early vigour can arise through improved competitiveness with weeds. Field trials were conducted at two sites in WA with low and medium rainfall, to assess the effect of greater early vigour in backcross lines of wheat on crop growth, yield and components of yield.

Materials and Methods

Field experiments with bread wheat (*T. aestivum*) were carried out in 1998 and 1999 at Wongan Hills (medium rainfall, 300 mm May to October) and Merredin (low rainfall, 210 mm) in Western Australia. Soil types were a deep yellow sandy loam and a yellow duplex, respectively. Entries included Amery and six backcross vigour lines of Amery in 1998 and 1999, and small (26mg) and large (48mg) seeded Amery in the 1999 trial only. The backcross lines were a small subset of a large number of BC_2:F_2-derived lines developed from an initial cross of Amery with a ‘high vigour’ donor line, Vigour 18, with two further round of backcrossing to Amery. The lines grown were very similar to Amery for height and flowering time. Each trial was sown in a nearest-neighbour design with four replicates at two sites over two years. Plots (1.42 m wide and 15 m long) were sown in late May to early June using an 8-row cone seeder to give a seeding depth of 3 cm and row spacing of 18 cm. Seeding rates were calculated for each cultivar to achieve a seeding density of 120 plants m^{-2}. The Merredin sites had a wheat:medic pasture rotation and received 26 kg N ha^{-1} at seeding. The Wongan Hills site previously had a lupin:clover:clover rotation and received 10.5 kg N ha^{-1} at seeding followed by 23 kg N ha^{-1} at tillering. One (1998) or two (1999) quadrat samples (0.405 m^2) were harvested at the 4 leaf stage (50 DAS) from each plot and at final harvest. Sub-samples of ten plants were used to derive leaf area and yield components. Plots were machine harvested to determine grain yield.

Results and Discussion

Field experiments were undertaken in Western Australia in 1998 and 1999 to establish whether selection for improved early vigour in backcrossed material could contribute to increased yield in dry environments. It is hypothesised that increased early leaf area development may increase yields through improving water-use efficiency at the start of the season while rainfall is readily available (4).

Early vigour of backcross lines

All of the six backcross lines used in this study, except AV126, were more vigorous than the recurrent parent, Amery (Table 1). Averaged across lines, sites and years the backcross lines had 10% greater leaf area than Amery when sampled at *ca.* 50 DAS. The most vigorous backcross lines were AV105 and AV108 that, on average, had early leaf area *ca.* 14% greater than Amery. The difference in early leaf area between the backcross lines and Amery was much smaller than that between Amery and the vigour donor parent, Vigour 18, which generates *ca.* 80% greater leaf area than Amery at a comparable stage of growth (R. A. Richards, unpublished).

Table 1. Effect of selecting for improved early vigour on early leaf area growth of backcross Amery vigour (AV) lines grown under field conditions and measured *ca.* 50 DAS at Merredin (MD) and Wongan Hills (WH). l.s.d, *P*=0.05.

Line	Vigour			
	1998		1999	
	WH (cm^2 $plant^{-1}$)	MD (cm^2 $plant^{-1}$)	WH (cm^2 $plant^{-1}$)	MD (cm^2 $plant^{-1}$)
Amery	28.5	31.4	34.6	32.5
AV42	34.3	35.0	33.0	30.6
AV51	30.3	36.4	35.6	29.5
AV103	32.8	36.9	36.3	35.0
AV105	35.0	34.7	36.5	39.9
AV108	34.0	33.5	39.8	41.4
AV126	27.0	33.2	27.0	30.4
l.s.d	5.3	3.3	8.5	9.9

The relatively small vigour advantage of the backcross lines may have been due to several factors. Selection of lines for this study that were similar to Amery for height and flowering time may have eliminated more vigorous lines. The majority of lines from the backcross population had been excluded because they were considerably taller and earlier flowering than Amery. Data from other populations indicates that the most vigorous lines are often tall and flower early (Rebetzke, unpublished).

There also appeared to have been some loss in vigour during successive generations of backcrossing. This may have been caused by incompatibility between the GA-sensitive, tall, high vigour donor (Vigour 18) and the GA-insensitive, semidwarf wheat used as the recurrent parents. GA-insensitivity may create an upper limit to breeding for improved leaf area. Breeding strategies are being pursued to use alternative, GA-sensitive dwarfing genes, such as *Rht*8 and *Rht*9. These sources for reduced height may have the potential to produce progeny with greater vigour when backcrossed to the vigour donor. This approach has already been shown to be successful in producing semidwarf wheats with much longer coleoptiles than current Australian varieties (7).

Grain yield of backcross lines

All six backcross lines had yields that were comparable to Amery (Table 2) even though there had been no prior selection for yield in the backcross population. The line, AV105, had a 4% yield advantage over Amery, averaged across sites and years. This relative yield advantage was greater at Wongan Hills than at Merredin (Table 2). Detailed yield component data has not been presented in this short paper. Averaged across lines, sites and years, the backcross lines produced fewer grains m^{-2} than Amery (86% of Amery) but grains were 11% heavier than Amery. The smaller grain number m^{-2} of the backcross lines was due to fewer grains per spike (81% of Amery). The backcross lines produced 6% more ears, on average, than Amery.

The early leaf area advantage of the backcross lines over Amery was translated into a greater spike number (data not shown) but that the yield potential of these lines may have been restricted by small spike size and/or greater floret infertility. Despite this limitation, one of the six lines outyielded Amery over all two environments.

Table 2. Effect of selecting for improved early vigour on grain yield of backcross Amery vigour (AV) lines grown at Merredin (MD) and Wongan Hills (WH). l.s.d, *P*=0.05.

Line	Grain yield			
	1998		1999	
	WH ($g\ m^{-2}$)	MD ($g\ m^{-2}$)	WH ($g\ m^{-2}$)	MD ($g\ m^{-2}$)
Amery	320	214	342	264
AV42	308	221	304	254
AV51	305	199	277	213
AV103	304	193	329	270
AV105	338	221	355	269

AV108	302	195	325	258
AV126	306	202	296	273
l.s.d	13	24	32	15

The yield advantage of AV105 was less at Merredin than at Wongan Hills. In fact there was very little variation in yield among any of the backcross lines or Amery at this drier site in either 1998 or 1999 (Table 2). Plant biomass and leaf area harvests throughout the season showed that the initial benefit in leaf area in the backcross lines at Merredin had dissipated by anthesis, presumably because the early vigour may have depleted the soil water faster, reducing any yield advantage.

Effects of variation in seed size

The yield component data indicated that deleterious traits (e.g. small ear size) might have been carried over into the backcross lines from the vigour donor. The potential effects of genetic background in the Amery backcross lines were eliminated in field trials in 1999 that used three seed size classes of small (26 mg), average (35 mg) and large (48 mg) to manipulate early vigour of Amery. Large seed increases the size of the embryo, which has been shown to increase leaf area and hence vigour in young wheat seedlings (1). Manipulation of vigour by using seed size was successful, with LAI increasing by 30 and 40% at Merredin and Wongan Hills, respectively, in large- compared to small-seeded Amery at 50 DAS (Table 3). This contrasts to previous studies (3) where there was no observed relationship between seed size and early vigour, measured as dry matter production 54 DAS in the same WA environments.

Table 3. Effect of improved early vigour through increased grain size on LAI, yield and above-ground dry matter (AGDM) at two sites, Wongan Hills (WH) and Merredin (MD) in 1999. l.s.d, *P*=0.05.

Line	LAI (50 DAS)		Yield (g m^{-2})		AGDM (g m^{-2})	
	WH	MD	WH	MD	WH	MD
Amery	0.35	0.33	342	265	688	631
Small Amery	0.23	0.27	317	262	627	648
Large Amery	0.40	0.37	369	259	734	606
l.s.d	0.09	0.09	31	15	85	45

There was a positive linear relationship between early LAI and final yield (yield=249+288LAI r^2=0.94) for the three seed size classes at Wongan Hills (Table 3). These results are consistent with the significant relationships between grain yield (per plant) and plant dry matter at early growth reported for a range of wheat varieties in WA (6). At Merredin, in contrast, there was no relationship between LAI and yield

(yield=266-17LAI r^2=0.09). The results at Merredin in 1999 were consistent with those from 1998 and 1999 for the Amery backcross lines.

Biomass partitioning and yield components at final harvest at Wongan Hills indicated that increased leaf area at 50 DAS was carried through until crop maturity (data not shown) and was a contributing factor to greater biomass production in large- compared to small-seeded Amery. For example, spikes and the number of grain per unit area (data not shown) increased with seed size at Wongan Hills . At Merredin, in contrast, there was no significant variation in spikes per unit area, while the number of grain per unit area declined with increasing seed size.

The potential benefit of the initial improved LAI at Merredin was dissipated by the time of canopy closure (data not shown). As for the backcross lines in 1998 and 1999, terminal drought at Merredin was likely to be the main factor contributing to the lack of significant relationship between LAI, biomass partitioning and yield at the Merredin site. Computer simulation modelling (A. Condon and M. Stapper, pers. comm.) indicates that combining greater early vigour with either earlier flowering or improved transpiration efficiency has the potential to maintain the initial biomass advantage generated through vigour to improve yield under conditions of terminal drought. Breeding is underway to pyramid these traits into current varieties.

Conclusion

Improving the yield of wheat through greater early vigour derived from backcrossed lines of Amery was moderately successful. Elimination of background genetic effects of backcrossing by selecting for different seed size classes in Amery did, however, confirm the hypothesis that increased yield could be achieved by improving early vigour, but only at the medium rainfall site. At the drier site, any initial benefit in leaf area development gained through improved vigour appeared to be dissipated by maturity, as there was no significant increase in dry matter or yield. It seems likely that at dry sites greater early vigour initiates terminal drought earlier to reduce yield. Combination of the traits of greater early vigour with earlier flowering and/or improved transpiration efficiency may improve the water use efficiency of the crop throughout the season at dry sites. The mixed success in improving early vigour through backcrossing with a high vigour donor with our current Australian wheats has led to a breeding program which aims to use alternative sources of semidwarfism to promote better expression of early vigour and improved plant establishment.

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