Developing high yielding wheat for water limited environments in northern Australia

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Abstract

A novel strategy linking physiology with plant breeding, molecular biology and computer simulation modelling is outlined here which aims to enhance selection of high yielding wheats with superior performance under conditions of water scarcity for the northern, subtropical, winter cereals region of Australia. In previous research, a source of high yield and performance under dry conditions for the target region was identified in a drought resistant parent. A large population of fixed lines for molecular genetic studies has been developed using the drought resistant line and widely grown current Australian variety. A preliminary study comparing the parent varieties was conducted in the winter of 2003. The two varieties were similar in many aspects of phenology, morphology and physiology. However, several important traits were identified that likely contribute to higher grain mass and yield of the drought resistant parent, including differences in the number and dry mass of tillers and spikes during development and the ability of drought resistant line to retain green leaves longer during grain filling.

Media summary

A novel strategy linking physiology, plant breeding, molecular biology and computer simulation modelling is being developed to produce wheats with high yield under conditions of water scarcity.

Key Words

Wheat; water scarcity; drought resistant wheat; molecular markers.

Introduction

Water scarcity is the single greatest constraint to rain-fed crop production worldwide. In NE Australia, the extreme interannual climate variability resulting largely from the *El Ni?o* phenomenon leads to wide variation in yields across years and among farms, with consequent economic, social and environmental effects. We are developing a novel strategy that links physiology with plant breeding, molecular biology and computer simulation modelling to enhance the selection of high yielding wheats resistant to water scarcity for the northern, subtropical, winter cereals region of Australia.

Apart from effects on farmers, this climatic variability generates a substantial Genotype by Environment interaction (GxE) for both yield and protein in breeder’s trials that results in re-ranking of genotypes and complicates the selection of better varieties (Cooper et al. 2000). Our research is based on the expectation that there exist underlying trait controls of yield that are subject to less GxE and for which selection will be more efficient (see review of Sinclair et al. 2004). These controls are likely to include integrative traits that can be ‘calculated’ using simulation models, given inputs of observed data.

The research will focus on lines developed from a cross between a drought resistant line, which is globally well-adapted to rainfed spring wheat regions, and a current variety which is well adapted to the northern wheat region and has better quality characteristics than the drought resistant line. Researchers at the University of Queensland have developed populations of recombinant, backcross and doubled-haploid lines from this cross as well as marker maps. In multi-environment trials over a number of seasons, yields of the drought resistant line were 12% higher than those of the current variety in both water-stressed and non-stressed conditions in the target region (Figure 1). The research aims to capture this advantage in locally adapted varieties by identifying the key developmental, morphological and physiological characters. It will use an integrated strategy of field measurements and computer simulation modelling that has previously been applied in sorghum, in particular to the study of stay-green (Borrell and Hammer 2000; Chapman et al. 2002; Hammer et al. 2002). The identification of rapid physiological screening methods and of molecular markers linked to regions of the genome associated with the physiological traits (quantitative trait loci; QTL) will provide the means for selection of high yielding and drought-resistant wheats (reviewed in Hammer et al. 2002). The ultimate objective is to utilise this understanding to increase the rate of crop improvement beyond that based on yield selection per se. Here we report on a preliminary study conducted to identify phenological, morphological and physiological differences between the parental lines.

Methods

Physiological and developmental comparison of parental lines

During the winter season of 2003, an experiment was conducted at the DPIF research station at Kingsthorpe (27^{o}30’43’S; 151^{o}46’53’ E). Four replicate plots of each variety were either irrigated to prevent water stress (irrigated treatment) or were not irrigated and had rainfall excluded from the time of head emergence (89 days after sowing; DAS) until maturity (dry treatment). Plants in the irrigated treatment received 127 mm of rainfall plus 150 mm irrigation during the season while those in the dry treatments received 28 mm of rainfall only prior to 89 DAS. The approximate amount of starting soil water, available for extraction was 229 mm.

Detailed observations of the phenology of the crop were taken throughout the season. Harvests at anthesis and maturity allowed the measurement of leaf area, biomass, number and dry mass of leaves, stems and spikes. At maturity, grain yield, grain number and grain mass were recorded. Between the time of canopy closer to maturity, measurements were made of canopy light interception using an LI188B 1 m light sensor (LI-cor, Lincoln, Nebraska); photosynthetic rate using an LI6400 portable gas exchange system (LI-cor, Lincoln, Nebraska); and leaf chlorophyll content using a Minolta SPAD 502 (Konica Minolta, Hong Kong). Data were analysed using the computer software package Genstat 6.

Results and Discussion

Phenology

The timing of development was similar for varieties until well into grain filling (Table 1). Both varieties reached maturity at approximately 128 DAS in the dry treatment. Both varieties reached maturity later in the irrigated treatments, with the current variety (ca 142 DAS) slightly ahead of the drought resistant line (ca 147 DAS).

Yield and yield components

Under irrigation, the yield of the drought resistant line was 29% greater than that of the current variety and was 23% greater in the dry treatment (Table 1). Yield for both varieties correlated highly with both grain number and mass ($R^2 > 0.85$). While much of the GxE in the region has been associated with variation in grain number (Cooper et al 1994), these results are in agreement with previous reports indicating that yield of the drought resistant line is consistently greater than the current variety in the target region, both in unstressed and in moisture stressed conditions (Figure 1), and that the difference in yield is related to both seed mass and grain number.

Morphology and biomass

Plant density, plant height and biomass were similar for varieties both at anthesis and maturity. Similarly, green leaf area at anthesis did not differ greatly between varieties. However, there were differences between varieties in the partitioning of resources during development. In both treatments, at anthesis, the current variety had a greater number of thinner tillers and smaller spikes compared to the drought resistant line (Table 1). Again, in both treatments, the current variety senesced tillers and spikes such that the final numbers of these were similar for the two varieties by the time of maturity. Other genotypic differences at anthesis were a slightly higher specific weight of green leaves of the current variety, and under irrigation, a greater biomass in green leaves (Table 1).

Leaf chlorophyll, photosynthetic rate and light interception

Leaf chlorophyll content as indicated by SPAD was similar for varieties until grain filling. Leaves of the current variety lost chlorophyll earlier than did those of the drought resistant line (Figure 2). Photosynthetic rates were similar for varieties (Table 1). Light interception was slightly higher for current variety in the irrigated treatment, and also under drought up until the commencement of grain filling at approximately 100 DAS (Figure 3). As indicated by leaf chlorophyll data, the leaves of the current variety lost chlorophyll and senesced earlier than those of drought resistant line, particularly in the dry treatment (Figure 3).

At about mid grain-fill, photosynthetic rates and chlorophyll contents were similar for the two varieties and the canopy of current variety intercepted more light than that of the drought resistant line until the onset of senescence. This suggests that differences in the rate of carbon acquisition before the onset of senescence were not responsible for the greater grain mass and higher yield of the drought resistant line. The ability of the drought resistant line to maintain leaf chlorophyll levels, and presumably to continue carbon acquisition for longer during grain filling as is seen in “stay green” sorghum (Borrell and Hammer 2000), is likely to be more important in contributing to the increased seed weight. Differences in the partitioning of carbon during development such as the production and later loss of thinner tillers and smaller spikes in the current variety are also likely to be important.

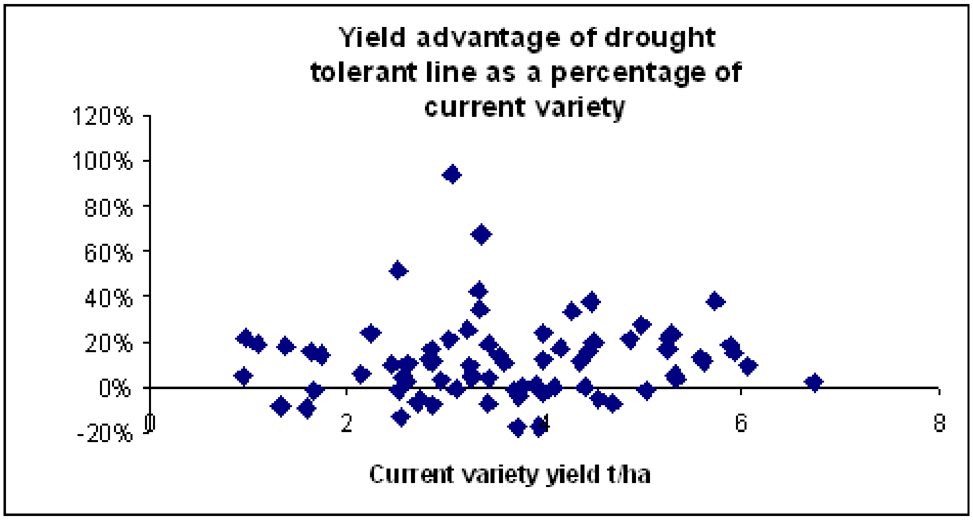
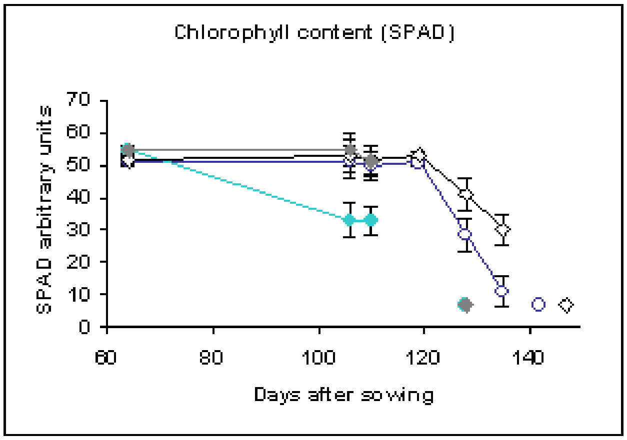


Figure 1. Yield advantage of the drought resistant line over the current variety expressed as a percentage of the yield of the current variety at 77 trials in NSW and Queensland from 1986 to 1999. Average yield advantage to the drought resistant line = 12%. There is an 80% probability that

the drought resistant line will equal or exceed the current variety and a 50% probability of the drought resistant line exceeding the current variety by at least 15%.



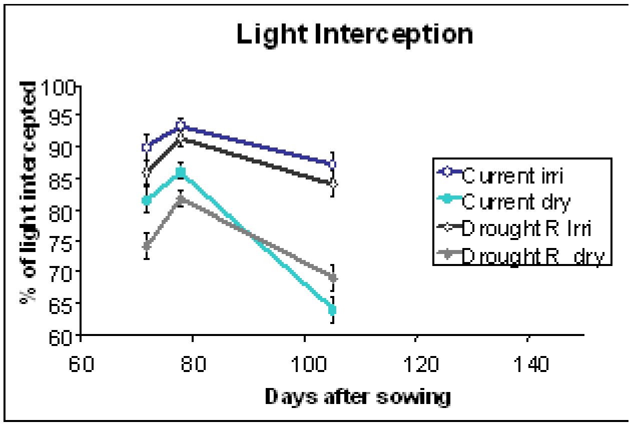


Figure 2. Chlorophyll content determined using the Minolta SPAD. Chlorophyll content was not measured at maturity but is typically in the range of from 2 to 10 SPAD units. Points at 7 SPAD units indicate approximate maturity values. Symbols are as for Figure 3. Error bars represent the standard error of the means for varieties.

Figure 3. Interception of photosynthetically active radiation (PAR) expressed as percent of PAR incident above the canopy that reached the soil surface. PAR was measured above the canopy and at 4 locations below the canopy near midday on clear days. Error bars represent the standard error of the difference of means for varieties.

Table 1. Phenology, yield, biomass, morphological and physiological data for the current variety and the drought resistant line grown at Kingsthorpe in 2003 either with irrigation to avoid moisture stress (irrigated treatment) or without irrigation and with rainfall excluded from 89 days after sowing (DAS; dry treatment). Dates for phenology stages are given in DAS. All other values represent the mean for 4 plots of each variety within each treatment and the standard error of the difference (s.e.d) for means of varieties. Means that are significantly different between varieties within treatments (p ≤0.05) are marked by an asterisk.

	Irrigated treatment		Dry treatment		s.e.d
	current variety	drought resistant line	current variety	drought resistant line	varieties
Floral initiation (double ridges)	49	49	49	49	
Head emergence (50%)	89	89	86	86	
Maturity	142	147	128	128	

Yield (t/ha)	6.06	7.81	2.59	3.18	.225
1000 seed wt (g)	39.0	43.9	24.6	28.5	.125
Grain number m^2	15520	17920	10820	9860	1240
At anthesis					
Tillers / 1m row	167.6	112.4	153	122	10
Spikes / 1m row	121.6	76.4	112	96.4	8.14
Stem dry mass (g / culm)	.602	.691	.548	.673	.024
Spike dry mass (g / spike)	.446	.567	.434	.529	.035
Green leaves (g dry mass/ 1m row)	52	38.5	28	32.5	1.02
Specific leaf weight (g dry mass/ m^2)	51.18	48	66.33	55.66	.811
At maturity					
Tillers at maturity / 1m row	115.6	115.6	125	120	10.88
Spikes at maturity / 1m row	93	94.4	99.6	104.4	9.9
Mature spike wt (g/spike)	2.15	2.59	1.05	1.35	.11
Photosynthetic rate during grain filling (µmol CO_2 / m^2 / sec; 110 DAS)	6.51	7.42	2.85	2.34	1.19

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