

Establishing a value proposition for future traits in a climate-changing world

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Abstract

Increasing climate variability is as great a concern as increasing air temperatures forecast with climate change. The challenge for breeders is in identifying and selecting traits that are genetically correlated with environments into the future and/or difficult to manage away from their breeding nurseries. We report on studies targeting constitutively-expressed traits (*e.g.* increased rates of spike and grain-filling and increased coleoptile length) to establish their value proposition for increasing grain yield in future environments. The work supports the potential for higher rates of grain-filling and longer coleoptiles as traits where genetics are available now in pre-emptive selection in breeding programs. Further, there is not expected to be any cost associated with these traits in grain yield or quality, or in cooler, wetter seasons.

Key Words

Breeding, pre-breeding, physiology

Introduction

Climate modelling predicts changes in the timing and availability of moisture, and increasing air (and soil) temperatures throughout the Australian wheat-belt (Lobell *et al.* 2015) to affect wheat yield and quality (Nuttall *et al.* 2017). Previous efforts at addressing climate effects on crop growth and development have focussed on high air temperatures at flowering (to affect grain number) and grain-filling (to affect grain size). We have demonstrated genetic diversity exists in wheat for rate of grain-filling (ROGF), and that useful variability for this trait is contained in both introduced, CIMMYT-derived and Australian commercial breeding populations. However, methods for screening breeding populations for ROGF are slow and the demonstrated value of this trait is not well understood. Similarly, genetic variation exists for greater coleoptile length in wheat yet the value proposition for increasing coleoptile length for improving wheat establishment is not well understood. This paper reports on less considered traits (rate of spike filling and coleoptile length) and their potential in complementing selection for existing future climate traits.

Methods

Greater coleoptile length

In wheat, genotypic differences in coleoptile length are controlled by two sets of genetics: dwarfing genes that affect cell size to affect stem height, and genes that affect coleoptile cell length via differences in the rate and duration of coleoptile cell elongation (Botwright *et al.* 2001). Approximately 120 BC4- to BC6-derived, near-isogenic lines containing a range of gibberellic acid sensitive (GAS) and insensitive (GAI) dwarfing genes were developed in the tall Halberd genetic background. A particularly promising GA-sensitive dwarfing gene, *Rht18* (derived from an Italian durum wheat variety Icaro), was separately backcrossed into a range of Australian commercial wheat varieties (*e.g.* EGA Gregory, Mace and Magenta). Coleoptile lengths were assessed at soil temperatures of 15 and 27°C for the Halberd NILs and at 22°C for the *Rht18* commercial wheat NILs. In all experiments, lines were replicated three times in a randomised complete block design.

Rate of spike-filling (ROSF)

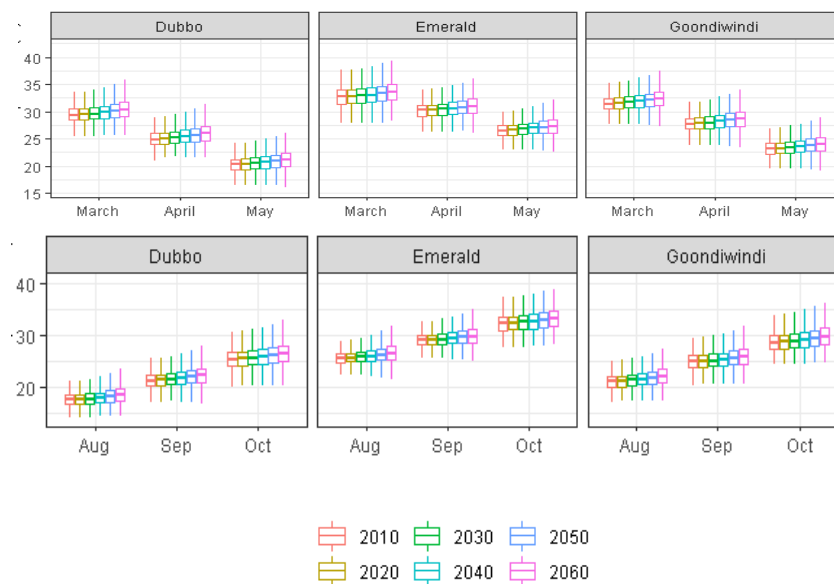
Four inbred populations (RAC875/Kukri, Drysdale/Kukri, Waggon/Drysdale and Seri/Babax) were identified and sown under favourable conditions in replicated experiments in SNSW. At flowering, 10 random heads were sampled and then dried before weighing. This was then repeated weekly to maturity before statistical

analysis and separation into tails representing the highest and lowest 15 rates of spike-filling (ROSF) for each population. Selected lines were carefully matched for development and plant height to minimise confounding. All selected lines were sown in irrigated and rainfed treatments in early May at the Merredin, Narrabri and Yanco Managed Environment Facilities in 2016 and 2017, and 10 heads randomly sampled weekly at and after flowering. Data were collated and then analysed using gompertz non-linear growth models to derive parameters needed to estimate the maximal rate and duration of spike filling, and maximal spike size for each entry (Xie *et al.* 2015). Grain yield and yield components were also measured.

Results and discussion

Maximum air temperature was predicted for 2020-2060 across the Australian wheatbelt for sowing and grain-filling months using the 33 General Circulation Models (Lobell *et al.* 2015). Figure 1 summarises the predicted change for Dubbo, Emerald and Goondiwindi, and together show increases in average daily maximum temperatures of 2-4°C, and variation in daily maximums of up to 8°C. Predicted soil temperatures will exceed optimal temperature for coleoptile elongation in wheat (*i.e.* 15°C; Radford 1987; Rebetzke *et al.* 2016) and air temperatures for photosynthesis during grain-filling (*i.e.* 15°C; Ni *et al.* 2018).

Figure 1. Boxplots summarising predicted increases in maximum air temperature for sowing (March-May) and grain-filling (August-October) in 2020-2060 at three locations in the eastern Australian wheatbelt. Predictions based on forecasts using the 33 General Circulation Models.



Longer coleoptiles

Earlier sowing is considered a strategy for increasing water-productivity in future wheat crops (Hunt *et al.* 2019). However, earlier sowing will likely occur in increasingly warmer soils particularly in March-April sowings. Figure 2 summarises reductions in coleoptile length when soil temperatures increase from 15 to 27°C. This reduction occurs across all dwarfing genes but lengths are particularly reduced in the GA-insensitive *Rht-B1b* (60mm) and *Rht-D1b* (56mm) green revolution dwarfing genes. By contrast, the GA-sensitive dwarfing genes (*e.g.* *Rht12* and *Rht13*) still attain coleoptile lengths of 96 and 93mm, respectively, when assessed at warmer soil temperatures. Similarly, when coleoptile length was assessed in *Rht18* dwarfing gene NILs grown at warmer 22°C, the *Rht18* NILs produced an average increase in coleoptile length of 32mm (or 51%) over their *Rht-B1b* and *Rht-D1b* siblings (Figure 3).

Rate of spike-filling (ROSF)

Tables 1 and 2 summarise means from ROSF analysis across MEF irrigated and rainfed experiments, respectively. Selection of high ROSF was associated with slightly reduced duration of ear growth and larger ear maximum size but greater grain yields in both irrigated and rainfed treatments. Greater yields reflected greater grain numbers and grain size while spike numbers were similar for irrigated but reduced for high ROSF in the rainfed treatments. High ROSF tails were developmentally similar to low ROSF tails. Interestingly, grains per spike were strongly correlated with ROSF across both irrigated and rainfed treatments suggesting a possible sink demand associated with differential ROSF.

Figure 2. Changes in coleoptile length (mm) for dwarfing gene NILs when sown at 15°C (darker blue and yellow) and at 27°C (lighter blue and yellow). Blue- and yellow-shaded histograms represent the GA-insensitive and GA-sensitive NILs, respectively.

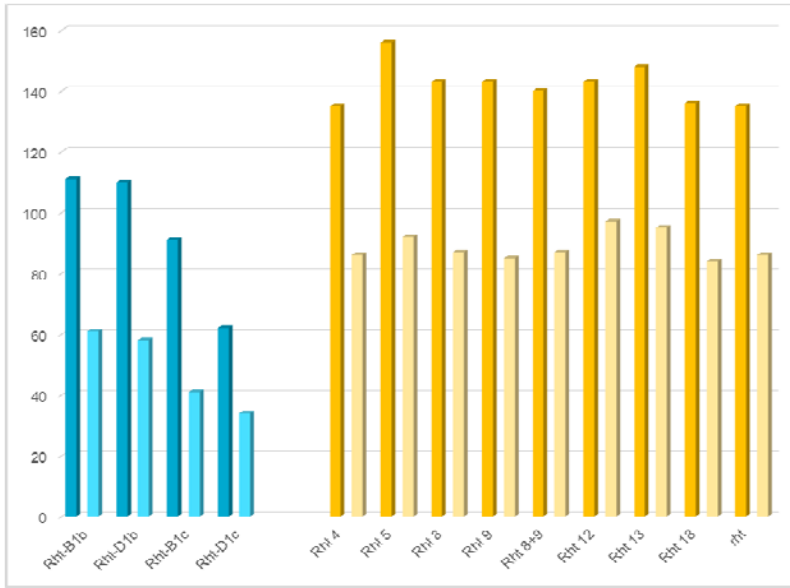


Figure 3. Coleoptile length (mm) for a range of commercial check entries, and *Rht18* dwarfing gene NILs (including original commercial donors) when sown at 22°C.

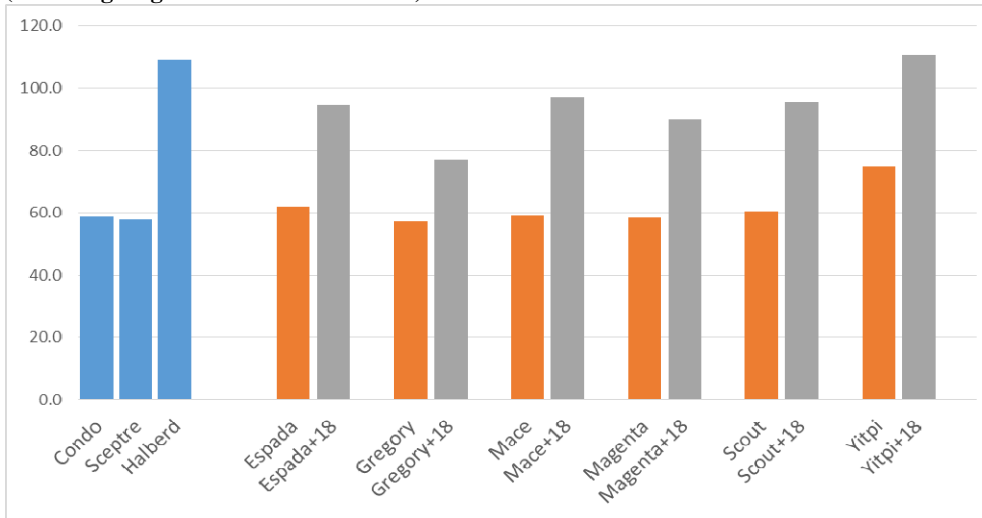


Table 3. Rate of spike filling (ROSF) and correlated changes for low- and high-selected ROSF tails averaged across four populations in 2016/17 and three MEF sites. Data represent averages for irrigated treatments.

Selected ROSF tail	ROSF (g/°Cd)	Growth duration (°Cd)	Max ear size (g)	Grain yield (t/ha)	No. grain (no./m ²)	Grain size (g)	Grains/spike	No. spikes (no./m ²)	Zadoks. (Z)
High	2.11	816	2.83	3.98	8854	4.55	35.5	269	56
Low	1.60	849	2.38	3.41	7544	4.15	30.1	271	57
	(+32%)	(-3.9%)	(+19%)	(+17%)	(+7%)	(+10%)	(+18%)	(-1%)	(0%)
<i>t-test</i>	***	***	***	***	***	***	***	ns	ns

Table 4. Rate of spike filling (ROSF) and correlated changes for low- and high-selected ROSF tails averaged across four populations in 2016/17 and three MEF sites. Data represent averages for the rainfed treatments

Selected ROSF tail	ROSF (g/°Cd)	Growth duration (°Cd)	Max ear size (g)	Grain yield (t/ha)	No. grain (no./m ²)	Grain size (g)	Grains/spike	No. spikes (no./m ²)	Zadoks (Z)
High	1.42	668	2.28	3.29	7113	4.63	29.9	276	52
Low	1.03	712	1.98	2.73	6641	4.11	23.3	293	54
	(+37%)	(-6%)	(+15%)	(+19%)	(+7%)	(+13%)	(+22%)	(-4%)	(-3%)
<i>t-test</i>	***	***	***	***	***	***	***	**	**

Conclusions

Likely increases in soil and air temperatures, and variability in rainfall, will require different agronomic and genetic strategies to reduce risk for farmers in rainfed cropping systems. In wheat, two simple traits targeting different ends of the cropping cycle, improved establishment through genetically longer coleoptiles and greater rates of grain-filling, provide opportunities now to identify and exploit genetic diversity in delivering varieties with adaptation to future climates. Further, their uptake is unlikely to compromise performance in current climates nor limit adoption through increased disease susceptibility or reduced grain quality.

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