Novel wheat genotypes for early sowing across Australian wheat production environments

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Abstract
Advances in summer fallow management and no-till seeding techniques have allowed Australian wheat growers to sow earlier than ever before. Research has demonstrated that slow developing cultivars sown early (mid-April) yield more than fast developing cultivars sown late (mid-May) when they flower at the same time. However, over the last century Australian wheat breeders have focussed on cultivars with increasingly rapid development through selection of insensitive photoperiod (Ppd) and vernalisation (Vrn) alleles, and few contemporary cultivars exist that are suitable for sowing early. Breeding programs must begin selecting for slower developing genotypes in order for growers to capitalise on yield advantages from early sowing. This study aimed to inform breeders on the combinations of Vrn and Ppd sensitive alleles that are best suited to early sowing in different production environments. It used near-isogenic lines that vary in alleles of major developmental genes planted at multiple times of sowing at 14 dryland locations across the Australian wheat belt. The fast developing winter genotype (FW - strong Vrn sensitivity, insensitive Ppd) was best suited to early sowing in medium-low rainfall southern and western environments. The mean yield advantage of this type sown early was 0.5-0.7 t/ha compared with a fast developing spring genotype (FS - representative of contemporary Australian cultivars) sown mid-late May which is representative of current practice. In cooler, higher rainfall environments in SW Victoria and S NSW, a winter type with additional Ppd sensitivity (MW) was the highest yielding. In warm northern environments with summer dominant rainfall, there was no significant time of sowing by genotype interaction.

Key words
Yield, phenology, development, adaptation

Introduction
In the wheat growing regions of southern and Western Australia, late autumn rainfall has declined in recent decades (Cai *et al*., 2012; Pook *et al*., 2009), which has prevented the mid-fast developing wheat cultivars favoured in the region from being established at their optimal date. Late establishing wheat crops flower too late and are exposed to drought and heat stress which substantially reduces grain yield (Flohr *et al*., 2015). Farmers have responded to this challenge by retaining crop residues on the soil surface over summer and improving control of summer weeds to in order to improve storage and capture of summer rain (Hunt *et al*., 2013). This improved soil water storage combined with rain in late summer and early autumn (which has not declined in recent decades) provides an opportunity for growers to establish wheat crops much earlier than previously practiced, and remove reliance on April-May rainfall for timely crop establishment. Crops can easily be established on stored soil water using modern no-till farming techniques, and weeds and diseases of early-sown crops controlled with recent advances in pesticides. However when crops are sown earlier, the rate of cultivar development needs to be adjusted so that crops do not flower too early and become exposed to greater frost risk. Slower developing cultivars sown early have also been shown to produce higher grain yields than fast developing cultivars sown later that flower at the same time (Coventry *et al*., 1993; Hunt *et al*., 2012; Kirkegaard *et al*., 2014). A lack of contemporary slow developing cultivars is preventing growers implementing this practice. Over the last century Australian wheat breeders have focussed on cultivars with increasingly rapid development through selection of insensitive photoperiod (Ppd) and vernalisation (Vrn) alleles (Davidson *et al*., 1985; Eagles*et al*., 2009). There are few contemporary cultivars with appropriate developmental delays in flowering suitable for sowing early in autumn. The notable exceptions are several mid-developing winter wheat cultivars (EGA Wedgetail, Wylah, Whistler) bred by the NSW Department of Agriculture breeding program at Temora that closed in 2002.

In order for growers to take full advantage of sowing opportunities in early autumn, new cultivars are required that combine the necessary developmental alleles with updated disease resistance genes and other traits. In response to these issues, this study aimed to inform breeding programs as to what combinations of Vrn and Ppd sensitive alleles are best suited to early sowing in different production environments of the Australian wheat belt.

Methods

Near isogenic lines (NILs) that vary in alleles of major development genes governing Vrn and Ppd response were developed by crossing desired alleles into the recurrent parent Sunstate to backcross five. Four NILS were selected that varied in their response to Vrn and Ppd. This included a Ppd insensitive winter line (fast winter, FW), a moderately Ppd sensitive winter line (mid-winter, MW), a strongly Ppd sensitive spring line (very slow spring, VSS) and Ppd insensitive spring wheat control (fast spring, FS = Sunstate) which is representative of currently favoured cultivars (Table 1).

Table 1. Alleles of the major genes which govern response to vernalisation (Vrn; v=sensitive, a=insensitive) and photoperiod (Ppd; b=sensitive, a=insensitive) in the four near-isogenic lines.

	Photoperiod		Vernalisation		
Cultivar	Ppd-B1	Ppd-D1	Vrn-A1	Vrn-B1	Vrn-D1
Mid winter (MW)	*a*	*b*	*v*	*v*	*v*
Fast winter (FW)	*a*	*a*	*v*	*v*	*v*
Very slow spring (VSS)	*b*	*b*	*a*	*a*	*a*
Fast spring (Sunstate - FS)	*a*	*a*	*v*	*a*	*a*

The four NILs were sown in replicated split-plot experiments which included multiple sowing dates, at 14 locations across the Australian wheat belt from 2012 to 2014. Sowing times were chosen such that the last time of sowing was optimal in that environment for a fast developing spring cultivar and additional times of sowing occurred at ~14 day intervals prior to this. This gave consistent sowing times across sites in some regions (e.g. SA & WA), but not in others (e.g. QLD) where sowing times needed to be on different calendar dates in different locations in order to achieve the optimal flowering period in that environment. Small amounts of irrigation (5-10 mm) applied using pressure-compensating drip line were used to establish different times of sowing if soil was too dry to guarantee establishment. Sufficient synthetic fertilisers were applied such that nutrients did not limit yield, and weeds, diseases, insects and fungal pathogens were controlled with registered pesticides such that they did not limit yield. Anthesis date of different NILs were recorded at key sites, and grain yield measured by machine harvest. All yields are reported at field moisture content. Yields were analysed as multiple experiments within agro-climatic clusters using linear mixed models (REML) accessed via the GenStat 16 user interface with sowing date and line as fixed effects and site and block structure as random effects.

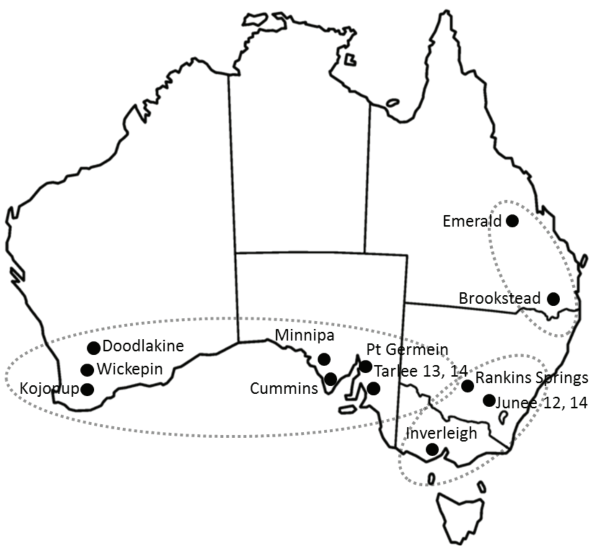


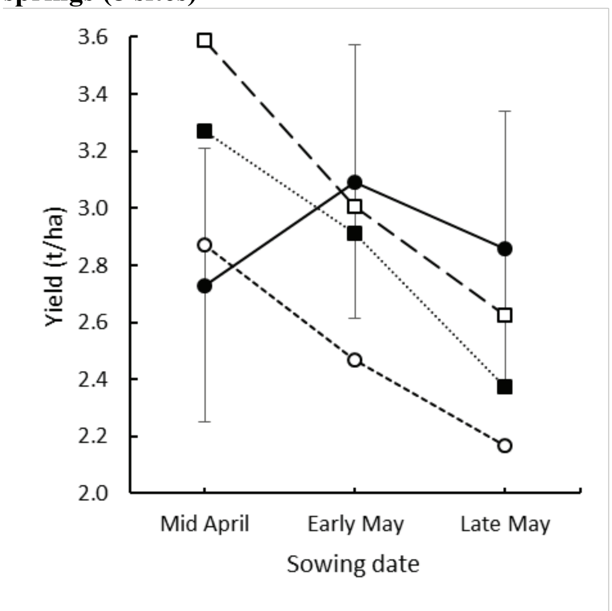
Figure 1. Experimental locations used in the study. Sites where more than one year of data has been collected are denoted with the last two digits of these years following the site name. Dotted lines define three different agro-climatic groupings (WA and SA sites with cool winters and hot springs, SW VIC and S NSW sites with cold winters and mild springs, QLD sites with mild winters) based on yield performance of NILs at early times of sowing.

Results

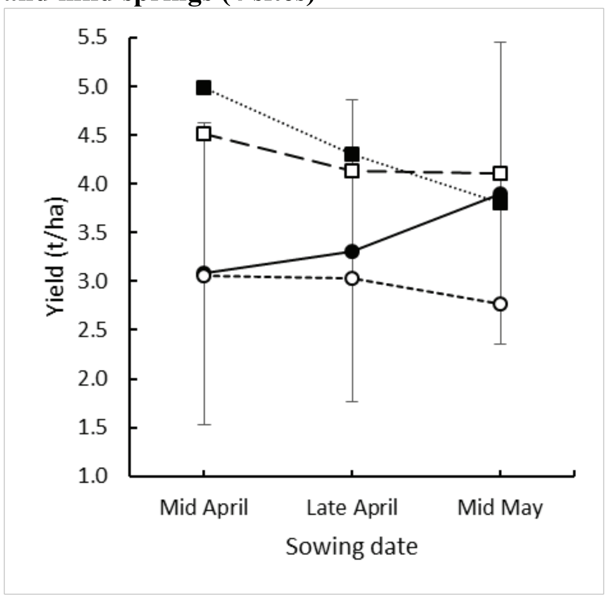
Sites were grouped according to which NIL yielded most at the first time of sowing. This gave three groups of sites which were geographically contiguous and agro-climatically sensible (Figure 1), and data reported herein are predicted mean yields from linear mixed model analysis of the different lines across multiple sites within each of the agro-climatic zones.

The largest group (8 sites) was comprised of sites in WA and SA that experience cool winters with hot, dry springs and typically have an optimal flowering period in the first half of September (Flohr *et al*., 2015). In these environments the FW line gave the highest yield at early (mid-April) times of sowing (Fig 2a). The mean yield advantage of FW sown mid-April over FS sown in early and late May (current practice) was 0.5 t/ha and 0.7 t/ha respectively (Figure 2a). Yields of the FW and FS lines were not significantly different when both were sown in early and late May. The MW line was too slow to flower in these environments and yields were reduced by terminal drought and heat stress. When sown early in all southern environments, the VSS line produced deformed, largely infertile spikes. This is possibly a response of the strong PPD sensitivity of this line when it initiates flowering under short days, and the same effect was not observed at the northern sites.

a) WA and SA sites with cool winters and hot springs (8 sites)



b) SW VIC and S NSW sites with cold winters and mild springs (4 sites)



c) QLD sites with mild winters (2 sites)

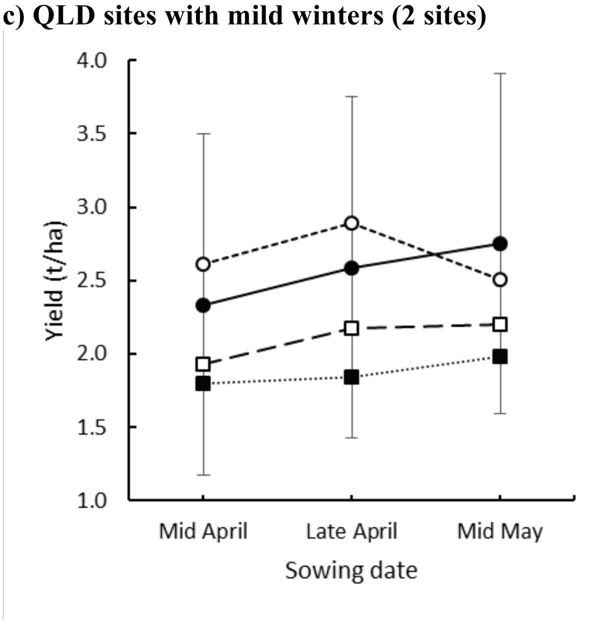


Figure 2. Yield of the NILs Fast Winter (□), Mid Winter (■), Very Slow Spring (○) Fast Spring (●) for the agroclimatic groupings in Figure 1. Error bars on Fast Spring values are +/- 2 x average standard error of the difference for the sowing date and genotype interaction from the linear mixed model analysis. Each error bar represents an approximate 5% least significant difference (LSD) for comparing all means. Error bars have only been added to the Fast Spring means to assist with clarity, as it is representative of current practice.

The second largest grouping (4 sites) comprised sites in S NSW and SW Victoria which experience cool winters and relatively mild springs and typically have an optimal flowering period from late September to mid-October. In these environments the highest yield treatment was the MW line sown in mid-April (Fig 2b). The mean yield advantage of MW over FS when both are sown in mid-April was 1.9 t/ha. However, the mean yield advantage of MW sown mid-April over FS sown mid-May (current practice) was not significant. This result supports the simulated study of Bell *et al*. (2015) who found significant yield advantage of winter wheats sown early in contrast to spring wheats sown later in these regions. The final grouping comprised the two QLD sites. When these sites were analysed individually there was a significant time of sowing x genotype interaction at each site, with the VSS line being highest or equal highest at the first two times of sowing (data not shown). However, when analysed together there was no significant ToS x genotype interaction due to small sample size and associated error (Fig 2c). At both of these sites, the winter lines were too slow to vernalise and flowered too late for stable yield (data not shown).

Conclusions

The results of this study demonstrate that when disease and nutrients were non-limiting, a significant yield advantage was associated with early sowing of slow developing NILs compared with later sowing of fast developing NILs in southern Australia. In order for growers to fully realise the benefits of early sowing in southern Australia, breeding programs are advised to develop FW and MW cultivars with good edaphic adaptation to these regions. Preliminary results from QLD environments with a relatively warm winter did not reveal significant yield advantages associated with earlier sowing of slower-developing NILs, although winter lines were unsuited to this environment and further investigation should focus on Ppd sensitive spring types. Additional experiments are being conducted in 2015 to further examine these trends in the Northern and South-Eastern agro-climatic zones where a smaller number of sites have been sampled.

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