Can the duration of the spike construction phase increase the yield of wheat?

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Abstract

It is proposed that increasing the duration of the spike construction phase (CPD, i.e. beginning of stem elongation to flowering) of wheat to increase the number and size of grains per m^2 will significantly increase grain yield in the High Rainfall Zones (HRZ). Field experiments undertaken in Canberra, Hamilton and Hobart in 2012, demonstrated genotypic variation in CPD in the CSIRO wheat Multiparent Advanced Generation Inter Cross (MAGIC) population compared with check cultivars. Variation in CPD was determined as the difference between dates of terminal spikelet (determined by microscopic dissection) and flowering and ranged from 309 to 950 °Cd (base (Tb) = 0^oC). Height of the ligule relative to the apex was investigated as a possible technique for easily estimating terminal spikelet without the need for microscopic dissection, but the results were inconclusive. This project has now entered its next phase with the testing of fifty lines selected from the MAGIC population, at multiple sites, together with commercial and near-isogenic wheat lines differing in vernalisation and photoperiod alleles. The sites used were Canberra, Hamilton, Cressy and at two sites in WA (Badgingarra and Kojonup) for up to two sowing dates (April, May) and were assessed for CPD and grain yield in 2014. These site locations were chosen to provide a range of sites that vary both in climatic and day length variation across the growing season. Implications for breeding a new ideotype of wheat for the HRZ are discussed.

Key words

Phenology, high rainfall zone, genotypic variation, terminal spikelet, construction phase duration

Introduction

Modelling studies indicate that the High Rainfall Zone (HRZ) of southern Australia has high yield potential but that this potential is not being realised (Zhang *et al*. 2006; Sylvester-Bradley *et al*. 2012). To identify important traits for wheat to maximise resource capture and partitioning into grain, an 'ideotype' was proposed specifically for the HRZ of southern Australia (Sylvester-Bradley *et al*. 2012). Traits relating to crop development (phenology) were identified as being of particular importance in defining the ideotype (Figure 1).

Phenology is considered the single most important factor for adaptation and maximising grain yield as it controls the timing of critical growth stages, which are affected by abiotic stresses and influence the partitioning of photosynthate (Richards 1992; Gomez-Macpherson and Richards 1995). Important phases within the life cycle of a crop include the vegetative or foundation phase (GS00 to GS31/terminal spike), stem extension or construction phase (GS31/terminal spike to GS65) and the grain fill phase (GS65 to GS 91). The ideotype identified an optimum foundation phase duration of 650°Cd (base (Tb) = 0^oC) that is considered sufficient to produce enough tillers to survive to produce 400-500 ears/m^2 at harvest. It also identified the need for a longer construction phase duration (CPD) (i.e. 800-1,200°Cd, Tb = 0^oC) to delay flowering beyond the period of high frost risk and to provide time to increase the carbon supply to the developing ear so as to increase grain number. A duration of 700°Cd (Tb = 0^oC) was identified for grain fill.

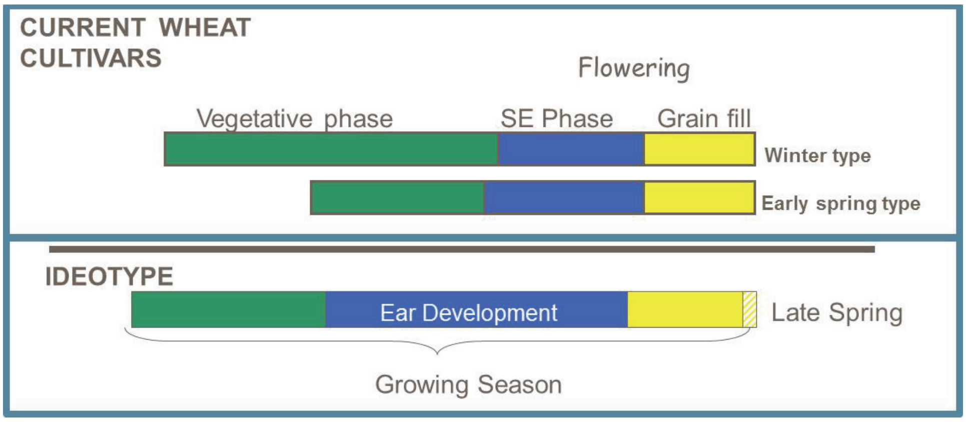

Figure 1. Differences in phase durations for current winter and spring wheat types and the crop ideotype proposed by Sylvester-Bradley *et al.* (2012). SE is stem extension or construction phase.

A lengthening of the CPD has also been identified as a means of increasing yields in other studies. Miralles *et al*. (2000) provided evidence that a longer construction phase increases floret fertility and grain number, which is associated with increased grain yield in temperate cereals (Miralles et al. 2000; Reynolds *et al*. 2005). Reynolds *et al*. (2005) showed that wheat lines containing the alien translocation 7DL.7Ag to have increase grains per m^2 (15%), grain yield (12%) and biomass (9%) compared with control lines. This was associated with 15% more spike biomass at anthesis and 10% more grains per spike. Furthermore, an increase in the amount of assimilates allocated to the spikes in semi-dwarf wheats led to an increase in partitioning to the spike relative to the stem which resulted in improved HI and grain yields (Syme 1970; Fischer and Stockman 1986).

The experiments reported here were undertaken in Canberra, Hamilton and Hobart in 2012 to determine if there was genotypic variation in construction phase duration in the CSIRO wheat Multiparent Advanced Generation Inter Cross (MAGIC) population (Canvanagh *et al*. 2008). In addition, accurate measurement of terminal spikelet typically requires microscopic dissection of the apex, which is not well suited to mass screening of this trait in a breeding population. Consequently, height of the ligule of the youngest fully-expanded leaf was also investigated for potential use as indicator of apical development.

Methods

To test the effects of a longer CPD on grain yield and yield components in the HRZ, MAGIC lines were selected so that when sown on the same date lines would have a similar flowering time but differ in the timing of terminal spike. More than four hundred lines together with eight check varieties were sown in single rows at three locations (Canberra, Hamilton and Hobart) on 7 June 2012 and dates to terminal spike and flowering were recorded. Terminal spikelet was assessed through microscopic dissection with the date deemed to be when the majority of five plants collected from the same day were at TS. The height of the apex and to the ligule of the youngest fully-expanded leaf was also recorded. Date of flowering (GS65) was recorded as when the anthers from mid spike are visible in 50% of main stems in the plot. Mean temperature data was used to determine the thermal time of phase durations at Tb=0°C.

Results

Determination of the CPD required the identification of key stages of development, including terminal spikelet and anthesis. We investigated whether height of the ligule of the youngest fully-expanded leaf could be used as an indicator of apical development. The purpose of this investigation was aimed improving the time efficiency of screening lines for terminal spikelet date. The length of the apex increases as it transitions from the production of leaf to spikelet primordia, culminating in terminal spikelet (data not shown). The height to the ligule of the youngest fully expanded leaf was correlated with the length of the apex (Figure 2). However, there was no relationship between height to the ligule and stage of apical development on a scale from 1 (vegetative) to 8 (reproductive), where 5 was terminal spikelet (Figure 2). Consequently, accurate determination of the date of terminal spikelet (TS) will continue to rely on microscopic dissection of the apex, which has implications for the efficiency of screening for this trait in a breeding program.

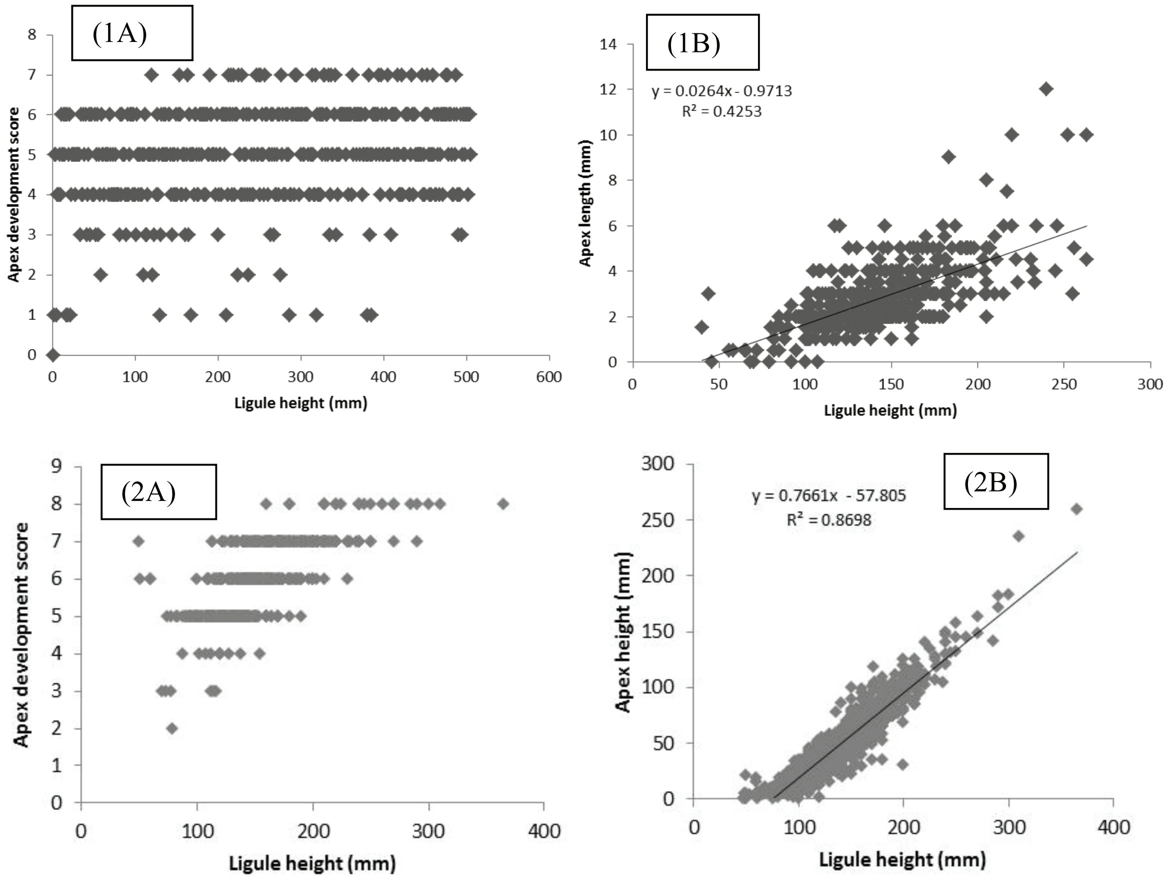

Figure 2. Relationship between stage of development of the apex, where 1 = vegetative and 5 = terminal spikelet with ligule height (A); and (B) ligule height and length of the apex. Data is from Hobart (1) and Hamilton (2), 2012. Data for Canberra is not reported.

Construction phase duration varied from 309 °Cd (in Canberra) to 1150 °Cd in Hobart (Figure 3). The check cultivar, Preston, had a relatively short CPD of 626 °Cd (Hobart), 614 °Cd (Hamilton) and 511 °Cd (Canberra), while Brennan was 1007, 626 and 658 °Cd for Hobart, Hamilton and Canberra, respectively, consistent with their maturity types. There was considerable variation in ranking between lines with the shortest and longest CPD across sites, potentially indicating a large genotype x environment interaction for this trait.

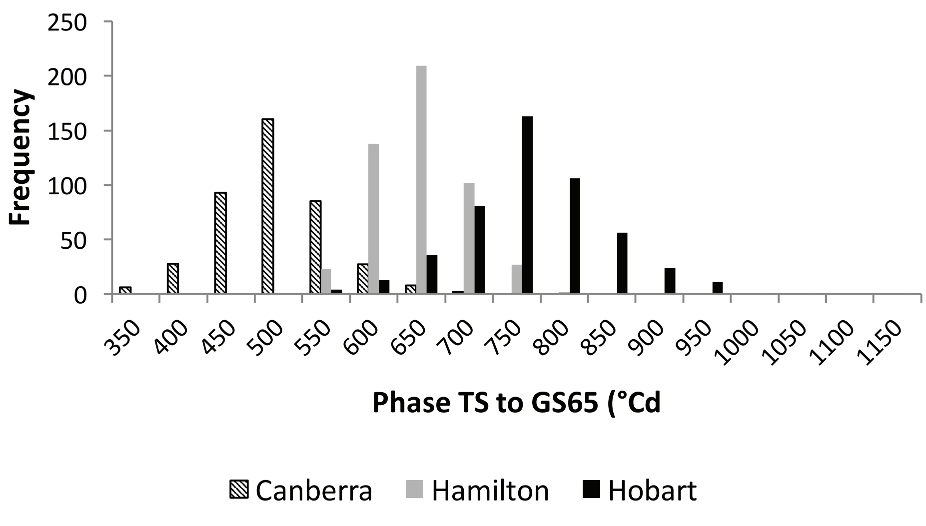

Figure 3. Frequency of lines varying in construction phase duration (terminal spikelet to anthesis, GS65). Data is from Hobart, Canberra and Hamilton in 2012.

Conclusion

Importantly, this work has confirmed using a large population of lines that genetic variation does exist for the length of the construction phase duration (CPD) needed to achieve the proposed ideotype of Sylvester-Bradley *et al*. (2012). Together with known information on the photoperiod and vernalisation genes involved, this should improve the ability to predict phenology in new lines across different environments. Attempts to identify a simple measurement of apex development, and hence terminal spikelet, were unsuccessful. Consequently, accurate determination of terminal spikelet will continue to rely on microscopic dissection. Although time-consuming, this level of detail in collecting data is necessary so to have confidence in reported variation in CPD.

In 2012 there was only sufficient seed to sow single rows in these preliminary experiments, so no yield data (per unit area) was measured. The relationship between an increase in the CPD and associated increase in the number of grains per spike and grain yield is being validated in the next phase of the project. The measured CPD across the three sites in 2012 was used to select the ranges of lines suited for testing in Tasmania, Victoria, ACT and Western Australia. We intend to quantify the contribution of genotype x environment interactions to CPD in this phase of the research. It is expected that within the life of the project breeders will have the capacity to incorporate different combinations of photoperiod and vernalisation genes into new germplasm specifically targeting the HRZ.

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