Optimising sowing time in frost prone environments is key to unlocking yield potential of wheat

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Abstract
Spring frosts can cause significant grain yield losses to cereal crops post head emergence. The aim of this study was to explore the relationships between sowing time, flowering time, frost and wheat maturity on grain yield. The results from two frost phenotyping nurseries in the central wheat belt of Western Australian wheat belt at Brookton in 2015 and Dale in 2016 are presented in this paper. Eight sowing dates were used from mid-April to late June to ensure wheat was flowering throughout the frost window, so that varietal comparisons could be made under frost. Grain yields in 2015 at Brookton and 2016 at Dale, Western Australia. were optimised when head emergence and flowering occurred during the most frequent frost period in spring. These results suggest that yield formation through biomass accumulation and converting this into yield, as well as interactions with frost, terminal drought and heat stress are as important in frost prone areas of the landscape as in other areas. In both years, despite very different growing conditions, the optimum sowing windows for short, mid, long and winter type maturity wheats were consistent across both years.

Keywords
Time of sowing, phenotyping, yield formation.

Introduction
In broad-acre cropping regions of Australia, frost risk is an important consideration for growers when implementing their cropping program. Estimates of the direct and indirect costs of frost vary across Australia. The cost of frost to the Western Australian (WA) wheat crop in 2016 was estimated to be 1.64 million tonnes or ~$410 million (GIWA 2016). In WA since 1990s the average grower's cropping program has considerably increased in size. Sowing dates of wheat have shifted earlier, with a considerable proportion of sown dry in most years to reduce heat and drought risk for the later part of the program. Conversely, in frost prone parts of the landscape, delaying sowing and/or using later maturing varieties has been the main agronomic approach to reduce frost risk. Late sowing (i.e. June) reduces yield potential and increases heat and drought risk during flowering and grain filling. This paper reports on the results of two trials located in frost prone areas of the Central WA wheatbelt in 2015 and 2016 and explores the relationship between sowing time, frost and wheat maturity.

Methods
Randomised block design trials with eight times of sowing (TOS) blocks were established at two sites in Western Australia: (1) Brookton; 30 km east of Brookton (-32.38°, 117.32°) in 2015 and (2) Dale; 20 km south-west of Beverly (-32.20°, 116.75°) in 2016. Both sites were located in a frost prone part of the landscape; stubble was burnt prior to sowing. To ensure germination occurred on the same day as sowing, one 20 mm application of irrigation was applied (via two water cannons) two weeks prior to seeding and a further 20 mm was applied the day before seeding, for the first six sowing dates at Brookton. The Dale trial site had higher average rainfall in a year of above average rainfall; therefore no irrigation was required due to an early break and consistent rainfall throughout the growing season. Sowing dates were selected based on a predicted equidistant thermal time of 250 growing degree days from April 15 to June 22 (or April 20 to June 21 in 2016). This was done to ensure that wheat would flower from early August to early October, the typical frost window for the area. Plant developmental stage in each plot was scored weekly (from Z45-70) according to Zadoks (Zadoks et al. 1974) and then used to estimate canopy heading (Z55) and flowering dates (Z65) of the varieties (Zheng et al. 2013). Each year and sowing block was considered a different environment and subject to REML analysis (VSN-International 2011). There were 108 commercial and pre-breeding wheat lines in the trials in 2015 and 144 in 2016, of which only five are reported in this paper. These had two replicates per TOS block and were randomised in two directions (Cullis and Smith 2015).

The canopy temperature was recorded in each TOS block using Tinytag TGP4017 temperature loggers, recording at 15 minute intervals. Loggers were installed facing north with the internal sensor facing upward, secured to a 50 mm PVC pipe 600 mm from the ground at anticipated head height and positioned in the centre of the plot. An onsite weather station recorded screen temperatures. Temperatures above 30˚C at the screen were defined was heat events. Temperatures below 2˚C at the screen or 0˚C at the canopy were defined as a frost event. Following a frost event (<2 ˚C in a Stevenson screen), 30 heads just reaching anther dehiscence in the middle of the head (Z65) were tagged and floret induced sterility (FIS) of the outside florets (discarding the top and bottom florets) was measured four to six weeks later during grain fill (Z85). FIS is the reduction in grain number per head expressed as a percentage of the total number of possible grains that could have formed in the distal florets. Harvest index (HI) cuts of 0.254 m^2 were taken at physiological maturity (Z87) and from these cuts yield components (harvest index, viable and non-viable tillers) were measured (Pask et al. 2012). Grain yield and quality were determined from the whole plot (1.65 x 3 m) using a small plot harvester specifically set up to retain the small frost affected grains.

Results and Discussion

Temperature at Brookton and Dale

In the 2015 trial at Brookton there were 29 frost events (≤0˚C at head height) from July to October. The majority of frost damage was observed in the first four TOS blocks. There were 10 heat events (≥30˚C in a Stevenson screen) from the last week of September until the end of October; these events coincided with grain filling and flowering in later times of sowing.

In the 2016 trial at Dale there were 57 frost events over the equivalent period. Temperatures were unusually low, with the South West of WA experiencing the coldest average minimum temperature for spring since 1969 (Australian Bureau of Meteorology 2016).

Grain yield at Brookton and Dale

At the 2015 Brookton site, there was a sowing window where grain yields maximised for each maturity type; flowering during this window occurred from late-August to late-September. Winter wheats (e.g. Wylah) achieved the highest yields in excess of 3 t/ha for April sowing and flowered outside the window of the spring wheats. Long maturity varieties (e.g. Yitpi and Magenta) showed a grain yield maximum of over 3 t/ha in the middle of the sowing window between 5 and 15 May. Mid maturity varieties (e.g. Mace) optimised its yield when planted on May 15. Whereas in short maturity varieties (e.g. Axe), there was little effect of sowing date on grain yield, but had lower overall yields of about 2 t/ha (Figure 1). Across all maturity types the highest grain yield occurred when flowering coincided with the highest frequency of frost. Yield declined sharply with the onset of heat events and high evaporative demand at the end of the flowering window.

Estimates of potential grain yield were calculated as (P.Y.= biomass x HI, where HI = 0.4). Comparison between the maturity classes showed: when sown in April, Wylah's grain yield is very close to its yield potential, whereas Yitpi, Magenta and Mace grain yields are quite a lot further away from their yield potential. Sowing short maturity varieties that have little to no photoperiod, or vernalisation requirement (e.g. Axe) in April, resulted in inadequate above ground maturity biomass production (5 t/ha). This is possibility due to the plants developing too fast and bolting. However for other varieties like Mace, Magenta and Yitpi, they produced good levels (8-11 t/ha) of biomass at maturity with April sowing, but were not able to convert the biomass they produced into yield (HI = 0.2-0.3). The low HI was due in part to frost damage. Winter wheats with a strong vernalisation requirement (e.g. Wylah), could produce both good maturity biomass and convert this into yield (HI = 0.4). Lower frost induced sterility was observed in Wylah than Mace, Magenta and Yitpi (data not shown).

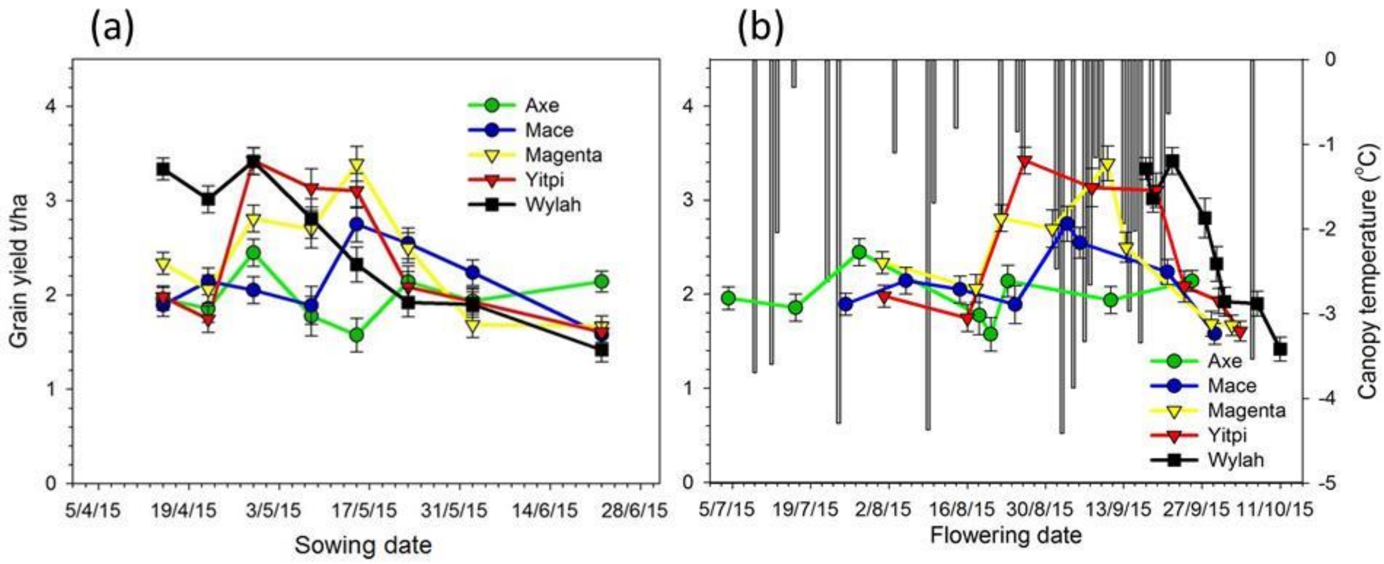

Figure 1. Time of sowing response of five wheat varieties representing the different maturities (Axe – short, Mace – mid, Magenta – mid-long, Yitpi – long, Wylah – winter) at Brookton in 2015 by their sowing date (a) and flowering date (b). Frost events in which canopy temperatures were ≤0˚C at head height are depicted by the grey bars in (b).

Flowering dates were much later in 2016 compared to 2015. For example, Mace was generally flowering four weeks, later than in 2015. Despite this significant difference in flowering time, yield patterns with sowing times (Figures 1a and 2a) were similar. Similarly to 2015 grain yield data, the highest yields generally occurred around the most frequent frost period of 4-5 t/ha (Figure 2b). The severe frosts of 2016, meant that yields of wheat flowering before ~20th September were much lower yielding (i.e. 1-2 t/ha) compared to 2.5-3 t/ha in 2015. There is a period of 10 days where there was a single minor (-1 ˚C at the canopy) frost and varieties could have avoided flowering frost damage. However, frosts occurred both before and after this period at heading and grain filling stages. These results seem to suggest that while frost reduces grain yield, it is not the only factor determining final grain yield. Yield formation – setting up greater above and below ground biomass, water use efficiency and high grain number m^{-2} (Hunt et al. 2016) – is of greater importance than frost avoidance (Figures 1 and 2). The influence of terminal drought and heat on grain yield and interactions with sowing time should still be considered. Both in 2015 and 2016 grain yield declined sharply with the onset of declining soil moisture and warmer temperatures in October (Figures 1 and 2).

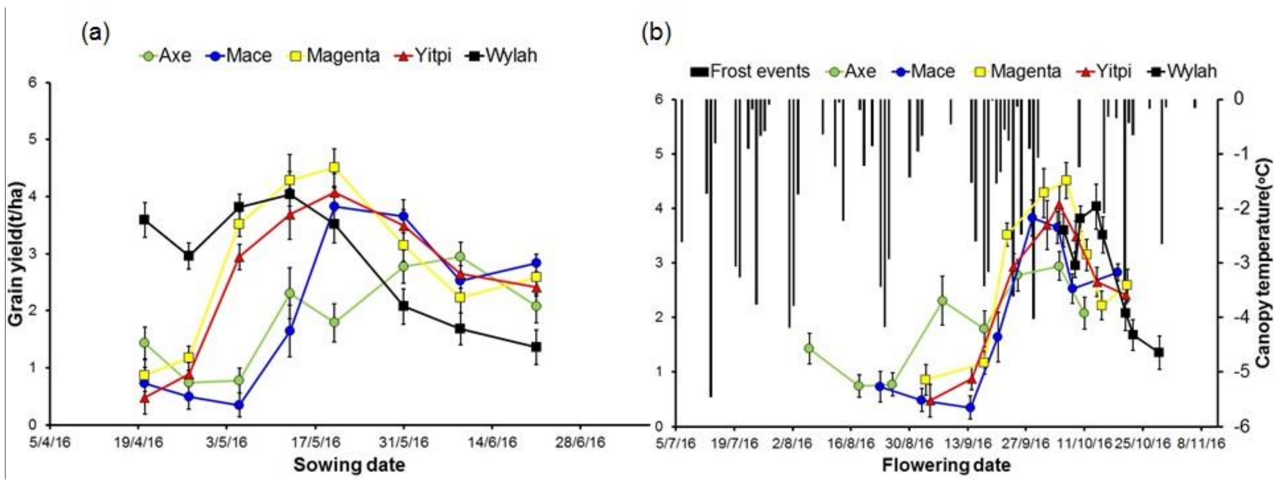

Figure 2. Time of sowing response of six wheat varieties representing the different maturities (Axe – short, Mace – mid, Magenta – mid-long, Yitpi – long, Wylah – winter) at Dale in 2016 by their sowing date (a) and flowering date (b). Frost events in which canopy temperatures were ≤0˚C at head height are depicted by the black bars in (b).

Conclusion

Growers in WA should look to add more diversity in the maturity of the wheat varieties that they grow, to give them more flexibility, given the wide variation in seasonal conditions that could eventuate pre and post seeding. Sowing short and mid maturing varieties in April and early May resulted yield penalties due to frost. Conversely, the unseasonably late and frequent frost events in spring 2016 could not have been avoided by late sowing. Over both seasons there was a sowing window from May 5th to May 20th where grain yield was maximised. For winter wheats, it was mid-April until early May (~15/4-5/4). For long maturity wheat varieties Yitpi and Magenta, it is early to mid-May (1-15th May); mid maturity varieties such as Mace, from the 15th to 30th May, and the short maturity varieties such as Axe in early June (1-15th June). The results emphasise the importance of optimising sowing time for a given variety in the wheat program, to optimise yield in frost prone areas of the landscape.

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