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

Brenton Leske[1], Dion Nicol[2] and Ben Biddulph[1]

The Department of Agriculture and Food Western Australia, Northam[1], Merredin[2] and South Perth[3]

Key messages

1. Matching wheat variety with sowing time is critical to ensure optimal flowering and biomass production occurs in order to maximize grain yield.
2. Growers should be planting longer maturity wheat varieties when early opportunity arises, rather than the currently used mid-season wheats. This will ensure adequate biomass is accumulated both above and below ground so that this can be converted into grain yield, while managing frost risk.

Aims

The aims of this research were to compare the performance of wheat varieties at different times of sowing under frost; and to determine appropriate sowing time and variety combinations to maximise yield, while managing frost risk.

Method

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; 20km south-west of Beverly (-32.20°, 116.75°) in 2016 (Table 1). Both sites were located in a frost prone part of the landscape. Prior to sowing at Brookton the canola stubble was burnt. 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 20mm was applied the day before seeding, for the first six sowing dates. In 2016 no irrigation was required due to the early break to the season. Each sowing block was sown at approximate 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. Each sowing block was considered a different environment for analysis purposes. There were 108 and 144 commercial and pre-breeding wheat lines in the trials in 2015 and 2016 respectively. These had two replicates per TOS block and were randomised in two directions.

The canopy temperature was recorded in each 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 a uniform part 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, 30 heads just reaching anther dehiscence in the middle of the head 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 outside florets. 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). Harvest index cuts of 0.254 m² 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 m x 3 m) using a small plot harvester.

Table 1. Site summary of Brookton and Dale trial sites.

	Brookton 2015	Dale 2016
Sowing dates	April 15, 22, 29, May 8, 15, 23, June 2 and 23	April 20, 27, May 5, 13, 20, 31, June 9, June 21
pH ($CaCl_2$)	Top soil: 5.8 (0-10cm) Mid-soil: 4.6 (10-20cm)	Top soil: 4.8 (0-10cm) Mid-soil: 4.7 (10-20cm) Prior to seeding lime and muriate of potash were applied at 2t/ha and 80kg/ha
Nutrition	All macro and micronutrients were in adequate supply. A basal application of Gusto Gold at 100kg/ha (10.2 N: 13.1 P: 12K: 7.2 S: 0.09 Cu: 0.13 Zn) treated with Uniform® and 50kg/ha of urea was supplied at seeding and two post seeding applications of UAN at 50L/ha.	The same rate of basal fertilizer applied at seeding was applied at Dale as at Brookton. Two post seeding applications of UAN were applied at 50L/ha and 30L/ha.
Climate summary	Brookton in 2015 had a good start to the season with an early break in the first week of April. The next significant rain was not until the middle of May. At the start of June the rainfall was tracking at decile 5, but the reminder of the season fell to a decile 1. This period of dryness occurred through flowering and grain filling stages of the commercial crop. May and June had warmer than average minimum temperatures.	The break of the season in 2016 came in mid-March and rain events were frequent throughout the whole growing season. The minimums and maximums were lower than average in winter which slowed plant development compared to 2015.

Results and Discussion

Temperature

Brookton

A total of 29 frost events (≤0˚C at head height) were recorded at the Brookton 2015 trial site from July to October. The majority of frost damage was observed in the first four TOS blocks. There were 10 heat events (≥30˚C at screen height) from the last week of September till the end of October; these events coincided with grain fill and flowering in later times of sowing (Figure 1).

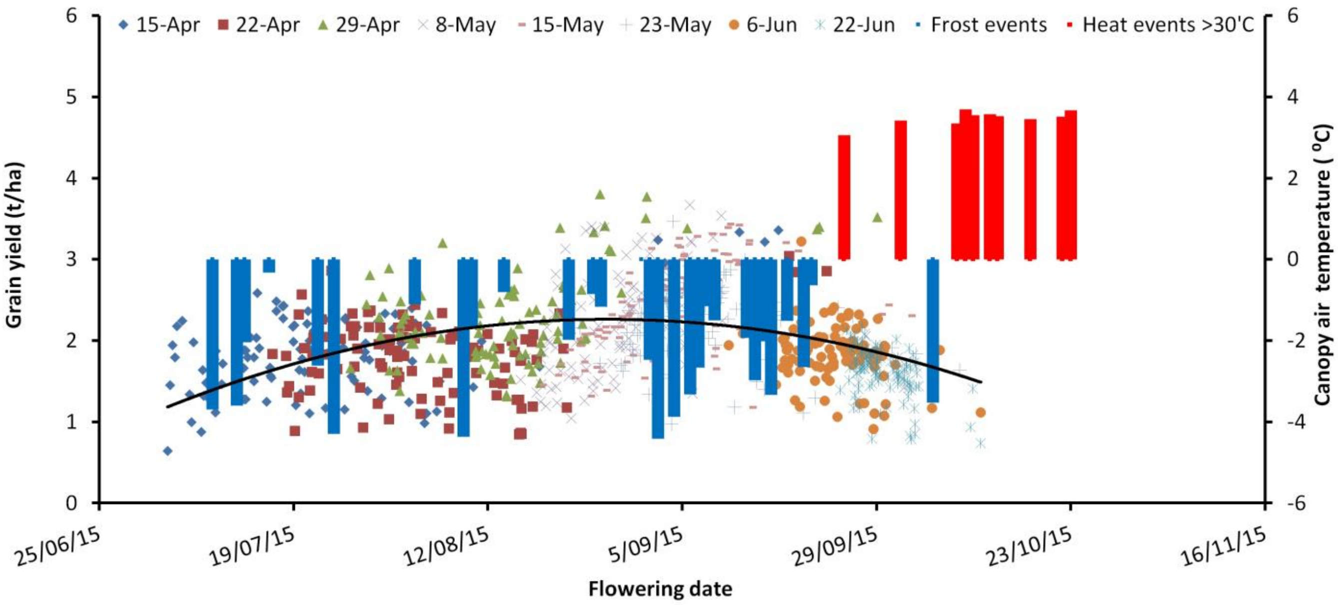

Figure 1. Yield response of 108 wheat lines to eight sowing times from mid-April to late-June in 2015 at Brookton. Canopy temperatures below 0˚C are depicted in the blue columns and heat events with screen temperatures above 30˚C (divided by a factor of 10) are depicted in the red columns.

Dale

In 2016 the South West of WA experienced the coldest average minimum temperature for spring since 1969 and the coldest minimum temperatures on record since 1910 (Australian Bureau of Meteorology, 2016). A total of 57 events with canopy temperatures below 0˚C were observed, thus the cumulative hours below zero was much greater at Dale (Figure 2 and 3).

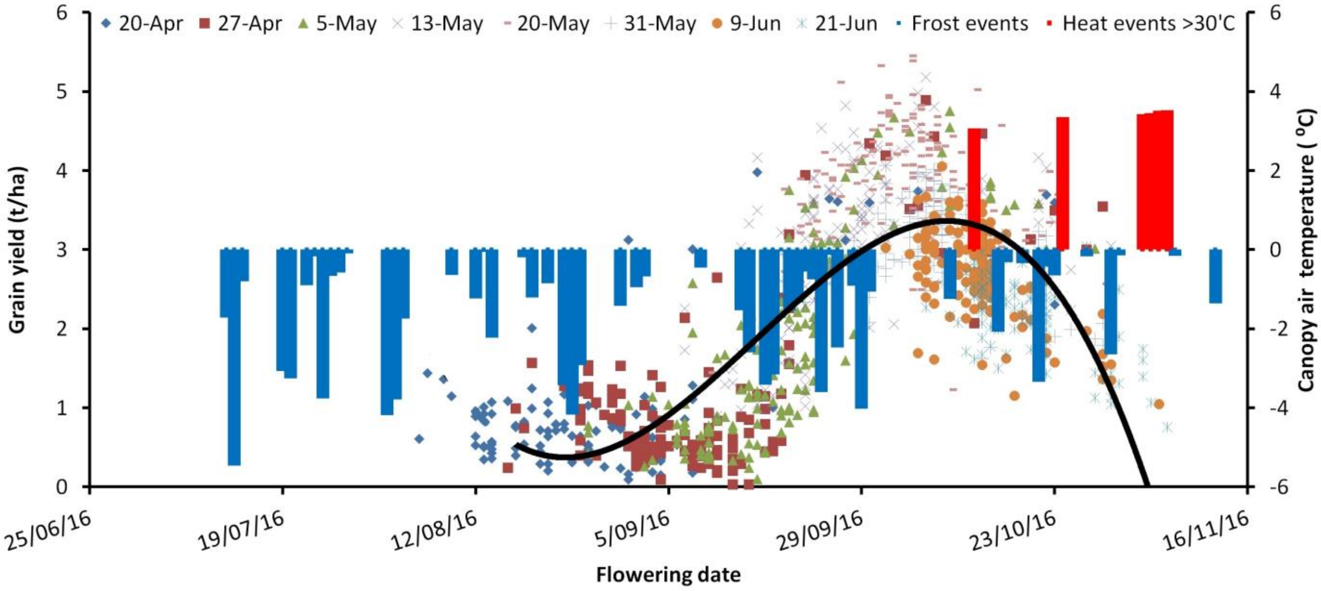

Figure 2. Yield response of 144 wheat lines to eight sowing times from mid-April to late-June in 2016 at Dale. Canopy temperatures below 0˚C are depicted in the blue columns and heat events with screen temperatures above 30˚C (divided by a factor of 10) are depicted in the red columns.

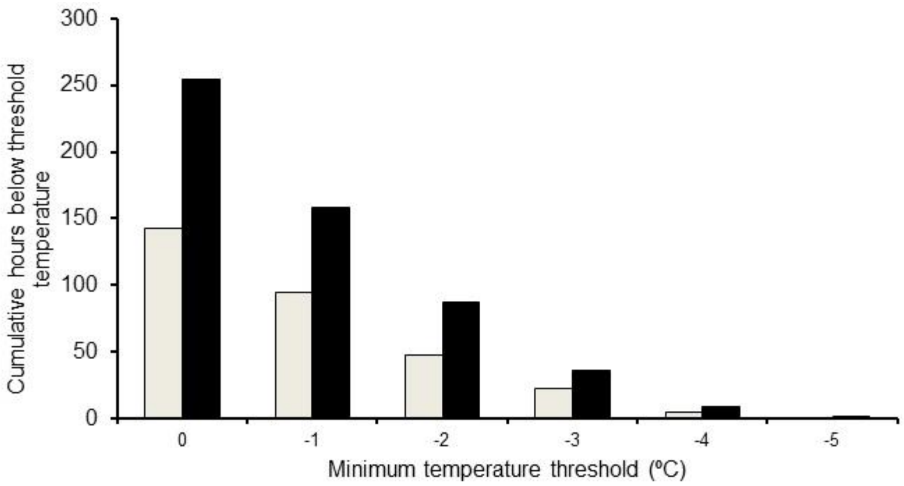

Figure 3. Cumulative hours below temperature thresholds at Brookton (shaded) in 2015 and Dale (black) in 2016 recorded 600mm above ground.

Grain yield

Brookton

Maturity effects on yield performance in the trial were quite evident in 2015 (Figure 4). The highest yields for mid-April sowing were achieved by the winter wheats (eg. Wylah). Long and mid-long maturity main season wheats (eg. Yitpi and Magenta) were best suited to a planting window May 5th to May 15th. Mace and similar maturity varieties were suited to a mid-May planting. Lastly short maturity wheats (eg. Axe) were suited to a mid-June planting date to optimise biomass production through late planting and in turn grain yield. There was a window where yields were maximised; flowering during this window occurred from late-August to late-September (Figure 2 and 4). This window corresponds to those advised by Anderson *et al.* (2000) for the Central region. It is important to note that what was considered a long maturity variety when those recommendations were developed had its maturity shortened in 2015 due to warmer seasonal temperatures (data not shown). Interestingly the highest grain yield across all maturities was during the highest frequency of frost events at flowering.

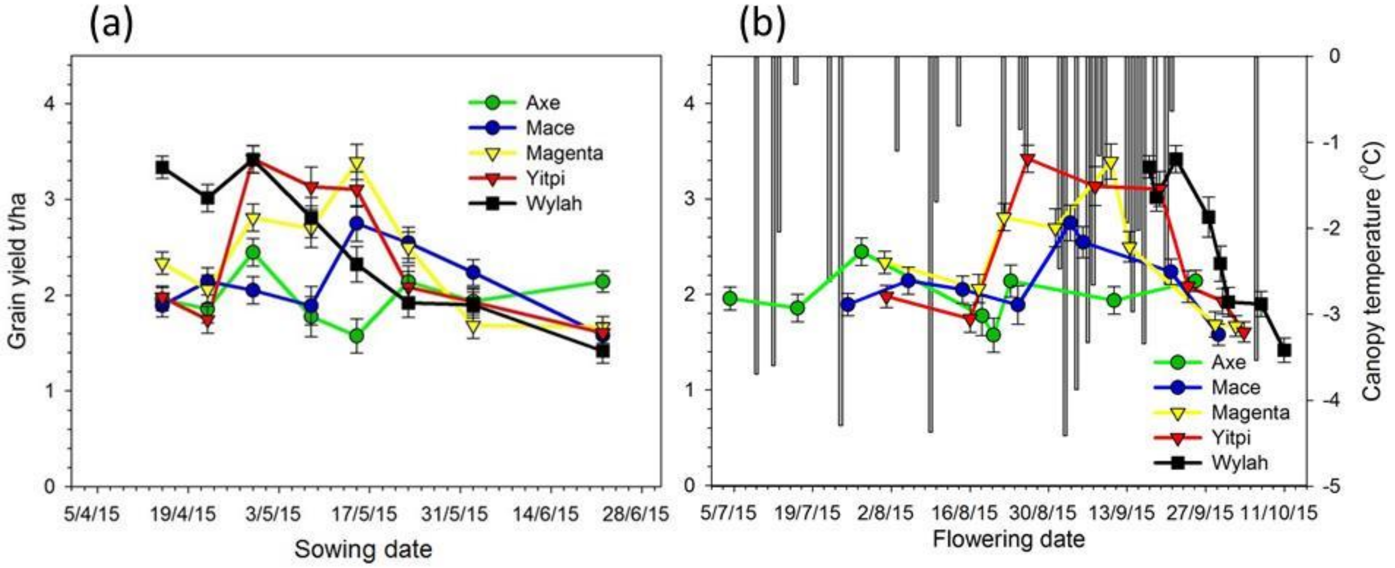

Figure 4. Time of sowing response of five wheat varieties representing the different maturities (Axe – short, Mace – mid, Magenta – mid-long, Yitpi – long, Wylah – winter) at Brookton in 2015 by their sowing date (a) and flowering date (b). Frost events in which canopy temperatures were ≤0˚C at head height are depicted by the grey bars in (b).

The grain yield and yield potential (Y.P. = biomass x 0.4 H.I.) comparison between the maturity classes shows 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 (Figure 5). Sowing varieties that have little to no photoperiod or vernalisation requirement (eg. Axe) in early in April resulted in inadequate above ground maturity biomass production (5t/ha). This was due to the plant growing too fast and bolting. However for other varieties like Mace, Magenta and Yitpi produced good levels (8-11t/ha) of biomass at maturity with April sowing, but were not able to convert the biomass they produced into yield (H.I. = 0.2-0.3). The low H.I. was due in part to frost damage. Winter wheats with a strong vernalisation requirement (eg. Wylah) could produce both good maturity biomass and convert this into yield (H.I. = 0.4) (Figure 4). Lower frost induced sterility was observed in Wylah that the other four wheat varieties in Figure 4 (data not shown).

A cropping program of consisting of a mix of wheat maturities sown at their optimal time produced a gross income per hectare over the whole program which was 36% higher compared to sowing all Mace (Table 2). This difference in income between the two sowing programs is largely due to yield difference between Mace and an alternative longer maturity wheat variety (for this example Wylah and Yitpi have been used) for April and early May sowing dates. The gross income indicates there is little incentive to sow early with a mid-maturity wheat variety; growers are better off delaying seeding till mid-May or plant longer maturity wheat (eg. Wylah).

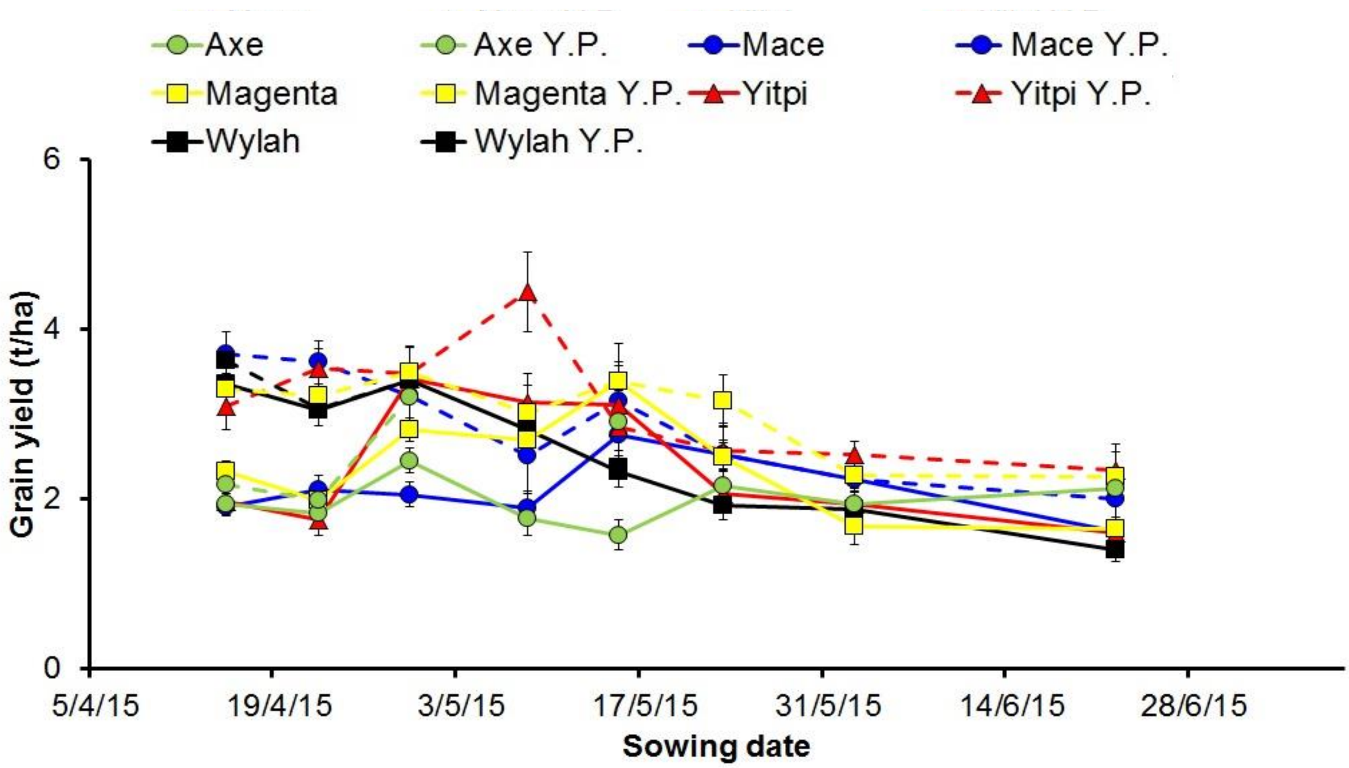

Figure 5. Grain yield (solid lines) and yield potential (Y.P.= biomass x H.I., maximum H.I. was assumed to be 0.4. Y.P. is depicted with dashed lines) of five wheat varieties representing the different maturities (Axe – short, Mace – mid, Magenta – mid-long, Yitpi – long, Wylah – winter) at Brookton in 2015 by their sowing date. Note: Y.P. data for Axe and Wylah is only available for sowing dates: April 15, 22, 29 and May 15.

Table 2. Gross income for a sowing program that used a range of wheat maturities across a range of sowing dates compared to sowing all Mace using the yields achieved at Brookton in 2015 and an average wheat price of $250/t.

Variety	Sowing date	Grain yield (t/ha)	Mace grain yield (t/ha)	Gross income for a mix of varieties ($/ha)	Gross income for sowing all Mace ($/ha)
Wylah	15/4/15	3.4	1.9	839	479
Wylah	22/4/15	3.0	2.1	761	526
Wylah	29/4/15	3.4	2.1	851	513
Yitpi	8/5/15	3.1	1.9	783	472
Magenta	15/5/15	3.4	2.7	848	687
Mace	23/5/15	2.5	2.5	632	632
Mace	2/6/15	2.2	2.2	557	557
Axe	22/6/15	2.1	1.6	532	405
			Total	**5803**	**4271**

Dale

The 2016 season produced a much different environment than what was observed in 2015 (taking into account of the change in location of the trial and higher average annual rainfall). The yield potential was much higher due to a number of factors some of which include: above average annual rainfall and mild daytime temperatures which prevented bolting and increased the days to flowering of all varieties compared to 2015 (Figure 1 and 4). Heat events occurred later in October than 2015. Due to the colder temperatures during the growing season in 2016 more varieties were flowering and at grain fill at this time. In addition to this, frosts occurred one to three mornings before or after these heat events, further putting the plants under stress. The result was a sharp decline in grain yield (Figure 5).

Similarly to 2015 yield data the highest yields occurred during the most frequent frost period (Figure 6). In addition to this frosts occurred at multiple stages of development for varieties flowering in the window when grain yield was maximised. 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 (Figure 4, 5 and 6). The influence of heat and terminal drought on grain yield and interactions with sowing time should not be underestimated. Both in 2015 and 2016 grain yield declined sharply with the onset of higher temperatures in October (Figure 1 and 2).

For early April sowing in frost prone environments there is significant yield to be gained by growing a winter type (eg. Wylah) wheat over a mid-maturity wheat (eg. Mace) as depicted in Figure 5a. The gross income was 71% higher when sowing the varieties depicted in Figure 5a at their optimal sowing date over the 8 sowing dates compared to sowing all Mace over the same sowing dates at Dale in 2016 (Table 3). For that season and location there were better yields and gross income by sowing Mace from the third week of May and into June than planting it in April and early May. While growers programs are not spread over such as wide period of time as the sowing dates in these trials, the grain yields and gross income show they do not gain much yield potential by sowing mid-maturity wheat in April. They are only increasing frost risk.

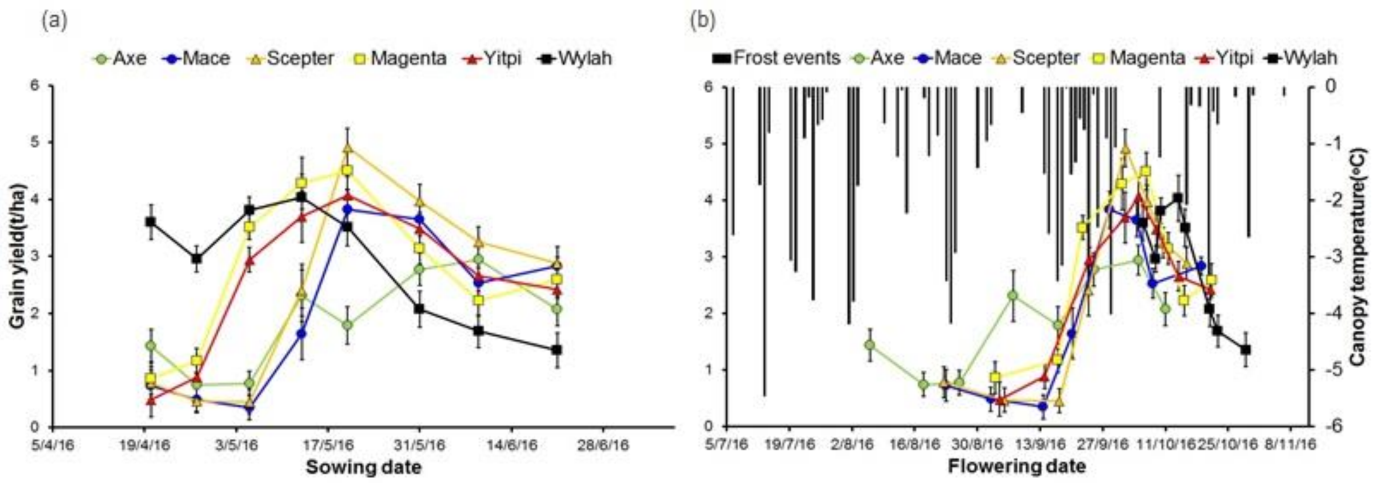

Figure 6. Time of sowing response of six wheat varieties representing the different maturities (Axe – short, Mace – mid, Magenta – mid-long, Yitpi – long, Wylah – winter) at Dale in 2016 by their sowing date (a) and flowering date (b). Frost events in which canopy temperatures were ≤0˚C at head height are depicted by the black bars in (b).

Table 3. Gross income for a sowing program that used a range of wheat maturities across a range of sowing dates compared to sowing all Mace using the yields achieved at Dale in 2016 and an average wheat price of $250/t.

Variety	Sowing date	Grain yield (t/ha)	Mace grain yield (t/ha)	Gross income for a mix of varieties ($/ha)	Gross income for sowing all Mace ($/ha)
Wylah	20/4/16	3.6	0.8	900	200
Wylah	27/4/16	2.9	0.5	725	125
Wylah	5/5/16	3.8	0.4	950	100
Magenta	13/5/16	4	1.6	1000	400
Magenta	20/5/16	4.5	3.8	1125	950
Mace	31/5/16	3.6	3.6	900	900
Axe	9/6/16	2.9	2.5	725	625
Axe	21/6/16	2.1	2.8	525	700
			Total	**6850**	**4000**

Analysis of 2016 sterility and yield component data is ongoing and future presentations will explore these results in more detail when they are available.

Conclusion

Growers in WA should look to add more diversity to the wheat varieties that they grow to give them more flexibility given the wide variation in seasonal conditions that could eventuate. Currently there are commercial varieties that differ in photoperiod (day-length) and vernalisation (cold) requirements for flowering. A mix of varieties with different combinations of these traits will go some way to prevent bolting of short or mid-maturity varieties in very early sowing (mid-April and earlier) in warmer growing seasons like 2015. The 2015 and 2016 data does not support the notion that frost can be 'beaten' by sowing early with those maturities. Conversely the unseasonably late and frequent frost events in spring in 2016 could not have been avoided by late sowing – late sowing produces lower biomass and exposes the crop to an increase heat stress risk. Over both seasons there was a sowing window from May 5th to May 20th where grain yield was maximised. For the longer season winter varieties it was mid-April until early May (~15/4-5/4). For the longer season wheat varieties Yitpi and Magenta it is early to mid-May (1-15th May , the mid-season varieties such as Mace from the 15th to 30th May and the short 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.

References

ANDERSON, W. K., BELFORD, R. K., CROSBIE, G. B., LOSS, S. P., MASON, M. G. & PERRY, M. W. 2000. Sowing Time. *In:* ANDERSON, W. K. & GARLINGE, J. (eds.) *The Wheat Book: Principles and Practice.* 2 ed. Perth, Western Australia: Department of Agriculture, Western Australia.

AUSTRALIAN BUREAU OF METEOROLOGY. 2016. *September minimum temperature anomaly - Southwestern Australia (1910-2016)* [Online]. Australian Bureau of Meteorology. Available: http://www.bom.gov.au/climate/change/#tabs=Tracker&tracker=timeseries&tQ=graph%3Dtmean%26area%3Dswaus%26season%3D09%26ave_yr%3D0 [Accessed 9/1/16].

HUNT, J., RHEINHEIMER, B., SAWN, T., GOWARD, L., WHEELER, R., WARE, A., DAVIS, L., NAIRN, J., PEARCE, A., LUDWIG, I., NOACK, S., HOOPER, P., FAULKNER, M., BRAUN, J. & FLOHR, L. 2016. Early sowing in South Australia results from 2015 and a summary of two years of trials. *GRDC Updates.* GRDC.

PASK, A. J. D., PIETRAGALLA, J., MULLAN, D. M. & REYNOLDS, M. P. 2012. Grain yield and yield components. *Physiological Breeding II: A Field Guide to Wheat Phenotyping.* Mexico: CIMMYT.

ZADOKS, J. C., CHANG, T. T. & KONZAK, C. F. 1974. A decimal code for the growth stages of cereals. *Weed Research,* 14**,** 415-421.

ZHENG, B., BIDDULPH, B., LI, D., KUCHEL, H. & CHAPMAN, S. 2013. Quantification of the effects of VRN1 and Ppd-D1 to predict spring wheat (*Triticum aestivum*) heading time across diverse environments. *Journal of Experimental Botany,* 64**,** 3747-3761.

Key words

Frost, wheat, time of sowing

Acknowledgments

The research was undertaken as part of the GRDC Yield under frost project, one of a number of projects within the GRDC National Frost Initiative. The research made possible by the support of GRDC and significant contributions of growers through both trial cooperation (Darrell and Suzanne Turner and Bill and Anne Cleland for hosting the trials in 2015 and 2016) and the support of the GRDC, the authors would like to thank them for their continued support. The authors would also like to thank Karyn Reeves at DAFWA for statistical support and Nathan Height and Mike Baker for technical support.

GRDC Project Number: DAW00234

Paper reviewed by: Andrew Fletcher, Brenda Shackley and Sue Knights

Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.