Winter is coming: the potential for a fast winter wheat to stabilise flowering and maximise yield in southern and Western Australia

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Abstract
Australian wheat (*Triticum aestivum*) producers facing reduced autumn rainfall, more extreme spring weather and increasing farm size, have moved to earlier sowing to adapt to these trends. Analysis of sowing date records indicate a shift of around 1.5 days/year over a 10-year period. Field experiments comparing a pre-release fast winter line (RAC2341 - derived from the high yielding spring cultivar Mace) with elite spring cultivars were conducted across a broad range of environments (SA, NSW, VIC and WA) and sowing times. We found that in the years 2013-2015, 42% of wheat crops in the Yield Prophet® database were sown prior to 10 May. In the cool environment of Temora NSW, RAC2341 could flower at an optimal time from a broader range of sowing dates (mid-April to early May) than either mid- or fast-developing spring wheats, thus minimising the combined damage from frost, heat and water stress and maximising yield. In warmer Mediterranean environments (Minnipa SA, Cunderdin WA and Berriwillock Vic), RAC2341 was only able to flower during the optimal period from sowing dates in early to mid-April. However, when sown at this time, yields of RAC2341 were comparable to those of elite mid- and fast-developing spring cultivars sown later and flowering concurrently. Given the change in grower sowing times, new wheat cultivars with altered development patterns are required to ensure flowering during optimal periods with earlier and extended sowing periods.

Keywords
Wheat, vernalisation, time of sowing, optimal flowering period.

Introduction
In Australia, the wheat growing season extends from the onset of lower temperatures and once reliable rainfall in autumn (April-May) to the period of increasing temperatures and declining rainfall in spring. Frost, heat and drought define a distinct optimal flowering period for wheat for each region (Flohr et al. 2017). Wheat genotypes have predominately been of spring development pattern (weak vernalisation sensitivity) since the end of the 19th century when William Farrer identified that cultivars from the northern hemisphere which were highly sensitive to vernalisation and photoperiod, were not suited to the southern Australian growing season (Pugsley 1983). Since the release of Federation in 1901, wheat breeders have continued to follow Farrer's lead and significant yield progress has been made by breeders selecting cultivars that develop from autumn establishment to flower during the optimal period (Pugsley 1983).

Since the mid 1990's rains that could once be relied upon to establish crops in autumn (April-May) have declined significantly (Cai et al. 2012). In response to changing rainfall patterns, extreme spring temperature events and increasing farm size (Fletcher et al. 2016), growers are sowing progressively earlier, though the extent of practice change has not been quantified. Commonly grown fast-developing spring genotypes if sown too early incur high risk of flowering outside the optimal flowering period, and suffer yield reductions due to frost damage and/or insufficient biomass accumulation. Consequently, growers need new genotypes to better align new sowing dates with the optimal flowering periods.

Penrose (1997) showed that obligate vernalisation sensitivity (i.e. winter habit) is more effective at stabilising flowering time from a broad range of sowing dates than photoperiod sensitivity. Penrose (1993) also demonstrated that winter genotypes sown early could yield at least as well if not better than faster spring genotypes sown later. Winter genotypes do exist in Australian germplasm, however were previously overlooked by growers, agronomists, breeders and researchers due to late sowing in national variety evaluations which did not express the genotype (G) by management (M) advantages of the longer development phase delivered by early sowing. No milling quality winter wheats have been released during the period 2002-2017. However, in response to recent research and grower interest in earlier sowing, the wheat breeding company AGT have selected RAC2341- a photoperiod insensitive 'fast' winter wheat (obligate vernalisation requirement) from a cross between the high-yielding spring cultivar Mace and a CIMMYT-derived spring breeding line. A cultivar of this development pattern has never previously been available to growers in WA, SA or NW Victoria. The aim of this study was to ascertain when growers in southern and Western Australia are currently planting wheat, and to compare the yield and flowering time of RAC2341 with those of currently grown spring cultivars across a broad range of environments, and at sowing times currently practiced by growers.

Methods

Analysis of sowing time data from Yield Prophet® database

In order to ascertain when growers are currently planting wheat crops, sowing date records were obtained from the Yield Prophet® database. Yield Prophet® is an online commercialised version of the crop production model APSIM. It has been delivered to growers across Australia since 2004 (Hochman et al. 2009). In order to use the service, growers must enter a sowing date for their subscribed paddocks. Sowing dates for all paddocks subscribed to the service between 2008 and 2015 (3260 paddocks) were analysed according to region. Linear functions were fitted to data using least-squares regression in GenStat 18. Sowing dates for paddocks in combined regions (SA, WA, Vic, and S NSW) recorded in 2013, 2014 and 2015 were split and summed into weekly intervals.

Field experiments comparing cultivar response to time of sowing

Field experiments were conducted at four locations in the southern and western Australian wheat belt (Table 1). Each experiment had 2-4 sowing dates commencing in mid-April and ending in mid-May. Time of sowing is defined as the calendar date at which seeds become imbibed and begin the process of germination. For instance, this could be the date on which they are planted into a moist seed bed, or the date on which they received rainfall/irrigation after being sown into a dry seed bed. At each site the pre-release fast winter line RAC2341 was compared to a locally adapted elite fast-developing spring wheat (either Mace, Scout or Condo), and a mid-developing spring wheat (either Magenta, Cutlass, Kiora or Gregory). Chemical fertilisers and pesticides were applied such that nutrient limitations, weeds, pests or diseases did not limit yield.

Table 1. Field experiment sites and details.

Site	State	Year	Growing season rainfall in year of experiment (mm)	Time of sowing	Cultivars grown	Development type
Temora	NSW	2016	591	1. 14 April 2. 26 April 3. 6 May 4. 15 May	Condo Gregory RAC2341	Fast spring Mid spring Fast winter
Temora	NSW	2015	276	1. 17 April 2. 27 April 3. 7 May 4. 15 May	Condo Gregory RAC2341	Fast spring Mid spring Fast winter
Berriwillock	Vic	2015	139	1. 9 April 2. 8 May	Scout Kiora RAC2341	Fast spring Mid spring Fast winter
Minnipa	SA	2015	248	1. 13 April 2. 29 April 3. 13 May	Mace Cutlass RAC2341	Fast spring Mid spring Fast winter
Cunderdin	WA	2015	258	1. 14 April 2. 28 April 3. 22 May	Mace Magenta RAC2341	Fast spring Mid spring Fast winter

Flowering time was recorded as the time when 50% of the spikes in each plot had visible anthers. Yields were measured by machine harvest and are reported at field moisture content. All experiments were split-plot designs (whole plot = time of sowing, sub-plot = cultivar) with four replicates. Yields were analysed within sites using linear mixed models (REML) accessed via the GenStat 16 user interface with sowing date and cultivar as fixed effects and site and block structure as random effects.

Results and Discussion

Analysis of sowing time data from Yield Prophet® database

All regions showed a significant ($P>0.001$) trend toward sowing earlier with different rates of change between 2008 and 2015. In WA the rate of change was 2.4 days/year, in SA 1.8 days/year, Victoria 1.9

days/year and southern NSW 1.3 days per year. During 2013-2015 42% of paddocks from across all regions were sown prior to 10 May (Figure 1), a date which approximates optimal time of sowing for fast developing cultivars in many environments (Flohr et al. 2017). These data clearly demonstrate the demand for cultivars which can be sown early but still flower during the optimal period in a given production environment.

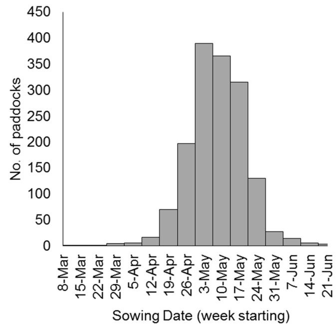

Figure 1. Number of paddocks (1549 in total) sown at weekly time intervals for combined regions (SA, Vic, WA, southern NSW) and combined seasons of 2013, 2014 and 2015 from the Yield Prophet® database.

Field experiments comparing cultivar response to time of sowing

At Temora in 2016, the fast spring cultivar Condo yielded most when sown on 15 May at 7.3 t/ha, but in a record warm growing season this was the only time of sowing for Condo to flower during the optimal period (Figure 2A). In 2015, autumn and winter were much cooler which slowed development and Condo flowered during the optimal period from three times of sowing (Figure 2B). In 2015 extreme high temperatures in the first week of October gave a large advantage to flowering at the start of the optimal window, which Condo was able to do from the 26 April sowing date (Figure 2B). In the favourable finish to the season in 2016 the mid-spring cultivar Gregory also yielded highest when sown on 15 May with 7.3 t/ha, and three out of four times of sowing flowered at the optimal time. In 2015, Gregory flowered during the optimal period from three times of sowing. In 2016 the fast winter cultivar RAC2341 achieved the highest yield out of the three cultivars at 7.5 t/ha sown on 6 May, and three times of sowing flowered within the optimal period (Figure 2A). In 2015 RAC2341 yielded most when sown on 14 April (5.5 t/ha) and three of the times of sowing flowered during the optimal period, with the last time of sowing (15 May) only just flowering outside the optimal period (11 October).

In 2015, Berriwillock (Figure 2C) experienced very low rainfall and extreme heat in the first week of October, so that Scout (fast developing cultivar) sown on 9 April flowered very early (18 August) escaping the heat, and was the highest yielding treatment in the trial. This site is an example of how in recent hot and dry seasons, sowing fast cultivars earlier than recommended has been an effective strategy to increase yields. However, it is a strategy that carries a high risk of reduced yields in frosty or higher yielding seasons. RAC2341 was able to achieve only slightly lower yield than Scout (1.57 vs 1.78 t/ha, LSD = 0.14) from the 9 April sowing date, but flowered during the optimal period for that environment (Figure 2C), thus reducing risk of frost damage and insufficient accumulation of biomass. Sown on 9 April, RAC2341 also out-yielded Scout (by 0.48 t/ha) sown at the conventional time of 8 May when both flowered at a similar time. At Minnipa the fast developing cultivar Mace yielded less than Cutlass and RAC2341 when both were sown on 13 April, and RAC2341 was the only cultivar to achieve the optimal flowering date from this time of sowing (Figure 2D). There was no difference between the three cultivars when sown on 29 April, but Mace yielded more than both cultivars when sown on 13 May. This yield response is largely explained by flowering time, as RAC2341 did not flower during the optimal period from later sowing times (Figure 2D) in warm environments such as Minnipa where it is too slow to vernalise. However, RAC2341 yields were not different to those of Cutlass at all times of sowing, despite flowering later. At Cunderdin, RAC2341 achieved a maximum yield of 3.1 t/ha at the 14 April sowing date, which was not different (LSD = 0.3 t/ha) to Magenta sown 28 April (3.3 t/ha) or Mace sown 22 May (3.3 t/ha). Plots of Mace and Magenta sown 14 April ripened early and were attacked by birds, and yields are not reported. Whilst flowering date was not recorded at Cunderdin, RAC2341 sown 28 April (2.6 t/ha) and 22 May (2.1 t/ha) yielded less than the spring wheats, implying that as at Minnipa it flowered outside the optimal period.

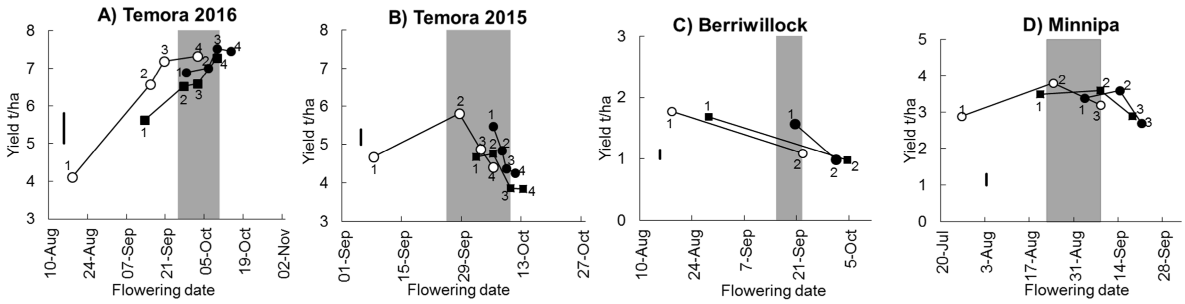

Figure 2. Mean grain yield of a fast developing winter wheat (●), fast developing spring wheat (○), and mid-fast developing spring wheat (■), cultivar details and sowing dates corresponding to numbers (1,2,3,4) for sites are shown in Table 1, plotted against flowering date at A) Temora, 2016 B) Temora, 2015 C) Berriwillock, 2015 and D) Minnipa, 2015. Grey columns are the optimal flowering period defined by Flohr et al. (2017). Thick black line is LSD. P-Value at all sites <0.001.

In the relatively cool environment of Temora, RAC2341 was consistently able to flower during the optimal period across a broad range of sowing dates (mid-April to early-May) and in seasons with contrasting temperature extremes. In this environment the potential sowing window for a fast winter wheat such as RAC2341 could extend from as early as March into mid-May, where it achieved similar yields to Gregory, a widely grown mid-developing spring type. In warmer environments such as Berriwillock, Minnipa and Cunderdin, RAC2341 was only able to flower during the optimal period when established from early to mid-April. In these environments, it is likely that RAC2341 will augment current mid and fast developing spring types by further opening the sowing window available to growers, but is unlikely to replace them.

Conclusion

Here we have shown a pre-release fast winter genotype can stabilise both flowering time and yield across a broad range of environments from the early establishment dates currently practiced by growers. Given the change in grower sowing times described here, greater breeding effort should be applied to winter cultivars with good local adaptation to different agro-ecological environments across the wheat growing areas of southern and Western Australia.

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