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# Fast winter wheat phenology can stabilise flowering date and maximise grain yield in semi-arid Mediterranean and temperate environments

B.M. Flohr[a,c,*], J.R. Hunt[b], J.A. Kirkegaard[a], J.R. Evans[c], B. Trevaskis[a], A. Zwart[a], A. Swan[a], A.L. Fletcher[d], B. Rheinheimer[a]

[a] CSIRO Agriculture and Food, GPO Box 1700 Canberra, ACT 2601, Australia
[b] Department of Animal, Plant and Soil Sciences, AgriBio Centre for AgriBiosciences, 5 Ring Rd., La Trobe University, Bundoora 3086, Australia,
[c] The Australian National University, Research School of Biology, Canberra, ACT 2601, Australia
[d] CSIRO Agriculture and Food, PB 5, Wembley, WA 6913, Australia,

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ABSTRACT

Australian wheat (*Triticum aestivum*) producers have been sowing crops earlier to adapt to reduced autumn rainfall, extreme spring weather and increasing farm size. Analysis of sowing date records indicate a shift of around 1.5 days/year over a 10 year period. The most suitable development patterns to maintain or increase yield at earlier sowing times have not been identified. Field experiments were conducted over two years at a range of sites and times of sowing (TOS), comparing a novel cultivar with fast-winter (FW) development to current elite spring and winter cultivars, and near-isogenic lines that differed only in major development genes. In cooler environments, the FW exhibited a more stable flowering time across a broader range of TOS compared to spring or slower developing winter cultivars. The optimal sowing window was shorter in warmer environments for the FW. Early-sown FW wheat yielded 8% more than fast-developing spring wheat sown later but flowering concurrently. FW wheat yielded 17% more than the elite mid-winter cultivar, and 18% more than elite slower developing spring cultivars when averaged across all TOS. The FW development pattern has potential to extend sowing periods while achieving 10–20% higher yields and flowering time stability. Wheat cultivars with altered development patterns must be developed to ensure crops flower during optimal periods from earlier sowing times.

## 1. Introduction

Global wheat yields need to increase by 38% from 2005 to 2050 to meet projected demand (Fischer et al., 2014). Australia will make an important contribution to this demand as it is one of the top ten major wheat producing countries and the fourth largest wheat exporter in the world (AEGIC, 2016). In south eastern and south west Australia, the wheat (*Triticum aestivum*) growing season traditionally extends from autumn (April–May) through to late spring. Crops are sown following the onset of autumn rains and lower temperatures, and flower and fill grain before the onset of high temperatures and terminal drought. Frost, heat and drought risk define a distinct optimal flowering period (OFP) for wheat in each region (Flohr et al., 2017). The semi-arid wheat belt of southern Australia has a predominately Mediterranean climate with hot dry summers and cool, wet winters. In this region annual rainfall ranges from 300 to 700 mm (Kirkegaard et al., 2014). There are areas in the south-eastern wheat belt where the climate is more temperate, with rainfall more evenly distributed through the year. In both temperate and Mediterranean environments the amount and variation of rainfall drives relatively low and highly variable grain yield from season to season (Hochman et al., 2017). In southern Australia, 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 required cold (vernalisation) and longer days (photoperiod) to flower were not suited to the southern Australian growing season (Pugsley, 1983) when sown on the typical sowing date. Since the release of the cultivar Federation by Farrer in 1901, Australian wheat breeders have continued to follow Farrer's lead and significant yield progress has been made by breeders selecting cultivars that develop from autumn

*Abbreviations:* FW, Fast-winter; VSS, very-slow spring; MS, mid-fast spring; FS, fast-spring; MW, mid-winter; OFP, optimal flowering period; TOS, time of sowing; VD, vernal days

* Corresponding author at: GPO Box 1700, Canberra, ACT 2601, Australia.
*E-mail addresses:* bonnie.flohr@csiro.au (B.M. Flohr), J.Hunt@latrobe.edu.au (J.R. Hunt), john.kirkegaard@csiro.au (J.A. Kirkegaard), john.evans@anu.edu.au (J.R. Evans), ben.trevaskis@csiro.au (B. Trevaskis), alec.zwart@data61.csiro.au (A. Zwart), tony.swan@csiro.au (A. Swan), andrew.fletcher@csiro.au (A.L. Fletcher), brad.rheinheimer@csiro.au (B. Rheinheimer).

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establishment to flower during the optimal period (Richards et al., 2014). The Millennium Drought experienced in Australia 1996–2009 (Verdon-Kidd et al., 2014), provided an additional impetus to breed fast developing wheats that could be sown after adequate autumn rainfall and mature quickly before the onset of terminal drought. Today, the most widely grown genotypes continue to be those with little photoperiod or vernalisation sensitivity, with fast-spring (FS) and mid-spring (MS) phenology types dominating grain deliveries in the 2015/16 growing season (GrainCorp, 2016).

Wheat yield gain in Australian has stalled since 1990, which has been attributed to reduced rainfall and rising temperatures, but balanced by improvements in technology (Hochman et al., 2017). Additionally, since the mid 1990′s, "breaking" rains that could once be relied upon to establish crops in autumn (April–May) have declined significantly (Pook et al., 2009; Cai et al., 2012). In response to changing rainfall patterns, extreme spring temperature events, increasing farm size, new technologies and availability of herbicides, Australian wheat producers are sowing progressively earlier (Stephens and Lyons, 1998; Anderson et al., 2016; Fletcher et al., 2016), though the extent of this practice change has not been comprehensively quantified. In drought-prone environments it is critical to optimise sowing such that the crop life-cycle accommodates flowering under optimal conditions to maximise yield (Bodner et al., 2015). Commonly grown FS genotypes incur high risk of flowering outside the OFP if sown too early, and suffer yield reductions due to frost damage and/or insufficient biomass accumulation. If sown too late, they risk yield loss through exposure to water and heat stress during the critical period for yield determination (Flohr et al., 2017). Flohr et al. (2017) have proposed that new robust genotype (G) by management (M) strategies need to be developed to stabilise flowering time and yield over wide sowing windows under current and future climates. Growers have already identified that sowing earlier is a beneficial management strategy to increase yield (Fletcher et al., 2016), but now require new elite genotypes with life-cycles that align earlier sowing dates with the OFP to maximise yield.

Wheat's wide adaptability and success around the world can largely be attributed to manipulation of flowering time to suit different growing environments. Three main gene systems control flowering in wheat, vernalisation (response to low temperatures, Trevaskis, 2010), photoperiod (response to day length, Slafer and Rawson, 1995) and earliness *per se* (temperature accumulation, Sukumaran et al., 2016). Vernalisation sensitivity has been noted as a key requirement for cultivars in northern latitudes e.g. cool temperate areas of continental Europe and North America, to ensure sensitive floral organs are not damaged by extreme low temperatures (Kamran et al., 2014), though the concept of breeding well-adapted vernalisation sensitive cultivars to environments with distinct OFP such as North Africa and West Asia has been discussed internationally (Fujita et al., 1992). Vernalisation sensitivity extends the vegetative phase of the plant, delaying reproductive development until the cold requirement has been saturated by an adequate number of vernal days (Porter and Gawith, 1999), and is considered saturated when the plant apex reaches double ridge (Fig. 1, Kirby and Appleyard, 1981). 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) and Coventry et al. (1993) also demonstrated that winter genotypes sown early could yield at least as well, if not better than FS genotypes sown later.

Winter genotypes (obligate vernalisation requirement) do exist in Australian wheat germplasm, but were previously overlooked by growers, agronomists, breeders and researchers due to the 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 2002–2016 (Hunt, 2017). In response to recent research and grower interest in earlier sowing, the wheat breeding company Australian Grains Technology (AGT) have selected Longsword – a photoperiod insensitive 'fast' winter (FW) wheat (obligate vernalisation requirement but short development phase from double ridge to anthesis) from a cross between the high-yielding spring cultivar (Mace) and a CIMMYT-derived spring breeding line. New FW cultivars with better adaptation than those currently available to growers (e.g. Longsword) will further increase benefits to growers, particularly those on mixed farms where dual purpose grazing is possible (Bell et al., 2015; Frischke et al., 2015). A cultivar with this development pattern has never previously been available to growers in Western Australia (WA), South Australia (SA) or north western Victoria (Vic, Hunt, 2017).

The aim of this study was to ascertain when growers in southern and western Australia are currently sowing wheat, and to compare the yield and flowering time of Longsword with those of currently grown spring and winter cultivars across a broad range of environments, and at sowing times practiced by growers. In order to isolate the specific impact of crop phenology, the experiment also included related cultivars (near-isogenic lines) that differed in flowering time but were otherwise genetically similar.

## 2. Materials and methods

### 2.1. Analysis of wheat sowing time using the Yield Prophet® database

In order to investigate trends in sowing dates for wheat, the sowing date records were obtained from the Yield Prophet® database. Yield Prophet® is an online commercialised version of the crop production model APSIM (Holzworth et al., 2014), and is used by farmers to make real-time assessments of crop water and fertiliser requirements and seasonal yield potential. 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 fields. Regardless of how many seasons' growers had been subscribed for, sowing dates for all fields sown to wheat and subscribed to the service between 2008 and 2015 (3260 fields) were analysed according to region. Linear functions were fitted to mean sowing dates using least-squares

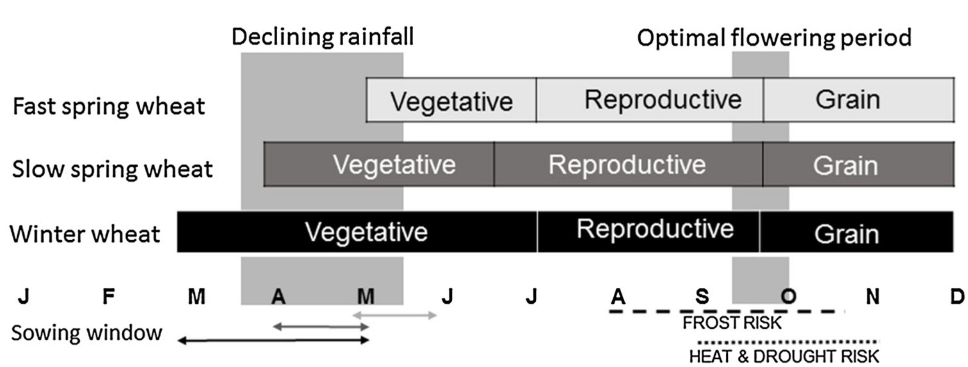


**Fig. 1.** Duration and timing of the different development phases of winter wheat, fast and slow developing spring wheat in relation to the months of the year, typical optimal sowing windows and flowering period for southern Australia (Flohr et al., 2017) and the autumn period during which rainfall has recently declined in southern Australia (Cai et al., 2012).