Managing frost and heat risk using wheat variety mixtures

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Abstract
Although there is a site specific optimum flowering window for wheat crops that balances the risks of frost, heat, terminal drought, frost and heat events are unpredictable leaving farmers uncertain about which wheat phenology to sow. Wheat variety mixtures that contain genotypes with different phenologies can mitigate this risk. Three varieties; Yitpi (long-season), Mace (mid-season) and Tammarin Rock (short-season); and each of the two and three variety mixtures; were sown on 8 May (early-sowing), 23 May (mid-sowing) and 2 Jun (late-sowing) 2015 at Brookton (WA) to expose the crops to varying degrees of frost around flowering and heat stress during grain filling. There were 14 frost events between 25 Aug and 11 Oct; and 15 heat events between 24 Sep and 31 Oct that coincided with flowering and grain filling, respectively. As expected, the long-, mid- and short-season varieties had the highest yields in the first-, mid- and late-sowing, respectively. A quadratic relationship between peak flowering date and yield showed that the optimum flowering window was from 7 to 25 Sep. For a given sowing date, the mixtures had yields that were intermediate between their component varieties, because they had a wider flowering spread than the single varieties. This meant that across the three sowing dates the mixtures had less yield variability than the single varieties. This research has demonstrated that wheat variety mixtures can stabilise the variable risks of frost, heat and drought stress in a frost prone environment.

Keywords
Sowing date, flowering window, shandy, blend, cereal.

Introduction
Flowering is a key factor determining crop adaptation to environment (Ludwig et al. 2009, Berger et al. 2016). For wheat crops in Australia there is an optimum flowering time that maximises yield and minimises risk to yield (Shackley 2000). This optimum is achieved by matching sowing time and appropriate crop phenology. Crops that flower before this optimum are subject to increased risk of frost, which has become an important factor limiting wheat productivity in Australia (Crimp et al. 2016), and may not accumulate enough biomass to ensure high yields. In contrast, crops that flower after this optimum are subject to an increased risk of heat stress and may encounter a terminal drought which limits yield.

In reality, the optimum flowering date varies between sites and from season-to-season depending on the prevailing weather conditions. Furthermore, the process of crop sowing often takes many days to complete on a farm and obtaining this optimum flowering date across large areas is impossible. Therefore, farmers often aim for a flowering window that reaches 80% of maximum yield across multiple seasons (Shackley 2000). However, due to the variable climate, a single frost or heat event may have a major impact on yield.

Wheat is a determinate crop that flowers over a relatively short time frame. Sowing a mixture of wheat varieties with different phenologies may help to mitigate the risks of a single frost or heat event (Sharma et al. 2011, Fletcher et al. 2016). Variety mixtures have been used previously as a way of managing crop disease in cereals due to increased genetic diversity (Kiaer et al. 2009). Mixtures can potentially buffer the impacts of water deficits on wheat crops (Adu-Gyamfi et al. 2015). In this paper we examine the potential to use wheat variety mixtures with varying phenology to increase yield stability in a variable frost prone Mediterranean environment. We used three sowing dates to mimic an environment with variable instance of frost around flowering and heat stress during grain filling.

Methods
Experimental
The experiment was located 30 km East of Brookton (32.38°S, 117.32° E) in the WA wheat belt. This location has a mean annual rainfall of 420 mm with frequent spring frosts. The site was chosen because it was low in the landscape and was frost prone. The experiment was sown into a low amount of Canola

stubble. The experiment was a split-plot design in randomised blocks with 4 replicates. The main plots were three sowing dates (8 May, 23 May and 2 Jun, representing early-, mid- and late-sowing, respectively) and the sub-plots were a combination of three spring wheat varieties (Yitpi: long-season, Mace: mid-season and Tammarin Rock: short-season) and each of the two (3 combinations) and three way (1 combination) mixtures of these varieties. Sowing dates were chosen to expose the varieties and mixtures to varying degrees of frost around flowering and heat stress during grain filling. Sowing rates were adjusted so that all treatments had a target population of 160 plants/m^2. Row spacing's were 25.4 cm. Equal amounts of each component were sown in the mixtures with the aim of producing a total population of 160 plants/m^2.

Soil nutrients, with the exception of N were all adequate for crop growth (Table 1). A total of 92 kg/ha of N was applied in the form of 100 kg/ha Urea (46% N) and 120 kg/ha Gusto Gold (10.2% N) applied before sowing and 80 L/ha of UAN (42.2% N) applied post emergent. Weeds were controlled by a mixture of preemergent (Sakura, Trifluralin, Diuron and Glyphosate) and post emergent (, Velocity and Boxer Gold) herbicides. Insect pests were controlled with a combination of preemergent (Chlorpyrifos and Bifenthrin) and post emergent (Transform) insecticides. Fungal diseases were controlled with Prosaro.

Table 1. Soil test results prior to planting.

Depth	Ammonium N (mg/kg)	Nitrate N (mg/kg)	Colwell P (mg/kg)	Colwell K (mg/kg)	Sulphur (mg/kg)	Organic C (%)	pH ($CaCl_2$)
0-20 cm	2	8	33	36	9.1	0.71	4.6
20-40 cm	2	4	8	54	17.7	0.24	5.3

From each plot a 0.54 m2 quadrat (2 × 1m row length) was cut at ground level on 10 Nov 2015. Samples were oven dried and weighed before being threshed to determine grain yield. Flowering was monitored every 2-5 days between 25 Aug and 5 Oct. At each monitoring date a visual estimate was made of the proportion of wheat ears that had visible anthers that were undergoing dehiscence. These data were used to determine the date of peak flowering for the single variety treatments by fitting a 3-parameter Gaussian curve to the pooled replicate data for each treatment using Sigmaplot 13.0 (Systat Software Inc).

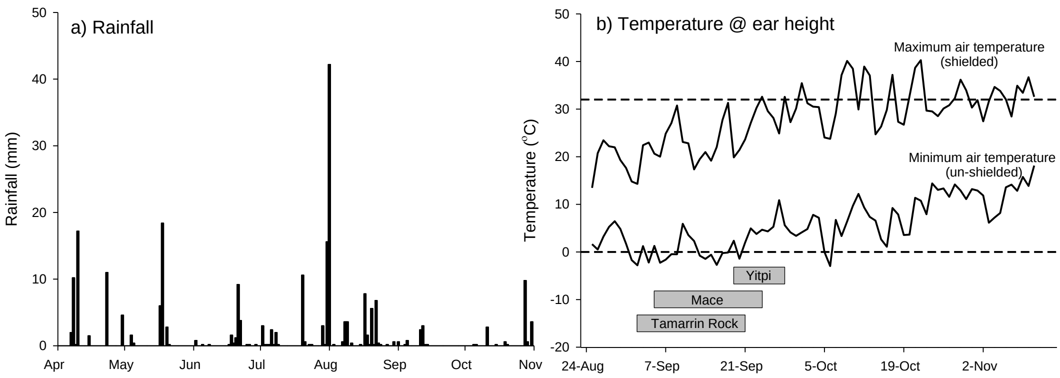

Figure 1. Growing season rainfall (a) and maximum and minimum air temperatures at the height of the wheat ears at Brookton in 2015. The dotted lines indicate the thresholds of 0°C and 32°C for frost and heat events, respectively. The grey bars represent the flowering periods for the single variety treatments across the three sowing dates.

Weather data

Weather data was obtained from a nearby meteorological station. In addition the maximum (shielded) and minimum (unshielded) air temperature at the height of the wheat heads was measured using Onset HOBO V2 external temperature loggers, between 25 Aug and 11 Nov. Cumulative growing season (Apr to Oct) rainfall during the experiment was 233 mm (Figure 1). In Sep there were 14 nights where the minimum air temperature at ear height fell below 0°C. This coincided with the range of flowering dates obtained in the experiment (Figure 1b). Between 24 Sep and 31 Oct there were 15 days where the maximum air temperature exceeded 32°C. This coincided with the grain filling period for the single variety treatments in the experiment.

Results

There was a significant interaction (p<0.001) between sowing date and variety for grain yield. Yields of the single varieties followed the expected pattern (Figure 2a). For the early-sowing date the long season variety (Yitpi) had the highest yield, followed by the mid-season variety (Mace), with the short season variety (Tammarin Rock) having the lowest yield. At the mid-sowing date there were far fewer differences between varieties with the long- and mid-season varieties having similar yields and then the short season variety yielded less than the mid-season variety. When sown late, the short and mid-season varieties had similar yields with the long season variety having the lowest yield.

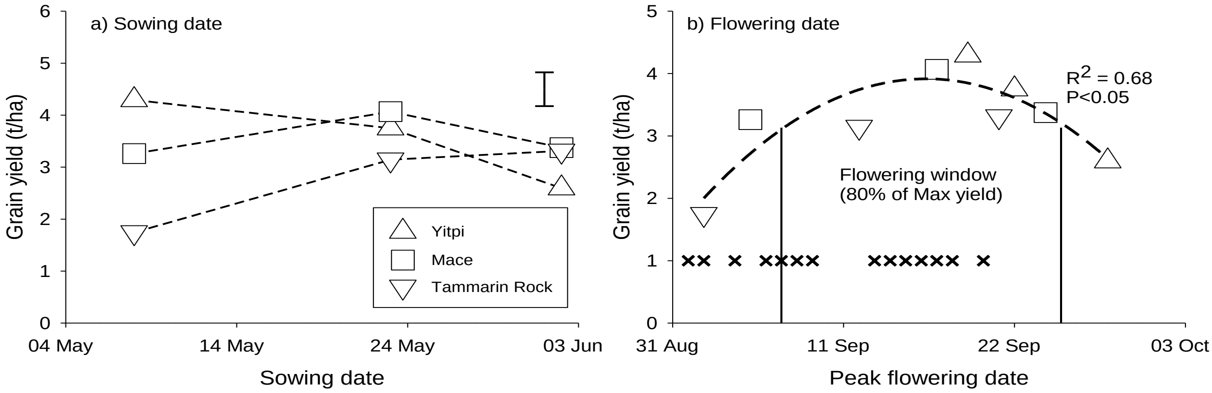

Figure 2. Effect of sowing (a) and flowering (b) date on yield of three wheat varieties at Brookton in 2015. The error bar is 1 least significant difference (with 36 d.f.) for comparing between varieties within the same sowing date. (The crosses represent individual frost events where air temperature at ear height fell below 0°C).

These yield differences were explained by a quadratic relationship ($r^2 = 0.68$, $p<0.05$) between peak flowering date and yield (Figure 1b). The highest yield of 3.92 t/ha was achieved when flowering occurred on 16 Sep. The flowering window which achieved 80% of maximum yield was between 7 and 25 Sep. Interestingly, this optimum flowering window coincided with a period with a large number of frosts. Unfortunately, this relationship is site and season specific and it is likely to vary considerably in different seasons depending on rainfall and the occurrence of frost, heat and terminal drought.

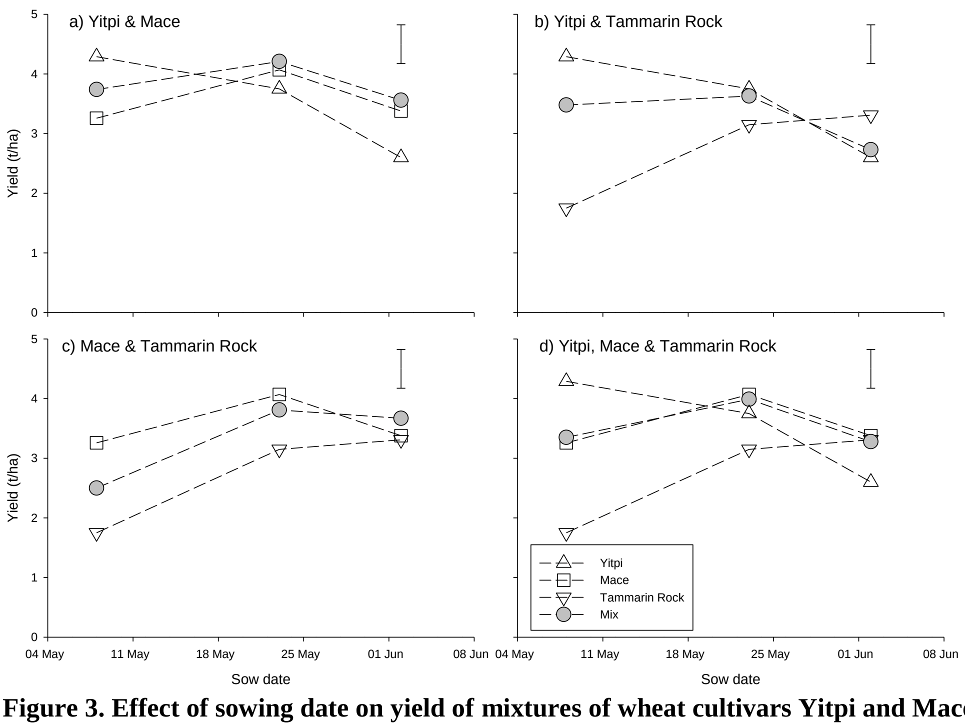

Figure 3. Effect of sowing date on yield of mixtures of wheat cultivars Yitpi and Mace (a), Yitpi and Tamarrin Rock (b), Mace and Tammarin Rock (c) and Yitpi, Mace and Tammarin Rock (d). For comparison, each single variety yield is repeated from Figure 1a. The error bar is 1 least significant difference (with 36 d.f.) for comparing between varieties within the same sowing date.

For the early sowing date, the mixtures had yields that were the average of their component varieties (Figure 3). However, for the middle and late sowing dates the mixtures had yields similar to the higher yielding component variety. Thus, across the three sowing dates the mixtures had far less yield variability than the single varieties. For example, the mean yield for the Yitpi-Tammarin Rock mixture was 3.28 t/ha with a CV of 15%. However, the mean yields of single Yitpi and Tammarin Rock crops were 3.55 t/ha and 2.74 t/ha with CVs of 24 and 31%, respectively. This was because the mixtures spread the risk of frost occurring during flowering by having a much wider spread of flowering (e.g. Figure 4). Across all three sowing dates the mixture of Yitpi and Mace was the highest yielding.

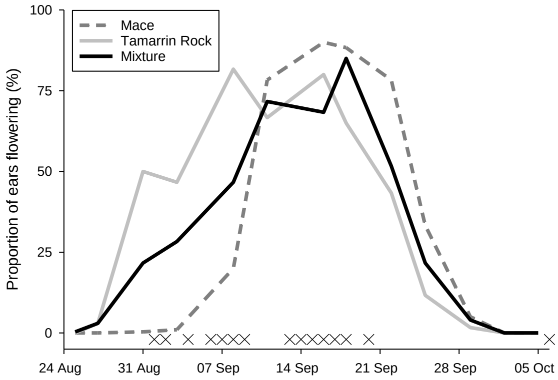

Figure 4. Time course of flowering for Mace, Tammarin Rock and a Mace-Tammarin Rock mixture sown on 23 May 2015 at Brookton. (The crosses represent individual frost events where air temperature at ear height fell below 0°C).

Conclusion

This research has demonstrated that wheat variety mixtures containing genotypes with varying phenologies can be used to mitigate the variable risks of frost, heat and drought stress in a frost prone environment, thereby stabilise yields. By having multiple flowering times in a single paddock the risk of a single frost or heat event impacting the crop during flowering is increased, however, the impact of each event on total yield is reduced. This approach is particularly relevant to paddocks that are low in the landscape and frequently impacted by frost.

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References

Adu-Gyamfi P, Mahmood T and Trethowan R (2015). Can wheat varietal mixtures buffer the impacts of water deficit? Crop and Pasture Science 66, 757-769.

Berger J, Palta J and Vadez V (2016). Review: An integrated framework for crop adaptation to dry environments: Responses to transient and terminal drought. Plant Science 253, 58-67.

Crimp SJ, Zheng BY, Khimashia N, Gobbett DL, Chapman S, Howden M and Nicholls N (2016). Recent changes in southern Australian frost occurrence: implications for wheat production risk. Crop and Pasture Science 67, 801-811.

Fletcher AL, Kirkegaard JA, Peoples MB, Robertson MJ, Whish J and Swan AD (2016). Prospects to utilise intercrops and crop variety mixtures in mechanised, rain-fed, temperate cropping systems. Crop and Pasture Science 67, 1252-1267.

Kiaer LP, Skovgaard IM and Ostergard H (2009). Grain yield increase in cereal variety mixtures: A meta-analysis of field trials. Field Crops Research 114, 361-373.

Ludwig F, Milroy S and Asseng S (2009). Impacts of recent climate change on wheat production systems in Western Australia. Climatic Change 92, 495-517.

Shackley BJ (2000). Crop management. In: The wheat book. Principles and practices. W. K. Anderson and J. R. Garlinge Eds. Agriculture Western Australia. pp. 131-164.

Sharma DL, Peek C, Riethmuller G and Pasqual G (2011). Building flexibility in cropping system through a variety shandying approach. In: GRDC Agribusiness Crop Updates, 2012 Burswood WA, 263-266.