The critical period for yield determination in chickpea

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Abstract

Chickpea is the most important grain legume crop in Australia; however biotic stresses such as Aschochyta blight and abiotic stress such as water and heat stress cause yield instability. Yield responds to the intensity, timing and duration of the stress. Crop species have a specific critical period for yield determination, where vulnerability to stress is greatest. The critical period for chickpea is previously unreported. To bridge this gap we exposed two chickpea varieties, PBA Slasher and PBA Boundary to sequential 14 day shading periods and compared their yield to the yield of unshaded controls in three different environments. Unshaded controls yielded between 2.9 and 3.1 t ha-1. Shade treatments reduced yield early in the season from emergence to the beginning of the critical period, 300◦Cd before flowering (base temperature = 0◦C), which differs from other species such as field pea and lupin which showed no early season yield loss. The critical period was centered 100◦Cd after flowering and was at least 800◦Cd duration. The majority of yield variation was accounted for by seed number, which was not related to seed size. The majority of the variation in seed number prior to the critical period was accounted for by pod number, while within the critical period seeds per pod also accounted for variation in seed number. Around the end of flowering, 400◦Cd after beginning of flowering, seeds per pod was the main component accounting for variation in seed number.

Keywords

Yield determination, critical period, yield components, stress, seed number, seed size

Introduction

Chickpea (*Cicer arietinum* L.) is grown predominantly in south Asian and Mediterranean environments where yield is constrained by abiotic stresses such as water deficit and extreme temperatures (Knights and Siddique, 2003, Kashiwagi et al., 2006, Leport et al., 2006). The effect of abiotic stresses on crop yield depends on the intensity, timing and duration, emphasising the importance of determination of the critical period for yield determination in major crops. Species specific critical periods have been determined for cereals; wheat, barley, triticale and maize, sunflower and the grain legumes; soybean, peas and lupin. In cereals the critical period has been commonly identified around the stage leading up to anthesis in barley (Arisnabarreta and Miralles, 2008), has extended into flowering for wheat and triticale (Estrada-Campuzano et al., 2008, Fischer and Stockman, 1980, Fischer, 1985), and even further post anthesis for maize (Cerrudo et al., 2013). In grain legumes, the majority of the critical period occurs further into seed set and filling with soybean identified as R1 (beginning of flowering) to R5 (beginning of seed set) and 10 days before R1 to R5 for lupin and field pea (Jiang and Egli, 1995, Board and Tan, 1995, Sandaña and Calderini, 2012).

The aim of this study was to determine the critical period for yield determination in chickpea using the most common method, sequential periods of shading to cause source reduction.

Methods

Plant material, environments and experimental design

Two chickpea varieties (PBA Slasher and PBA Boundary) were grown in three environments.: Roseworthy (34º52’S, 138º69’E) sown on 7th June, Turretfield (34º33’S, 138º49’E) at recommended sowing date (14th June – TOS 1) and Turretfield late sown (9th of July – TOS 2). Daily weather data was obtained from the Queensland Government, Long Paddock website (http://www.longpaddock.qld.gov.au/silo/). Thermal time was calculated from daily mean temperature using a base temperature of 0ºC (Berger et al., 2006).

A split-plot design with four replicates was used where varieties were allocated to main plots and shading treatments, including unshaded controls, to randomised subplots. Shading treatments lasted for 14 days each, and were designated sequentially from 1 to 8, starting at 31 days (353 ºCd) after sowing at Roseworthy and

24 days (251 ^{o}Cd) after sowing at Turretfield TOS 1. Turretfield TOS 2 had a shorter growing season and had 6 shading treatments in sequence beginning 35 days (399 ^{o}Cd) after sowing. Plants were hand harvested at maturity. The shades were constructed from black shade cloth that intercepted 90% of solar radiation.

Traits
Weekly phenology observations recorded time of first flower (FF), fifty percent flowering (50F), pod emergence (PE), and end of flowering (EOF). Maturity was scored when 50% of pods in a plot had matured. Phenological stages are expressed on a thermal time scale. Yield and yield components were measured including pod number, pod weight, seed size, seeds per pod, shoot biomass and the derived traits pod wall ratio PWR (pod wall weight/ whole pod weight, (Sadras et al., 2013) and harvest index HI (seed /shoot biomass).

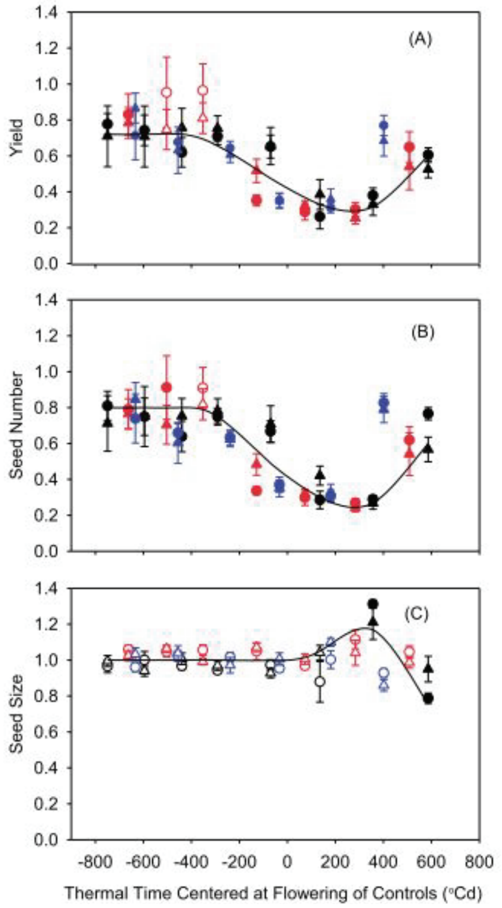
Results
Seed yield and components
There was no difference between the yield and yield components of PBA Boundary and PBA Slasher in any of the environments with the exception of seed number and seed size at Turretfield. Shading affected yield and all yield components, with the exception of Turretfield TOS 1, where seed size and pod wall ratio where unaffected. There was no interaction between shade and variety on any trait, except seed size at Roseworthy and Turretfield TOS 2. Yield had a strong positive correlation with both biomass and harvest index. The relationship between harvest index and biomass varied between environments, with a positive relationship at Turretfield and no relationship at Roseworthy. Yield was closely related to seed number and unrelated to seed size. Seed number was related with both pod number and seeds per pod, but the relationship was stronger with pod number, reflecting the greater plasticity of this trait.

Critical period
The effect of time of shading on yield and yield components was consistent for both varieties and was consistent across environments on a phenological scale (Figures 2, 3). Yield decreased for most shading treatments, with reductions in response to early shading of between 20 and 30% up to approximately 300oCd before flowering. The greatest reductions started approximately 300oCd before flowering and increased to 75% approximately 200oCd after flowering (Fig. 2A). After this critical point, yield increasingly recovered toward maturity. The most critical period for yield determination, with a reduction of at least 40%, spanned the window of 800oCd centred 100oCd after flowering.

Reduction in yield was almost fully accounted for by reduction in seed number (Fig. 2A vs 2B). Seed size was largely unaffected by shading except for a ~20% increase when shade was imposed 200-300 oCd after flowering and a ~20% decrease after this time (Fig. 2C). Seed number correlated with both pod number and seeds per pod, with no trade-off between the components of seed number. Comparison of Figures 2B and 3 shows that reduction in seed number was associated with (i) pod number from crop establishment until ~450 oCd after flowering, (ii) both pod number and seeds per pod between ~300 oCd before and ~450 oCd after flowering, and (iii) seeds per pod after ~450 oCd after flowering. Reductions in seed per pod were the result of both empty pods and fewer seed per pod.

Discussion
The critical period for chickpea differed with other grain legumes such as lupin, field pea and soybean, where the majority of the critical period occurs after flowering (Sandaña and Calderini, 2012, Jiang and Egli, 1995, Board and Tan, 1995). The reasons for the broader critical period in chickpea are unknown, and deserve further research.

The response of seed number and seed size to shading was in accordance with empirical evidence and current theory of crop yield determination (Sadras and Denison, 2009, Sadras, 2007, Sadras and Slafer, 2012, Andrade et al., 2005). A significant increase in seed size was associated with shading around pod emergence. This may be due to preferential carbohydrate partitioning to developing seeds that have passed the final stage in seed abortion (Munier-Jolain et al., 1998), rather than younger flowers and embryos. Pod number contributed more to the variation in seed number than seeds per pod. This is expected from the relatively low variation in seeds per pod in chickpeas compared to other legumes.



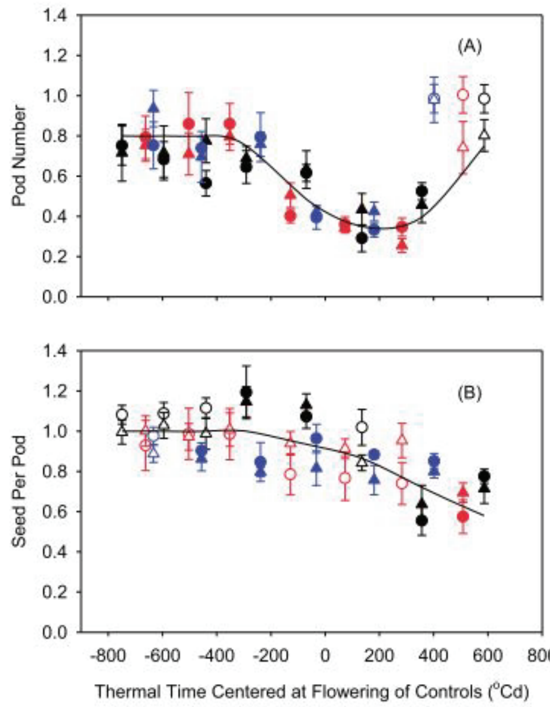


Fig. 1. Effect of timing of shading on (A) yield, (B) seed number and (C) seed size of chickpea PBA Boundary (circles) and PBA Slasher (triangles) compared to unshaded controls, at Roseworthy (black), Turretfield TOS 1 (red) and (C) Turretfield TOS 2 (blue). Open symbols are not significantly different from the control, while closed symbols are significantly different. The lines are spline curves fitted by eye. Error bars are ±S.E and are not shown when smaller than symbol. The phenological scale is based on the unshaded controls.

Fig. 2. Effect of timing of shading on (A) pod number and (B) seeds per pod for chickpea PBA Boundary (circles) and PBA Slasher (triangles) compared to unshaded controls, at Roseworthy (black), Turretfield TOS 1 (red) and Turretfield TOS 2 (blue). Open symbols are not significantly different from the control, while closed symbols are significantly different. The lines are spline curves fitted by eye. Error bars are ±S.E and are not shown when smaller than symbol. The phenological scale is based on the unshaded controls.

Conclusions

This research has identified the critical period for yield determination and the associated critical periods for yield components. This knowledge will allow for more targeted stress mitigation practices, e.g. combining sowing date and cultivar phenology to reduce the likelihood of severe stress in the critical window. Increased knowledge of the critical period will also enhance the ability of breeders to screen for stress tolerance with more targeted stress impositions.

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