The critical period of canola: impacts of environment and variety

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Abstract
The critical period of a crop is the physiological stage in which abiotic stresses have the largest impact on yield determination through the influence on grain number and size. We conducted field experiments at two locations in southern Australia at Wagga Wagga (NSW), and Riverton (SA) over a three-year period (2016-2018) to identify the critical period in canola. We applied successive 100 °Cd shading periods (15 % PAR transmitted) from early vegetative growth until maturity for different variety types (hybrid, conventional, TT, rate of phenological development) and sowing times across the 5 site-years of experiments. Despite the significant difference between the experiments for yield in the unshaded control (180-450 g/m^2), the critical period remained consistent, between 100 to 500 °Cd after the start of flowering. Confirmation of the critical period under a range of genotypes and environments provides confidence in its use in ongoing agronomic and genetic studies to improve canola productivity.

Keywords
Stress, yield components, seed number, seed size, oil content.

Introduction

Canola (*Brassica napus* L.) is the third most important oilseed produced globally and its area of production is expanding from relatively reliable growing areas in which it is well adapted, into more marginal and drier areas. Climate change is predicted to increase the future exposure of canola to abiotic stress such as temperature extremes and water deficit (Dreccer et al. 2018). As a result, there is an increasing need to understand the effects of the intensity, timing and duration of stress on yield determination to target breeding and management strategies to maintain or increase canola productivity.

The critical period for yield determination is defined as the physiological stage in which abiotic stresses have the largest impact on yield determination (Robertson et al. 1934). Critical periods are typically determined using successive and discrete periods of shading to reduce the photosynthetic assimilates available for growth, mimicking the effects of abiotic stresses. The critical period for yield determination has been defined in this way for numerous crops including cereals, grain legumes and sunflower however previous studies on canola either had confounding effects on yield or they used different intensity, timing and durations of shading which did not elucidate a clear critical period. The study of Kirkegaard et al. (2018) defined a discrete critical period most sensitive to stress from 100 to 500 °Cd after the start of flowering (BBCH 60), centred 300 °Cd after BBCH 60. That study involved shading experiments on a single variety at two different locations in southern Australia in 2016. Here we present a combined analysis of the Kirkegaard et al. (2018) study and three additional field experiments using similar protocols but using cultivars with a range of vigour, phenological development and herbicide tolerance. The aim was to confirm that the critical period for yield development of canola was consistent for diverse varieties under different seasonal conditions.

Methods

Field experiments were carried out in 2016 (Kirkegaard et al. 2018), 2017 and 2018 in two regions of south-eastern Australia: In each year a site was chosen near Wagga Wagga in southern New South Wales (NSW) and Riverton in South Australia (SA). Detailed description of the field experiments in 2016 can be found in Kirkegaard et al. (2018). In all experiments, canola was sown in plots 4 m to 12 m in length and 1.5 m wide comprising 6 rows spaced 0.25 m apart. The crops were managed using recommended agronomy to manage weeds, pests and diseases and were fertilised to avoid nutrient limitations to growth. In all experiments, crops received N and P as starter fertiliser at sowing and were topdressed with urea in winter. Sowing date, cultivar, starting soil N and fertiliser addition is shown in Table 1.

Table 1. Details of location, cultivars and agronomic management for 5 site-years of experiments.

Year	Site	Latitude Longitude	Cultivar	Sowing Date	In crop rainfall (mm)	Initial soil N (kg/ha)	Fertiliser N (kg/ha)	Harvest Date
2016	Wagga Wagga, NSW	-34.96 147.31	44Y89 (CL)	2 May	573	133	211	8 Nov
2016	Riverton, SA	-34.12 138.76	44Y89 (CL)	3 May	502	124	100	7 Nov
2017	Wagga Wagga, NSW	-34.89 147.31	44Y89 (CL)	27 Apr	196	154	77	14 Nov
2017	Wagga Wagga, NSW	-34.89 147.31	Bonito (TT)	27 Apr	196	130	77	14 Nov
2017	Riverton, SA	-34.12 138.76	44Y89 (CL)	2 May	284	43	100	3 Nov
2017	Riverton, SA	-34.12 138.76	Bonito (TT)	2 May	284	43	100	6 Nov
2018	Wagga Wagga, NSW	-35.05 147.35	Archer	4 Apr	170	158	150	5 Nov
2018	Wagga Wagga, NSW	-35.05 147.35	Diamond	14 May	144	158	150	5 Nov

In 2016, the shading treatments commenced around 30 days after sowing (DAS) at Wagga Wagga and 48 DAS at Riverton which corresponded to the 4-6 leaf stage at both sites and continued to physiological maturity (15 shade timings at Wagga Wagga and 14 at Riverton). In 2017, the number of shading periods was reduced to 5 due to limited resources, and shade treatments commenced later, around the start of flowering - 120 and 106 DAS in Wagga Wagga and Riverton, respectively. Two cultivars with similar rates of phenological development were sown. The same hybrid as the previous year (44Y89 CL) was sown and an open pollinated triazine tolerant cultivar, Bonito. Bonito has a lower yield potential that 44Y89 as triazine tolerance is known to decrease crop vigour while hybridity increases vigour (Robertson and Lilley, 2016). In 2018, the experiment was conducted at Wagga Wagga and 7 shade treatments were applied, commencing before the start of flowering at around BBCH 55. Two cultivars with different rates of phenological development were sown on different dates to match the flowering date and environmental conditions at the same stage of phenological development. The slow-developing hybrid, Archer was sown on 4 April, and fast developing hybrid, Diamond was sown 40 days later on 14 May. Shade treatments commenced 135 and 95 DAS respectively for Archer and Diamond. Treatments were arranged in a randomised complete block design in each experiment with four blocks, and the shaded areas (2 m x 3 m Wagga Wagga; 2 m x 1.5 m Riverton) were established within the randomised plots in each block. Shading (85 % PAR excluded) was applied with stabilised nylon net set onto steel frames that were mobile, and height adjustable as the crop grew.

Crop phenology was recorded weekly using the BBCH development code (Meier, 2001) and the start of flowering was taken when 50 % of plants had one open flower (BBCH 60). The phenology was reported in thermal time (°Cd), using a base temperature of 0 °C. Bordered quadrats comprising the central 4 rows (1 m^2 in 2016, 1 m^2 at Riverton in 2017 and 2 m^2 at Wagga Wagga in 2017 and 2018) were sampled from each shaded area of the plots at maturity and oven dried to determine biomass, seed yield and yield components. A subsample of seed was analysed for oil content and protein in 2016 and 2018. Weather data (rainfall and temperature) was collected from each site using automatic weather stations while radiation data was sourced from patched point data from the Bureau of Meteorology. Statistical analyses to compare the effects of shading treatments are described in Kirkegaard et al. (2018). The yield, its various components along with seed oil and protein were expressed as a ratio of the unshaded control for each timing of shading.

Results and Discussion

In 2016, in-crop rainfall exceeded 500mm at both sites (Table 1) and crops were not limited by water or nutrient stress producing high yields in the unshaded treatment (Table 2). As a result, shade periods were the main yield limitation in the imposed treatments. In 2017 and 2018, rainfall was significantly lower and biomass production and yield were limited by water stress and the imposed shading treatments. This was particularly noticeable at Wagga Wagga in 2017 where yield of 44Y89 was approximately half of that achieved in 2016. Yield reduction was less at Riverton in 2017 and Wagga Wagga in 2018. The yield and biomass production of the open pollinated TT cultivar Bonito was 18-24 % less than that the hybrid 44Y89, typical of the reduction reported by others (Robertson and Lilley, 2016). In 2018, in-crop rainfall was even lower (140-174 mm, Table 1) however yields were slightly greater than the previous year with Archer (longer growing season) yielding more than Diamond (4 and 3 t/ha, respectively; Table 2).

Table 2. Average canola yield and yield components for the unshaded controls in five experiments at Wagga Wagga, NSW and Riverton SA in 2016, 2017 and 2018.

Year	Site	Cultivar	Start of Flowering	Yield (g/m^2)	Biomass (g/m^2)	Seed (‘000/m^2)	Seed size (mg)	Seed oil (%)	Seed protein (%)	Oil yield (g/m^2)
2016	Wagga	44Y89	18 Aug	453	1347	133	3.39	44.8	19.7	203
2016	Riverton	44Y89	22 Aug	340	1252	93	3.65			
2017	Wagga	44Y89	25 Aug	225	843	72	3.14			
2017	Wagga	Bonito	27 Aug	172	691	44	3.94			
2017	Riverton	44Y89	16 Aug	311	972	104	3.02			
2017	Riverton	Bonito	18 Aug	260	816	83	3.14			
2018	Wagga	Archer	23 Aug	400	1454	121	3.31	43.9	22.9	176
2018	Wagga	Diamond	3 Sep	302	1178	99	3.05	39.3	23.6	119

Kirkegaard et al. (2018) concluded from the shading periods imposed in 2016 (from early vegetative growth until close to maturity) that the critical period for yield determination in canola occurred between 100 and 500 °Cd after flowering (Figure 1a). In 2017 shading periods did not extend across the entire critical period. For cultivar 44Y89, the greatest yield reduction was caused by the last shade period (around 400 °Cd after flowering) and as shade was not imposed around 500 to 600 °Cd after flowering there was no evidence of late grain-filling insensitivity to shade. However, cv. Bonito did not appear as sensitive to shading during the critical period, with increased seed size compensating more fully for the reduced grain number (Fig. 1 c, g, k). In 2018, shading treatments were imposed later into the grain filling period and shading occurred across the full duration of the previously defined critical period. While the relative reduction in yield was smaller in 2018 (20 % in 2018 *cf.* 40 % in 2016), both Archer and Diamond responded to timing of shading in a similar pattern to 44Y89.

Kirkegaard et al. (2018) attributed the yield reduction in the critical period to a 48 % reduction in seed number which was partially compensated by an increase in seed size of 29 %. In the subsequent experiments a similar pattern was observed (Figure 1) with reductions in seed number between 25 and 40 %, depending on the crop, and seed size partially compensated yield with an increase of between 15 and 32 %. In Bonito, the changes in seed number were largely compensated by the increase in seed size, explaining the minimal yield response to shading during the critical period.

Conclusion

Despite the significant difference between the experiments in favourability of the environment and consequent yield in the unshaded control (180-450 g/m^2), the critical period remained consistent, between 100 to 500 °Cd after the start of flowering. Confirmation of the critical period under a range of genotypes and environments provides confidence in its use in ongoing agronomic and genetic studies to improve canola productivity.

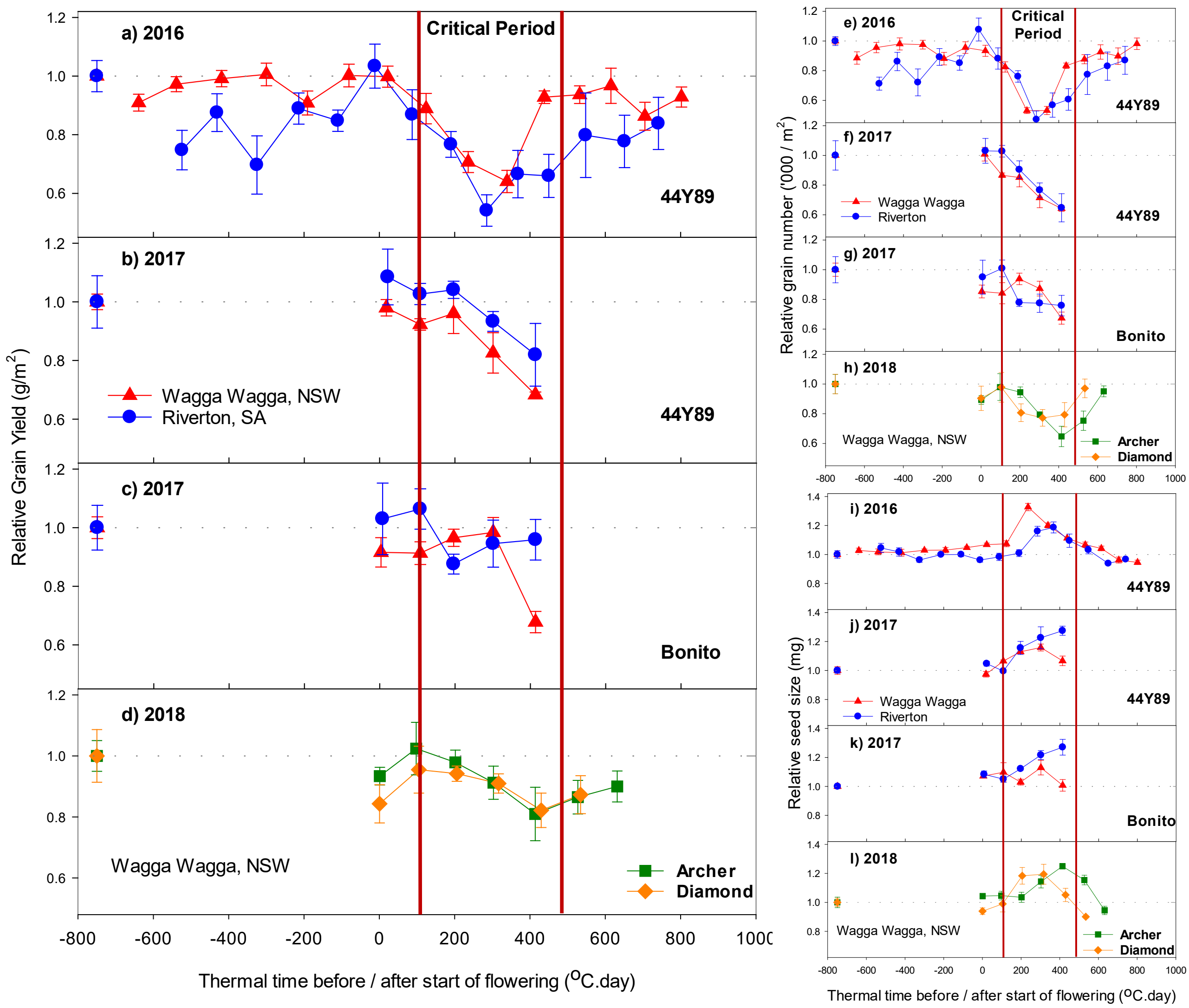

Figure 1. Effect of timing of shading on grain yield (a-d), grain number (e-h) and grain size (i-l) compared to unshaded controls for 4 canola cultivars at 2 sites over 3 years. Error bars are ± standard error. Phenology scale is based on the unshaded controls. Critical period defined by Kirkegaard et al. (2018) is shown by vertical lines at 100 and 500 °Cd after start of flowering.

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