Components of yield in winter and spring canola types in the HRZ of southern Australia

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Abstract
Pod numbers are a major component of yield in canola and therefore improvements in pod development and survival will help maximise yields. Field experiments were conducted in the high rainfall zone (HRZ) of southern Australia to determine if the physiological processes of pod development and survival are different between varieties with vastly different maturities and when supplied with different amounts of water post flowering. Varieties showed considerable plasticity and adopted different strategies for pod development depending on maturity type and water supply. Environments with high yield potential such as the HRZ will need different maturity types and strategies to increase yields than those where yields are severely limited by water and heat stress. To sustain very high pod and seed numbers in high yielding environments it may be necessary to alter the canopy and spread the duration of pod set over a longer period to better match crop demand and assimilate supply. New types of crop simulation models should be developed to better account for different physiological strategies of pod development and survival to design canola ideotypes and optimise management for high yielding environments.

Keywords determinate, winter, spring maturity

Introduction
Seed number per unit area is the major component of yield in canola, comprising pod numbers per unit area and seeds per pod. Of these, pod numbers generally have the greatest bearing on yield and are most strongly influenced by environment. The potential number of pods is determined soon after flowering (Tayo and Morgan 1975, Habekotte 1997, Kirkegaard et al 2018). During this period the crop is most sensitive to stresses including frost and high temperature, water (drought and waterlogging) and limited supply of assimilates, all of which can significantly reduce pod numbers and hence grain yields. Improvements in yields within specific environments has been achieved through strategies of either tolerance or avoidance of stress through breeding (e.g. phenology) and agronomic practises (e.g. time of sowing). In Australia, breeders have focused on selecting for earlier flowering varieties to avoid drought and higher temperatures and to accommodate the expansion of canola into the lower rainfall regions with less than 350 mm annual rainfall. More recently, production has expanded into the higher rainfall regions of southern Australia where later maturing winter varieties are providing yield increases (Christy et al 2019). It is expected that such contrasting environments with different assimilate supplies and abiotic stresses would require different physiological approaches to maximise yields. This study was conducted to test the hypotheses that the physiological processes involved in pod development and survival are different between winter, spring and winter-spring cross varieties and under different amounts of water supplied post flowering. An improved understanding of these physiological processes will help design ideotypes for genetic gain and identify agronomic strategies to maximise grain yields.

Materials and Methods
Experiments were conducted on the Agriculture Victoria research farm at Hamilton in Victoria (37°49'S, 142°04'E) in 2016 and 2017. A total of six canola varieties were sown across the two years under two (2016) or three (2017) different post flowering water regimes. Varieties were all hybrids and included three winter types (W1, W2, W3), two spring types (S1, S2) and a winter spring cross, mid type (WS1). The maturity groups were sown at different times to synchronise flowering (Table 1) using the photothermal model of Christy et al 2019.

Crops were sown on raised beds at a target plant density of 50 plants m^{-2} and at a row spacing of 15 cm. Plot sizes were 1.2 m wide by 20 m in length. The three different water regimes included irrigated (Irr, 2017 only) where water was non-limiting, rain exclusion (RainEx) applied during rainfall events from flowering to maturity through automated rain out shelters each covering an area of 42 m^2 and rain fed (RainFed) treatments which were exposed to the season's rainfall events. Drip irrigation treatments were applied to the plots when soil moisture tension at a depth of 30 cm was within the range of 30-50 KPa as determined by gypsum block sensors logged half hourly. Soil water content to 180 cm was measured monthly between sowing (April) and final harvest (December) under each replicate of the different water treatments using a neutron moisture meter (503DR Hydroprobe, Boart Longyear CPN, Martinez, CA, USA.) calibrated through the volumetric water content from soil cores taken when the tubes were installed and at the end of the season. The experimental design was an unbalanced randomised block with water treatment the main plot replicated three or six times for RainEx, RainFed and Irr. Variety treatments were applied randomly to the plot level. All varieties were sown under rainfed conditions. Due to limited space under the shelters only S1 and WS1 were sown under RainEx and irrigation was only applied to W3 and WS1.

Table 1. Details of the treatments including varieties, water treatments and sowing times for the experiments sown at Hamilton in 2016 and 2017.

Year	Variety	Canola type	Maturity	Water Treatment	Date Sown	Flowering Date
2016	W1	Winter Hybrid CL	Late	RainEx	2-May	6-Oct
	W1	Winter Hybrid CL	Late	RainFed	2-May	3-Oct
	S1	Spring Hybrid CL	Early	RainEx	15-Jun	27-Sep
	S1	Spring Hybrid CL	Early	RainFed	15-Jun	26-Sep
	S2	Spring Hybrid CL	Early	RainEx	15-Jun	27-Sep
	S2	Spring Hybrid CL	Early	RainFed	15-Jun	27-Sep
	W2	Winter Hybrid CL	Late	RainEx	2-May	7-Oct
	W2	Winter Hybrid CL	Late	RainFed	2-May	3-Oct
2017	W3	Winter Hybrid CL	Late	Irrigated	11-Apr	26-Sep
	W3	Winter Hybrid CL	Late	RainFed	11-Apr	26-Sep
	S1	Spring Hybrid CL	Early	RainEx	7-Jun	26-Sep
	S1	Spring Hybrid CL	Early	RainFed	7-Jun	26-Sep
	WS1	WinterxSpring Hybrid CL	Mid	RainEx	3-May	22-Sep
	WS1	WinterxSpring Hybrid CL	Mid	Irrigated	3-May	22-Sep
	WS1	WinterxSpring Hybrid CL	Mid	RainFed	3-May	22-Sep

In 2016, plants were taken from quadrat cuts at the start of flowering (SF), end of flowering (EF <5% flowers remaining on the plot) and at maturity (M) giving 3 sampling times. Plants were counted and separated into components including leaves, stems, 500 pods and remaining pods. The number of pods per m^{-2} (pods > 2 cm in length) were calculated as the weight of 500 pods divided by 500 (pods g^{-1}) x total pod weight. Sampling times in 2017 were the same as in 2016 but with additional samples taken at SF + 3 weeks and EF + 3 weeks giving 5 post flowering sampling times. The differences between treatments for yield components and pod survival were determined by ANOVA with significance nominated at the 5% level. All data was analysed using GenStat for Windows 18th Edition.

Results

In 2016 annual rainfall was 20% above the long-term average (LTA) with 90 mm extra falling over spring causing significant waterlogging damage to crops under the RainFed treatment (total annual rainfall 830 mm). The RainEx treatment received up to 229 mm less water (including soil water used) post SF than the RainFed treatment. The 2017 season also had above average annual rainfall, 15 mm more than the LTA overall with 64 mm more falling in late November. Irr treatments received up to 43 mm more post SF water than the RainFed treatments and RainEx 200 mm less (Table 2).

The physiological process of pod development and survival differed between the different variety x water treatment combinations. For the winter types, maximum pod numbers of ~12,000 m^{-2} were generally achieved by EF (Figure 1A and 1C). The exception being W3-Irr in 2017 where numbers were fewer (~7,000 m^{-2}) but were sustained until M. For the spring types in 2016, maximum pod numbers (~13,000 m^{-2}) and patterns of development were similar to the winter types under RainEx but under RainFed numbers were only about half these (Figure 1B and 1C). For S2 maximum numbers were measured at M. In 2017 pod numbers for S1 gradually increased until M. Maximum pod numbers were greatest for WS1-RainFed and Irr at 15,000 m^{-2} and were measured approximately 15 days earlier at SF + 3 weeks (Figure 1D). In contrast, for WS1-RainEx fewer numbers at SF + 3 weeks were sustained during grain filling so that final pod numbers at M were similar to RainFed and Irr.

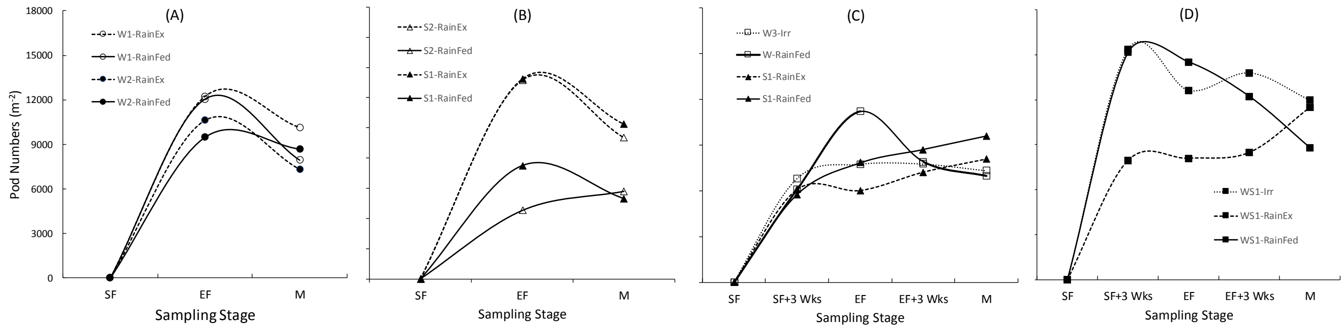

Figure 1: Pod development for six varieties sown in 2016 (A and B) and 2017 (C and D). Data is mean of replicates for each treatment at each sampling time. Sampling times; SF is start of flowering, SF+3 is SF + 3 weeks, EF is end of flowering, EF+3 is EF+ 3 weeks, M is maturity.

In 2016, with the exception of W2, final pod numbers at M tended to be greater under the RainEx treatments and suffered fewer losses between the EF and M than RainFed (Table 2). Despite large differences in water-use, numbers at M were not significantly affected by water supply in 2017. For the spring types in 2016 seeds per pod were also greater under RainEx but differences in seed size between water treatments within a variety were not significant. In 2017 differences in pod numbers, survival and seeds per pod were not significantly different but seed size tended to be greater under RainFed compared to RainEx conditions.

Table 2. Water use, pod loss between end of flowering (EF) and maturity (M) and yield components at maturity (M) for experiments sown at Hamilton in 2016 and 2017. *Water-use includes rainfall, irrigation and soil water.

Year	Treatment	*Total Water Use Sow to Harvest	*Total Water Use Flower to Harvest	Pod loss EF-M	Pod No.s (m^{-2})	Seeds Per Pod	Seed Wt (mg)
2016	W1-RainEx	460	200	16%	10132	18.8	3.60
	W1-RainFed	686	218	33%	7935	19.5	3.77
	S1-RainEx	330	200	18%	10228	19.5	3.42
	S1-RainFed	555	252	29%	5302	16.9	3.72
	S2-RainEx	330	200	28%	9339	19.0	3.10
	S2-RainFed	555	246	-31%	5789	16.2	3.25
	W2-RainEx	457	197	30%	7333	22.5	3.39
	W2-RainFed	686	218	5%	8694	21.9	3.58
	F Prob			0.076	0.003	<0.001	0.002
	l.s.d.			39%	2727	2.39	0.337
2017	W3-Irr	582	267	7%	7319	20.9	3.30
	W3-RainFed	593	239	31%	6976	19.5	2.84
	S1-RainEx	317	99	-48%	8081	22.5	3.13
	S1-RainFed	474	247	-24%	9594	21.0	3.84
	WS1-RainEx	367	101	-37%	11504	19.9	3.46
	WS1-Irr	463	233	0%	11966	20.8	3.55
	WS1-RainFed	503	239	39%	8795	17.4	3.89
	F Prob			0.132	6979	0.771	0.005
	l.s.d.			ns	ns	ns	0.479

Discussion

Findings confirmed that the physiological processes involved in pod development and survival were different between the variety x water treatments. In most cases, limiting water supply post flowering increased pod numbers, seeds per pod and improved pod survival but tended to reduce seed size. The lack of a negative response to the RainEx treatments was unexpected. However, both seasons had above average rainfall and in 2016, crops experienced waterlogging. The later sown spring types were less able to cope with the waterlogging during flowering with RainFed producing nearly half the pod numbers as RainEx. Crops under the RainEx treatments accessed up to 95 mm more soil water than the Irr treatments and extracted water from 50 cm deeper (data not shown). Despite the later sowing times and lower initial pod numbers, in the absence of waterlogging the spring types were able to sustain pod development until M. The increase in pod numbers measured after EF means that many of the pods must have been formed late in the flowering period and were too small to fall within the counting threshold of more than 2 cm in length. Although only tested in a single year, the mid maturing WS crosses set a higher yield potential through more pods (15,000 m^{-2}) without penalty to the other yield components. However, these numbers could not be sustained until maturity with the maximum final numbers falling to less than 12,000 m^{-2}. This indicates that in these seasons, factors other than water limited yields. In the absence of water, heat or frost stress it is likely that the plants were unable to provide enough assimilates (radiation or stored carbohydrates) to sustain the high demand and therefore pods were aborted. High assimilate demand from developing pods usually coincides with a severe reduction in assimilate supply caused by lower light interception due to greater light reflectance from the canopy from flowers, the senescence of leaves and small developing pods with limited photosynthetic capacity (Mendham *et al* 1981, Spink and Berry 2005). To increase yields in high yielding environments, strategies to improve radiation capture will be needed. Strategies such as manipulating plant density, branching, pod length, pod angle and apetalous flowers have been proposed to increase radiation capture (Diepenbrock 2000, Fray et al 1996). A longer post flowering period through earlier flowering and delayed maturity has also been identified as a strategy for increasing radiation interception during the critical yield forming period and therefore grain yield in high yielding environments in the U.K. (Spink and Berry 2005) and in Germany (Habetoke 1997). To sustain very high pod and seed numbers in high yielding environments it may be necessary to spread the duration of pod set over a longer period to better match demand from the crop with assimilate supply. Determining the optimum strategy for pod development for a specific environment is complex and will need to integrate variety, management and environmental factors. The investigation of different scenarios can be enhanced through appropriate crop simulation modelling. However, most current models do not include the parameters required to manipulate partitioning during grain filling. Data from this study can be incorporated into new models which can then be used to help design ideotypes for genetic gain and identify agronomic strategies to raise grain yields in high yielding environments.

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