Frost response in lentil. Part 1. Measuring the impact on yield and quality

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Abstract

Radiant frost limits production of lentil in southern Australia, reducing grain yield, causing deformation of grain and reducing grain quality. Increased understanding of the impacts of frost at different growth stages and severities are important factors to enable effective management to limit financial losses. Frost chambers were used to apply frost treatments to field-grown lentil (*cv*. PBA Jumbo 2) to define the response of yield components to frost exposure at different growth stages and intensities. Lentil crops differentially affected by frost also provided a backdrop for testing the utility of remote sensing to detect damage. Lentil was most susceptible to frost during the pod filling stage, when every degree hour below zero, reduced yield by 2%. This compared to a response at flowering, where a threshold of 31°C.hr (<0°C) was reached prior to yield reduction, and after which yield declined at 3.8% per °C.hr. Importantly, the current methodology effectively created a backdrop of lentil differentially effected by frost which could provide utility to breeding and agronomic programs to characterise in-field frost damage.

Key Words

Pulse, chilling, remote sensing

Introduction

Radiant frost can significantly reduce the yield and quality of lentil, with economic losses due to frost damage in broadacre cropping estimated to be $360 million per year in Australia (March et al.2015, Watt. 2013, Rebbeck et al. 2007). Recent increases in the severity and duration of frost across southern Australia (Crimp et al. 2016), combined with the widespread adoption of early sowing, have increased crop exposure to frost damage at key times during the growing season. Lentil is traded on visual characteristics and its susceptibility to abiotic and biotic stresses, such as frost, affects the appearance of seed and contributes to the volatility of the market. In lentil, frost damage can occur at any development stage following emergence, but the greatest potential for damage coincides with the reproductive period; typically, during spring in Mediterranean-type environments.

Current management strategies to mitigate frost damage are through avoidance, manipulating variables such as sowing date, crop and cultivar selections. However, these strategies can create other problems, including shifting the reproductive period into the heat wave window. Limiting the impact of frost requires improved adaptation strategies through breeding and agronomic management. While not a solution, rapid estimation of frost damage, using remote and proximal sensing, would allow for tactical decision making for reducing frost risk to limit financial losses through precision harvesting and quality segregation opportunities. The current study was designed to identify the fundamental response of lentil to frost using mobile frost chambers at targeted growth stages under field conditions and provide a backdrop for diagnostics using remote sensing as outlined in Perry et al (2019).

Methods

Mobile frost chambers were used to examine the impact of simulated frost on lentil (*cv*. Jumbo 2) growth and yield, in a field experiment at Horsham, Victoria. The experiment was designed as a randomised complete block design with four replicates and 12 frost treatments. Temperatures below 0°C were applied at four development stages (Erskine et al, 1990): flowering, early pod, flat pod and filling pod. For each treatment there were three different intensities of frost (mild, medium, severe). These were compared with two sets of control plots: an open control where lentil was grown under ambient air and a chamber control where plants were protected during the reproductive period from frost using chambers which were installed overnight when frost (< 4□C) conditions were forecast.

Frost treatments were applied based on a methodology developed by Nuttall et al (2018). Briefly, mobile frost chambers consisted of insulated foam boxes (Foilboard®), with internal platforms suspended 300 mm above the canopy supporting three trays which allowed for stepped additions of dry ice prills. The chilling process commenced at 2000 H with dry ice added to a single tray. Differential chilling was achieved by varying 'top-up' regime of dry ice at 2115H and 2300H for the three cold scenarios (increased amount for cooler temperature). The frost treatments were applied at night time, where chilling was imposed earlier in the night compared to the timing of natural frost, due to experimental constraints.

Canopy temperatures were monitored using thermistors installed at canopy height, and temperature was logged at five-minute intervals using TGP-4505 external temperature and relative humidity probes. To account for the varying severity in frost (temperature × duration) imposed, we calculated the cold load as the sum of degrees Celsius (°C) below 0°C for the logged temperature data to give a °C.hr.

Results & Discussion

Frost chambers reduced the canopy temperature of lentil to below 0 ˚C and treatments varied in intensity and duration across the four treatment times (Fig. 1). At flowering the average minimum temperature ranged from -4.1 to -6.8°C, which corresponded to a range in cold load of 19.4 to 30.2 °C.hr (<0°C) (Table 1). Cold loads during early pod and flat pod treatments were lower, with minimum temperatures of -2.4 and -3.3 °C.hr respectively. The corresponding colds loads were, 6.5 and 10.1 °C.hr (<0°C) respectively. The warmer temperatures observed were due to environmental effects (prevalent winds). At filling pod, the minimum temperature ranged between -4.2 and -7.5, corresponding to a range in cold load of 23.5 to 40.2 °C.hr (<0°C). During the treatment window (risk of frost damage 10 days pre and 10 days post the frost applications), there were two natural frost events which corresponded to a cold load of 13.7 °C.hr (<0°C). All plants were exposed to this frost excluding the chamber controls which received 5.0 °C.hr (<0°C).

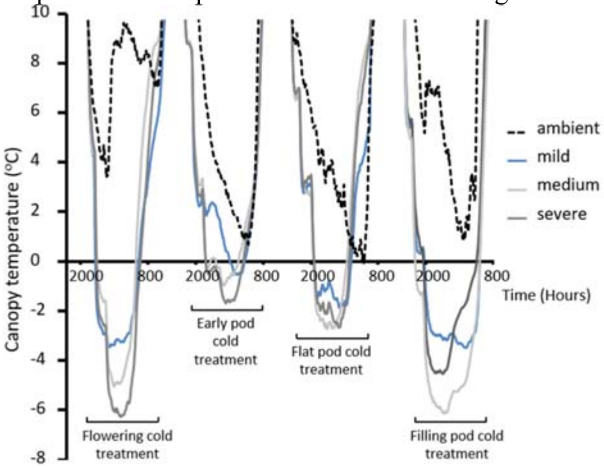

Figure 1. Range in mean canopy temperature for frost treatments applied to lentil (*cv.* Jumbo 2) at flowering and during podding (early, flat and filling pod) compared with ambient air temperature. Frost treatments were applied over a single night varying in chilling intensity (mild, medium and severe).

Table 1. Frost treatments applied to lentil and their corresponding minimum temperatures and cold loads. Standard error of mean for four replicates in parentheses.

	Frost regime	Temperature (°C)			Cold load (°C.hr < 0°C)
		Minimum	Average	Dew point	
	Protected control	-1.8	-1.1	-1.1	5.0 (0.7)
	Ambient control	-2.6	-1.1	-1.4	13.7 (0.4)
Flowering	1	-4.1	-2.7	3.3	19.4 (0.8)
	2	-5.3	-3.3	4.3	20.7 (0.8)
	3	-6.8	-4.3	2.7	30.2 (1)
Early pod	1	-0.7	-0.4	N/A	0.9 (0.2)
	2	-1.5	-0.8	5.7	2.6 (1)
	3	-2.4	-1.3	5.0	6.5 (2)
Flat pod	1	-2.6	-1.4	4.0	7.3 (2)
	2	-3.5	-2.1	4.5	10.1 (0.4)
	3	-3.1	-1.9	3.4	9.7 (1)
Filling pod	1	-4.2	-2.7	5.3	23.5 (2)
	2	-5.5	-3.0	5.7	22.5 (4)
	3	-7.5	-4.3	3.4	40.2 (5)

Table 2. Yield and grain nitrogen concentration (GNC) response of lentil (*cv.* Jumbo 2) to frost treatments (applied frost plus risk window of 10 days pre and post 10 days).

Growth stage	Intensity	Grain yield (kg/ha)	GNC
Protected control		2843	3.74
Ambient control		2387	3.85
Flowering	1	2763	3.76
	2	2780	
	3	1623	
Early pod	1	2683	3.75
	2	2698	
	3	2635	
Flat pod	1	2687	3.95
	2	2416	
	3	2441	
Filling pod	1	1597	4.22
	2	1203	
	3	700	
LSD (P <0.05)	GS×I	527	0.15

Frost treatments applied during the reproductive stage caused a significant reduction in yield compared to lentil grown under minimal frost conditions (Table 2). The effect of frost on yield exhibited a significant interaction between growth stage at the time of frost and frost intensity, where lentil was more susceptible to yield reduction during pod filling (early/ flat and filling pod) compared to flowering. Yield was equivalent when frost was applied at early and flat pod compared to ambient, potentially due to the low corresponding cold loads applied for these treatments (Table 1). Frost applied during flat pod and filling caused a significant increase in grain nitrogen concentration (GNC), while there was no effect on GNC for the earlier treatments (flowering and early pod).

The relationship between lentil yield response and cold load was defined for the flowering and pod filling growth stages (Fig. 2), where at flowering, damage occurred when a threshold of 31°C.hr (<0°C) was reached, thereafter the yield decline was 3.8% per °C.hr. At pod filling, there was a linear relationship between yield and cumulative cold load, where for every degree hour below zero there was a 2% reduction in grain yield. The difference in response to frost at flowering and pod filling, indicates that timing, intensity and duration are key factors in determining the extent to which lentil recover from frost.

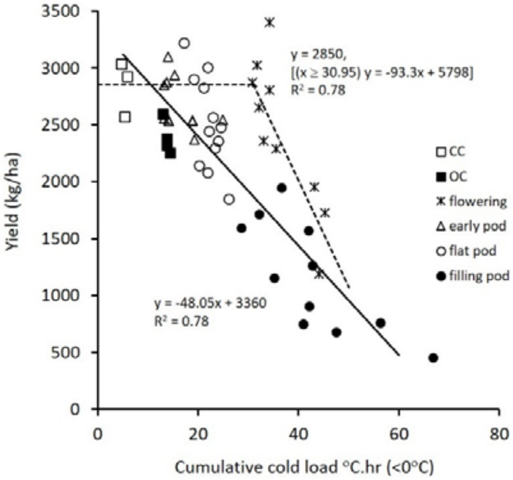

Figure 2. Relationship between lentil (*cv.* PBA Jumbo 2) grain yield and cold load (°C.hr <0°C) associated with frost treatments applied at four different growth stages: flowering, early pod, flat pod and filling pod (applied frost plus risk window of 10 days pre and post 10 days). The data is fitted by two regression models. The protected control (CC) and flowering data were fitted with a segmented regression (dash line), and the ambient control (OC), CC and pod filling stages were fitted with a linear regression (solid line). Outliers have been excluded.

Lentil marketability is strongly influenced by the visual characteristics of the seed, such as discolouration, deformation and shrivelling, and frost can significantly affect these qualities. For lentil exposed to a range of frost treatments during podding (early, flat and filling pod) there corresponding degradation in visual quality with increasing cold load, where damage was most severe at filling pod (Fig. 3). In contrast, there was minimal damage to lentil grain when frost occurred at flowering, regardless of intensity and duration (data not shown).

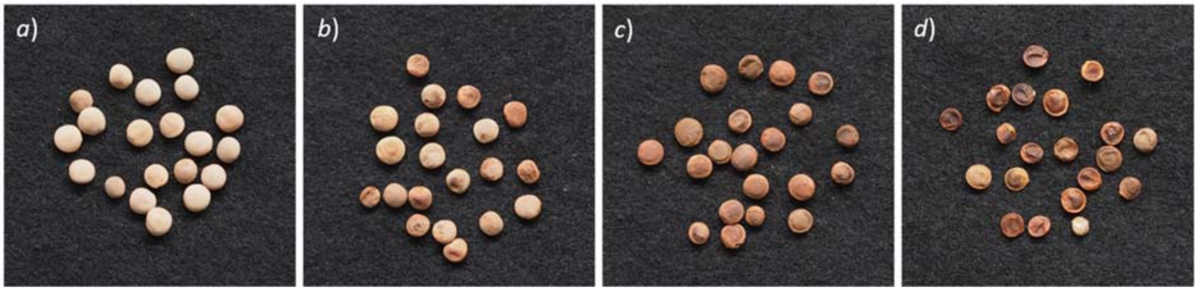

Figure 3. Frost affected lentil grain. Visual characteristics of lentil (*cv.* Jumbo 2) where frost treatments of varying intensities have been imposed on plants during the filling pod stage. A control (5°C.hr <0°C) a) is compared with b) 16, c) 22 and d) 43 °C.hr.

Conclusion

Radiant frost continues to limit lentil production in southern Australia, reducing yield and causing deformation of grain. Lentil is susceptible to frost damage at any time from emergence to maturity but is most susceptible to frost during the pod filling stage, where we define for every degree hour below zero, there is a 2% reduction in grain yield. This work confirms that the indeterminate nature of lentil offers a mechanism of recovery, which is determined by timing, intensity and duration, where at flowering yield reduction occurred beyond a threshold of 31°C.hr (< 0°C). The current methodology provides a means to apply frost at targeted growth stages in field conditions, refinement is, however, required where plants were exposed to less cold load during the early and flat pod stages. Despite this, the current methodology provides a platform to test the utility of remote and proximal sensors to assess pre-visual crop. Further research is required to build on the fundamental response of lentil to frost, to define genetic differences across varieties and to develop diagnostic method using remote sensing.

Acknowledgments

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