Crop canopy temperature as an explanation for early flowering of safflower (*Carthamus tinctorius* L.) in response to water stress

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Abstract
A series of field experiments with the safflower cultivar Sironaria, were conducted in the Victorian Wimmera district during 2000/01 and 2001/02. For the range of sites and sowing times (July to October), flowering occurred between 66 and 155 days after sowing (DAS), but the accumulated growing day degrees (°Cd $_{base8}$) only ranged from 654 to 789 °Cd (mean = 709). When sites were categorised according to available moisture, the duration between sowing and flowering was 684 °Cd at the drier sites and 743 °Cd at the wetter sites. In two identically designed and managed sowing rate experiments, Sironaria flowered 142 DAS (690 °Cd) when total water use between sowing and flowering was 340 mm, compared to 150 DAS (755 °Cd) when 446 mm was used. Crop canopy temperatures (December) were significantly cooler at the wetter site (mean = 20 °C), compared to 27 °C at the drier site. It is proposed that reduced transpiration at the drier site led to higher canopy temperatures and more rapid thermal time accumulation, thereby at least partly explaining earlier flowering at the drier site.

Introduction
To maximise yields in most southern Australian environments, it is important to ensure that crop species/cultivar selection and management ensure that annual crops complete their life cycle before the annual summer drought. Phenological development in safflower (*Carthamus tinctorius* L.) is generally considered to be driven by temperature, although some genotypes may exhibit a photoperiod response. This paper draws on 9 experiments designed to measure the growth, yield and water use of safflower. Overall, the cultivar Sironaria had similar growing day degree (GDD) requirements to initiate flowering, despite a range of sowing times between July and October. However, drier sites flowered before sites with more available water. Focusing on two identical sowing rate experiments at Longerenong in 2001/02 (except for water availability), this paper seeks to offer an explanation as to why the rainfed (RF) site flowered 8 days before the pre-watered (PW) site.

Materials and methods
a) Safflower development
To evaluate GDD requirements to initiate flowering, data were pooled from 9 experiments conducted in Victoria's Wimmera during 2000/01 and 2001/02. All experiments were appropriately designed and managed. A range of phenology, growth, water use and seed yield measurements were taken. Because there were only small differences in the chronological or thermal time to flowering between individual treatments within an experiment, only means for Sironaria in each experiment are used here. Plots were deemed to be flowering when 50 % of terminal capitula had opened and temperature data were collected by onsite weather stations. Thermal times were calculated with a base temperature of 8 °C (°Cd). Total water use is given as the sum of the change in soil water (2 m depth) plus rainfall.

b) Canopy temperatures
The degree of water stress was estimated using an infrared thermometer to measure the canopy temperature of each plot, in the Longerenong RF and PW sowing rate experiments, on 4 occasions over 3 days around the time of flowering. Treatments in these identically managed experiments were 10, 20, 30 and 40 kg/ha. Both experiments were sown on 30 July 2001 in paddocks a few hundred metres apart, but with different amounts of stored soil water.

Results and discussion

a) *Safflower development*

Depending on the site and sowing time, flowering occurred between early December and mid January. The period between sowing and flowering ranged from 66 to 155 days and the duration declined as sowing was delayed further into spring (July to October). Despite the differences in calendar days from sowing to flowering, thermal times were similar for all sowing times, sites and years. The range for Sironaria treatments in the 9 experiments (including treatments sown in July, Aug., Sept. and Oct. 2000 and 2001) was 654 – 789 °Cd, with a mean of 709 and a 5 % coefficient of variation (CV). This combined with the range of flowering dates, indicates that, at least for a given latitude (day length), phenological development in Sironaria is strongly dependent on GDD accumulation, rather than photoperiod.

When sites were classed according to water use between sowing and flowering, Sironaria treatments using an average of < 350 mm of water, flowered 684 °Cd after sowing (range = 654 – 710 °Cd, CV = 2 %), whilst treatments using > 350 mm of water flowered 743 °Cd after sowing (range = 697– 789°Cd, CV = 4 %). On average, the drier sites flowered 59 °Cd before the wetter sites. In the sowing rate experiments, Sironaria flowered 142 DAS (690 °Cd) at the RF site, but this was extended by 8 days (65 °Cd) to 150 DAS (755 °Cd) at the PW site, where moisture was available. In addition to being driven by thermal time, these observations suggest that Sironaria can exhibit a "drought response" in dry conditions.

b) *Canopy temperatures*

Between sowing and flowering, the RF sowing rate experiment (340 mm) used significantly (P = 0.02) less water than its PW counterpart (446 mm), although there were no treatment effects on water use. The lower water use at the RF site was due to limited water availability, and with less water being transpired, one might expect crop canopy temperatures to be greater due to reduced evaporative cooling. When crop canopy temperatures were measured, there was little difference between treatments within a site, but on each occasion, the RF site was significantly (P = < 0.001) warmer than the PW site (Table 1). Higher canopy temperatures at the RF site would have allowed thermal time to accumulate more rapidly, compared to the PW site, thereby offering an explanation as to why the RF site flowered more than one week before the PW site. Insufficient data were collected to predict how this might change during the day, or to develop a model for the purpose of adjusting GDD calculations.

Table 1: Mean canopy temperatures for each sowing rate experiment on different days and times (° C)

Site means Treat × site ANOVA	20 Dec 01 [a] 11:00	20 Dec 01 13:00	21 Dec 01 9:00	24 Dec 01 10:00
Rainfed	36.3 ***	26.0 ***	23.7 ***	22.7 **
Pre-watered	26.5	21.2	15.0	20.4
CV %	6.4	5.8	4.8	5.6

[a] Values appear unrealistically high, *** $P < 0.001$, ** $P < 0.01$

Conclusion

These data indicate that the development of the safflower cultivar Sironaria is highly dependent on thermal time. However, this response could be moderated by water availability. Crop canopy temperatures were warmer at the drier site, due to less water being transpired and the associated cooling effect. Crops on drier sites would therefore more rapidly accumulate GDDs, which could explain part of the earlier flowering response under water stress. Although these data are more observations and conjecture, there is sufficient evidence presented here to warrant further investigation into whether the so called "drought response" in GDD plants is actually due to higher canopy temperatures caused by reduced transpiration rates. This is likely to apply to crops other than safflower.