The physiology and genetics of cold temperatures in chickpeas

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AT A GLANCE…

- During flowering, chickpeas are sensitive to cold (<15°C) temperatures which cause flower abortion and results in a delay between flowering and pod onset.
- While early sowing has the potential to reduce the risk of terminal drought, it moves the flowering window to cooler temperatures.
- Current work aims to identify new sources of chilling tolerance for chickpea variety development and to assess the suitability of elite breeding lines for flowering and podding during cool conditions.

CHICKPEAS are well adapted to the northern cropping region in Australia and provide a valuable, economically sound, broadleaf rotation in our farming systems. But various biotic and abiotic factors cause actual yields to fall between 1.7–2.7 tonnes per hectare below potential yield. Cold temperatures during the flowering window can significantly reduce crop yield through delaying and interrupting pod set, causing loss of early pods. In 2016, agronomists estimated yield losses due to cool spring temperatures in north-west NSW ranged from 0.5–0.7 tonnes per hectare.

Chickpeas can suffer damage during the flowering window from both frosts, when temperatures fall below -1.5°C, and 'chilling' where average day temperature does not exceed 15°C. This article will focus on chilling temperatures and their impacts on flowering and podding.

The discussion also has relevance for those 'cooler' cropping regions of Australia where chickpeas may become a very valuable addition to the rotation.

While cool spring temperatures have been historically avoided through late sowing, changes to our farming systems mean there is a greater need for flexibility to sow chickpeas earlier to increase subsequent cropping options and to avoid heat and terminal drought at the end of the season. But this pushes the flowering window to coincide with cooler ambient temperatures.

In north west NSW (Tamworth region), average daily temperatures are not consistently above 15°C until late September and in the cool 2016 season, average temperatures remained below the critical temperature until late October (Figure 1).

In addition, short bursts of cool temperatures occurring weeks after temperatures have begun to rise, can interrupt pod and seed set even in areas that generally experience warm spring temperatures.

The story so far

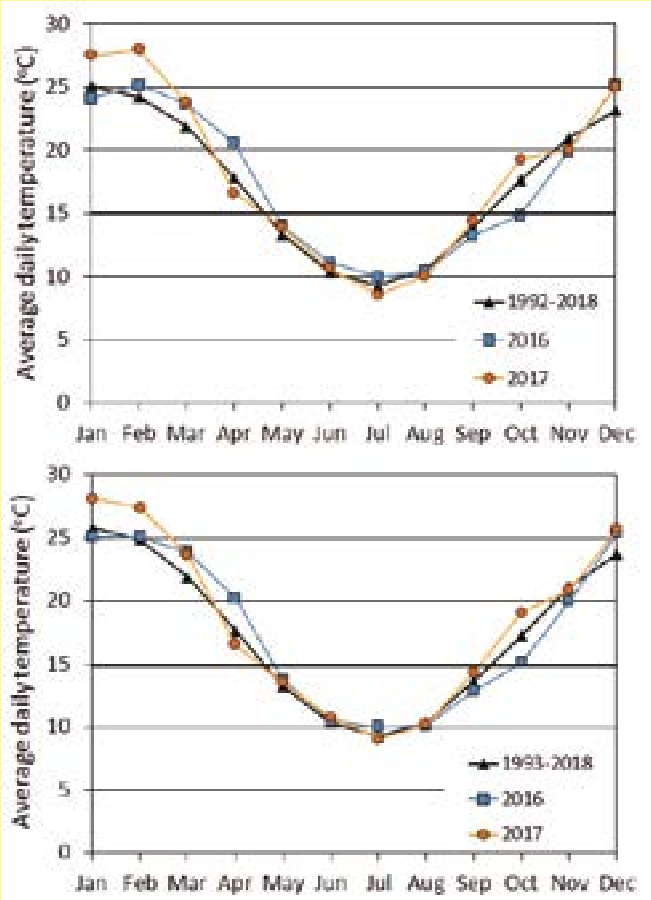
This article outlines current knowledge of chickpea's physiological response to cool temperatures during flowering and what opportunities and challenges exist for improving chilling tolerance through breeding and variety selection.

Early sown chickpeas consistently suffer from an extended gap between commencement of flowering and first pod appearance. In ideal conditions, chickpeas will produce pods within a couple of days of flowering. But under cool conditions, the time from the beginning of flowering to the first pods appearing can be more than two months if temperatures remain consistently cool. At Warwick (southern Queensland), Berger *et al*. (2004) found early flowering genotypes took more than 30 days to begin podding when average temperature after flowering did not exceed 14.4°C.

While the length of time between flowering and pod initiation varies across locations and between varieties, the delay in podding remains closely linked to temperature. For every degree drop in average daily temperature between 14 and 10°C, the time between flowering and podding is extended 12 days. During this time plants may continue to produce flowers that are subsequently aborted, or may cycle back into and out of a vegetative state.

While chickpeas may continue flowering under cool conditions, most flowers are subsequently aborted rather than

FIGURE 1: Average daily temperature for Tamworth (top) and Dubbo (bottom) shows cool spring conditions can continue into late September and October



producing pods. In their work with early sown chickpea in Western Australia, Siddique and Sedgley (1986) found only 38 per cent of flowers carried through to produce harvestable pods among early sown plants, compared to 83 per cent in later sowings. This difference was largely due to flower abortion at low temperature – up to 800 flowers per square metre were aborted when average daily temperature was below 15°C, but no flower abortion occurred once temperature rose above this critical value (see Table 1).

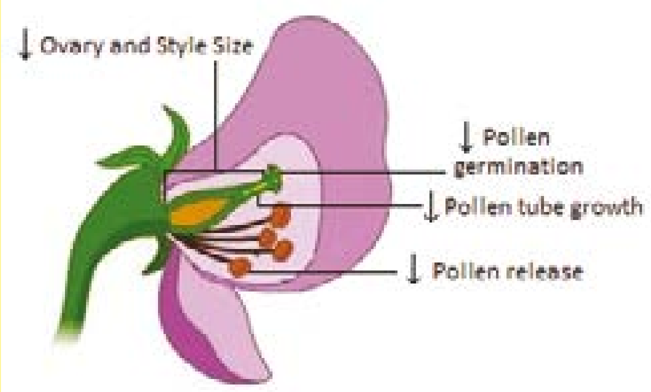
This WA research found that although early sown crops suffer a high flower abortion penalty, this does not necessarily result in inferior yields when compared to later sown crops. Despite high flower abortion, the earliest sown chickpeas still produced the greatest yield. Flower abortion under cool temperatures therefore constitutes a significant lost opportunity, as early flowering plants that also set pods early have the greatest potential to produce high yields.

TABLE 1: Effect of cool temperatures at 50 per cent flowering on flower abortion at Merredin, Western Australia 1983

Planting date (1983)	Mean daily temperature (°C) at 50% flowering	Aborted flowers (per metre)
May 17	12.5	800
May 31	13.6	500
June 14	14.7	200
June 30	16.8	0
July 20	17.7	0

Note: Modified from Croser *et al*., 2003

FIGURE 2: Impacts of cool temperature (<15°C) on male and female reproductive organs of chickpea flowers



Note: Modified from Science Learning Hub – Pokapu Akoranga Putaiao (2011)

On the small scale…

Cool temperatures reduce pollen vigour and ovary and style size of chickpea flowers – alterations that have been implicated in reduced flower fertilisation and increased flower abortion. Pollen development and function is affected by cool temperature from the early stages of pollen production from nine days before anthesis through to pollen tube growth and ovary fertilisation (see Figure 2).

Clarke and Siddique (2004) found cold spells at key points during pollen development at either nine or four to six days prior to anthesis can reduce pod set by 30–60 per cent in susceptible varieties. Cool temperature may also decrease the quantity of pollen reaching the flower stigma due to reduced pollen release from anthers as well as a reduction in ovary and style size. The resulting mismatch increases the difficulty of pollen transfer from anther to stigma.

Once pollen reaches the stigma, pollen germination can be reduced by 30 per cent in susceptible varieties, although some susceptible varieties exhibit normal pollen germination.

Once pollen has germinated on the stigma, pollen tube growth is particularly sensitive to cool temperatures. As a result, far fewer pollen tubes reach the ovary for fertilisation. Srinivasan *et al*. (1999) found while 100 per cent of flowers at an average temperature of 20°C had pollen tubes reach the base of the style, as few as 23.5 per cent of flowers at 10°C had more than 10 fully grown pollen tubes one day after flower opening.

This resulted in fertilisation of as few as 8 per cent of flower ovules. In highly susceptible varieties, no pollen tubes will reach the ovary within 24 hours of pollen germination under cool conditions.

As average day temperature increases from 5 to 25°C, rate of pollen tube growth increases exponentially with only marginal increases in growth rate between 5–15°C. Knowledge about these specific impacts of cool temperatures on chickpea reproduction have led to development of breeding practices such as pollen selection that are better able to target chilling tolerance.

Opportunities for breeding chilling tolerant varieties

While cool temperature during flowering is a relatively new issue for the northern region, it has been identified as yield limiting across southern and western Australia since the early introduction of the crop. As a result, significant work has been conducted in Western Australia to develop chilling tolerant material for breeding programs. Around 15 years ago two chilling

Current Australia-wide research is identifying more cold-tolerant chickpea lines for use in plant breeding programs.

tolerant cultivars, Rupali and Sonali, were developed that could produce pods at 10–12°C and as result pod 20–27 days earlier than existing Western Australian varieties.

But these cultivars have insufficient disease resistance and do not yield comparably to the best yielding varieties in the northern region. In addition, time from flowering to podding can range from 30–70 days at temperatures ranging from 10–12°C. While not suited to northern environments, both Rupali and Sonali have been included in the northern breeding program since 2011 in an attempt to produce well adapted varieties with the ability to set pods at lower ambient temperature.

But the chilling tolerance during flowering and early pod set of progeny derived from either Rupali or Sonali has been insufficient to confer a significant improvement in the ability to set pods early under cool temperatures.

Limited genetic variation within domesticated chickpea restricts further progress in producing cultivars capable of podding at low temperature. But some wild relatives of chickpea show considerably greater chilling tolerance and are able to set pods within 20 days of the beginning of flowering under cool temperatures, compared to the best chickpea cultivar doing so at 30 days.

While chickpea pod production is reduced by three to five times when plants are kept at an average temperature of 10°C compared to 19°C, one particularly promising accession of *Cicer echinospermum* showed no reduction in pod set, setting more than six times the number of pods compared to chickpea at the lower temperature.

There is, therefore, potential to include hybrids between chickpea and its wild relatives in breeding programs to make faster progress towards varieties that produce pods and seeds under suboptimal temperatures.

Where are we now?

Current research aims to identify useful sources of tolerance to suboptimal temperatures that can be used in breeding programs to improve future varieties. In Western Australia, both collections of chickpea and wild relatives are being screened by researchers at CSIRO as potential new sources for chilling tolerance during the early reproductive phase.

Since current methods for identifying chilling tolerant chickpea lines is an expensive and labour-intensive process, several projects are working on developing tools to streamline identification of chilling tolerant breeding lines.

At the University of Western Australia, Dr Janine Croser and her team are working to improve controlled environment screening for chilling tolerance amongst a wide set of chickpea genotypes.

The underlying genetics of early flowering and chilling tolerance in chickpea during flowering is being investigated by NSW DPI at Wagga Wagga and Tamworth to improve knowledge about genetic control of early flowering and podset to potentially work towards developing genetic markers. This project uses a set of recombinant inbred lines formed from hybridisation between domestic chickpea and the wild relative *Cicer echinospermum* which were observed to flower and pod comparatively early in 2016.

In northern and southern NSW, current varieties and elite breeding lines are being assessed for flowering and pod set characteristics under cool spring temperatures through manipulation of sowing date. The aim of this work is to; quantify yield loss from cool temperatures during flowering in the northern and southern NSW regions, expand knowledge of drivers that may improve chilling tolerance, and identify future breeding directions.

In 2018, field trials were conducted to benchmark current varieties and identify breeding lines with potential superior chilling tolerance when compared to existing varieties in northern environments. This data is being processed for analysis.

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