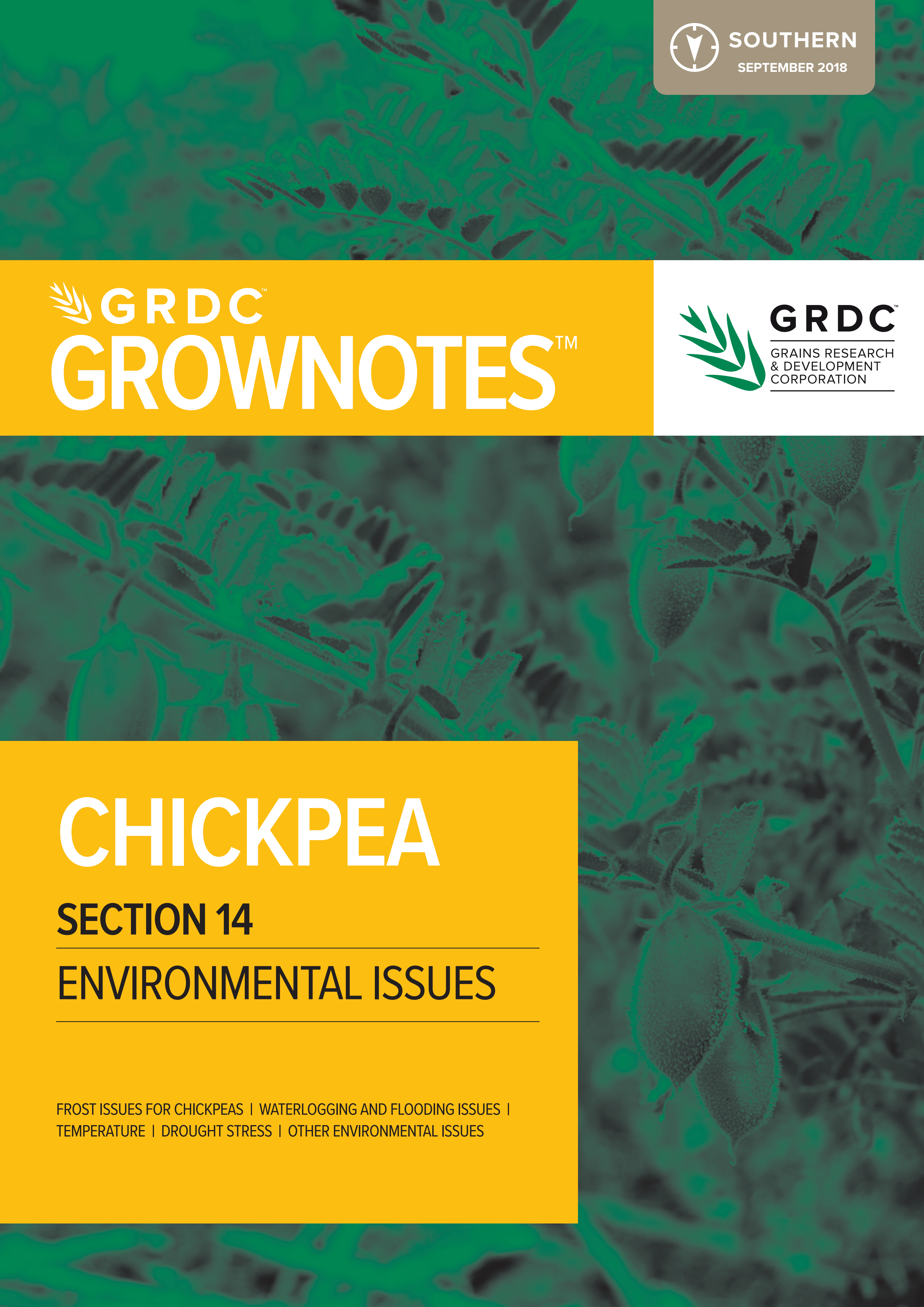

SOUTHERN
SEPTEMBER 2018

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CHICKPEA

SECTION 14

ENVIRONMENTAL ISSUES

FROST ISSUES FOR CHICKPEAS | WATERLOGGING AND FLOODING ISSUES | TEMPERATURE | DROUGHT STRESS | OTHER ENVIRONMENTAL ISSUES

Environmental issues

Key messages

- Environmental stresses during seed development have a negative effect on the quality of chickpea seeds.
- Freezing temperatures at the late vegetative stage can cause considerable damage and yield losses.
- Chickpeas are prone to waterlogging, and as there are no in-crop control measures to deal with waterlogging, a critical management tool is avoidance of high-risk paddocks.
- Both low and high temperatures can limit the growth and grain yield of chickpea at all phenological stages. Temperature is a major environmental factor that regulates the timing of flowering, and thus influences grain yield.
- After disease, the major constraint to greater chickpea production is its sensitivity to the end-of-season (terminal) drought that occurs in both the Mediterranean-type climates and when grown on stored soil moisture in the summer-rainfall region of Australia. Unlike many other crops, chickpea is unable to escape terminal drought through rapid development because low temperatures (<16°C) often cause flower and pod abortion.
- Chickpeas are extremely sensitive to salinity, and can have difficulty accessing water and nutrients from saline layers in the soil.
- Chickpeas are classified among the most sensitive of all field crops to sodic soil conditions.

14.1 Frost issues for chickpeas

Radiant can be frost is a major stress to crops, and one of the principal limiting factors for agricultural production worldwide, including Australia. Radiant frosts occur when plants and soil absorb sunlight during the day and radiate heat during the night when the sky is clear and the air is still. Dense, chilled air settles into the lowest areas of the canopy, where the most serious frost damage occurs. The cold air causes nucleation of the intracellular fluid in plant tissues, and this causes the plasma membrane to rupture. [1]

Legumes, including chickpeas, field peas, faba beans and lentils, are very sensitive to chilling and freezing temperatures, particularly at the stages of flowering, early pod formation and seed filling, although damage may occur at any stage of development.

Frosts (or isolated freezing events) are a problem for chickpeas (Photo 1) in southern Australia, especially when they occur in the late vegetative and reproductive phenological (climate-induced developmental) stages, and the air temperature drops to 2°C or less on clear nights in early spring. They occur most frequently after the passing of a cold front, when the moisture and wind dissipates, leaving cold and still conditions with clear skies.

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[1] A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops: a review. Euphytica 172 (1), 1–12.

VIDEOS

1. GCTV: Extreme temperature analysis to better understand frost events.

2. GCTV3: Frost R&D.

3. Frost's emotional impact, is it greater than its economic impact?

Photo 1: *Frost damage to a chickpea crop.*

Source: ABC Rural 2013

Areas of high frost risk in southern Australia include the Eyre Peninsula, Murray Mallee and the mid-north of South Australia, and the Wimmera Mallee region of Victoria. Over the last few years, the worst-affected areas have had crop production losses close to 100%. [2]

The occurrence and extent of frost damage tends to be affected by the microclimate, with great variability occurring within paddocks and even on the same plant. Therefore, soil type, soil moisture, position in the landscape, and crop density can have a bearing on the damage caused by a frost. In some species, crop nutrition has been shown to mitigate the effect of freezing range temperatures on the plant. It is thought that fertilisation of the plant, and consequent fast growth rates, can exacerbate the effect of freezing, particularly on the part of the plant undergoing elongation.

14.1.1 Industry costs

Crop losses due to frost are estimated to average more than $33 million a year in SA and Victoria, and over the whole of Australia may cost the grains industry on average more than $100 million a year. [3] The real cost of frost is a combination of the monetary cost due to both reduced yield and quality, and the hidden cost of management tactics used to minimise frost risk. These include:

- delaying sowing and its associated yield reduction
- sowing less profitable crops such as barley and oats
- avoiding cropping on the valley floors, which are among the most productive parts of the landscape.

14.1.2 Impacts on chickpea

Chickpea seedlings are tolerant of frost; however, the plants have low tolerance to frost during the flowering stage due to the exposed nature of flowers. Isolated frost events during the reproductive stage commonly results in flower or pod abortion, and this can be detrimental to yield in environments that experience terminal drought.

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[2] M Rebbeck, G Knell. (2007) Managing frost risk: a guide for southern Australian growers. SARDI, GRDC.

[3] M Rebbeck , G Knell (2007) Managing frost risk: a guide for southern Australian growers. SARDI, GRDC.

As well as causing the rupture of the plasma membranes of cells, frosts can also cause the dehydration of cells as a result of the freezing of the extracellular spaces. [4]

Different varieties of chickpeas and other pulses have different levels of tolerance to frost, allowing farmers to choose the varieties best suited to conditions in their district (Table 1).

Table 1: *Chickpea varieties differ in their frost susceptibility and risk exposure times.*

Frost tolerance of pods & seeds	Commencement of flowering	Duration of flowering	Example variety	How frost is tolerated or avoided
Low	Early	Medium	Genesis™079	Vulnerable to early frosts and flowering under cool conditions
Low	Medium	Medium	Genesis™ 090	Avoids early frosts, but forces flowering to occur in heat
Low	Late	Short–medium	Almaz$^{\phi}$, Nafice$^{\phi}$	Avoids early frosts, but forces flowering to occur in heat

Source: Pulse Australia

MORE INFORMATION

Pulse Australia (2015) Minimising frost damage in pulses. Australian Pulse Bulletin. Updated 20 November.

Damage to vegetative growth

Damage is more likely to occur where the crop has grown rapidly during a period of warm weather and is then subjected to freezing temperatures. In chickpeas, the elongation regions are often the first affected by freezing, and this can show up in a frost-damaged plant by sigmoidal curves around the elongation point: this is commonly referred to as 'hockey stick' (Photo 2). Depending on the minimum temperature and the duration of the frost, plants may be partially damaged, resulting in lower yield and quality at harvest or even complete crop failure; or they may be killed outright.

Sub-zero temperatures in winter and spring (late frosts) can damage the leaves and stems of the plant. Frosts can cause bleaching of the leaves, especially on the margins. However, chickpeas have an excellent ability to recover from this superficial damage, and are able to regenerate new branches in severe cases. Late frosts also cause flower, pod and seed abortion.

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[4] A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops: a review. Euphytica 172 (1), 1–12.

Photo 2: *Frost can cause bends like a hockey stick in chickpea stems.*

Photo S. Loss, DAFWA

The effect is readily visible, and may be seen as patches in the field, or on individual plants or branches of plants. Damage is usually more severe where stubble has been retained. Regrowth will generally occur provided soil moisture levels are adequate.

Chickpeas may be able to recover sufficiently to flower and set pods following an isolated frost event during the reproductive growth stage, provided soil moisture conditions are favourable during the subsequent periods.

In the field, frost tolerance decreases from the vegetative stage to reproductive stage. [5]

Damage to flowers and pods

Freezing temperatures damage leaves and destroy flowers and developing seeds (Photos 3 and 4). The time and duration of flowering affects tolerance and the ability to compensate after the frost. Early flowers are often aborted in chickpeas, but if soil moisture is available long-duration cultivars can compensate for the loss. Frosts that occur toward the end of the reproductive period following podset are more damaging, resulting in the abortion of pods and large yield reduction. [6]

Frost will normally affect the earliest-formed pods low on the primary and secondary branches. (By contrast, pod abortion induced by moisture stress is normally noted on the last-formed pods at the tips of the branches.) Pods at a later stage of development are generally more resistant to frost than flowers and small pods, but may suffer some mottled darkening of the seed coat. Provided soil moisture is adequate, varieties with an extended podding period can compensate for damage better than varieties that tend to pod up over a shorter period.

Minimum temperatures <5°C during the reproductive stage will kill the crop, but new regrowth can occur from the base of the almost-killed plants if moisture conditions are favourable. [7]

Frost is most damaging to yield:

- when it occurs during later flowering and early pod fill

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[5] A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops: a review. Euphytica 172 (1), 1–12.

[6] JS Croser, HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (*Cicer arietinum* L.) improvement. Critical Reviews in Plant Sciences 22 (2), 185–219, https://www.researchgate.net/publication/234520461_Low-Temperature_Stress_Implications_for_Chickpea_Cicer_arietinum_L_Improvement

[7] Pulse Australia (2013) Northern Chickpea—Best Management Practices Training Course: Manual 2013. Pulse Australia.

- under dry conditions where moisture limits the plant's ability to re-flower and compensate for frost damage

Photo 3: *Frost damage to leaves.*

Photo: G. Cumming, Pulse Australia

Photo 4: *Chickpea frosted at flowering.*

Source: Pulse Australia

14.1.3 Managing to lower frost risk

The different conditions under which the frost occurs will influence what management practices will be more effective. The options are to:

- Delay flowering.
- Avoid high inputs.
- Sow more frost-tolerant crops and pastures.
- Grow hay.
- Avoid sowing susceptible crops in frost-prone areas, such as low lying places.
- Sow and graze dual-purpose crops.
- Encourage cold-air drainage. Consult a specialist.
- Add clay to paddocks with sandy surfaces.

Frost risk is difficult to manage in pulses, however some management strategies may reduce the risk or the extent of damage. These include:

- Knowing the topography, and map areas of greatest risk so that they can be managed to minimise frost damage.
- Choosing the right crop type, crop variety and sowing time to reduce exposure or impact at vulnerable growth stages.
- Carefully assessing the soil type, condition, and soil-moisture levels, and managing stubble and the crop canopy.
- Correcting crop nutrition and minimising stressors of the crop to influence the degree of frost damage.

Ensure crops have an adequate supply of trace elements and macro-nutrients. Crops deficient or marginal in potassium and copper are likely to be more susceptible to frost damage; this may also be the case for molybdenum. [8]

Problem areas and timings

Mapping or marking areas identified as frost-prone will enable growers to target frost and crop management strategies to these high-risk areas.

Knowing when the period of greatest probability of frost occurs is also important for crop management.

Crop and sowing time

The main strategy used to minimise frost risk in broadacre cropping has been to sow crops later. Risks exist with delayed sowing, even though this practice can reduce the probability of crops flowering in a frost-risk period. Crops sown later can still be affected by frost.

Strategies to minimise frost damage in pulses work in combinations of:

- growing a more tolerant species
- trying to avoid having peak flowering and early podding during the period of most risk
- extended flowering to compensate for losses to frost
- ensuring that most grain is sufficiently filled to avoid damage when frost occurs (Table 1).

Targeting flowering and early podding to periods of the lowest probability of frost is achieved through combinations of sowing date and variety choice based on flowering time and flowering duration. Local experience will indicate the best choices.

By planting for late flowering, farmers target the avoidance of early frosts, but in the absence of frost, late flowering may reduce yields if moisture is deficient or there are high temperatures.

Very early flowering can allow pods to be sufficiently developed to escape frost damage, and ensure some grain yield at least before a frost occurs. Increased disease risk needs to be considered with early sowing.

Spread the risk

Match different pulses to risk areas by sowing a different variety or species into targeted areas within the same paddock. Matching the crop, variety, sowing date and subsequent inputs to the frost-risk location spreads the risk.

Have forage as an optional use. Designating hay or forage as a possible use for the pulse in paddocks with a high frost risk provides flexibility.

Mixing two pulse varieties (e.g. long and short season, tall and short) balances the risks of frost and of end-of-season (terminal) drought, and reduces the risk of losses from any one-frost event. Multiple frost events can damage both varieties. If grain

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[8] Pulse Australia (2015) Minimising frost damage in pulses. Australian Pulse Bulletin. Updated 20 November, http://pulseaus.com.au/growing-pulses/publications/minimise-frost-damage

from both varieties is not of the same delivery grade, then only the lowest grade is achieved. The only realistic, practical options are in peas, narrow-leafed lupins, kabuli chickpeas; perhaps desi chickpeas are an option. Differences in flowering times are minimal in lentils and beans.

Sowing a mixture of pulse species is feasible, but not common. Complications in crop choice include achieving contrasting grain sizes, herbicide requirements, harvest timing and grain cleaning. Multiple frosts may damage both crops. Pulses grown in a mix will be suitable for feed markets only unless they can be cleaned to enable purity in segregation. If these difficulties can be overcome there is an opportunity for alternate-row sowing of different pulses.

Reduce frost damage

Managing inputs. To minimise financial risk in frost-prone paddocks when growing susceptible crops, growers can:

- Apply conservative rates of fertilisers to frost-prone parts of the landscape.
- Avoid using high sowing rates.

Advantages of avoiding high inputs are:

- Less financial loss if the crop is badly frosted.
- Lower-input crops, though potentially lower yielding during favourable seasons, are less like to suffer severe frost damage than higher-input crops with a denser canopy.
- Input costs saved on the higher frost-risk paddocks may be invested in other areas where frost risk is lower.

Lower sowing rates may result in a less dense canopy that increases crop tillering and may allow more heating of the ground during the day, and transfer of this heat to the canopy at night. However, there is no hard evidence that lower sowing rates will reduce frost damage.

The main disadvantage of this practice is that in the absence of frost, lower grain yield and/or protein may be the result during favourable seasons, contributing to the hidden cost of frost. (This is a particular disadvantage in barley and wheat delivery grades.) Less-vigorous crops can also result in the crop being less competitive with weeds.

Managing nodulation and nutrition. Ensure pulse crops are adequately nodulated and fixing nitrogen. Ensure pulses have an adequate supply of trace elements and macronutrients, although supplying high levels is unlikely to increase frost tolerance. Crops deficient or marginal in potassium and copper are likely to be more susceptible to frost damage, and this may also be the case for molybdenum. Foliar application of copper, zinc or manganese may assist, but only if the crop is deficient in the element applied.

Managing the canopy. A bulky crop canopy and exposure of the upper pods may increase frost damage to pulses. Semi-leafless, erect peas may be more vulnerable than conventional, lodging types because their pods are more exposed. A mix of two varieties of differing height, maturity and erectness may also assist in reducing frost damage.

Sow in wider rows, so that frost is allowed to get to ground level, and the inter-row soil is more exposed. An open canopy does not trap cold air. Wide rows require the soil to be moist to trap the heat in the soil during the day. With wide or paired rows and a wide gap, the heat can radiate up, however this may not always be effective.

Channel cold air flow away from the susceptible crop by using wide rows aligned up and down the hill or slope. Where cold air settles, a sacrifice area may be required.

The presence of cereal stubble makes the soil cooler in the root zone, worsening the frost effect compared with bare soil. Standing stubble is considered less harmful than slashed stubble as less light is reflected and the soil is more exposed to the sun. Dark-coloured stubble will be more beneficial than light-coloured types.

Rolling can help keep soils warm by slowing soil-moisture loss, but not necessarily on self-mulching or cracking soils. Note that press wheels roll only in the seed row, and not the inter-row. With no-till practice, avoid having bare, firm, moist soil as it will lose some of its stored heat.

Claying or delving sandy soils increases the ability of the soil to absorb and hold heat by making the soil colour darker, and retaining moisture nearer the surface.

Higher carbohydrate levels in the plant during frost leads to less leakage during thawing. A higher sugar content (high Brix) will also have a lower freezing point, and associated protection against frost damage. The effectiveness of various products applied to soil and plants to increase plant carbohydrates is unknown.

Better varieties coming. Through Pulse Breeding Australia, the GRDC is investing in germ plasm enhancement and variety breeding to increase frost tolerance in pulses. The focus is on altered flowering time and duration to avoid frost, and screening of pulse varieties for relative levels of frost tolerance in the field. New varieties will be released when available. [9]

A five-year research project funded by GRDC examined the effects of agronomic practices on frost risk in broadacre agriculture in southern Australia. The researchers manipulate the soil heat bank to store heat during the day and release heat into the canopy of the crop at night. The research examined how the crop canopy could be manipulated to allow for warm air from the soil to rise and increase the temperature at crop head height (Figure 1). They have identified strategies that could be used to significantly reduce the impact of frost.

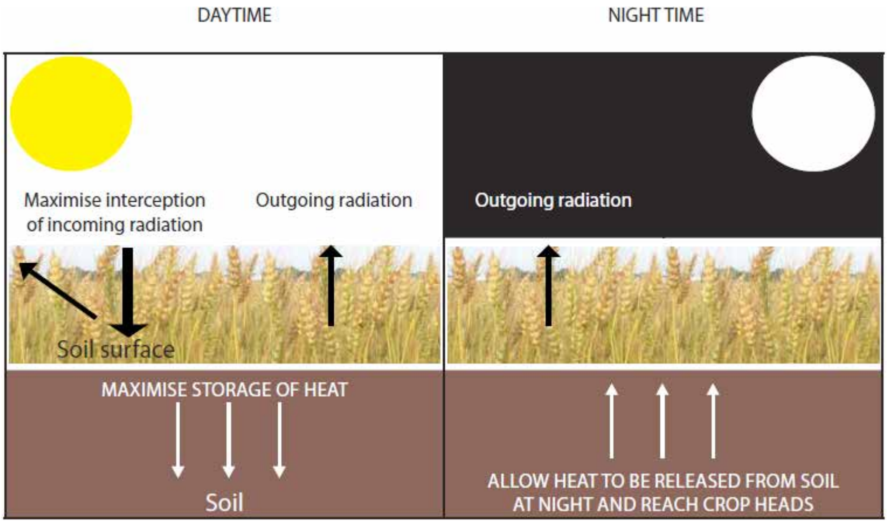

Figure 1: *Temperature dynamics in a crop canopy and canopy interactions.*

Source: Rebbeck and Knell 2007

Importance of soil moisture

Soil moisture is the most important factor for storing soil heat that will be released to and through the crop canopy at night. Because water has a high specific heat, radiation cooling overnight will be reduced when moisture is present in the soil. On a daily basis, heat is transferred into and out of approximately the top 300 mm of soil. When the soil is wet, heat transfer and storage in the upper soil layer is higher, so more heat is stored during daytime for release during the night.

There is also some evidence that moist soils can retain their warming properties for more than 24 hours, allowing some scope for an accumulation of heat from sunlight for more than one day. Heavier textured soils hold more moisture (and therefore heat) than lighter textured soils. A more dense soil can hold more moisture within the

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[9] Pulse Australia (2015) Minimising frost damage in pulses. Australian Pulse Bulletin. Updated 20 November, http://pulseaus.com.au/growing-pulses/publications/minimise-frost-damage

soil surface for heat absorption and subsequent release. Darker soils also absorb more light energy than lighter soils. Water-repellent sandy soils are usually drier at the surface than normal soils, and are therefore more frost prone. Frost studies in SA have found that crops were likely to be more damaged on lighter soil types because the soil temperature is lower as a result of lower soil moisture and the more reflective nature of these soils. On such soils, clay spreading or delving may be an option for reducing frost risk.

Use of agronomic practices

Table 2 shows the rankings of agronomic practices, adopted in both SA and WA, in order of importance. The table shows the paddock management strategies that manipulate the soil heat bank or manipulate the canopy air flow within the paddock, followed by paddock management strategies that also may assist crops to better tolerate frost. The final column in the table shows the reduction in frost damage from adopting these various practices in frost prone regions (derived from project trials).

The frost avoidance strategies, described in Table 2, are whole farm approaches to reduce or spread risks of frost injury. [10]

Table 2: *Agronomic practices to reduce frost risk ranked in order of importance.*

Soil heat bank manipulation ranking	**Description**	**Increased temp at canopy height (ave) (°C)**	**Reduction in frost damage**
Clay delving or clay spreading	In soils with a sandy surface, clay delving increases heat storage, nutrient availability and infiltration rate. Reducing frost risk by increasing the clay content of sandy-surfaced soils is the strongest finding in South Australia.	1.0	Up to 80%
Rolling	Rolling sandy soil and loamy clay soil after seeding has reduced frost damage, although the results were not statistically significant.	0.5	Up to 18%
Removing stubble	Removing stubble had a negligible effect on yield and frost risk. The role stubble plays in retaining soil moisture could be more important.	0.5	Minimal
Manipulation of the crop canopy ranking	**Description**	**Increased temp at canopy height (ave) (°C)**	**Reduction in frost damage**
Blending varieties and variety selection	Blending long- and short-season wheat varieties is a way to hedge your bets against frost or end-of-season drought within a paddock. A similar risk profile occurs when sowing one paddock with each variety at the same time. Successful results have been achieved in SA and WA blending Krichauff or Wyalkatchem with Yitpi. Certain varieties, such as Yitpi, Stiletto and Camm, flower later. Long-season varieties frequently avoid frost by flowering later in the growing season, when frost incidence is less. To further reduce frost risk, these varieties should be sown towards the middle or end of a wheat-sowing program rather than first.	0.0	Yitpi 12% less damaged than Krichauff
Cross-sowing	Crops sown twice with half the seed sown in each run gives an even plant density and has been found to more slowly release the soil heat, so that it can have an impact on air temperature at head height in early morning when frosts are most severe. This practice will incur an increased sowing cost. This result is based on two trials in WA.	0.6	13%

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[10] M Rebbeck, G Knell (2007) Managing frost risk: a guide for southern Australian growers. SARDI, GRDC.

Soil heat bank manipulation ranking	Description	Increased temp at canopy height (ave) (°C)	Reduction in frost damage
Wide row spacing	Wide-row sowing (e.g. 230–460 mm spacings) were ineffective for reducing frost damage. Wide-row crops consistently yield 10–15% less than the standard sowings with or without frost. In the presence of minor or severe frost, frost damage was similar for normal and wide row spacings.	0.2	0%
Lower sowing rate	A lower sowing rate (35–50 kg/ha) on frost-prone paddocks has not yet been proven to minimise frost damage. In WA, the plants in thinner crops appear more robust and able to better withstand frost events. The extra tillers formed per plant spread flowering time over a longer window. However, the crop is less competitive with weeds.	0.0	0%

Source: Rebbeck and Knell 2007

VIDEOS

4. Managing the effects of frost.

14.1.4 Managing frost affected crops

There are a number of options available for managing crops that have been frosted (Table 3). The following table highlights these options and the pros and cons of each. The suitability of each option will depend on the severity of the frost and analysis of costs versus returns. [11]

Table 3: *Options to manage frosted crops.*

Option	Advantages	Disadvantages
Harvest	No damage estimates required Salvage remaining grain Condition stubble for seeding	Costs may be greater than returns Need to implement weed control Threshing problems Need to remove organic matter
Hay and silage*	Stubble removed Weed control	Cost per hectare Quality may be poor (especially in wheat)
Chain or rake	Retains some stubble and reduces erosion risk Allows better stubble handling	Cost per hectare Time taken
Graze	Feed value Weed control	Inadequate stock to utilise feed (see Figure 6) Remaining grain may cause acidosis Stubble may be difficult to sow into
Spray	Stops weed seedset Preserves feed quality for grazing Gives time for decisions Retains feed Retains organic matter	Difficulty getting chemicals onto all of the weeds with a thick crop May not be as effective as burning Boom height limitation Cost per hectare Some grain still in crop

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[11] DAFWA (2016) Frost and cropping, https://www.agric.wa.gov.au/frost/frost-and-cropping

Option	Advantages	Disadvantages
Plough	Recycles nutrients and retains organic matter Stops weed seedset Green manure effect	Requires offset discs to cut straw Soil moisture needed for breakdown and incorporation of stubble
Swath	Stops weed seedset Windrow can be baled Regrowth can be grazed Weed regrowth can be sprayed	Relocation of nutrients to windrow Low market value for straw Poor weed control under swath Cost per hectare
Burn	Recycles some nutrients Controls surface weed seeds Permits re-cropping with disease control Can be done after rain	Potential soil and nutrient losses Fire hazard Organic matter loss

Source: DAFWA

* Less likely option with chickpea.

Photo 5: *Frosted pulses make excellent quality forage, although chickpea may be less so.*

Source: Pulse Australia.

14.2 Waterlogging and flooding issues

Waterlogging is probably one of the most important factors limiting the growth of crops and pasture in the high rainfall regions (>500 mm per annum) of southern Australia. [12] Chickpeas are prone to waterlogging (Photo 6), and as there are no in-crop control measures to deal with this problem, a critical management tool is the avoidance of high-risk paddocks, based on previous experience and paddock history.

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[12] K Moore, M Ryley, M Sharman, J van Leur, L Jenkins, R Brill (2013) Developing a plan for chickpeas 2013. GRDC Update Papers. February 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Developing-a-plan-for-chickpeas-2013

Photo 6: *Water logging in chickpeas.*

Source: Australian UAV

14.2.1 Symptoms

Chlorosis has been observed after four days of waterlogging, firstly on the upper leaves. Reddish-brown anthocyanin pigmentation also develop on midribs, stems and some leaflets. Leaflets fold upward, a symptom typical of moisture stress. Unexpanded leaves have necrotic margins. Abscission (shedding) of chlorotic leaflets can begin six days after waterlogging and will progress until most of the plant is defoliated. [13]

Symptoms of waterlogging can be confused with those of Phytophthora root rot but differ as follows (Table 4):

- Plants are most susceptible to waterlogging at flowering and early pod-fill.
- Symptoms develop within two days of flooding, compared to at least seven days for Phytophthora root rot.
- Roots are not rotted, and at first are not easily pulled from the soil.
- Plants often die too quickly for the lower leaves to drop off.

Table 4: *Differences between Phytophthora root rot and waterlogging.*

Phytophthora root rot	Waterlogging
Organism kills roots	Insufficient oxygen kills roots
Chickpeas, medics, lucerne are hosts	No link with cropping history or weed control
Occurs at any time of year	Usually occurs later in the year
Symptoms begin after a week or more	Symptom begin within two days
Lower leaves often yellow and fall off	Plants die too fast for leaves to yellow or fall
Roots always rotted and discoloured	Initially roots not rotted or discoloured (tips black)
Plants easily pulled up and out	Plants not easily pulled up initially

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[13] AL Cowie, RS Jessop, DA MacLeod (1989) Effect of waterlogging on photosynthesis and stomatal conductance of chickpea leaves. 5th Australian Agronomy Conference, University of New England.

Effect of waterlogging on stomatal conductance and photosynthesis

Stomatal conductance is the measure of the rate of passage of carbon dioxide (CO_2) entering, or water vapour exiting through the stomata of a leaf, and photosynthesis is a process that converts light energy into chemical energy that can fuel growth. Within 24 hours, stomatal conductance of waterlogged chickpeas can decline, and will completely stop within three days. One day after waterlogging, photosynthesis and stomatal conductance have been recorded at 87% and 36%, respectively, of unaffected plants. Rapid decline in stomatal conductance over 24 hours, followed by a sharp decrease in photosynthesis between two and four days, suggest that waterlogging decreases photosynthesis through stomatal closure. Stomatal closure may also be caused by a decrease in potassium uptake, or production of abscisic acid or ethylene by the plant. Reduction in photosynthesis may result from the effects of waterlogging on carboxylation enzymes and the loss of chlorophyll, in addition to the effect of stomatal closure. [14]

IN FOCUS

How the timing of waterlogging affects chickpeas

The effect of the timing of waterlogging on chickpeas was examined in two pot trials. Plants were waterlogged for 10 days at different stages of growth: from 21 days after sowing (DAS); at flowering or at mid-pod fill; and combinations of these times.

Waterlogging at any stage reduced seed yield; waterlogging at 21 DAS had the least effect, reducing yield relative to the non-waterlogged control by 35%.

The ability of the plants to survive and regrow following waterlogging decreased with increasing age: mortality rate averaged 0% after waterlogging at 21 DAS, 30% when it occurred at flowering, and 100% at pod fill (Table 5). Tolerance to waterlogging was not enhanced by previous exposure to waterlogging.

In a second experiment, waterlogging was imposed at six different times shortly before or after flowering began. Ability to survive waterlogging declined sharply as flowering commenced: the mortality rate increased from 13% when waterlogging was imposed six days before flowering, to 65% one day after flowering, and 100% when waterlogging began 7.5 days after flowering (Table 5). it is suggested that survival and recovery after waterlogging may have been inhibited in flowering plants by an inadequate supply of nitrogen or carbohydrates. [15]

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[14] AL Cowie, RS Jessop, DA MacLeod (1989) Effect of waterlogging on photosynthesis and stomatal conductance of chickpea leaves. 5th Australian Agronomy Conference, University of New England.

[15] AL Cowie, RS Jessop, DA MacLeod (1996) Effects of waterlogging on chickpeas. I. Influence of timing of waterlogging. Plant and Soil 183 (1), 97–103, http://www.regional.org.au/au/asa/1992/poster/soil-stress/p-04.htm

Table 5: *Mortality rate and regrowth following waterlogging imposed at five stages of floral development. Means followed by the same letter are not significantly different.*

Planting times	1	2	3	4	5
Time of waterlogging (days after sowing)	66	61	56	51	46
Time of flowering (days after waterlogging)	-7.5	-6	-1	+2	+6
Mortality rate (%)	100a	94a	63b	38c	13d
Total regrowth per pot (mg dry weight)	0a	0.4ab	18.1bc	32.6c	50.6d

Source: Cowie *et al.* 1996

14.2.2 Management options for waterlogging

- Avoid poorly drained paddocks and those prone to waterlogging.
- Do not flood-irrigate after podding has commenced, especially if the crop has been stressed.

A rule of thumb is that if the crop has started podding and the soil has cracked do not irrigate. Overhead irrigation is less likely to result in waterlogging, but consult your agronomist before proceeding. [16]

Innovative management techniques to reduce waterlogging

Waterlogging should be seen as a major threat to a farmer's potential income. The losses attributed to waterlogging in Tasmania, especially in high-rainfall years, run into the millions of dollars. What management techniques can be used to mitigate these losses and how can they be justified financially?

Before making any management decisions to reduce waterlogging, it is beneficial to understand where the problem areas lie, the size of these areas, how often losses occur in them, and how much potential earnings might increase if waterlogging is significantly reduced.

A monitoring program can be implemented to analyse all of the available data. These can include, but are not limited to, the following:

- Soil aspects—type, health, depth, characteristics, organic matter, electrical conductivity, compaction, topography, capacity to hold available water.
- Water—soil moisture, depth of water table, entry point (e.g. next door, over-irrigation, rainfall), direction of movement (on surface or sub-surface), exit points, irrigation management.
- Crop analysis – visual inspections (by ground or air), vigour mapping (NDVI), health/sap checks, yield mapping.

Once all the data have been collected, informed decisions can be formed to make management changes to reduce losses.

There are many tools available to reduce crop losses from waterlogging; some are listed below.

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[16] K Moore, M Ryley, M Schwinghamer, G Cumming, L Jenkins (2015) Chickpea: Phytophthora root rot management. Australian Pulse Bulletin. Updated 20 November 2015. Pulse Australia, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot

Management systems:

- controlled traffic farming
- minimum tillage, no tillage, conservation or strip tillage
- sub-soiling
- crop selection
- managing livestock to reduce compaction
- surveying and planning for drainage, including watershed simulation

Drainage:

- Surface drainage:
- shallow field drains
- large excavated ditches
- land forming
- open excavated drains
- raised beds
- hump and hollow
- Sub-surface drainage:
- agpipe or tile installation
- mole ploughing
- gravel mole ploughing

Irrigation management:

- machinery selection—choosing the right pivot nozzles for your soil type
- irrigation scheduling
- control systems
- variable rate irrigation (VRI)
- salinity considerations

After making changes, it is vitally important to continue monitoring to gauge improvement and to prompt further action. This system helps ensure that there is a reduction in crop losses attributed to waterlogging. As it is far easier to select the low-hanging fruit first, it is recommended that you choose the easiest option first and then progress to the harder projects. [17]

VIDEOS

5. GCTV3: Big wet: Managing strategies after flooding.

14.3 Temperature

Both low and high temperatures can limit the growth and grain yield of chickpeas at all phenological stages. Temperature is a major environmental factor regulating the timing of flowering, thus influencing grain yield. The production of the cool-season chickpea is constrained by low temperatures across much of its geographical range, including southern Australia. Cold stress generally occurs in the late vegetative and reproductive stages across the geographical areas of chickpea production. Cold and freezing temperatures (–1.5°C to 15°C) are considered to be a major problem during the seedling stage of winter-sown chickpea in Mediterranean-climate areas and of autumn-sown crops in temperate regions. Southern Australia is most affected by chilling temperatures at flowering. On the other hand, high day and night temperatures (>30 during the day, and >16°C at night) may cause damage during the reproductive stage on winter-sown chickpeas in Mediterranean-type rainfall areas. [18]

Temperatures that chill or freeze plant tissue are one of the three most important abiotic stresses that cause flower sterility and pod abortion. [19] Heat stress and

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[17] G Gibson G (2016) Innovative management techniques to reduce waterlogging. GRDC Update Papers. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Innovative-management-techniques-to-reduce-waterlogging

[18] V Devasirvatham, DK Tan, PM Gaur, RM Trethowan (2014) Chickpea and temperature stress: An overview. Legumes under Environmental Stress: Yield, Improvement and Adaptations 81.

[19] A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops—a review. Euphytica 172 (1), 1–12.

drought are also major factors. Chilling temperatures occur from 15°C to –1.5°C, and freezing temperatures are –1.5°C and below.

14.3.1 Impact of freezing range (less than –1.5°C)

Plants sensitive to freezing are damaged or killed by temperatures below –1.5°C. Damage from freezing commonly occurs due to ice forming into lattices within the intercellular spaces. The rigid ice structure extends as the temperature drops, and may penetrate cellular walls and membranes to an extent that cells are unable to repair themselves and the plant dies.

The tolerance of a plant to freezing varies greatly between different tissues, i.e. upper and lower leaves of the plant canopy, stems, meristems, and roots. Tolerance to freezing-range temperatures has been shown to decrease as the plant progresses from the seedling stage to flowering.

Freezing stress predominantly occurs during the seedling and early vegetative stages of crop growth.

Prolonged periods of freezing-range temperatures can prevent germination, reduce the vigour and vegetative biomass of the developing plant, and can be fatal to plants, especially those at the late vegetative and reproductive phenological growth stages.

The main effects of freezing temperatures on the developing seedling are related to membrane injury, which reduces respiration and photosynthesis, and causes loss of turgor, resulting in wilting and temperature-induced drought stress. Some observations have indicated that freezing can reduce seed size and cause seed-coat discolouration, probably due to stress conditions affecting the mobilisation of plant resources. [20]

14.3.2 Impact of chilling range (–1.5°C to 15°C)

In chickpeas, the upper limits of the chilling range are quite acceptable, and even optimum for early growth in some genotypes, but reproductive processes can become susceptible to damage from temperatures of around 15°C and lower.

In the Mediterranean-type environment of southern Australia, chickpea yields are limited by chilling-range temperatures during flowering, when chilling causes extensive flower and pod abortion. This is especially a problem for early-sown crops when growers are aiming for high yield potential (high biomass) and for early-flowering genotypes. The abortion of flowers and pods in late winter and early spring leads to low harvest index.

Desi chickpea seed can germinate in soil as cold as 5°C, but seedling vigour is greater if the soil temperature is at least 7°C. Kabuli chickpea seed is more sensitive to cold soils and should not be seeded into excessively wet soil or into soil with a temperature below 12°C at the placement depth.

In chickpeas, sensitivity to freezing- and chilling-range temperatures increases as the plant progresses from germination to flowering. Temperatures within the chilling range can limit the growth and vigour of chickpeas at all stages, but are considered most damaging to yield at the reproductive stages. Southern Australia is most affected by chilling-range temperatures at flowering. A prolonged period of chilling-range temperatures at any phenological stage of development in chickpeas has detrimental effects on the final seed yield.

During germination, chilling-range temperatures result in poor crop establishment, increased susceptibility to soil-borne pathogens, and reduced seedling vigour. At the seedling stage, long periods of chilling-range temperatures can retard the growth of the plant and, in severe cases, cause plant death. Visual symptoms of chilling injury at the seedling stage include the inhibition of seedling growth, accumulation of anthocyanin (red, purple and blue) pigments, waterlogged appearance with browning

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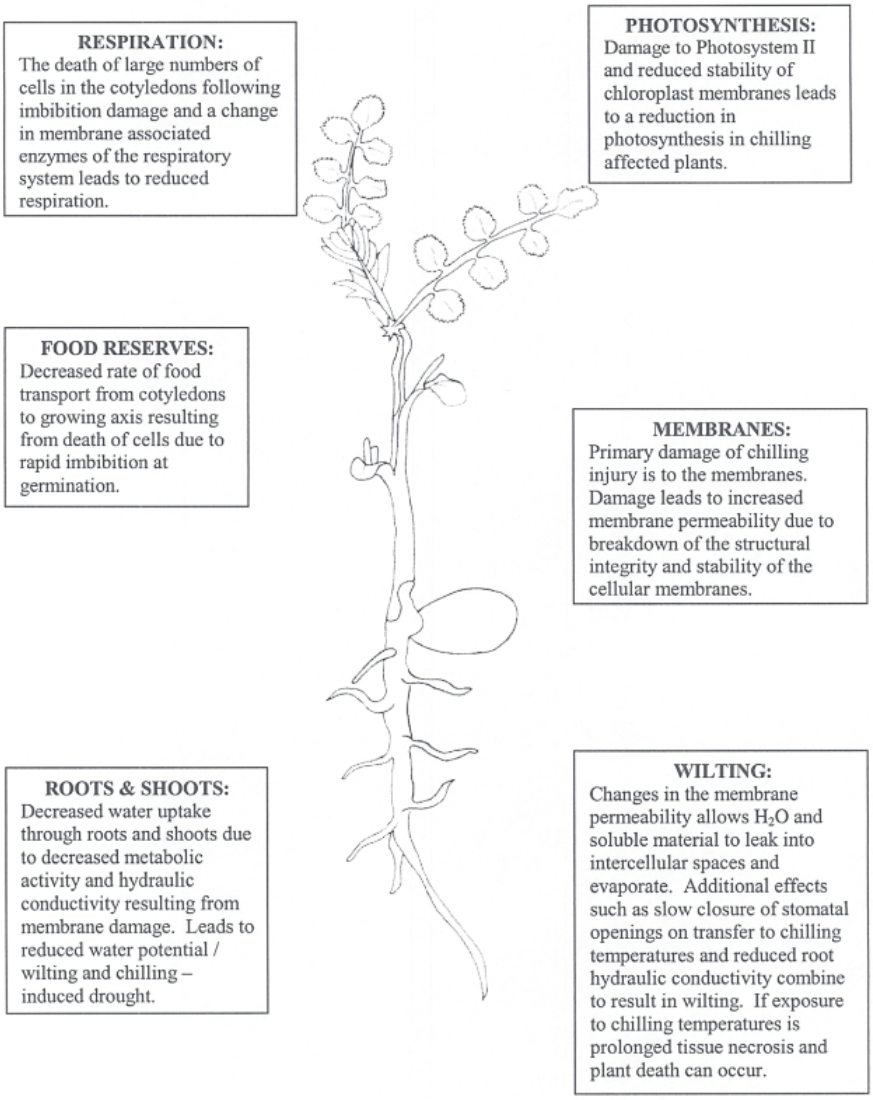
[20] JS Croser,, HJ Clarke,, KHM Siddique, TN Khan (2003). Low-temperature stress: implications for chickpea (*Cicer arietinum* L.) improvement. Critical Reviews in Plant Sciences 22 (2), 185–219, https://www.researchgate.net/publication/234520461_Low-Temperature_Stress_Implications_for_Chickpea_Cicer_arietinum_L_Improvement

of the mesocotyls, and the browning and desiccation of coleoptiles and undeveloped leaves. At the vegetative stage, chilling-range temperatures markedly slow down plant growth and dry matter production. Less dry matter production reduces the reproductive sink that the plant can support, which, in turn, reduces yield. Flower, pod, or seed abortion are further symptoms of chilling-range temperatures (Figure 2).



RESPIRATION:
The death of large numbers of cells in the cotyledons following imbibition damage and a change in membrane associated enzymes of the respiratory system leads to reduced respiration.

PHOTOSYNTHESIS:
Damage to Photosystem II and reduced stability of chloroplast membranes leads to a reduction in photosynthesis in chilling affected plants.

FOOD RESERVES:
Decreased rate of food transport from cotyledons to growing axis resulting from death of cells due to rapid imbibition at germination.

MEMBRANES:
Primary damage of chilling injury is to the membranes. Damage leads to increased membrane permeability due to breakdown of the structural integrity and stability of the cellular membranes.

ROOTS & SHOOTS:
Decreased water uptake through roots and shoots due to decreased metabolic activity and hydraulic conductivity resulting from membrane damage. Leads to reduced water potential / wilting and chilling – induced drought.

WILTING:
Changes in the membrane permeability allows H_2O and soluble material to leak into intercellular spaces and evaporate. Additional effects such as slow closure of stomatal openings on transfer to chilling temperatures and reduced root hydraulic conductivity combine to result in wilting. If exposure to chilling temperatures is prolonged tissue necrosis and plant death can occur.

Figure 2: *Effect of chilling injury on chickpeas at the seedling to vegetative phenological stages.*

Source: Croser *et al.* 2003

Chilling range temperatures at the mid to late vegetative stage retard growth rate and reduce plant vigour. These effects are due to the same mechanisms that affect post-emergent seedling growth, that is, reduced respiration and photosynthesis, and in severe cases a loss of turgor and subsequent water stress.

Air temperature and photoperiod have a major influence on the timing of reproductive events in chickpea (Tables 6 and 7), with the rate of progress to flowering being a linear function of mean temperature. Pollen germination and vigour is affected by chilling-range temperatures. [21]

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[21] JS Croser, ,HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (*Cicer arietinum* L.) improvement. Critical Reviews in Plant Sciences 22 (2), 185–219, https://www.researchgate.net/publication/234520461_Low-Temperature_Stress_Implications_for_Chickpea_Cicer_arietinum_L_Improvement

Table 6: *Effect of chilling-range temperatures on chickpea reproduction.*

Effect	Description
Flower shedding/floral abortion Pod shedding/drop	Sudden low temperatures (0° to 10°C) during flowering induces flower shedding, which causes partitioning of assimilates to vegetative growth, resulting in lowered Harvest Index. Major cause of low pod and seed set in subtropical South Asia and Australia.
Interrupted pollen tube growth	Temperatures up to 25°C shown to interrupt pollen tube growth. Failure of fertilisation results from poor germination and slow growth of pollen tubes in susceptible genotypes at low temperatures (Figure 4).
Lowered pollen viability	Pollen in tolerant genotypes more viable (90%) compared to susceptible genotypes (60%). Two stages of pollen sensitivity at 5 and 9 days before anthesis have been identified.
Reduced ovule size	Ovules in flowers opening on cool days were 9–45% smaller than warm day ovules – more pronounced in chilling susceptible than tolerant genotypes.
Reduced pistil size	Heterostyly – the distance between the anther and stigma at the time of flower opening is greater in sensitive than in tolerant genotypes.
Reduced stigmatic esterase activity	Reduced esterase activity was identified in susceptible genotypes suggesting the stigmas were less receptive to pollen tube growth.
Delayed anther dehiscence	Anther dehiscence is delayed by chilling temperatures, reducing fertilisation events.
Reduced pollen germinability	Possibly due to smaller amount of storage material in pollen from sensitive genotypes.
Reduced pollen turgor	Turgidity is an absolute requirement for germination. Pollen cells with leaking membranes cannot become turgid and germinate.

Source: Croser *et al.* 2003

Table 7: *Effect of chilling range temperatures at flowering on chickpea productivity in Mediterranean climate.*

Date of planting	Date of 50% flowering	Mean daily temperature (°C) at 50% flowering	Number of aborted flowers (m-2)	Biological yield (t/ha-1)	Seed yield (t/ha-1)	Harvest index
17 May	19 August	12.5	800	6.76	1.25	0.18
31 May	1 September	13.6	500	5.34	1.13	0.21
14 June	14 September	14.7	200	4.84	1.12	0.23
30 June	29 September	16.8	0	3.98	1.11	0.28
20 July	6 October	17.7	0	3.23	0.94	0.29

Source: Modified from Siddique, Marshall and Sedgley (1983) [22]

Exposure to prolonged periods of temperatures at the lower end of the chilling range can cause poor germination, slow growth, flower shedding, and pod abortion, and in severe cases cell necrosis and plant death. The resulting yield penalty or reduction in harvest index varies dramatically in the field, but can be substantial (Photo 7).

Photo 7: *Chilling damage in chickpea- sown paddock.*

Source: Pulse Breeding Australia

In Australia, flower shed and pod abortion due to chilling-range temperatures at flowering is a major cause of poor yield. It should be noted that this is in combination with terminal drought. Early sowing (winter) is essential in these environments in order to maximise yield and avoid terminal soil-moisture stress.

The development of cultivars with a higher degree of cold tolerance would facilitate the spread of chickpea-growing regions to both higher altitudes and colder latitudes and therefore are worthy of considerable agronomic and breeding attention. [23]

Tolerance to low temperature

Low temperature at flowering is a major constraint to improving yields of chickpeas in many regions of the world. In particular, cool dryland environments such as that of southern Australia would benefit from cultivars with the ability to flower and set pods early in the growing season before soil moisture becomes a limiting factor.

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[22] KHM Siddique, C Marshall, RH Sedgley (1983) Temperature and leaf appearance in chickpea. International Chickpea Newsletter 8, 14–15.

[23] JS Croser, ,HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (*Cicer arietinum* L.) improvement. Critical Reviews in Plant Sciences 22 (2), 185–219.

Desi types generally suffer less damage from low temperatures at germination than kabuli types. Research overseas and within Australia has demonstrated a range of cold tolerance among chickpea varieties. In parts of the world where chickpeas are grown as a spring crop because of the very cold winter, varieties have been developed that tolerate freezing conditions during vegetative growth. These varieties can be sown in autumn, survive over winter, and are ready to flower and set pods when temperatures rise in summer.

However, chickpea varieties resistant to low temperatures during flowering have not yet been developed. Some genotypes from India are less sensitive than those currently grown in Australia, and these are being utilised in chickpea-breeding programs.

Controlled-environment studies at the University of Western Australia have identified two stages of sensitivity to low temperatures in chickpeas. The first occurs during pollen development in the flower bud, and results in infertile pollen even in open flowers. The second stage occurs at pollination, when pollen sticks to the female style, and produces a tube that grows from the pollen down the style to the egg (Photo 8).

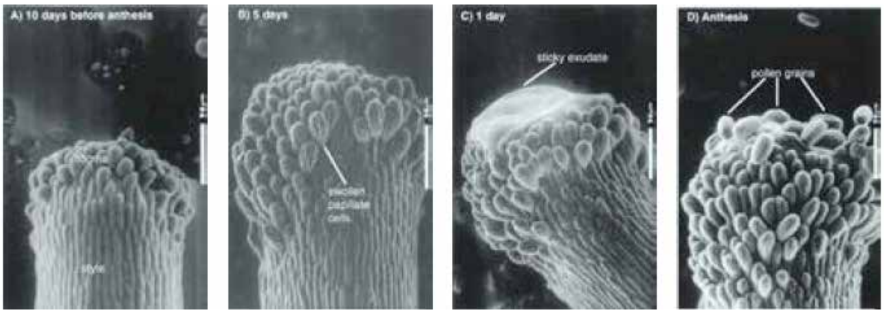

Photo 8: *Development of the style and stigma of chickpea flowers taken with an electron microscope.*

Photo H. Clarke, UWA

At low temperatures pollen tubes grow slowly, fertilisation is less likely and the flower often aborts. The rate of pollen-tube growth at low temperature is closely related to the cold tolerance of the whole plant. This trait can therefore be used to select more tolerant varieties (Figure 3).

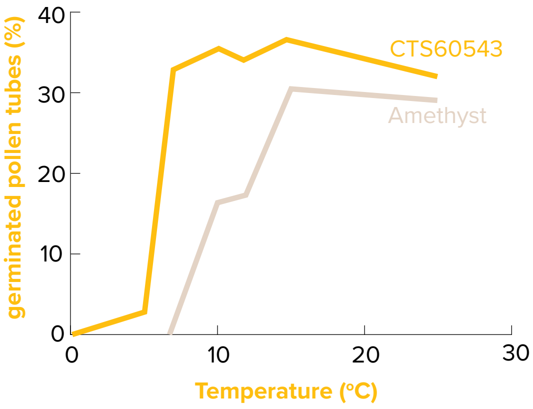

Figure 3: *Proportion of pollen germination at various temperatures in cold-sensitive (Amethyst) and cold-tolerant (CTS60543) varieties.*

The critical average daily temperature for abortion of flowers in most varieties currently grown in Australia is about 15°C. New hybrids that set pods at ~13°C are being developed.

In the field, cold-tolerant varieties set pods about 1–2 weeks earlier than most current varieties. As well as conventional methods for plant improvement, DNA-based techniques are also being investigated. [24]

IN FOCUS

Response of chickpea genotypes to low-temperature stress during reproductive development

Clarke and Siddique (2004) showed temperatures of less than 15°C affect both the development and the function of reproductive structures in the chickpea flower.

The function of pollen derived from chilling-sensitive plants is the most affected by low-temperature stress, and particularly the growth of the pollen tubes down the style before fertilisation occurs. Pollen tubes derived from chilling-tolerant plants continue to grow down the style under low-temperature stress.

Two periods of sensitivity to low temperature were identified during pollen development (sporogenesis) in both Amethyst (cold tolerant) and CTS60543 (cold sensitive), each of which resulted in chilling-stressed plants having flowers with only 50% viable pollen (Figure 4 top).

The researchers estimated that the first stage of sensitivity occurred nine days before anthesis. The significant decrease in pollen viability coincided with lower podset (approximately 70%) in both genotypes. This was followed by a recovery in pollen viability and podset.

The second period of sensitivity occurred 4–6 days before anthesis. In Amethyst a dramatic drop to 40% podset correlated with the decrease in pollen viability (Figure 4 bottom), while normal pods formed at other nodes before and after this chilling-sensitive stage. Despite lower pollen viability in CTS60543, podset was not affected at this time, and all of the flowers gave rise to full pods in this genotype.

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[24] Clarke, H. J., & Siddique, K. H. M. (2004). Response of chickpea genotypes to low temperature stress during reproductive development. Field Crops Research, 90(2), 323-334

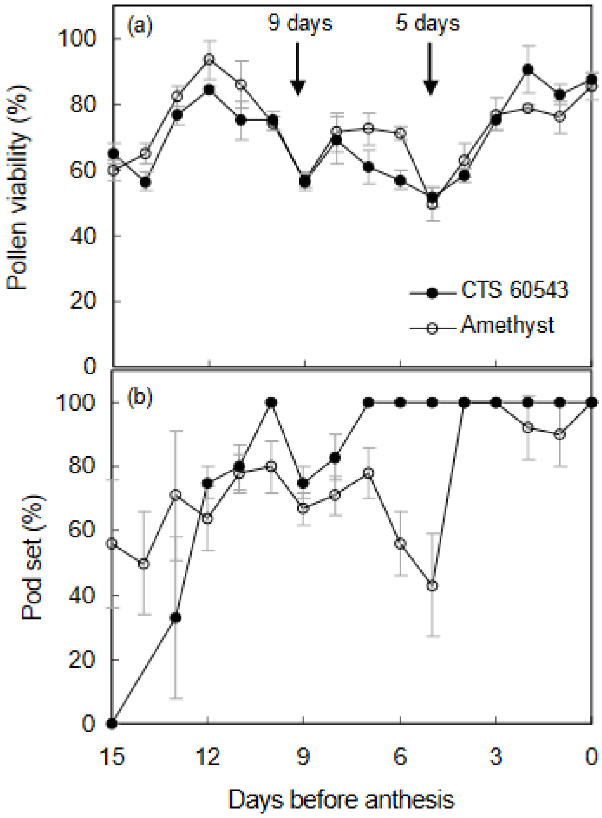

Figure 4: *The effects of stressing plants with a temperature of 3°C during flower development in tolerant and sensitive genotypes. (A) Pollen viability. (B) Podset. Arrows indicate susceptible periods at 9 days and 5–6 days before anthesis.*

Temperatures from 7–25°C did not affect the proportion of pollen grains which germinated after four-hour incubation in vitro, and 80–90% germination occurred in all of the genotypes examined (Figure 5). The percentage that germinated was significantly lower at 3°C than at other temperatures, but no significant difference was measured between genotypes at this temperature when samples were examined at four hours.

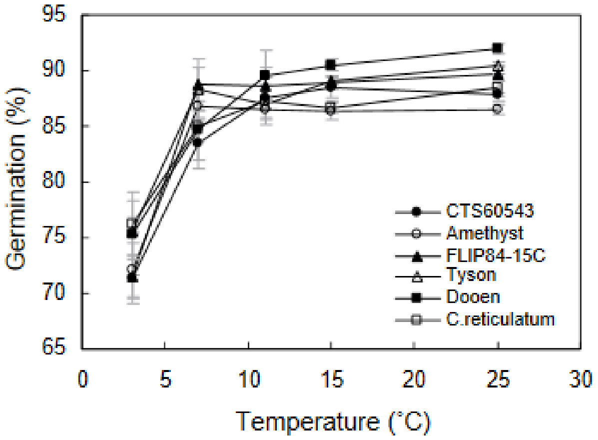

Figure 5: *The effect of temperature on pollen germination in chickpea genotypes after four-hour culture in lab conditions.*

A second experiment was therefore designed to examine the rate of germination with selected genotypes at 3°C in the period up to four hours *in vitro*. The researchers found that low temperature delayed the onset of germination by 20–40 minutes compared to the control at 25°C, and it decreased the rate at which the pollen germinated (Figure 6). No significant difference was measured in germination between genotypes in the first 40 minutes in culture. After this time the percentage that germinated was significantly different between genotypes.

However, no link was observed between the rate of pollen germination in vitro at 3°C and the chilling tolerance of the whole plant. In fact, pollen from CTS60543 was slightly slower to begin germination.

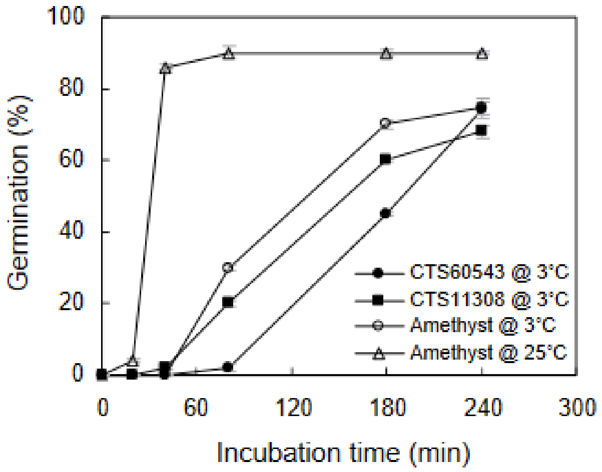

Figure 6: *Rate of pollen germination during 4 hour culture in lab conditions at low temperature (3°C) in sensitive and tolerant genotypes.*

Figure 7 illustrates a greater number of pollen tubes in the style in CTS60543 compared to Amethyst when hand-pollinated plants are stressed at 7°C for 24 h after pollination. [25]

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[25] HJ Clarke, KHM Siddique (2004) Response of chickpea genotypes to low temperature stress during reproductive development. Field Crops Research 90 (2), 323–334.

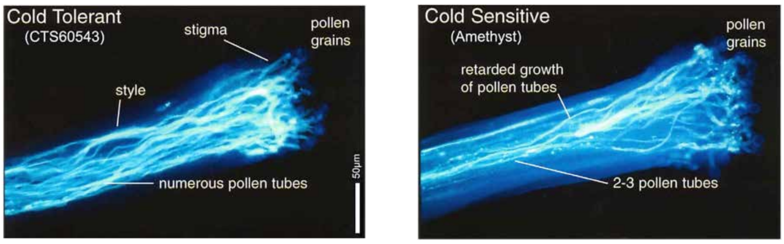

Figure 7: *More pollen tubes of CTS60543 grow down the style to the ovary at low temperature stress (7°C) compared to Amethyst. Styles were fixed 24 h after pollination and stained with aniline blue.* [26]

14.3.3 Heat stress

High-temperature stress in chickpeas causes substantial loss (Photo 9) in crop yield due to damage to the reproductive organs, increased rate of plant development, and reduced length of the reproductive period. [27]

Photo 9: *Chickpea varieties planted under hot conditions: heat-sensitive plant with no pods (left) and heat-tolerant plant with healthy pods (right).*

Photo: D. Tan, University of Sydney

Chickpeas are sensitive to heat stress (36/16°C or higher as day/night temperatures) in their reproductive stage with potential loss of yields at high temperatures. The anthers of heat-sensitive genotypes have been found to have reduced synthesis of sugars due to the inhibition of the appropriate enzymes. Consequently, affected plant pollen can have considerably lower sucrose levels, which results in reduced pollen function, impaired fertilisation and poor podset in the heat-sensitive genotypes.

IN FOCUS

Reproductive failures in heat-stressed chickpeas are associated with impaired sucrose metabolism in leaves and anthers

In the heat-stressed plants, phenology accelerated as days to flowering and podding, and biomass decreased significantly. The significant reduction in podset was associated with reduced pollen viability, pollen

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[26] HJ Clarke, KHM Siddique (2004) Response of chickpea genotypes to low temperature stress during reproductive development. Field Crops Research 90 (2), 323–334.

[27] Y Gan, J Wang, SV Angadi, CL McDonald (2004) Response of chickpea to short periods of high temperature and water stress at different developmental stages. Proceedings of the 4th International Crop Science Congress, Brisbane. http://www.cropscience.org.au/icsc2004/poster/1/3/3/603_ganyd.htm

load, pollen germination (*in vivo* and in *vitro*) and stigma receptivity in all four genotypes researched.

Heat stress inhibited pollen function more in the sensitive genotypes than in the tolerant ones, and consequently showed significantly less podset.

Heat stress significantly reduced stomatal conductance, leaf water content, chlorophyll, membrane integrity and photochemical efficiency, with a larger effect on heat-sensitive genotypes. Because the plants were heat stressed, rubisco (a carbon-fixing enzyme) along with sucrose phosphate synthase (SPS) and sucrose synthase (SS) (sucrose-synthesising enzymes) decreased significantly in the leaves, and this led to reduced sucrose content. Invertase, a sucrose-cleaving enzyme, was also inhibited along with SPS and SS. The inhibition of these enzymes was significantly greater in the heat-sensitive genotypes. Concurrently, the anthers of these genotypes had significantly less SPS and SS activity and thus, less sucrose content. Pollen had considerably lower sucrose levels, resulting in reduced pollen function, impaired fertilisation and poor podset. [28]

Chickpea pollen grains are more sensitive to heat stress than the stigma. High temperatures have been found to reduce pollen production in each flower, the amount of pollen germination, podset and seed number and size (Photo 10). [29]

Photo 10: *Comparison of seed size under heat stress. The larger seeds (left) are from non-stressed plants, and the smaller seeds (right) from heat-stressed conditions.*

Photo: V. Devasirvatham 2015

Heat stress during the reproductive stage can cause significant yield loss. Very little of the germ plasm will set pods when temperatures exceed 36°C. During the reproductive stage heat stress can cause asynchrony of male and female floral organ development and impairment of male and female floral organs resulting in lower yields. [30]

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[28] N Kaushal, R Awasthi, K Gupta, P Gaur, KH Siddique, H Nayyar (2013) Heat-stress-induced reproductive failures in chickpea (*Cicer arietinum*) are associated with impaired sucrose metabolism in leaves and anthers. Functional Plant Biology, 40 (12), 1334–1349, https://www.researchgate.net/publication/265209338_Heat-stress-induced_reproductive_failures_in_chickpea_Cicer_arietinum_are_associated_with_impaired_sucrose_metabolism_in_leaves_and_anthers

[29] V Devasirvatham, PM Gaur, N Mallikarjuna, RN Tokachichu, RM Trethowan, DK Tan (2012) Effect of high temperature on the reproductive development of chickpea genotypes under controlled environments. Functional Plant Biology, 39 (12), 1009–1018, http://www.publish.csiro.au/FP/pdf/FP12033

[30] V Devasirvatham, DKY Tan, PM Gaur, TN Raju, RM Trethowan (2012) High temperature tolerance in chickpea and its implications for plant improvement. Crop and Pasture Science, 63 (5), 419–428, http://www.plantstress.com/Articles/up_heat_files/Heat tolerance (chickpea) 2012.pdf

14.3.4 Heat and water stress

IN FOCUS

Response of Chickpea to Short Periods of High Temperature and Water Stress at Different Developmental Stages.

This study was conducted to determine the effect of short periods of high temperature and water stress on pod production, seedset and yield of chickpeas.

Plants stressed at 35/16°C during flowering produced 53% fewer fertile pods on the main stem and 22% fewer pods on the branches than those kept at 20/16°C. Nearly 90% of the pods formed during stress were infertile. Due to high temperature stress, kabuli crop filled 58% of the pods formed and decreased seeds pod-1 by 26% from the check. Consequently, desi chickpea seed yield decreased by 54% when stressed during pod development and 33% when stressed during flowering. Kabuli chickpea seed yield decreased by 50% when stressed during pod formation and 44% when stressed during flowering. [31]

14.4 Drought stress

Chickpeas are an important winter pulse crop for the neutral-to-alkaline heavy-textured soils in both the Mediterranean climatic region and the summer-rainfall region of Australia. Mediterranean chickpea-growing regions generally have cool, wet winters, and in spring, increasing temperatures and reduced rainfall result in a terminal drought for most crops. Unlike many other crops, chickpeas are unable to escape terminal drought through rapid development because low temperatures (<15°C) often cause flower and pod abortion, especially in cool southern areas. [32]

Yield losses can be the result of intermittent drought during the vegetative phase, due to drought during reproductive development, or due to terminal drought at the end of the crop cycle. [33]

After disease, the major constraint to greater chickpea production is its sensitivity to the end-of-season drought that occurs in both the Mediterranean climates and when grown on stored soil moisture in the summer-rainfall region of Australia. Terminal drought in a Mediterranean climate affects chickpeas because rainfall starts decreasing and evaporation starts increasing just as they enter their reproductive stage. The summer-rainfall regions are more dependent on stored soil moisture, and terminal drought occurs because the soil moisture is exhausted during the seed-filling stage.

Terminal drought reduces leaf photosynthesis in chickpeas before seed growth commences, so that seed filling is, in part, dependent on carbon and nitrogen accumulated prior to podding. For example, under terminal drought, more

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[31] Y Gan, J Wang, SV Angadi, CL McDonald (2004) Response of chickpea to short periods of high temperature and water stress at different developmental stages. Proceedings of the 4th International Crop Science Congress, Brisbane. http://www.cropscience.org.au/icsc2004/poster/1/3/3/603_ganyd.htm

[32] RJ Jettner, SP Loss, KHM Siddique, RJ French (1999) Optimum plant density of desi chickpea (*Cicer arietinum* L.) increases with increasing yield potential in south-western Australia. Crop and Pasture Science, 50 (6), 1017–1026, https://www.researchgate.net/publication/234520394_Optimum_plant_density_of_desi_chickpea_Cicer_arietinum_L_increases_with_increasing_yield_potential_in_south-western_Australia

[33] A Mafakheri, A Siosemardeh, B Bahramnejad, PC Struik, Y Sohrabi (2010) Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. Australian Journal of Crop Science, 4 (8), 580–585, http://eprints.icrisat.ac.in/422/1/AustralianJofCropScience.pdf

than 90% of the seed nitrogen in chickpea comes from pre-podding sources, particularly leaves. [34]

IN FOCUS

How chickpeas respond to terminal drought: leaf stomatal conductance, pod abscisic acid concentration, and seedset

At flowering, pod production and seedset, chickpeas are sensitive to drought stress. It is already known that drought stress impairs pollen viability and the function of the stigma and style, but it was not clear whether flower and pod abortion was due to the failure of the pollen tube to reach the ovary, or to other factors.

In one study, pollen viability and germination decreased when the fraction of transpirable soil water (FTSW) decreased below 0.18 (i.e. 82% of the plant-available soil water had been transpired); however, at least one pollen tube in each flower reached the ovary. The young pods which developed from flowers produced when the FTSW was 0.50 had viable embryos, but contained higher concentrations of abscisic acid (ABA) than those of the well-watered plants; all pods ultimately aborted in the drought treatment. Cessation of seedset at the same soil-water content at which stomata began to close and ABA increased strongly suggested a role for ABA signalling in the failure to set seed either directly through abscission of developing pods or seeds or indirectly through the reduction of photosynthesis and assimilate supply to the seeds. [35]

Drought after podding is a common feature of chickpea production in southern Australia. One study investigated the effect of water stress, which was imposed after podding, on yield and on the accumulation of amino acids and soluble sugars in seeds. Although terminal water stress decreased the total plant dry mass by 23% and seed yield by 30%, it had no effect on the mass of individual pods and seeds which remained on the plant after the imposition of stress treatment. The deleterious effect of water stress on yield was due to increased pod abortion and a decrease in pod formation. Water stress improved the seed's nutritive value in terms of higher accumulation of soluble sugars, amino acids and proteins. [36]

Plants grown under drought conditions have a lower stomatal conductance in order to conserve water. (Stomatal conductance is the rate at which carbon dioxide enters and water vapour exits the stomata of a leaf.) Consequently, CO_2 fixation is reduced and photosynthetic rate decreases, resulting in less assimilate production for growth and yield of plants. Drought stress during vegetative growth or anthesis significantly decreases chlorophyll and therefore photosynthesis. Drought stress at anthesis phase can reduce seed yield more severely than when it occurs during the vegetative stage. [37]

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[34] JA Palta, AS Nandwal, S Kumari, NC Turner (2005) Foliar nitrogen applications increase the seed yield and protein content in chickpea (*Cicer arietinum* L.) subject to terminal drought. Crop and Pasture Science, 56 (2), 105–112, http://www.publish.csiro.au/AR/pdf/AR04118

[35] J Pang, NC Turner, T Khan, YL Du, JL Xiong, TD Colmer, R Devilla, K Stefanova, KHM Siddique (2016) Response of chickpea (*Cicer arietinum* L.) to terminal drought: leaf stomatal conductance, pod abscisic acid concentration, and seed set. Journal of Experimental Botany. Published online 19 April 2016. DOI 10.1093/jxb/erw153, http://jxb.oxfordjournals.org/content/early/2016/04/19/jxb.erw153.full

[36] MH Behboudian, Q Ma, NC Turner, JA Palta (2001) Reactions of chickpea to water stress: yield and seed composition. Journal of the Science of Food and Agriculture, 81 (13), 1288–1291, http://onlinelibrary.wiley.com/doi/10.1002/jsfa.939/abstract

[37] A Mafakheri, A Siosemardeh, B Bahramnejad, PC Struik, Y Sohrabi (2010) Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. Australian Journal of Crop Science, 4 (8), 580–585, http://eprints.icrisat.ac.in/422/1/AustralianJofCropScience.pdf

IN FOCUS

Variation in pod production and abortion among chickpea cultivars under terminal drought

The researchers studied the effect of terminal drought on the dry matter production, seed yield and its components, including pod production and pod abortion, was investigated in chickpeas. Two desi chickpea cultivars (with small, angular and dark brown seeds) and two kabuli cultivars (with large, rounded and light coloured seeds) differing in seed size were grown in a greenhouse where the temperature was controlled and water stress was applied by withholding irrigation one week after podset commenced (early podding water stress, ES), two weeks after (mid-podding water stress, MS) or three weeks after (late-podding water stress, LS). In addition, the pod and seed growth of well-watered plants was followed for the first 19 days after podset.

The results show that pod abortion is one of the main reasons for decreases in seed yield in chickpeas exposed to terminal drought and that, irrespective of differences in phenology, kabuli types have greater pod abortion than desi types when water deficits develop shortly after first podset. [38]

A lack of water can also impair light interception and light-use efficiency (and photosynthesis) by affecting chickpea development during leaf expansion. Therefore, the timing of water stress during chickpea canopy development will determine how well the plant intercepts and uses light. [39]

IN FOCUS

Physiological responses of chickpea genotypes to terminal drought in a Mediterranean-type environment

Two field experiments were carried out to investigate the effects of terminal drought on chickpeas grown under water-limited conditions in the Mediterranean-climatic region of Western Australia.

In the first experiment, five desi chickpeas (with small, angular seeds) and one kabuli chickpea (with large, round seeds) were grown in the field with and without irrigation after flowering. In the second experiment, two desi and two kabuli cultivars were grown in the field with either irrigation or under a rainout shelter during pod filling. In bother experiments, researchers measured leaf-water potential, dry-matter partitioning after podset and yield components, and in the first experiment they also measured growth before podset, photosynthesis, pod-water potential and leaf osmotic adjustment.

In the rain-fed plants, leaf-water potential decreased below −3 MPa while photosynthesis decreased to about a tenth of its maximum at the start of seed filling. Osmotic adjustment varied significantly among genotypes.

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[38] L Leport, NC Turner, SL Davies, KHM Siddique (2006) Variation in pod production and abortion among chickpea cultivars under terminal drought. European Journal of Agronomy, 24 (3), 236–246, http://www.sciencedirect.com/science/article/pii/S1161030105000985

[39] s Thoma, GL Hammer (1995) Growth and yield response of barley and chickpea to water stress under three environments in southeast Queensland. II. Root growth and soil water extraction pattern. Aust J of Ag Research. 46 (1), 35–48.

Although flowering commenced from about 100 days after sowing (DAS) in both experiments, podset was delayed until 130–135 DAS in the first experiment, but started at 107 DAS in the second experiment. The shortage of water reduced seed yield by 50–80%, due to a reduction in seed number and seed size.

Apparent redistribution of stem and leaf dry matter during pod filling varied from 0–60% among genotypes, and suggests that this characteristic may be important for a high harvest index and seed yield in chickpea. [40]

14.4.1 Managing for drought

Long-term historical records indicate that our climate is becoming progressively warmer and dryer. This trend is expected to continue due to increased levels of greenhouse gas in the atmosphere, with dry seasons likely to become more frequent over southern Australia. [41]

For crops exposed to terminal drought, the application of nitrogen fertiliser to the soil during podset and seed filling is unlikely to assist in delaying the withdrawal of nitrogen from the leaves and maintaining leaf photosynthesis because nitrogen is not taken up from dry soil. However, foliar applications of urea have been effective in increasing the nitrogen availability for seed filling. [42]

IN FOCUS

Foliar nitrogen increases the seed yield and protein content in chickpeas subject to terminal drought

Researchers hypothesised that applying urea to the leaves of chickpeas may increase the amount of nitrogen available for seed filling when chickpeas are grown under terminal drought. The study was conducted in a glasshouse where they were able to mimic terminal drought.

Nitrogen was applied at: (i) first flower; (ii) 50% flowering; (iii) 50% pod set; and (iv) the end of podding; with (v) being an unsprayed control. Terminal drought was induced from pod set onward.

Foliar applications of urea at first flower and at 50% flowering, before terminal drought was induced, resulted in greater yield and higher seed protein content.

The increase in yield occurred because of an increase in the number of pods with more than one seed (rather than from greater numbers of pods per plant or increased seed size). This indicated that more seeds survived terminal drought. The increase in the seed-protein content occurred because there was more nitrogen available for seed filling.

The foliar application of urea during flowering, before terminal drought was induced, resulted in 20% more biomass at maturity. This suggested that growth that occurred before the water shortage gave the plant more carbon resources which allowed it to sustain seed filling even under conditions of terminal drought.

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[40] L Leport, NC Turner, RJ French, MD Barr, R Duda, SL Davies, D Tennant, KHM Siddique (1999) Physiological responses of chickpea genotypes to terminal drought in a Mediterranean-type environment. European Journal of Agronomy, 11 (3), 279–291, http://www.sciencedirect.com/science/article/pii/S1161030199000398

[41] DAFWA. Drought, https://www.agric.wa.gov.au/climate-land-water/climate-weather/drought

[42] JA Palta, AS Nandwal, S Kumari, NC Turner (2005) Foliar nitrogen applications increase the seed yield and protein content in chickpea (*Cicer arietinum* L.) subject to terminal drought. Aust J Ag Research. 56 (2), 105–112.

> Foliar applications of urea at 50% podset and at the end of podding did not affect the yield or seed-protein content, primarily because the uptake of nitrogen was limited by the leaf senescence that occurs with the development of terminal drought.
>
> The results indicate the potential to increase yields of chickpeas by applying foliar nitrogen near flowering in environments in which terminal droughts reduce yield. [43]

14.4.2 Adaptation to drought stress

There are three strategies of crop adaptation to drought-stressed environments, all of which are useful in the Mediterranean climate:

1. Drought escape, where the crop completes its life cycle before the onset of terminal drought.
2. Drought avoidance, where the crop maximises its water uptake and minimises water loss.
3. Drought tolerance, where the crop continues to grow and produce even with reduced water. [44]

Despite the ability of chickpeas to thrive in a wide range of environments, there has been little development of specifically adapted varieties, and at this stage the same cultivar may be seen in farmers' fields from Queensland to Western Australia. The basis of the wide adaptation in chickpeas is important as new cultivars are developed.

Chickpeas may adapt to drought stress by maximising water uptake through continuous root growth up to seed filling, and by maintaining substantial water uptake until the fraction of extractable moisture in the root profile falls to 0.4. [45] In addition to these strategies, the early sowing of chickpeas in south-western Australia helps to develop a large green area that rapidly covers the ground. This means that plants absorb a significant proportion of photosynthetic-active radiation early in the season when vapour-pressure deficits are low, and that they use more water in the post-flowering period. [46] Consequently, such crops produce large biomass and grain yield. Application of supplemental irrigation at flowering and early pod-filling can relieve drought stress and substantially increase seed yield. [47]

Plants can partly protect themselves against mild drought stress by accumulating osmolytes (compounds that affect osmosis). Proline is one of the most common compatible osmolytes in drought-stressed plants. It does not interfere with normal biochemical reactions, and allows the plants to survive under stress. The more drought-tolerant varieties have a greater capacity to accumulate proline, which gives them a buffer against the effects of drought. [48]

One study found that a strain of symbiotic rhizobia (nitrogen-fixing bacteria) was effective in root-nodule symbiosis, partially alleviated decreased growth and yield, and increasing root biomass of chickpeas under drought stress. [49]

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[43] JA Palta, AS Nandwal, S Kumari, NC Turner (2005) Foliar nitrogen applications increase the seed yield and protein content in chickpea (*Cicer arietinum* L.) subject to terminal drought. Aust J Ag Research, 56 (2), 105–112.

[44] MM Ludlow (1989) Strategies of response to water stress. Structural and Functional Responses to Environmental Stresses, 269–281.

[45] KHM Siddique , RH Sedgley (1987) Canopy development modifies the water economy of chickpea (*Cicer arietinum* L.) in south-western Australia. Aust J Ag Research, 37 (6), 599–610.

[46] Cited in H Zhang, M Pala, T Oweis, H Harris (2000) Water use and Water Use Efficiency of chickpea and lentil in a Mediterranean environment. Crop and Pasture Science, 51 (2), 295–304.

[47] H Zhang, M Pala, T Oweis, H Harris (2000) Water use and Water Use Efficiency of chickpea and lentil in a Mediterranean environment. Crop and Pasture Science, 51 (2), 295–304.

[48] A Mafakheri, A Siosemardeh, B Bahramnejad, PC Struik, Y Sohrabi (2010) Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. Australian Journal of Crop Science, 4 (8), 580–585, http://eprints.icrisat.ac.in/422/1/AustralianJofCropScience.pdf

[49] A Bano, R Batool,, F Dazzo. (2010) Adaptation of chickpea to desiccation stress is enhanced by symbiotic rhizobia. Symbiosis, 50 (3), 129–133, http://link.springer.com/article/10.1007/s13199-010-0051-9/fulltext.html

IN FOCUS

The role of phenology in adaptation of chickpeas to drought

Chickpeas are grown from autumn to early summer in both Mediterranean-type climates with winter dominant rainfall, and in sub-tropical climates with stored soil moisture and summer-dominant rainfall. In both environments, water shortages can occur at any time during the growing season, but terminal drought predominates. A study of 73 genotypes conducted over two years showed that high-yielding genotypes flowered early, podded early and had a relatively long flowering period at most, thought not all, low-yielding sites. Thus drought escape was an important phenological characteristic for successful chickpea production at sites with terminal drought. However, these characteristics did not predominate at a site where drought was severe throughout the growing period.

Studies under rain-fed conditions at a dry site in Western Australia have shown that a high degree of biomass redistribution from leaves to stems to the pod is associated with high yield. This suggests that, in addition to rapid phenological development, physiological mechanisms play a role in the adaptation of chickpeas to water-limited environments. [50]

Breeding chickpeas for drought tolerance and disease resistance

A GRDC-funded project, Breeding chickpea for drought tolerance and disease (project ICA00008), aimed to enhance production, productivity and yield stability of chickpeas grown in Mediterranean and similar Australian environments by improving genetic factors and agronomic options. Most chickpea cultivars grown in Mediterranean-type environments are susceptible to Ascochyta blight, affected by terminal drought, and susceptible to cold at the vegetative and flowering stages.

One of the reasons the project was important is that the identification of new sources of resistance or tolerance to Ascochyta blight, drought and Fusarium wilt is a continuous process, as the pressure from these stresses is continuously evolving.

The researchers sought to validate the results of a previous project, and to provide more efficient and reliable screening tools for the evaluation of germ plasm and breeding materials.

They shared new materials and methodologies with National Agricultural Research Systems in west Asia and north Africa, and with pulse-breeding programs in Australia.

This project delivers improved germ plasm to make chickpeas better able to combat these stressors. It also delivered germ plasm for other desirable traits, such as making the plant better suited to mechanical harvesting. Resistance to Ascochyta blight, to drought, and to Fusarium wilt were bred into adapted Australian cultivars, and the newly derived progenies are being advanced at International Center for Agricultural Research in Dry Areas (ICARDA).

These materials are shared with Australian partners at the advanced stage, to screen under local conditions. Selected lines will be used either in crossing programs or for testing in yield trials for direct release as cultivars. The pathway to the market is through the release and adoption of improved chickpea varieties.

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[50] J Berger, NC Turner, RJ French (2003) The role of phenology in adaptation of chickpea to drought. Solution for a Better Environment. Proceedings of the 11th Australian Agronomy Conference, Geelong, Victoria, Australia. February 2003, 2–6, http://www.regional.org.au/au/asa/2003/c/4/turner.htm

All these efforts are contributing to widen the genetic base of Australian chickpeas, which will give the industry more plasticity in the face of future threats to production. Farmers who adopt the new varieties developed in these materials derived from this project will contribute to greater and more sustainable chickpea production, and thereby to raising the level of the chickpea industry in Australia. [51]

14.5 Other environmental issues

14.5.1 Salinity

One of the most significant causes of soil degradation in Australia is salinity, which is the presence of dissolved salts in soil or water. It occurs when the water table rises, bringing natural salts to the surface; in sufficient quantity, the salts become toxic to most plants. They cause iron toxicity in plants and impede their ability to absorb water (Photos 11 and 12). Salinity, a major abiotic stress, is a major environmental production constraint in many parts of the world. In Australia, saline soils have been caused by extensive land clearing, predominantly for agricultural purposes. Chickpeas are extremely sensitive to salinity, and can have difficulty accessing water and nutrients from saline layers in the soil. This effectively limits water extraction from the subsoil, and consequently limits yields. Salinity impairs vegetative growth in chickpeas, but reproductive growth is particularly salt sensitive.

Photo 11: *Salt effects seen on soil and in subsequent chickpea growth.*

Source: Pulse Breeding Australia

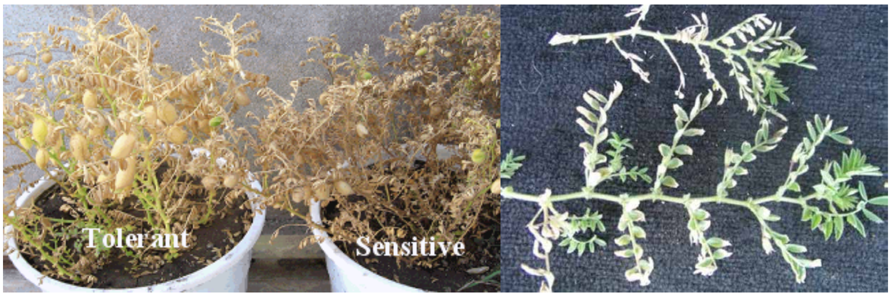

Photo 12: *Left: pod setting in saline soils in a salt-tolerant and a salt-sensitive genotype. While the biomass of the two genotypes may be similar, podset can be markedly different.* [52] *Right: typical salt effects on chickpea leaves.*

Photos: left - V Vadez *et al* (2006)52; right - Pulse Australia.

Nut grass (Photo 13) is often a good indicator of increased salt levels.

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[51] GRDC. Breeding chickpea for drought tolerance and disease resistance. Project ICA00008, http://projects.grdc.com.au/projects.php?action=view_project&project_id=1238

[52] V Vadez, L Krishnamurthy, PM Gaur, HD Upadhyaya, DA Hoisington, RK Varshney, NC Turner, KHM Siddique (2006) Tapping the large genetic variability for salinity tolerance in chickpea. Proceeding of the Australian Society of Agronomy. Meeting 10–14 September 2006, http://agronomyaustraliaproceedings.org/images/sampledata/2006/concurrent/environment/4561_vadez.pdf

Photo 13: *Nut grass growing in saline soil.*

Photo: Pulse Australia

All current varieties of chickpeas are considered highly sensitive to salinity. Levels of electrical conductivity (EC) >1.5 dS/m will cause a yield reduction in chickpeas (Table 8). During growth chickpeas are very sensitive to salinity, with the most susceptible genotypes dying in just 25 mM of sodium chloride (NaCl), and resistant genotypes unlikely to survive 100 mm NaCl in hydroponics. They are more tolerant at germination, with some genotypes tolerating 320 mM NaCl. When chickpeas are grown in a saline medium, Cl–, which is secreted from glandular hairs on the leaves, stems and pods, is present in higher concentrations in the shoots than Na+. Salinity reduces the amount of water extractable from soil by a chickpea crop and induces osmotic adjustment, which is greater in the nodules than in the leaves or roots. Chickpea rhizobia show a higher salt resistance than chickpea plants, and salinity can cause large reductions in nodulation, nodule size and N_2-fixation capacity. [53]

Table 8: *Crop tolerances to salinity (EC: mmhos/cm = dS/m = mS/cm).*

Crop	Expected yield reduction (%)				
	0	**10**	**25**	**50**	**100**
Chickpeas	1.3	2.0	3.1	4.9	8.0
Barley	8.0	10.0	13.0	18.0	56.0

Source: adapted from Mass and Hoffman 1977; and Abrol (1973)

Salinity is known to depress the growth and symbiotic performance of nodulated legumes. Nodulation capacity and nodule function are adversely affected even under mild stress that otherwise would have no adverse effect on plant growth. Under salt stress, the symbiotic relationship between the bacteroids and host plant is adversely affected. Salinity tolerance is related to a higher nodulation capacity, which enables the maintenance of a higher level of nitrogen fixation in saline conditions. [54]

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[53] TJ Flowers, PM Gaur, CLL Gowda, L Krishnamurthy, S Samineni, KHM Siddique, NC Turner, V Vadez, RK Varshney, TD Colmer (2010) Salt sensitivity in chickpea. Plant, Cell & Environment, 33 (4), 490–509, http://onlinelibrary.wiley.com/doi/10.1111/j.1365-3040.2009.02051.x/full

[54] B Singh, BK Singh, J Kumar, SS Yadav, K Usha (2005) Effects of salt stress on growth, nodulation, and nitrogen and carbon fixation of ten genetically diverse lines of chickpea (*Cicer arietinum* L.). Aust J Ag Research. 56 (5), 491–495.

IN FOCUS

Effects of salt stress on growth, nodulation, and nitrogen and carbon fixation

Researchers compared 10 genetically diverse chickpea lines for salt tolerance over two dry seasons. They studied growth, nodulation, moisture content, and nodule nitrogen and carbon fixation. The chickpea lines were raised in an open-air chamber in soil supplied with 0, 50, 75, and 100 mm NaCl. The shoot, root, and the single-plant weight declined as the level of salt increased. An almost identical pattern of response was observed for nodule number, weight per nodule, and nitrogen and carbon fixation. They found no distinct relationship among root/shoot ratio, plant moisture content, and salt-tolerance response of the chickpeas.

However, they did find that nodulation capacity (number and mass) under salt stress was related to salt-tolerance response. This trait could be used to improve salt tolerance of this legume species in order to increase its productivity and stability in saline soils. The researchers also demonstrated that nodule number, and not nodule mass, is the trait that can be used as a useful marker in studying salt stress in chickpeas. [55]

A 2016 study concluded that salt sensitivity in chickpeas is determined by Na(+) toxicity. [56] Another study suggested that Na+ accumulation in leaves is associated with delayed flowering, and this plays a role in the lower reproductive success of the sensitive lines. The delay is longer in sensitive genotypes than in tolerant ones. Filled pod and seed numbers, but not seed size, have been associated with reduced seed yield in saline conditions. [57]

It has also been found that salt stress reduces photosynthesis, decreases tissue sugars by 22–47%, and severely impairs vegetative and reproductive growth. [58]

Salt stress is thought to reduce germination either by making less water available for imbibition or by altering enzymatic activity, growth-regulator balance or protein metabolism in germinating seeds. One study has found that pre-soaking seeds for 24 hours in normal ground or tap water (0.8 dS m-1) increased germination by 27% compared to direct sowing. Sowing at depth of 4 cm also increased seedling growth under saline soils compared with sowing at 2 cm and 6 cm. [59]

Altered growth-hormone balance during germination is another factor resulting in poor germination and seedling growth under salt stress. The application of growth regulators such as gibberellic acid and kinetin have been found to increase germination (32%), root (32%) and shoot (153%) dry mass of seedlings stressed by salt.

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[55] B Singh, BK Singh, J Kumar, SS Yadav, K Usha (2005) Effects of salt stress on growth, nodulation, and nitrogen and carbon fixation of ten genetically diverse lines of chickpea (*Cicer arietinum* L.). Aust J Ag Research, 56 (5), 491–495

[56] HA Khan, KHM Siddique, TD Colmer (2016) Salt sensitivity in chickpea is determined by sodium toxicity. Planta, 244 (3), 1–15, https://www.ncbi.nlm.nih.gov/pubmed/27114264

[57] R Pushpavalli, J Quealy, TD Colmer, NC Turner, KHM Siddique, MV Rao, V Vadez (2016) Salt stress delayed flowering and reduced reproductive success of chickpea (*Cicer arietinum* L.), a response associated with Na+ accumulation in leaves. Journal of Agronomy and Crop Science, 202 (2), 125–138, http://onlinelibrary.wiley.com/doi/10.1111/jac.12128/abstract

[58] HA Khan, KHM Siddique, TD Colmer (2016) Vegetative and reproductive growth of salt-stressed chickpea are carbon-limited: sucrose infusion at the reproductive stage improves salt tolerance. Journal of Experimental Botany. Published online May 2016. DOI 10.1093/jxb/erw177, http://jxb.oxfordjournals.org/content/early/2016/04/29/jxb.erw177.full

[59] S Samineni (2010) Physiology, Genetics and QTL Mapping of Salt Tolerance in Chickpea. Thesis. University of Western Australia.

IN FOCUS

Physiological, chemical and growth responses to irrigation with saline water

Research in southern Morocco investigated the effect of irrigation with saline water on a local variety of chickpeas.

Results showed that, the more saline the irrigation water became, the less plants grew, and the less biomass they accumulated, and these led to reduced water uptake, water productivity and grain yield. In contrast, proline, soluble sugars, Na+ and Na+:K+ ratio increased as the irrigation water became more saline. The findings highlighted the role of proline and soluble sugars as osmolytes produced by chickpeas to mitigate the effect of salt stress.

Information can be used to determine threshold values. [60]

14.5.2 Soil chloride levels

Soil chloride levels >600 mg/kg have been found to reduce root growth in crops such as chickpeas, lentils and linseed. Soil analysis should be conducted to identify the level of chloride and at what depth it changes. Thresholds for chloride concentration in soil and yield reductions differ between crops (Tables 9 and 10).

Table 9: *Thresholds for chloride concentration in soil (mg/kg).*

Crop	10% yield reduction	50% yield reduction
Chickpeas	**600**	**1,000**
Bread wheat	700	1,500
Durum wheat	600	1,200
Barley	800	1,500
Canola	1,200	1,800

Source: Queensland Natural Resources and Water Bulletin

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[60] A Hirich, H El Omari, SE Jacobsen, N Lamaddalena, A Hamdy, R Ragab, A Jelloul, R Choukr-Allah (2014) Chickpea (*Cicer arietinum* L.) physiological, chemical and growth responses to irrigation with saline water. Australian Journal of Crop Science, 8 (5), 646–654, http://research.ku.dk/search/?pure=en%2Fpublications%2Fchickpea-cicer-arietinum-l-physiological-chemical-and-growth-responses-to-irrigation-with-saline-water(d1e5a11e-b2a9-4d12-b9dd-7ac6d9937dea).html

Table 10: *Soil constraint ratings for concentration of chloride (Cl) and sodium (Na).*

Low	Medium	High
Surface soil (top 10 cm)		
<300 mg Cl/kg	300–600 mg Cl/kg	>600 mg Cl/kg
<200 mg Na/kg	200–500 mg Na/kg	>500 mg Na/kg
Subsoil (10 cm to 1 m)		
<600 mg Cl/kg	600–1,200 mg Cl/kg	>1,200 mg Cl/kg
<500 mg Na/kg	500–1,000 mg Na/kg	>1,000 mg Na/kg

Source: Queensland Natural Resources and Water Bulletin

Agronomic practices and crop choices

Agronomic practices and crop choices may have to vary for differing levels of soil salinity or sodicity constraints. Pulses such as chickpeas can be grown only where there is low salinity.

Low constraints of Na and Cl (<600 mg Cl/kg, <500 mg Na/kg in top 1 m of soil):

- Cereal–legume rotations are possible.
- Canola can be grown.
- Opportunity cropping to utilise available soil water can be tried.

Medium constraints of Na and Cl (600–1,200 mg Cl/kg, 500–1,000 mg Na/kg in top 1 m of soil), growing tolerant crops such as wheat, barley and canola:

- Consider tolerant crop varieties.
- The more tolerant of the pulses (vetch, faba beans, and possibly lupins and field peas) will likely suffer yield reductions if grown.
- Match inputs to realistic yields.
- Cereal diseases must be managed.
- Avoid growing salt-susceptible pulses (i.e. lentils, chickpeas) or legumes, and durum wheat.
- Opportunity cropping to utilise available soil water can be tried, but options may be more limited.

High constraints of Na and Cl (>1,200 mg Cl/kg, >1,000 mg Na/kg in top 1 m of soil):

- Avoid growing crops, or grow tolerant cereals.
- Match inputs to realistic yields.
- Consider alternative land use to cropping (e.g. saline-tolerant forages, pastures).

14.5.3 Soil pH

Chickpea crops are best suited to well-drained loam and clay loam soils that are neutral to alkaline (pH 6.0 to 9.0). [61]

Acidic soils

Acid soils can significantly reduce production and profitability before paddock symptoms are noticed. Danger levels for crops are when soil pH is <5.5 (in $CaCl_2$) or 6.3 (in water). Monitor changes in soil pH by testing the soil regularly. If severe acidity is allowed to develop, irreversible soil damage can occur. Prevention is better than cure, so apply lime regularly in vulnerable soils. The most effective liming sources have a high neutralising value and a high proportion of material with a particle size <0.25 mm. More lime is required to raise pH in clays than in sands. Liming can induce manganese deficiency where soil manganese levels are already marginal. Low soil pH often leads to poor or ineffective nodulation in pulses because acid soil conditions affect initial numbers and multiplication of rhizobia. Field peas, faba

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[61] Agriculture Victoria.(2016). Growing Chickpea. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-chickpea

beans, lentils and chickpeas are vulnerable, as are vetches. Lupins are an exception because their rhizobia (Group G) are acid-tolerant. Granular inoculums seem to provide greater protection to rhizobia in acid soils.

Between pH Ca 5.5 and pHCa8 is the ideal pH range for plants. Soil pH targets are 5.5 in the topsoil, 0–10 cm, and >4.8 in the subsurface soil, 10 cm and below. At pH ca of 4.8 or lower, levels of aluminium in the soil become toxic. Free aluminium has a large impact on crop yield. It reduces root growth, which in turn reduces the depth of soil the plant has access to.

In terms of lime movement through the soil, a pH level of 5.5 is required in the top 0–10 cm of soil before lime can influence any soil deeper than this. Lime applied to the surface will be worked in with the traffic of the seeding implement. This creates a layer where the pH is ameliorated to the depth of the seeding point but no further. Lime must be in contact with the soil of low pH in order to react. This layering effect has an impact on yield potential of rotation crops and pastures. An ameliorated surface, above pH Ca 5.5, and subsurface with pH Ca below 4.8 reduces the yield potential of rotation crops and the efficacy of N fixation. After lime has been applied, the subsurface pH will remain unchanged until the lime is able to leach through the profile.

It is difficult to make the correct decisions on soil treatment and crop choice if you do not have full knowledge of the soil pH to depth. This is particularly so when the crop is susceptible to low pH or aluminium toxicity, as are break crops such as chickpeas. Poor yields of these rotation crops may be the result of low pH at depth, in spite of good pH at the surface.

Alkaline soils

Soil alkalinity is mainly caused by bicarbonates and carbonates, although phosphates, borates and some organic molecules can also contribute. In a soil with pH from 7 to 8.2, bicarbonates and carbonates of calcium and magnesium dominate.

Calcareous soils contain from 1–90% lime material as calcium carbonates, and these sparingly soluble salts cause the soil to have a pH of 8.0–8.2, which is not a severe problem for plant growth or agricultural production.

Problems are encountered in alkaline soils when sodium occurs or accumulates and forms salts such as sodium bicarbonate and sodium carbonate. These are highly soluble and increase the soil pH above 8.

When the pH is more than 9, the soils are considered to be highly alkaline and often have toxic amounts of bicarbonate, carbonate, aluminium and iron. The high amount of exchangeable sodium in these soils reduces soil physical fertility, and nutrient deficiency is also likely to be a major problem.

In alkaline soils, the abundance of carbonates and bicarbonates can reduce crop growth and induce nutrient deficiencies. The presence of free lime has a major impact on lupin growth, inducing iron and manganese deficiency, which cannot be corrected by foliar sprays of those nutrients.

Managing soil pH

- Growers are applying more lime per hectare than in the past but, in many cases, much more lime is needed to replenish the soil profile.
- Liming to remove soil acidity as a production constraint can also bring the benefits of increasing yields, increasing crop and pasture choice, and helping to protect the soil resource.

Soil acidification is an ongoing issue

Soil acidification is an ongoing and unavoidable result of productive agriculture. The main practices that cause soil acidification include the removing of products by harvest (Photo 14) and the leaching of nitrate from soil. Because soil acidification is an ongoing consequence of farming, management also needs to be ongoing.

Photo 14: *Hay production, especially legume hay, is one of the most acidifying practices.*

Source: Black Diamond Images, Flickr

Acid soils

Acid soils can be economically managed by the addition of agricultural lime, usually in the form of crushed limestone. Sufficient lime should be added to raise the pH to above 5.5. The amount of lime required to ameliorate acid soils will vary, depending mainly on the quality of the lime, the soil type and how acidic the soil has become.

Soils prone to becoming acidic will need liming every few years. Seek advice on an appropriate liming regime from your local agricultural adviser.

Alkaline soils

Treating alkaline soils by the addition of acidifying agents is not generally a feasible option due to the large buffering capacity of soils and uneconomic amounts of acidifying agent (e.g. sulfuric acid, elemental sulfur or pyrites) required.

Gypsum will reduce sodicity and this can reduce alkaline pH to some extent. Growing legumes in crop rotations may help in sustaining any reduction in pH.

In high-pH soils, using alkalinity-tolerant species and varieties of crops and pasture can reduce the impact of high pH. [62]

The importance of soil testing

Soil testing has a vital role in the management of soil acidity. It is important that decisions on where and when to apply lime and how much lime to apply are based on objective measures of soil acidity. While it is possible to estimate maintenance liming rates based on farm inputs and outputs, the most direct method, and the only way to measure existing acidity, is to regularly test the surface and subsurface soil layers.

Yield increases from liming

Liming can increase grain yield when soil pH is below recommended targets, and when soil pH is one of the factors constraining yield. Trials in WA found that, on average, applying lime increased yield by 0.2 t/ha, or 10%. This result is similar to what has been found in most other trials around Australia.

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[62] P Rengasamy (n.d.) Soil pH—South Australia. Fact sheet. Soilqualiy, http://www.soilquality.org.au/factsheets/soil-ph-south-austral

MORE INFORMATION

B Upjohn, G Fenton, M Conyers (2005) Soil acidity and liming. 3rd edn. Agdex 534. NSW Department of Primary Industries.

However, the yield increases from liming may be even higher than this. When trials have included ripping or tilling, increases in yield have been even greater. Also, it takes a few years for lime to react with the soil and increase the soil pH. When yield was calculated starting from the third harvest after lime was applied, the average yield increase was 0.25 t/ha, or 16%.

Yield and yield gains from liming will depend on the relationship between paddock yield and yield potential. If the paddock yield is low relative to the yield potential there are likely to be additional constraints present, and there may be little gain from liming. If the paddock yield is already close to potential, pH is not likely to be a constraint and there is little immediate gain to be made from liming.

However, maintenance liming will be required to counter ongoing acidification and maintain the productivity of the paddock. [63]

14.5.4 Sodicity

- Sodic soils occupy almost one-third of the land area of Australia.
- Sodicity has serious impacts on farm production, as well as significant off-site consequences such as:
- surface crusting
- reduced seedling emergence
- reduced soil aeration
- increased risk of run-off and erosion
- less groundcover and organic matter
- less microbial activity
- Sodic soils are known as dispersive clays and reduce seedling emergence (Photo 15).
- Sodic soils are can lead to tunnel erosion—they turn to slurry when wet, and channels are easily created through them by moving water. [64]

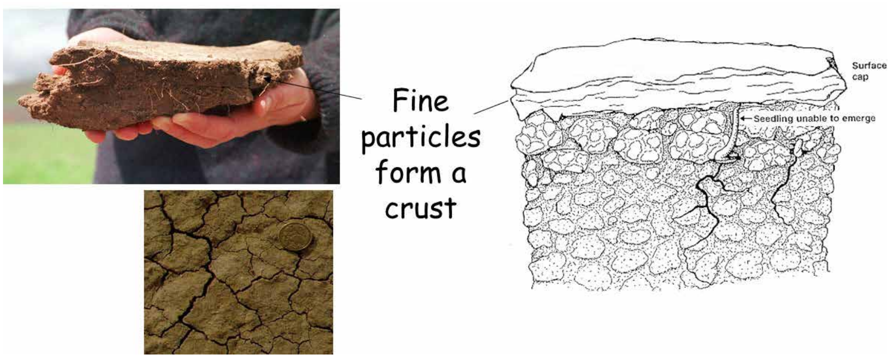

Photo 15: *The impact of sodic soils on seedling emergence: surface crusting and dispersive clay limit emergence.*

Source: Corangamite CMA

Chickpeas are classified among the most sensitive of all field crops to sodic soil conditions.

Soils high in sodium are structurally unstable, with clay particles dispersing when wet. This subsequently blocks soil pores, which reduces water infiltration and aeration, and retards root growth. On drying, a sodic soil becomes dense and forms a hard surface crust up to 10 mm thick. This can restrict seedling emergence. Some indicators of surface sodicity include:

- soils being prone to crusting and sealing up

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[63] C Grazey, J Carson (n.d.) Managing soil acidity—Western Australia Fact sheet. Soilquality, http://www.soilquality.org.au/factsheets/managing-soil-acidity-western-australia

[64] Corangamite CMA (2013) How do I manage the impact of sodic soils? Corangamite CMA, http://www.ccmaknowledgebase.vic.gov.au/brown_book/04_Sodic.htm

- ongoing problems with poor plant establishment
- the presence of scalded areas in adjoining pasture

Exchangeable sodium percentage is the measure for sodicity, and soils are rated thus:

- ESP <3: non-sodic soils
- ESP 3–14: sodic soil
- ESP >15: strongly sodic

Soils that are sodic in the topsoil have the greatest impact on crop performance (see Figure 8 for effect of ESP on chickpea yield). Sodic layers deeper in the soil profile are not as great a concern but can still affect yields by restricting root development and water extraction. The net effect of severely restricted root growth in chickpeas is usually the early onset of drought stress.

It is unlikely that soil sodic layers deeper than 90 cm will have significant impact on chickpea yields. [65]

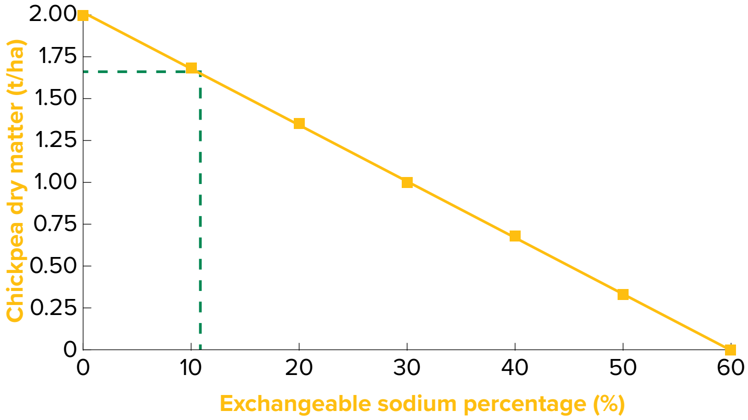

Figure 8: *Impact of sodicity on the production of chickpea dry matter.*

Source: Pulse Australia

Managing sodic soils

- Growers need to correctly identify the problem first and ensure that the soils are in fact sodic.
- Sodic soils can be directly treated through the application of gypsum (particularly on the surface), which serves to replace the excess sodium in the soil with calcium.
- In southern Victoria, typical application rates of gypsum are around 2.5 t/ha and applied every 3–5 years.
- The application of lime to sodic soils acts in a similar manner to gypsum, but is much slower acting and less effective.
- Although the application of gypsum can effectively counter sodicity in the short run, longer-term management strategies need to be in place to increase, and then maintain, organic matter in soils. Increased organic matter can improve hard-setting soils, and it can also enhance the effect of gypsum.
- Sodicity can also be reduced by maintaining adequate vegetation cover, leaf litter or stubble on the soil surface.
- Trials in the high-rainfall zone of southern Victoria have shown that the amelioration of dense sodic subsoil using organic amendments can increase wheat yield more than using gypsum. [66]

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[65] Pulse Australia (2013) Northern Chickpea—Best Management Practices Training Course Manual. Pulse Australia.

[66] P Sale, J Gill, R Peries, C Tang (2008) Amelioration of dense sodic subsoil using organic amendments increases wheat yield more than using gypsum in a high rainfall zone of southern Australia. La Trobe University, Bundoora, Victoria.