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GRAINS RESEARCH & DEVELOPMENT CORPORATION

DURUM

SECTION 8

FROST AND HEAT STRESS

FROST OVERVIEW | STAGES OF FROST DAMAGE | MANAGING SOWING TIMES AND THE SEASON FOR FROST RISK | RISK MANAGEMENT TACTICS FOR FROST | RESEARCH AND THE GRDC NATIONAL FROST INITIATIVE (NFI) | HEAT STRESS

MORE INFORMATION

GRDC 'Frost – Frequently asked questions': www.grdc.com.au/frost-faq

GRDC Western Wheat, Western Canola, Western Oat and Northern Durum wheat GrowNotes™: www.grdc.com.au/GrowNotes

GRDC Tips and Tactics 'Managing Frost Risk': www.grdc.com.au/ManagingFrostRisk

GRDC 'National Frost Initiative': www.grdc.com.au/GRDC-Video-NationalFrostInitiativePlaylist

DPIRD 'Frost and Cropping': www.agric.wa.gov.au/frost/frost-and-cropping

GRDC Ground Cover 'Frost Supplement': www.grdc.com.au/GCS109

GRDC Back Pocket Guides 'Frost': https://grdc.com.au/resources-and-publications/all-publications/bookshop/2012/01/cereals-frost-identification-the-back-pocket-guide-grdc416 and www.grdc.com.au/GRDC-BPG-FrostPulses

GRDC Hot Topic 'What to do with a Frosted Crop': www.grdc.com.au/FrostedCrop

GRDC Hot Topic 'Pre-seeding Planning to Manage Frost Risk in WA': www.grdc.com.au/HT-PreseedingForFrostManagement

Frost and heat stress

8.1 Frost Overview

On nights when still and cold air, clear skies and low humidity combine, temperatures can drop rapidly and result in radiant frost that can affect Western Australian crops.

Damage can be significant when frost is severe, prolonged and/or occurs at susceptible stages of plant development.

The temperatures experienced and recorded in the crop during a frost can vary widely due to differences in topography, microenvironment and recording method.

Widespread spring frosts were reported across many eastern, central and southern grainbelt areas in 2016, when WA experienced its coldest September average minimum temperatures on record. It is estimated (conservatively) that two million tonnes of total grain was shaved off WA deliveries – worth about $600 million in losses to growers. In 2005, WA grain growers lost about 700,000 tonnes of grain due to frost, worth an estimated $90 million.

The risk, incidence and severity of frost varies between and within years and across landscapes, so growers are advised to assess their individual situation regularly.

The occurrence of frost and subsequent frost damage to grain crops is determined by a combination of factors, including:

- Temperature
- Humidity
- Wind
- Topography
- Soil type, texture and colour
- Crop species and variety
- Crop management.

Highest cereal crop losses (in terms of grain yield and quality) tend to occur when there are frosts between the booting and grain ripening stages of growth.

Frost damage is not always obvious and crops should be inspected for five to seven days after a suspected event.

Strategies to deal with the financial and personal impact of frost also need to be considered as part of whole farm and full year risk management plans.

FEEDBACK

MORE INFORMATION

DPIRD 'Frost - diagnosing the problem' https://www.agric.wa.gov.au/frost/frost-diagnosing-problem

GRDC Frost videos https://www.youtube.com/watch?v=GC2P2Tha5Es&list=PL2PndQdkNRHGLPDeHqGVmEcUP-4B2Ka93

8.1.1 The changing nature of frost

The length of the frost season has increased across much of the Australian grainbelt — by 10-55 days between 1960 and 2011.[1]

CSIRO analysis of climate data for this period suggests increasing frost incidence was due to the southerly displacement and intensification of high-pressure systems (sub-tropical ridges) and heightened dry atmospheric conditions associated with more frequent El Niño conditions. The southern shifting highs brought air masses from farther south than in the past. This air was very cold and contributed to frost conditions.

In the WA grainbelt, the data showed there were fewer earlier frosts and a shift to frosts later into the season in the period 1960-2011, but the frost window remained the same length.

The frost window lengthened by three weeks in the Victorian grainbelt and by two weeks in the New South Wales grainbelt.[2]

8.1.2 Frost identification

It is recommended to use accurate paddock-based weather stations or temperature data loggers (such as Tiny Tags and iButtons) to identify if a frost has occurred.

For best results, at least two or three field thermometers are required to give representative temperatures across a crop.

In undulating country, it is advised to use thermometers at various heights in the landscape.

Even if Bureau of Meteorology (BoM) data says the conditions for a frost were not quite reached, it is still worth checking crops.

Minimum air temperatures measured at crop canopy height can sometimes differ by as much as 2-4˚C or more from temperatures recorded at the weather station.[3] Temperatures and other weather conditions typically leading up to a frost are shown in Table 1.

Table 1: Atmospheric conditions leading up to a frost event.[4]

Measurement	3pm -6pm	6pm-9pm	Frost
Temperature at Screen height	16 → 8°C	12 → 6°C	<2°C
Cloud Cover	V low	Low	Nil
Wind Speed	<3 m/s	<1 m/s	0 m/s
Barometric Pressure	1008-1009	1008 — 1009	1004 — 1008

Some crop symptoms will appear in the first 24 hours after a frost event, but most damage will take at least a few days to become apparent.

The more time that passes after the frost event, the easier it will be to observe plant and grain symptoms. But fewer management options may be available.

In frost-prone areas of a farm, particularly low-lying areas, it is advised to inspect cereal heads regularly during the later growing stages to ensure yield losses due to frost are identified well before harvest.

1 GRDC (2016) Tips and Tactics, Managing Frost Risk, GRDC, www.grdc.com.au/ManagingFrostRisk

2 GRDC (2016) Tips and Tactics, Managing Frost Risk, GRDC, www.grdc.com.au/ManagingFrostRisk

3 GRDC (2016) Tips and Tactics, Managing Frost Risk, GRDC, www.grdc.com.au/ManagingFrostRisk

4 GRDC (2016) Tips and Tactics, Managing Frost Risk, GRDC, www.grdc.com.au/ManagingFrostRisk

8.1.3 Tips for measuring temperature

Plant surfaces cool more quickly than the surrounding air, so measuring air temperature is not entirely accurate in determining plant temperature.

Temperature increases above the canopy of a crop and, if the canopy is reasonably developed, it can also rise below the canopy.

Measuring temperature in-crop at weather station height, such as when a Stevenson Screen is installed at 1.4 metres, will not be the same as measuring temperatures at the canopy height or ground level.

Overnight temperatures at ground level (where heat is being lost) can be as much as 4°C lower than those measured in a Stevenson Screen. Differences of 10°C have been recorded.[5]

A typical rule-of-thumb is the canopy temperature will be about 1.5 to 2.5°C lower than the Stevenson Screen temperature during a frost.

Several live weather stations are set up across WA by the Department of Primary Industries and Regional Development (DPIRD) and BoM. These record up-to-the-minute information about climatic conditions and can be readily accessed by growers through the DPIRD website at this link: www.agric.wa.gov.au[6]

Major frost events are recorded by satellites, which provide land surface temperatures. Frost maps (current and historical) are then generated by the Department of Land Information (DLI) and can be viewed at its website at this link www.rss.dola.wa.gov.au.

8.1.4 Frost effects on crops

Figure 1: *variability in the incidence and severity of frost means WA growers are advised to adopt a range of pre-season, in-season, and post-frost event tactics as part of whole-farm management plans.*

(SOURCE: DPIRD)

Wheat plants are most susceptible to frost damage during and after flowering and are also vulnerable at the earlier stages of booting (from Zadoks Growth Scale stage GS39 to GS71).

Losses in wheat grain yield and quality due to frost primarily occur between stem elongation and late grain filling.

5 GRDC (2016) Tips and Tactics, Managing Frost Risk, GRDC, www.grdc.com.au/ManagingFrostRisk

6 Rebbeck, M and Knell, G (2007) Managing Frost Risk: A Guide for Southern Australian Grains, GRDC, https://grdc.com.au/Resources/Bookshop/2007/06/Managing-Frost-Risk-a-guide-for-southern-Australian-grains

Frost damage may be sporadic across a paddock. Not all plants will show obvious symptoms and damage may not be evident until five to seven days after the frost event has occurred.

Frost can affect crops in several complex ways, from cold or chilling to desiccation and — finally — freezing.

This tends to be a 'stepped' response, in that desiccation will not occur without cold damage first and freezing damage will only occur after first experiencing cold and desiccation damage.

Freezing damage tends to be random throughout the crop canopy and tissues, due to the random nature of the ice nucleation and formation.

8.2 Stages of frost damage

Cold

Cold, or chilling, damage occurs when wheat plants are exposed to temperatures less than 10°C and down to –2°C.[7]

If the changes in temperature are sudden, the plant is typically unable to increase the fluidity of membranes (largely made of fats) at the lower temperature and this compromises cellular and plant energy balances.

If this occurs at critical stages in reproductive development, it can cause a few or all florets to abort during pollen development.

The damage is not related to the formation of ice within plant tissue, although it may appear to be.

Desiccation

Desiccation from ice formation occurs at temperatures from 0°C to –2°C.[8]

When plants are exposed to freezing temperatures during a white frost, the dew initially freezes on the outside of the plant, but then the ice nucleation can move in the leaf through cracks in the leaf cuticle and stomata.

The water inside the leaf then starts to freeze. Initially the water around the cells freezes but it then draws out the water from inside the cells and dehydrates them.

The cells may not always freeze or have ice form inside them. This process will not necessarily kill the cells if the dehydration and desiccation do not go too far.

When the ice thaws, these cells can rehydrate and recover — but can still suffer from desiccation.

Freezing

Freezing damage is the final stage of frost damage and occurs when there is rapid ice nucleation and ice crystals form. The ice crystals physically rupture cell walls and membranes.

Freezing damage typically is not reversible, but can be limited to specific tissues in the plants — for example, stem nodes, individual florets and individual tillers.

7 Rebbeck, M and Knell, G (2007) Managing Frost Risk: A Guide for Southern Australian Grains, GRDC, https://grdc.com.au/Resources/Bookshop/2007/06/Managing-Frost-Risk-a-guide-for-southern-Australian-grains

8 Rebbeck, M and Knell, G (2007) Managing Frost Risk: A Guide for Southern Australian Grains, GRDC, https://grdc.com.au/Resources/Bookshop/2007/06/Managing-Frost-Risk-a-guide-for-southern-Australian-grains

8.3 Managing sowing times and the season for frost risk

Sowing time remains a big driver of yield in all crops, with the primary objective in WA conditions being to achieve a balance between the plant flowering after the risk of frost has passed — but before the onset of heat stress.

The potential loss of yield from late sowing to avoid frost risk is often outweighed by the potential gains from sowing on time to reduce heat and moisture stress in spring.

To minimise frost risk, it is advised to use a mix of sowing dates, crop types and maturity types to allow incorporation of frost avoidance strategies into the cropping system.

In years of severe frost, regardless of which strategy is adopted, it may be difficult to prevent damage.

Research trials have found blending a short season wheat variety with a long season variety could be an effective strategy.

But the same effect may be achieved by sowing one paddock with one variety and other paddocks with other varieties to spread risks.

No wheat or barley varieties are tolerant to frost.

It is advised to consider using wheat and barley varieties that have lower susceptibility to frost during flowering to manage frost risk of the cropping program, while maximising yield potential.

Preliminary ranking information for current wheat and barley varieties for susceptibility to reproductive frost, developed through GRDC-funded research, is now available on the National Variety Trials (NVT) website at this link: www.nvtonline.com.au

A new variety is best managed based on how known varieties of similar ranking are currently managed.

MORE INFORMATION

GRDC RCSN Case Study Booklet 'Managing Frost Risk': https://grdc.com.au/ManagingFrostRiskWA

8.4 Risk management tactics for frost

The variability in the incidence and severity of frost means WA growers are advised to adopt a range of pre-season, in-season and post-frost event tactics as part of whole farm management plans and plans for particularly frost-prone areas of farms.

Tactics that may be worth consideration are outlined in Tables 2-5.

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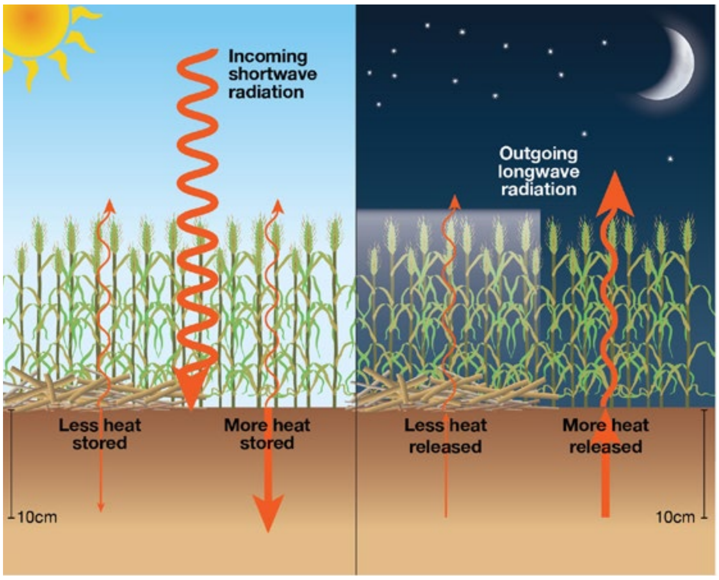
Table 2: Pre-season frost risk management strategies.[9]

Assess personal approach to risk
Individuals will each have a different approach
Identify and measure extent of risk
Evaluate risk management alternatives
Tailor risk advice to risk attitude
Review conservative farming practices in light of latest research.
Assess frost risk of property
Consider frost risk for location
Use historic seasonal records and forecasts
Consider spatial variability (topography and soil type) across the landscape
Consider using temperature monitoring equipment (e.g. Tinytags, iButtons and weather stations).
Diversify the business
Consider enterprise options to spread financial risk
Take into account business location and manager skills
Intensive cropping systems can be more at risk of frost.
Zone property/paddock
Identify frost-prone paddocks or areas in paddocks
Precision tools, such as topographic, electromagnetic and yield maps and temperature monitors can locate frost-prone zones
Frost-prone paddocks can be high yielding areas when frosts do not occur
Options for frost-prone zones can be crop grazing, hay or oat production
It may be best to avoid expensive or highly susceptible crops.

Figure 2: *The soil heat bank has an important role in frost risk and damage to cereal crops in WA.*[10]



9 GRDC (2016) Tips and Tactics, Managing Frost Risk, GRDC, www.grdc.com.au/ManagingFrostRisk

10 GRDC (2016) Tips and Tactics, Managing Frost Risk, GRDC, www.grdc.com.au/ManagingFrostRisk

Table 3: In-season frost risk management strategies.[11]

Review nutrient management
Assess nutrient levels using soil and plant tissue testing
Target fertilisers, including nitrogen (N), phosphorus (P), potassium (K), on high-risk paddocks
Consider re-allocating nutrients to lower-risk areas
High levels of N can increase biomass and risk of frost damage
Manage N to frost risk and yield potential
Avoid deficiencies in K or copper (Cu) if possible.
Modify the soil heat bank
This is important in reducing frost risk, as illustrated in Figure 2
Storage and release of heat from the soil heat bank into the crop canopy at night can be manipulated
Practices include clay delving, mouldboard ploughing or spading (primarily used to alleviate water repellency)
Rolling sandy soil and loamy clay soil may reduce frost risk
Lower stubble loads — more than 1.5 tonnes per hectare in low production environments (with average wheat yields of 2-3t/ha) and 3 t/ha in high production environments (with average wheat yields of 3-5 t/ha) can increase frost severity and duration
Cross-sowing/seeding may work in some areas.
Select appropriate crops
Crop type and variety selection is key to managing frost-prone paddocks and zones
Crops grown for hay are harvested for biomass and can reduce grain loss from frost
Pasture rotations are a lower-risk enterprise
Oats are the most frost tolerant crop during the reproductive stage
Barley is more tolerant than wheat at flowering (not necessarily during grain fill)
Decision support tools include: Flower Power (DAFWA) https://www.agric.wa.gov.au/frost/flower-power and Yield Prophet® www.yieldprophet.com.au.
Manipulate flowering times
Ensure flowering windows for wheat are spread widely
Use more than one variety with a range of phenology
Manipulating sowing dates to spread the flowering window
Consider impact of hot, dry finishes due to heat and moisture stress
If sowing more than one variety, sow winter wheat first, then a long season spring wheat (or a day-length-sensitive wheat), then an early maturing wheat
Sowing at the start of a variety's preferred window typically achieves higher yields.
Crop grazing
Key to success is grazing early — start at crop four-five leaf stage or earlier
Graze hard for a short period — may need high stock numbers
Fourteen days of grazing typically delays crop flowering by about seven days
Grazing after first node (GS31) can significantly delay flowering and reduce crop yield so it is best to remove stock before the crop reaches GS31
Crops provide extra fodder for livestock and livestock reduce crop biomass.

11 GRDC (2016) Tips and Tactics, Managing Frost Risk, GRDC, www.grdc.com.au/ManagingFrostRisk

Table 4: Post-frost event frost risk management strategies.[12]

Inspection
Inspect crops after a suspected frost event/s — especially at/after flowering
Collect a (random) sample of heads to estimate yield loss
Monitor for up to two weeks after the event
When damage is estimated, closely analyse options for the affected crop.
Take through to harvest
If frost is prior to/around GS31-GS32, cereals can produce new tillers to compensate for damaged plants (if spring rainfall is adequate)
These may contribute to grain yield
Later frost allows less time for compensatory growth
Undertake gross margin analysis to determine the required grain yield to recover harvesting costs.
Cut and bale
An option when frosts occur at flowering and through grain fill
Assess crops for hay quality within a few days of a frost event
Be prepared to cut a bigger area than originally intended
Can reduce stubble, weed seedbanks and disease loads for the next season
Potential for more rotation options in the following season
Hay production can be expensive — have a path to market or plan for on-farm use.
Grazing, manuring and crop-topping
Grazing frosted crops is an option after a late frost (where chance of plant recovery is low or hay is not an option)
Crop-topping for weed seed control may be incorporated
Ploughing-in/manuring the green crop can return organic matter and nutrients to the soil
Manuring can help manage crop residues, weeds and improve soil fertility
Economics need to be considered carefully.
Harvesting and marketing frosted grain
At flowering — wheat grain is typically aborted and yield reduced, but quality can be high
At watery stage — grain does not develop any solids, frosted grains do not appear in the sample and unfrosted grains can be bigger with high test weight
At milk stage — grains may continue development but be light and shrivelled with low hectolitre weight and high screenings
At late dough stage — grain can be wrinkly/scalloped, have low hectolitre weight and higher screenings and further cleaning may be required
Adjust header settings to maximise quality of grain harvested
Frosted grain in the category 'Dry Green, Sappy and Frost Distorted' has maximum limit of 1 percent in the sample
Samples with 1-10 percent frosted grain is classified as Australian General Purpose (AGP)
Grain exceeding this level will be classified as and suitable for stock feed
Cleaning grain may lead to higher classification — consider economics.

12 GRDC (2016) Tips and Tactics, Managing Frost Risk, GRDC, www.grdc.com.au/ManagingFrostRisk

Retaining seed from frosted crops
Frost at flowering — grain is often plump and makes good quality seed
Frost during grain fill — can lead to poorer seed germination and establishment
If graded, frosted grain can still lead to 20-50 percent lower crop establishment
It may be necessary to retain more seed than usual
Sow into an optimum seed bed and increase seeding rates.

Table 5: Strategies for recovering from frost.[13]

Strategies for recovering from frost
Act early if frost damage has had a serious financial impact.
Prepare a future business plan
Where necessary, seek advice about tactics from advisers and rural counsellors
Communicate and discuss likely impact of frost with financiers
Consider how finances can be adjusted
Assess factually physical, financial and manager/staff implications
Develop alternate strategies for dealing with frosted crops in future
Prepare a draft budget and physical plans for next year
Provide this information to business partners and financiers
Review budgets and plans as information and circumstances change
Be conscious frost can be an emotional rollercoaster and trigger feelings of depression, grief and loss
Maintain contact with family, friends and colleagues
Seek professional advice if necessary
Be aware of the impact on neighbours and the community
Frost can be easily forgotten from one year to the next — don't let early rain distract from having plans in place.

8.5 Research and the GRDC National Frost Initiative (NFI)

In some cases, frost is costing WA growers average yield losses of up to 10-20 percent per year across their total cropping programs in a 10-year period.

The National Frost Initiative (NFI) is a GRDC-funded project tackling frost from several angles to deliver growers a combination of genetic, management and environmental solutions to help mitigate risk.

Projects that come under the multi-disciplinary approach of the NFI include:

1. Genetics

- Developing more frost-tolerant wheat and barley germplasm
- Ranking current wheat and barley varieties for susceptibility to frost.

2. Management

- Developing best practise crop canopy, stubble, nutrition and agronomic management strategies
- Searching for innovative products.

13 GRDC (2016) Tips and Tactics, Managing Frost Risk, GRDC, www.grdc.com.au/ManagingFrostRisk

3. Environment

- Predicting the occurrence, severity and impact of frost events on crop yields and frost events at the farm scale
- Enabling better risk management.

Supported by the NFI, new tools to spatially assess frost risk and pinpoint crop damage rapidly and accurately are being tested by researchers nationally in efforts to improve understanding of frost and effective farm-scale responses.

At sites in WA, South Australia and Victoria, researchers are trialling:

- Satellite and other spatial information to develop high-resolution frost risk maps
- Remote sensing approaches and temperature data loggers to assess and map frost damage in wheat
- A range of platforms for the sensors, including satellite, unmanned aerial vehicles (UAVs), hand-held and static mounted.

There is potential to use the data generated from these sources in paddock zoning and planning, along with other precision agricultural data such as topographic, electro-magnetic and yield maps, temperature monitors and the grower's own experiences in previous seasons.

8.6 Heat stress

Heat and/or drought stress has potential to affect the processing quality of durum wheat.

Nationally, researchers are investigating how to boost wheat plant ability to withstand higher temperatures at development stages that are critical for yield.

This is typically from booting, around August, through anthesis to grain filling, around the end of October.

The optimum ambient temperature for wheat anthesis and grain filling ranges from 12°C to 22°C and exposure to temperatures above this has potential to significantly reduce grain yield.

Heat stress (defined as four consecutive days with maximum daily temperatures above 22°C) is increasingly affecting wheat yield potential in WA — particularly in parts of the northern grainbelt — and 2014 crop losses in this area were severe.[14]

A marked increase in heat stress events during spring since 1975 has been identified in WA's northern agricultural region.[15]

Globally, temperatures are predicted to rise by 2°C by the year 2050 and researchers say growers in some areas will need to adapt to warmer spring temperatures and expected less rainfall.[16]

New adaptations will be required for crop growth, potentially including tolerant varieties, changes of species, shifting planting seasons and a change in management tactics.

8.6.1 Effects of heat stress

Heat stress typically causes a significant reduction in grain number and grain size, the two key wheat yield components.

14 GRDC Ground Cover (2015) Issue 118: Researchers Hope to Take the Heat Off Warm Springs, GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-118-Sep-Oct-2015/Researchers-hope-to-take-the-heat-off-warm-springs

15 GRDC Ground Cover (2015) Issue 118: Researchers Hope to Take the Heat Off Warm Springs, GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-118-Sep-Oct-2015/Researchers-hope-to-take-the-heat-off-warm-springs

16 GRDC Ground Cover (2015) Issue 118: Researchers Hope to Take the Heat Off Warm Springs, GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-118-Sep-Oct-2015/Researchers-hope-to-take-the-heat-off-warm-springs

Some wheat varieties are able to retain grain number and others can retain grain size after heat stress, offering the potential to combine the positive effects of both grain number and grain size to improve heat stress tolerance in future varieties.

National research is being carried out to assess international wheat introductions from regions that experience heat stress.

Screening of this exotic material to date has uncovered promising genetic variation in grain number and size. Crosses have been made and evaluation of gene mapping populations from contrasting lines is being conducted.

8.6.2 Developing heat tolerant wheat

Research is studying wheat traits that are important to heat stress tolerance, undertaking genetic mapping of genomic regions affecting heat tolerance and characterising parents to select for this trait.[17]

Effects of heat on wheat quality traits relating to baking and pasta are also being investigated, along with varieties that have stable quality under heat stress conditions.

The aim is to help wheat breeders develop varieties that are better able to handle the harsh, and generally warming, growing conditions across southern Australia.

Trials have found a 3-5 percent reduction in wheat yield — about 190 kg/ha — for every 1°C increase in temperature above 15°C during flowering and grain filling.[18] This can be day or night-time temperatures.

Studies in 2010-11 showed that, at critical stages, increases in daily minimum temperatures above 20°C could reduce wheat yield more than increases in daily maximum temperatures above 22°C.[19]

The researchers found heat stress increased pollen sterility and reduced grain numbers and size. Therefore, breeders could potentially select for heat tolerance using traits for grain number, size and rate of filling under heat stress.

Research using controlled heat chambers and field trials in SA found significant variation in wheat variety tolerance to heat stress.[20]

Growing locally adapted varieties and ensuring timely sowing suited to their maturity are the best ways growers can reduce the risks of crops being damaged by heat stress in spring.

Later sown crops tend to have more likelihood of being exposed to heat stress at more sensitive growing stages, particularly during flowering and grain filling, and a higher risk of losing yield potential.

Researchers are quantifying the level of heat stress tolerance in current wheat varieties, advanced breeding lines and exotic lines, as well as using 'gene mapping' to understand the genetics of heat tolerance sources identified to date.[21]

The goal is to develop molecular markers allowing plant breeders to easily select for heat tolerance on a large scale.

A wide range of variation for heat stress tolerance has been found in the material screened to date.

17 Telfer, P, Edwards, J, Bennett, D and Kuchel, H (2015) Heat Stress Tolerance of Wheat, GRDC Update Papers, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Heat-stress-tolerance-of-wheat

18 Telfer, P, Edwards, J, Bennett, D and Kuchel, H (2015) Heat Stress Tolerance of Wheat, GRDC Update Papers, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Heat-stress-tolerance-of-wheat

19 Telfer, P, Edwards, J, Bennett, D and Kuchel, H (2015) Heat Stress Tolerance of Wheat, GRDC Update Papers, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Heat-stress-tolerance-of-wheat

20 Telfer, P, Edwards, J, Bennett, D and Kuchel, H (2015) Heat Stress Tolerance of Wheat, GRDC Update Papers, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Heat-stress-tolerance-of-wheat

21 Telfer, P, Edwards, J, Bennett, D and Kuchel, H (2015) Heat Stress Tolerance of Wheat, GRDC Update Papers, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Heat-stress-tolerance-of-wheat