

Tomato Critical Temperature Thresholds

Research Team – **Peter Deuter**, Horticultural Consultant, PLD Horticulture & **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Tomato – Critical Temperature Thresholds

Local weather conditions influence all stages of plant establishment, development and growth, ultimately determining crop productivity and marketability. Every crop has a unique range of optimum and tolerable environmental conditions that favour its growth. Identifying and understanding the relationships between crop growth stages and ‘expected’ weather is very important in maximizing crop productivity. For a crop to be successfully grown and marketed in a region, the sequences of its growth stages must align with the climate to maximise the potential of plant growth, product quality and marketable (harvestable) yield.

Most major agricultural commodities do not have well-defined yield or crop damage thresholds for a range of climate variables. Thresholds which have been identified have ranges, due to the ability of different cultivars to continue to perform (or otherwise) under the effects of high and low temperatures during different growth stages. When temperatures outside the optimum range occur at sensitive plant growth stages, physiological and cellular processes will result in adverse effects on plant growth and development, and crop productivity, marketability and profit (Hasanuzzaman, et al., 2013).

Plant growth rates may also decrease or stop above or below certain thresholds. A high temperature threshold may mark a point where growth and development are not halted but become increasingly impacted as temperature rises further.

Yield and quality can similarly be impacted as the temperature rises (or falls) outside the threshold. Diurnal temperature range is also important and may be cited in the literature as the mean temperature (daily or monthly). This distinction is sometimes not clear in the literature.

Grotjahn, R. (2021) demonstrates the effect of short durations of temperatures, above or below the optimum, which can have devastating consequences on horticultural crops and their produce. For high temperatures it may be measured in hours to days. Two days in a row, above the optimum, are more severe than one day.

This makes the task of identifying Critical Temperature Thresholds (CTT) difficult, and exacerbated by the fact that, “The thresholds have ranges due to the variation among cultivars and the conditions each plant experiences over time” (Grotjahn, R., 2021, p.40).

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Introduction

The tomato (*Lycopersicon esculentum*) a member of the Solanceae, or nightshade family, originated in South America and is now grown as a commercial crop around the world.

In Australia, fresh outdoor tomatoes are produced in Queensland (Bowen, Bundaberg, Lockyer Valley, Granite Belt), NSW (Narromine, MIA, Sydney Basin), Vic (Goulburn Valley), SA (Murray Bridge, Adelaide Plains) and WA (Swan Coastal Plain).

Bowen production is predominantly an autumn to spring crop, Bundaberg production is grown all year round with production peaks in autumn and late spring to summer, and in the Lockyer valley and Granite Belt, tomatoes are produced through summer and autumn.

Tomatoes are grown for the fresh market in outdoor fields and in glasshouses and greenhouses, and outdoor fields for processing. Greenhouse and glasshouse production is concentrated in South Australia, Victoria and NSW, with much smaller production in each of the other states. The majority of processing tomatoes are grown in Victoria, with the remainder in NSW.

This report applies to the **fresh outdoor tomato industry** only, as the environment in greenhouses and glasshouses can be modified to a varying extent to overcome the effects of adverse temperatures. The processing industry also is based on different varieties, and the varieties and agronomy are designed for mechanical harvesting.

A wide range of growing locations, varieties and maturity times means that tomato harvests in Australia occur year-round. Tomatoes are cold and frost sensitive, and production times in each region are regulated by both low and high temperatures.

Tomatoes are very susceptible to variations in temperature, and varieties vary in their tolerance to above (or below) optimum temperatures. Varieties are selected to suit markets, locations and production timing, but unseasonal warm or cool conditions will affect plant growth and product quality and yield. Tomatoes are sensitive to very low and very high temperatures. Heavy frosts will kill plants, while light frosts will kill the tops of plants and can cause fruit to crack. Pollination is reduced outside the optimum temperature range of 18° to 24°C.



Affected fruit may be puffy because few seeds and little gel are formed, or scarred by a disorder commonly known as catface. There is a noticeable reduction in fruit set when temperatures fall outside the range of 10° to 27°C. Varieties respond differently to temperature variation.

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Summary

Changes in temperature affects many crops, and these effects can be complex in species such as tomato, where distinct stages of growth are affected by temperature in different ways.

Tomatoes have four distinct growth stages which are affected by temperature - viz. Seed Germination, Early Vegetative Growth, Flowering, Pollination and Fruit Set and Fruit Growth.

The optimum range for germination is between 20 and 30°C, but decreases rapidly below 15°C and is reduced above 35°C.

Temperatures in the range of 26° to 30°C daily maximum and 17° to 23°C night minimum are typically optimum for tomato varieties grown in Queensland. Vegetative growth is minimal above 35°C.

Fruit setting is reduced when temperatures fall below 10°C or rise above 27°C. Optimum temperature for fruit set is 18° to 24°C. For tomato, the 7 to 15 day period prior to anthesis is the most critical developmental phase. The critical temperature, as identified by the literature, for this phase varies according to the cultivar tolerance to elevated temperatures.

Researchers have proposed the following temperatures for fruit growth; 6°C (Base temperature); 22° – 25°C (Optimum), and 32°C (Maximum).

Significant genetic variability exists between tomato cultivars, providing opportunities to utilise these differences in breeding for high temperature tolerance.

In Australia, fresh outdoor tomatoes are produced in Queensland (Bowen, Bundaberg, Lockyer Valley and Granite Belt), NSW (Narromine, MIA and Sydney Basin), Vic (Goulburn Valley), SA (Murray Bridge, Adelaide Plains) and WA (Swan Coastal Plain).

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Critical Temperatures – Tomato Growth and Development Stages.

In attempting to determine the influence of above or below optimum temperatures on crop performance, it would be convenient if our major agricultural commodities had well-defined temperature thresholds beyond which damage or yield declines could be identified. A survey of the literature demonstrates that such thresholds are often imprecise, and due to variation among cultivars of the same species, thresholds have ranges (Grotjahn, 2021). For example - temperature sensitive tomato cultivars are impacted when mean daily temperatures exceed 25°C, and heat tolerant cultivars are affected when temperatures exceed 32°C (Sato, et al., 2006).

The optimum temperature for **vegetative growth of tomatoes**, as reported by Peet, et al., (1997), is 18–25°C.

The optimum for **tomato fruit growth**, has been defined by Rosales, et al., (2010), as between 23 and 26°C.

Under marginal conditions tomato fruit may set without adequate pollination but the internal fruit segments will contain few seeds and the tomato will be flat sided and puffy. Irregular pollination can also cause the fruit disorder known as catface. Fruit setting is reduced when temperatures fall below 10°C or rise above 27°C. Optimum temperature for **fruit set** is 18° to 24°C (Lovatt, et al., 1998). The 7–15 day period before anthesis has the greatest sensitivity to high-temperature stress, because of reduced pollen grain release (Sato, et al., 2000; Higashide, 2009 and Adams et al., 2001).

Small increases in mean daily temperature (from 28/22°C to 32/26°C day/night) can significantly affect the number of fruit set (Peet, et al., 1997; Rudich, et al., 1977; Went, 1944 and Sato, et al., 2006).

Significant genetic variability exists between tomato cultivars, providing opportunities to utilise these differences in breeding for high temperature tolerant cultivars (Rudich, et al., 1977).

Tomato growth stages.

1. Seed germination.

Optimum temperatures between 20 and 25°C have been reported by Heuvelink, et al., (2020), with a minimum temperature of 8.7°C for germination. However, they considered 13°C as the “practical” minimum temperature.

The optimum range for germination is between 20 and 30°C, but decreases rapidly below 15°C and is reduced above 35°C (Lovatt, et al., 1998).

2. Early Vegetative growth.

Temperatures in the range of 26° to 30°C daily maximum and 17° to 23°C night minimum are typically optimum for tomato varieties grown in Queensland. Vegetative growth is minimal above 35°C (Lovatt, et al., 1998).

Boote, et al., (2012), and (Heuvelink et al., 2020) reported the optimum temperature range for early vegetative growth of tomato plants as 18 to 25°C, with a base temperature of 7°C.

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Experiments conducted by Boote, et al., (2012), demonstrated that there is a linear increase of leaf appearance rate as temperatures rise, with a maximum of 0.5 leaf/day at 28°C and decreasing thereafter until reaching zero at 48°C.

For most plant species, vegetative development usually has a higher optimum temperature than for reproductive development (Hatfield and Preuger, 2015).

As tomato is a tropical species, no growth occurs below 12°C, and long-term exposure to these low temperatures causes chilling injury. (Heuvelink et al., 2020).

3. Flowering, Pollination and Fruit Set.

Fruit setting is reduced when temperatures fall below 10°C or rise above 27°C. Optimum temperature for fruit set is 18° to 24°C (Lovatt, et al., 1998), and experiments by Boote, et al., (2012) put the optimum range between 17° and 24°C, and Heuvelink et al., (2020), put the optimum temperature for anthesis is between 18° and 20°C.

Peet, et al. (1997), reported a significant reduction in fruitset in tomatoes when average maximum daily temperatures exceed 30°C. This was as a result of adverse effects on flower formation, pollen grain and ovule formation, style elongation, pollen germination, fertilization, and seed formation (Faruq Golam, 2012).

Sato, et al., (2000) and Boote, et al., (2012) reported similar effects in experiments where maximum temperatures exceeded 32°C, and considered the adverse effect of high temperatures being on pollen release and viability. Dane, et al., (1991) confirmed that prolonged periods of high temperature caused drastic reductions in pollen fertility in most genotypes in the experiments which they conducted. (Dane et al., 1991).

Boote, et al., (2012), proposed the following temperatures; 6°C (Base temperature); 21° – 26°C (Optimum), and 33°C (Maximum) for fruit set, and partitioning to fruit is reduced above 28°C and falls to zero at 34°C), whereas Camejo et al. (2005) put 30°C as the upper threshold temperature for tomato fruit set.

Faruq Golam, (2012) put the upper threshold at 35°C.

For the purposes of this review, 27°C (mean monthly temperature) during the 2 week period up to anthesis has been selected as the critical temperature at a critical development phase for tomato production. **In Queensland this critical period occurs ~ 9 weeks before harvest.**

4. Fruit Growth

For fruit growth rate (dry matter and water accumulation), Rylsky (1979) found an optimum equal to 26°C, whereas Adams et al. (2001) found that 25/25°C (day/night) to be optimum for fruit growth.

Boote, et al., (2012), proposed the following temperatures; 6°C (Base temperature); 22° – 25°C (Optimum), and 32°C (Maximum) for fruit growth.

Increasing temperatures increase fruit growth rate, but at the same time hastens maturity and the result is a reduced weight of fruit (Adams et al., 2001).

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Blossom-end rot (BER) occurs when calcium and/or water levels in the root zone are low, and genetic and environmental factors contribute to the development of this disorder. BER first appears as a small, water-soaked spot near the blossom scar, which then enlarges.

Calcium transport and calcium demand, both have an influence on the occurrence of BER. Large-fruited cultivars are generally more susceptible, and BER increases with high temperature and high light during the period of rapid fruit growth. Low humidity, high temperature and high light increase leaf transpiration and decrease the calcium supply to the fruit (Heuvelink et al., 2020).

Seed Germination

The optimum range for germination is between 20 and 30°C, but decreases rapidly below 15°C and is reduced above 35°C (Lovatt, et al., 1998).

The Optimum Temperature range for Seed Germination is 20 to 30°C.

The **Critical Temperature Thresholds for Seed Germination** are <15°C and >35°C.

Early Vegetative growth.

Temperatures in the range of 26° to 30°C daily maximum and 17° to 23°C night minimum are typically optimum for tomato varieties grown in Queensland. Vegetative growth is minimal above 35°C (Lovatt, et al., 1998).

The Optimum Temperature range for Early Vegetative Growth is 26°C to 30°C.

The **Critical Temperature Thresholds for Early Vegetative Growth** are <12°C and >35°C.

Flowering, Pollination and Fruit Set

Fruit setting is reduced when temperatures fall below 10°C or rise above 27°C. Optimum temperature for fruit set is 18° to 24°C (Lovatt, et al., 1998).

The Optimum Temperature range for Flowering, Pollination and Fruit Set is 18° to 24°C.

The **Critical Temperature Threshold for Flowering, Pollination and Fruit Set** is <10°C and >27°C.

Fruit Growth

Boote, et al., (2012), proposed the following temperatures; 6°C (Base temperature); 22° – 25°C (Optimum), and 32°C (Maximum) for fruit growth.

The Optimum Temperature range for Fruit Growth is 23 to 26°C.

The **Critical Temperature Threshold for Fruit Growth** is >32°C.

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Future climate implications – crop performance and yield.

A diverse range of commercial tomato varieties are available to Australian growers. Australian commercial seed supplier catalogues indicate suggested variety, timing and location production slots - (Terranova Product Guide – 2022¹; South Pacific Seeds Product Guide – 2023²; Seminis Product Guide 2022-2024³ [This product guide includes a growing calendar for each Australian State].

Varietal suitability and timing varies according to geographic production location.

Australia and Queensland's climate is warming, meaning that some current summer tomato production locations and varieties are likely to become commercially non-viable in the future. Producers will need to continue to adapt to these changes, revising their production location, variety selection and timing. Plant breeders will need to develop and introduce new heat tolerant varieties. These summer production locations that are currently on the verge of being too hot in certain months will experience more days that are above their best summer varieties' CTT. This will cause a shortening of the current summer season, so that producers can avoid quality and crop loss in a hotter summer.

Locations or months previously deemed non-viable due to minimum temperature constraints may become commercially viable. For example, the summer production season in the Granite Belt region (currently late spring and summer), could extend further into the autumn and begin earlier in the spring, extending the production window, as temperatures rise. Variety choices and production windows will need to be adjusted accordingly.

Queensland is already experiencing the impacts of climate change:

The Climate Change in Australia website –

CSIRO and Bureau of Meteorology, Climate Change in Australia website⁴ [accessed April 2023] contains the following statements.

- All of Queensland has warmed since 1910.
- Average annual temperature has increased by 1.5°C since 1910,
- Under a high emissions scenario (RCP8.5), by mid-century, Queensland can expect an average annual temperature increase of around 1.3-2.5°C (central **estimate of 1.9°C**).

These statements about Queensland's changing climate refer to annual average temperature increases (1.3 – 2.5°C), so they smooth out the usual fluctuations in daily, weekly and monthly temperature at any location. The State of the Climate 2022 Report⁵ (Web link:), Future Climate section states, "new research in Australia and around the world, together with the IPCC's Sixth Assessment Report, enhance our understanding of the state of Australia's future climate. In coming decades, Australia is projected to experience continued warming with more extremely hot days and fewer extremely cool days."

¹ <https://terrnovaseeds.com.au/wp-content/uploads/2022/03/Terranova-Product-Guide-2022.pdf>

² <https://spssales.com.au/product/round-gourmet/>

³ <https://www.vegetables.bayer.com/au/en-au/resources.html>

⁴ <https://www.climatechangeinaustralia.gov.au/en/changing-climate/state-climate-statements/queensland/>

⁵ <https://www.csiro.au/en/research/environmental-impacts/climate-change/State-of-the-Climate>

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This has serious implications for horticultural production in Queensland, where higher temperatures will impact existing crops, production timing, product quality and production locations. While some production may be able/forced to move to a new location, land suitability, water availability, workforce and supporting infrastructure (e.g., road networks & power availability) pose significant constraints.

For tomato, the 7 to 15 day period prior to anthesis is the most critical developmental phase. The critical temperature, as identified by the literature for this phase, varies according to the cultivar tolerance to elevated temperatures.

Elevated temperature impacts are complex, but for the purposes of this review, 27°C (mean daily temperature) during the 2 week period up to anthesis has been selected as the critical temperature and critical development phase.

As temperatures continue to rise, then the adverse effects of high temperature on tomato yields will demand more heat tolerant cultivars which will allow growers to maintain production. Without these more tolerant cultivars, the production season in all regions in Queensland will contract to the cooler months. Summer production will be very difficult in all regions except the Granite Belt.

As there is significant genetic variability between cultivars in their capacity to set fruit under high temperature conditions, there is a capacity to utilise these differences in breeding programs to deliver high temperature tolerant commercial cultivars.

In experiments conducted to determine critical temperature effects, sensitive cultivars are impacted when mean daily temperatures exceed 25°C, whereas more heat tolerant cultivars are not impacted until daytime (maximum) temperatures exceed 32°C, and the most sensitive period is 7-15 days prior to anthesis.

Climate change scenarios which include even moderate temperature increases in the order of 0.8°C, as published by the IPCC, are likely to affect the reproductive capacity of tomato plants, which will then have the potential to reduce yields of current cultivars.

Tomato - Temperature Thresholds (from published research).

	Optimum Temperature Range °C		Critical Temperature(s) °C	
Growth Stage	Lower	Upper	Lower	Upper
Seed germination	20	30	<15	>25
Early Vegetative Growth	26	30	<12	>35
Flowering, Pollination and Fruit Set	18	24	<10	>27 [29°C for 3 consecutive days]
Fruit Growth	23	26	<0	>32

Table 1. Optimum and Critical Temperatures for Tomato

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It is important to realise that to achieve a mean monthly maximum above 27°C (for example), there will be a spread of cooler and hotter days. In a biological system, plant stress caused by several days in a row above a critical temperature tends to tip the system into decline. To simulate the effects of high temperatures on consecutive days, we have used the critical temperature + 2°C for 3 days, and applied this to each crops' threshold. So for tomato at the flowering, pollination and fruit set development stage, the literature puts the Critical Temperature Threshold at 27°C mean monthly maximum temperature. To simulate the effects of high temperatures, we have chosen **29°C for 3 consecutive days as the Critical Temperature Threshold for Tomato at the flowering, pollination and fruit set development stage**, a critical development phase in tomato production.

Commodity production data.

Data from the Australian Horticulture Statistics Handbook 2020/21 (pp. 349-353)⁶

The tomato industry in Australia can be separated into two distinct sectors, those grown for use in processed foods and those grown for the fresh market.

The fresh tomato industry also can be divided into outdoor field production and greenhouse (glasshouse) production.

There are number of tomato types grown in Australia (Hort Innovation, 2023). These major types include:

- Field - (a round to oval tomato with a red skin), most commonly grown outdoors and accounting for 39% of fresh production.
- Large Truss – (a round to oval tomato with a red skin), typically sold with the vine still attached, most commonly grown in glasshouses, and accounted for 32% of fresh production.
- Cherry and Grape – (a smaller round to oval shaped tomato with a red or orange skin), grown both outdoors and more commonly in glasshouses, and accounting for 24% of fresh production.
- Roma – (including baby Roma tomatoes, an oval egg-shaped tomato with red skin), accounting for 5% of fresh production.

Tomatoes are grown in every state of Australia, with Queensland and Victoria being the major suppliers of **outdoor grown fresh** tomatoes.

Queensland produces the majority of fresh outdoor tomatoes, accounting for 67%, while Victoria, New South Wales and Western Australia produced 8%, 6% and 16% respectively (ABS, 2022).

There is a significant **fresh greenhouse** tomato industry in Australia, based mainly in southern states (SA – 48%; Vic – 28% and NSW – 20%; with small amounts of production in each of the other states (ABS, 2022).

⁶ <https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/grower-resources/mt21006-assets/australian-horticulture-statistics-handbook/>

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Victoria is the major producer for the **processed market** accounting for 78% of total production followed by New South Wales at 22% (ABS, 2022).

In Queensland, fresh outdoor tomatoes are grown all the year round. The main production areas are Bowen, Bundaberg and south-east Queensland. Bowen production is predominantly an autumn to spring crop. Bundaberg production is grown all year round with production peaks in autumn and late spring to summer. In South East Queensland, the crop is produced through summer and autumn because the winters are too cold for production.

Tomatoes are cold and frost sensitive, and production times in each region are regulated by both low and high temperatures.

This Report applies to the **fresh outdoor tomato industry** only.

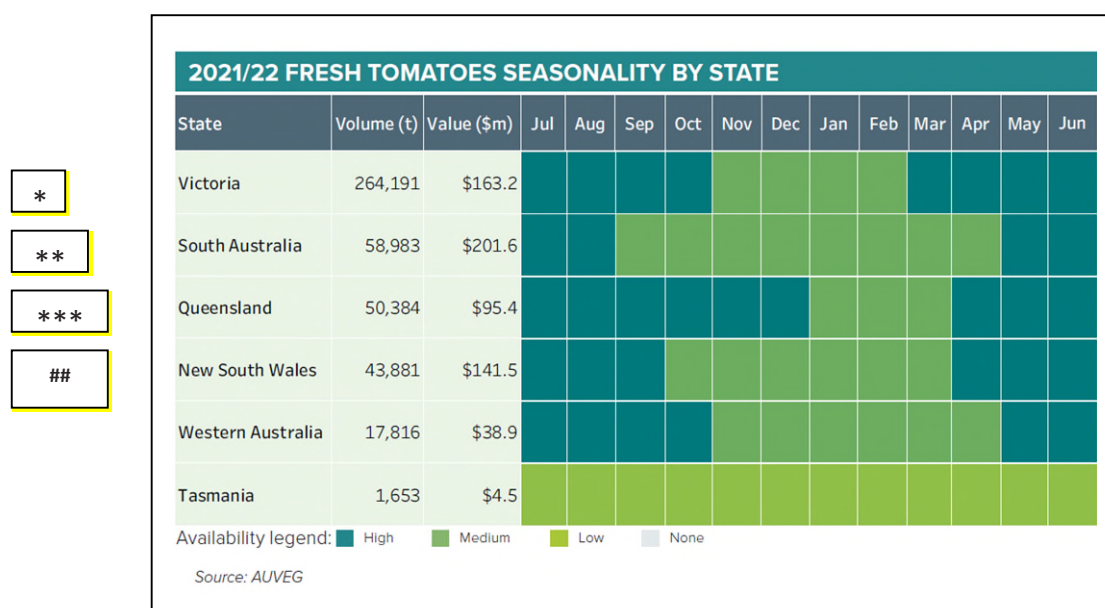


Figure 2. Fresh Tomato production by State – Outdoor (Fresh and Processing) and Greenhouse Production.

- * Tomato production in Victoria includes Outdoor and Greenhouse (Fresh) and for Processing.
- ** Tomato production in South Australia is mainly Greenhouse with some Outdoor (Fresh).
- *** The majority of Queensland tomato production is Outdoor (Fresh).
- ## Tomato production in NSW includes Outdoor and Greenhouse (Fresh) and for Processing.

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Field Grown Round



Large Truss Tomato



Cherry and Grape Tomato



Roma

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Production regions, seasons and critical temperature thresholds

Critical Temperature Thresholds - Climate Monitor analysis/verification of annual historical temperatures at selected Australian tomato production areas.

i) Queensland

a) Bowen (North Queensland)

Using 29°C for 3 consecutive days as the Critical Temperature Threshold for Tomato at the flowering, pollination and fruit set development stage, and the temperature data from Bowen, Qld (Fig. 2), it would be expected that tomato harvesting at Bowen would commence in June and cease by December. This closely describes the production system in this district.

As maximum temperatures continue to rise, due to further climate change, the upper critical temperature threshold of 27°C (and 29°C for 3 consecutive days) will gradually reduce the length of the winter production season in Bowen. The impact will be manifest in reduced yields, in the absence of more adaptable cultivars.

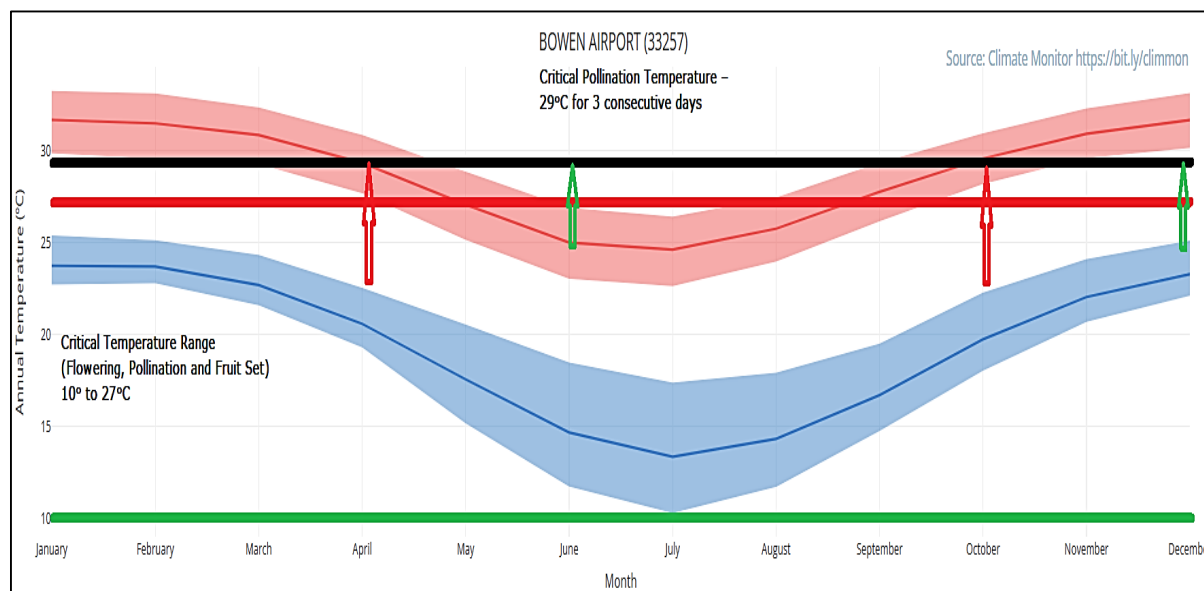


Figure 2. Monthly historical mean maximum (red) and mean minimum (green) temperatures at Bowen (solid lines within each coloured band), with Tomato critical temperatures – overlaid (red – upper; green – lower). Green arrows denote the beginning and end of the harvest season [June to December], and the Red arrows denote the 9 week period from pollination to harvest. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Using the unique weather data analysis of the Climate Monitor Web App⁷, producers can easily review historical spring temperatures at any location in Australia. It is important to realise that to achieve a mean monthly maximum above 27°C there will be a spread of cooler and hotter days. In a biological system, plant stress caused by several days in a row above a critical temperature tends to

⁷ <https://www.longpaddock.qld.gov.au/dcap/horticulture-industry/>

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tip the system into decline. To simulate the effects of high temperatures on consecutive days, a critical temperature + 2°C for 3 days has been used, and applied to Climate Monitor (Figs 3a and 3b).

An analysis of the number of times a maximum temperature of 29°C has occurred for 3 consecutive days in April (Fig 3a) and September to October (Fig 3b) in Bowen is displayed below. A similar analysis for June (not shown), demonstrates a significantly less number of times (only twice since 1960) that a maximum temperature of 29°C has occurred for 3 consecutive days.

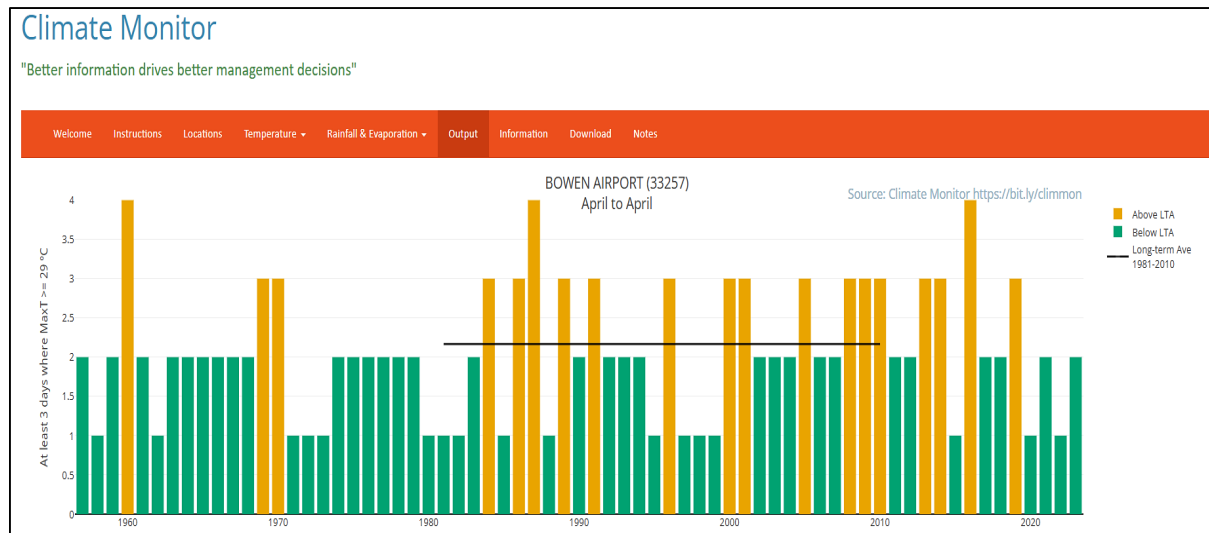


Figure 3a. Climate Monitor analysis showing the number of times that Bowen has experienced at least 3 consecutive days that were 29°C or above in April.

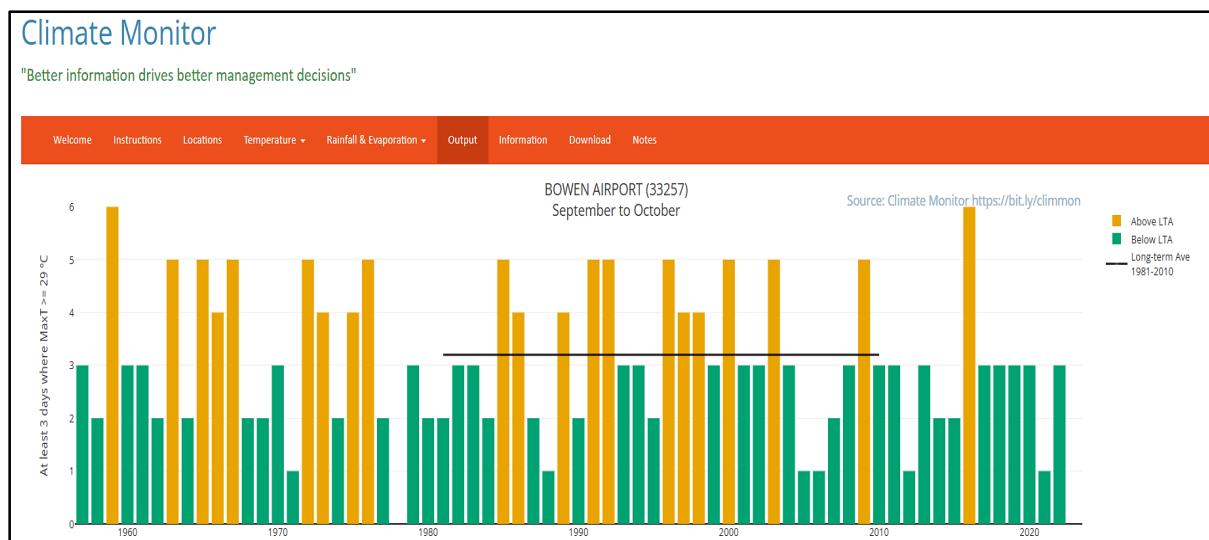


Figure 3b. Climate Monitor analysis showing the number of times that Bowen has experienced at least 3 consecutive days that were 29°C or above in September to October. This brings to an end the Tomato harvest season in Bowen, nine (9) weeks later in December.

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](https://bit.ly/climmon), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

b) Bundaberg

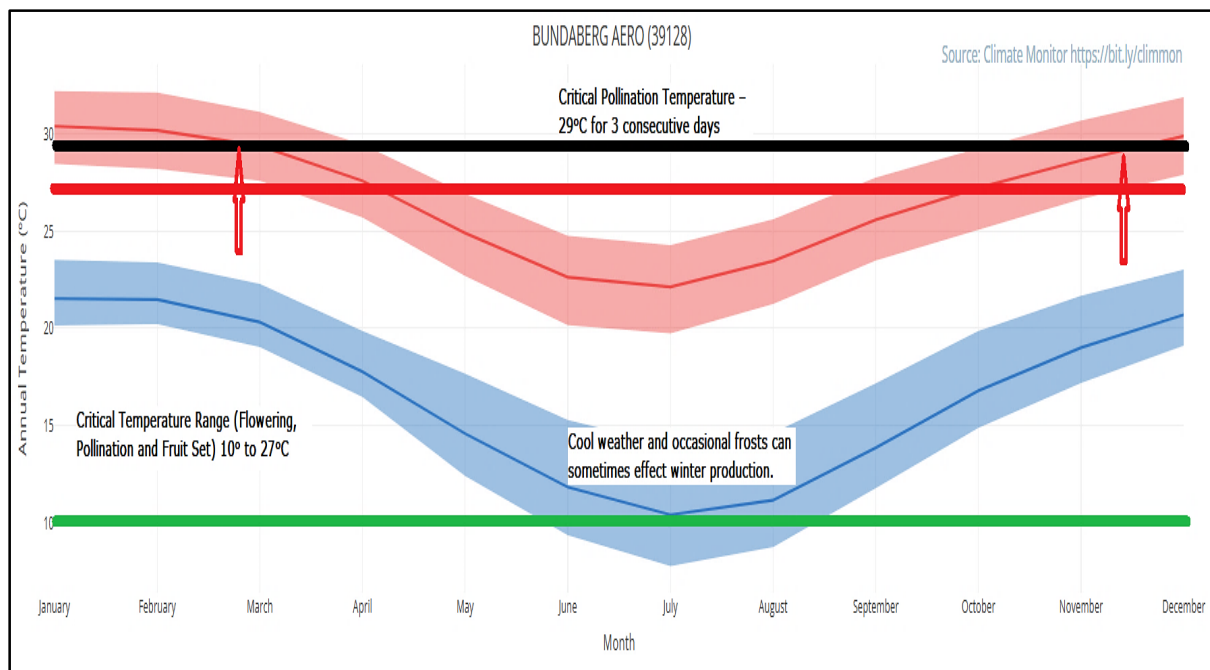


Figure 4. Monthly historical mean maximum (red) and mean minimum (green) temperatures at Bundaberg (solid lines within each coloured band), with Tomato critical temperatures – overlaid (red – upper; green – lower). Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

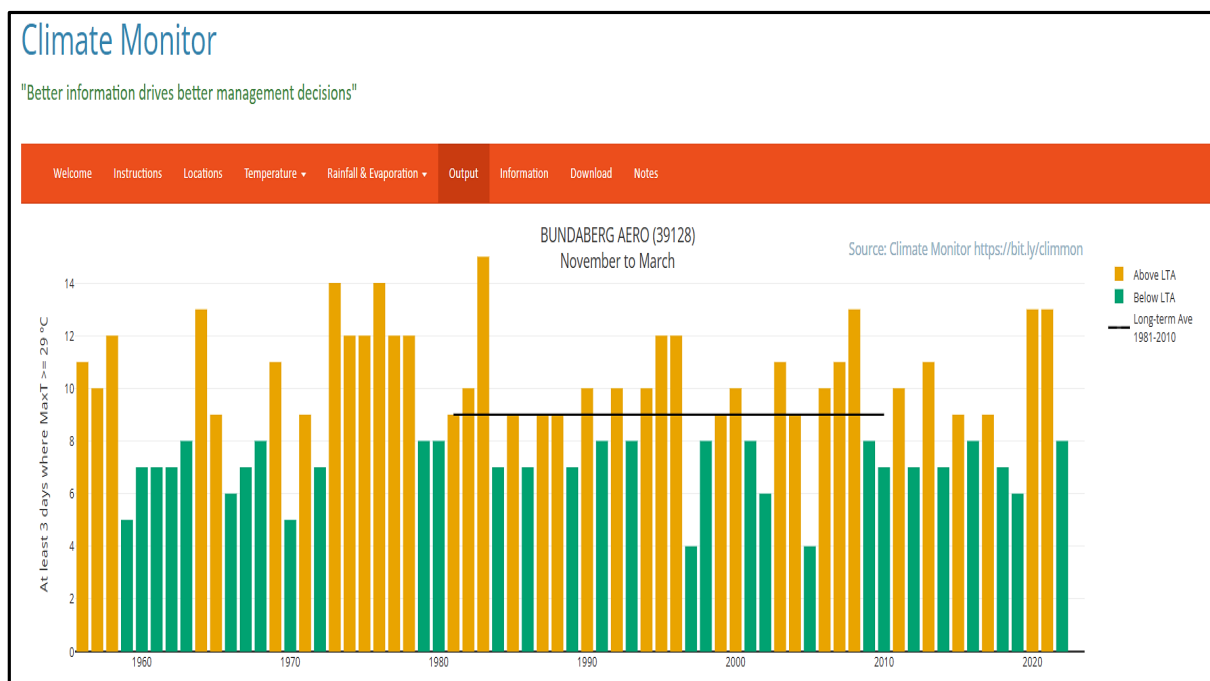


Figure 5. Climate Monitor analysis showing the number of times that Bundaberg has experienced at least 3 consecutive days that were 29°C or above in November to March. Yields are affected during this period, but winter production is not affected.

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

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Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

c) Lockyer Valley (SE Queensland)

Using 29°C for 3 consecutive days as the Critical Temperature Threshold for Tomato at the flowering, pollination and fruit set development stage, and the temperature data from Gatton, Qld, it would be expected that tomato harvesting at Gatton would not occur over the summer months from November to March. This does not describe the production system in this district – i.e. the first harvests of tomatoes at Gatton occur in November. This corresponds with the first planting made after the risk of frosts is reduced in August. The final harvests at Gatton occur in May, approximately 9 weeks after the 29°C threshold is reached, and the risk of frosts increases.

Therefore there is an expectation that growers in this region will suffer a yield and/or quality loss, and this is then expected to be compensated in some way to allow growers to continue to profitably produce tomatoes under such apparently adverse conditions. This has been compensated for by a significant switch from the field grown round tomato varieties over the past 15 years, to cherry tomato varieties, which are inherently more temperature tolerant.

As temperatures continue to rise in the Lockyer Valley, then the adverse effects of high temperatures on tomato yields will demand more heat tolerant cultivars to allow growers to maintain supply especially in mid-summer. Without these more tolerant cultivars, mid-summer production will continue to decline and potentially cease in the Lockyer Valley.

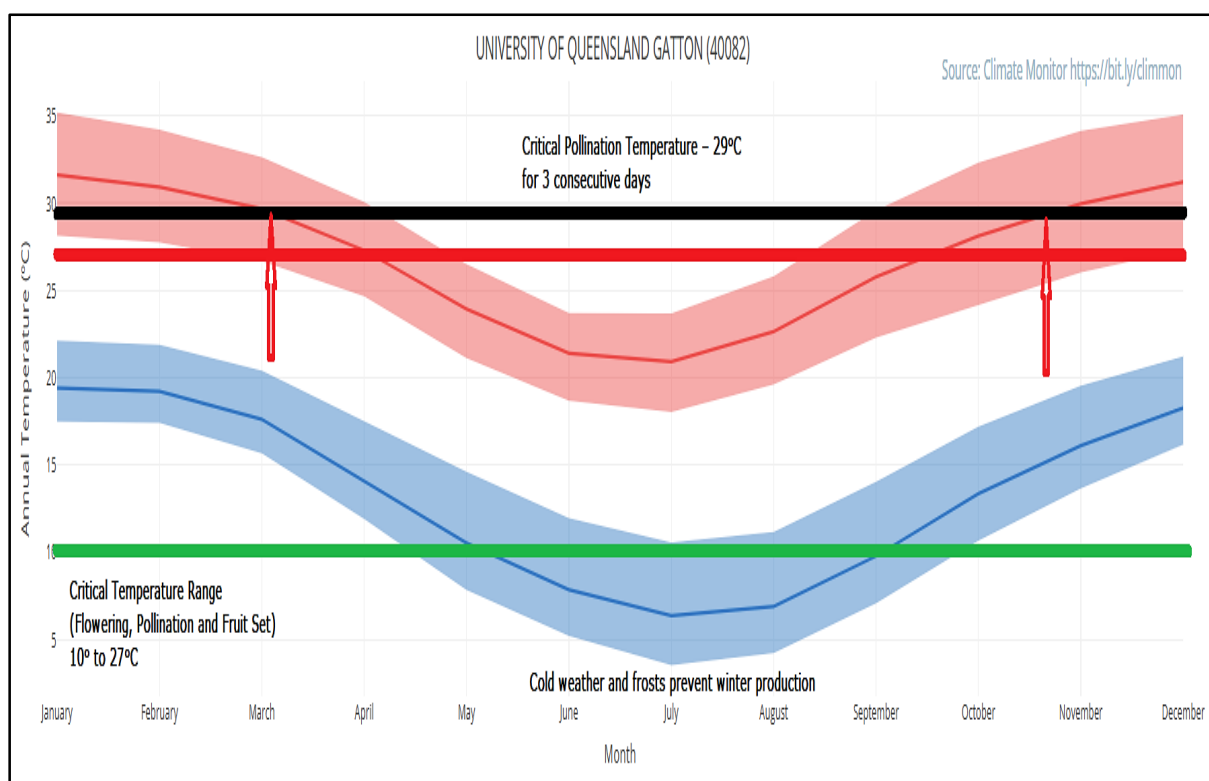


Figure 6. Monthly historical mean maximum (red) and mean minimum (green) temperatures at Lawes (solid lines within each coloured band), with Tomato critical temperatures – overlaid (red – upper; green – lower). Red arrows denote the beginning (mid-October) and end (March) of the critical temperature threshold for pollination. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

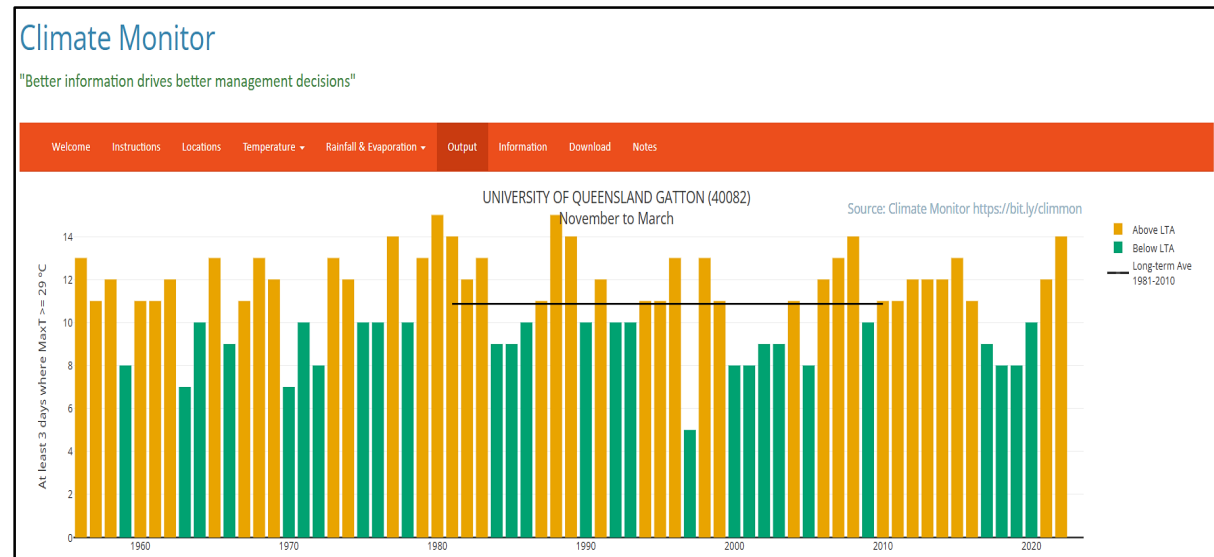


Figure 7. Climate Monitor analysis showing the number of times that Lawes has experienced at least 3 consecutive days that were 29°C or above in November to March. Yields are affected during this period, but winter production is not possible because of low temperatures and the occasional frost.

d) Granite Belt (SE Queensland)

Mean Maximum Temperatures never exceed 29°C for 3 consecutive days at Applethorpe. Using 29°C for 3 consecutive days as the Critical Temperature Threshold for Tomato at the flowering, pollination and fruit set development stage, the temperature data from Applethorpe, Qld (Fig. 6), it would be expected that tomato harvesting in the Granite Belt would not be constrained by temperatures in excess of 29°C. This closely describes the production system in this district, which is a summer tomato production district, due to the influence of altitude on maximum temperatures, especially during the summer. Because tomatoes are frost and cold sensitive, winter production in the Granite belt is constrained by low temperatures, rather than high temperatures.

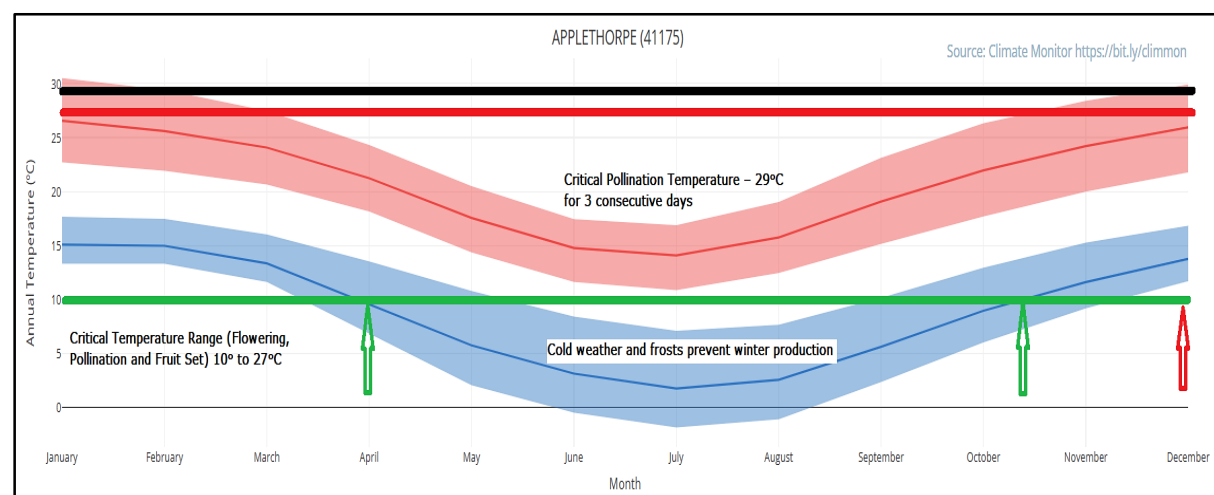


Figure 8. Monthly historical mean maximum (red) and mean minimum (green) temperatures at Applethorpe (solid lines within each coloured band), with Tomato critical temperatures – overlaid (red – upper; green – lower). Red and Green arrows denote the beginning (October) and end (March) of harvests at Applethorpe. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](https://climate-monitor.org/), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – **Peter Deuter**, Horticultural Consultant, PLD Horticulture & **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

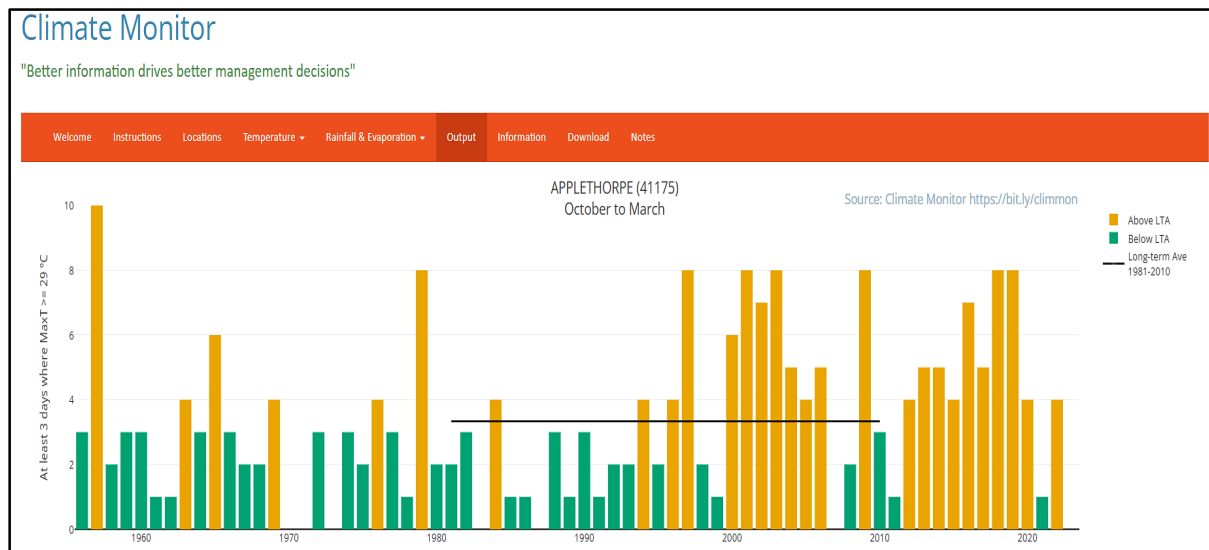


Figure 9. Climate Monitor analysis showing the number of times that Applethorpe has experienced at least 3 consecutive days that were 29°C or above in October to March. Winter production is not possible because of low temperatures and the occasional frost.

As maximum temperatures continue to rise due to further climate change, the temperature threshold of 29°C will eventually be reached in the Granite Belt. The impact will be in reduced yields, in the absence of more adaptable cultivars. This may be compensated for by higher returns, as other summer producing districts are more adversely affected. Eventually, this has the potential to induce a break in summer production, in the first instance in the hottest month which is January.

As maximum temperatures continue to rise through to 2040, due to further climate change, the temperature threshold of 29°C will impact on all other production districts in Queensland, and the Granite Belt to a much lesser extent. The impact will be in the form of reduced yields, in the absence of more adaptable cultivars.

As temperatures continue to rise, then the adverse effects of high temperature on tomato yields will demand **more heat tolerant cultivars which will allow growers to maintain production**. Without these more tolerant cultivars, the production season in all regions in Queensland will contract to the cooler months. Summer production will be very difficult in all regions except the Granite Belt.

At beginning and end of the summer season in the **Granite Belt, growers may be able to take advantage of earlier planting in the spring, and later planting in the autumn**. These future early and late plantings are currently constrained by low minimum temperatures. The availability of a profitable market at these times of the year will also have a significant influence over the capacity of growers to take advantage of these earlier plantings, which will extend future planting and harvest times in this summer tomato growing district.

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – **Peter Deuter**, Horticultural Consultant, PLD Horticulture & **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Future temperature insight.

As underlying temperatures continue to rise, and warmer and hotter days become more frequent⁸, it is likely that the Granite Belt summer production window will lengthen with rising minimum temperatures, while the Lockyer Valley's summer season will shorten as late spring maximums continue to rise and early autumn temperatures remain high for longer. Similarly, the autumn/winter/spring season in Bowen will shorten, as temperatures increase at the beginning and ends of the season. The negative impacts of cooler winters in Bundaberg will be reduced as minimum temperatures rise.

The Representative Concentration Pathways scenario RCP8.5 (Schwalm, et al., 2020), has been chosen in this study to represent a future climate (2016-45), in an effort to understand the impacts on each of the current tomato production locations.

Queensland - a) Bowen (North Queensland)

Projected future (2016-45) and current climate data for **Bowen**.

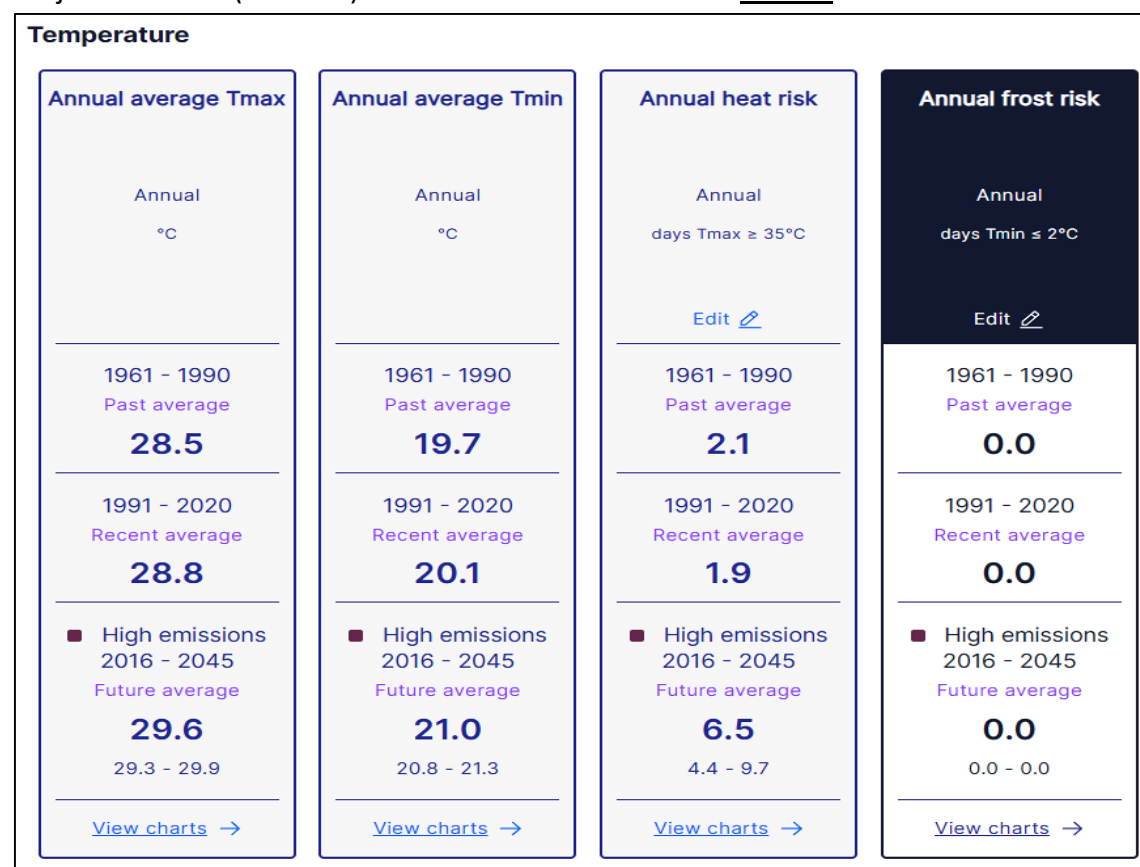


Figure 10. Projected future temperature outlook for **Bowen** under high emissions scenario RCP 8.5, where Australian emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1961 – 1990 for comparison of the 2016 to 2045 average temperature shift.

⁸ <http://www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml>

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Projected Annual Heat Risk shift* (1961 – 90 baseline period), for Tomato production at Bowen, Qld.

Year Range	Number of years with annual heat risk below 237 (days Tmax ≥ 27°C)	Number of years with annual heat risk above 274 (days Tmax ≥ 27°C)
1961-1990	2.3 in 10 years	0.3 in 10 years
1991-2020	1 in 10 years	0.7 in 10 years
2016-2045	0 in 10 years	6.9 in 10 years

* This Figure shows the average number of years out of 10, and the number of days in those years, that the Tomato upper Critical Temperature Threshold has, or is, projected to occur. The default **annual heat risk days** (below and above columns shown for **Tomato production at Bowen**), is the 90th percentile (right column – 274 days at or above 27°C), of the observed 1991-2020 and projected 2016-2045 values.

Figure 11. Bowen annual average Heat Risk shift comparison table.

Data source: Climate Services for Agriculture⁹

Therefore, by the year 2045, it is expected that 69% of years (almost 7 years in 10) will have 274 days (or more) where the maximum temperature is equal to, or exceeds 27°C, at Bowen, whereas currently, this is 7% (less than 1 year in 10).

Bowen

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days T Max ≥ 35°C	Annual Frost Risk Days ≤ 2°C
1961-1990 Past Average	28.5	19.7	2.1	0.0
1991 -2020 Recent Average	28.8	20.1	1.9	0.0
2016-45 High Emissions Future Average	29.6	21.0	6.5	0.0

Table 2. Projected future temperature comparison for Bowen under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking.

The high emissions pathway model indicates a temperature shift, showing a 1.1°C increase in maximum temperatures and a 1.3°C increase in minimum temperatures by 2045. Importantly the number of days when the maximum temperature in Bowen exceeds 35°C increases from 2 to 7 (Figure 10 and Table 2).

⁹ <https://climateservicesforag.indraweb.io/>

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

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Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Future temperatures at Bowen and the impact on the timing and occurrence of tomato critical temperature thresholds (CCT).

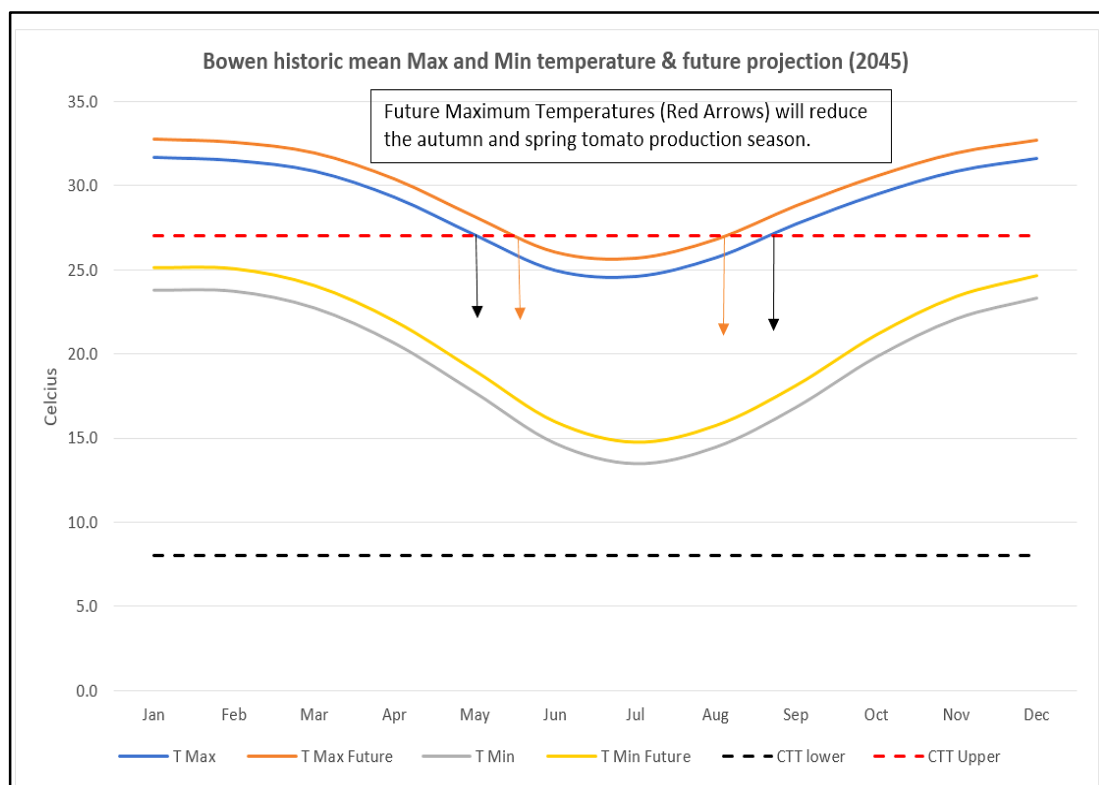


Figure 12. Current mean monthly temperatures at Bowen, Tomato upper CTT (27°C) & the impact of future temperatures on the optimum growing season.

Projected increases in maximum temperatures in both autumn and in spring will reduce the length of the Bowen winter production season.

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

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Tomato Critical Temperature Thresholds

Research Team – **Peter Deuter**, Horticultural Consultant, PLD Horticulture & **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

b) Bundaberg

Projected future (2016-45) and current climate data for Bundaberg.



Figure 13. Projected future temperature outlook for Bundaberg under high emissions scenario RPC 8.5, where Australian emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1961 – 1990 for comparison of the 2016 to 2045 average temperature shift.

Projected Annual Heat Risk shift* (1961 – 90 baseline period), for Tomato production at Bundaberg, SE Qld.

Year Range	Number of years with annual heat risk below 176 (days Tmax ≥ 27°C)	Number of years with annual heat risk above 223 (days Tmax ≥ 27°C)
1961-1990	4.3 in 10 years	0 in 10 years
1991-2020	1 in 10 years	1 in 10 years
2016-2045	0 in 10 years	5.7 in 10 years

* This Figure shows the average number of years out of 10, and the number of days in those years, that the Tomato upper Critical Temperature Threshold has, or is, projected to occur. The default **annual heat risk days** (below and above columns shown for **Tomato production at Bundaberg**), is the 90th percentile (right column – 223 days at or above 27°C), of the observed 1991-2020 and projected 2016-2045 values.

Figure 14. Bundaberg annual average Heat Risk shift comparison table. Data source: Climate Services for Agriculture

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Bundaberg

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days T Max ≥ 35°C	Annual Frost Risk Days ≤ 2°C
1961-1990 Past Average	26.6	16.6	0.9	0.0
1991 -2020 Recent Average	27.3	16.9	1.1	0.0
2016-45 High Emissions Future Average	28.1	17.9	3.1	0.0

Table 3. Projected future temperature comparison for Bundaberg under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking.

The high emissions pathway model indicates a temperature shift, showing a 1.5°C increase in maximum temperatures and a 1.3°C increase in minimum temperatures by 2045. Figure 14 also indicates that by 2045, 6 out of 10 years would have an annual average maximum above 27°C, and this has never occurred in the 1961-90 base period and only occurred once in the 1991-1920 period, a significant shift.

Future temperatures at Bundaberg and the impact on the timing and occurrence of tomato critical temperature thresholds (CTT).

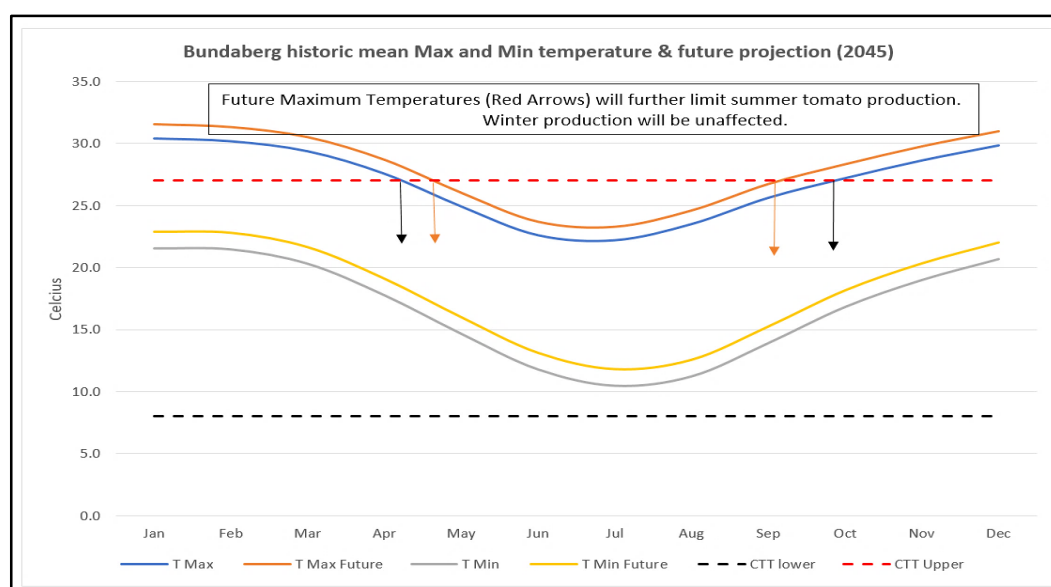


Figure 15. Current mean monthly temperatures at Bowen, Tomato upper CTT (27°C) & the impact of future temperatures on the optimum growing season.

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

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Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

c) Lockyer Valley (SE Queensland)

Projected future (2016-45) and current climate data for Gatton.

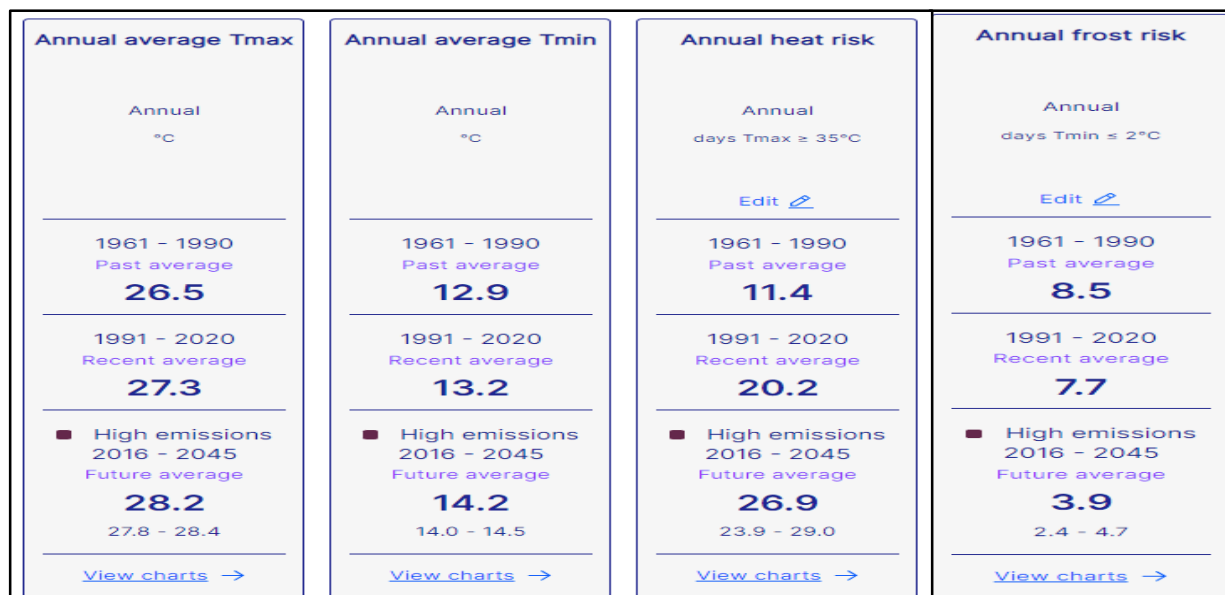


Figure 16. Projected future temperature outlook for Gatton under high emissions scenario RPC 8.5, where Australian emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1961 – 1990 for comparison of the 2016 to 2045 average temperature shift.

Projected Annual Heat Risk shift* (1961 – 90 baseline period), for Tomato production at Lawes, Lockyer Valley, SE Qld.

Year Range	Number of years with annual heat risk below 165 (days Tmax ≥ 27°C)	Number of years with annual heat risk above 216 (days Tmax ≥ 27°C)
1961-1990	5 in 10 years	0 in 10 years
1991-2020	1 in 10 years	1 in 10 years
2016-2045	0 in 10 years	4.7 in 10 years

* This Figure shows the average number of years out of 10, and the number of days in those years, that the Tomato upper Critical Temperature Threshold has, or is, projected to occur. The default **annual heat risk days** (below and above columns shown for **Tomato production at Lawes**), is the 90th percentile (right column – 216 days at or above 27°C), of the observed 1991-2020 and projected 2016-2045 values.

* Default threshold values are the 10th percentile for lower extremes and 90th percentile for higher extremes, of the observed 1991-2020 values.

Figure 17. Gatton annual average Heat Risk shift comparison table.

Data source: Climate Services for agriculture site¹⁰

¹⁰ <https://climateservicesforag.indraweb.io/>

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Tomato Critical Temperature Thresholds

Research Team – **Peter Deuter**, Horticultural Consultant, PLD Horticulture & **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Gatton

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days T Max ≥ 35°C	Annual Frost Risk Days ≤ 2°C
1961-1990 Past Average	26.5	12.9	11.4	8.5
1991 -2020 Recent Average	27.3	13.2	20.2	7.7
2016-45 High Emissions Future Average	28.2	14.2	26.9	3.9

Table 4. Projected future temperature comparison for Gatton under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking.

The high emissions pathway model indicates a temperature shift, showing a 1.7°C increase in maximum temperatures and a 1.3°C increase in minimum temperatures by 2045. Importantly the number of days when the maximum temperature in Gatton exceeds 35°C increases from 11 to 27 (Figure 16 and Table 4).

Figure 17 also indicates that by 2045, 5 out of 10 years would have an annual average maximum above 28°C, and this has never occurred in the 1961-90 base period and only occurred once in the 1991-2020 period, a significant shift.

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

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Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Future temperatures at Gatton and the impact on the timing and occurrence of tomato critical temperature thresholds (CCT).

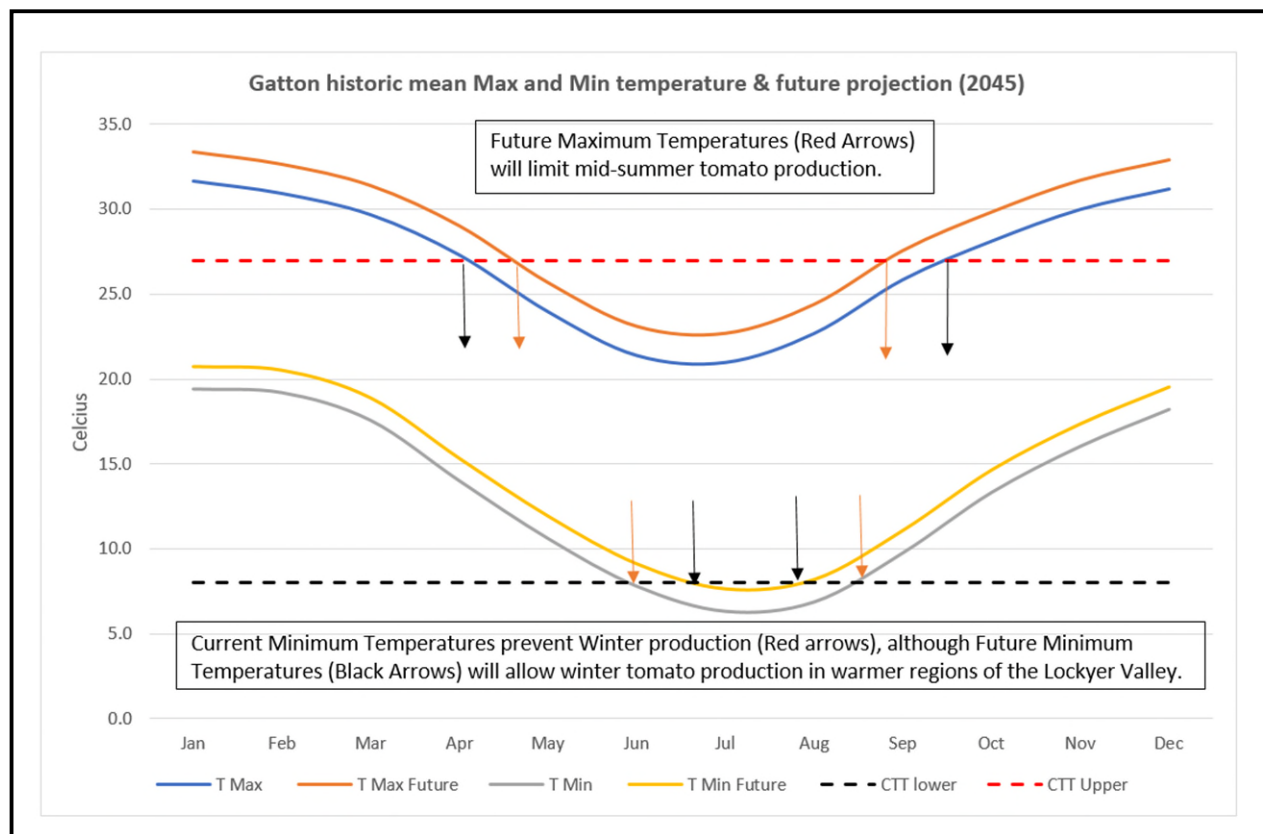


Figure 18. Current mean monthly temperatures at Gatton, Tomato lower CTT (8°C) & the impact of future temperatures on the optimum growing season.

Forecast increases in minimum temperatures in both early autumn, and in late spring will allow an extension of the production season. As maximum temperatures also increase, warm season production will increase the limitation of production to the autumn and spring periods. In the future, some production will be possible over the winter, in warmer and more protected areas of the Lockyer Valley. This is currently the case in some years.

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

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Tomato Critical Temperature Thresholds

Research Team – **Peter Deuter**, Horticultural Consultant, PLD Horticulture & **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

d) Granite Belt (SE Queensland)

Projected future (2016-45) and current climate data for **Applethorpe**.



Figure 19. Projected future temperature outlook for **Applethorpe** under high emissions scenario RPC 8.5, where Australian emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1961 – 1990 for comparison of the 2016 to 2045 average temperature shift.

Projected Annual Heat Risk shift* (1961 – 90 baseline period), for Tomato production at Applethorpe, SE Qld.

Year Range	Number of years with annual heat risk below 36 (days Tmax ≥ 27°C)	Number of years with annual heat risk above 73 (days Tmax ≥ 27°C)
1961-1990	3 in 10 years	0.3 in 10 years
1991-2020	1 in 10 years	1 in 10 years
2016-2045	0.1 in 10 years	5 in 10 years

* This Figure shows the average number of years out of 10, and the number of days in those years, that the Tomato upper Critical Temperature Threshold has, or is, projected to occur. The default **annual heat risk days** (below and above columns shown for **Tomato production at Applethorpe**), is the 90th percentile (right column – 73 days at or above 27°C), of the observed 1991-2020 and projected 2016-2045 values.

Figure 20. **Applethorpe** annual average Heat Risk shift comparison table. Data source: Climate Services for agriculture site

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – **Peter Deuter**, Horticultural Consultant, PLD Horticulture & **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Applethorpe

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days T Max ≥ 35°C	Annual Frost Risk Days ≤ 2°C
1961-1990 Past Average	20.3	8.8	0.5	57.2
1991 -2020 Recent Average	21.2	9.1	1.2	53.3
2016-45 High Emissions Future Average	22.1	10.1	1.8	39.7

Table 5. Projected future temperature comparison for Applethorpe under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking.

The high emissions pathway model indicates a temperature shift, showing a 1.3°C increase in average monthly minimum temperatures and a 1.8°C increase in average monthly maximum temperatures by 2045. The existing tomato production season will be lengthened due to a decrease in the number of days when the minimum temperature in Applethorpe is below 8°C, decreases. This change is underlined by the reduced future Annual Frost Risk which decreases from 57 to 40 days (Figure 16 and Table 5).

As maximum temperatures continue to rise, due to further climate change, the temperature threshold of 29°C will eventually be reached in the Granite Belt. The impact will be in reduced yields, in the absence of more adaptable cultivars. This may be compensated for by higher returns, as other summer producing districts are more adversely affected. Eventually, this has the potential to induce a break in summer production, in the first instance in the hottest month which is January.

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

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Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Future temperatures at Applethorpe and the impact on the timing and occurrence of tomato critical temperature thresholds (CCT).

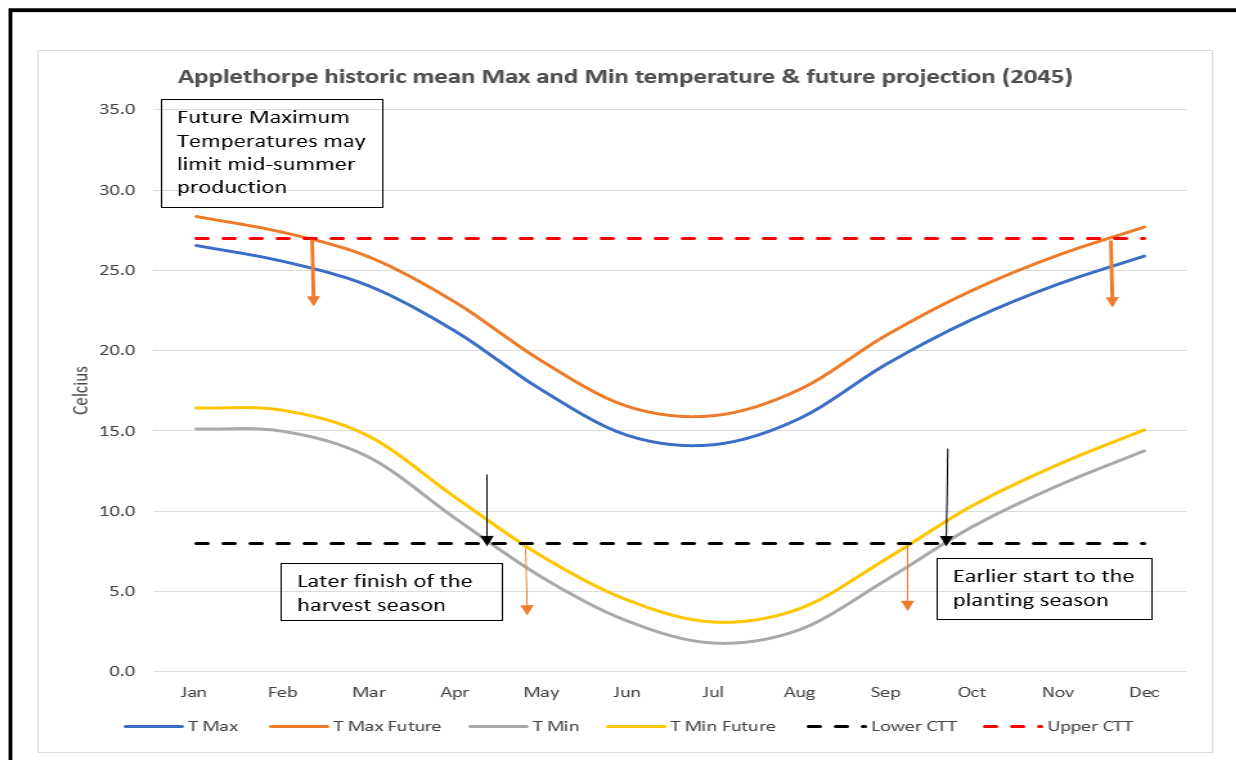


Figure 21. Current mean monthly temperatures at Applethorpe, Tomato lower CTT (8°C) & the impact of future temperatures on the optimum growing season.

Forecast increases in minimum temperatures in both early autumn, and in late spring will allow an extension of the production season. This would result in a 3-4 week extension of the Granite Belts' (historical) tomato growing season, enhancing product availability.

Figure 21 above shows how this minimum temperature shift will lengthen the Granite Belt growing season. Transplanting of the first crops could be brought forward by several weeks, with last harvests also extended later into the autumn.

Maximum temperatures will also increase as shown in Figures 19 & 20, potentially limiting mid-summer tomato production in the Granite Belt.

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Interstate production – future insights.

Future climate data analysis for all locations (2016-2045) is based on current projections sourced from Australia's **Climate Services for Agriculture** web site¹¹

New South Wales – Sydney Basin (Richmond)

Using 29°C for 3 consecutive days as the Critical Temperature Threshold for Tomato at the flowering, pollination and fruit set development stage, and the temperature data from Richmond, it would be expected that tomato harvesting will be limited to late summer, autumn and spring, as the mid-summer months are warmer than the threshold and the winter months are colder than the threshold. Future annual monthly maximum temperature increases will further reduce the growing window for tomato at Richmond. Increased summer maximum temperatures will further shorten the local production season.

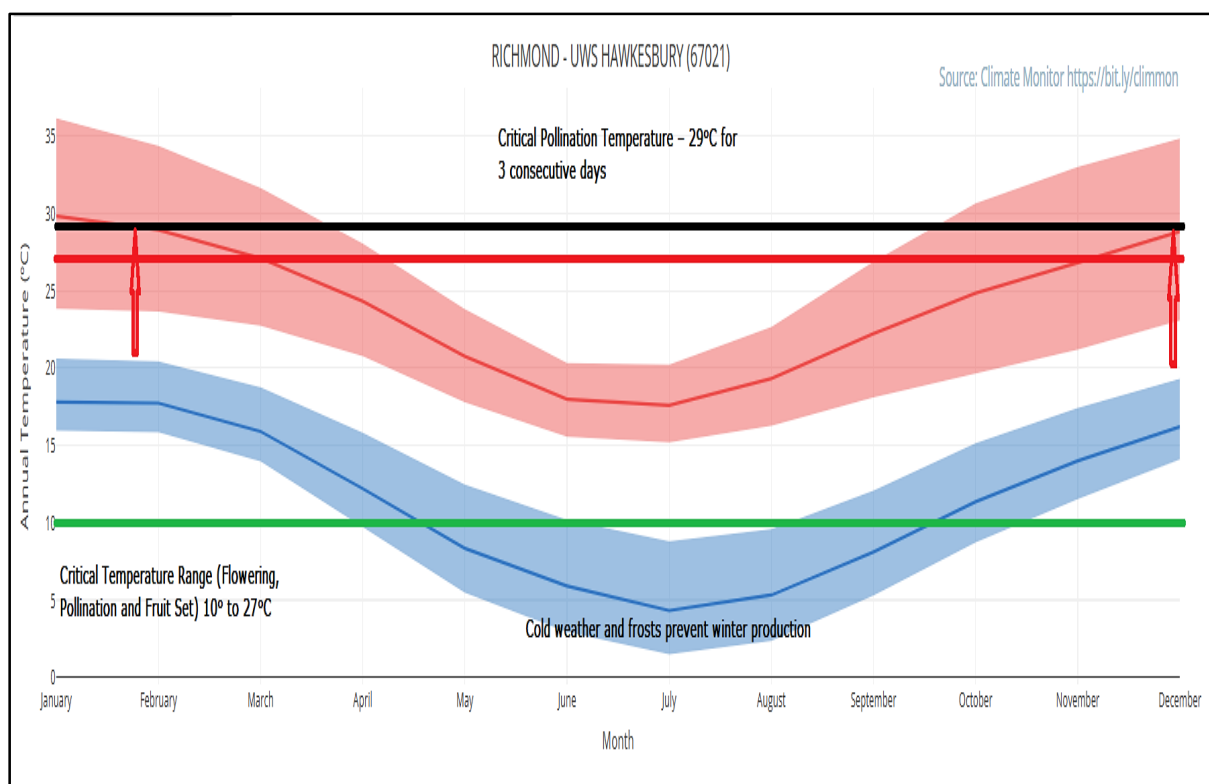


Figure 22. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (green) temperatures and mean temperatures, with lettuce critical temperatures – overlaid, at Richmond, NSW.

¹¹ <https://climateservicesforag.indraweb.io/>

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Projected future (2016-45) and current climate data for Richmond, NSW.

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days T Max ≥ 35°C	Annual Frost Risk Days ≤ 2°C
1961-1990 Past Average	23.8	11.2	11	14.3
1991 -2020 Recent Average	24.5	11.6	16.3	11.7
2016-45 High Emissions Future Average	25.3	12.5	19.8	5.7

Table 6. Projected future temperature comparison for Richmond under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

Projected Annual Heat Risk shift* (1961 – 90 baseline period), for Tomato production at Richmond, NSW.

Year Range	Number of years with annual heat risk below 99 (days Tmax ≥ 27°C)	Number of years with annual heat risk above 139 (days Tmax ≥ 27°C)
1961-1990	4.3 in 10 years	0.3 in 10 years
1991-2020	1 in 10 years	1 in 10 years
2016-2045	0 in 10 years	4.1 in 10 years

* This Figure shows the average number of years out of 10, and the number of days in those years, that the Tomato upper Critical Temperature Threshold has, or is, projected to occur. The default **annual heat risk days** (below and above columns shown for **Tomato production at Richmond, NSW**), is the 90th percentile (right column – 139 days at or above 27°C), of the observed 1991-2020 and projected 2016-2045 values.

Figure 23. Richmond, NSW annual average Heat Risk shift comparison table.

Data source: Climate Services for agriculture site¹²

The high emissions pathway model indicates a temperature shift, showing a 1.5°C increase in maximum temperatures and a 1.3°C increase in minimum temperatures by 2045. Importantly the number of days when the maximum temperature in Richmond exceeds 35°C increases from 11 to almost 20 (Table 6).

Figure 23. above also indicates that by 2045, 4 out of 10 years would have an annual average maximum above 27°C, and this has occurred less than 1 in 10 years in the 1991-2020.

¹² <https://climateservicesforag.indraweb.io/>

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – **Peter Deuter**, Horticultural Consultant, PLD Horticulture & **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Victoria - Goulburn Valley (Shepparton)

Using 29°C for 3 consecutive days as the Critical Temperature Threshold for Tomato at the flowering, pollination and fruit set development stage, and the temperature data from Shepparton, it would be expected that tomato harvesting will be limited to autumn, spring and early summer, as the latter summer months are warmer than the threshold and the winter months are colder than the threshold.

Future annual monthly maximum temperature increases will further reduce the growing window for tomato at Shepparton. Increased summer maximum temperatures will further shorten the local production season.

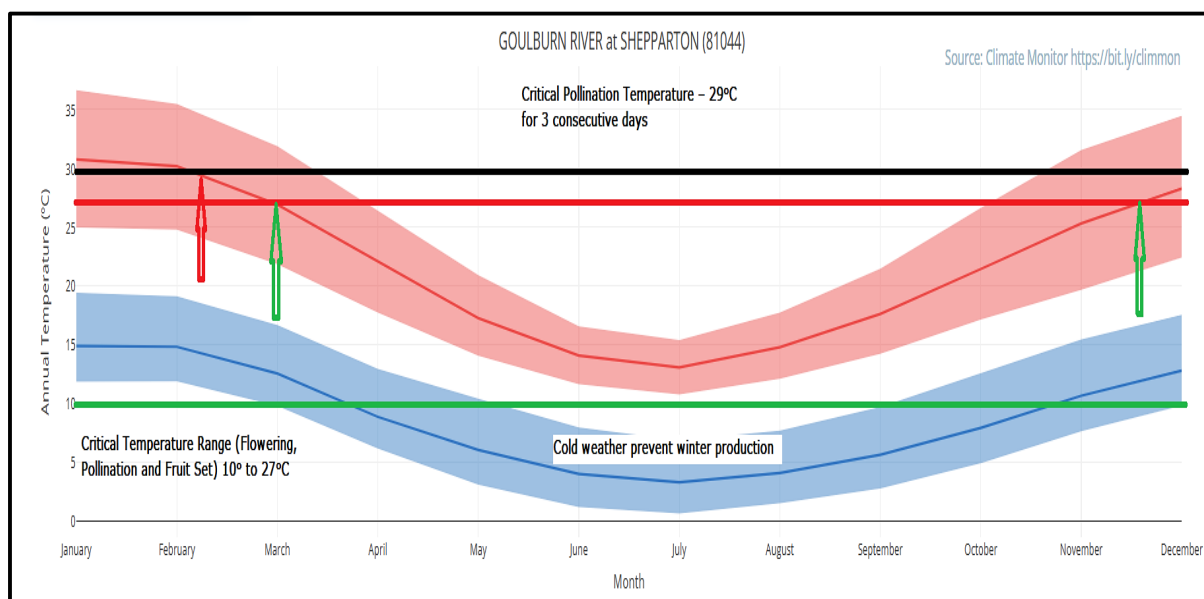


Figure 24. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (green) temperatures and means, with Tomato critical temperatures – overlaid, at Shepparton.

Projected future (2016-45) and current climate data for Shepparton.

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days T Max ≥ 35°C	Annual Frost Risk Days ≤ 2°C
1961-1990 Past Average	21.5	8.8	12.8	33.1
1991 -2020 Recent Average	22	9	17.1	39.8
2016-45 High Emissions Future Average	22.9	9.8	22.4	26.6

Table 7. Projected future temperature comparison for Shepparton under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](https://climate-monitor.com.au/), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Projected Annual Heat Risk shift* (1961 – 90 baseline period), for Tomato production at Shepparton, Vic.

Year Range	Number of years with annual heat risk below 77 (days Tmax ≥ 27°C)	Number of years with annual heat risk above 120 (days Tmax ≥ 27°C)
1961-1990	1.3 in 10 years	0 in 10 years
1991-2020	1 in 10 years	1 in 10 years
2016-2045	0 in 10 years	2.1 in 10 years

* This Figure shows the average number of years out of 10, and the number of days in those years, that the Tomato upper Critical Temperature Threshold has, or is, projected to occur. The default **annual heat risk days** (below and above columns shown for **Tomato production at Shepparton, Vic**), is the 90th percentile (right column – 120 days at or above 27°C), of the observed 1991-2020 and projected 2016-2045 values.

Figure 25. Shepparton annual average Heat Risk shift comparison table.

Data source: Climate Services for agriculture site¹³

The high emissions pathway model indicates a temperature shift, showing a 1.4°C increase in maximum temperatures and a 1.0°C increase in minimum temperatures by 2045. The number of days when the maximum temperature in Shepparton exceeds 35°C increases from 13 to 22 (Table 7).

Figure 25 above also indicates that by 2045, 2 out of 10 years would have an annual average maximum above 27°C, and this has never occurred in the 1961-90 base period and only occurred once in the 1991-1920 period.

¹³ <https://climateservicesforag.indraweb.io/>

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – **Peter Deuter**, Horticultural Consultant, PLD Horticulture & **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

South Australia - Adelaide Plains (Virginia)

Using 29°C for 3 consecutive days as the Critical Temperature Threshold for Tomato at the flowering, pollination and fruit set development stage, and the temperature data from Virginia, it would be expected that tomato harvesting will be limited to late summer, autumn and spring, as the mid-summer months are warmer than the threshold and the winter months are colder than the threshold.

Future annual monthly maximum temperature increases will further reduce the growing window for tomato at Virginia. Increased summer maximum temperatures will further shorten the local production season.

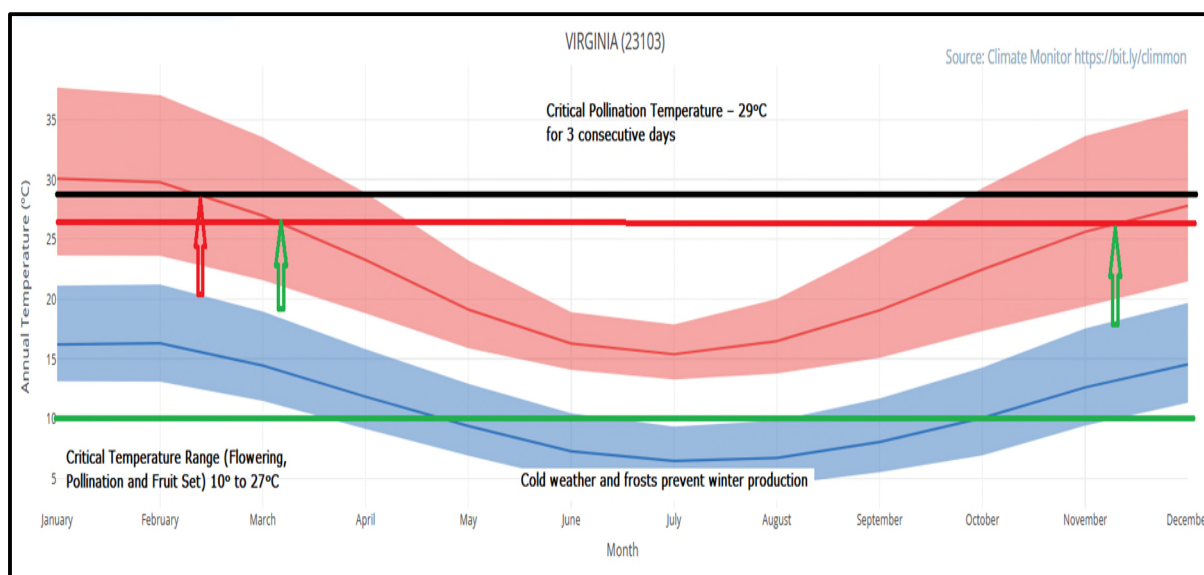


Figure 26. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (green) temperatures and means, with Tomato critical temperatures – overlaid, at Virginia.

Projected future (2016-45) and current climate data for Virginia.

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days T Max ≥ 35°C	Annual Frost Risk Days ≤ 2°C
1961-1990 Past Average	22.4	11.2	21.1	2.3
1991 -2020 Recent Average	23.0	11.5	25.4	1.9
2016-45 High Emissions Future Average	23.8	12.3	29.9	0.8

Table 8. Projected future temperature comparison for Virginia under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](https://bit.ly/climmon), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Projected Annual Heat Risk shift* (1961 – 90 baseline period), for Tomato production at Virginia, SA.

Year Range	Number of years with annual heat risk below 82 (days Tmax ≥ 27°C)	Number of years with annual heat risk above 113 (days Tmax ≥ 27°C)
1961-1990	1.7 in 10 years	0 in 10 years
1991-2020	1 in 10 years	1 in 10 years
2016-2045	0 in 10 years	2.4 in 10 years

* This Figure shows the average number of years out of 10, and the number of days in those years, that the Tomato upper Critical Temperature Threshold has, or is, projected to occur. The default **annual heat risk days** (below and above columns shown for **Tomato production at Virginia, SA**), is the 90th percentile (right column – 113 days at or above 27°C), of the observed 1991-2020 and projected 2016-2045 values.

Figure 27. Virginia annual average Heat Risk shift comparison table. Data source: Climate Services for agriculture site

The high emissions pathway model indicates a temperature shift, showing a 1.4°C increase in maximum temperatures and a 1.1°C increase in minimum temperatures by 2045. The number of days when the maximum temperature at Virginia exceeds 35°C increases from 21 to 30 days (Table 8).

Figure 27 above also indicates that by 2045, 2 out of 10 years would have an annual average maximum above 27°C, and this has never occurred in the 1961-90 base period and only occurred once in the 1991-1920 period.

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Western Australia - Swan Coastal Plain (Gingin)

Using 29°C for 3 consecutive days as the Critical Temperature Threshold for Tomato at the flowering, pollination and fruit set development stage, and the temperature data from Gingin, it would be expected that tomato harvesting will be limited to autumn and spring, as the mid-summer months are warmer than the threshold and the winter months are colder than the threshold.

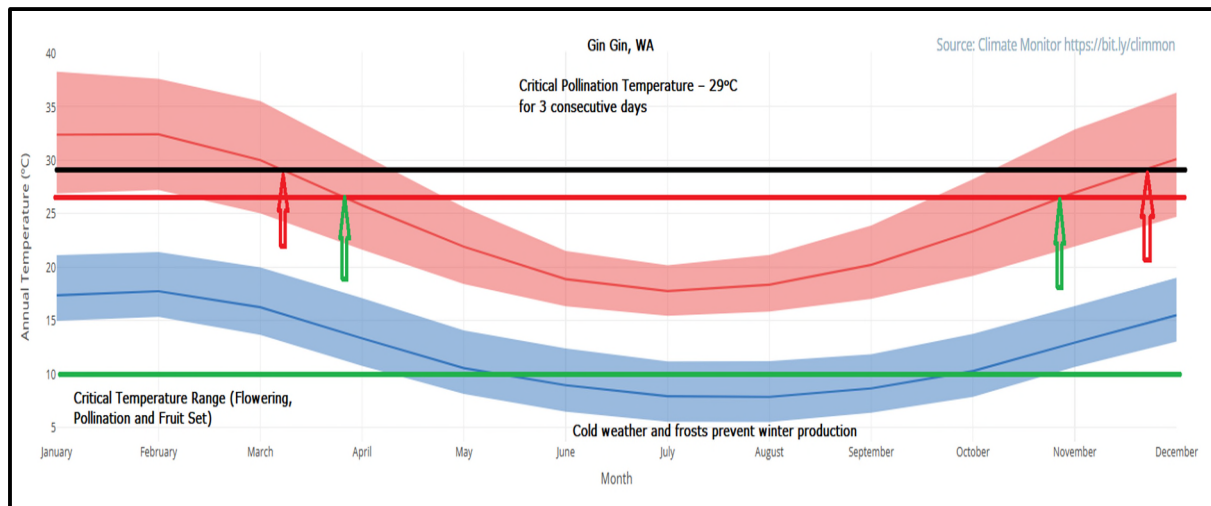


Figure 28. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (green) temperatures and means, with lettuce critical temperatures – overlaid, at Gingin.

Future annual monthly maximum temperature increases will further reduce the growing window for tomato at Gingin. Increased summer maximum temperatures will further shorten the local production season.

Projected future (2016-45) and current climate data for Gingin.

Time Period	Annual Average T Max °C	Annual Average T Min °C	Annual Heat Risk Days T Max ≥ 35°C	Annual Frost Risk Days ≤ 2°C
1961-1990 Past Average	24.5	12.5	26.5	0.7
1991 -2020 Recent Average	25.2	12.7	30.1	1.4
2016-45 High Emissions Future Average	25.8	13.4	35.7	0.7

Table 9. Projected future temperature comparison for Gingin under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](https://climate-monitor.com.au/), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.

Projected Annual Heat Risk shift* (1961 – 90 baseline period), for Tomato production at Gingin, WA.

Year Range	Number of years with annual heat risk below 119 (days Tmax ≥ 27°C)	Number of years with annual heat risk above 151 (days Tmax ≥ 27°C)
1961-1990	4.3 in 10 years	0 in 10 years
1991-2020	1 in 10 years	0.7 in 10 years
2016-2045	0.4 in 10 years	3.3 in 10 years

* This Figure shows the average number of years out of 10, and the number of days in those years, that the Tomato upper Critical Temperature Threshold has, or is, projected to occur. The default **annual heat risk days** (below and above columns shown for **Tomato production at Gingin, WA**), is the 90th percentile (right column – 151 days above 27°C), of the observed 1991-2020 and projected 2016-2045 values.

Figure 29. Gingin annual average Heat Risk shift comparison table.

Data source: Climate Services for agriculture site¹⁴

The high emissions pathway model indicates a temperature shift, showing a 1.3°C increase in maximum temperatures and a 0.9°C increase in minimum temperatures by 2045. The number of days when the maximum temperature in Gingin exceeds 35°C increases from 26 to 36 (Table 9).

Figure 29 above also indicates that by 2045, 3 out of 10 years would have an annual average maximum above 27°C, and this has never occurred in the 1961-90 base period and occurred less than 1 in 10 years in the 1991-1920 period, a significant shift.

¹⁴ <https://climateservicesforag.indraweb.io/>

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP web-tool.

Tomato Critical Temperature Thresholds

Research Team – Peter Deuter, Horticultural Consultant, PLD Horticulture & David Carey, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.



Drought and Climate
Adaptation Program

Annual Heat and Frost Risk, by the year 2045, for Tomato production at various locations in Australia

Growing Location	Current Max Temp °C	Projected Max temp change °C by 2045	Current Min Temp °C	Projected Min temp change °C by 2045	Current number of days ≥ 27°C	Projected number of days ≥27°C by 2045	Current number of frost days	Projected number of frost days by 2045
Bowen (Qld)	28.8	0.8	20.1	0.9	255	284	0	0
Bundaberg (Qld)	27.2	0.9	17.3	0.9	202	227	0	0
Lawes (Qld)	27.3	0.9	13.4	0.9	192	215	7	3
Applethorpe (Qld)	21.2	0.9	9.1	1.0	58	74	57	40
Richmond (NSW)	24.5	0.8	11.6	0.9	116	133	12	6
Shepparton (Vic)	22	0.9	9	0.8	97	109	40	27
Gingin (WA)	25.2	0.6	12.7	0.7	134	145	<1	<1
Virginia (SA)	23.0	0.8	11.5	0.8	97	107	2	<1

Table 10. Annual Heat and Frost Risk, by the year 2045, for Tomato production at various locations in Australia.

The projected future climate data used in this CTT document was sourced from the original (July - Nov 2022) Climate Services for Agriculture website (now My Climate View). The site has undergone several format and projected data period changes in the last 18 months. The data format available and used at the time of writing this CTT document are for the 2045 period.

The historic location specific, high quality climate information use herein, is sourced from [Climate Monitor](#), a free, publicly available DCAP web-tool.



Do your own analysis.

If you are interested in other production locations within Australia, you can evaluate a location yourself.

1. Use Climate Monitor to easily analyse and graph the location of interest.

Access Climate Monitor at

<https://www.longpaddock.qld.gov.au/dcap/horticulture-industry/>

Click on the Go to Climate Monitor button under the picture.

2. Use the Climate Services for Agriculture site to explore the projected temperature, rainfall and evaporation changes.

Access Climate Services for Agriculture at

[My Climate View](#)



Appendix I

<https://www.climatechangeinaustralia.gov.au/en/changing-climate/future-climate-scenarios/greenhouse-gas-scenarios/>

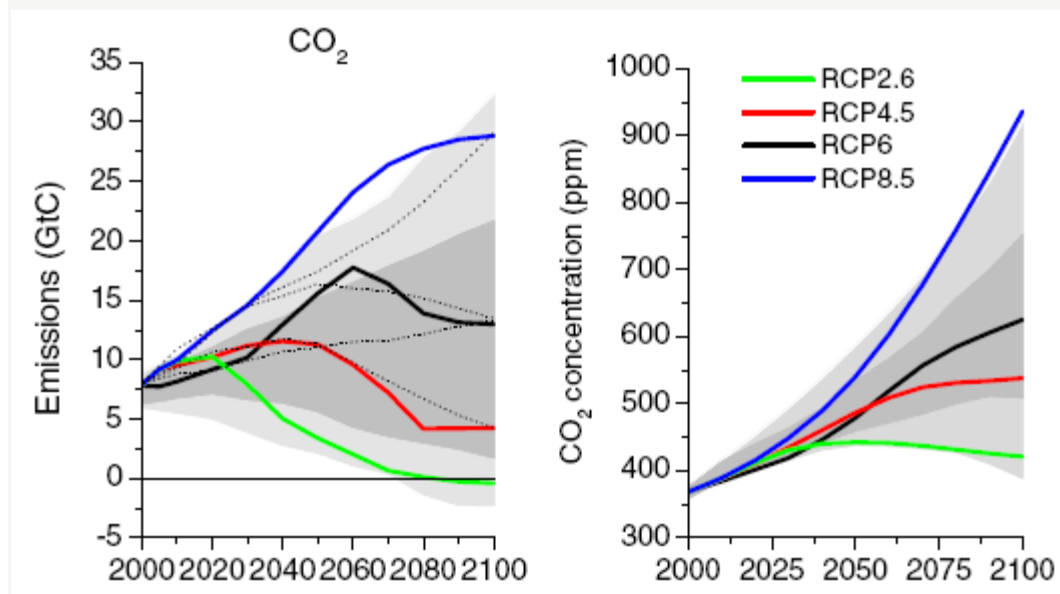
GREENHOUSE GAS SCENARIOS

(REPRESENTATIVE CONCENTRATION PATHWAYS - RCPs)

The future of anthropogenic greenhouse gas and aerosol emissions (and hence their resultant radiative forcing) is highly uncertain, encompassing substantial unknowns in population and economic growth, technological developments and transfer, and political and social changes.

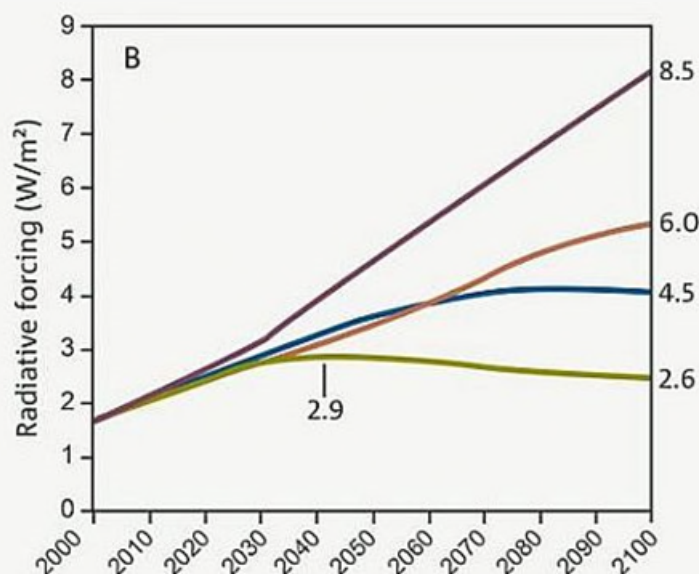
The climate modelling community has developed Representative Concentration Pathways (RCPs) to explore credible future options. The Australian climate change projections found on this site are derived from climate models forced by the RCPs.

These scenarios span the range of plausible global warming scenarios. They provide a range of options for the world's governments and other institutions for decision making.



Emissions of CO₂ across the RCPs (left), and trends in concentrations of carbon dioxide (right). Grey area indicates the 98th and 99th percentiles (light/dark grey) of the values from the literature). The dotted lines indicate four of the SRES marker scenarios.

SOURCE: van Vuuren et.al. (2011)



Radiative forcing for the different RCPs. The numbers on the right show the final radiative forcing at 2100 and give each scenario its name (8.5, 6.0, 4.5 and 2.6 W/m²)

SOURCE: Climate Change in Australia Technical Report

RCPs are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modelling community. The pathways are characterised by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per square metre (W/m²).

The RCPs represent a wider set of futures than the previous emissions scenarios used by climate modelling community (SRES), and now explicitly include the effect of mitigation strategies. As with SRES, no particular scenario is deemed more likely than the others, however, some require major and rapid change to emissions to be achieved.

THERE ARE FOUR RCPS

RCP8.5- a future with little curbing of emissions, with a CO₂ concentration continuing to rapidly rise, reaching 940 ppm by 2100.

RCP6.0– lower emissions, achieved by application of some mitigation strategies and technologies. CO₂ concentration rising less rapidly (than RCP8.5), but still reaching 660 ppm by 2100 and total radiative forcing stabilising shortly after 2100.

RCP4.5- CO₂ concentrations are slightly above those of RCP6.0 until after mid-century, but emissions peak earlier (around 2040), and the CO₂ concentration reaches 540 ppm by 2100.

Tomato **Critical Temperature Thresholds**

Research Team – **Peter Deuter**, Horticultural Consultant, PLD Horticulture & **David Carey**, Senior Horticulturist, Horticulture and Forestry Science, DAF, Qld.



**Drought and Climate
Adaptation Program**

RCP2.6 - the most ambitious mitigation scenario, with emissions peaking early in the century (around 2020), then rapidly declining. Such a pathway would require early participation from all emitters, including developing countries, as well as the application of technologies for actively removing carbon dioxide from the atmosphere. The CO₂ concentration reaches 440 ppm by 2040 then slowly declines to 420 ppm by 2100).



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