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

Capsicum – Critical Temperature Thresholds

Critical Temperature Thresholds (CTT).

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 phases must align with the climate, in order to maximise the potential of good growth, quality and marketable (harvestable) yield.

Introduction

Capsicums (*Capsicum annum*) and chillies, or "peppers", as they are often referred to collectively, are perennial sub-shrubs, native to South America. Commercially, modern capsicums (Bell Peppers) are generally grown as annuals. Capsicums are part of the nightshade family, Solanaceae, and are closely related to tomatoes, potatoes, tobacco and eggplant. The genus *Capsicum* includes all the peppers, from the mildest, large bell type to the hottest habanera. *Capsicum annuum*, the most cultivated species includes the bell type capsicums, (Meurant 1999).
Modern Australian commercial capsicum production is considered a plasticulture system (Lamont 1996). This system, based on plastic mulch for weed control, soil temperature modification, and soil moisture retention, is reliant on frequent soluble fertilizer applications (fertigation) to provide crop nutrition needs. The CTT of capsicum (bell pepper) is the focus of this review.

High temperature causes flower and fruit abscission in many crops. In capsicum, flower abscission (loss) is high if day temperatures are in the range of 32 – 38°C while, fruit retention is maximised when daily temperatures are in the range of 16-21°C (Rylsky 1986). Overnight temperatures (minimums) are also important with warmer nights above 21°C increasing flower abscission, while daily temperatures below 18°C causes the formation of malformed fruit (Aloni et al., 2001). Interestingly Moury et al., (1998) also reported that high temperatures reduce the effectiveness of a gene that confers resistance to tomato spotted wilt virus in capsicum. Continuous high temperatures for at least 9 days can inhibit this resistance in younger plants.

Capsicums (bell or sweet peppers) are grown in most states of Australia. The majority of Australia's capsicum production (53%) occurs in Queensland. Bundaberg, Bowen, & the Granite Belt are the major production regions[1].

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[1] 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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Summary

Changes in temperature affect many crops and these effects can be complex, especially in fruiting species. A wide range of capsicum varieties are grown for both the fresh market and processing in Queensland. Capsicum is very sensitive to adverse weather conditions such as high temperatures and excessive sunlight, which cause flowers and young fruit to drop (abscise) and can result in significant yield loss due to sunburn damage on maturing fruit (Nguyen and Lantzke, 2022). According to Saqib and Akbar Anjum (2021) capsicum (sweet pepper) is considered the 3rd most important crop in Solanaceae family after potato and tomato.

The selection of the appropriate planting window for a specific crop and variety, in the selected production location is very important. The time of planting has a marked effect on crop yield due, to changes in climatic conditions (temperature variations, frequency and amount of wet and dry periods) that strongly correlates with crop phenological phases (Drewniak, et al., 2013; Tsimba, et al., 2013). Climate change has the potential to affect capsicum production through an increase in pollination failures and floral abortion, reduced fruit size and quality under higher temperature, increased incidence of physiological disorders (sun scald and blossom end rot), and increased risk of soil borne diseases (leaf blight and fruit rot) according to Srikanth, et al., (2019).

Capsicum has five distinct growth phases, germination, vegetative development (juvenile), flowering, pollination, fruiting and ripening. A warm-season crop, capsicum is sensitive to freezing temperatures at any growth stage (Hartz, et al., 2008).

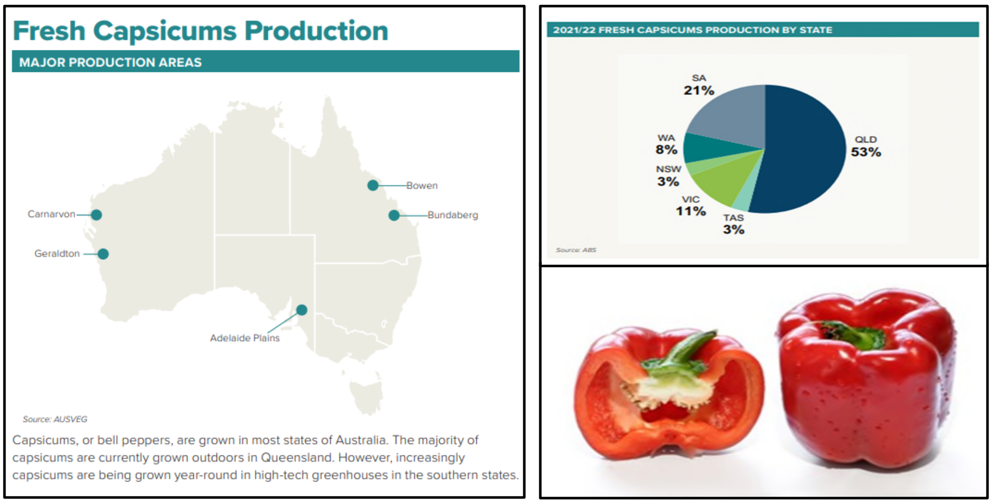

Figure 1. Major capsicum field production locations in Australian and contribution to national crop.

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Critical Temperatures and Development Phases.

Hartz et al., (2008) from the University of California indicates that bell pepper (capsicum, sweet pepper), prefer day temperatures ranging from, 24 – 30°C and night temperatures from 9 – 12°C. Rylski (1973) in detailed studies investigating the effect of night temperatures (minimums) on capsicum fruit shape and size, determined that the fruit of capsicum produced the highest length/diameter ratio when low minimum (night) temperatures (8 to 10°C) occurred during fruit development. Hartz (2008) states that although capsicum can tolerate temperatures of 38°C, these conditions affect pollination, fruit set and yield. This research is complemented by results from Aloni et al., (1990), who determined that capsicum flower loss is high if day temperatures are in the range of 32 – 38°C, while fruit retention is maximised at 16 – 21°C day temperatures (Rhylski, 1986). Saha et al., (2010) assessed the heat tolerance of 12 sweet pepper varieties and found high temperature reduced both fruit set and fruit size. These researchers documented differing heat tolerances in these 12 varieties. They state that sweet pepper (capsicum) yield is usually retarded when the temperature exceeds 32°C.

Queensland research carried out over 3 years demonstrated that commercial capsicum crops grown in the Lockyer Valley's summer season could suffer severe sunburn damage and (25 – 40%) yield loss when summer maximum temperatures became extreme (Carey et al., 2016)[2].

Capsicum growth phases.

Capsicum has five distinct growth phases, germination, vegetative development (juvenile), flowering, pollination, fruiting and ripening. A warm-season crop, capsicum plants are sensitive to freezing temperatures at any growth stage (Hartz, et al., 2008)

Sexual reproduction processes in plants are more sensitive to high temperatures than vegetative processes, with plant reproductive organs more vulnerable to short episodes of high temperatures before, and during the flowering stage. Fruit set in capsicum, according to many researchers, including Erickson and Markhart (2002), is sensitive to high temperatures. Flower and young fruit, drops (flower and fruit abortion) are common in capsicums (Rathinasabapathi 2020).

Germination phase.

Maynard & Hochmuth (2006) recommend capsicum seed be germinated at temperatures between 20° C and 30° C. Bierhuizen & Wagenvoort, (1974), determined that capsicum seed germinates best at temperatures between 15 & 25°C. While Hartman (1988) states that pepper is a warm climate crop and requires 25-27°C for optimum seed germination and emergence. Californian research by Hartz and Cantwell determined that the rate of seed germination decreases rapidly below (25°C),

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[2] https://www.horticulture.com.au/globalassets/laserfiche/assets/project-reports/vg12103/vg12103-final-report.pdf

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with germination below (20°C) exceedingly slow. Due to the high seed cost of modern hybrids, nearly all Australian capsicum crops are transplanted in the field. Capsicum transplants are commonly grown by commercial nurseries under controlled temperature conditions, maximising seed germination, plant growth and transplant uniformity.

> The optimal temperature for seed germination is > 25°C & < 27°C
> **The Critical Temperature Threshold for seed germination is > 15°C & < 30°C**

Juvenile phase – critical temperatures.

Once capsicum seed has germinated, the young seedling enters the vegetative (juvenile) phase. According to Kratky and Bowen in the text edited by Plunknett (1989), capsicums are very sensitive to temperature and are considered a warm weather crop, even more so than tomatoes. Capsicums grow very poorly at temperatures below 13°C, and a light frost will kill plants. Many cultivars require 65 to 80 days after transplanting to reach maturity.

Vegetative growth and development of capsicum mainly depends on the 24 hour mean temperature, while the effect of the day/night amplitude is of minor importance according to Bakker and van Uffelen, (1988).

The optimal temperature for growth and plant development is between 20 – 25°C, according to Saha et al., (2010), while Bakker (1989) identified the optimum temperature for vegetative growth to be between 21 – 23° C. Californian information from Hartz & Cantwell (2008) indicates that day temperatures of 24° to 30°C with night temperatures about 9° to 12°C are ideal for capsicum growth and development.

> The optimal temperature for vegetative growth is > 20°C & < 25°C
> **The Critical Temperature Threshold for vegetative growth is > 10°C & < 31°C**

Flowering and pollination – critical temperatures.

Sexual reproduction in plants is more sensitive to high temperatures than vegetative processes, and therefore plant reproductive organs will be more vulnerable to changes in temperature, especially high temperatures prior to and during the early flowering and fruit set stage. Being a tropical plant, capsicums are frost sensitive, so it is not surprising that low night temperatures (14 °C or lower) have negative influences on both pollen viability, and number as well as the functioning of female organs of the flower (Pressman et al. 1998; Cruz-Huerta et al., 2011).
Reddy and Kakani (2006), state that successful fruit set depends on several reproductive processes including pollen germination and successful pollen tube growth. This over-arching observation is backed up by numerous researchers across many flowering crops, Erickson and Markhart (2002)

investigated capsicum, Porch and Jahn (2001) investigated green beans, while Herrero and Johnson (1980) investigated and identified this same issue in corn (maize).

Minnesota based researchers, Erickson and Markhart (2002) found that flowering stage capsicum plants, exposed to 33°C continued to produce flowers but these same flowers dropped (abscised) after opening, greatly reducing fruit set.
Temperatures >32°C are known to reduce pollen germination, pollen tube growth and fruit set in peppers (Aloni et al., 2001; Erickson and Markhart, 2002). Furthermore, Erickson and Markhart (2002) went on to state that capsicum plants that had experienced temperatures of 33°C for 48 hours or more when the flower buds were opening (anthesis), had reduced fruit set. These authors also documented and identified poor pollen viability when young flower buds (2.5mm in length) were exposed to 33°C for 120 hours.

Aloni (2001) found that the number of seeds per capsicum fruit was reduced by approximately 66% when plants were exposed to 32°C day, and 26°C night temperatures for 8 days compared to plants grown at 28°C day and 22°C night temperatures. Rylski (1986), like many other researchers, reported a high correlation between fruit size and seed number, i.e., capsicum plants exposed to temperatures outside the optimum range during the flower pollination phase had fewer seeds and smaller fruit size. Bakker and van Uffelen (1988), identified that an unbalanced leaf-to-fruit ratio (low leaf number) reduced mean fruit weight, underlining the critical role temperature plays in capsicum's vegetative growth, flowering and fruit development. Cochran (1932) reported that high temperature and low humidity during flowering increase the transpiration pull within the plant, resulting in the abscission of flower buds and small fruits. Mends-Cole et al. (2019) reported that high temperatures caused flower drop, reduced fruit set and caused lower yields in several chilli and capsicum varieties. Erickson & Markhart, (2002) specifically examined flower development and organ sensitivity in capsicum and concluded that the duration of high-temperature exposure and the developmental stages of flowers exposed, are important factors in fruit set success, and should be considered when examining the effects of heat stress on fruit set, and the potential of global warming to reduce crop productivity.
Tothne et al., (2010) determined that night air temperature is considered more important than day temperature for better capsicum production, stating that flowers drop and do not set fruit when night air temperature exceeds 32°C.

In their 2021 paper examining the impact of climate change on capsicum production, Pakistani researchers Saquib and Anjum state that pollen fertilization is severely reduced below 15 °C and above 32°C due to poor pollen development.

The optimal temperatures for flowering and pollination are nightly minimums of 17°C - 21°C & daily maximums of 28°C.

The Critical Temperature Threshold for flowering and pollination is > 15°C & < 28°C

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Fruit development & ripening– critical temperatures.

Most commercial capsicum varieties harvest over 6 – 8 weeks, with 3 – 4 picks occurring as the fruit matures.

Capsicums grow best between 21 and 24°C according to Berke et al (2003). The authors reviewing capsicum production in the lowlands of Taiwan state that when temperatures fall below 18°C or exceed 27°C for extended periods, growth and yield are usually decreased. Capsicums can tolerate daytime temperatures over 30°C, if night temperatures are between 21 and 24°C, according to these same researchers. The impact of high temperatures is also identified by Erickson and Markhart (2001), who state that high day and night temperatures negatively affect vegetative growth, flowering, fruit set and yield of capsicum. The authors state that capsicum is more sensitive to high temperatures and will set less fruit at high night temperatures compared to hot pepper (chilli). Rajametov et al., (2021) determined that the optimum temperature for vegetative growth and fruit development of capsicum crops is proximately 20–25°C.

Srikanth et al., (2019) determined that capsicum plants require 25°C day and 18°C night temperature for higher yield, fruit weight, length, girth, number of fruits per plant and pericarp (fruit wall) thickness. Rathinasabapathi (2020) determined that in capsicum, a fleshy pericarp (3 mm to 6 mm thickness) is preferred by consumers. Rylski (1973), in detailed studies investigating the effect of night temperatures (minimums) on capsicum fruit shape and size, determined that the fruit of capsicum produced the highest length/diameter ratio when low minimum (night) temperatures (8 to 10°C) occurred during fruit development. While Hartz et al., (2008) from the University of California determined that capsicum, prefers day temperatures ranging from, 24 – 30°C and night temperatures from 9 – 12°C.

Yanez-Lopez et al., (2012) showed that capsicums grown under high temperatures (33°C) produced less fruit. This agrees with work by Erickson and Markhart (2001), who concluded that although capsicum is a warm-season crop, yield is **severely** reduced in hot summers when the temperature exceeds 35°C.

The optimal temperature for fruit development and ripening is > 10°C & < 30°C

The Critical Temperature Threshold for fruit development and ripening is > 10°C & < 31°C.

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Future climate implications – crop performance and yield.

A diverse range of commercial capsicum varieties are available to Australian growers. These varieties are grouped according to their fruit characteristics and suitability to a geographic production location and timeslot. Variety selection can also vary depending upon the production system being used, either field grown or one of the more expensive protected cropping systems. Protective cropping is more likely to occur in cooler southern Australian locations where field production is not viable.

Australia's climate is warming (see below), meaning that some current summer capsicum production locations and production timeslots will change or become commercially non-viable. The number of capsicum growers in the Lockyer Valley has declined greatly in the last ten years. Higher summer maximum temperatures can cause huge yield loss (up to 40%) due to fruit abortion and sunburn, especially in the hotter, El Niño years. Most of this Lockyer Valley summer capsicum production capacity (volume) has moved to the cooler (higher altitude) Granite Belt region over the last 10 years. This ongoing warming trend, could see the Granite Belt capsicum production window lengthen as early autumn minimum temperatures stay warmer for longer and spring temperatures become warmer, sooner.

Producers must continue to adapt to these changes, revising their production location, varieties and timing in response to their ongoing seasonal experiences.

Plant breeders may be able to develop and introduce new, more heat-resistant varieties, although this option appears limited (non-existent) in the case of summer capsicum production, e.g., in the Lockyer Valley. The genetic diversity and breeding potential of capsicum to adapt further, it seems, has been reached. Chillies can tolerate the extreme summer heat of El Niño years better, so growers may need to adapt, as the capsicum plant cannot. Taking this thought a little further, while capsicum growers could grow a "similar" alternate crop – chilli, in this case, consumer demand, picking and packing costs, as well as product use patterns are very different.

Consumer demand drives product supply, and modern consumers have no tolerance for blemished produce. Capsicum fruit quality will determine consumers buying patterns, and locations that produce lower-quality produce will inevitably see production decline.

Locations or months previously deemed non-viable due to maximum or minimum temperature constraints may become commercially viable. For example, the capsicum production season in the Granite Belt region (currently very late spring (November), summer and early autumn), could extend further into the autumn and begin earlier in the spring, extending the production window, as minimum temperatures rise.

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Queensland is already experiencing the impacts of climate change:

The Climate Change in Australia website, CSIRO and Bureau of Meteorology, Climate Change in Australia website (http://www.climatechangeinaustralia.gov.au/, cited [January 2023]) contains the following statements[3]. All of Queensland has warmed since 1910.

The 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 – 2.5ºC), so they smooth out the usual fluctuations in daily, weekly and monthly temperature at any location. The State of the Climate 2022 Report [4], Future Climate section states, "new research in Australia and around the world, together with the IPCC's Sixth Assessment Report, enhance 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."

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

Capsicum -Critical Temperatures Thresholds (from published research).

	Critical Temperature ⁰C	
Growth Stage	**Lower**	**Upper**
Juvenile (vegetative)	>10	<31
Flowering & pollination	>15	< 28
Fruit development & ripening	>10	<31

It is important to realise that to achieve a mean monthly maximum of 30ºC (for example), there will be a spread of cooler and hotter days. In a biological system, plant stress caused by several days in

[3] https://www.climatechangeinaustralia.gov.au/en/changing-climate/state-climate-statements/queensland/.

[4] https://www.csiro.au/en/research/environmental-impacts/climate-change/State-of-the-Climate

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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^{o}C for 3 days and applied this to each crops' threshold. So, for capsicum at the fruit development and ripening stage, the literature indicates the Critical Temperature Threshold is 31^{o}C mean maximum temperature. To simulate the effects of high temperatures, we have chosen **33^{o}C for 3 consecutive days as the Critical Temperature Threshold** for the **Fruit development & ripening** stage.

Commodity production data.

Australia produced around $211.8 million worth of capsicum in 2021-22. Capsicums, or bell (sweet) peppers, are grown in most states of Australia. The majority of capsicums are currently field grown, outdoors in Queensland. However, increasingly capsicums are being grown year-round in high-tech, high-cost greenhouses in the southern states. In 2021-22 Queensland produced 53% of the national crop, with South Australia the next largest producing state selling 21 % of the total national crop. Capsicum production in Australia occurs in three distinct farming systems, and their contributions to production are Field grown 67%, Glasshouse 22%, Polyhouses & Tunnels 11% [5].

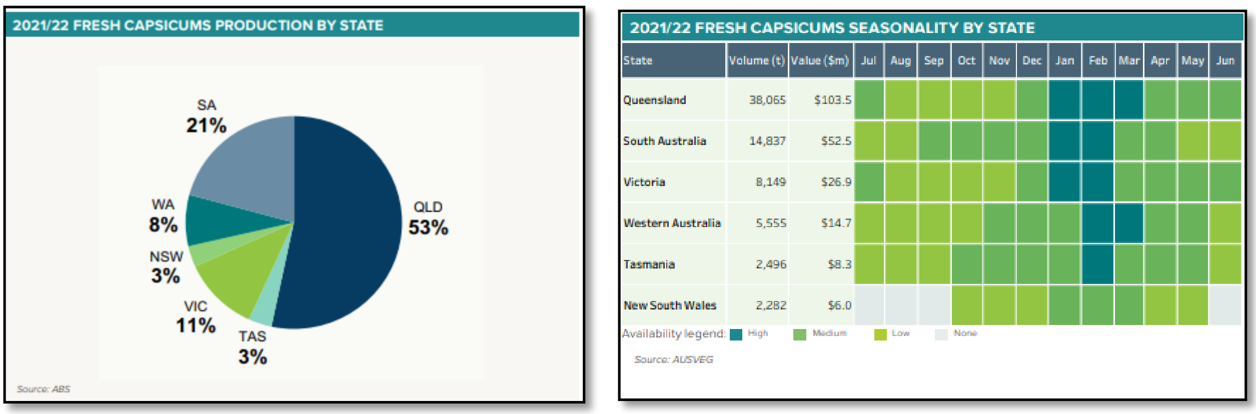

Figure 2. Fresh capsicum production in each state and corresponding seasonal availability (Source: web reference above).

[5] https://www.horticulture.com.au/globalassets/hort-innovation/australian-horticulture-statistics-handbook/ahsh-2021-22-vegetables-r.pdf

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

I. Queensland

a) Gatton, Lockyer Valley, Southeast Queensland (summer and autumn crops).

Local specialist growers traditionally plant an early spring and a late summer crop, harvesting fruit in early summer and again in autumn.

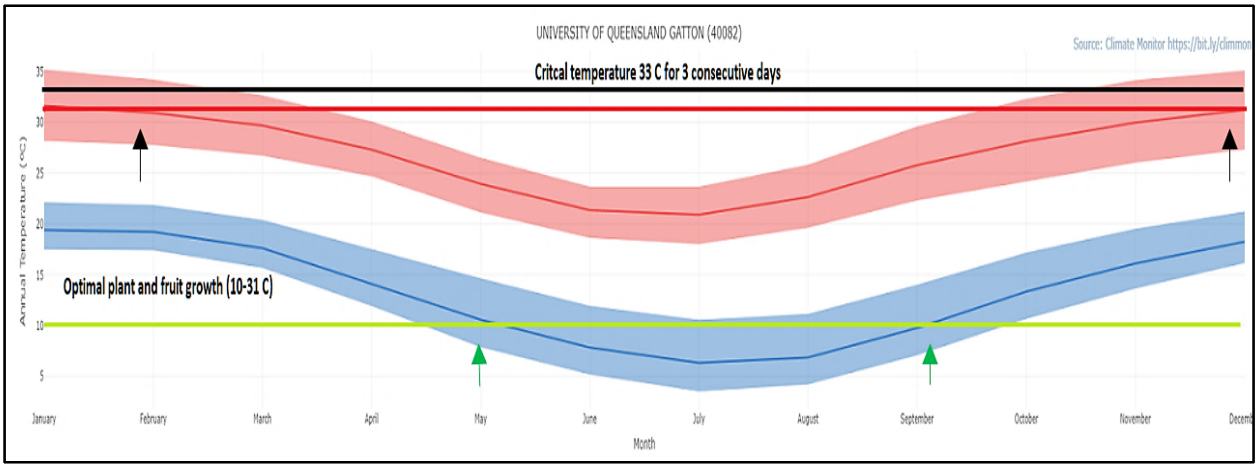

Figure 3. Monthly historical maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), at Gatton, with capsicum critical temperatures – overlaid. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

** Climate Monitor is a Web-based Tool that allows the user to analyse and graph minimum and maximum temperature and rainfall for all available years, calculate the thermal time (chill and heat units) and be able to retrieve, analyse and graph temperature thresholds (for a chosen location).

Capsicum production in the Lockyer Valley historically consists of two distinct production seasons (transplant to harvest) each year. The summer season begins with transplanting in September, with mature fruit harvested to the end of December when the mean monthly maximum temperature at Gatton reaches 31°C[6].

Summer capsicum prices are usually higher due to increased consumer demand in the warmer weather, so although crop yields may be reduced by heat, fruit sunburn and summer storms, local Lockyer Valley producers historically targeted this potential high return production period. Recent years, particularly during and since the Millennium Drought have seen the Lockyer Valley experience extreme summer temperatures, often over consecutive days (and nights).

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[6] http://www.bom.gov.au/climate/averages/tables/cw_040082_All.shtml.

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These conditions made summer capsicum production extremely difficult as fruit set was reduced and more importantly fruit sunburn caused up to 45% loss of maturing fruit (B. Fisher, S. Alush (commercial growers) pers comm).

High maximum temperatures (>31° C) during the fruit development and ripening stage of capsicum production reduce fruit number, quality (fruit colour and fruit wall thickness), as well as size. In hotter years, when late spring and early summer temperatures rise quickly above the historic "norm", yield, fruit quality and consequent demand drop. Prices for local product plumets as wholesalers and chain stores source better quality produce from alternate (cooler) locations. This exact scenario has resulted in a shift to more summer capsicum production occurring in the higher altitude and cooler Granite Belt production region in the last 10 – 15 years.

Using the unique weather data analysis capability of Climate Monitor, producers can easily review historical temperatures at any location in Australia. It is important to realise that to achieve a mean monthly maximum above 31°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 tip the system into decline. An analysis of the number of times a maximum temperature of 33°C has occurred for 3 consecutive days in spring (Sept to November) in Gatton is displayed below. The years (2009, 2015 & 2019) with hotter springs caused a decline in capsicum quality, significant fruit sunburn, crop downgrades and yield loss.

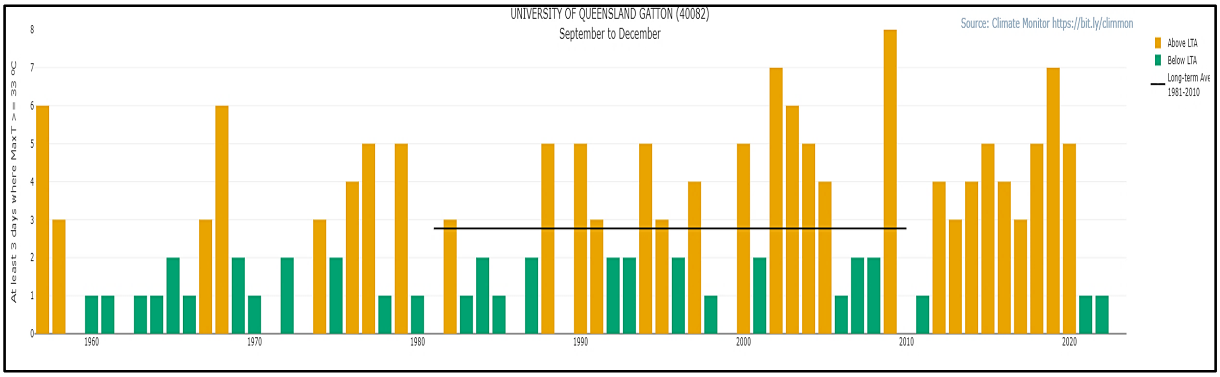

Figure 4. Climate Monitor analysis showing the <u>number of times each year</u> and season (September – December) that Gatton has experienced at least 3 consecutive days that were 33°C or above.

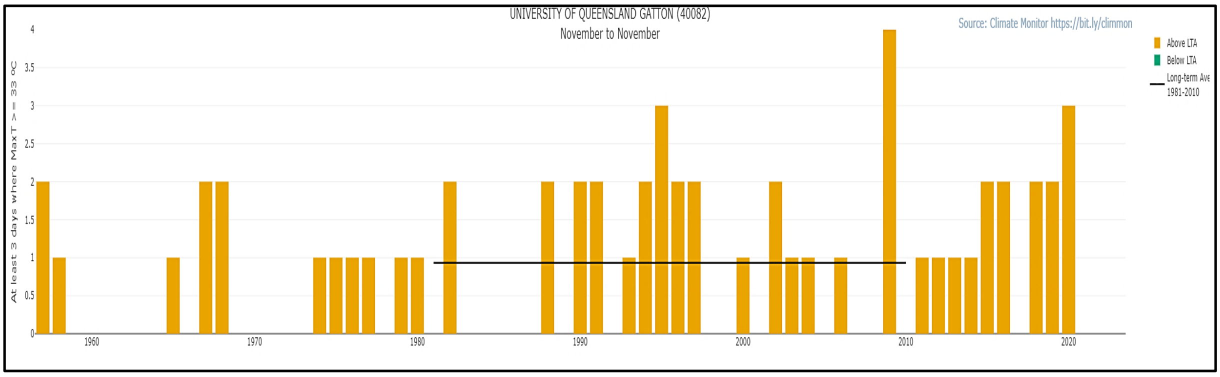

Figure 5. Climate Monitor analysis showing the number of times in each year that Gatton has experienced at least 3 consecutive days that were 33°C or above in November. The capsicum summer season starts to end as the Lockyer Valley as summer temperatures begin to exceed the CTT.

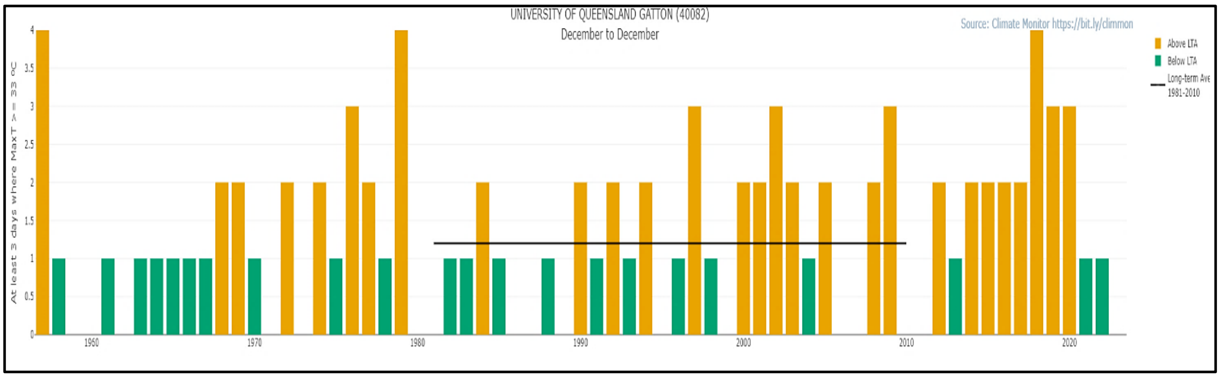

Figure 6. Climate Monitor analysis showing the number of times in each year that Gatton has experienced at least 3 consecutive days that were 33°C or above in December. Excessive high temperatures in mid – December reduce both yield and quality, bringing an end to the season.

The Lockyer Valley autumn capsicum season begins with the transplanting of young vegetative plants into the late January or early February summer heat, which results in mature fruit harvesting in March, April and into early May.

The autumn season plantings grow, develop and flower as maximum daily temperatures begin to cool and become more moderate. Flower retention on the plant and subsequent fruit set and yield are higher in the autumn crop as the more temperature sensitive reproductive stages of plant growth (flowering, pollination, and fruit set) occur as cooler autumn temperatures prevail, refer Figure 7 below.

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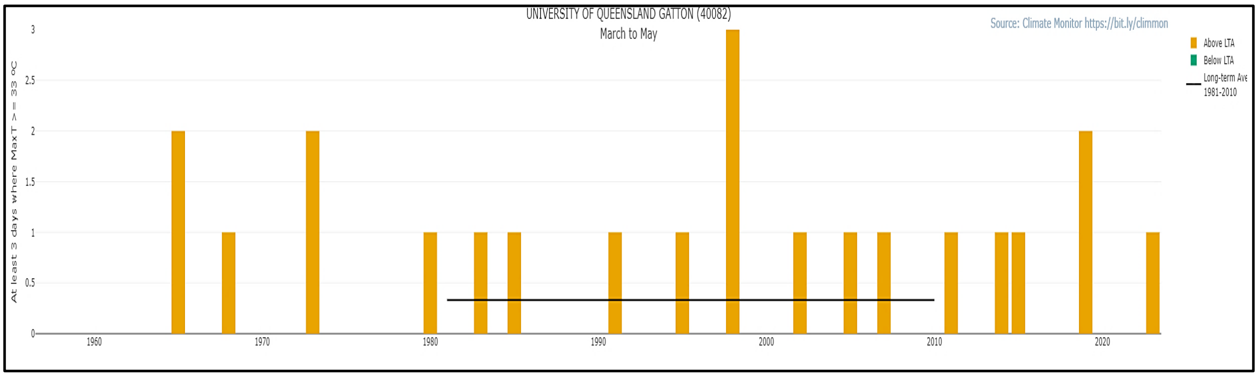

Figure 7. Climate Monitor analysis showing the number of times each year and season (March – May) that Gatton has experienced at least 3 consecutive days that were 33°C or above.

Mean monthly minimum temperatures at Gatton do not drop below Capsicums lower CTT (10°C) until May as shown in Figure 3. These lower minimum temperatures slow fruit growth rates, however, the warm sunny autumn days and mean monthly maximum in late autumn allow the existing fruit to mature and fill out through late May and into June (Figure 3).

Consumer demand is lower in this cooler part of the year, while marketable fruit yields are higher, due to the milder daily maximum temperatures. This results in lower prices for autumn harvested fruit in most years, when compared to summer prices. In addition, the expansion of high-cost protective cropping production systems growing capsicums in the cooler southern states has resulted in additional fruit supply throughout the year, increasing national capsicum supply, changing the supply pattern, and putting downward pressure on prices over the last decade.

b) Granite Belt, Southern Queensland (summer production).

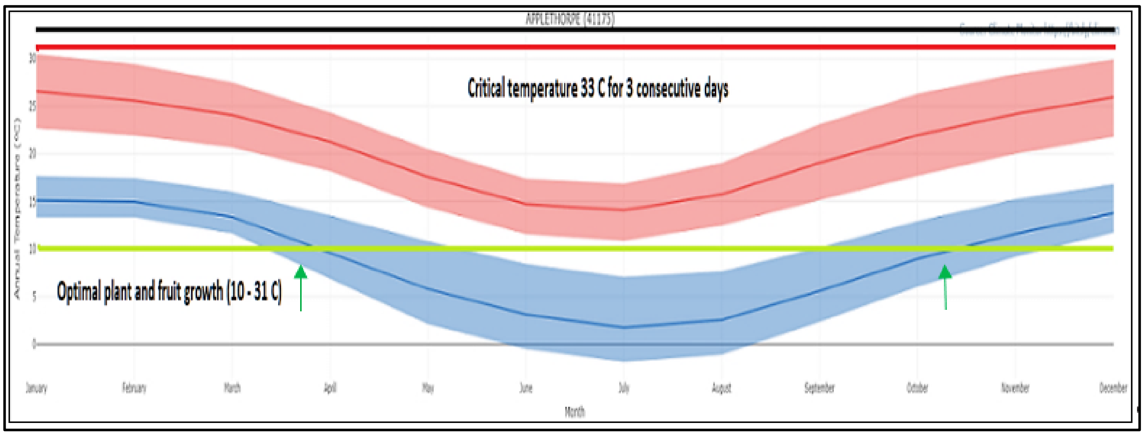

Figure 8. Climate Monitor analysis showing the annual historic monthly maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with capsicum critical temperatures – overlaid, at Applethorpe on the Granite Belt. Note: The graph shows the 10th to 90th 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.

Using 10 and 31^{0}C as the critical temperature thresholds for marketable capsicum fruit production and the annual temperature data from Applethorpe, Qld (above) it would be expected that capsicum transplanting would occur in September and fruit harvest would end in early May as the minimum CTT is reached and the corresponding daytime mean monthly maximum temperature falls, dramatically reducing the mature plants ability to “fill out”, (finish off) any undersize mature fruit left on the plant. This reflects reality. It must be remembered that varietal differences also play an important part in production time slots, for example Granite Belt growers use a variety that produces slightly larger fruit and is more adapted to cooler temperatures, compared to the variety grown in summer in the Lockyer Valley. This allows the Granite Belt growers to start planting at slightly cooler spring temperatures and harvest for longer into the cooling autumn. In the Granite Belt summer, the capsicum plants upper CTT (mean monthly maximum temperature) is not currently reached, and this allows high quality fruit production to occur throughout summer.

This is in stark contrast to the situation in summer in the Lockyer Valley where, maximum temperatures that exceed the plants upper CTT, halt production. This explains why production of high-quality capsicum fruit in the Granite Belt in summer has evolved over the last decade to supply, peak summer demand.

Cold late Autumn temperatures see capsicum production in the Granite Belt cease as fruit number, size, and quality drop in this high-altitude, cool climate.

The Granite Belt is well known as a summer capsicum production area, and using the analysis power of Climate Monitor, growers can easily review historical temperatures at their production location (Figure 9). Maximum Critical Temperature Thresholds are not reached or exceeded at present, though minimum temperature thresholds already determine the viable production season for capsicums in the Granite Belt. As a result of correct variety choice (locals have identified and use a variety that is slightly more tolerant of cooler temperatures) Granite Belt growers have slightly extended their growing season beyond the internationally accepted and published minimum monthly CTT. This extends their “production window” by several weeks.

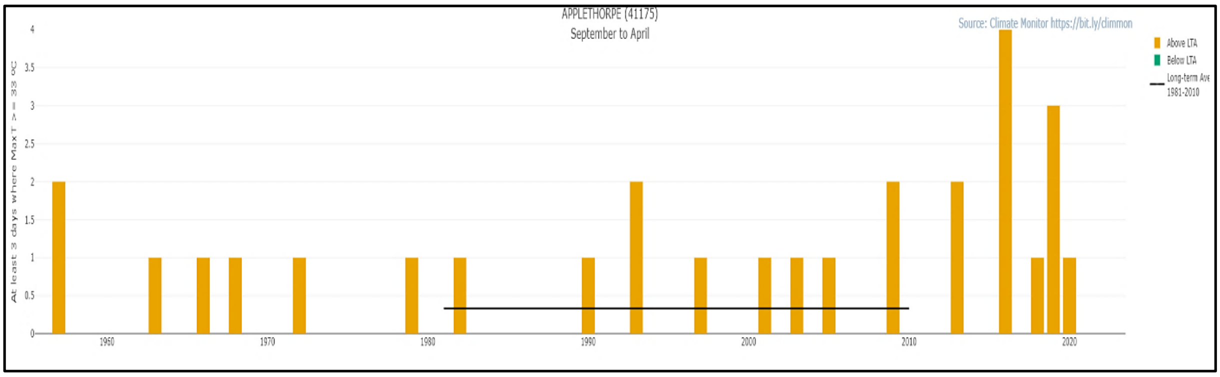

Figure 9. The number of times in all years to-date (Sept – April) at Applethorpe when 3 consecutive days or more have reached or exceeded 33ºC.

Future temperature insight.

As underlying temperatures continue to rise, and extreme heat days become more frequent [7], it is likely that the Granite Belt production window will lengthen with rising minimum temperatures, while the Lockyer Valley’s season will shorten as late spring maximums continue to rise and early autumn temperatures remain high for longer.

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 production locations.

[7] 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.

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

a) Lockyer Valley (Gatton)

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

Figure 10. Projected future temperature outlook for Gatton under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1991 – 2020 for comparison of the 2016 to 2045 average temperature shift.

The high emissions pathway model indicates a temperature shift, showing a 1.7°C annual increase in maximum temperatures and a 1.3°C annual increase in minimum temperatures by 2045 at Gatton. Importantly the number of days when the maximum temperature in Gatton exceeds 35°C increases from 20 to 27 (Figure 10).

Year Range	Number of years with annual heat risk below 27 (days Tmax ≥ 33°C)	Number of years with annual heat risk above 63 (days Tmax ≥ 33°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	0.3 in 10 years	4.3 in 10 years

Projected annual crop specific upper CTT heat risk shift (1961 – 90 baseline period).

** This chart shows the average number of years out of 10 and the number of days in those years that **the crop specific upper CTT** has or is projected to occur. The default annual heat risk days (below and above columns) shown for this location and crop, are the 10th percentile (left column) and 90th percentile (right column) of the observed 1991-2020 and projected 2016-2045 values.*

Figure 11. Gatton annual heat risk shift comparison table for capsicum crop upper CTT of 33 C.

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.

Data source: Climate Services for agriculture site:https://myclimateview.com.au/

Figure 11 above indicates that by 2045, 43 % of years (4.3 in 10) will have at least 63 days when the maximum temperature is 33°C (capsicums upper CTT), or above and this has never occurred in the 1961-91 base period and only occurred in 7% of years in the once in the 1991-2020 period, a significant shift.

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

Maximum temperatures currently prevent capsicum planting and production in the Lockyer Valley during the peak of summer. Excessive heat in late December, January and into February exceed the crops maximum CTT. Higher daily maximum temperatures that will occur throughout February and persist for longer into March in the Lockyer Valley autumn in the years leading up to 2045, will delay both transplanting and fruiting. This will alter the current capsicum production window. The transplanting date for the autumn harvested crop will be delayed by about 4 weeks from late February until early March (Figure 12). The hotter January and February maximum (daytime) temperatures will make it more difficult to establish young transplants due to both the higher daily maximums and warmer nights (minimums). The warmer minimum (night) temperatures that result from the increased annual minimum temperatures will see the autumn crops harvest window lengthen by about a month, as both day and night temperatures rise. The autumn cropping season will move deeper into the late autumn and early winter months.

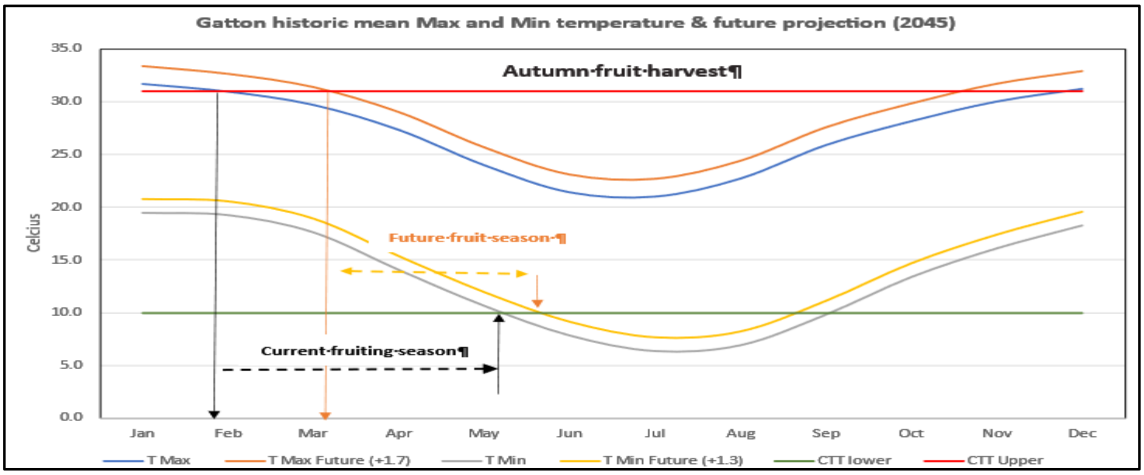

Figure 12. Current mean monthly temperatures at Gatton, capsicum upper (31° C) and lower (10° C) CTT & the impact of future temperatures on the autumn crop growing season. High summer temperatures will persist throughout February pushing the transplant date back from February into March. Minimum temperatures will stay warmer for longer, with the season extending into June.

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.

The Lockyer Valley capsicum summer crop is traditionally transplanted in early spring (September) and harvested in late November and through December. In the years leading up to 2045 this cropping window will be shortened. Higher minimum temperatures at the beginning of the spring could allow transplanting 2 weeks earlier in mid-August, instead of September. However, higher maximum temperatures (above CTT) will occur about 4 weeks earlier in the summer harvest window. This effectively shortens the growing season by 2 weeks and increases the likelihood of poor fruit set, increased heat damage and increased fruit loss to sunburn as fruit matures into the extreme summer heat. This is likely to make the shortened, already difficult, summer fruit production slot uneconomic. This would see an end to the traditional Lockyer Valley summer harvest capsicum season.

The temperature data in Figure 12-A, below shows how and why this shift will severely shorten the Lockyer Valley summer (spring planted) capsicum cropping season. Maturing, fruit bearing capsicum plants will experience maximum temperatures that exceed the capsicum plants CCT, a month earlier than the current "norm". Though warmer minimums in late winter will allow transplanting to occur around 2 weeks earlier, due to less chance of frost, increased November maximum temperatures will greatly reduce potential plant yield. Overall, the summer cropping season is likely to be 3-4 weeks shorter, and not economically viable.

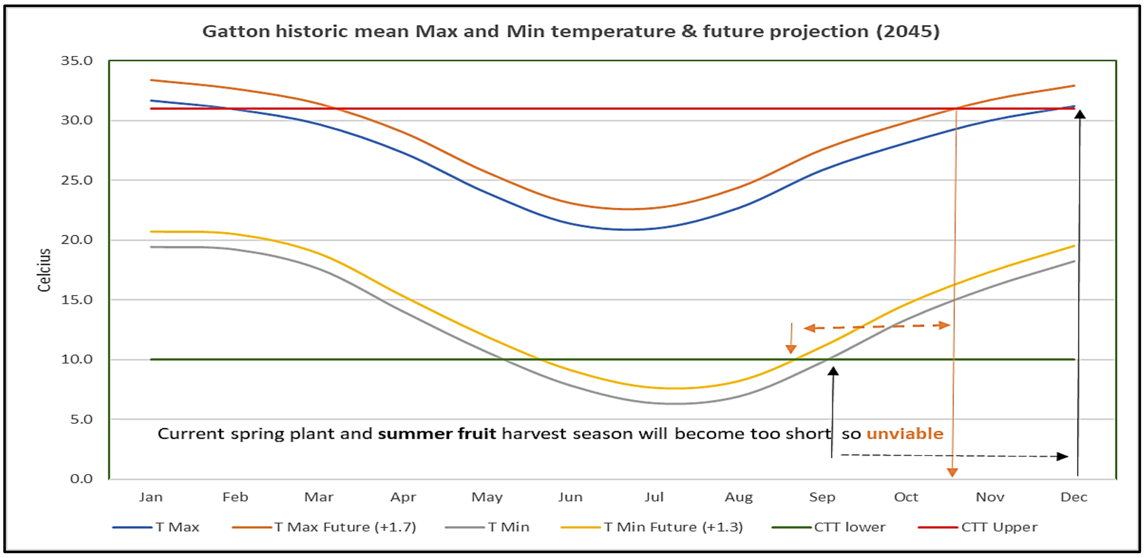

Figure 12-A. Current mean monthly temperatures at Gatton, capsicum upper (31º C) and lower (10º C) CTT & the impact of future temperatures on the summer & autumn growing season. High summer temperatures will persist throughout February and into March pushing the transplant date back by around 4 weeks. Maximum temperatures will stay warmer for longer and the shortened season will greatly reduce marketable yield and crop viability.

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.

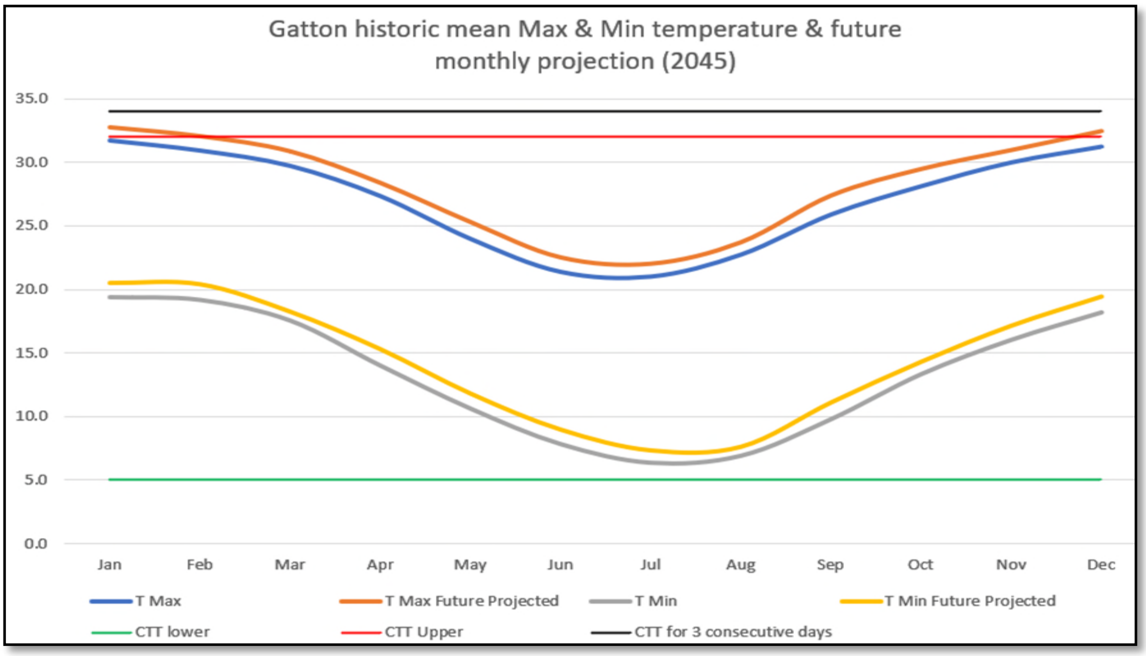

Figure 13.Current mean monthly temperatures at Gatton, capsicums upper CTT (31º C) & the impact of projected future mean monthly temperature shifts (2016-2045) on the optimum growing season. (Note, the monthly future climate data displayed here is not publicly available but reflects the individual monthly changes that underpin the projected annual changes in maximum and minimum temperatures).

Minimum temperatures will increase as shown in Figure 10 and Figure 12 above, allowing the autumn capsicum crop harvest window to extend further into early winter. The projected warmer minimums will help increase plant growth rates, potentially shortening the time between planting and fruit harvest in the autumn harvest crop.

Figure 13 above displays the mean monthly temperatures at Gatton, & the projected future mean monthly temperature shifts (2016-2045) at Gatton. The monthly future climate data displayed here is not publicly available but displays the projected individual monthly changes that underpin the projected annual changes in both maximum and minimum temperatures. The monthly projected change data has been included here, so the reader can appreciate and better understand the actual monthly changes that underpin the publicly available projected annual changes (2016-45).

Projected maximum temperature changes will exacerbate the already challenging impacts of high temperature on the early summer capsicum crop. The projected 1.7ºC increase in the annual maximum temperature at Gatton will shorten this traditional production slot by at least 2 weeks. This combined with the increased likelihood of lower yield, smaller fruit and more fruit loss to sunburn could well see the demise of summer grown capsicum crops in the Lockyer Valley.

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.

b) Granite Belt, Stanthorpe (Applethorpe)

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

Annual average Tmax	Annual average Tmin	Annual heat risk	Annual frost risk
Annual	Annual	Annual	Annual
°C	°C	days Tmax ≥ 35°C	days Tmin ≤ 2°C
		Edit	Edit
1961 - 1990 Past average **20.3**	1961 - 1990 Past average **8.8**	1961 - 1990 Past average **0.5**	1961 - 1990 Past average **57.2**
1991 - 2020 Recent average **21.2**	1991 - 2020 Recent average **9.1**	1991 - 2020 Recent average **1.2**	1991 - 2020 Recent average **53.3**
High emissions 2016 - 2045 Future average **22.1** 21.7 - 22.4	High emissions 2016 - 2045 Future average **10.1** 9.9 - 10.5	High emissions 2016 - 2045 Future average **1.8** 1.4 - 2.4	High emissions 2016 - 2045 Future average **39.7** 34.9 - 43.9
View charts →	View charts →	View charts →	View charts →

Data source: Climate Services for agriculture site: https://myclimateview.com.au/

Figure 14.. Projected future temperature outlook for Applethorpe under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020). The graphic uses 1991 – 2020 for comparison of the 2016 to 2045 average temperature shift.

Projected annual crop specific upper CTT heat risk shift (1961 – 90 baseline period).

Year Range	Number of years with annual heat risk below 1 (days Tmax ≥ 33°C)	Number of years with annual heat risk above 14 (days Tmax ≥ 33°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	0.9 in 10 years	1.7 in 10 years

** This chart shows the average number of years out of 10 and the number of days in those years that **the crop specific upper CTT** has or is projected to occur. The default annual heat risk days (below and above columns) shown for this location and crop, are the 10th percentile (left column) and 90th percentile (right column) of the observed 1991-2020 and projected 2016-2045 values.*

Figure 15. Applethorpe annual heat risk shift comparison table for capsicum crop upper CTT of 33 C.

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.

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

Drought and Climate Adaptation Program

Data source: Climate Services for agriculture site: https://myclimateview.com.au/

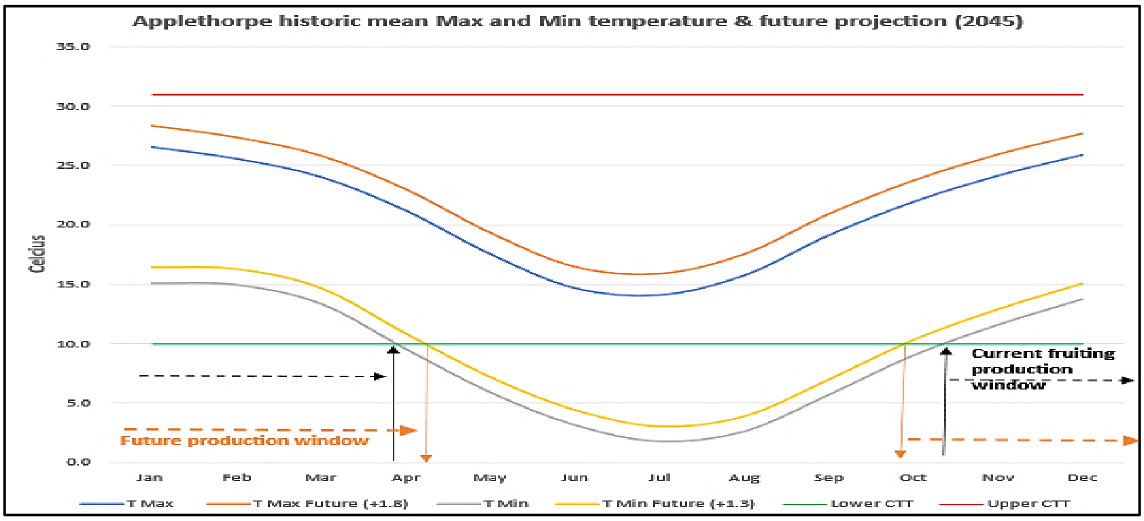

Figure 16. Current and projected future mean monthly temperatures at Applethorpe in Queensland's Granite Belt. Projected minimum temperature changes by 2045 will see an extension of the growing season. Temperatures below capsicums lower CTT (10ºC) will occur less often in early spring and late autumn. This will see an extension of the growing season, further enhanced by the warmer projected maximum monthly temperatures in the spring and summer. Importantly, Capsicums upper CTT (31º C) will not be reached in the Granite Belt summer, allowing high quality fruit production.

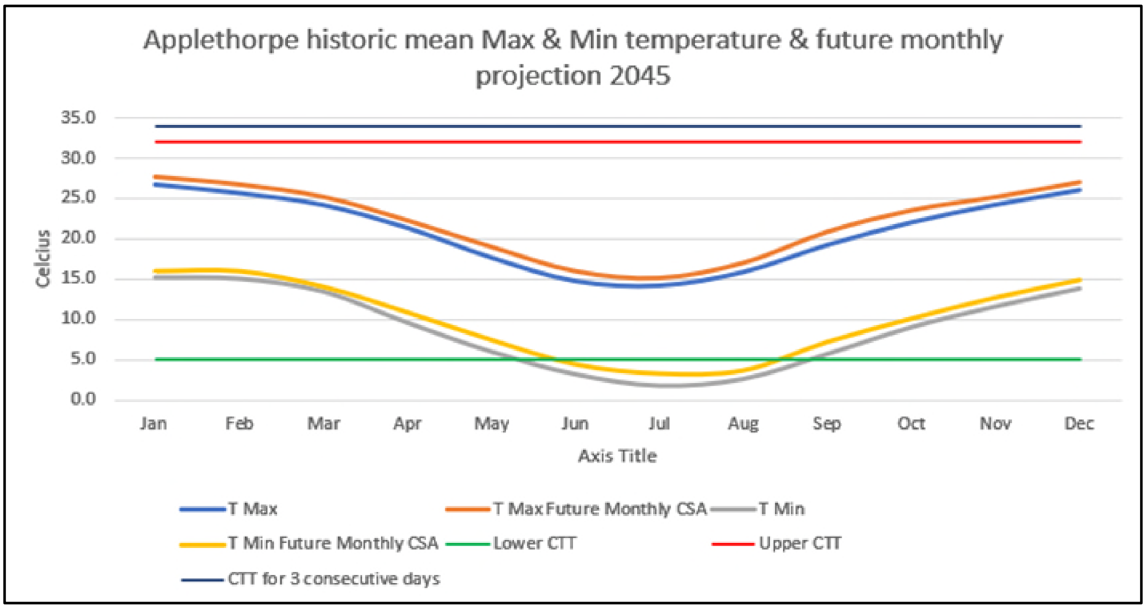

Figure 17. above displays the mean monthly temperatures at Applethorpe, & the projected future mean monthly temperature shifts (2016-2045) at Applethorpe. The monthly future climate data displayed here is not publicly available but displays the individual monthly changes that underpin the projected annual changes in both maximum and minimum temperatures. The monthly projected change data has been included here, so the reader can appreciate and better understand the actual monthly changes that underpin the publicly available projected annual changes (2016-45).

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.

Minimum temperatures currently prevent quality capsicum fruit production in the Granite Belt from mid-autumn (late April) onward. Low temperatures slow plant growth, and reduce fruit size dramatically, bringing the season to an end. The projected rise in minimum temperature (+1.3°C) should see the harvesting season extended further into late autumn (by around 14 days) with the projected future warmer daily maximum temperatures in April and May further assisting fruit filling and maturation. The forecast increase in average monthly minimum temperatures in the Granite Belt as detailed above (2016-45) will allow both earlier transplanting as well as an extension of the traditional harvest period – so extending the existing high value summer capsicum production window.

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 capsicum production season will be lengthened due to a decrease in the number of days when the minimum temperature in Applethorpe is below 10°C. This change is underlined by the reduced future Annual Frost Risk which decreases from 57 to 39days (Figure 14).

Figure 16 above shows how this minimum temperature shift will lengthen the Granite Belt growing season. Capsicum plants will not experience minimum temperatures that are below their lower CCT until later in the autumn. This minimum CTT period that currently delays quality capsicum production will also be shortened further by a warmer spring. 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 Figure 14 & Figure 16 above, however, annual maximum monthly temperatures will remain well below 33°C, capsicums upper CTT. Projected changes in annual monthly summer maximum temperature do not exceed capsicums upper CTT in the Granite Belt.

Minimum temperature is the critical weather factor that will continue to dictate the capsicum production window in the Granite Belt. Projected increases in minimum temperatures in early autumn, and in late spring will allow an extension of the existing production season. This could result in a 3-to-4-week extension of the Granite Belts' (historical) capsicum growing season, enhancing product availability, yield and fruit quality.

Figure 17 above displays the mean monthly temperatures at Gatton, & the projected future mean monthly temperature shifts (2016-2045) at Gatton. The monthly future climate data displayed here is not publicly available but displays the projected individual monthly changes that underpin the projected annual changes in both maximum and minimum temperatures. The monthly projected change data has been included here, so the reader can appreciate and better understand the actual monthly changes that underpin the publicly available projected annual changes (2016-45).

Interstate production – future insights.

Future climate data analysis for all locations (2016-2045) is based on current projections sourced from Australias, **Climate Services for Agriculture** site: https://myclimateview.com.au/.

Western Australia is the only other state apart from Queensland that produces a significant volume of field grown capsicums. The southern states, South Australia, New South Wales & Victoria mostly grow in heated, protected cropping structures.

ii) Western Australia (Carnarvon)

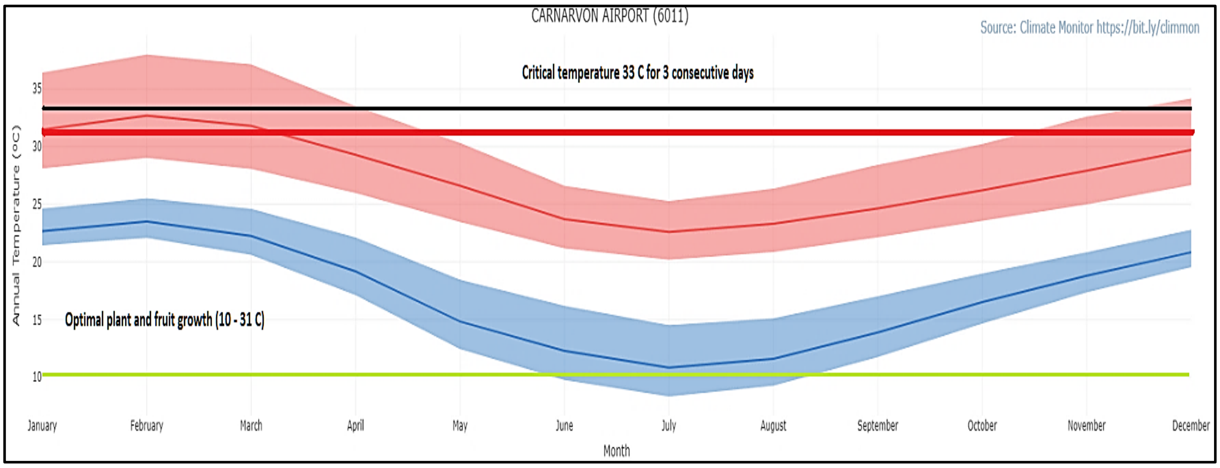

Figure 18. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with critical temperatures – overlaid, at Carnarvon. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Commercial Australian seed catalogues (e.g., Terranova Seeds [8]), indicate that by using modern varieties in the Carnarvon district, capsicum crops can be transplanted from February onward with first harvest occurring in May and last harvest occurring in mid-November. The Critical Temperature Threshold analysis above indicates that from March onward optimal plant and fruit growth temperature criteria are met, though in some years early March maximum temperatures (when the plant is still in the vegetative stage) exceed the upper CTT. Minimum temperatures in July in some years fall below capsicums lower CTT, but warm daily maximums still allow fruit to grow, fill and mature.

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[8] https://terranovaseeds.com.au/wp-content/uploads/2021/05/Cauliflower_Planting_Guide_April_2021.pdf

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.

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

Table 1. Projected future temperature comparison for Carnarvon under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020).

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	27.5	17.4	29.9	0.0
1991 -2020 Recent Average	28.0	17.8	28.4	0.0
2016-45 High Emissions Future Average	28.6	18.6	34	0.0

The high emissions pathway model indicates a temperature shift, showing a 1.1°C increase in maximum temperatures and a 1.2°C increase in minimum temperatures by 2045. The number of days when the maximum temperature in Carnarvon exceeds 35°C increases from 28 to 34 (Table 1).

Projected annual crop specific upper CTT heat risk shift (1961 – 90 baseline period).

Year Range	Number of years with annual heat risk below 34 (days Tmax ≥ 33°C)	Number of years with annual heat risk above 68 (days Tmax ≥ 33°C)
1961-1990	1 in 10 years	0.3 in 10 years
1991-2020	1 in 10 years	1 in 10 years
2016-2045	0.3 in 10 years	1.8 in 10 years

** This chart shows the average number of years out of 10 and the number of days in those years that **the crop specific upper CTT** has or is projected to occur. The default annual heat risk days (below and above columns) shown for this location and crop, are the 10th percentile (left column) and 90th percentile (right column) of the observed 1991-2020 and projected 2016-2045 values.*

Figure 19. Carnarvon annual heat risk shift comparison table for capsicum crop upper CTT of 33 C.

Figure 19 indicates that by 2045, 18 % of years (1.8 in 10) will have at least 68 days that will reach or exceed 33°C capsicums upper CTT, and this has only occurred in 3 % or years in the 1916-90 base period and only occurred in 10% of years 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.

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

iii) Victoria (Whorouly - near Wangaratta)

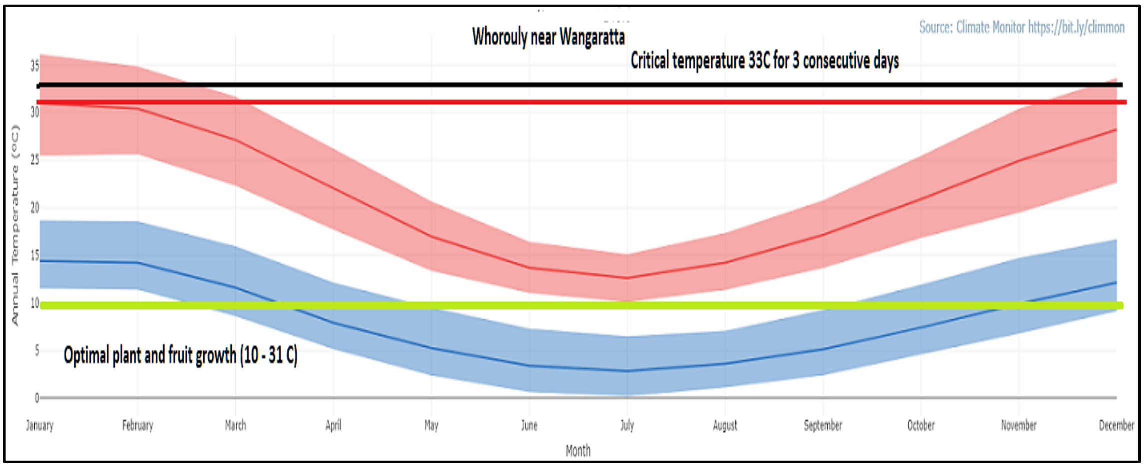

Figure 20. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with capsicum critical temperatures – overlaid, at Whorouly on the Ovens River flats. Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Both minimum and maximum temperatures do limit capsicum production and yield potential at this location. Minimum temperatures from mid-March until mid-October prevent economically viable crop growth and development. While transplanting from late October is possible, high maximum temperatures, above capsicums upper CTT in hotter summers would reduce flower set and pollination. Historically, harvesting at this location begins in February (November planting) and ends in April each year. CTT data analysis reveals that the fruit yield from early transplanted crop (November) is limited by high January maximums in most years. The December planted crop grows and matures through the best temperature conditions at this location, while the late January planted crop with fruit harvesting into April would see yield, fruit size and quality reduced by cool maximum and minimum temperatures.

Summer harvested fresh capsicum fruit usually attracts a premium price, because consumer demand is at its highest. Wholesale market price usually drops dramatically as temperatures cool in the autumn and less salads are eaten[9].

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[9] https://www.horticulture.com.au/globalassets/hort-innovation/levy-fund-pages/vegetable-fund/vegetable-market-price-reports/monthly-pdfs/february-2019/monthly-wmr-capsicum-february.pdf

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

Table 2. Projected future temperature comparison for Whorouly under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020)

Time Period	Annual Average T Max ^{0}C	Annual Average T Min^{0}C	Annual Heat Risk Days T Max ≥ 35^{0}C	Annual Frost Risk Days ≤ 2^{0}C
1961-1990 Past Average	21.7	7.6	13.0	51.4
1991 -2020 Recent Average	22.2	7.8	17.8	56.6
2016-45 High Emissions Future Average	23.1	8.6	25.5	40.3

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. Importantly the number of days when the maximum temperature in Whorouly exceeds 35°C increases significantly from 18 to 25 (Table 2).

Projected annual crop specific upper CTT heat risk shift (1961 – 90 baseline period).

Year Range	Number of years with annual heat risk below 15 (days Tmax ≥ 33°C)	Number of years with annual heat risk above 51 (days Tmax ≥ 33°C)
1961-1990	0.7 in 10 years	0 in 10 years
1991-2020	1 in 10 years	1 in 10 years
2016-2045	0.1 in 10 years	3 in 10 years

** This chart shows the average number of years out of 10 and the number of days in those years that **the crop specific upper CTT** has or is projected to occur. The default annual heat risk days (below and above columns) shown for this location and crop, are the 10th percentile (left column) and 90th percentile (right column) of the observed 1991-2020 and projected 2016-2045 values.*

Figure 21.Whorouly annual heat risk shift comparison table for capsicum crop upper CTT of 33° C.

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.

Figure 21 shows that by 2045, 30% of years (3 in 10) will have at least 51 days when the maximum temperature equal or exceed 33°C, capsicums upper CTT and this never occurred in the 1916-90 base period and only occurred in 10% of years in the 1991-2020 period, a 3-fold increase and shift.

During a recent phone discussion with this capsicum and mixed farming business owner at Whorouly, he stated that challenging weather impacts over the last 4 or 5 years, combined with reduced crop returns had resulted in them exiting the capsicum industry.

iv) New South Wales (Riverina – Yenda)

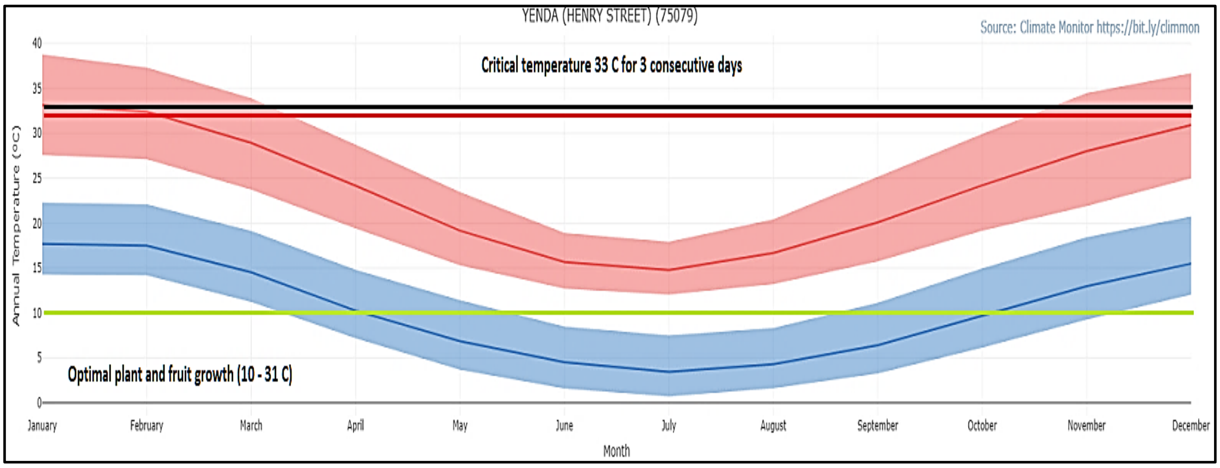


Figure 22. Climate Monitor analysis showing the annual historic monthly temperatures maximum (red) and minimum (blue) temperatures and mean temperatures (solid lines within each coloured band), with capsicum critical temperatures – overlaid, at Yenda (NSW, Riverina production area). Note: The graph shows the 10th to 90th percentile, i.e., you expect the temperature to be in this range for 8 out of 10 years.

Maximum temperatures in January and February above, capsicums upper CTT will impact plant productivity (flowering and potential fruit set), of capsicum crops transplanted in November and December. Harvest at this location usually begins in late February with picking ending at the end of April as minimum temperatures fall below the plants lower CTT and mean maximum temperatures begin to decline. The current short growing season in this location makes production viability marginal, especially with the recent increases in all input costs, seed, fertilizer, packaging etc. High spring and summer temperatures (above capsicum CTT) from mid-October until early February prevent viable production. The short production window means growing capsicums for local (NSW) consumption as part of a mixed vegetable farming business has (in the past) made this cropping location viable.

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

Table 3. Projected future temperature comparison for Yenda under high emissions scenario RPC 8.5, where cumulative global emissions are currently tracking (Schwalm, et al., 2020)

Time Period	Annual Average T Max ⁰C	Annual Average T Min⁰C	Annual Heat Risk Days T Max ≥ 35⁰C	Annual Frost Risk Days ≤ 2⁰C
1961-1990 Past Average	23.6	10.0	27.2	36.4
1991 -2020 Recent Average	24.4	10.4	37.2	33.9
2016-45 High Emissions Future Average	25.2	11.3	44.6	24

The high emissions pathway model indicates a temperature shift, showing a 1.6°C increase in maximum temperatures and a 1.3°C increase in minimum temperatures by 2045. Importantly the number of frost days at Yenda will decrease from 34 to 24 but the number of heat risk days that reach a maximum of 35° C or above at Yenda increases from 37 to 44 both, significant changes (*Table 3*).

Projected annual crop specific upper CTT heat risk shift (1961 – 90 baseline period).

Year Range	Number of years with annual heat risk below 35 (days Tmax ≥ 33°C)	Number of years with annual heat risk above 78 (days Tmax ≥ 33°C)
1961-1990	1.3 in 10 years	0 in 10 years
1991-2020	1 in 10 years	1 in 10 years
2016-2045	0.1 in 10 years	2.2 in 10 years

** This chart shows the average number of years out of 10 and the number of days in those years that **the crop specific upper CTT** has or is projected to occur. The default annual heat risk days (below and above columns) shown for this location and crop, are the 10th percentile (left column) and 90th percentile (right column) of the observed 1991-2020 and projected 2016-2045 values.*

Figure 23. Yenda annual heat risk shift comparison table for capsicum crop upper CTT of 33° C.

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.

Figure 23 above indicates that by 2045, 22% of years (2.2 in 10) will have at least 78 days when the maximum temperature will reach or exceed 33^{o} C, capsicums upper CTT this has never occurred in the 1961-90 base period and only occurred in 10% of years in the 1991-2020 period.

During a recent discussion in May 2023 with this farming business owner, a well know, established capsicum grower in Yenda, it was revealed that challenging weather conditions over the recent 4- 5 years, combined with lower returns had resulted in the business ceasing to grow capsicums.

Note: Only known field grown capsicum production locations have been reviewed in this document. As stated earlier in this review, capsicum production in the southern states of Australia is mostly carried out in protective cropping (glasshouse) structures. These high input / high cost, heated structures allow temperatures and growing conditions to be artificially managed and controlled. There could well be changes to the amount of heating used and required at these locations in future years. Businesses in these locations can now easily analyse and investigate these projected changes using the techniques and methodology described above – should they wish to do so.

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

Drought and Climate Adaptation Program

Annual Heat and Frost Risk, by the year 2045, for capsicum production at reviewed 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 ≥ 33° C	Projected number of days ≥33° C by 2045	Current number of frost days	Projected number of frost days by 2045
Gatton (Qld)	**27.3**	+0.9	**13.2**	+1.0	**44**	61	**7**	4
Applethorpe (Qld	**21.2**	+0.9	**9.1**	+1.0	**5**	7	**53**	40
Yenda (NSW)	**24.4**	+0.8	**10.4**	+0.9	**59**	67	**34**	24
Whorouly (Vic)	**22.2**	+0.9	**7.8**	+0.8	**34**	43	**56**	40
Carnarvon (WA)	**28.0**	+0.6	**17.8**	+0.9	**48**	58	**0**	0

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 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

   https://climateservicesforag.indraweb.io/

Appendix I

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

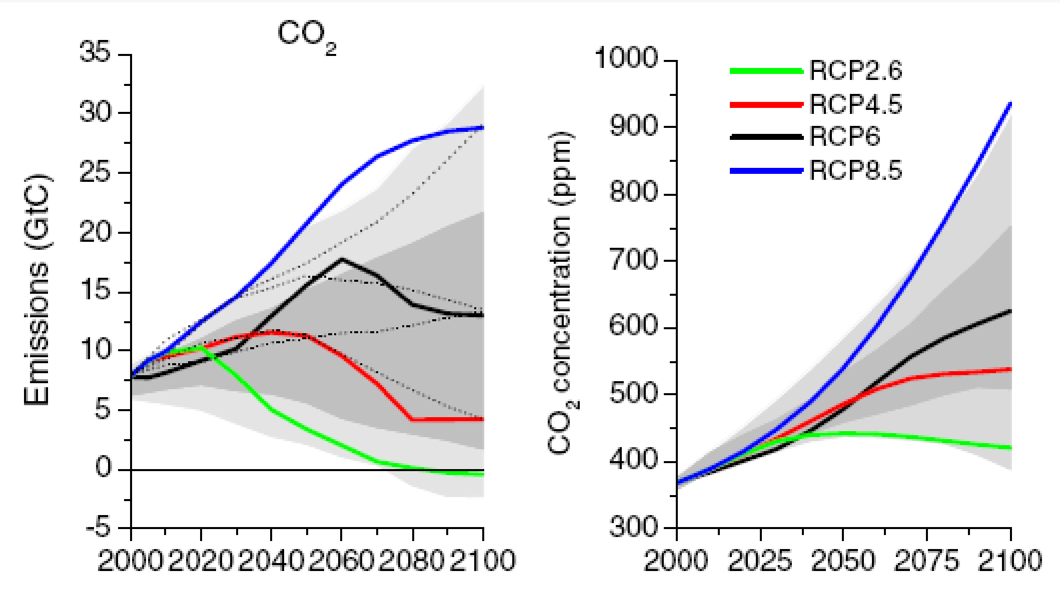
GREENHOUSE GAS SCENARIOS

(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.

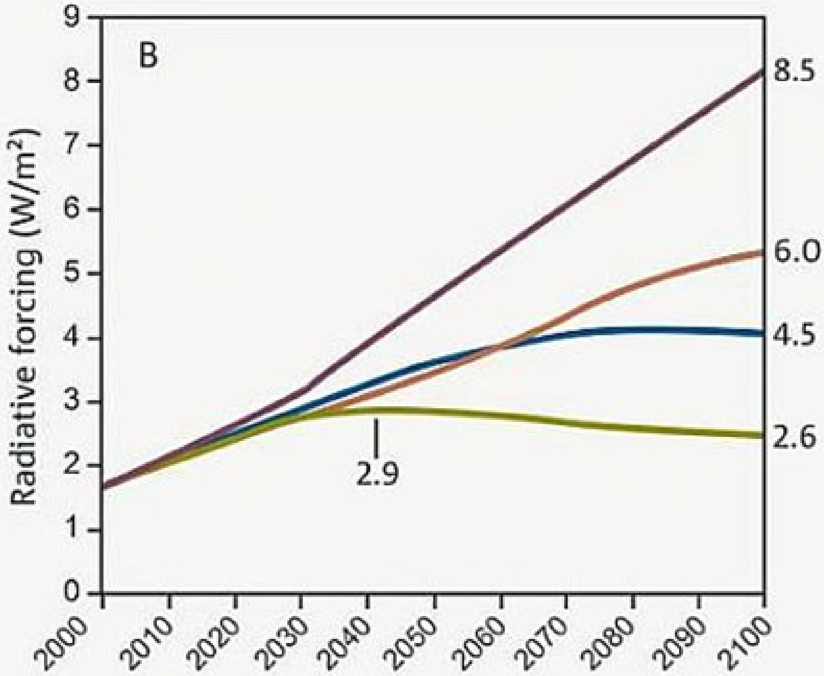
The climate modelling community has developed Representative Concentration Pathways (RCPs) to explore credible future options. The Australian climate change projections found on this site are derived from climate models forced by the RCPs.

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 CO_2 across the RCPs (left), and trends in concentrations of carbon dioxide (right). Grey area indicates the 98th and 90th 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 that 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 CO_2 concentration continuing to rapidly rise, reaching 940 ppm by 2100.

RCP6.0– lower emissions, achieved by application of some mitigation strategies and technologies. CO_2 concentration rising less rapidly (than RCP8.5), but still reaching 660 ppm by 2100 and total radiative forcing stabilising shortly after 2100.

RCP4.5- CO_2 concentrations are slightly above those of RCP6.0 until after mid-century, but emissions peak earlier (around 2040), and the CO_2 concentration reaches 540 ppm by 2100.

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 CO_2 concentration reaches 440 ppm by 2040 then slowly declines to 420 ppm by 2100).

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