Critical temperature thresholds
Case study

Tomato

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Contents

Introduction 3

Commodity production data 3

Production regions 4

Current level of knowledge on temperature thresholds 4

Bowen, North Queensland 5

Lockyer Valley (SE Queensland) 6

Granite Belt (SE Queensland) 7

Projected regional temperature changes 8

Bowen, North Queensland 8

Lockyer Valley (SE Queensland) 9

Granite Belt (SE Queensland) 9

Impact of projected temperature increases 10

Bowen, North Queensland 10

Lockyer Valley (SE Queensland) 10

Granite Belt (SE Queensland) 11

Adaptation through management practices 12

References 12

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 tomatoes are produced in Queensland (Bowen, Bundaberg, Lockyer Valley), NSW (Narromine, MIA, Sydney Basin), Vic (Goulburn Valley – including processing), SA (Murray Bridge, Adelaide Plains) and WA.

Commodity production data

***Table 1** : Australian fresh tomato production. Year ended 30 June 2007*

	NSW	Vic	Qld	SA	WA	Tas	NT	Total
Production (tonnes)	35,937	123,640	120,656	4,313	11,009	434	46	296,035
Area (ha)	798	2312	3,743	78	355	6	2	7,293

(Source: ABS Catalogue 7121, 2006-07)

Processing tomato production (147,544 tonnes in 2007-08) is largely confined to Victoria.

***Table 2** : Value of fresh tomato industry. Year ended 30 June 2006*

	NSW	Vic	Qld	SA	WA	Tas	Australia
Value($m)	19.7	74.7	145.2	13.6	18.6	0.8	272.8

(Source: ABS Catalogue 7121, 2006-07)

***Table 3** : Proportion of Vegetables Produced from each State – 2008-09*

Proportion of vegetables produced by each state, 2008–09

percentage

	NSW	Vic	Qld	SA	WA	Tas	NT	Aust
Potatoes	8	26	3	34	8	20	0	100
Pumpkins	35	4	43	3	9	1	6	100
Green peas	3	21	11	0	0	65	0	100
Beans	2	12	68	0	0	18	0	100
Tomatoes	3	82^^	11**	1	3	0	0	100
Onions	6	7	17	35	10	25	0	100
Carrots	3	27	6	14	23	28	0	100
Cauliflowers	39	8	18	4	15	17	0	100
Other vegetables	16	33	42	2	6	0	2	100
Lettuce	26	9	38	6	20	0	0	100
Broccoli	11	42	14	3	20	10	0	100
Cabbage	10	59	3	9	18	1	0	100
Other vegetables	16	33	42	2	6	0	2	100
All vegetables	11	32	17	18	10	13	0	100

*** Predominately Processing Tomatoes* *^^ All Fresh Market Tomatoes*

Source : Crooks, S 2010, *Australian vegetable growing farms: an economic survey, 2008–09*, ABARE–BRS research report 10.12, Canberra.

Production regions

Queensland accounts for around 70% of fresh market tomato production. Processing tomatoes are grown as an irrigated summer crop in Victoria and New South Wales.

In Queensland, tomatoes are grown all the year round (Table 5). 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 Case Study applies to the fresh tomato industry only.

Current level of knowledge on temperature thresholds

Table 4 *: Critical Temperature Threshold - Tomato*

Crop	Development Phase	Critical Temperature Threshold
Tomato	2 week period Pre-anthesis.	29°C – mean maximum.

For tomato, the 8 to 13 day period prior to anthesis is the most critical developmental phase (Higashide, 2009). The critical temperature, as identified from the literature for this phase, varies according to the cultivar tolerance to elevated temperatures.

In tomato, elevated temperature impacts are complex, and it is difficult to determine one critical temperature effect during the reproductive development phase. 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.

Varieties vary in their sensitivity to temperature and this will influence pollination and fruit set. Under marginal conditions 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).

Even moderate increases in mean daily temperature (from 28/22°C to 32/26°C day/night) have been shown to result in a significant decrease in the number of fruit set (Peet, et al., 1997; Rudich, et al., 1977; Went, 1944 and Sato, et al., 2006). This occurs because temperatures slightly above the optimal range disrupt sugar metabolism and proline translocation during the narrow window of male reproductive development.

For the purposes of this review, 29°C (mean monthly temperature) during the 2 week period up to anthesis has been selected as the critical temperature and critical development phase for tomato (Higashide, 2009). In Queensland this critical period occurs ~ 9 weeks before harvest (Table 6).

Results of experiments conducted by Sato, et al. (2006) on tomato, under moderately increased daily temperatures, suggest that the productivity of vegetable crops under elevated CO_2 levels may not be significantly enhanced because reproductive development is significantly more sensitive to elevated temperatures, than to increasing CO_2 levels.

As there is significant genetic variability between cultivars in their capacity to set fruit under high temperature conditions (>35°C), there is a capacity to utilise these differences in breeding programs to deliver high temperature tolerant commercial cultivars (Rudich, et al., 1977).

Table 5 : Tomato Production Districts - Queensland

District	Planting	Harvest	Critical Development Phase
North Queensland	February – early September	June – early December	April to early October
Lockyer Valley	Late August – February	November - May	September to March
Granite Belt	September – December	December - April	November to Feb

Source – Lovatt, et al., 1998

Table 6 : Tomato Production Growth Stages - Queensland

Plant Stage	Time
Sowing to germination	4-10 days
Emergence to field planting	4-8 weeks
Field planting to first flower	3-4 weeks
First Flower to harvest	6-8 weeks
Duration of harvest	1-12 weeks
Critical Development Phase (2 weeks pre-anthesis)	8-10 (9) weeks prior to harvest

Source – Lovatt, et al., 1998

The engagement process with growers, consultants, researchers and supply chain participants, was designed to confirm or otherwise the following assumption – "If maximum temperatures have a significant effect on the yield and/or quality of tomatoes, then it is to be expected that first and final harvests will closely follow the maximum temperature threshold of 29°C, identified from the literature, for each of the production locations in Queensland".

The maximum temperature threshold of 29°C for tomato during the 2 week period up to anthesis, identified from the literature, **has been confirmed** by comparing mean monthly maximum temperature data with the commencement and the end of the tomato season for a number of the major locations where tomatoes are grown in Queensland :-

North Queensland (winter)

Lockyer Valley (summer)

Granite Belt (summer)

Bowen, North Queensland

Using 29°C as the mean maximum temperature threshold, and the temperature data from Bowen, Qld (Fig. 1), 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.

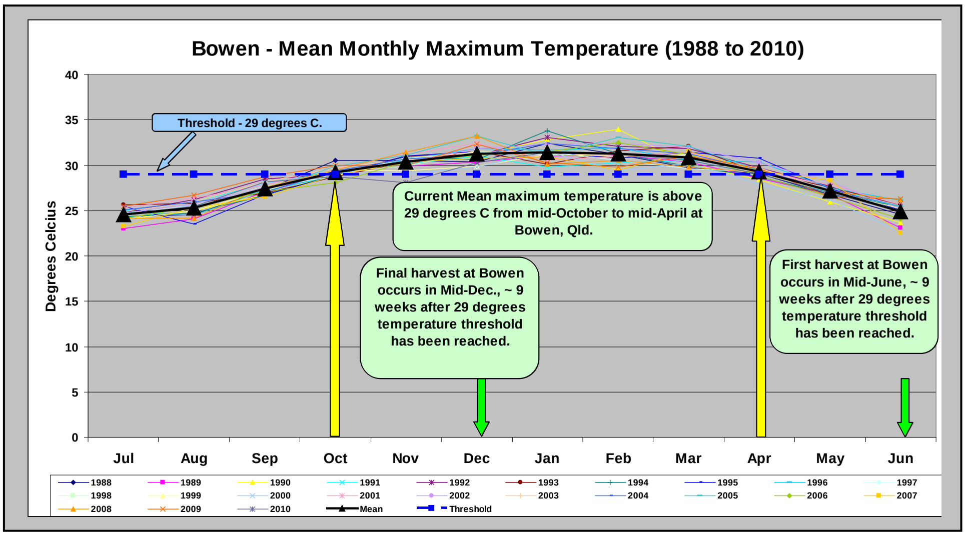

Fig. 1 – Bowen, Qld - Mean Monthly Maximum Temperatures

As maximum temperatures continue to rise, due to further climate change, the temperature threshold of 29^{o}C 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.

Lockyer Valley (SE Queensland)

Using 29^{o}C as the mean maximum temperature threshold, and the temperature data from Gatton, Qld (Fig. 2), 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 6 weeks after the 29^{o}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.

Information provided by tomato growers in the Lockyer Valley (Gatton), shows that growers have historically been largely compensated for the temperature induced decrease in yields (and quality) which occur in the summer, through higher returns in most years in the past. Returns are subject to supply and demand, with quality playing a part as well. These higher returns are being continually eroded by competition from other summer producing districts, which are not impacted by temperatures over the threshold. If higher returns were available for producing at a time when high temperatures reduce yields, then growers will continue to plant for this market.

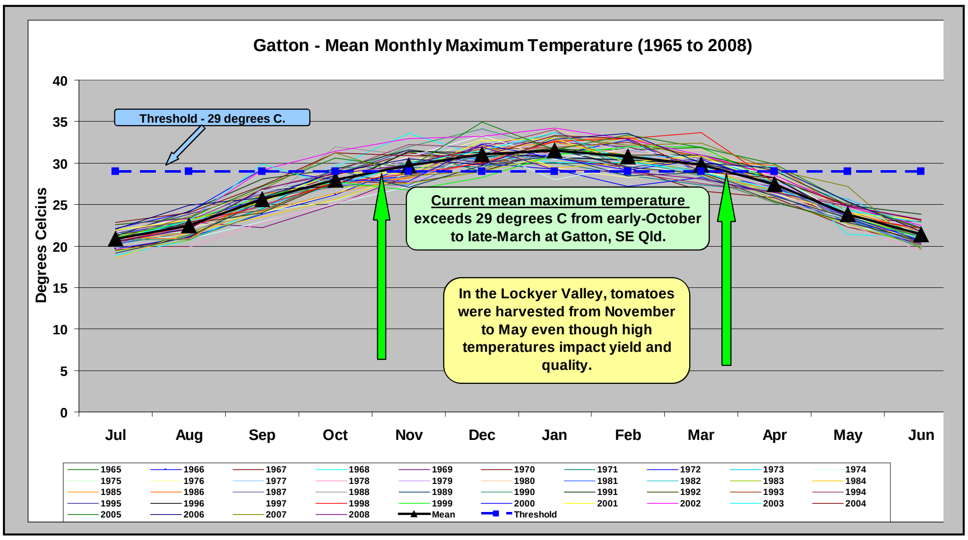

Fig. 2 – Gatton, Qld - Mean Monthly Maximum Temperature

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

Granite Belt (SE Queensland)

Mean Maximum Temperatures never exceed 29°C at Applethorpe. Using 29°C as the mean maximum temperature threshold, and the temperature data from Applethorpe, Qld (Fig. 3), 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.

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.

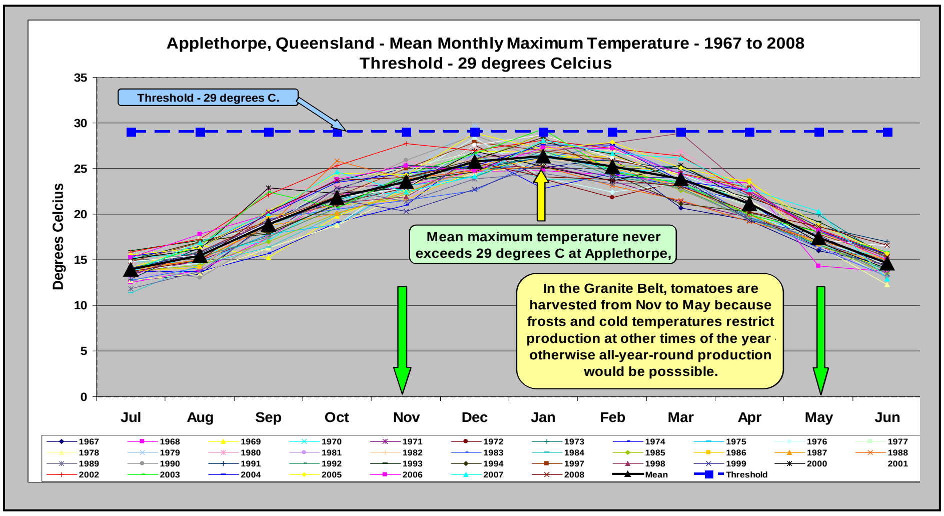

Fig. 3 – Granite Belt, Qld - Mean Monthly Maximum Temperatures

At beginning and end of the summer season, growers may be able to take advantage of earlier planting in the spring, and later planting in the autumn, which 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 extend their future planting and harvest times in this tomato growing district.

Projected regional temperature changes

The projections of future maximum temperature change for the major tomato production regions have been produced using the OZCLIM scenario generator developed by CSIRO Atmospheric Research and the International Global Change Institute (http://www.cmar.csiro.au/ozclim).

OZCLIM generates future climate change scenarios based on twelve different Global climate models (GCMs) and eighteen different greenhouse gas emission projections (IPCC, 2001). In this way it represents a comprehensive range of future climate uncertainties for use in climate change impact and adaptation research.

The CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, chosen to represent a change in temperature, is a scenario based on the world community taking less action on climate change and remaining fossil fuel dependant.

Bowen, North Queensland

***Table 7** : Bowen, North Queensland – Temperature ^{o}C*

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Current Mean Max ^{o}C	24.5	25.3	27.5	**29.2**	30.4	31.3	31.5	31.3	30.9	**29.3**	27.1	24.9
Threshold	29	29	29	**29**	29	29	29	29	29	**29**	29	29
2030 Mean Max – A1FI Scenario	24.9	25.9	28.0	**29.9**	31.2	32.3	32.2	32.3	31.4	**29.7**	27.5	25.4

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, by 2030 the mean maximum temperature at Bowen (Queensland) exceeds 29^{o}C from early-October through to the end of April - a potential reduction in season length of up to 4 weeks (Fig. 4).

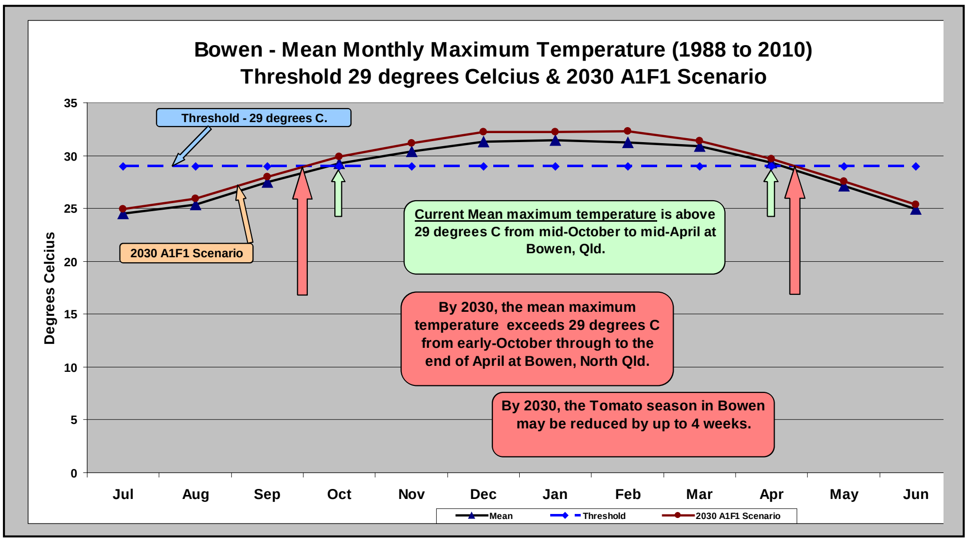

***Fig. 4** – Bowen, North Qld - Mean Monthly Maximum Temperatures & Projected Increases*

Lockyer Valley (SE Queensland)

Table 8 : Gatton, SE Queensland – Temperature °C

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Current Mean Max °C	20.8	22.5	25.7	**28.0**	29.7	31.0	31.5	30.8	**29.8**	27.4	23.9	21.4
Threshold	29	29	29	**29**	29	29	29	29	**29**	29	29	29
2030 Mean Max – A1FI Scenario	20.8	22.6	26.0	**28.6**	30.3	32.0	32.0	31.1	**30.1**	27.6	24.2	21.4

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, by 2030 the mean maximum temperature at **Gatton (SE Queensland)** exceeds 29°C from late-October through to early-April (Fig. 5).

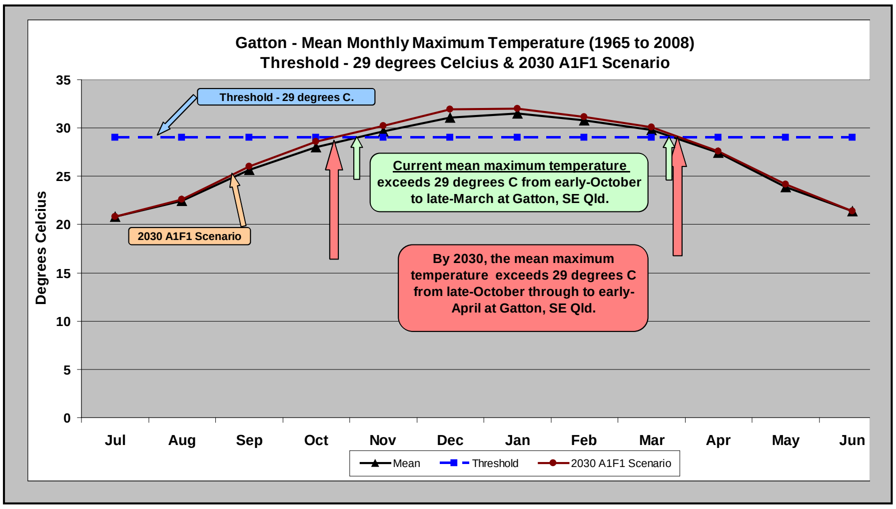

***Fig. 5** – Gatton, Qld - Mean Monthly Maximum Temperatures & Projected Increases*

Granite Belt (SE Queensland)

Table 9 : Applethorpe, SE Queensland – Temperature °C

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Current Mean	13.9	15.5	18.8	21.8	23.5	25.8	**26.4**	25.2	23.9	21.1	17.4	14.6
Threshold	29	29	29	29	29	29	**29**	29	29	29	29	29
2030 Mean Max – A1FI Scenario	15.4	17.1	20.6	23.5	25.5	27.6	**27.9**	26.9	25.6	22.7	19.1	15.9

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, by 2030 the mean monthly maximum temperature at **Applethorpe (SE Queensland)** does not yet exceed 29°C, enabling a continuation of planting and harvests over the summer as is currently occurring.

For January (the hottest month of the year in the Granite Belt), the mean maximum temperature is expected to almost reach the threshold by 2030 (Fig. 6), so actual temperatures for individual years at or about 2030 will most likely exceed the threshold of 29°C, at times.

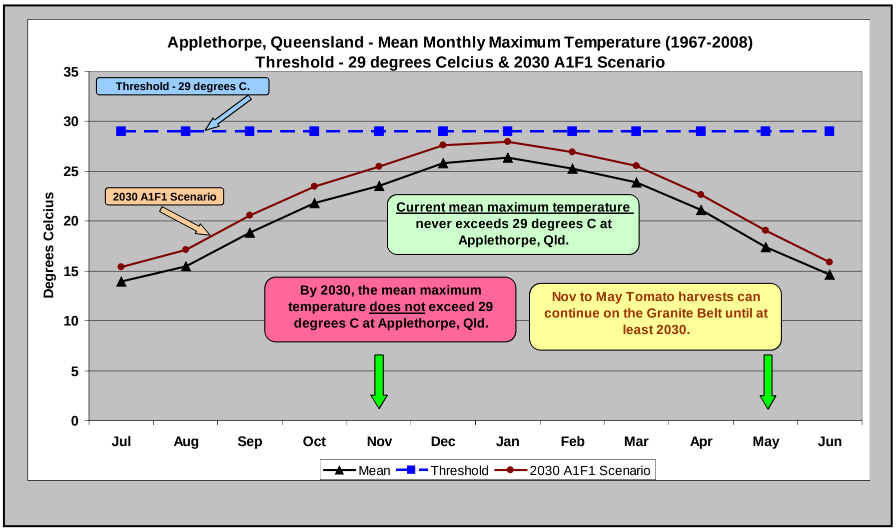

Fig. 6 – Applethorpe, SE Qld - Mean Monthly Maximum Temperatures & Projected Increases

Impact of projected temperature increases

For tomato, the 8 to 13 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, 29°C (mean daily temperature) during the 2 week period up to anthesis has been selected as the critical temperature and critical development phase. This has been confirmed through engaging with growers, researchers and other supply chain participants and by comparing mean monthly maximum temperature data with the commencement and the end of the tomato harvesting season for a number of locations where tomato is grown in Queensland.

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.

Bowen, North Queensland

The **"Buffer Level"** between the current mean temperature and the threshold temperature in September at Bowen, is **1.5°C**. **This will be reduced to 1.0°C in 2030** (Table 7).

Consequently, by 2030, the tomato season in Bowen may be reduced by up to 4 weeks.

Lockyer Valley (SE Queensland)

Using 29°C as the mean maximum temperature threshold, 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 6 weeks after the 29^{o}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 compensated in some way to allow growers to continue to profitably produce tomatoes under such apparently adverse conditions.

Information provided by tomato growers in the Lockyer Valley (Gatton), shows that they have historically been largely compensated for the temperature induced decrease in yields (and quality) which occur in the summer, through higher returns in most years. Returns are subject to supply and demand, with quality playing a part as well.

These higher returns are being continually eroded by competition from other summer tomato producing districts, which are not as heavily impacted by temperatures over the threshold. If higher returns were available for producing at a time when high temperatures reduce yields, then growers will continue to plant for this market.

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.

The **"Buffer Level"** between the current mean temperature and the threshold temperature in October at Gatton, is **1.0^{o}C**. **This will be reduced to 0.4^{o}C in 2030** (Table 8).

Granite Belt (SE Queensland)

Using CSIRO Mk3.5 Climate Model with the SRES Marker Scenario A1FI, **by 2030** the mean monthly maximum temperature at Applethorpe (SE Queensland) does not yet exceed 29^{o}C, enabling a continuation of planting and harvests over the summer, as is currently occurring.

As maximum temperatures continue to rise through to 2030, due to further climate change, the temperature threshold of 29^{o}C will impact on all other production districts in Queensland, except the Granite Belt. The impact will be in the form of reduced yields, in the absence of more adaptable cultivars.

Consequently, by 2030 individual January mean monthly maximum temperatures in the Granite Belt could exceed 29^{o}C.

As maximum temperatures continue to rise, due to further climate change, the temperature threshold of 29^{o}C will eventually be reached in the Granite Belt. In the absence of more adaptable cultivars, the impact will be in reduced yield and quality, initially for short periods in mid summer whilst the threshold is exceeded. 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 February.

At beginning and end of the summer season, 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 **"Buffer Level"** between the current mean temperature and the threshold temperature in January, the hottest month in the **Granite Belt, is 2.6^{o}C**. **This will be reduced to 1.1^{o}C in 2030** (Table 9).

Adaptation through management practices

As there is significant genetic variability between cultivars in their capacity to set fruit under high temperature conditions (>35^{o}C), 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^{o}C, whereas more heat tolerant cultivars are not impacted until daytime (maximum) temperatures exceed 32^{o}C, and the most sensitive period is 8-13 days prior to anthesis.

Climate change scenarios which include even moderate temperature increases in the order of 0.8^{o}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.

As maximum temperatures continue to rise through to 2030, due to further climate change, the temperature threshold of 29^{o}C will impact on all production districts in Queensland, except the Granite Belt. 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.

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