Is Climate Change a Threat to the Blackcurrant Industry in Tasmania?

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Abstract
Deciduous fruit crops require a sufficient period of cold temperature to break winter dormancy (Saure, 1985). The effect of winter chilling on dormancy breaking of blackcurrant (Ribes nigrum L.) in Tasmania was studied by subjecting cuttings to artificial chilling (2, 4, and 10°C; for 500, 750, 1000, 1250, and 1500 hours), followed by a six week forcing treatment. Except for 500 and 750 hours, at which no bud-break was observed, bud-break increased with chilling time at all temperatures. Bud-break also increased as chilling temperature decreased. 2°C was between 1.5 and 2 times more effective than 4°C, which in turn was up to twice as effective as 10°C. This invalidates the current winter chill model used in the Tasmanian blackcurrant industry, which assumes chilling is constant at all temperatures below 7.2°C. Furthermore, the accepted theory that 6°C is the optimum chilling temperature for blackcurrant is questioned. Analysis of two different models to calculate the accumulation of chilling over winter showed that, over the last twenty years, winter chilling in areas of southern Tasmania decreased substantially. Depending on the model and optimum chilling temperature used, calculations showed that chilling fell by between13 and 32 percent.

Introduction

Deciduous fruit crops that originate in temperate and subarctic zones undergo an annual period of dormancy, or rest, from late autumn to early spring. This enables them to avoid cold damage to vegetative and reproductive organs (Peereboom Voller, 1986). A sufficient period of chilling is required to break this dormancy and induce bud-break in spring (Saure, 1985).

There has been increasing concern that warmer winters in recent years are providing insufficient winter chilling for some of Tasmania's fruit crops. As a subarctic species, blackcurrant *(Ribes nigrum L.)* is the biggest concern because of its very high winter chill requirement. Although a relatively minor crop, blackcurrant might act as an early indicator of potential problems for other deciduous fruit crops.

Tasmanian blackcurrant growers believe that abnormal growth patterns and decreasing yields evident for several years may be a result of lack of winter chilling. Evidence also suggests that blackcurrants at lower altitudes have suffered to a much greater extent than those at higher altitudes (Westmore, unpublished data, 2004).

The number of viable buds on the cane each year is the most important key profit driver in blackcurrant production. The number of buds formed on new shoots grown in a season sets a maximum potential yield for the harvest in the following year. As buds can produce either fruit or new vegetative shoots, for every bud that does not break, a length of potential fruiting wood for the following season is also lost. The effects are therefore cumulative.

Bud-break patterns can also be uneven under low winter chill (Allan, 1999). Under low chill, apical buds may break first, while buds lower on the cane remain dormant. This results in a stronger than normal apical dominance, which may prevent or reduce lateral bud-break lower on the cane, even when these buds have reached their chill requirement (Erez & Lavee, 1974). Uneven bud-break also leads to inter-fruit competition. Yield is further reduced by a shorter period available for fruit maturation, and quality is lower due to irregular ripening.

The optimum temperature for meeting the chill requirement is between 0°C and 10°C, with general agreement that 5±1°C is satisfactory (Shirazi, 2003). Richardson et al. (1974) and Erez & Lavee (1971) found 6°C to be the optimum chilling temperature for peach buds. Although optimum temperatures may vary with species and cultivar (Sharik & Barnes, 1976), plant age (Nienstaedt, 1966), and climatic conditions (Gurdian & Biggs, 1964), 6°C is widely accepted as an optimum for most deciduous fruit crops.

Up to a point, sub- and supra-optimal temperatures also have a chilling effect (Saure, 1985). Richardson et al. (1974) and Gilreath & Buchanan (1981) showed that temperatures up to 14°C and down to 0°C have chilling effects, albeit decreasing at the marginal temperatures. These findings led to the development of weighted chilling hours, or “chill units”, as developed by Richardson et al. (1974), where lower values are assigned to less effective temperatures.

High temperatures (16-35°C) during winter prolong dormancy (Allan & Burnett, 1995; Erez et al., 1993). Intermittent days of very high temperature delay bud-break far more than a longer period of moderate but continuous temperature elevation of 2-3°C (Saure, 1985). The obvious conclusion is that chill accumulation is at least partially reversible. In addition to reduced chilling from warmer average temperatures, if hot days during winter become more common, then the opportunity for chilling to be “fixed” would be reduced, and chilling reversal or negation would be more likely. In addition, the chilling requirement increases under higher summer temperatures (Peereboom Voller, 1986), which would magnify any reduction in winter chilling. However, the basic chilling mechanism means that any effect of climate change on blackcurrant production will be far greater if daily winter minimum temperatures increase rather than the maxima.

Winter chill models have been used with some success in deciduous fruit crops to determine depth of dormancy, and whether or when dormancy breaking treatments should be applied (Saure, 1985). A winter chill model is a mathematically derived expression, which relates temperature to rest completion (Gilreath & Buchanan, 1981).

Models have also been widely used to assess suitability of cultivars for a particular site, using chill averages over a number of years. In warm seasons, when models indicate natural chilling may not be sufficient, chemical and cultural practices can be employed to increase bud-break (Allan, 1999). Conversely, in cold seasons when models indicate that the chilling requirement may be reached early, other practices can be employed to delay bud-break, thereby reducing the risk of frost damage (Allan, 1999).

The only winter chill model used in Tasmania for blackcurrants is the Below Critical Threshold (7.2°C) model. Other models used internationally include the Utah model (Richardson et al., 1974), Modified Utah model (Linvill, 1990), Daily Positive Chill Unit model (Linsley-Noakes, 1995), and Dynamic model (Erez et al., 1990).

The Below Critical Threshold model relates the number of hours below a critical temperature to the completion of rest. 7°C was first proposed as the chilling threshold in 1932 by Hutchins (Weinberger, 1950). The Tasmanian blackcurrant industry currently uses 7.2°C (converted from the cardinal temperature of 45°F). This method does not take into account the differential effects of a wide range of chilling and chill-negating temperatures. Two years with the same number of hours below 7.2°C, but with different temperature regimes, may have very different effects on chill accumulation (Richardson et al., 1974).

The Utah model recognises the differential effect of temperature on chill accumulation. The model was designed as a step function, with hourly temperatures multiplied by an appropriate chill unit. The Utah model has been criticised for being inaccurate in coastal areas (Aron, 1975) and areas with mild winters (Allan, 1999). The model was developed at 40°N at high altitude, where winters are very cold and snow frequent (Allan, 1999). Linvill (1990) determined a sine function to represent a smoothed form of the original step function of Richardson et al. (1974).

The first objective of this study was to quantify how much winter chilling blackcurrants require to reach varying levels of bud break, both in terms of time and the effect of different temperatures. The second objective was to identify any long-term winter chill trends in blackcurrant-growing areas of southern Tasmania, using the Below Critical Threshold (7.2°C) and Modified Utah models, to gauge any threat to the industry from climate change.

Materials & Methods

Chilling treatment

Ninety unbranched, healthy canes (current fruiting wood only) of the cultivar White Bud, of approximately equal length, free from visible disease or insect damage, were cut from four year old plants at Valleyfield, New Norfolk.

Cuttings were taken on 1 May 2004 (from which time all chilling periods have been calculated by the industry). This corresponded to 75 percent leaf fall, which has previously been regarded as an approximate time for the onset of dormancy (Peereboom Voller, 1986). This date was a negligible eight days earlier than the time at which maximum negative chill accumulation occurred, which is a more widely accepted method of determining the beginning of rest (Seeley, 1996). Any leaf matter remaining on the cane at this stage was manually removed.

Six canes per experimental unit were randomly assigned to a temperature treatment (2°C, 4°C, 10°C), and to a chill hour period (500, 750, 1000, 1250, 1500 hours). The canes were placed in three temperature-control rooms in sealed plastic containers, with a saturated sponge to prevent desiccation. The bases were sealed with grafting wax to prevent water loss from cutting wounds.

At the conclusion of each chill hour period, the six canes from each temperature treatment were removed. The bases were recut and the canes subjected to a forcing treatment at 15°C and 12-hour photoperiod, chosen because they were very close to the early spring averages. This also lessened the possibility of any chilling negation from a high forcing temperature. Light source was 143 μmol $m^{-2}s^{-1}$ photosynthethic photon flux density (cool white fluorescent). Relative humidity was set at 60 percent. The canes were placed standing up in wide containers, in approximately 4cm of water, which was changed every three days. Forcing was continued for six weeks.

Canes were examined for evidence of bud-break (green tip, which is the appearance of the calyx through bud scales) every three days. This was recorded as a percentage of total viable buds on the cane. Regression analyses of bud-break after six weeks and on bud-break after one week as a percent of total, against both chilling time and temperature, were performed using the general linear models package of SPSS®. Results are presented as bar charts with standard error bars to highlight temperature/time effects, with regression results also given.

Winter chill model comparisons

Models were compared using twenty years of temperature data from New Norfolk. Daily minimum and maximum temperatures were obtained from the Australian Bureau of Meteorology (BoM). Records from regional weather stations were adjusted by the BoM to more accurately reflect temperatures at exact crop positions, by interpolation using a trivariate thin plate smoothing spline (Wahba & Wendelberger, 1990) with latitude, longitude and elevation as independent variables. Hourly temperature data were obtained by interpolation of daily maximum and minimum temperatures, using the widely accepted equations of Linvill (1990), as below:

Temperature wave from sunrise to sunset:

$$T(t) = (T_{max}–T_{min}) \text{ x } \sin[(\pi \text{ x } t)/(DL+4)] + T_{min} \text{ [1]}$$

where T(t) is temperature at time t after sunrise, T_{max} is daily maximum temperature, T_{min} is the morning minimum temperature, and DL is daylength in hours.

Temperature wave from sunset to sunrise:

$$T(t) = T_s – [(T_s–T_{min})/\ln(24–DL)] \text{ x } \ln(t) \text{ [2]}$$

where T(t) is temperature at time t > 1 hour after sunset, and T_s is the sunset temperature obtained from Eq. [1]. Sunrise and sunset times were obtained from the BoM. Interpolated hourly temperature values obtained from the above equations were applied to the following winter chill models.

For the Below 7.2°C model, chill hours from sunrise until the critical temperature were calculated by solving equation [1], to give:

$$CH = [(DL+4)/\pi] \text{ x } \arcsin[(T_c–T_{min})/(T_{max}–T_{min})] \text{ [3],}$$

where T_c is the critical temperature (7.2°C).

To take into account chill hours before sunset in the evening, the following test from Linvill (1990) was used:

If CH > 4, then CH = 2 x CH–4.

Chill hours between sunset and sunrise were calculated by solving Eq. [2] to give:

$$CH = (24–DL) – \exp\{[(T_c–T_s)/(T_s–T_{min})] \text{ x } \ln(24–DL)\} \text{ [4]}$$

Chill hours calculated from equations [3] and [4] were then accumulated from 1 May to 31 August.

For the Modified Utah model, chill units were calculated using a sine function developed by Linvill (1990), to replace most of the original Utah step function. Chill Units were accumulated as for chill hours. Linear trend lines were calculated for winter chill model data, and slope used to estimate percentage reduction in chill. Regression analyses were performed using the general linear models package of SPSS®.

Results

Chilling treatment

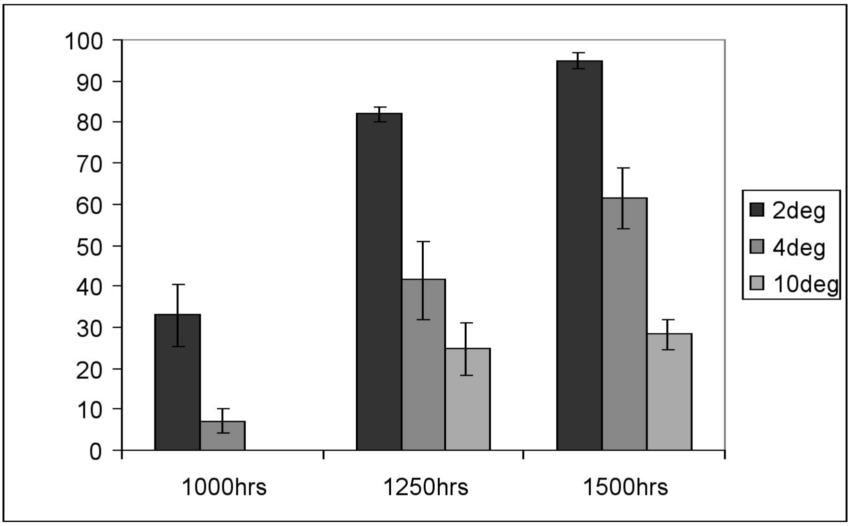

Figure 1.
Chilling time had a significant (P<0.01) and positive effect on bud-break after six weeks of forcing at all temperatures. Chilling temperature had a significant (P<0.01) and negative effect on bud-break.

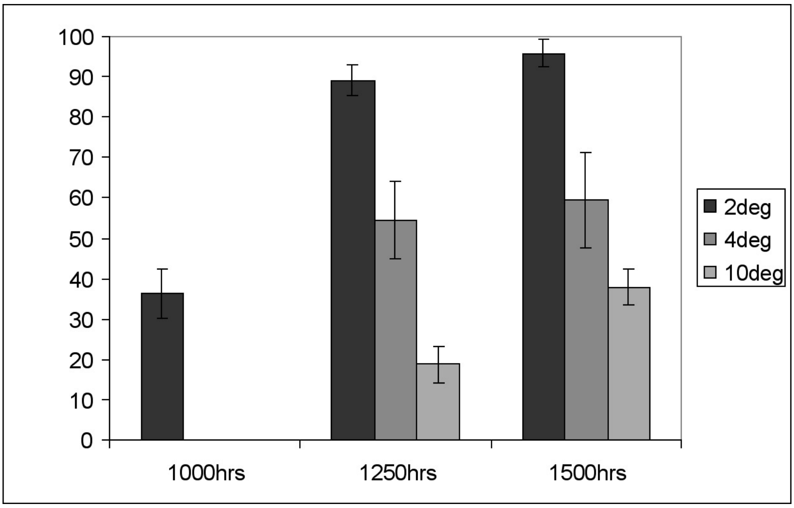

Figure 2.
Chilling time had a significant (P<0.01) and positive effect on bud-break after one week as a percent of total at all temperatures. Chilling temperature had a significant (P<0.01) and negative effect on bud-break after one week as a percent of total.

Overall bud break, measured after 6 weeks, increased with the period of chilling and with decreasing temperature (Fig. 1.) There were significant (P<0.001) positive regressions between percent bud-break and time at 2°C (r^2=0.89), 4°C (r^2=0.69) and 10°C (r^2=0.59). There were significant (P<0.01) negative regressions between chilling temperature and bud-break for temperature exposure times of 1000 h (r^2=0.44), 1250 h (r^2=0.54) and 1500 h, (r^2=0.79). No bud-break occurred at any temperature after 500 or 750 hours of chilling. 2°C was between 1.5 and 2 times more effective than 4°C, which in turn was up to twice as effective as 10°C.

Longer chilling periods and lower temperatures also resulted in faster bud-break (Fig. 2). For initial percent bud-break measured after one week of forcing, there were significant ($P<0.01$) positive regressions between percent bud-break and time at 2°C ($r^2=0.85$), 4°C ($r^2=0.56$) and 10°C ($r^2=0.36$). There were significant ($P<0.01$) negative regressions between chilling temperature and bud-break for temperature exposure times of 1250 h ($r^2=0.61$) and 1500 h, ($r^2=0.43$). There was no significant regression between bud break after the first week and temperature for 1000 h of chilling. Canes chilled for 1500 h at 2°C reached 96 percent of their maximum bud-break after one week, 1250 h at 2°C reached 89 percent, with all other treatments reaching less than 60 percent.

Model Comparisons

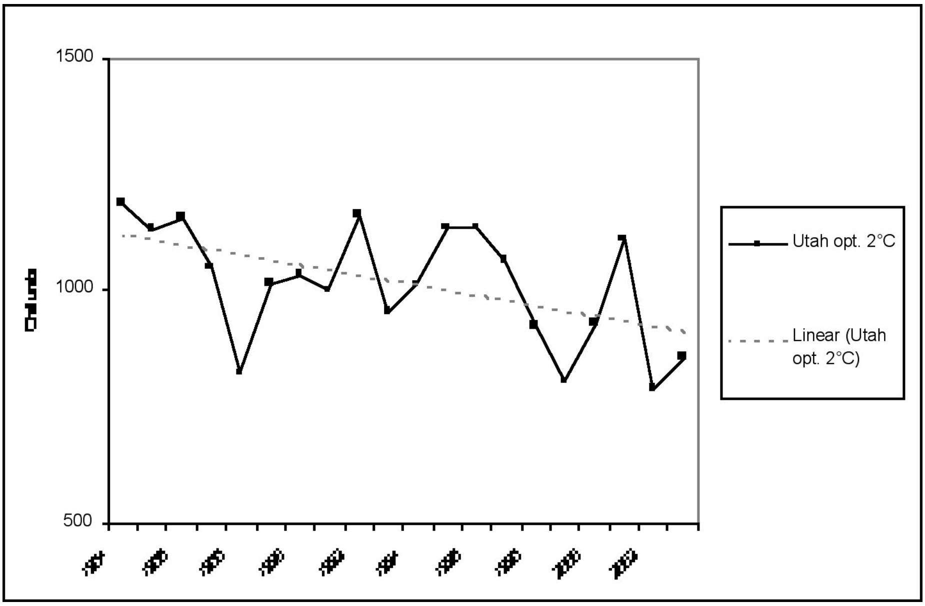

Figure 3.
Winter chill accumulations over twenty years with linear trend line showing a twenty percent decrease in chilling for the lower chilling optimum Utah model.

The Below 7.2°C did not show a significant ($P>0.79$) reduction in winter chill over the last 20 years. The Utah model showed a significant ($P<0.05$) reduction of 15 percent, but variability was high and the r2 value low at 0.27. After application of a lower chilling optimum (6°C down to 2°C), the Utah model showed a significant ($P<0.05$) reduction of 20 percent, also with high variability and the r2 value low at 0.26 (Fig. 3). Over the last ten years (data not shown) winter chilling fell by a significant ($P<0.05$) 18 percent with an r2 of 0.47 for the Below 7.2°C model. The Utah and lowered optimum Utah models did not give significant regressions over the same period.

Discussion

There was a clear increase in bud-break with increased chilling time and decreased temperature. This invalidates the current winter chill model used in the Tasmanian blackcurrant industry, which assumes chilling is constant at all temperatures below 7.2°C. Furthermore, this study questions the assumption that 6°C is the optimum chilling temperature for blackcurrant, and suggests it may be up to 4°C lower. Blackcurrant production is therefore likely to be affected to a far greater extent by a reduction in hours around 2°C than previously thought. The current model may not have picked this up, as such a loss of hours could occur without any change in the total hours below 7.2°C.

The increasing speed of bud-break, shown as bud-break as a percent of total after one week of forcing, with higher chilling time and lower chilling temperature, is almost as important as the total bud-break reached. Unlike most other fruit crops in Tasmania, blackcurrants are harvested by machine in one pass. Consequently the longer the period of bud-break, the greater the proportion of fruit that may be unripe at harvest and the larger the price discount. Increased apical dominance resulting from uneven bud-break exacerbates this situation.

Although the methods of this study have been widely used and validated, it is important to bear in mind that field responses may differ to those under laboratory conditions. Fluctuating field temperatures may increase chilling (Norvell & Moore, 1982), spring temperatures increase continually (as opposed to a constant forcing temperature over six weeks), and whole plants with intact roots may show different responses to cuttings (Dennis, 2003).

Adopting a lower chilling optimum closer to 2°C, winter chill model analysis shows that over the last twenty years, winter chilling has decreased markedly in areas of southern Tasmania. Over a number of continents since 1951, night-time minimum temperatures have risen at a rate up to three times greater than that of daily maximum temperatures (Karl et al., 1992). This is also the case for Australia generally, and for winter months in southern Tasmania (Torok & Nicholls, 1996). Climate change predictions suggest warming will increase, although with less difference between changes to minimum and maximum temperatures (CSIRO Atmospheric Research, 2001). Nevertheless, there will be fewer hours below 4°C, posing a serious threat to blackcurrant production in marginal areas.

It is difficult to relate changes in winter chilling to past blackcurrant production beyond anecdotal evidence, as long-term yield data in the Tasmanian blackcurrant industry is sparse and poorly recorded. Given that winter chilling of blackcurrant occurs at a much lower optimum temperature than previously thought, and that winter chilling is likely to have decreased markedly over the last two decades, a more in depth study is recommended. This would involve evaluating the dormancy breaking effect of a wider range of temperatures, including whether the temperature range at which chilling negation occurs is also different to other crops. Clearly a simple shift downwards of the Utah model is not sufficient to predict the effects of winter chilling, because the result is to push accumulated chill units for each of the last twenty years below 1250. Detailed calculation of chilling temperature effects would enable a more accurate model to be constructed. Other areas for investigation include the expected future performance of current crop locations based on their temperature profiles and climate change predictions, and the extent to which reduced winter chilling can be ameliorated by changes to cultural practice.

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