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# Heat model for pistachio bloom and harvest

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ABSTRACT

To determine the heat accumulation required for bloom and harvest of 'Sirora' pistachio (*Pistacia vera*) trees, 6510 and 25,609 combinations of base temperature ($T_b$), optimum temperature ($T_u$) and critical temperature ($T_c$) were tested. Using eight seasons' data, we attempted to find the smallest variation for heat accumulation for bloom and harvest. The combination of $T_b = -1$, $T_u = 26$ and $T_c = 26$ for bloom and $T_b = 14$ and $T_c = 32$ for harvest resulted in the lowest value for the coefficient of variation. Validation was performed using actual harvest data from 2 further years from the orchard used for the initial modelling and 10 years from other orchards in different regions. Reasonable results were obtained for the major Australian pistachio production areas. The data from the cooler Nhill area did not fit this model. The reason for this has been explored.



## 1. Introduction

Pistachio is a desert plant that is tolerant of saline soil, needs a sunny position and well-drained soil. Long, hot summers are required for proper ripening of the nuts. Production is alternate bearing or biennial bearing, meaning the harvest is heavier in alternate years (Johnson and Weinbaum, 1987). Deciduous trees, like pistachios, have certain requirements for both chill and heat accumulation to achieve optimum production.

The influence of chilling has been well described (Weinberger, 1950; Richardson et al., 1974; Fishman et al., 1987a,b). Compared with the requirement for chill, there have been fewer studies of heat accumulation requirement (Egea et al., 2003).

Growing degree hours (GDH) are a valuable tool to estimate heat accumulation (Azarenko et al., 2008). Arnold (1960) developed a model which calculates growing degree day accumulation based on averaging the daily maximum and minimum, subtracting the base temperature and summing this value for each day. Baskerville and Emir (1969) refined this model by fitting a sine curve to daily maximum and minimum temperatures allowing for a greater range of threshold temperatures. Improvements in automated weather monitoring have made it feasible to calculate heat unit accumulation on an hourly basis and calculate growing degree hours more accurately (Black et al., 2000).

Richardson et al. (1974,1975) proposed base temperatures of 4.4 °C and 4.5 °C and an upper temperature of 25 °C where any temperatures above 25 °C are assumed equal to 25 °C for peach bloom. Shaltout and Unrath (1983) used 4.5 °C and 6.1 °C as base temperatures to calculate GDH required for full bloom in apples. Anderson et al. (1986) posed an asymmetric curvilinear (Asymcur) GDH model. To produce a curvilinear model, they introduced a cosine function for temperature which results in bias weighting the temperature compared with simply using the mean temperature (Fig. 1). They continued to use a base temperature ($T_b$) of 4 °C. They also posed an optimum temperature ($T_u$) of 25 °C, and a critical temperature ($T_c$) of 36 °C. To distinguish this model from normal straight-line GDH accumulation, this paper uses the term Asymcur GDH. At temperatures between $T_b$ and $T_u$, the following formula was applied:

$$\text{Asymcur GDH} = \frac{T_u - T_b}{2} \cdot \left(1 + \cos\left(\pi + \pi \cdot \frac{T_h - T_b}{T_u - T_b}\right)\right)$$

At temperatures between $T_u$ and $T_c$, a second formula was applied:

$$\text{Asymcur GDH} = T_u - T_b \cdot \left(1 + \cos\left(\frac{\pi}{2} + \frac{\pi}{2} \cdot \frac{T_h - T_u}{T_u - T_u}\right)\right)$$

When hourly temperature ($T_h$) < $T_b$ or > $T_c$, Asymcur GDH = 0.

Many authors (Seeley et al., 1987; Marra et al., 2002; Azarenko et al., 2008) have used Asymcur GDH. Caruso et al. (1993) stated that Asymcur GDH was more accurate than heat unit summation in predicting harvest date of peaches. Marra et al. (2002) tested 500 random sets of $T_b$, $T_u$ and $T_c$ and found $T_b = 7.5$, $T_u = 26$ and $T_c = 38.5$

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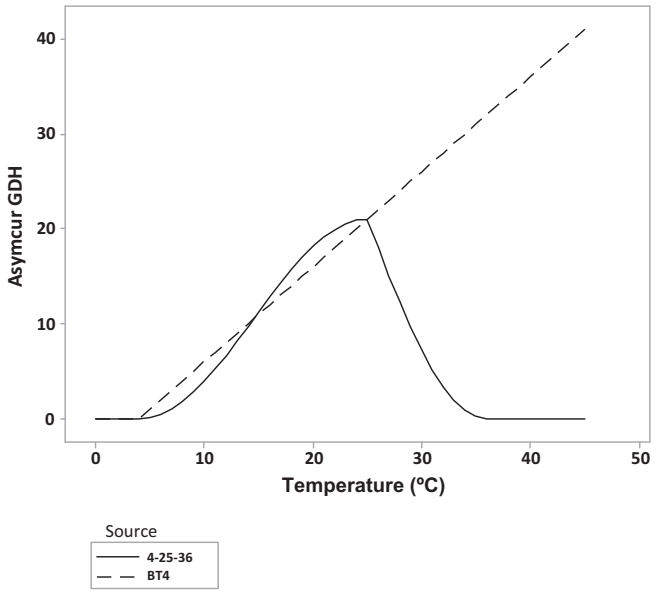


**Fig. 1.** Heat accumulation of Asymcur GDH at $T_b$ = 4 °C, $T_u$ = 25 °C and $T_c$ = 36 °C comparing with straight line GDH at $T_b$ = 4 °C. 4-25-36 represents $T_b$ = 4 °C, $T_u$ = 25 °C and $T_c$ = 36 °C while BT4 represents the straight line with only $T_b$ = 4 °C. From the figure, it can be seen that line 4-25-36 increased from 0 to 25 °C shows an "S" shape.

led to the lowest average error in terms of days between harvest and calculated harvest date in peach. Darbyshire et al. (2013) calculated full bloom date using 34,020 combinations based on 7 datasets for 6 pome fruit varieties and 3 locations and found different base temperatures for different varieties. Further estimation of parameters for Asymcur GDH is necessary.

Rather than GDH, some authors (Orlandi et al., 2005; Reginato et al., 2010) calculated growing degree days (GDD). GDD is calculated on the basis of averages of the daily maximum and minimum temperature. $T_b$ is also used in this calculation. Orlandi et al. (2005) compared different $T_b$ (from 1 °C to 20 °C in 1 °C intervals) for olives, using 3-years of temperature data and found that 12 °C was the best $T_b$ for GDD calculation with the smallest coefficient of variation (C.V.). However, Reginato et al. (2010) found that GDH resulted in a more accurate estimation of heat requirements when compared with GDD in grapes.

Very few studies of GDH requirements in pistachio (*Pistacia vera*) have been undertaken. In Turkey, Küden et al. (1995) found that the pistachio cultivars 'Ohadi' and 'Kirmizi' required 11,500 and 10,700 GDH respectively from bloom to harvest but the authors did not mention which threshold temperature was used. In Iran, heat requirements of pistachio trees are between 8852 and 15,420 GDH for bloom with $T_b$ of 4.5 °C. 'Kalle-Ghuchi' pistachio requires 8852–9637 GDH, 'Owhadi', 12,871–13,320 GDH and 'Akbari' 14,208–15,420 GDH (Rahemi and Pakkish, 2009). In Australia the cultivar 'Sirora' requires 9633 GDH from chill completion to full bloom with a base temperature of 4.4 °C (Zhang and Taylor, 2011).

To calculate GDH accumulation, chill completion must first be established. Zhang and Taylor (2011) established the chill requirement model for 'Sirora' pistachio in Australia using the Dynamic model. This model offers reliable predictions. Thus, chill completion in this paper is based on the Dynamic model only.

The objective of this paper is to systematically observe the Asymcur GDH model response when temperature parameters are changed and to find the base, optimal and critical temperatures that when applied to the model best predict the GDH required for pistachio from bloom to harvest in southern Australia. This work can also predict the GDH required for pistachio trees from chill completion to harvest. However, many orchards apply winter oil sprays to mitigate the effect of low winter chill. The application of winter oil prevents heat models from being able to correctly predict GDH bloom dates. Thus prediction of time from chill completion to harvest can only work for orchards which have not applied winter oil or orchards for which accurate bloom date records are available even though winter oil has been applied.

In low chill winters, winter oil application can mitigate the effect of low chill and stimulate normal bud break (Beede et al., 1998; Zhang and Ranford, 2015). It is believed that winter oil inhibits oxygen absorption by the buds resulting in dormancy breaking. It seems oil applications result in the increasing of respiration and leads to buds blooming (Beede et al., 1999). However, after winter oil application, the process is no longer natural and the GHD calculations are not suitable.

## 2. Material and methods

### 2.1. Field data collection

For the period of 2004–2012, dates for chill completion and full bloom were collected from two orchards: one near Robinvale, Victoria where winter oil was routinely applied but full bloom dates were recorded and one near Mildura, Victoria, without winter oil application. The first day of harvest in the Robinvale orchard was also noted (Table 1).

### 2.2. Model calculation

Hourly temperature data were collected from the Mildura meteorological station at latitude −34.2358 and longitude 142.0867. Asymcur GDH was calculated for bloom (between chill completion and full bloom for the non-winter oiled orchard), and harvest (between full bloom and harvest date for the Robinvale orchard) using the Asymcur GDH model (Anderson et al., 1986).

To discern the best $T_b$, $T_u$ and $T_c$ values, different combinations were tested and are listed in Table 2. Models using base temperature alone and those using both base and critical temperatures were examined. All integers within the ranges listed were included. The

**Table 1**
Phenological data for two pistachio orchards, one where winter oil was routinely applied and one without winter oil application.

| Season | Estimated chill completion date[z] | Full bloom for Mildura orchard (no oil applied) | Full bloom for Robinvale orchard (oil applied) | First day of harvest Robinvale orchard (oil applied) |
|---|---|---|---|---|
| 2004/05 | 10 Aug | 2 Oct | 2 Oct | 12 Mar |
| 2005/06 | 3 Sep | 18 Oct | 2 Oct | 3 Mar |
| 2006/07 | 1 Aug | 24 Sep | 24 Sep | 20 Feb |
| 2007/08 | 24 Aug | 15 Oct | 5 Oct | 27 Feb |
| 2008/09 | 14 Aug | 9 Oct | 6 Oct | 4 Mar |
| 2009/10 | 1 Sep | 24 Oct | 7 Oct | 05 Mar |
| 2010/11 | 16 Aug | 14 Oct | 11 Oct | 11 Mar |
| 2011/12 | 8 Aug | 7 Oct | 5 Oct | 28 Feb |

[z] Based on 59 Dynamic model chill portions (Zhang and Taylor, 2011).