Thermal Time Requirement and Harvest Time Forecast for Peach Cultivars With Different Fruit Development Periods

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Abstract

Non-linear models using growing degree hours (GDH), based on the choice of base, critical and optimum temperatures, have been successfully applied to calculate thermal time required for spring bud burst in deciduous fruit trees. The flexibility of the model can fit the wide range of temperatures that occur during the peach fruit development period (FDP), which takes place from early spring to late summer. In this experiment, fruit growth was studied in relation to thermal time accumulated from bloom to fruit harvest for peach and nectarine cultivars whose fruit development period range from 70 to 150 days. Thermal time was calculated in terms of degree days (DD) (base temperature 7 °C, and critical temperature 35 °C) and GDH (base temperature 7.5 °C, optimum temperature 26 °C and critical temperature 38.5 °C). Climatic and phenological data (bloom and harvest dates) were available for a minimum of three to a maximum of nine years. GDH showed a lower coefficient of variation and a higher predictive capacity, in terms of days, than degree days for all of the cultivars tested. Taking into account the whole FDP, the accuracy of the GDH model in predicting harvest time ranged from 1 day, in the early ripening peach cultivar 'Maycrest,' to 4 days in late ripening peach cultivar 'O'Henry.' An accurate early forecast of fruit harvest time was obtained using the GDH accumulated during the first 25-52 days of FDP, depending on the cultivar.

INTRODUCTION

The development period of peach fruits is genetically controlled (Vileila-Morales et al., 1981) but ranges greatly with season (Blake, 1930) and environment (Weinberger, 1948; Topp and Sherman, 1989; Caruso et al., 1993). Time of ripening depends on bloom time and on the length of the fruit development period (FDP), which is regulated chiefly by the temperature range from bloom to ripening and by the cultivar response to temperature (Boonprakob et al., 1992); as a matter of fact, temperature has been used for building models to predict harvest time (Muñoz et al., 1986; Boonprakob et al., 1992; Caruso et al., 1993; Motisi et al., 1992; Motisi et al., 1998). FDP has been associated to the average daily mean temperature (Muñoz et al., 1986) or to mean monthly temperature (Topp and Sherman, 1989). Anyhow, prevailing temperatures during the first 2 months after full bloom vary the most and are the best correlated to the FDP, serving as the best predictor for harvest time (Lilleland, 1965; Boonprakob et al., 1992; Caruso et al., 1993).

Motisi et al. (in press), re-examining FDP data by Muñoz et al. (1986), showed that the coefficient of variation (c.v.) of thermal time accumulated from bloom to harvest, for five early ripening peach cultivars grown in four different environments, is much lower than the c.v. relative to the same period and expressed in term of days. As a matter of fact, thermal time requirement, during fruit growth, is cultivar dependent and its c.v. between years or environments, should be close to zero. Based on this hypothesis the

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coefficient of variation has been widely applied as a tool to test different heat accumulation models or to optimize them (Motisi et al., in press; Muñoz et al., 1986; Motisi et al., 1992).

Several authors have used heat unit summation to predict fruit ripening (Arnold, 1959). The assumption is that no growth occurs below and above specific threshold values. Arnold (1959) showed that the appropriate base temperature (BT) could be calculated using heat unit summation (degree days = DD) by choosing the BT giving the smallest c.v. More recently, Anderson et al. (1986) proposed a non-linear model to estimate the heat requirement, calculated in terms of Growing Degree Hours, needed to achieve bud break after the offset of winter dormancy. The model (ASYMCUR) takes into account optimal (OT) and critical temperature (CT) beside BT. In a field vs. greenhouse experiment, ASYMCUR was more accurate than heat unit summation in predicting harvest, with same values of GDH accumulated from bloom to harvest in greenhouse or in the field (Caruso et al., 1993).

Objectives in this study were: 1) to set up a non-linear model based on BT, OT and CT, that could accurately predict peach fruit growth. 2) to compare different non-linear models in terms of predictor capacity, 3) to test the model for early forecasting of the ripening for a set of peach and nectarine cultivars with different FDP.

MATERIALS AND METHODS

Three peach (‘Early Maycrest’, ‘Elegant Lady’, ‘O’Henry’) and 2 nectarines (‘Mayglo’, ‘Fantasia’) which had a range of mean FDP from 70 to 150 days were analyzed. The orchard is located at the Kearney Agricultural Center (Fresno, CA). Maximum and minimum daily temperatures were obtained from the Agricultural Weather Station at Parlier (Fresno, CA), and the date of full bloom (50-70% open flowers) and harvest time were recorded for each cultivar in each of 3 (‘Mayglo’) to 9 (‘O’Henry’) years. Harvest date was calculated as the weighted mean from all the picking dates for each cultivar in each year. Hourly temperatures were calculated according to the sine-exponential function proposed by Linvill (1990), which takes into account the time of sunrise and sunset.

Hourly temperatures and phenological data (Julian days of full bloom and average harvest date) were used as input to run a Visual basic computer program that was able to calculate GDH.

The Beta function was used, with 6 parameters:

$$Y = a + b * \left(\frac{x - c + dm}{d}\right)^{(e-1)} * \frac{\left(1 - \frac{x - c + dm}{d}\right)^{(f-1)}}{m^{(e-1)} * n^{(f-1)}}$$

where:

- *a*= GDH minimum (y minimum=0)
- *b*= GDH maximum (y maximum=21)
- *c*= Optimal temperature *(OT)*
- *d*= Curve range *(BT-CT)*
- *e*= 2-*(BT/OT)*
- *f*= *CT/OT*
- *m= e-1/e+f-2*
- *n= f-1/e+f-2*

Beta function was chosen for its flexibility and shapes variability that it can adopt.

The function’s target was to minimize the average error of harvest time date (days) between years and for each cultivar. The program was built to generate 500 random sets of cardinal temperatures to optimize the model, as proposed by Motisi et al. (1994). The combination of cardinal temperatures which gave the lowest average error, was used to calculate the GDH accumulated for each cultivar. Thermal time from full bloom to harvest was also calculated using DD phenological model (base temperature 7 °C, and critical temperature 35 °C) available from the CIMIS (California Irrigation Management Information System) Web Site.

To early forecast the ripening date, the relation between GDH accumulated within 2 months after full bloom and the length of FDP was tested. The research of best parameterization was done following the same method as above, whereas the function's target was the best correlation coefficient between the number of GDH accumulated within two months after full bloom and the length of the FDP.

RESULTS

The best set of BT, OT and CT, obtained from a 500 random set of parameters calculated by the Beta function, which gave the lowest average error in terms of days between observed and calculate harvest date, was obtained when BT was 7.5 °C, OT 26 °C and CT 38.5 °C (Fig. 1). This set of temperatures resulted in a bell shaped curve which defined the temperature/GDH relationship (Fig. 2). For each cultivar (Table 1) the prediction ability of the GDH model was higher than that based on the variability of the length, in days, of the FDP or on the thermal time measured with the DD model. The average error in terms of days between calculated and actual harvest date, for all cultivars was about 3 days with the GDH based model, and 6 and 4 days for the FDP and the DD model, respectively. For all cultivars tested GDH showed the lowest c.v. (Table 1).

The combination of cardinal temperatures which gave the best correlation coefficient between the number of GDH accumulated within two months after full bloom and the length of the FDP was 1.8 °C, 31.9 °C and 32 °C for BT, OT and CT, respectively (Fig. 3) and the curve shape changed accordingly (Fig. 4). BT and CT were lower than that obtained when the entire cycle was taken into account, while OT was higher.

Even if for each cultivar the correlation between GDH accumulated within 30 days after full bloom (DAFB) and the length of FDP was significant, the highest correlation coefficients were obtained after a cultivar-specific DAFB period, which ranged from 25 to 52 days, depending the length of the whole FDP (Table 2).

For all cultivars tested, the relationship between thermal time accumulated during the first 25-52 days after bloom and the length of fruit development period was linear (Fig. 5), with very high correlation coefficients (Table 2).

From the five linear equations it was possible to calculate each year the harvest date and compare it with the actual one. The average error (days between given and calculated harvest date) ranged between 0 days in 'Mayglo' to 4.5 days in 'O'Henry' (Table 2). DD model was also able to early predict harvest time on the studied peach cultivars with slight worst differences respect Beta model (data not showed**).**

DISCUSSION

The use of GDH (Beta function) made possible an accurate prediction of harvest date for peach and nectarine cultivars with a very different fruit development period. GDH gave better prediction than the Degree Days model, which does not involve in its parametrization the use of the optimal temperature, as does Beta model (Motisi et al., 1994). The model gave always very low coefficient of variation (< 5%), with the lowest values for the cultivar with the shortest FDP. Early forecasting of harvest time was even more accurate than that calculated from climatic data of the whole FDP. This confirms previous findings on peach, based on average daily or monthly temperature (Lilleland, 1965; Boonprakob et al., 1992) and the role of the early stages of fruit growth in determining the length of the whole FDP (Caruso et al., 1993). The temperature data utilized to run the model varied according to the period of the FDP considered. When the prediction was done on the base of meteorological data for the first 4-7 weeks after bloom, the Beta function gave, within a set of 500 random combinations, BT and CT lower than those given when the entire FDP was used. The lack of high temperatures during the early stage of fruit development may account for this and may also explain the coincidence of OT and CT. However, these differences could also indicate a different thermal requirement specific for each of the ontogenetic stages of FDP, so that temperature chosen to run predicting models should change by physiological stages of fruit growth.

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Tables

Table 1. Average fruit development period (FDP) and thermal time accumulated in terms of degree days (DD) and growing degree hours (GDH), with relative average errors (days from calculated and actual harvest date), for a set of five peach and nectarine cultivars grown in California.

Cultivar	Sampled years (n)	Average FDP (days)	c.v.	Average error (± days)	DD*	c.v.	Average error (± days)	GDH**	c.v.	Average error (± days)
Maycrest	7	72	11.3	6,5	639,3	4.8	2,1	22779,1	3.1	1,4
Mayglo	3	90	5.6	3,6	803,7	8.6	4,9	28505,7	4.1	2,3
E. Lady	7	123	7.2	6,1	1437,2	6.5	4,4	44592,0	4.2	3,3
Fantasia	8	137	5.3	6,1	1691,7	6.1	4,6	49625,4	3.7	3,2
O'Henry	9	150	6.3	7,8	1977,4	6.2	4,7	56893,4	4.9	4,0
Mean			7.1	6,03		6.6	4,24		4.1	2,96

***** (BT = 7 °C; CT= 35 °C). **(BT=7.5 °C, OT=26 °C, CT=38.5 °C).

Table 2. Linear equation, correlation coefficient (R) and number of error days between the observed and predicted harvest date, calculated at a cultivar-specific day after bloom for 5 peach and nectarine cultivars grown in California.

Cultivar	Days after bloom (n)	Equation	R	Average error (±days)
Maycrest	32	Y=-0,0093X + 136,4	-0.96	2.0
Mayglo	25	Y=-0,0080X + 128,6	-1	0.2
E. Lady	34	Y=-0,0111X + 204,3	-0.98	1.3
Fantasia	52	Y=-0,0062X + 208,6	-0.90	2.5
O'Henry	25	Y=-0,0087X + 197,5	-0.74	4.5

Y=FDP, X=GDH accumulated among at n DAFB.

Figures

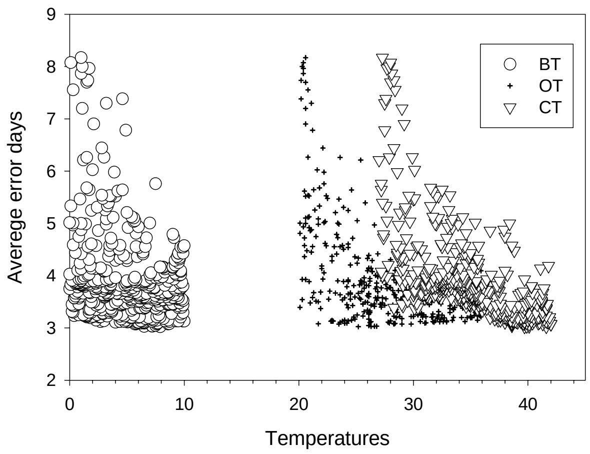

Fig. 1. Effect of parameters on goodness of fit of beta model to phenological data (500 random set of cardinal temperatures) for 5 peach and nectarine cultivars grown in California. BT; OT and CT are Base, Optimal and Critical temperatures respectively

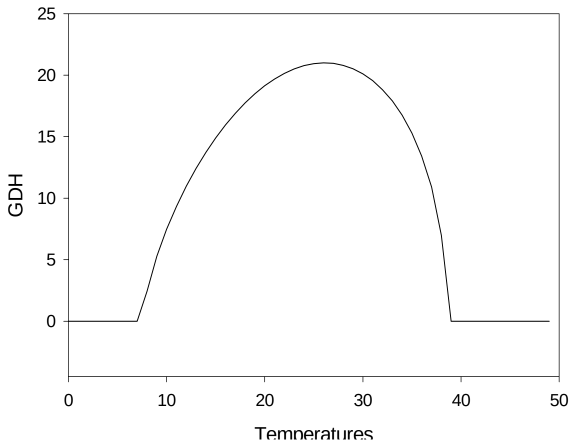

Fig. 2. Beta function resulting from the best combination of cardinal temperatures. Were BT; OT and CT are 7.6, 26.1 and 38.6 respectively

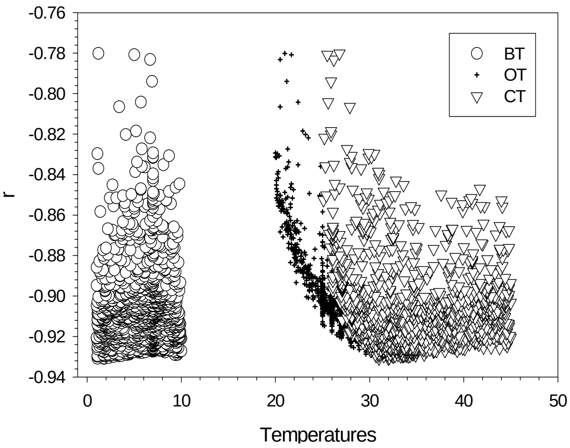

Fig. 3. Effect of parameters on goodness of fit of beta model to early forecast the ripening date (500 random set of cardinal temperatures) for 5 peach and nectarine cultivars grown in California. BT; OT and CT are base, optimal and critical temperatures, respectively .

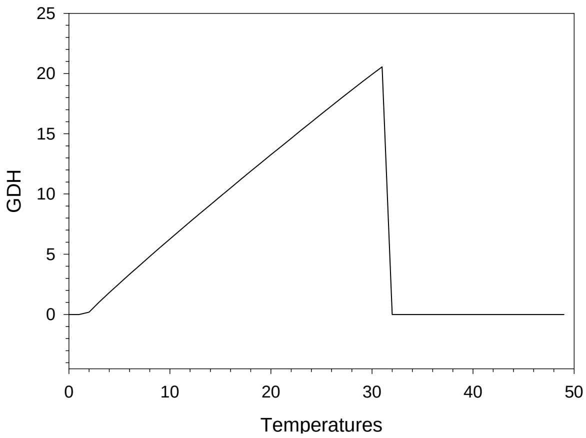

Fig. 4. Beta function resulting from the best combination of cardinal temperatures. Were BT; OT and CT are 1.8, 31.9 and 32, respectively.

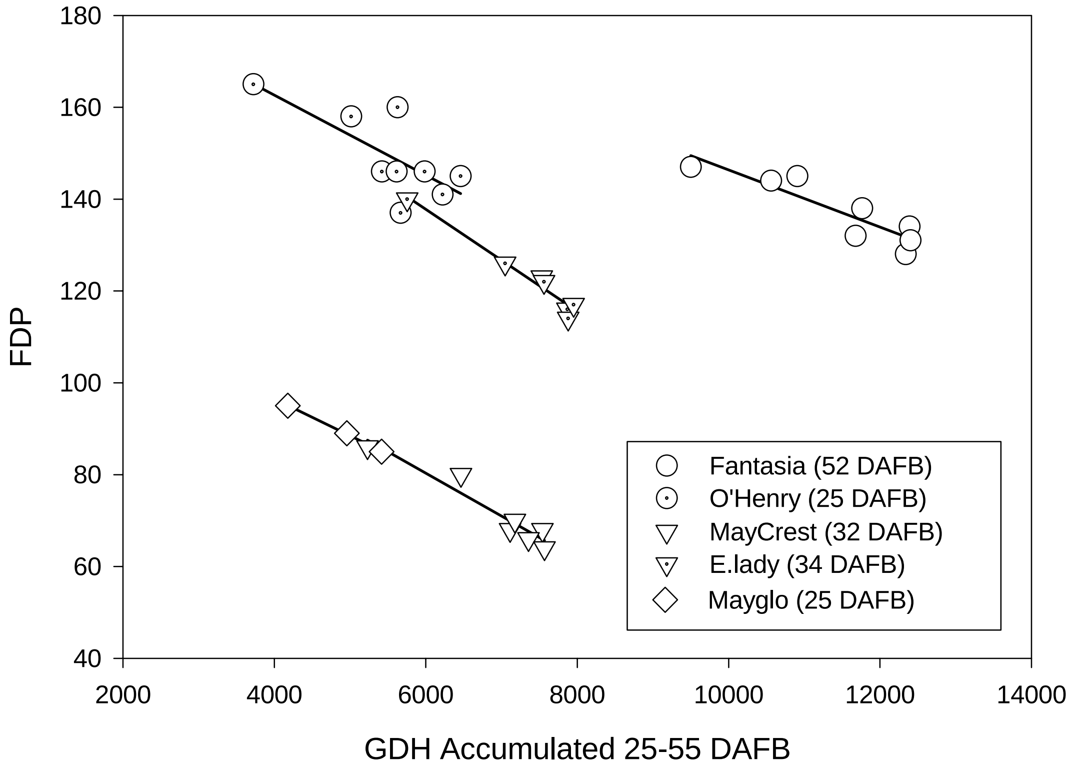

Fig. 5. Linear correlations between actual fruit development period (FDP) and growing degree hours (GDH) accumulated within 25-55 DAFB for 5 peach and nectarine cultivars grown in California.