Estimation of chilling and heat requirement of 'Chemlali' olive cultivar and its use to predict flowering date

Article *in* Acta horticulturae · May 2012

DOI: 10.17660/ActaHortic.2012.949.21

Sahli Ali
Institut national agronomique de Tunisie (INAT)

M.K. Aounallah
Institut national agronomique de Tunisie (INAT)

Mouna Aïachi Mezghani
Institution of Agricultural Research and Higher Education - Tunisia

Estimation of Chilling and Heat Requirement of 'Chemlali' Olive Cultivar and Its Use to Predict Flowering Date

A. Sahli, H. Dakhlaoui, M.K. Aounallah and R. Hellali
Institut National Agronomique de Tunisie
Tunis
Tunisia

M. Aïachi Mezghani
Institut de l'Olivier
Station Régionale de Sousse
Sousse
Tunisia

S. Bornaz
Ecole Supérieure des Industries Alimentaires de Tunis
Tunis
Tunisia

Keywords: flowering date, chilling requirement, heat requirement, base temperature, olive tree, 'Chemlali' cultivar

Abstract

Temperature is recognized as being the main variable regulating the timing of recurring biological phases. Many studies on the prediction of olive flowering have been developed. Some consider only the action of forcing temperature and estimate the heat requirements from a fixed date until flowering, while other consider also the action of low temperature and estimate chilling requirements for breaking of dormancy and heat requirements for flowering. The aim of the present paper is firstly the comparison of the flowering dates between years and to calculate the chilling requirements (CR) for breaking of dormancy and threshold temperature (T_{base}) and heat requirements (HR) for flowering of 'Chemlali' olive cultivar. Considering the high year-to-year variability of climate conditions, the observed flowering dates varied between 17 April and 7 May. For the same period, the simulated start day of chilling accumulation varied between 21 November and 10 January. The comparison of flowering dates observed in field conditions to those computed using identified parameters (CR, HR and T_{base}) revealed that the difference is small considering the nine years studied. Both the Mean Absolute Error (MAE) and the Root Mean Square Error (RMSE) of the comparison were less than 4 days, reflecting the weak errors in the estimation of the flowering model parameters. Also, this work confirms recent research which documented that the winter conditions in the period after chilling accumulation are highly correlated with yearly differences in flowering date for a given fruit tree specie and cultivar.

INTRODUCTION

Olea europaea L. 'Chemlali' olive orchards are a key component of oil production systems of Tunisia. Thus, the purpose of this study was to provide a better understanding of tree development and improve the description of its phenology in relation to climatic variability. In fact, knowledge and forecasting of the flowering behaviour provides useful data for both forecasting olive fruit yields (Galàn et al., 2004) and useful information to optimize crop management and to prevent allergic symptoms (Dominguez et al., 1993; Osborne et al.; 2000; Galàn et al., 2005).

Olive flower phenology is characterised by an annual cycle, including bud formation during the previous summer, dormancy during the cold period, budburst in late winter, and flower structure development from budburst to flowering in spring (Orlandi et al., 2005). The timing of phenological events is clearly correlated with different climatic factors including air temperature, soil temperature, precipitation, solar radiation, evapotranspiration, day length, snow cover, etc. Early experiences conducted by Hartmann (1953), Hartmann and Porlingis (1957) and Hackett and Hartmann (1963) showed that the olive (*Olea europaea* L.) requires winter chilling to induce flower-bud differentiation and olive flowering was very sensitive to the rates of temperature change during the vernalization period. This chilling requirement of the olive explains the absence of flowering in warm winter areas, making them unsuitable for olive production. After bud break, the time to flowering decreases as temperature increases. Furthermore, high temperatures shorten the flowering period (De Melo-Abreu et al., 2004).

Different phenoclimatological models based on the relationships between the phenological phases of the treating species and the various climatological parameters have been described in the literature. Temperature is recognized as being the main variable regulating the timing of recurring biological phases. Some models consider only the action of forcing temperature and estimate the heat requirements from a fixed date until flowering (Galàn et al., 2005; Orlandi et al., 2005), while others consider also the action of low temperature and estimate chilling requirements for breaking of dormancy and heat requirements for flowering (De Melo-Abreu et al., 2004; Orlandi et al., 2006). It is still not clear whether olive cultivars have specific chilling requirements for the breaking of dormancy and specific heat requirements for flowering or whether flowering date is determined basically by chilling requirements. On the other hand, the thermal model for determining the heat requirements of blooming consist essentially of establishing the heat accumulation, above a threshold (base) temperature, to which a tree is exposed from breaking of dormancy until flowering date. Up to now, it also still not clear if cultivars have a specific base temperature or if it is a bio-geographical characteristic parameter.

Up to now, no systematic calculation of chilling requirement and heat requirements of blooming has been developed for olive cultivars and new selections. Consequently, problems related to the inaccurate selection of cultivars with unsuitable chilling and/or heat requirements occur, affecting the olive production, especially in mild-winter climates and/or for early-flowering cultivars. Available information is scarce, and often dissimilar, because it is frequently based on different calculation methods and expressed as different measures, such as chill hours and chill units or growing degree days and growing degree hours, which makes its utilisation difficult.

The scarce data available for the olive specie show that the range of chilling requirements in some olive cultivars is from 200 to 500 chill units (De Melo-Abreu et al., 2004). Reported data concerning heat requirement to induce olive tree flowering was from 180 to 560 growing degree days (De Melo-Abreu et al., 2004; Galàn et al., 2005). These results indicate also that base temperature is a bio-geographical characteristic. Its value can change from 5 to 15°C depending on the growing region (De Melo-Abreu et al., 2004; Galàn et al., 2005; Orlandi et al., 2005).

The aim of this work is the calculation of the chilling requirements for breaking of dormancy and the heat requirement and base temperature for flowering of 'Chemlali' olive cultivars. Hence, the information obtained will provide a better understanding of the olive species regarding chill and heat requirements and flowering dates, which will be very useful for improving olive cultivation.

MATERIALS AND METHODS

Phenology modelling requires four essential steps (1) a data collection, (2) a model definition, (3) adjustments of the model to the data and (4) test the model hypothesis (Chuine et al., 1999).

Data Collection

The data base used in this study include the flowering dates observed over nine years in a traditional 'Chemlali' olive-growing region situated at Monastir province (center of Tunisia: latitude 35°40'N; longitude 10°49'E; elevation 15 m a.s.l.). The daily maximum and minimum temperature data for the entire period were supplied by the National Institute of Meteorology (INM) from their station situated near the olive grove.

Model Definition

The constructed phenoclimatological model assumes that there are two processes in the flower formation chain: a process leading to dormancy release which is dependent on chilling accumulation (CR in CU); and a forcing phase that depends upon the accumulation of thermal time (HR in GDH) above the base temperature (T_{base} in °C). In this modeling approach, daily maximum and minimum temperatures are input to the model. The hourly course of air temperature is described by a truncated sine wave in daylight and a logarithm decrease in temperature at night as suggested by Linvill (1990). Chilling accumulations were estimated in chilling unit (CU) following a sine function proposed by Linvill (1990). This sine function was defined according to the step function proposed by Richardson et al. (1974). The start day of chilling accumulation was considered to be the day after the last negative CU accumulation of every season as it was proposed by Richardson et al. (1974). When the required chilling (CR in CU) was accumulated, the forcing phase starts. To assess heat requirement for the flowering stage (HR in GDH), the asymmetric sine function proposed by Anderson et al. (1986) was chosen using the three cardinal temperatures: a base temperature (T_{base} in °C) which is a model parameter, an optimum temperature of 25°C, and a critical temperature of 36°C.

Model Calibration and Validation

As mentioned below, three constants are necessary to model full bloom: the CR[(1)] necessary to complete rest and the HR[(2)] above T_{base}[(3)] and subsequent to rest completion, required to reach full bloom. These constants are specific for each fruit cultivar and can readily be determined provided end of rest dates, full bloom dates and temperature data are available for several years. Unfortunately, end of rest dates are not readily available. Consequently, an optimization algorithm was developed by which these constants can be estimated. This algorithm is derived from the statistical approach presented by Ashcroft et al. (1977). In this numerical procedure, the first and the second constants (CU and T_{base}) are unknown and thus must be estimated. A good estimate introduces a smaller error into the calculation of the third constant (HR) than a poor estimate. Thus, the better the estimation of the two first constants, the smaller the coefficient of variation of the third constant. Accurate estimation is realized via the following steps:

- Using different set of chilling requirement (CR) and base temperature (T_{base}), the GDH accumulations until observed full bloom are calculated for all the studied years: the fixed chilling requirement (CR) is used to calculate dates for end of rest and the second constant (T_{base}) is used in the estimation of heat accumulation (HR) from the end of rest dates to full bloom dates.
- Using the fixed (CR) and (T_{base}) and the average value of the estimated (HR), full bloom dates is then recalculated for each year.
- Using the estimated days of flowering, the algorithm produced the statistics of the comparison between the modelled and measured values. The performance measures for comparing model predictions and observations used in this study were: (1) the mean bias error (MBE), (2) the mean-absolute error (MAE), (3) the root mean square error (RMSE) and (4) the slope (a) and the coefficient of determination (R^2) of the simple linear regression between estimated and observed flowering dates when forced through the origin ($FD_{estimated}=a \times FD_{observed}$). These results are presented for the validation of the model.

RESULTS AND DISCUSSION

Experimental Data Analysis

The *Olea* flowering season usually occurs in Monastir during the end of April (30/04) although, as Table 1 shows, the date varies from the second fortnight of April (17/04) to early May (07/05), depending on temperatures in the previous period. In fact, the characteristic dates corresponding to the studied period are shown in Table 1. The mean date of the beginning of chill unit accumulation being 14 December, although dates vary from year to year between 21 November to 10 January. Table 1 shows also that in Monastir, the maximum number of chilling units may be achieved from mid February to end of March. The mean value is 482 CU; however maximum chilling accumulation can vary from 136 to 482 CU.

Owing to the fact that some authors have determined 6-15°C to be the optimum base temperature for olive trees to flower, different base temperatures were tested. Table 1 shows the results of heat accumulation obtained when taken 8, 10, 12, 14 and 16°C as the possible thresholds and the chilling maximum accumulation date as the starting points of the heat accumulation period and 15 May as ending date. The average heat unit accumulation ranged from 16530 GDH calculated over a base temperature of 8°C to 3481 GDH calculated over a base temperature of 16°C. Moreover, heat accumulation results show relatively low range of coefficient of variation than chilling accumulation (11 versus 41%).

Parameters Identification and Validation

Examples of performance measures comparing predicted and observed flowering dates for some set of chilling requirement (CR) and base temperature (T_{base}) are reported in Table 2. From these results it is possible to note, for a fixed value of T_{base}, a particular trend of the performance measures in relation to CR value: the performance measure decrease (i.e., increase) at the CU increment, reach a minimum (i.e., maximum) value at CR=125 CU and rise again (i.e., fall again) with higher CR. The trend phenomena evidenced above by fixing T_{base} are carried out even when fixing CR (Table 2): the performance measures decrease (i.e., increase) at the T_{base} increment, reach a minimum value (i.e., maximum) at T_{base}=15°C and rise again (i.e., fall again) with higher T_{base}. Figure 1 shows the case of a fixed CR=125 CU. In the figure, the lower root mean square error (RMSE) and the higher determination coefficient (R^2) between observed and simulated flowering dates were carried out when considering a base temperature of 15°C.

This mathematical occurrence permits to identify CR, T_{base} and HR which minimize the inter-annual variances. In this manner, CR=125 CU, T_{base}=15°C and HR=2920 GDH were considered as the best values in relation to optimum values of performance measures recorded (Table 2). The linear regression without intercept of predicted and observed flowering dates was highly significant with both slope (a) and determination coefficient (R^2) close to unity (Fig. 2). Also, there is a reasonably good agreement between the model and the observation since the MBE, MAE and RMSE values were less than 3.6 days. Thus, these values of CR, T_{base} and HR can be considered as the more interpretative of the climate-tree relationships.

Our results support the finding of the earlier works of Hartmann and Porlingis (1957) and De Melo-Abreu et al. (2004) that olive cultivars have specific chilling requirements for the breaking of dormancy and specific heat requirements for flowering. However, in spite of the common methodology approach with De Melo-Abreu et al. (2004), comparisons between chilling and/or heat requirements results are difficult due to both the difference between calculation methods and units and the bio-climatic effects.

Concerning chilling calculation, those authors defined the chilling requirements as hours under 7°C ($CH_{De\ Melo}$) or as chilling units ($CU_{De\ Melo}$) by using a generalized Richardson et al. (1974) model. The range of chilling requirements for the studied olives cultivars was between 340 and 500 $CU_{De\ Melo}$ or between 150 and 300 $CH_{De\ Melo}$ below 7°C. It is well known that, depending on climatic conditions, the ratio between hours below 7°C and/or the CUs of any model of chilling unit accumulation could be very different. In fact, in many previous studies (Ruiz et al., 2007; Essoussi et al., 2005; Egea et al., 2003) high correlation between chilling models were reported. For example, in our field conditions, the following relations were obtained when comparing the Linvill (1990) chilling unit model to those used by De Melo-Abreu et al. (2004):

$$CH_{De\ Melo} = 0.24\ CU_{Linvill} - 1.74 \qquad (n=285;\ R^2 = 0.832)$$

$$CU_{De\ Melo} = 1.27\ CU_{Linvill} + 49.02 \qquad (n=285;\ R^2 = 0.932)$$

Concerning base temperature, the use of heat units to determine the most suitable threshold temperature for a specific olive growing region has been widely reported. Some researchers have determined the threshold temperatures of several olive growing sites by means of GDD computation and/or field or green house experimentation. Badr and Hartmann (1971) obtained a threshold temperature interval of 10-13°C for olive trees grown in a glasshouse. Alcalá and Barranco (1992) and Galán et al. (2005) determined a threshold temperature values between 10.0-12.5°C for the Spanish olive groves located in the termo-mediterranean bioclimatic belt. Besides, Orlandi et al. (2005) and Galán et al. (2005) reported that most of the Spanish olive groves located within the meso-mediterranean bioclimatic step showed threshold values between 5-9°C. Our result of a threshold temperature value about 15°C was in concordance with the optimum threshold temperature interval of 11-15°C obtained by Orlandi et al. (2005) for olive trees grown in the region of Sicily, Italy and confirm the fact that threshold temperature is related to bio-geographical characteristics.

More difficult is the comparison of our results on heat requirements with those obtained in others works (De Melo-Abreu et al., 2004; Galán et al., 2005). Difficulty is due to both the difference between calculation methods and units and the level of the threshold temperature. In fact, previous studies defined the heat requirements as GDD and it is well known that, depending on climatic conditions, the ratio between GDD and GDH could be very different. For example, Valentini et al. (2004) obtained for a same threshold temperature a ratio between GDD and GDH varying from 1:24 to 1:33 depending on the temperature level before flowering. Furthermore, heat units depend also on threshold temperature value. For example, Table 1 points out that when threshold temperature is increased by 2°C, heat accumulation intensity can be reduced by about 25% for the same period.

Predictive Relations

Several authors have used accumulated meteorological parameters as independent variables in statistical analyses of *Olea* pollen. The obtained results reveal a highly significant relationship between the start of the olive pollen season and the temperature and/or heat recorded during the months prior to the flowering period (Galán et al., 2001, 2005; Vazquez et al., 2003). Our results confirm this fact, revealing a direct effect of physiological heat on the onset of olive flowering (Fig. 3). Moreover, this study reveals a clear relationship between the date of chilling satisfaction and the remaining period to flowering (Fig. 4). Thus, flowering date depends on the temperature increase and its distribution (warmer winter, warmer spring or both) whether the reduced chilling accumulation will imply a later end of the dormancy, and thus, a potential delay of flowering.

CONCLUSIONS

Our results concerning flowering dates of the 'Chemlali' olive cultivar showed important differences between years. The range of its chilling and heat requirements was about, respectively 125 CU and 2920 GDH with a base temperature in the forcing period of 15°C. These results prove that the 'Chemlali' olive cultivar has good possibility for successful cultivation in areas with very mild winters. Besides, results obtained confirm the relationship between heat accumulation and flowering date but a higher correlation coefficient was obtained when using chilling satisfaction date as predictive parameter of the flowering date.

Besides, the statistical approach described herein is an adequate method for determining chilling and heat requirements and base temperature for flowering of olive tree when just bloom dates are available. With this method it is possible to assess the requirements of a great number of cultivars in regard to their biometeorological conditions and to single out those having interesting values. These cultivars can be used as parents for olive breeding program from a more reliable point of view because the selection based only on the blooming time does not ensure the largest requirements for both chilling and heat. On the other hand, regional maps indicating the capacity of the new areas to satisfy chilling and heat requirements would be of special interest in the study of the possibilities of growing this cultivar or new selected ones in a given area.

Therefore, the results obtained represent an advance with regard to the global knowledge of the olive species, concerning chilling requirements for breaking of dormancy and heat requirements for flowering in our field conditions.

Literature Cited

Alcalá, A.R. and Barranco, D. 1992. Prediction of flowering time in olive for the Cordoba Olive Collection. HortScience 27(11):1205-1207.

Anderson, J.L., Richardson, E.A. and Kesner, C.D. 1986. Validation of chill unit and flower bud phenology models for 'Montmorency' sour cherry. Acta Hort. 184:71-78.

Ashcroft, G.L., Richardson, E.A. and Seeley, S.D. 1977. A statistical method of determining chill unit and growing degree hour requirements for deciduous fruit trees. HortScience 12:347-348.

Badr, S.A. and Hartmann, H.T. 1971. Effect of diurnally fluctuating vs. constant temperatures on flower induction and sex expression in the olive (*Olea europaea* L.). Physiol. Plant. 24:40-50.

Chuine, I., Cour, P. and Rousseau, D.D. 1999. Selecting models to predict the timing of flowering of temperate trees: implications for tree phenology modelling. Plant Cell and Env. 22:1-13.

De Melo-Abreu, J.P., Barranco, D., Cordeiro, A.M., Tous, J., Rogadoe, B.M. and Villalobos, F.J. 2004. Modelling olive flowering date using chilling for dormancy release and thermal time. Agr. Forest Meteorol. 125:117-127.

Domínguez, E., Infante, F., Galán, C., Guerra, F. and Villamandos, F. 1993. Variation in the concentrations of airborne *Olea* pollen and associated pollinosis in Córdoba (Spain); a study of the ten years period 1982-1991. J. Investig. Allergol. Clin. Immunol. 3(3):121-129.

Egea, J., Ortega, E., Martinez-Gomez, P. and Dicenta, F. 2003. Chilling and heat requirements of almond cultivars for flowering. Environmental and Experimental Botany 50:79-85.

Essoussi, H., Trabelsi, F., Sahli, A., Ben Mimoun, M. and Hellalli, R. 2005. Etude de la répartition du froid en Tunisie. 12ème J. Sc. Rech. Agro. Hammamet, 8-9 décembre 2005, Tunisia. (in press).

Galán, C., Carinanos, P., García-Mozo, H., Alcazar, P. and Domínguez-Vilches, E. 2001. Model for forecasting *Olea europaea* L. airborn pollen in south-west Andalusia, Spain. Int. J. Biometeorol. 45:59-63.

Galán, C., García-Mozo, H., Vázquez, L., Ruiz, L., Díaz de la Guardia, C. and Trigo, M.M. 2005. Heat requirement for the onset of the *Olea europaea* L. pollen season in several sites in Andalusia and the effect of the expected future climate change. Int. J. Biometeorol. 49:184-188.

Galán, C., Vazquez, L., García-Mozo, H. and Domínguez, E. 2004. Forecasting olive (*Olea europaea*) crop yield based on pollen emission. Field Crops Res. 86:43-51.

Hackett, W.P. and Hartmann, H.T. 1964. Morphological development of buds of olive as related to low-temperature requirement for inflorescence formation. Bot. Gaz. 124:383-387.

Hartmann, H.T. and Porlingis, I. 1957. Effect of different amounts of winter chilling on fruitfulness of several olive varieties. Bot. Gaz. 119:102-104.

Hartmann, H.T.1953. Effect of winter chilling on fruitfulness and vegetative growth in the olive. Proc. Amer. Soc. Hort. Sci. 62:184-190.

Linvill, D.E. 1990. Calculating chilling hours and chill units from daily maximum and minimum temperature observations. HortScience 25:14-16.

Orlandi, F., Lanari, D., Romano, B. and Fornaciari, M. 2006. New model to predict the timing of olive (*Olea europaea*) flowering: a case study in central Italy. New Zealand J. Crop and Hort. Sci. 34:93-99.

Orlandi, F., Vazquez, L.M., Ruga, L., Bonofiglio, T., Fornaciari, M., Garcia-Mozo, H., Domínguez, E., Romano, B. and Galan, C. 2005. Bioclimatic requirements for olive flowering in two Mediterranean regions located at the same latitude (Andalucia, Spain

and Sicily, Italy). Ann. Agric. Environ. Med. 12:47-52.
Osborne, C.P., Chuine, I., Viner, D. and Woodward, F.I. 2000. Olive phenology as a sensitive indicator of future climatic warming in the Mediterranean. Plant Cell Environ. 23:701-710.
Richardson, E.A., Seeley, S.D. and Walker, D.R. 1974. A model for estimating the completion of rest for Redhaven and Elberta peach trees. HortScience 9:331-332.
Ruiz, D., Campoy, J.A. and Egea, J. 2007. Chilling and heat requirements of apricot cultivars for flowering. Environmental and Experimental Botany 61:254-263.
Valentini, N., Me, G., Spanna, F. and Lovisetto, M. 2004. Chilling and heat requirement in apricot and peach varieties. Acta Hort. 636 :199-303.
Vazquez, L.M., Galán, C. and Domínguez-Vilches, E. 2003. Influence of meteorological parameters on *Olea* pollen concentrations in Cordoba (south-western Spain). Int. J. Biometeorol. 48:80-93.

Tables

Table 1. Observed flowering date, chilling accumulation and heat accumulation over different base temperature, from maximum chilling accumulation date to 15 May.

	Flowering date	Chilling accumulation			Heat accumulation to 15/05 (GDH) over a base temperature of				
		Date of beginning	Date of maximum	Maximum amount					
	(dd/mm)	(dd/mm)	(dd/mm)	(CU)	8°C	10°C	12°C	14°C	16°C
Mean	30/04	14/12	28/02	482	16530	12542	8913	5839	3481
Minimum	17/04	21/11	12/02	136	13058	10139	7324	4892	2962
Maximum	07/05	10/01	26/03	776	18169	14001	10266	6994	4355
SD	7	15	14	197	2008	1405	927	598	402
CV (%)	-	-	-	41.0	12.2	11.2	10.4	10.2	11.5

Table 2. Chilling requirement, heat requirement and base temperature determination by different performance measures between estimated and observed flowering dates.

T_{base} (°C)		CR (CU) 50	75	100	125	150	175	200	225	250
12	GDH[x]	6983	6886	6783	6700	6653	6617	6529	6507	6474
	CV(%)	19.7	20.9	20.4	20.1	20.6	21.3	20.9	21.0	21.6
	BE[y]	4.1	4.2	4.7	3.2	3.3	3.6	3.1	3.3	3.4
	MAE	4.8	4.9	5.1	3.7	3.8	3.8	3.3	3.6	3.7
	RMSE	5.5	5.6	6.3	4.8	5.1	5.1	4.8	5.0	5.3
	Slope[z]	0.9654	0.9645	0.9607	0.9731	0.9721	0.9703	0.9737	0.9720	0.9711
	R^2	0.7059	0.7001	0.6330	0.7619	0.7201	0.7388	0.6983	0.7096	0.6790
13	GDH	5382	5318	5247	5193	5161	5138	5080	5067	5047
	CV(%)	19.0	20.2	19.7	19.5	20.0	20.7	20.5	20.6	21.0
	BE	3.4	3.6	3.3	2.8	2.8	3.3	2.9	2.9	3.1
	MAE	4.1	4.2	4.0	3.4	3.4	3.6	3.1	3.1	3.6
	RMSE	4.8	4.9	4.9	4.4	4.6	4.8	4.5	4.5	5.0
	Slope	0.9710	0.9701	0.9720	0.9768	0.9767	0.9721	0.9756	0.9756	0.9737
	R^2	0.7428	0.7544	0.7364	0.7677	0.7290	0.7637	0.7252	0.7252	0.6716
14	GDH	4056	4017	3969	3935	3914	3899	3863	3855	3844
	CV(%)	18.5	19.6	19.2	19.1	19.5	20.2	20.2	20.3	20.6
	BE	2.8	2.9	3.0	2.6	2.6	2.7	2.8	2.7	2.7
	MAE	3.7	3.8	3.9	3.2	3.2	3.3	3.0	2.9	3.1
	RMSE	4.3	4.4	4.7	4.2	4.2	4.4	4.3	4.3	4.5
	Slope	0.9766	0.9758	0.9747	0.9786	0.9785	0.9775	0.9765	0.9774	0.9775
	R^2	0.7590	0.7641	0.7134	0.7772	0.7572	0.7300	0.7402	0.7336	0.7167
15	GDH	2993	2970	2940	2920	2906	2896	2874	2869	2863
	CV(%)	18.6	19.5	19.1	19.1	19.5	20.3	20.2	20.3	20.6
	BE	2.1	2.2	2.3	2.0	2.0	2.3	2.1	2.3	2.3
	MAE	3.2	3.1	3.2	2.9	2.7	3.0	2.8	3.0	3.2
	RMSE	3.8	3.7	4.0	3.6	3.5	3.9	3.8	4.2	4.3
	Slope	0.9823	0.9814	0.9804	0.9834	0.9831	0.9804	0.9820	0.9801	0.9803
	R^2	0.7944	0.8165	0.7787	0.8222	0.7982	0.7745	0.7334	0.6910	0.7103
16	GDH	2165	2152	2133	2122	2113	2106	2093	2091	2087
	CV(%)	19.2	20.0	19.7	19.8	20.1	20.8	20.8	20.9	21.0
	BE**	1.7	1.8	1.6	1.4	1.7	1.7	1.4	1.4	1.7
	MAE	3.2	3.1	3.1	3.0	3.0	3.0	2.8	2.8	2.8
	RMSE	3.7	3.7	3.5	3.3	3.4	3.4	3.4	3.4	3.3
	Slope	0.9860	0.9851	0.9870	0.9880	0.9861	0.9861	0.9876	0.9876	0.9859
	R2	0.7749	0.7870	0.7966	0.8099	0.8086	0.8086	0.7490	0.7490	0.8003
17	GDH	1535	1528	1517	1511	1506	1501	1494	1492	1491
	CV(%)	20.7	21.3	21.0	21.1	21.4	22.1	22.0	22.0	22.1
	BE	1.1	1.2	1.2	1.2	1.2	1.2	1.7	1.7	1.4
	MAE	3.3	3.2	3.2	3.2	3.2	3.2	3.0	3.0	3.2
	RMSE	3.8	3.7	3.6	3.6	3.6	3.6	3.6	3.6	3.7
	Slope	0.9907	0.9898	0.9897	0.9897	0.9897	0.9897	0.9860	0.9860	0.9879
	R^2	0.7441	0.7510	0.7640	0.7640	0.7640	0.7640	0.7803	0.7803	0.7713

[x] GDH: the mean value of calculated heat accumulation from the end of rest dates to full bloom dates, CV(%): the coefficient of variation between years of the calculated heat accumulation from the end of rest dates to full bloom dates.

[y] MBE: the mean bias error, MAE: the mean-absolute error; RMSE: the root mean square error.

[z] a the slope and R^2 the coefficient of determination of the simple linear regression when forced through the origin.

Figures

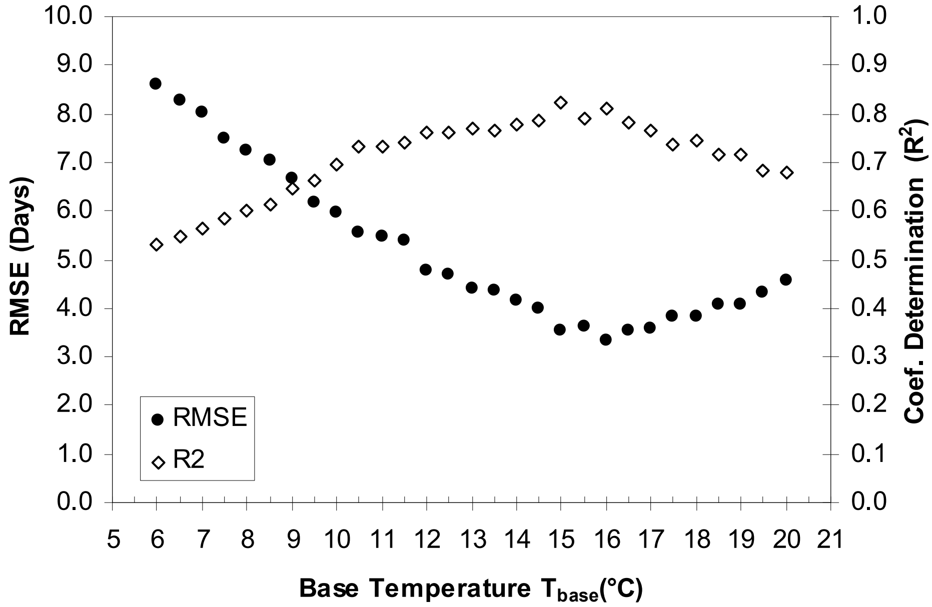

Fig. 1. Base temperature and heat requirement determinations by RMSE and R^2 in the case of fixed CR=125 CU.

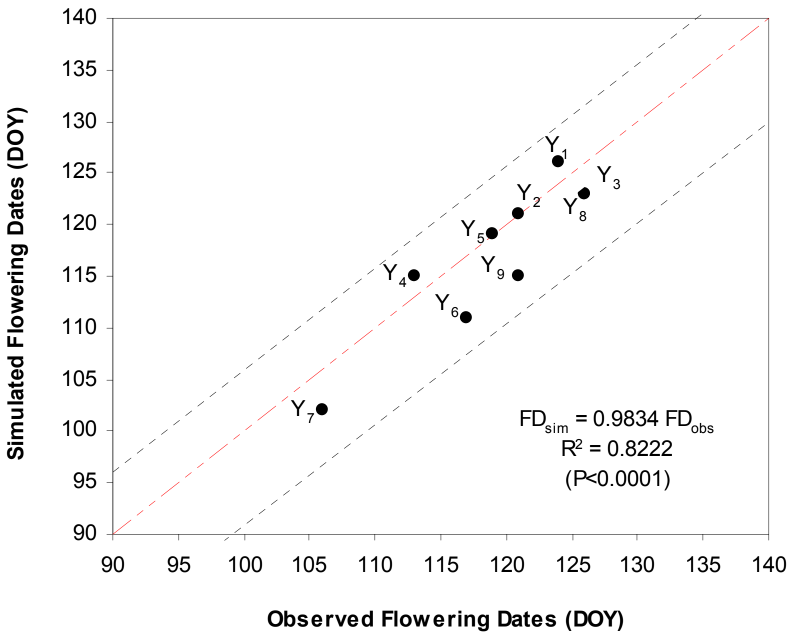

Fig. 2. Linear regression between the predicted and observed flowering date with CR=125 CU, T_{base}=15°C and HR=2920 GDH (Broken lines marks the interval of confidence of 95%).

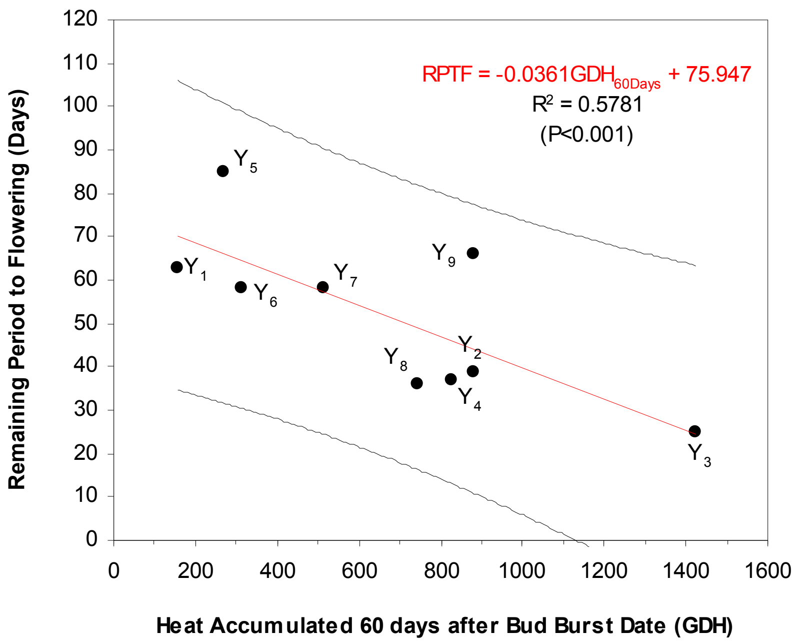

Fig. 3. Relationship between accumulated growing degree hours 60 days after chilling satisfaction and remaining period to flowering.

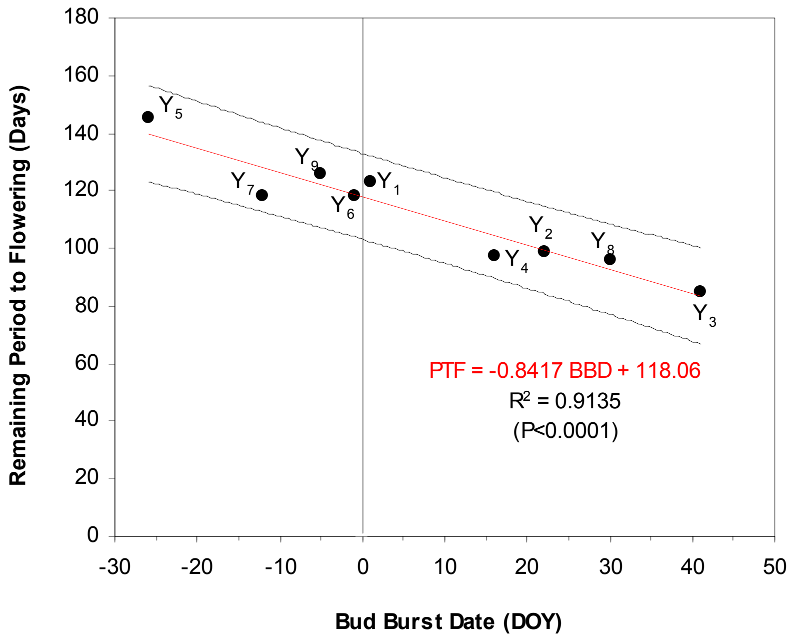

Fig. 4. Relationship between the date of chilling satisfaction and remaining period to flowering.