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SUMMARY – Almond (*Prunus amygdalus* Batsch) blooming date is determined by the temperatures during the dormancy period, from the onset of the winter rest to just before blooming. In this work we have developed a model to estimate the end of winter rest in almond based on the relation between the date of full bloom and the previous temperatures during several years and their application to the estimation of blooming chill and heat requirements.

Key words: *P. amygdalus*, chill requirements, heat requirements, dormancy breaking, blooming, temperature, breeding.

RESUME – *"Mise au point d'une méthode pour estimer la levée de la dormance des bourgeons floraux chez l'amandier". La date de floraison de l'amandier (*Prunus amygdalus *Batsch) est déterminée par les températures pendant la période de dormance depuis le commencement du repos hivernal jusqu'au le moment avant la floraison. Dans ce travail on a développé un modèle pour estimer la fin du repos hivernal chez l'amandier basé sur la relation entre la date de la pleine floraison et les températures antérieures pendant plusieurs années et son application à l'estimation des besoins en froid et en chaleur pour la floraison.*

Mots-clés : P. amygdalus*, besoins en froid, besoins en chaleur, fin de la dormance, floraison, température, amélioration.*

Introduction

Almond has been traditionally considered as the first fruit species to bloom. This trait limits its growing to regions with a low risk of spring frosts (Kester *et al*., 1990) because frosts may reduce or even completely destroy the crop. Consequently, most almond breeding programmes seek to obtain later blooming cultivars in order to avoid the damages produced by frosts, as these cultivars would bloom after the period of frequent frosts and also when temperatures are higher and thus more favorable for the pollination and fertilization processes (Kester and Asay, 1975).

Almond cultivars probably show the widest range of blooming dates among all the fruit species (Socias i Company and Felipe, 1992), due to the adaptation of the different cultivars to the distinct climatic environments of their original region. Consequently, almond breeders may choose the parents from among a wide variability of possibilities to retard bloom. Blooming date in almond is a quantitative trait (Grasselly and Gall, 1967), but some families originating from 'Tardy Nonpareil' show a locus (Ballester *et al*., 2001) with a dominant allele (*Lb*) which induces a very late bloom (Socias i Company *et al*., 1999).

Temperature is the climatic variable with the largest influence on the development of flower buds. Although the sequence of blooming of the different almond cultivars is maintained over the years with small shifts (Felipe, 1977), the exact blooming date depends on the evolution of the temperature during the winter to disrupt endodormancy (Lang *et al*., 1987). To accomplish this disruption, it is necessary to cover the chilling requirements to break the winter rest period (Tabuenca, 1972) and also the heat requirements to complete the bud development until flower opening (Tabuenca *et al*., 1972). The temperature variation during bloom also has an effect on its duration, making it possible to model bloom progression as a function of temperature (DeGrandi-Hoffman *et al*., 1996).

The objective of this work was to develop a model to estimate the dormancy breaking date in almond for chill and heat requirements estimation in almond. The chill and heat characterization may allow a more reliable election of cross-pollination cultivars as well as the selection of parents in a breeding programme with extreme values (Spiegel-Roy and Alston, 1979), in order to obtain very late blooming individuals.

Materials and methods

Plant material and data collection

The data on blooming dates to develop the model were collected for 'Marcona' and 'Guara' cultivars represented by three trees grafted on the peach seedling rootstock 'GF 305' in the National Almond Germplasm Collection placed at the Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA). This Center is located at 41°38'50" N and 0°53'07" E, at 220 m over sea level, with an average annual rainfall of 328.5 mm and average annual temperatures of 8.5°C (minimum), 14.5°C (medium) and 20.6°C (maximum). The dates of opening of 50% of flowers (F^{50}) were recorded during the blooming seasons from 1994 to 2000. The data on daily maximum, minimum and mean temperatures were obtained from a meteorological station placed in a nearby plot, using only the data from the months previous to bloom, from October to March for the same years.

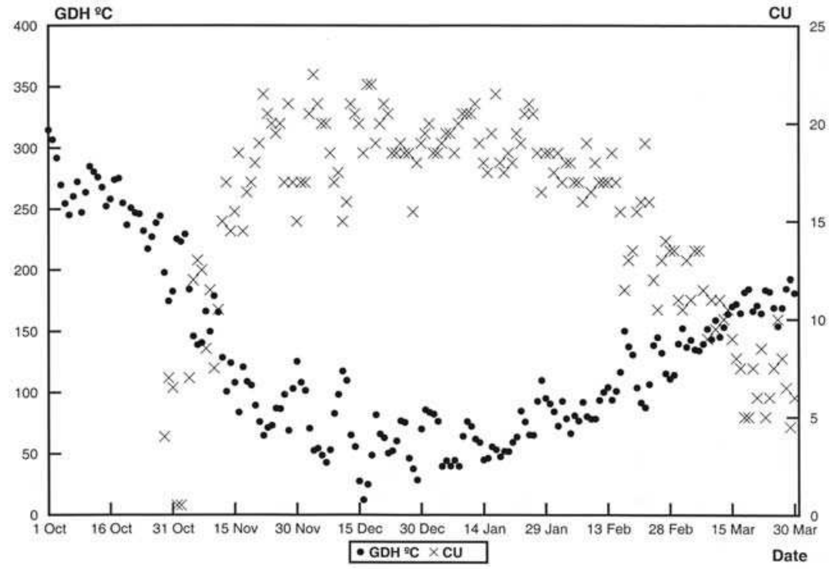

Fig. 1. Mean daily chill units (CU) and growing degree hours (GDH°C) in Celsius degrees for the period 1994-2000 at Zaragoza (Spain).

Development of the method to assess dormancy breaking

The method was based on the relationship between the temperatures occurring during different periods of time previous to bloom, and their effect on the date of full bloom by distinguishing the different effect of the temperatures during the two periods of endodormancy and ecodormancy.

The method consists of the calculation of correlation coefficients between two matrices, one with the flowering dates of each cultivar for every year considered, and the other with the averages of the daily temperatures of a defined period (p) of different days of length. The lengths of the periods (p) used in this work were 5, 10, 15, 20, 25 and 30 days and the daily temperatures used were T_{dy}, $T_{m\ dy}$ and $T_{M\ dy}$ (Table 1). The average temperature values were computed for every day since the beginning of October until the bloom of each cultivar.

Table 1. Symbols of the method

Symbol	Meaning	Unit
n	Number of years for the study	Years
y	Year	Years
p	Period of days of each mobile interval	Days
d	Days from October 1	Days
x	Day of the end of the analysis (February 28 = 179)	Days
$F^{50}_{v\,y}$	Date in which cultivar *v* shows 50% of the flowers opened in the year *y*	Days
$\overline{F}^{50}_{v}$	Mean date in which cultivar *v* shows 50% of the flowers opened for the years studied	Days
T_{dy}	Daily mean temperature for the day d in the year y	°C
T_{mdy}	Daily minimum temperature for the day d in the year y	°C
$T_{M\,dy}$	Daily maximum temperature for the day d in the year y	°C
T_{pdy}	Mean of the daily mean temperature for the previous period of length p of day d in the year y	°C
$T_{mpd\,y}$	Mean of the minimum temperatures for the previous period of length *p* for the day *d* in the year *y*	°C
$T_{M\,pdy}$	Mean of the maximum temperatures for the previous period of length *p* for the day *d* in the year *y*	°C
$\overline{T}_{pd}$	Mean of the mean temperature for the previous period of length p of a day d	°C
$\overline{T}_{mpd}$	Mean of the minimum temperature for the previous period of length p for the day d	°C
$\overline{T}_{M\,pd}$	Mean of the maximum temperature for the previous period of length p for the day d	°C
r_{pdv}	Pearson correlation coefficient at day d between mean temperatures of a previous period of length p and the blooming date for the cultivar v	

The flowering matrix was developed as follows:

$\boldsymbol{F^{50}_{v\,y}}$	$F^{50}_{v\,1}$	$F^{50}_{v\,2}$	$F^{50}_{v\,3}$	$F^{50}_{v\,4}$	$F^{50}_{v\,5}$	....	$F^{50}_{v\,n}$

The temperature matrix was developed as follows for T_{dy}, being developed similarly for T_{mdy} and T_{Mdy}:

$\boldsymbol{T_{p\,1\,y}}$	$T_{p\,1\,1}$	$T_{p\,1\,2}$	$T_{p\,1\,3}$	$T_{p\,1\,4}$	$T_{p\,1\,5}$	....	$T_{p\,1\,n}$
$\boldsymbol{T_{p\,2\,y}}$	$T_{p\,2\,1}$	$T_{p\,2\,2}$	$T_{p\,2\,3}$	$T_{p\,2\,4}$	$T_{p\,2\,5}$	....	$T_{p\,2\,n}$
$\boldsymbol{T_{p\,3\,y}}$	$T_{p\,3\,1}$	$T_{p\,3\,2}$	$T_{p\,3\,3}$	$T_{p\,3\,4}$	$T_{p\,3\,5}$	....	$T_{p\,3\,n}$
....	....	....	....	....	....	....	....
$\boldsymbol{T_{p\,x\,y}}$	$T_{p\,x\,1}$	$T_{p\,x\,2}$	$T_{p\,x\,3}$	$T_{p\,x\,4}$	$T_{p\,x\,5}$	....	$T_{p\,x\,n}$

The correlation coefficients were calculated according to the formulae:

$$r_{pxv} = \frac{\sum_{y=1}^{n} T_{pxy}.F^{50}{}_{vy} - n.\overline{T}_{px}.\overline{F}^{50}{}_{v}}{\sqrt{\left(\sum_{y=1}^{n} T_{pxy}{}^{2} - n.\overline{T}_{px}{}^{2}\right).\left(\sum_{y=1}^{n} F^{50}{}_{vy}{}^{2} - n.\overline{F}^{50}{}_{v}{}^{2}\right)}}$$

where:

$$\overline{T}_{pd} = \frac{\sum_{y=1}^{n} T_{pdy}}{n} \quad ; \quad \overline{F}^{50}{}_{v} = \frac{\sum_{y=1}^{n} F^{50}{}_{vy}}{n}$$

The correlation coefficient measures the strength of the relationship between the temperature of the defined period and the date of F^{50} for each cultivar, the coefficients being over 0.754 significant at the 5% level for 5 df (n-2) using the *t* test.

Results

A correlation coefficient between the date of full bloom and the temperatures is obtained every day for each of the different lengths of the mobile periods and for each temperature (maximum, mean, and minimum). With these daily values it is possible to draw the evolution of the coefficient values, as shown in Figs 2 and 3 for 'Marcona' and 'Guara' cultivars' with each of the six different day intervals used to design the matrices.

The correlation coefficients are shown for each period length with the three daily temperatures considered. Although the values for the three temperatures follow a similar pattern, they do not have the same magnitude or the same sign, positive or negative, for any given day during the rest period. During this period, high temperatures retard the rest outbreak and, consequently, the bloom date; as a consequence, correlation coefficients are positive, as shown in the initial portion of all the figures. Once the rest is broken, high temperatures accelerate bud development, thus advancing the bloom date. As a consequence, correlation coefficients are negative, as observed in the final portion of all the figures. The date of rest outbreak is assumed to be the day in which the first negative coefficients are significant (< -0.754). The magnitude of the correlation coefficients and the number of significant coefficients was higher when using the daily mean and maximum temperatures and lower when using the minimum temperatures. As a consequence, to estimate the end of the rest period, only the correlation coefficients obtained with the mean temperatures were used.

The longer the mobile period used to obtain the correlation coefficients (from 5 to 30 days), the smoother the evolution of the value of these coefficients, as shown in Fig. 2 and 3. This smoothness may be explained by the fact that the longer the period, the lesser the effect of extreme occasional temperatures occurring during that period. On the other hand, the longer the mobile period, the lower the values of the correlation coefficients. Thus, the mobile periods of 15 and 20 days generate the largest amount of significant coefficients.

As a result, the mobile period of 15 days was selected as the optimum to estimate the end of winter rest because the correlation coefficients obtained with this period show a uniform evolution (Figs 2-C and 3-C). The average of dormancy breaking for the seasons from 1994 to 2000 was December 2 for 'Marcona' whereas in 'Guara' it was December 4.

Discussion

To estimate the chill and heat requirements of any cultivar, besides climatic data, three chronological dates are needed: the chill accumulation start date, the dormancy breaking date and the full bloom date (F^{50}). The chill accumulation start date is determined by the annual temperature pattern and is considered to be the day when CU measured according to the Utah model shifts from negative to positive. The full bloom date is fixed by visual observation in the field. Unfortunately, the dormancy breaking date is complicated to assess, and its establishment will be conditional for the chill and heat requirement calculation because calculations are made until or from that date.

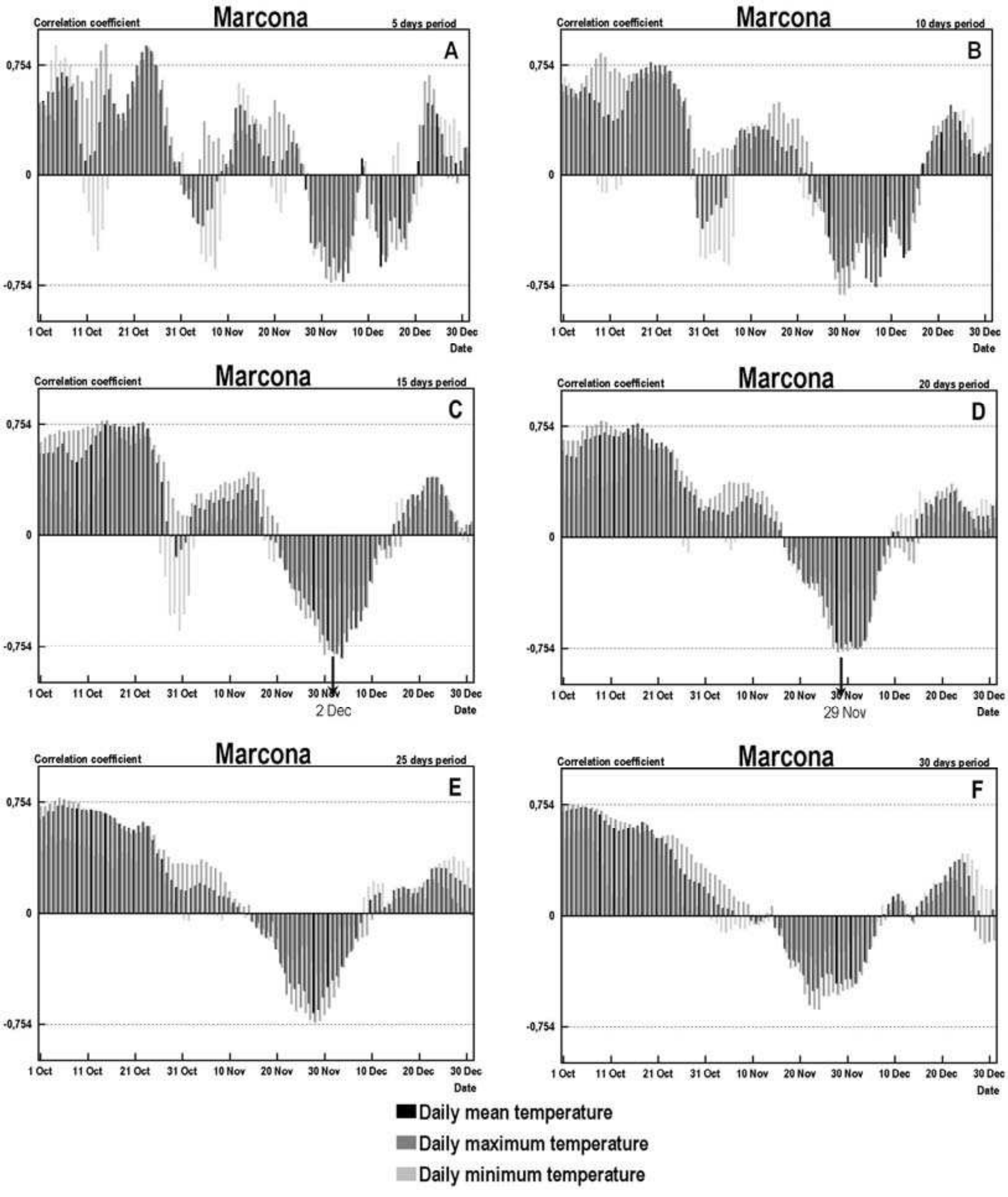

Fig. 2. Establishment of dormancy breaking of 'Marcona' almond by analyzing the evolution of the correlation coefficients between the temperatures in different subsequent periods and full bloom for the 1994 to 2000 seasons. (A) Periods with amplitude of 5 days; (B) Periods with amplitude of 10 days; (C) Periods with amplitude of 15 days; (D) Periods with amplitude of 20 days; (E) Periods with amplitude of 25 days; (F) Periods with amplitude of 30 days.

A method often used to estimate the end of the winter rest is based on the dry weight increase of the flower buds after their permanence in a temperate chamber. However, this method requires the manipulation of plant material, which becomes sometimes tedious, and causes an abrupt change of the environmental conditions of the buds. Furthermore, this method is based only on the behavior of the flower buds, and, most often, on the temperature data of a single year.

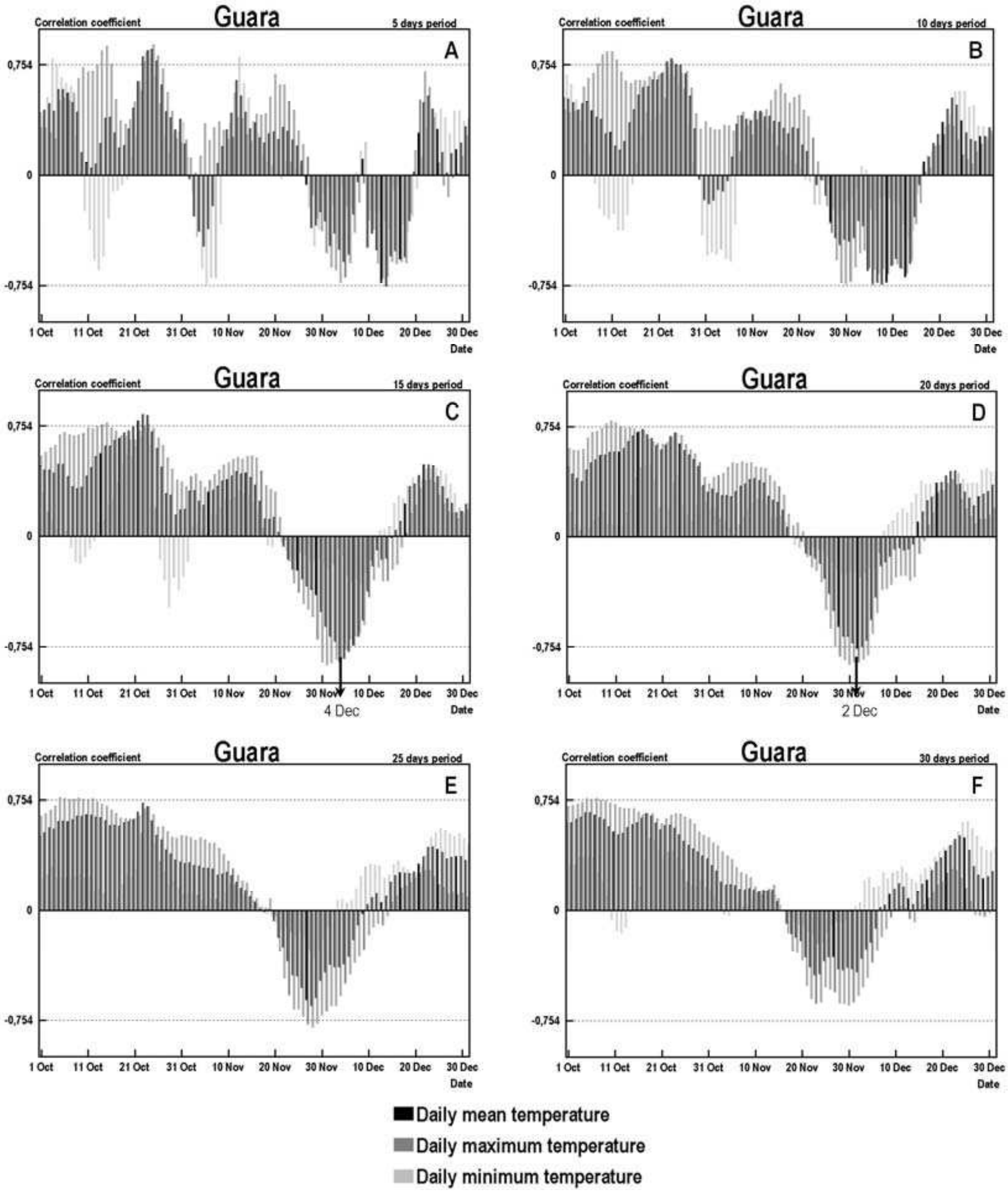

Fig. 3. Establishment of dormancy breaking of 'Guara' almond by analyzing the evolution of the correlation coefficients between the temperatures in different subsequent periods and full bloom for the 1994 to 2000 seasons. (A) Periods with amplitude of 5 days; (B) Periods with amplitude of 10 days; (C) Periods with amplitude of 15 days; (D) Periods with amplitude of 20 days; (E) Periods with amplitude of 25 days; (F) Periods with amplitude of 30 days.

On the other hand, the method developed in this work is very simple and helpful to assess the dormancy breaking date. The modification introduced over the previous model (Tabuenca *et al.*, 1972) consists of the utilization of overlapped periods instead of serial periods of days, and has shown a higher precision in assessing the dormancy outbreak. With our method 18 correlation coefficients per day are obtained (six lengths and three daily temperatures), which gives more information on the effect of the temperatures of the following period on the bloom date. Tabuenca and Herrero (1966) only obtained the correlation coefficients of days 1 and 15 of each month, whereas Tabuenca *et al.* (1972) only obtained the correlation coefficients of the first day of each consecutive period, with a very small number of coefficients in both cases. The use of overlapped periods allows a much more precise estimation of the end of the winter rest (Figs 2 and 3) and gives much more information on the behavior of any cultivar in a given climate.

The dormancy breaking date obtained by the proposed method, based on the behavior on the intact plant material, under the climatic conditions of several years, can be used in the estimations of the chilling and heat requirements because the estimations deduced from a single year are not reliable (Tabuenca, 1972 and 1975).

Conclusions

The estimation of the end of the winter rest period of a cultivar by the model of correlation coefficients between the winter temperatures of mobile periods of 15 or 20 days and the dates of full bloom is very useful and reliable to calculate its chilling and heat requirements. With this method it is possible to assess quickly the requirements of a great number of cultivars and to single out those having extreme values.

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