Prediction of Flowering Time in Olive for the Cordoba Olive Collection

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Abstract. The date of full bloom for olive (*Olea europaea* L.) tree varieties planted in the World Collection in Córdoba, Spain, has been determined from 10 years of data. The full bloom dates were analyzed using three methods to develop a model predicting flowering time. The method of heat units accumulated before flowering was the most accurate. The heat accumulation periods were determined from phenological and temperature data. Prediction methods were evaluated for the earliest-flowering variety, a model variety representing the mean values for the collection, and the latest-flowering variety. The most appropriate threshold temperature for heat accumulation has been confirmed to be 12.5C; it can be used to predict the flowering time in olive.

For most deciduous fruit trees, floral initiation occurs in the summer, with subsequent winter low temperatures satisfying the chilling requirement. Hartmann (1951) suggested that low temperatures played a fundamental role in floral initiation in olive, which occurs after the winter cold period. However, recent research (Navarro et al., 1990; Rallo and Martin, 1991) indicated that floral initiation in olive begins in late summer and early fall as in the other fruit trees. Taking this recent information into consideration, we have evaluated various time periods for determination of heat accumulation until flowering for each olive variety in the

Córdoba olive collection. The cold and heat requirements for olives are now only partly defined (Hartmann and Porlingis, 1957). Hartmann and Whisler (1975) determined that 12.5C was the optimum temperature for

Table 1. Number of days with a mean temperature >12.5C and heat units that have to accumulate before flowering for the earliest and latest olive variety and the mean of the Córdoba World Collection.

Criterion	No. ² days with mean temp >12.5C	Accumulated heat units
Earliest variety	56 ± 3.46 ^y	148 ± 21.6
Mean of collection	61 ± 3.50	185 ± 12.8
Latest variety	55 ± 4.19	173 ± 13.2

²Each number is the mean of 10 years.

^yS.D.

flowering of olive trees grown in a greenhouse. The formation of floral buds was normal with this temperature, and it was inhibited above 15C. The 12.5C temperature is higher than 7C, which is considered the optimum temperature for most fruit trees for dormancy release.

The objectives of this paper were to: 1) determine the most appropriate threshold temperature for olive anthesis, and 2) evaluate flowering time prediction models based on the air temperatures recorded during the

Fig. 1. Coefficients of variation of the number of days with a higher mean temperature than the threshold for various dates of beginning of heat accumulation, and for various threshold temperatures for anthesis in olive. Data are for the mean of the collection.

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Table 2. Correlation coefficients between the flowering time of various olive varieties and the mean maximum temperature of selected months.

Variety	January	February	March	April	March and April	February, March, and April	Regression equations for March and April ²
Borriol de Castellón	0.15	-0.29	-0.53	-0.90	-0.93	-0.93	$f = 140.23 - 1.75T_m - 3.31T_a$ ($r^2 = 0.86$)
Cañivano Negro	0.17	-0.30	-0.61	-0.89	-0.95	-0.95	$f = 137.88 - 2.11T_m - 2.72T_a$ ($r^2 = 0.90$)
Gordal Sevillana	0.10	-0.14	-0.58	-0.82	-0.94	-0.94	$f = 144.5 - 2.54T_m - 2.46T_a$ ($r^2 = 0.87$)
Manzanilla de Sevilla	0.22	-0.24	-0.50	-0.80	-0.88	-0.88	$f = 140.98 - 2.19T_m - 2.59T_a$ ($r^2 = 0.77$)
Picudo	0.29	-0.22	-0.50	-0.95	-0.97	-0.97	$f = 129.91 - 1.25T_m - 3.01T_a$ ($r^2 = 0.93$)
Ascolana Tenera	0.23	-0.07	-0.50	-0.93	-0.95	-0.96	$f = 134.91 - 1.26T_m - 3.19T_a$ ($r^2 = 0.90$)
Hojiblanca	0.24	-0.20	-0.53	-0.90	-0.92	-0.92	$f = 133.93 - 1.49T_m - 2.86T_a$ ($r^2 = 0.85$)
Picual	0.27	-0.16	-0.43	-0.82	-0.87	-0.87	$f = 134.58 - 1.73T_m - 2.67T_a$ ($r^2 = 0.76$)
Moraiolo T. Corsini	0.08	-0.08	-0.58	-0.79	-0.91	-0.92	$f = 123.15 - 1.93T_m - 1.79T_a$ ($r^2 = 0.83$)
Verdial de Huelva	0.07	-0.17	-0.64	-0.77	-0.93	-0.94	$f = 135.32 - 2.46T_m - 1.92T_a$ ($r^2 = 0.87$)
Mean of collection	0.20	-0.20	-0.57	-0.77	-0.89	-0.89	$f = 142.43 - 2.53T_m - 2.35T_a$ ($r^2 = 0.79$)

²f: no. days from 1 Apr. until the date of full bloom; Tm: mean maximum temperature of March; Ta: mean maximum temperature of April; r^2 : coefficient of determination.

Fig. 2. Mean cv and SE of the number of days with a higher mean temperature than the threshold for all dates of beginning of heat accumulation evaluated and various threshold temperatures for anthesis in olive. Data are for the mean of the collection.

Fig. 3. Coefficients of variation of the number of days with a mean temperature $> 12.5^{\circ}\text{C}$ for various dates of beginning of heat accumulation in the earliest-flowering olive variety, the mean of the collection, and the latest-flowering variety. The data were obtained by the number-of-days method.

heat accumulation period.

Flowering time has been recorded for olive trees planted in the World Collection in Córdoba, which is composed of >170 varieties obtained from various countries (Caballero and Eguren, 1986). Flowering dates were taken in 1973, 1976, 1977, 1978, 1982, 1983, 1985, 1986, 1987, and 1989. Daily mean, maximum, and minimum temperatures were obtained from the Córdoba airport for 1973-89. The airport is located 2 km from the World Collection. Phenological data were taken on all 170 varieties every 3 days as described by Barranco et al. (1992).

The three methods described by Tabuenca and Herrero (1965) were used to predict the

flowering time based on: 1) Number of days with a higher mean temperature than the threshold temperature for heat accumulation, starting at the date the heat accumulation period began until full bloom. 2) Heat units accumulated starting at the date of beginning of heat accumulation until full bloom. The heat units were calculated as the difference between the daily mean temperature and the threshold temperature for anthesis. Methods 1 and 2 require that the number of days and the heat units accumulated (until full bloom) must be constant. 3) Correlation between the mean maximum temperature of selected months and the date of full bloom.

Method 1, number of days, was used to

determine the threshold temperature for anthesis. First, the number of days with mean temperatures higher than the threshold for anthesis and their coefficients of variation (cv) were determined for the whole collection, assuming 10, 11, 12, 12.5, 13, or 14°C as the threshold temperature for anthesis and taking various dates as the starting points for the heat accumulation period. A graphic representation of the cv was obtained from December to April each 15 days. In the graphic representation of the cv in relation to threshold temperatures, Castonguay et al. (1984) obtained curves composed of two characteristic segments: in the first one, a rapid drop of the cv is observed; in the second, the decline is much less pronounced. The point of inflection is defined as the optimum statistic threshold. The interpretation of these curves is somewhat subjective.

Various dates to use as the start of the measurement period for methods 1 and 2 were evaluated for the first variety to flower, the mean of the collection, and the last variety to flower. Those dates that result in the lowest cv in prediction of flowering are preferred (Tabuenca and Herrero, 1965). For method 3, simple and multiple correlations between temperatures of different periods of time and flowering were evaluated. The regression equation that had the highest coefficient of determination was identified for each variety.

Flowering time. The mean flowering date of the collection (defined as the date at which 50% of the varieties of the collection have reached full bloom) varied over the years. The earliest mean flowering date in 1977 was 23 days earlier than the latest mean flowering date in 1976. The mean flowering date of the collection for all the years studied was 10 May. The duration of flowering (defined as the number of days between the full bloom date of the first and the last varieties) varied between 7 days in 1986 and 21 days in 1977, with 14 days as the mean for the years studied. These responses vary as a result of temperature influence on commencement and duration of flowering.

Threshold temperature for anthesis. The method based on the number of days with a higher mean temperature than the threshold for anthesis was used to evaluate different dates for the beginning of heat accumulation (Fig. 1). Results shown are for the mean of

Fig. 4. Coefficients of variation of accumulated heat units for various dates of beginning of heat accumulation in the earliest-flowering olive variety, the mean of the collection, and the latest-flowering variety. The data were obtained by the accumulated heat units method.

Table 3. Difference between the predicted and actual mean flowering date of the World Olive Collection in Córdoba, using three methods of prediction.

Method	Deviation from real flowering date (days) ²	SD
No. days Tm >12.5C ³	2.8	±4.96
Accumulated heat units	1.5	±2.25
Mean maximum temp	3.1	±2.29

²Each number is the mean of 10 data.

³Tm: mean temperature.

the collection. Coefficients of variation were higher for the threshold temperatures for anthesis of 13 and 14C than for the threshold temperatures for anthesis of 10, 11, 12, and 12.5C. The lowest cvs were on 1 and 15 Jan. (Fig. 1).

The mean and SE of the cv for all the possible threshold temperatures for anthesis were averaged across all dates (Fig. 2). The lowest mean cv was obtained for the threshold temperature for anthesis of 12.5C. Thus, we conclude that 12.5C is the most appropriate threshold temperature for anthesis in olive. There is heat accumulation above that temperature, and it possibly also has some chilling effect. Hartmann and Whisler (1975) concluded that the flowering of the olive tree was promoted more at 12.5C than at any other constant temperature. These authors considered 12.5C as optimal for chilling completion and heat accumulation for anthesis.

Number-of-days method. The date of the lowest cv, 1 Jan., was the date at which the earliest-flowering variety ('Borriol de Castellón') began heat accumulation (Fig. 3). The date at which a model variety illustrative of the mean values for the collection began to respond to heat was 15 Jan. Finally, 1

Mar. was the date at which the latest-flowering variety ('Verdial de Huevar') began heat accumulation. Table 1 shows the number of days with a mean temperature >12.5C that has to accumulate before flowering. The latest-flowering variety needs fewer days with mean temperatures >12.5C compared with the mean for the whole collection because of its late date of heat accumulation onset.

Accumulated heat units method. The date at which the earliest-flowering variety began heat accumulation was 1 Feb. This was also the date at which a model variety reflecting the mean values for the collection began heat accumulation. The latest-flowering variety began accumulation of heat units on 15 Mar. The heat unit requirements of the model variety and the latest-flowering variety were higher than the earliest-flowering variety (Table 1). The differences in the predicted date of beginning of heat accumulation between methods 1 and 2 are 15 days for the mean of the collection and the last variety to flower and 1 month for the first variety to flower (Figs. 3 and 4). These differences are probably due to the lower accuracy of the number-of-days method.

Mean maximum temperature method. Our earlier work showed better predictive capability when the mean maximum temperature of the month was used instead of the mean temperature or the mean minimum temperature of the month (unpublished). The explanation is that the maximum temperatures are nearer the optimum growing temperatures in this time of year (Tabuenca and Herrero, 1965). Correlation coefficients were calculated between the mean maximum temperature of January, February, March, April, and combinations between them, and the flowering time of 10 olive varieties (Table 2). Positive and low correlation coefficients

were obtained for all the varieties in January. Thus, the olive tree continues to accumulate hours of low temperatures in January. The correlation coefficients were negative and low for all the varieties in February. The negative and higher correlation coefficients obtained in March suggest that heat accumulation in March had more effect than in February on flowering time. April is the month in which an increase of the maximum temperature had the greatest influence on flowering time (Table 2).

The highest correlation coefficients were obtained with the multiple correlation between the flowering time and the mean maximum temperature of March and April (Table 2). When the mean maximum temperature of February was included in the analysis, the correlation coefficients did not increase significantly. The regression equations enable prediction of the date of full bloom of each variety based on the mean maximum temperatures of March and April.

The most accurate prediction of date of full bloom for the mean of all varieties in the collection was accomplished with the method of accumulated heat units. With this method, the deviation from the real flowering date was about half that for the other two methods (Table 3).

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