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Increase in the chill and heat requirements for blooming of the new almond cultivars

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Abstract. Almond (*Prunus amygdalus* (L.) Batsch) has been considered the earliest blooming fruit species, although it has become the species with the widest blooming range of all deciduous fruits after the release of the newly bred cultivars. Blooming of any cultivar takes place once its chill and heat requirements have been satisfied. Estimation of chill and heat requirements for blooming is very complex, due to the difficulty of assessing the theoretical date of transition from endodormancy to ecodormancy, when quantification of chill requirements ends and quantification of heat requirements starts. This date may be assessed by a statistical method based on the different effect of temperatures on blooming date depending on their incidence during endodormancy or ecodormancy. This method has been applied to obtain the chill and heat requirement of the almond cultivars released by the Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA). G-2-25 is an elite selection from the Zaragoza breeding programme, characterized by a very late blooming time. It shows 503 Utah CU, much higher than the other almond cultivars released by the CITA, such as 329 CU in 'Felisia' or 353 CU in 'Aylés' and 'Belona'. It also shows a very high heat requirement, with 10233 Utah GDHºC, higher than 7221 GDHºC in 'Blanquerna' or 9465 GDHºC in 'Felisia'. These results show that the combined increase in chill and heat requirements in a genotype may ensure a late blooming season in all climatic conditions.

Keywords. *Prunus amygdalus* – Chill units – Growing degree hours – Endodormancy break – Breeding – Adaptability.

Augmentation des besoins en froid et en chaleur pour la floraison des nouveaux cultivars d'amandier

Résumé. *L'amandier (*Prunus amygdalus *(L.) Batsch) a été considéré l'espèce fruitière à floraison la plus précoce, bien qu'elle soit devenue l'espèce avec l'intervalle de floraison le plus étendu de toutes les espèces fruitières après l'introduction des nouveaux cultivars améliorés. La floraison de tout cultivar vient quand les besoins en froid et en chaleur ont été satisfaits. L'estimation des besoins en froid et en chaleur pour la floraison est très complexe, étant donné la difficulté d'établir la date théorique de transition entre l'endo-dormance et l'éco-dormance, quand la quantification des besoins en froid finit et que commence la quantification des besoins en chaleur. Cette date peut être déterminée par une méthode statistique basée sur l'effet différent des températures sur la date de floraison en fonction de leur incidence pendant l'endo-dormance ou l'éco-dormance. On a appliqué cette méthode pour obtenir les besoins en froid et en chaleur pour les cultivars introduits par le Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA). G-2-25 est une sélection élite du programme d'amélioration génétique de Zaragoza, caractérisée par une date de floraison très tardive. Elle a montré 503 Utah CU, beaucoup plus que les autres cultivars d'amandier obtenus par le CITA, comme 329 CU pour 'Felisia' ou 353 CU pour 'Aylés' et 'Belona'. Elle a aussi montré de grands besoins en chaleur, avec 10233 Utah GDHºC, une valeur beaucoup plus élevée que 7221 GDHºC pour 'Blanquerna' ou 9465 GDHºC pour 'Felisia'. Ces résultats montrent qu'une augmentation combinée de besoins élevés en froid et en chaleur peut assurer, pour un génotype, une époque de floraison tardive dans toutes les conditions climatiques.*

Mots-clés. Prunus amygdalus *– Besoins en froid – Besoins en chaleur – Fin de l'endo-dormance – Amélioration – Adaptabilité.*

Introduction

Almond shows the widest range of blooming dates among all the fruit and nut species (Socias i Company and Felipe, 1992). Blooming date is considered dependent on the winter progression of temperatures affecting the different stages of dormancy (Lang *et al*., 1987). However, the sequence of blooming of the different almond cultivars is maintained over the years with small shifts (Felipe, 1977).

During endodormancy, the first dormancy stage, buds are accumulating chilling and their growth is hardly perceptible, although constant. Once the chilling accumulation concludes, ecodormancy starts. At this stage, flower bud growth mostly depends on heat accumulation, showing a correlation with favorable warm temperatures (Kester and Gradziel, 1996; Westwood, 1978). Ecodormancy end is considered at the anthesis of 50% of the flowers, the F^{50} date (Tabuenca *et al*., 1972).

To estimate the chill and heat requirements for blooming of any cultivar, besides temperature data, three chronological dates must be fixed: the chill accumulation start date, the endodormancy breaking date and the F^{50} date. Unfortunately, there is no way to infer the endodormancy break date directly from phenological observations in the field, and this date is essential for chill and heat requirement estimations because calculations are made until or from that date.

The determination of this date may be done by two different approaches, by the assessment of increment of the bud weight or size, after maintaining branches during a fixed period in favourable growth conditions (Brown and Kotob, 1957) or by statistical methods, trying to explain the phenological responses to temperature in natural conditions (Alonso *et al.,* 2005; Tabuenca and Herrero, 1966).

In almond, only a few reports have dealt with the evaluation of chill and heat requirements. The first estimates of chill requirements were quantified as the number of hours under 7ºC, and the heat requirement as the addition of maximum and minimum daily temperatures in few cultivars and local Spanish clones (Tabuenca, 1972; Tabuenca *et al*., 1972). Later, the different studies in almond started to use the parameters developed in the Utah University, the Chill Units (CU) (Richardson *et al.*, 1974) and the Growing Degree Hours (GDH) (Richardson *et al.*, 1975) for quantification of the chill and heat requirements. In 1986, Rattigan and Hill applied the statistical method of Ashcroft *et al.* (1977) to estimate the chill and heat requirements of 12 almond cultivars using only field and climatic data. In 2003, Egea *et al*., determined the chilling and heat requirements of 10 almond cultivars and breeding selections by the classical method of bud breaking, when the flower buds are able to sprout by placing branches in warm conditions during the progress of dormancy. More recently, Alonso *et al.* (2005) improved the statistical method of Tabuenca *et al.* (1972) that allows to assess the endodormancy breaking date by the correlation between climatic and blooming data, applying this new method for calculation of the chill and heat requirements of 44 almond cultivars.

In this manuscript, chill and heat requirements for blooming of the cultivars released from the "Centro de Investigación y Tecnología Agroalimentaria de Aragón" were determined and their implications for blooming time and breeding are discussed.

Materials and methods

The CITA has released the almond cultivars 'Guara', 'Blanquerna', 'Felisia', 'Ayles', 'Cambra', 'Moncayo', 'Belona' and 'Soleta' with the aim of improving yield and fruit quality. For this reason the CITA almond breeding programme is stressing the efforts on late blooming and selfcompatibility, using as parents elite self-compatible selections and traditional Spanish cultivars with standing fruit quality. The very late blooming selection 'G-2-25' is being considered for release. Each cultivar was represented by three trees grafted on the peach x almond hybrid rootstock 'GF 677' in the Spanish National Almond Germplasm Collection located at the CITA in Zaragoza.

The date of the end of ecodormancy was recorded every year in the cultivars as the day of 50% of the flowers (F^{50}) are in anthesis stage (Couvillon and Erez, 1985). Daily maximum, minimum and mean temperatures were obtained from a meteorological station placed in a nearby plot.

The endodormancy breaking date of every cultivar was determined applying the statistical method explained in Alonso *et al.* (2005) based on significance of correlation coefficients between the average of maximum daily temperatures of overlapping periods of fifteen days and the blooming dates of seven years data. Chilling requirements were estimated by the addition of chilling units (CU) from the first day of chilling accumulation until the endodormancy breaking date (Table 1). Heat requirements were estimated as accumulation of growing degree hour Celsius (GDH) (Richardson *et al.*, 1975) from the endodormancy breaking date until the average of full bloom dates (F^{50}) of each cultivar (Table 1).

Results and discussion

In the cold climatic conditions of the Ebro Middle Valley, where 1800 CU are accumulated until the end of February, chill requirements are early satisfied whereas heat requirements are satisfied much slowlier, needing a long period for heat accumulation completion. Consequently, blooming date depends more on the climatic conditions of the final period of bud development.

In this situation, the general pattern is that chilling requirement completion in almond takes place during the first ten days of December, even in cultivars considered as late blooming, accumulating between 250 and 500 CU. With the exception of 'G-2-25', with 503 CU, the CITA almond cultivars show very close chilling requirements, from 329 CU in 'Felisia' to 353 CU in 'Aylés' and 'Belona' (Table 1).

Table 1. Chilling and heat requirements calculated for the CITA almond cultivars

Cultivar	**Chilling requirements**			**Heat requirements**		
	CU†	**Days from the start of chill accumulation**	**Breaking of dormancy**	**GDH**††	**Days from breaking of dormancy**	**Blooming (F^{50})** †††
'Ayles'	353	34	1 Dec.	8333	94	5 Mar.
'Belona'	353	34	1 Dec.	7741	91	2 Mar.
'Blanquerna'	340	33	30 Nov.	7221	87	25 Feb.
'Cambra'	340	33	30 Nov.	8005	93	3 Mar.
'Felisia'	329	32	29 Nov.	9465	103	12 Mar.
'G-2-25'	503	44	11 Dec.	10233	100	22 Mar.
'Guara'	340	33	30 Nov.	8159	94	4 Mar.
'Moncayo'	340	33	30 Nov.	8854	99	9 Mar.
'Soleta'	340	33	30 Nov.	2872	92	2 Mar.

†Chill units; ††Growing Degree Hours; †††Date of anthesis (50% of open flowers).

A great diversity of heat requirements between the different cultivars had already been observed in these conditions: it was ranging from 5,500 to more than 10,000 GDH (Alonso *et al*., 2005). Thus, cultivars having similar chilling requirements may have very different heat requirements. This large variability was observed also for the CITA almond cultivars in their heat requirements, from 7221 GDHºC in 'Blanquerna' to 9465 GDHºC in 'Felisia' or 10233 GDHºC in G-2-25. Thus, the latest blooming cultivars are those with the highest heat requirements (Table 1).

'Blanquerna' shows similar chill and heat requirements than 'Marcona' and, thus, a good adaptability to warmer areas than the Ebro Middle Valley. 'Aylés', 'Guara', 'Cambra', 'Belona' and 'Soleta' show intermediate requirements, similar to those of 'Nonpareil', 'Ferraduel' and 'Ferragnès'. 'Moncayo' and 'Felisia' showed higher heat requirements, conferring a late blooming time independently of the climatic conditions. Finally, 'G-2-25' has the highest chill and heat requirements and, as a consequence, a very late blooming time, about 10-13 days later than 'Felisia'. Cultivars showing high heat requirements may be adapted to a wider spectrum of environments and may produce good crops even in years when or sites where there is a limited chilling accumulation (Citadin *et al*., 2001). Cultivars with a combination of high chill and heat requirements will have a stable late bloom in all conditions, although demanding environments where their chilling requirements could be satisfied in order to obtain good yields.

Cultivars having extreme large values of chill and heat requirements may be used as parents in a breeding program for late bloom (Socias i Company *et al*., 2003) from a more reliable point of view because selection only based on the date of blooming time does not ensure the largest requirements for both chilling and heat.

The knowledge of cold and heat requirements of any genotype is essential in choosing the cultivars to be planted in a given region in relation to their climatic conditions, especially to avoid frost risks, as well as in designing crosses in a breeding programme to obtain new cultivars with a definite blooming period.

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