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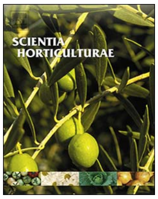

Evaluation of breaking dormancy, flowering and productivity of extra-late and ultra-late flowering almond cultivars during cold and warm seasons in South-East of Spain

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ABSTRACT

Flowering time in almond is a complex process involving chilling and heat requirements. After being exposed to periods of low and high temperatures, the buds are able to break their dormancy state and sprout or flower. For suitable flowering, vegetative growth and fruit set, the chilling requirements have to be fully satisfied. In cold areas, where many new almond orchards are being established, late flowering is an indispensable trait for avoiding damage from late frosts. Due to the expansion of almond cultivation, late-flowering cultivars are also being grown in warm areas, although the long-term behaviour of these cultivars in such climates remains uncertain. In this work, we studied the extra-early flowering almond “Desmayo Largueta”, the extra-late “Penta” and the ultra-late “Tardona” for a period of three years, calculating the chilling requirements of reproductive buds for breaking dormancy, the heat requirements for flowering and the productivity in the warm conditions of South-East of Spain. “Tardona”, bred at our centre, CEBAS-CSIC, is the latest flowering almond cultivar released in the world to date. The chilling requirements (CR) of the cultivars were calculated according to the Richardson and Dynamic models, and the heat requirements (HR) were estimated according to the Richardson model. Results showed important differences in CR and HR between almond cultivars and years. Furthermore, the Dynamic model provided more stable CR estimations than the Richardson model over the years under our experimental conditions especially during warmer seasons. Finally, we observed a decrease in productivity in extra-late- and ultra-late-flowering cultivars in a particularly warm season, when chilling requirements were not fulfilled. This effect demonstrates the importance of growing cultivars in climatically suitable areas and the effect of increase of temperature in flowering and productivity of almond.

1. Introduction

One of the main objectives of almond [*Prunus dulcis* (Miller) D.A. Webb] breeding is the development of new extra-late-flowering cultivars to avoid damage from spring frosts. The expansion of almond cultivation from the Mediterranean Basin to colder areas in Northern Europe and America has been made possible by delaying flowering time through classical breeding methods (Sánchez-Pérez et al., 2004; Gradziel and Martínez-Gómez, 2013; Dicenta et al., 2016; Martínez-Gómez et al., 2017). This delay in flowering time has its limits, however, and success is conditioned by the extent to which the climatic requirements are met for the suitable development of vegetative and flower buds and the processes of pollination, fruit set and fruit development (Alonso Segura et al., 2017; Dicenta et al., 2017).

The chilling (CR) and heat requirements (HR) determine the breaking of flower bud dormancy and the subsequent flowering in temperate fruit species (Campoy et al., 2011). Although chill and heat accumulation are inter-dependent processes (Erez and Couvillon, 1987), CR is considered to be the major factor that determines flowering time in almond and the rest of the *Prunus* species, rather than HR (Egea et al., 2003; Ruiz et al., 2007;Alburquerque et al., 2008; Atkinson et al. 2013; Sánchez-Pérez et al., 2012; 2014). CR is therefore a very important adaptive trait specific to each cultivar (Egea et al., 2003; Ruiz et al., 2007; Campoy et al., 2011), and it determines the length of the dormancy period. The dormant state is cumulative and quantitative with endogenous and environmental signals continually altering its depth in woody plants (Cooke et al., 2012). For an adequate flowering the chilling and heat requirements of each cultivar have to be fulfilled. Otherwise this essential process could be negatively affected also affecting final production (Luedeling, 2012). In addition, chilling accumulation has been found to affect fruit shape in peach (Yong et al., 2016).

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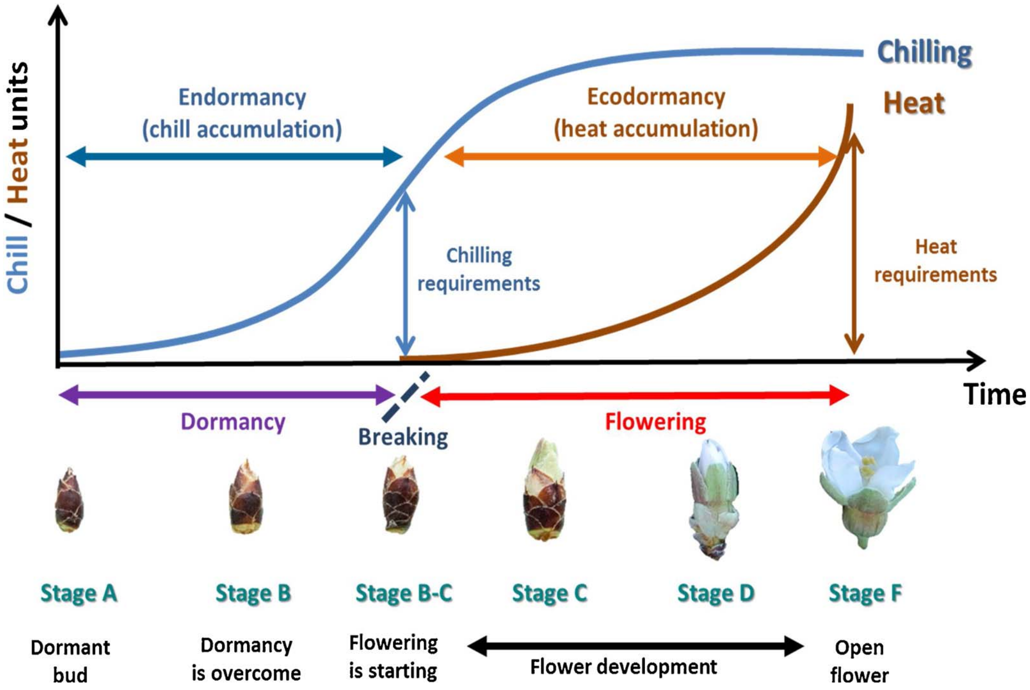

Fig. 1. Dormancy breaking of reproductive buds and flowering in almond referenced to the phenological stages described by Felipe (1977). Adapted from Lang et al. (1987) and Luedeling et al. (2009).

According to Lang et al. (1987), there are three distinct types of dormancy: endodormancy, due to control factors inside the bud; paradormancy, controlled by agents outside the dormant bud; and ecodormancy, depending on the temperature once the CR has been supplied (Fig. 1). CR therefore mainly affects the endodormancy period, with high CR determining long endodormancy periods and vice versa. Plant production can be affected by dormancy in two ways: through increasing the chances of survival during inclement climatic conditions, and through affecting flower and fruit development during the growing season (Campoy et al., 2011; Martínez-Gómez et al., 2017).

To explain dormancy breaking, different models have been developed, including the Richardson model (Richardson et al., 1974) for cold areas and the Dynamic model (Fishman et al., 1987a; 1987b; Erez et al., 1990) for mild-winter areas. Studies comparing the Richardson and Dynamic models have been performed using historical phenology records in peach (Maulion et al., 2014), almond (Benmoussa et al., 2017) and sweet cherry (Gannouni et al., 2017). These studies have shown clear differences in the estimation of chill requirements using both methods. Maulion et al. (2014) recommended Richardson model for the evolution of chilling requirements in peach in Argentina conditions whereas Benmoussa et al. (2017) and Gannouni et al. (2017) recommended the Dynamic models in almond and sweet cherry in the North of Africa conditions.

From the perspective of global climate change, dormancy regulation has recently drawn the attention of more researchers (Luedeling et al., 2009; Luedeling, 2012; Campoy et al., 2011; Viti et al., 2013). Such studies are of great interest in mild-winter areas like South-East of Spain where warmer winters are anticipated in the future due to the climate change (IPCC, 2013; Ponti et al., 2014). In the Mediterranean region, a delay has been observed in dormancy release and flowering time in peach (Ghrab et al., 2014) and cherry (Oukabli and Mahhou, 2007; Gannouni et al. 2017) in the context of this climate change. This situation has also been observed in Western Europe for apple (Legave et al., 2013).

In this work, the chilling requirements for breaking dormancy, the heat requirements for flowering and the productivity were calculated for almond cultivars with different flowering times during three climatically different seasons. To compare the accuracy of the models for chill estimation in our warm conditions, the Richardson model (Richardson et al., 1974) and the Dynamic model (Fishman et al., 1987a; 1987b; Erez et al., 1990) were used. Heat requirements were estimated using the Growing Degree Hours model according to Richardson et al. (1975).

2. Materials and methods

2.1. Plant material

The plant material assayed included the traditional Spanish extra-early-flowering almond cultivar "Desmayo Largueta" in addition to the extra-late "Penta" and the ultra-late "Tardona", both releases of the CEBAS-CSIC breeding programme (Table 1). This study has been performed onto ten-years old trees grafted onto "Garrigues" seedling rootstocks. "Penta" is a cross between the Spanish late-flowering selection S5133 (open pollination of the Ukrainian "Primorskii") and the cultivar "Lauranne" ("Ferragnès" × "Tuono"). "Tardona" is a cross between the late-flowering Spanish selection "S5133″ and the late-flowering French selection "R1000″ ('Tardy Nonpareil' × 'Tuono').

Table 1
Almond cultivars assayed including the pedigree, origin and main agronomic characteristics (self-compatibility, shell hardness and flowering time).

Cultivar	Pedigree	Origin	Self-compatibility	Flowering	Shell hardness
Desmayo Largueta	Unknown	Spain, traditional cultivar	Self-incompatible	Extra-Early	Hard
Penta	S5133 × Lauranne	Spain, new breeding release CEBAS-CSIC	Self-compatible	Extra-Late	Hard
Tardona	S5133 × R1000	Spain, new breeding release CEBAS-CSIC	Self-compatible	Ultra-Late	Hard