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Chilling and heat requirements of Japanese plum cultivars for flowering

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ABSTRACT

The chilling requirements for dormancy release and heat requirements for flowering were studied for three successive years in eleven *Prunus salicina* L. cultivars that spanned the range of flowering times in this species. Different methods for estimating chilling requirements were evaluated and compared, and correlations between chilling requirements, heat requirements and flowering date were established. The cultivars examined showed a range of chilling requirements (chill units, CU), spanning from 334.3 CU ('Pioneer') to 987.5 CU ('Songold'). The heat requirements for flowering ranged between 5990 and 9228 growing degree hours. The chilling requirements were significantly different among cultivars, whereas no cultivar effect was found for the heat requirement values. In addition, chill portions were the variable that correlated the most with flowering date in Japanese plum. The dissection of flowering date into chilling and heat requirements indicates that chilling requirements is the main variable driving the variation of flowering time within Japanese plum cultivars.

1. Introduction

The survival of temperate fruit trees grown in well-differentiated seasons depends on the synchronization of the dormancy-growth cycle with favorable conditions for development. Dormancy release occurs upon the accumulation of the cold temperatures (chilling requirement - CR) during the autumn-winter period, and subsequently, the action of warm temperatures (forcing or heat requirement -HR) leads to flowering and leafing. Knowing the CR of woody plants has practical and economic implications in the control, maintenance, production and survival of such plants (Fennell, 1999) and is necessary for cultivating Japanese plum cultivars in the most suitable areas. The CR for breaking dormancy in temperate fruit trees must be fully satisfied to obtain the desired vegetative growth and the best fruit-bearing capacity (Samish, 1954). A cultivar grown in a location where its CR is not adequately satisfied will therefore show several associated problems affecting its vegetative and reproductive cycle (Coville, 1920). To the contrary, low-chill cultivars grown in cold-winter areas will show early blooming, as their CR are quickly satisfied, and low temperatures can produce an important loss in yield due to frost (Scorza and Okie, 1990). Determining the suitability of cultivars and growing areas requires deep knowledge of the chilling and heat requirements of a given cultivar, or knowledge of how this cultivar compares to reference cultivars, and the chilling accumulation in the growing areas.

Plums, including European plums and Japanese plums, are the second fruit stone production among *Prunus* crops at the world behind peaches and nectarines, with total world production reaching 11 million tonnes (FAOSTAT, 2016 (data 2013–2016)). Plum species are grown worldwide, but mainly in temperate zones. The major Japanese plum-producing countries worldwide are China, Chile, Spain, Italy, United States and Argentina (FAOSTAT, 2016 (data 2013–2016)).

It is particularly urgent to develop low-chill cultivars adapted to evolving climatic conditions within the context of global warming (Campoy et al., 2011a). Japanese plum breeding has already been undertaken in warm areas and the subtropics in several countries: USA, Brazil, Mexico, South Africa, Australia, Taiwan and Spain (Sherman et al., 1992; Wen and Sherman, 2003; Topp et al., 2012; Ruiz et al., 2016).

However, references concerning the chilling requirements of Japanese plum are scarce. Some reviews have reported a high variability among cultivars, ranging from 200 and < 1000 chill hours (below 7°C) (Okie and Weinberger, 1996; Okie and Ramming, 1999; Okie and Hancock, 2008; Gasic and Preece, 2014). Wen and Sherman (2003) reported that some local Japanese plums in Taiwan are characterized by low chill requirements, and very low-chill Japanese plums have been developed in Florida (Sherman and Lyrene, 2003). 'Gulfruby', an early Japanese plum cultivar, was recommended for cultivation in warm areas of Rio Grande do Sul in Brazil (ca. 30 °S), avoiding areas subjected

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to frost (Fioravanco et al., 2008). Japanese plum cultivars requiring < 450 chill hours (below 7°C) have been described from Brazil, Australia, United States, South Africa and Argentina (Okie and Hancock, 2008), although they are not widely grown cultivars in the main growing areas worldwide.

Other studies provide an interesting overview of plum-related species. Sel and Gigleux (2005), for instance, estimated the dormancy breaking of the Mirabelle (*Prunus domestica* subsp. *syriaca*). Tabuenca (1983) evaluated the CR of 17 *Prunus domestica* cultivars for three years, obtaining CR ranging from 800 to 1150 h below 7 °C. The available information is therefore scarce, and often dissimilar, because it is frequently expressed as different units, such as chill hours (CH) (Bennett, 1949; Weinberger, 1950), chill units (CU) (Richardson et al., 1974) or chill portions (CP) (Fishman et al., 1987a, b). These units have been shown to not be transferable among different regions (Luedeling and Brown, 2011), making it more difficult to compare results and reflecting the need for a study in the same area of the main cultivars showing different chilling requirements. Several multi-year studies have been performed that have become references for other stone fruit species, establishing the CR and HR of a wide number of cultivars in species such as almond (Egea et al., 2003), apricot (Ruiz et al., 2007) and sweet cherry (Alburquerque et al., 2008). However, to date, there is no study based on several years' data of the chilling and heat requirements of the most-cultivated Japanese plum cultivars.

The aim of this work was therefore to evaluate over three successive years the chilling requirements for dormancy breaking and the heat requirements for flowering of a group of Japanese plum cultivars that cover the full range of flowering times in this species. In addition, they are reference cultivars worldwide. These results allow us to determine whether variability in flowering date is due to variations in chilling requirements, heat requirements or both. Moreover, this study helps us decipher the interaction between chilling and heat requirements and flowering date, making it possible to predict suitable growing conditions not only for the studied varieties, but also as a reference for forthcoming cultivars. Finally, this study has a practical application, making it possible to determine potential growing areas for Japanese plum cultivars by estimating the probability of satisfying the chilling requirements as well as avoiding spring frost periods in a given area.

2. Material and methods

2.1. Plant material

The plant material comprised 11 Japanese plum cultivars spanning the range of flowering time in the Japanese plum species. The cultivars selected are international references: 'Black Diamond', 'Angeleno', 'Fortune', 'Santa Rosa', 'Golden Japan', 'Laetitia', 'Songold', 'Golden Globe', 'Pioneer', 'Black Splendor' and 'Red Beauty'.

2.2. Experimental design

The experiments were conducted in 2012, 2013 and 2014 in a commercial orchard located in Cieza (South-East Spain, 241 m above sea level, lat. 38°16'N, long. 1°16'W). Data from 3 consecutive years (2012, 2013 and 2014) were collected from all cultivars, with the exception of 'Fortune' and 'Songold' to which data from 2 years were collected. Hourly temperatures were collected each year from November to April by an automatic data-logger (Escort Data Logging Systems). In these field conditions, the initial date for chilling accumulation was considered to be when consistent chilling accumulation occurred and temperatures producing a negative effect (chilling negation) (Erez et al., 1979; Richardson et al., 1974) were scarce.

Forcing experiments were conducted as previously described for apricot by Ruiz et al. (2007). From the beginning of the chilling accumulation in the orchard, for each cultivar, three branches (with lengths of around 40 cm and diameter of 5 mm) were picked from trees in the field every 3 to 4 days and placed in a growth chamber in controlled conditions. We made a fresh cut on the base of the Japanese plum branches before placing them in a 5% sucrose solution. The branches were maintained at 25 ± 1 °C under white fluorescent tubes (55 molm − 2 s − 1) during a photoperiod of 16 h and at 18 ± 1 °C during a dark period of 8 h, with a constant relative humidity of 65%. After 5 days, the sucrose solution was changed, and the basal branch cuts were refreshed. The branches were maintained in the growth chamber for 10 days to accumulate sufficient heat.

2.3. Determination of chilling requirements

Both physical and physiological parameters were used to determine the date of dormancy breaking (Ruiz et al., 2007). After 10 days in the growth chamber, the development stage of the flower buds was recorded. The date of dormancy breaking was established when, after 10 days in the growth chamber, 30% of the flower buds were in Baggiolini's stage B–C, and there was a 30% weight increase in the flower buds compared with the relatively constant previous weights. The CR coincided with the chill accumulated until the date of dormancy release. Quantification of CR was done using chill hours (CH) (hours below 7 °C) (Weinberger, 1950), chill units (CU) of the Utah Model (Richardson et al., 1974) and chill portions (CP) of the Dynamic Model (Fishman et al., 1987a, b). All methods for quantifying CR were included to ease comparison with previous works.

2.4. Determination of heat requirements

The heat requirements of the evaluated cultivars were calculated as the growing degree hours (GDH) accumulated from dormancy breaking to the date that 50% open flowers (F50) were recorded in the orchard, following the models proposed by Richardson et al. (1974) and Anderson et al. (1986). In addition, days of heat accumulation (ΔJD) were calculated from dormancy breaking date to F50 date.

2.5. Statistical analysis

Normality, homocedasticity and ANOVA tests were performed for each variable. Spearman correlations were performed using individual values (year and cultivar) for each variable. Correlations were calculated between chilling requirements for breaking of dormancy: Hours below 7°C (CH), Chill Units (CU) and Chill Portions (CP); heat requirements for flowering: days of heat accumulation, Growing Degree Hours using Anderson and Richardson models; flowering date and date of dormancy release of 11 Japanese plum cultivars in Spain. All Statistical analysis were performed using the RCommander package R 2.15.0 (R_Development_Core_Team, 2012).

3. Results

3.1. Chill accumulation in field conditions

The chill accumulation between November 1 and February 28 in three consecutive years (2011–2012, 2012–2013 and 2013–2014) is shown in Table 1. Similar chill accumulation by February 28 was registered among years for all chill models. Chill accumulation in the experimental field conditions characterized the climate as moderately cold. The most efficient months for accumulating chill were December and January (Table 1). The fortnight accumulation data revealed that, although the final amount of chill accumulation was quite similar between years, there were significant differences between years with respect to periods of higher chill accumulation. The high coefficient of variation (*cv*) values also showed differences at the beginning of chill accumulation in November.