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Determination of chilling and heat requirements of 69 Japanese apricot cultivars

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ABSTRACT

Chilling requirement, together with heat requirement, which has an impact on the climatic distribution of the genotypes of tree species, determines the flowering date. It also played an important role in the protected cultivation of fruit trees. In our study, we estimated chilling requirements for breaking of dormancy and heat requirements for flowering for 2 successive years in 69 Japanese apricot cultivars of Nanjing (China). The chilling requirements of those Japanese apricot cultivars ranged from 24 to 82 chill portions according to the dynamic model, and the heat requirements of those cultivars fluctuated between 691.9 and 2634.7 growing degree hours. The Japanese apricot cultivars were classified into three groups according to their chilling requirements: the low chilling requirement cultivars with less than 50 chill portions, the medium chilling requirement cultivar ranging from 50 to 70 chill portions, and the high chilling requirement cultivars with more than 70 chill portions. In our study, cultivars originated in Guangdong of China generally have a low chilling requirements, and originated in Zhejiang and Jiangsu of China have a high chilling requirements. Cultivars with lower or higher chilling requirement are not suitable for introduction of Nanjing due to their abnormal phenotype. We also observed that the heat requirement of Japanese apricot had no obvious relationship with their origins. The determination of chilling requirements of 69 Japanese apricot cultivars provided some basis for their rationalized introduction and distribution, and was also important in a breeding program. Those results also expanded our understanding of the temperature responses of flower bud in Japanese apricot during the dormancy progress.

1. Introduction

Most temperate deciduous fruit trees need a low-temperature exposure to be released from endodormancy, termed as 'chilling requirement' (Fan et al., 2010). Chilling requirement is an important phenological trait that controls the flowering date and impacts the climatic distribution of temperate deciduous fruit trees. The amount of chilling requirements varies among different species, and also varies among different varieties within the same species (Arora et al., 2003). If the chilling requirement is not sufficient, the tree behavior will be affected in three main ways: delayed budburst, reduced budburst and uneven budburst and flowering (Erez, 2000). Knowledge of the chilling requirement has practical and economic implications for the production of deciduous fruit trees (Fennell, 1999). Therefore, estimating the chilling requirement of fruit tree and the amount of winter chilling accumulation available at a given location has been a central theme of horticultural research.

Many researchers studied the chilling requirement of many temperate fruit trees in various conditions. However, up to now, the effect of heat requirement on flowering date is not clear. Alonso et al. (2005) found that heat requirements of almond cultivars was more important for regulation of flowering date than chilling requirements in north-east Spain, while Egea et al. (2003) reported that the flowering date of some almond cultivars was influenced more by chilling than by heat requirement in south-east Spain. Citadin et al. (2001) come to an inverse effect on the flowering date of peach cultivars between chilling requirement and heat requirement. Gao et al. (2012) found that heat requirement contributed a limited effect to the variation in flowering date of Japanese apricot in Nanjing, China. The risks related to the lack of knowledge of the heat requirement of apricot cultivars are scarce, but their knowledge will provide us with more possibilities for the management of those fruit trees.

Many reasons encouraged studies concerning the chilling and heat requirements of temperate fruit trees in various conditions.

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Firstly, the development of communications has led to a wider cultivation of temperate fruit trees, cultivars being selected and grown in different environmental conditions; secondly, due to rapid climate change and the noteworthy reduction of chilling accumulation observed and/or predicted for several temperate zones, concern about climatic adaptation in temperate fruit trees has arisen (Luedeling et al., 2011; Campoy et al., 2011). Doi (2007) analyzed the first flowering date of the Japanese apricot from 1953 to 2005 at 32 locations in Japan, varying from 30 to 44° N latitude, which observed that temperatures were noticeably warmer in the period 1990–2005 in comparison with 1953–1989, and plants flowered earlier, averaging 7 days earlier across the sites. Lastly, the programs in China and Japan are directed to develop lower-chill cultivars suitable for protected culture production.

Japanese apricot (*Prunus mume* Sieb. et Zucc.), belonging to *Prunus*L. in Rosaceae, originated in China, which has been widely cultivated for about 3000 years in Asia (Chu, 1999). Japanese apricot has the earliest flowering date in Rosaceae family, and the flower of which can tolerate much lower temperatures (−4 °C to −2 °C) in early spring (Chu, 1999). These attributes make it an importantly economical and excellently ornamental tree. However, Japanese apricot is mainly cultivated in south of China, Japan and Korea and rarely in other countries due to their severe restrictions with climatic conditions, especially for the temperature (Ou and Chen, 2003). Many researchers had determined the chilling requirements of Japanese apricot with different methods (Ou and Chen, 2003; Wang et al., 2007; Yamane et al., 2006). Unfortunately, they used different models to determine their chilling requirements, hindering us to use them in other conditions. Gao et al. (2012) found that Japanese apricot had a broad chilling requirement ranges and the dynamic model was the best method for determining the chilling requirement of Japanese apricot in Nanjing, China.

In this study, we determined the chilling requirements and heat requirements of 69 Japanese apricot cultivars at Nanjing, China. Base on the obtained information such as chilling requirements, date of breaking dormancy, heat requirement, flowering date, we could provide a reference for the introduction and breeding of Japanese apricot. At the same time, the obtained information could also be used to advise Japanese apricot farmers about which cultivars were best suited to their area and which areas of our region were the most appropriate for Japanese apricot production.

2. Materials and methods

2.1. Plant materials

The Japanese apricot trees used in our study were cultured in the 'National Field Genebank for Japanese Apricot', which located in Nanjing (altitude 10 m, lat. 32°03′N, long. 118°46′E), China. It has 108 Japanese apricot cultivars, and we selected 69 cultivars, which are very widely used in cultivation distribution of Japanese apricot in China, to determine their chilling requirement and heat requirement. The trees used here were eight years old at the beginning of the study, and received similar cultural practices, such as irrigation and fertilization.

2.2. Sample collection

We conducted our experiments in two consecutive years (2009–2011) at the 'National Field Genebank for Japanese Apricot'. The major differences between these two years were that they had different chilling accumulations and precipitation in the field. Compared with the year of 2009, the year of 2010 had lower chilling accumulations and less precipitation. The other environmental conditions were almost the same. The hourly temperatures were recorded by a thermohygrograph and an automatic datalogger (Hangzhouzeda Instrument Co., Ltd., Hangzhou, China) from November to April in the experimental orchard, and the instrument was located at a height of 1.5 m in the field among the orchard rows.

Before the winter leaf drops from the Japanese apricot trees in the orchard, five branches (with diameter of 5 mm and lengths of around 25 cm) were collected weekly from the same parts of the selected trees, and almost branches were collected from the middle parts of trees, and then took them back to the laboratory. In the laboratory, after making a fresh cut at the base of the branches, the bases were placed in a 5% sucrose solution in a growth chamber. The branches were maintained under the controlled conditions (25 ± 1 °C/18 ± 1 °C (16 h day/8 h night), white fluorescent tubes with 55 μmol m^{-2} s^{-1}, 70% constant relative humidity).

The sucrose solution was refreshedevery 3 days, and at the same time, we removed approximately 1 cm of the basal part of the branch to ensure that the vascular system remained functional. The development stage of the flower buds was recorded after 10 days in the growth chamber. The period of 10 days was based on previous studies, indicating that longer periods were not suitable for the study of the material in the controlled conditions.

2.3. Determination of chilling and heat requirement

The start date for chilling accumulation was considered to be when a consistent chilling accumulation occurred and the temperatures producing a negative effect (chilling negation) were rare (Erez et al., 1979; Guerriero et al., 2002; Richardson et al., 1974). The date of endodormancy breaking was established when 50% of the flower buds on the branch cuttings were in 'green tip' after 10 days incubation in the growth chamber (Baggiolini, 1952 Zhuang et al., 2013). The chilling requirement of Japanese apricot cultivars coincided with the chilling accumulated between the start date and the endodormancy breaking date. As our previous study has proven that the dynamic model was the best method for determining the chilling requirement of Japanese apricot in Nanjing, China (Gao et al., 2012). Therefore, we used the Dynamic model to determine the chilling requirement (Darbyshire et al., 2011; Fishman et al., 1987a,b).

Heat requirement was calculated as growing degree hours (GDH), following the model proposed by Richardson et al. (1974). GDHs are hourly average temperatures (°C) minus 4.5 °C. For each cultivar, heat requirement was calculated as the number of GDH accumulated between the date of endodormancy breaking and the date when 50% of flowers were open (F_{50}) in the orchard. For the determination of F_{50}, we used three persons to observe the ratio of open flowers at the front of the selected Japanese apricot trees (about 3 m). When all 3 persons concluded 50% of flowers were open in one cultivar, we used that date as the date of F_{50}.

2.4. Statistical analysis

Analysis of variance using SPSS 17.0 Windows was done for each year during the test. The data were statistically analyzed and the means were compared by Dancan's multiple rang test (DMRT). Differences between means at 5% ($p < 0.05$) level were considered as significant.

3. Results and discussion

3.1. The chilling requirements of 69 Japanese apricot cultivars

The 69 Japanese apricot cultivars showed a wide range of chilling requirement for breaking dormancy and flowering, ranging from 24 to 82 chill portions (Table 1). We classified those cultivars into three groups according to their chilling requirements: low-chilling