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Review

Japanese plum pollination: A review

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ABSTRACT

The reproductive behavior of Japanese plum has not been studied as in other *Prunus* species. Thus, a number of cultivars are particularly prone to erratic fruit set showing low yield for reasons that are not clear. Traditionally, the factors related to pollination have not been considered as causes of low yield in this crop, but in the last years lack of fruit set was recorded in different cultivars due to reproductive failure. Japanese plum, like other *Prunus* fruit tree species, is self-incompatible and requires cross pollination to ensure fruit set because this genus is unable to bear fruit parthenocarpically. Therefore, knowledge of pollination requirements of cultivars is essential to solve problems of low yield related to lack of pollination and for new orchard plantation plan with adequate proportion of pollinizers. The incompatibility relationships between Japanese plum cultivars have not been studied comprehensively until the last decade. An important amount of information has been revealed in this period, since a high number of commercial cultivars are currently available and new cultivars are being obtained from different breeding programs. In this article, the information available on the reproductive process in Japanese plum is reviewed, paying special attention to pollination factors and incompatibility relationships between cultivars. The *S-RNase* genotype of 222 cultivars compiled herein, allocated in 26 Incompatibility Groups, five of them described for the first time, will be valuable for fruit growers to choose adequate pollinators in commercial orchards, and for breeders to choose parental genotypes and select offsprings in breeding programs.

Contents

1. Introduction

Japanese plum (*Prunus salicina* Lindl., formerly *Prunus triflora* Roxb.) belongs to the genus *Prunus* within the Prunoideae, a subfamily within the flowering plant family Rosaceae, which contains all the stone fruits. The genus *Prunus* comprises five subgenera: *Amygdalus*, *Cerasus*, *Laurocerasus*, *Padus* and *Prunus* (= *Prunophora*). The subgenus *Prunus* includes three sections: *Euprunus* (= *Prunus*), the Eurasian plums; *Prunoceraus*, the North American plums; and *Armeniaca*, the apricots (Rehder, 1940). Japanese and other Asian plums are placed in section *Euprunus*, although they could fit both taxonomically and horticulturally with American plum species in section *Prunocerasus* (Okie and Hancock, 2008; Okie and Weinberger, 1996). The basic chromosome number for *Prunus* is

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$x = 8$. *P. salicina* and hybrids are diploid with $2n = 16$ (Darlington, 1928).

Japanese plum originated in the Yangtze River basin (Yoshida, 1987) and was spread across eastern China, where it has been cultivated for several thousand years (Hedrick, 1911). It was introduced from China to Japan, where it has also been cultivated from ancient times and it was initially improved (Faust and Surányi, 1999; Yoshida, 1987). In the late XIX century, Japanese plum was introduced into the United States from Japan (Das et al., 2011; Karp, 2015). From these initial importations, some cultivars of *P. salicina* were selected such as 'Kelsey', 'Abundance', 'Satsuma' and 'Burbank' (Burbank, 1914; Hartmann and Neumuller, 2009; Okie and Weinberger, 1996). In California, Luther Burbank intercrossed *P. salicina* with *Prunus simonii* Carriere and other native North American diploid plums such as *Prunus americana* Marshall, *Prunus hortulana* L.H. Bailey or *Prunus munsoniana* W.Wight and Hedrick (Burbank, 1914; Okie and Hancock, 2008). In the late XIX and early XX centuries, from these hybridizations Burbank selected cultivars such as 'Beauty', 'Eldorado', 'Formosa', 'Gaviota', 'Santa Rosa', 'Shiro', and 'Wickson', some of which are still widely grown (Burbank, 1914; Das et al., 2011; Faust and Suranyi, 1999; Hartmann and Neumuller, 2009; Okie and Hancock, 2008). In the XX century, these cultivars were spread from California to temperate zones around the world, where they were crossed with local plums, including *P. americana, Prunus nigra* Aiton and *Prunus besseyi* Bailey in the northern United States; *Prunus angustifolia* Marshall in the southeastern United States, and *Prunus cerasifera* Ehrhart in South Africa and Australia (Byrne, 1989; Faust and Suranyi, 1999; Okie, 2006; Okie and Hancock, 2008; Okie and Weinberger, 1996).

World production of plums, including both Japanese and European plum (*Prunus domestica* L.), has increased about 50% in the last decades from 5.5 Mt (average for the years 1973–1983) to reach more than 11 Mt in 2013 (Faostat, 2015). In this period, plum production area has increased from 0.6 in 1973 to 2.6 Mha in 2013, and productivity has decreased from 0.9 t in 1973 to 0.43 in 2013. Production of Japanese plums has been increasing particularly in Europe and Asia. The main producing country of Japanese plums is China, followed by the United States of America, Mexico, Italy, Spain, Pakistan, Korea, Australia, Chile, France, South Africa and Argentina (Faostat, 2015; Okie, 2006; Okie and Hancock, 2008).

Traditionally, the factors related to pollination have not been considered to be causes of low yield in this crop, but in the last years different cultivars and situations of lack of fruit set have been related to reproductive failures as male sterility or lack of pollination (Hartmann and Neumuller, 2009; Herrero and Salvador, 1980; Ramming, 1994), ovule degeneration (Guerra et al., 2011) and self-incompatibility (Griggs, 1953; Guerra et al., 2009; Hendrickson, 1919, 1922; Jia et al., 2008; Ramming and Cociu, 1990; Sapir et al., 2008a,b; Wang et al., 2013).

Japanese plum, like other *Prunus* fruit tree species, is self-incompatible and requires cross pollination to ensure fruit set because this genus is unable to bear fruit parthenocarpically (Hartmann and Neumuller, 2009; Sedgley and Griffin, 1989). Despite of the economic importance of Japanese plum worldwide and its self-incompatibility nature which has been reported in since early XX century (Alderman and Angelo, 1933; Dorsey, 1919), the incompatibility relationships between cultivars have not been studied comprehensively until the last decade. A considerable number of informations on this aspect have been generated till date, since a high number of commercial cultivars are currently available and new cultivars are being obtained from different breeding programs (Okie and Hancock, 2008; Topp et al., 2012). In this article, the information available on the reproductive process in Japanese plum is reviewed, with special attention to inter-varietal pollination factors and incompatibility reactions.

2. Flower biology

Buds start development in leaf axils during the summer preceding the spring in which the flowers open. The time of floral initiation depends upon the cultivar and the physiological condition of the tree, which is affected by weather, site conditions, and cultural practices, and also may differ with shoot location on the tree (Kozlowski and Pallardy, 1997). After flower induction, vegetative buds contain a vegetative axis, and flower buds contain flower primordia. Japanese plum flower buds are produced both on one-year shoots and on spurs on older wood (Dorsey, 1919). Flower differentiation starts in late summer after the development of fruit of the previous season is completed, and requires several months until blooming in late winter or early spring. Each flower bud, which is surrounded by several bud scales, contains one to three or more flowers but no leaves (Okie and Hancock, 2008). After leaf fall, flower bud development arrests and enters dormancy. Dormant flower buds are completely closed and covered by brown scales, corresponding to stage A (Baggiolini, 1952) (Fig. 1A). As in other *Prunus*, in each flower four concentric whorls (sepals, petals, stamens and carpel) differentiate in a centripetal way. Initially stamens and carpel are enclosed in the petals, and the sepals are fused to form a cup at the base of the petals (Diaz et al., 1981; Fadon et al., 2015a; Julian et al., 2010; Lamp et al., 2001).

Japanese plum trees, as other temperate *Prunus* spp., need a cultivar-specific amount of chilling expressed as chilling hours during dormancy in winter months and heat units after fulfilment of chilling hours for sprouting of buds, enabling the tree bloom and foliate normally (Campoy et al., 2011; Fadon et al., 2015b; Luedeling, 2012). The chilling requirements of Japanese plum have been little studied, but high variability among cultivars has been identified, ranging from 200 (cv. 'Red Beaut') and 1000 (cv. 'Bella Zee') chill hours (below 7 °C) (Gasic and Preece, 2014; Okie and Hancock, 2008; Okie and Ramming, 1999; Okie and Weinberger, 1996). Once chilling requirements are fulfilled, the trees need a certain amount or warm weather to budbreak and bloom. Thus, after temperatures rise, flower buds resumed growth following a pattern involving biochemical and morphological changes similar to all other temperate fruit species (Fadon et al., 2015a; Julian et al., 2010; Luna et al., 1991). Bud burst and flower development proceeds rapidly in late winter or early spring, depending upon cultivars and locations. With increased temperatures, the flower buds swell and show light brown scales (Fig. 1B), corresponding to stage B (Baggiolini, 1952). When the bud opens, the single flowers appear separated on short stalks, showing the green sepals (stage C, Fig. 1C), and later the white petals are visible forming a baloon (stage D, Fig. 1D). The flowers open gradually, showing first the anthers, corresponding to stage E (usually only a few hours) (Fig. 1E), and followed by the pistil. The flower is fully open at anthesis (stage F, Fig. 1F). Japanese plum, as other *Prunus*, is a histerant deciduous species in which flower buds open first and leaf buds several days later (Fadon et al., 2015a; Rodrigo et al., 2009).

Blooming time depends not only on the cultivar but also on the weather. In general, Japanese plum flowering occurs very early in the season and the blooming period is shorter amongst all stone fruits. In warmer regions or mild winters, the time span between the full bloom of early and late flowering cultivars is more prolonged than in cooler climates (Hartmann and Neumuller, 2009). Inflorescence is an umbel containing usually one to three flowers each on a separate pedicel (Ashworth, 1984). The flowers are smaller than other *Prunus*, ranging in diameter from 5 to 25 mm, with petals opening flat atop the cup-shaped corolla. Flowers are hermaphrodite, with a single pistil and 20-30 stamens that are enclosed in five petals and five sepals. The basal portions of sepals, petals and stamens are inserted in the hypanthium, a cup-shape tube structure. At anthesis, the stamens are about the same length