A Purple and Double-flowered Crabapple Cultivar: ‘Double-flowered Prince’

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Malus crabapples are popular ornamental plants in the Rosaceae family that have a beautiful shape; colorful leaves, flowers, and fruits; and extensive environmental adaptability. Among crabapples, there are some important varieties with purple-red leaves, flowers, fruit peel, and pulp that can serve not only as excellent landscape varieties but also breeding material for apple varieties with red flesh. In addition, they can be used for the development of products (teas, beverages, and essential oils) as well as the breeding of resistant apple rootstocks, due to the higher antioxidant activity conferred by their rich flavonoid content (Chen et al., 2014; Li et al., 2014). As a result, increasing attention has been given to these varieties in recent years.

The double flower is the result of the interaction between long-term artificial and natural selection with environmental factors; it improves the ornamental quality of the flower, possibly through the degradation of stamens and bracts, causing an increase in the number of petals. Moreover, it enhances the functions and services of the trees in landscape ecosystems by increasing the diversity

of plants and attracting pollinators (Zhao and Lin, 2009). As an important woody perennial plant in ornamental landscapes, the purple-red double flower of crabapple has long been sought by breeders. Fiala (1994) recorded nearly 1200 flowering crabapple cultivars; however, the semidouble- or double-flowered cultivars, including the outstanding rose-like double-flowered *M.* ‘Branzam’, red-purple double-flowered *M.* ‘Diamond’, red double-flowered *M.* ‘Kelsey’, and pink double-flowered *M.* ‘Van Eseltine’, accounted for less than 5% of those cultivars. In recent years, some excellent double-flowered cultivars,

such as the white double-flowered *M.* ‘Spring Bride’ (Spongberg, 1996), pink double-flowered *M.* ‘Jarmin’ (Jarmin, 2003), pink double-flowered *M.* ‘Fenghong Nichang’ (Fan et al., 2019), pink double-flowered *M.* ‘Fen Bali’ (Zhou et al., 2019), and light pink double-flowered *M.* ‘Yangzhi Yu’ (Jiang et al., 2020), have been bred and used in landscape construction. However, purple double-flowered cultivars are still rare and their development through ornamental crabapple breeding is needed.

In this study, we report a new purple double-flowered cultivar, *M.* ‘Double-flowered Prince’; its maternal parent was *M.* ‘Royalty’, which has continuously purple leaves, flowers, and fruits, unique traits that differentiate it from many varieties of ornamental crabapple. *M.* ‘Royalty’ is frequently used in landscape construction and forms excellent parent materials. In addition, we found that *M.* ‘Royalty’ not only possesses outstanding ornamental quality but also contains high flavonoid levels, resulting in high antioxidant ability and resistance to environmental stress (Jiang et al., 2014; Qin et al., 2018). However, double-flowered varieties are very rare; among the double-flowered crabapple cultivars, most are pink. Therefore, we employed ^{60}Co - γ radiation to induce mutants of *M.* ‘Royalty’ tissue culture seedlings (Al-Safadi and Simon, 1996), resulting in *M.* ‘Double-flowered Prince’. This cultivar has gained much attention because it not only inherited purple leaf, purple flower, and purple fruit

Table 1. Comparisons of the plant traits and the shoots and leaves of *M.* ‘Double-flowered Prince’ and its maternal parent *M.* ‘Royalty’.

Trait	<i>M.</i> ‘Royalty’	<i>M.</i> ‘Double-flowered Prince’
Tree		
Tree habit	Upright	Spreading
Crown type	Ovale	Suborbicular
Tree vigor	Strong	Strong
Shoots		
Shoot length (cm)	14.64 ± 0.51	24.11 ± 1.21 s
Shoot diameter (cm)	0.74 ± 0.06	0.56 ± 0.09 ns
Internode length (cm)	3.33 ± 0.12	2.65 ± 0.05 ns
Shoot color	Grayish brown (RHS 166A)	Red brown (RHS 187A)
Branching ability	5.04 ± 0.14	7.00 ± 0.11 s
Leaves		
Leaf length (cm)	8.92 ± 0.29	8.66 ± 0.25 ns
Leaf width (cm)	5.22 ± 0.15	5.32 ± 0.15 ns
Leaf length/width ratio	1.74 ± 0.06	1.65 ± 0.05 ns
Leaf area (cm ²)	33.81 ± 3.12	32.57 ± 2.36 ns
Color of leaf blade	Purple (RHS N77A)	Deep purple (RHS N186C)
Lightness (L*)	26.78 ± 0.25	29.16 ± 0.24 s
Chroma (C*)	7.55 ± 0.10	7.89 ± 0.15 ns
Anthocyanin (μg/g)	88.53 ± 0.79	98.57 ± 0.83 s
Leaf tip shape	Acuminate	Sharp acuminate
Leaf margin	Crenate	Crenate
Foliar state	Lightly clasped	Clasped upward
GUSL	Medium	Strong
Leaf shape	Elliptic	Elliptic
Petiole length (cm)	3.8 ± 0.32	3.5 ± 0.24 ns
Length of lobes (cm)	0.45 ± 0.09	0.58 ± 0.07 s
Width of lobes (cm)	0.0875 ± 0.007	0.145 ± 0.011 s

Data are shown as means ± SE. Lightness (L*): the lightness (from dark to light) on the upper side of a leaf blade; Chroma (C*): the chromatic value from green to red (hue a*) and from blue to yellow (hue b*) on the upper side of leaf blade, $C^* = (a^{*2} + b^{*2})^{1/2}$; GUSL = the glossiness of the upper side of a leaf blade. Significant differences between *M.* ‘Double-flowered Prince’ and *M.* ‘Royalty’ were determined by Student’s *t* tests ($P < 0.05$, $P < 0.01$). s = significant; ns = not significant. Qualitative descriptions were made according to UPOV (2003).

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traits from its maternal parent but also developed a double-flowered trait, spreading habit, and early first flowering, thus enriching the double-flowered germplasm resources in *Malus* plants and significantly prolonging the ornamental period. These characteristics were found to be stable and consistent in a three-point regional trial located in the same climate in China during a 3-year observation period. Moreover, serious pests or diseases of *M. 'Double-flowered Prince'* have not been observed so far, but little damage to young tips and leaves caused by apple aphids, spider mites, and apple rust occurs occasionally. This cultivar is suitable for street greening, courtyard adorning, park landscaping, and other attractions. Predictably, because of the spreading tree habit, purple-red coloration, double flowering, and high flavonoid content of this variety, it could possibly be extended as a pollinizer and resistant dwarf rootstock for apple varieties of interest for fresh markets.

Origin

In Aug. 2006, we employed ^{60}Co - γ radiation at 0, 10, 30, 50, 70, 90, and 110 Gy doses to induce the mutation of *M. 'Royalty'*, resulting in 100×3 groups of tissue culture seedlings. The radiation energy of the cobalt source was 5000 Curies at a dose rate of $5 \text{ Gy} \cdot \text{min}^{-1}$. In Spring 2008, 150 healthy mutants from the 30- to 70-Gy doses with purple-red lines were initially screened out from the radiation mutagenesis population through phenotype identification. The mutants that received doses of less than 30 Gy did not show significant differences from the maternal parent (*t* test, $P > 0.05$), most mutants that received doses of more than 70 Gy showed malformation, and all the mutants that received doses of 110 Gy died. Thereafter, the preferred mutants were grafted onto rootstocks of *M. robusta*, with three buds per line (Zhang et al., 2020). Two years later, the grafted mutant lines blossomed. Three excellent double-flowered lines, named 'DF-

mutant-08', 'DF-mutant-86', and 'DF-mutant-26', were screened out based on purplish-red leaves and double flowers as well as strong tree vigor. Consecutive identification and comprehensive evaluation from 2010 to 2012 indicated that some grafted plants showed spreading habit, vigor, continuously purple-red leaves, double flowers with purple-red petals, long flowering periods, purple-red fruit peel and flesh, high levels of anthocyanin, and high drought and cold resistance. 'DF-mutant-08' was selected as the target plant by repeated selection. Through 3 years of regional trials in Pinggu district (40.14°N, 117.10°E), Shunyi district (40.13°N, 116.65°E), and Changping district (40.10°N, 116.32°E), Beijing (39.56°N, 116.20°E), 'DF-mutant-08' showed distinctness, uniformity, and stability according to a DUS analysis [International Union for the Protection of New Varieties of Plants (UPOV), 2003; Liu, 2018]. On 11 Dec. 2019, the new cultivar was designated 'Double-flowered

Table 2. Comparisons of the flower and fruit traits of *M. 'Double-flowered Prince'* and its maternal parent *M. 'Royalty'*.

Trait	<i>M. 'Royalty'</i>	<i>M. 'Double-flowered Prince'</i>
Flower		
UF/UI	5.32 ± 0.15	7.22 ± 0.05 s
Flower type	Single	Double
Number of Petals/Flower	5.60 ± 0.36	13.14 ± 0.23 HS
Petal shape	Ovate	Ovate or narrow ovate
Petal length (cm)	2.01 ± 0.03	2.34 ± 0.08 s
Petal width (cm)	1.37 ± 0.06	1.53 ± 0.09 NS
Petal color	Deep purplish red (RHS 59A)	Deep purplish red (RHS 60D)
Flower diameter (cm)	4.17 ± 0.11	5.28 ± 0.05 s
Pedicle length (cm)	2.44 ± 0.02	3.67 ± 0.03 s
Pedicle diameter (cm)	0.06 ± 0.00	0.07 ± 0.00 NS
Flowers/branches	57.44 ± 2.66	69.94 ± 1.5 s
Anthocyanin (μg/g)	199.58 ± 27.93	234.45 ± 8.58 s
Lightness (L*)	31.48 ± 0.91	42.48 ± 0.88 s
Chroma (C*)	40.94 ± 1.34	42.87 ± 0.17 NS
Flower shape	Shallow cup	Flat
Petal veins	Not prominent	Not prominent
Fruit		
Fruit setting rate	3.26 ± 0.32	3.73 ± 0.17 s
Fruit shape	Obloid	Obloid
Fruit height (cm)	1.30 ± 0.04	1.29 ± 0.04 NS
Fruit diameter (cm)	1.41 ± 0.04	1.41 ± 0.03 NS
Fruit Height/Diameter Ratio	0.92 ± 0.03	0.92 ± 0.03 NS
Single Fruit Weight (g)	1.95 ± 0.05	1.88 ± 0.04 NS
Length of stalk (cm)	4.04 ± 0.10	4.42 ± 0.09 NS
Diameter of Stalk (cm)	0.10 ± 0.00	0.09 ± 0.00 NS
Peel color	Purplish red (RHS 179A)	Purplish red (RHS 61A)
Cover color	Deep purplish red (RHS 185A)	Deep purplish red (RHS 83B)
Color of flesh	Purplish red (RHS 61A)	Purplish red (RHS 61A)
Color area	Total	Total
Anthocyanin (μg/g)	173.64 ± 3.46	188.46 ± 0.87 s
Lightness (L*)	48.80 ± 0.79	49.17 ± 0.46 s
Chroma (C*)	28.50 ± 0.49	48.38 ± 0.40 s
Fruit Hardness (kg/cm ²)	21.12 ± 2.54	24.08 ± 0.89 NS
Soluble solids (%)	22.33 ± 0.41	25.50 ± 0.23 s
Vc (mg/100 g)	16.54 ± 0.61	19.56 ± 0.84 s
Acid (mmol/100 g)	2.63 ± 0.21	3.59 ± 0.14 s
Pedicle cavity	Slightly concave	Slightly concave
Calyx cavity	Slightly convex	Slightly convex
Fruit calyx	Always present	Always present
Fruit waxy powder	Thick	Thin
Fruit Persistence (d)	180–185	185–190

Data are shown as means ± SE. UF/UI: unopened flowers/umbellate inflorescences; lightness (L*): the lightness (from dark to light) on the inner side of a petal and on the peel of the fruit equator; chroma (C*): the chromatic value from green to red (hue a*) and from blue to yellow (hue b*) on the inner side of a petal and on the peel of the fruit equator, $C^* = (a^{*2} + b^{*2})^{1/2}$. Significant differences between *M. 'Double-flowered Prince'* and *M. 'Royalty'* were determined by Student's *t* tests ($P < 0.05$, $P < 0.01$). HS = highly significant; s = significant; NS = not significant. Qualitative descriptions were made according to the International Union for the Protection of New Varieties of Plants (2003).

Prince' by the Beijing Forest Variety Examination and Approval Committee (accession no. S-SC-CMO-008-2020).

Description

We evaluated morphological traits according to the Guidelines for the Conducts of Tests for Distinctness, Uniformity and Stability (UPOV, 2003) to compare *M.* 'Double-flowered Prince' with plants of the maternal parent, *M.* 'Royalty', as the control (Tables 1 and 2). All the test plants were 12 years old and were grafted onto *M. robusta* rootstock in the Ornamental Crabapple Germplasm Resource Garden of Beijing University of Agriculture, Shunyi district, Beijing, China. From the six trees of each test cultivar, we selected 30 branches ≈ 20 cm long from the south side of the upper, middle, and lower canopy of each plant to investigate plant morphological traits. We collected samples of young leaves in early May, mature leaves in mid-June, autumn leaves (main color just before leaf fall) in mid-October, flower samples in mid-April, and fruit samples in late September. Data comparisons were performed to determine the differences (*t* test) in

traits of the new cultivar *M.* 'Double-flowered Prince' and CK cultivar *M.* 'Royalty'. All references to color are based on the Royal Horticultural Society (RHS, 2007) color chart.

Anthocyanin content, which was determined by high-performance liquid chromatography (Agilent 1100 series HPLC system; Agilent Technologies, Wilmington, DE), fruit soluble solid contents, which were determined by refractometry (ATAGO PAL-BX/ACID5; ATAGO, Minato-ku, Tokyo, Japan), titratable acid and vitamin C (Vc) contents, which were determined by titration and spectrophotometry (Yuoke UV725N Spectrophotometer; Youke Instruments, Shanghai, China), and fruit hardness, which was measured with a durometer (Top instrument GY-4; Top Cloud-agri Technology, Hangzhou, China), were determined in 10 samples ($n = 10$) with three replicates (Bejaei et al., 2021; Peng et al., 2019; Shen et al., 2011; Stevens et al., 2006). The surface color on the leaf, flower petal and fruit peel were determined by a spectrophotometer (Konica Minolta CR-400; Konica Minolta, Minato-ku, Tokyo, Japan) under a C/2° light source. The parameter L^* indicates the change in lightness from

dark to light, hue a^* means a decrease in green and an increase in red, and hue b^* represents a gradual decrease in blue and an increase in yellow. The chroma (C^*) can be calculated as $C^* = (a^{*2} + b^{*2})^{1/2}$ (McGuire, 1992; Tai et al., 2014).

Tree *M.* 'Double-flowered Prince' exhibited a spreading habit, suborbicular crown and strong vigor (Fig. 1B). The branches of 1-year-old plants were red brown (RHS 187A) with a small number of lenticels, whereas shoots of 2-year-old plants were grayish brown (RHS 166A). The shoot length and branching ability were higher in *M.* 'Double-flowered Prince' plants than those in plants of the maternal parent, *M.* 'Royalty' (Table 1, Fig. 3B).

Leaf. The upper side of the leaf blade of young leaves was bright purplish red (RHS N34A) in the early spring, mature leaves were dark purple-red (RHS N77A) or deep purple (RHS N186C) in midsummer, and the main color just before leaf fall in autumn was dark yellowish purple (RHS N163A) (Fig. 3E). The glossiness on the upper side of the leaf blade was strong. The leaf shape was elliptic, with an average length of 8.66 cm and width of 5.32 cm (length/width ratio equal

Fig. 1. Phenotypic characteristics of double flowers (A) and tree habit during the full-bloom stage (B) in *M.* 'Double-flowered Prince' crabapple and those phenotypic characteristics of flowers (C) and tree habit (D) in *M.* 'Royalty' crabapple.

to 1.65), and the leaf tip was sharp acuminate. There was a smooth curve with multiple crenate in the leaf margin. The petiole length was medium, at an average of 3.5 cm. The lobes of the leaf blade were always present, with an average length of 0.575 cm and width of 0.145 cm. The lightness (L^*) and the anthocyanin content in *M. 'Double-flowered Prince'* leaves were significantly higher than those in the maternal parent leaves (Table 1).

Phenological period *M. 'Double-flowered Prince'* generally sprouted buds in late March, the time of beginning of flowering was in early April, and flowers blossomed in mid-April and fully bloomed in late April; there were ≈ 20 d from unopened flowers (balloon stage) to the end of flowering in Beijing, China. There were ≈ 11 to 14 d of full blooming at an air temperature more than $\approx 20^\circ\text{C}$ in the Northern Hemisphere, which is an important feature of this double-flowered cultivar. In early May, the leaves spread and shoots grew. Young fruits developed in late April, matured in late September, and fell in mid-October. The leaves fell in late October in Beijing.

Flower *M. 'Double-flower Prince'* has a strong flower bud formation ability. Each umbellate inflorescence comprised more than seven unopened flowers (balloon stage) with a deep purplish red (RHS 59A) color (Fig.

2C). The flower petals were double, with an average of 13 petals per flower and a maximum of 15 petals per flower (Fig. 2B). The petals were narrow ovate or ovate, with an average length of 2.34 cm and an average width of 1.53 cm, and exhibited a deep purplish red color (RHS 60D), which was not different between the marginal zone and middle zone of the inner side or the outer side of the petal. The petal veins were not prominent. The blooming flowers were flat and 5.28 cm in diameter on average; the average length of the pedicel was 3.67 cm, and the average diameter of the pedicel was 0.07 cm (Fig. 2A). The average number of flowers per branch was ≈ 70 . All of the preceding data were collected during the full blooming stage. In total, the number of petals per flower, petal length, diameter of a single flower, pedicel length, number of flowers per branch, lightness (L^*), and anthocyanin content of *M. 'Double Flower Prince'* flower petals were significantly higher than those from its maternal parent during the full blooming stage (Table 2, Fig. 2C and D).

Fruit. All of the data were collected when the fruit were fully ripe (170 d after full bloom). The fruit was obloid in shape, with an average fruit height of 1.29 cm and fruit diameter of 1.41 cm, and the average weight of a single fruit was 1.88 g (Fig. 3A). Both

the fruit peel and flesh were deep purplish viviparity red (RHS 61A) at fruit setting and then brownish red (RHS 61A), with the latter color remained throughout the growing season. The length and diameter of the fruit stalk were 4.42 cm and 0.09 cm, respectively. On the fruit surface, there was a thin layer of waxy powder without fruit dots (Chu et al., 2018; Hao et al., 2017). The calyx was always present and had a slightly convex calyx cavity. The pedicel cavity was slightly concave. The average fruit setting rate was 3.73 per umbellate inflorescence when no thinning was applied. The fruit hardness was 24.08 kg/cm^2 , and the soluble solid content and Vc content were 25.50% and 19.56 mg/100 g in the flesh of the fruit equator, respectively. Fruit persistence was 185 to 190 d, from late April to mid-October on average. The anthocyanin content, lightness (L^*), and chroma (C^*) of the fruit peel at the fruit equator and the soluble solid, Vc, and titratable acid contents in the flesh of the fruit equator were higher than those in the maternal parent (Table 2, Fig. 3C and D).

Cultivation and Pest Management

M. 'Double-flowered Prince' has strong adaptability and is suitable for cultivation in Beijing and regions with similar climatic

Fig. 2. Morphological features of umbellate inflorescences (A) and individual double flowers (B) and the dynamic characteristics from small and large buds (unopened) to the early flowering and blooming stages in *M. 'Double-flowered Prince'* (C) and its maternal parent *M. 'Royalty'* (D).

Fig. 3. Morphological features during the fruit setting stage (A), of a 1-year-old branch (B), of a single fruit during developmental stages (C) (D, the maternal parent *M. 'Royalty'*), and of a single leaf blade (E) in *M. 'Double-flowered Prince'*.

conditions in China. Using an asexual propagation method, the plant was propagated primarily by budding, using *M. robusta* and *M. hupehensis* as the rootstocks and by selecting healthy, plump buds as the scions (Zhang et al., 2020). The grafted plants in the nursery were transplanted at rates of 800 to 1000/666.67 m². We recommend that trees used for landscape construction be shaped and trained early in the nursery for future ornamental applications. The crown shape of the tree was regular and natural. The trees were pruned regularly to improve wind flow and light transmission. To construct and maintain the architecture of the tree crown, it is suggested that large branches and over-dense branches be cut back or thinned out once during winter. Branches of 1-year-old trees should be cut back, and the excessive growth of branches should be thinned out twice to improve illumination inside the tree crown in summer. In natural plantings, no significant plant diseases or insect pests were observed, but occasional red spiders and aphids on young leaves were controlled with pesticide application. In addition, *Juniperus sabina* should be kept away from planting to avoid rust.

We recommend planting *M. 'Double-flowered Prince'* in fertile light sandy loam in full sunlight and in an area that is not

excessively waterlogged to support and highlight its outstanding qualities, such as a high double-flowering rate; rich coloration of leaves, flowers, and fruits; and large blooming diameter. This variety is suitable for planting and use in garden landscapes and afforestation in northern China and for breeding new varieties of ornamental crabapple.

Availability

Malus 'Double-flowered Prince' is available from the Ornamental Crabapple Germplasm Resource Garden of Beijing University of Agriculture, Beijing Hengcheng Tongtai Agricultural Science and Technology Co. Ltd and Beijing Huafengyiyuan Agricultural Science and Technology Co. Ltd.

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