A Rose-red-flowered Crabapple 'Chunmei Donghong'

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Crabapple (*Malus* spp.) is conventionally regarded as a group of species or varieties in the *Malus* genus that are characterized by many flowers and small fruits (fruit diameter ≤ 5 cm) (Guo et al., 2009; Wyman, 1953). After more than 2000 years of evolution (Li, 2001; Qian, 2005), and especially with the progress in breeding in recent years, ornamental crabapple produces significant color diversity, exhibiting green, purple, red, and yellow leaves; purple, red, pink, and white flowers; and green, red, yellow, and white fruits (Fiala, 1994). Additionally, these plants are highly adaptable and resistant to environmental stress, but they prefer sufficient sunshine and fertile light sandy loam because their distribution is mainly in the northern temperate zone (Li, 1999). Crabapples play an increasingly important role in the natural environment, improving the urban and rural landscape, and enriching the diversity of ornamental plants.

The color, shape, and pattern of the flowers are the main goals of germplasm selection and breeding in ornamental crabapple (Dudash et al., 2011; Endress, 2011; Kumari et al., 2016; Mojica and Kelly, 2010; Santos et al., 2011). In recent years, the rose-type double-flowered crabapple *M.* 'Branzam', the

red to purple *M.* 'Diamond', the double pink *M.* 'Van Eseltine', the white-flowering *M.* 'Spring Bride' (Spongberg, 1996), and the double pink *M.* 'Jarmin' (Jarmin, 2003) were bred and released into the North American market. Some double red-purple, pink, and white cultivars, such as *M.* 'Fenghong Nishang', *M.* 'Fen Balei', *M.* 'Yangzhi Yu', and *M.* 'Zi Dieer', were also used for landscaping in China (Fan et al., 2019; Jiang et al., 2020; Zhou et al., 2019, 2020). However, it is rare to see the varieties with bright rose-red petals and persistent fruits during the winter. The persistent fruits during the winter can serve as a food source for birds and small animals during winter food shortages in the northern area. Therefore, the development of these resources is important not only to expand the characteristics of ornamental plants but also ecological multifunctionality and services.

Here, we report a new crabapple cultivar, *M.* 'Chunmei Donghong', that has been selected from mutants of *M.* 'Radiant' that were induced by ^{60}Co radiation. This new cultivar has attracted much attention due to its bright rose-red flowers with larger flower diameter and long blossoming period; red and yellow leaves in spring and autumn, respectively; and larger fruits with early coloration that are persistent in winter. This cultivar has enriched the rose-red-flowered germplasm resources in *Malus* and significantly prolonged their ornamental periods. These characteristics have been stable and consistent based on a three-point regional trial during the 3-year observation period. Moreover, serious pests or diseases have not been observed thus far. Damage to young tips and leaves caused by apple aphids, spider mites, and apple rust is rare. This cultivar is suitable for use as a street tree and in courtyard greening, park landscaping, and other theme attraction construction.

Origin

M. 'Chunmei Donghong' was bred from *M.* 'Radiant' in the Ornamental Crabapple Germplasm Resource Garden of Beijing University of Agriculture, Changping District, Beijing (lat. 40.10°N, long. 116.32°E), in Spring 2000. *M.* 'Radiant' was preserved and

the tissue culture seedlings were cultured at the Tissue Culture Center of Beijing University of Agriculture. In Aug. 2006, we employed ^{60}Co radiation at doses of 0, 20, 40, 60, 80, and 100 Gy to induce mutations in *M.* 'Radiant' tissue culture seedlings with 100 seedlings $\times$ 3 replicates per dose. The radiation energy of the cobalt source was 5000 Curie at a rate of 5 Gy $\cdot$ min $^{-1}$. In Spring 2008, 180 mutants with full-health and red leaves in spring were primarily selected from the radiation mutagenesis population through phenotypic identification and then grafted onto the rootstock (*M. robusta*) at three buds/line. Two years later, the grafted mutant lines blossomed. Five excellent, fresh rose-red-flowered lines were screened out and named RF-mutants 8, 23, 27, 35, and 37. From 2010 to 2012, some of the trees showed the different degrees of rose-red coloration in the flowers, high levels of anthocyanins, strong growth potential, and high drought and cold resistance through consecutive identification and comprehensive evaluation. Thereafter, 'RF-mutant-27' was selected as the target plant by repeated selection because it had lighter rose-red petals, a larger flower diameter, a longer flowering period and larger fruit, and a higher fruit persistence rate in winter than the other mutant plants. During a regional trial in Pinggu, Shunyi, and Changping districts, Beijing, China in 2013–19, with repeated propagation, observation, and selection, the 'RF-mutant-27' showed distinctness, uniformity, and stability by DUS analysis (International Union for the Protection of New Varieties of Plants, 2003; Liu, 2018). On 11 Dec. 2019, the new cultivar was designated *M.* 'Chunmei Donghong' by the Beijing Forest Variety Examination and Approval Committee (accession no. S-SC-CMO-009-2020).

Description

Morphological traits of 'Chunmei Donghong' were evaluated according to the guidelines for conducting DUS (International Union for the Protection of New Varieties of Plants, 2003) and compared with those of the mother parent 'Radiant' as the control. These plants were 12 years old and grown on the *M. robusta* rootstock in the Ornamental Crabapple Germplasm Resource Garden of Beijing University of Agriculture, Shunyi District, Beijing. For the five plants tested, 30 branches $\approx$ 20 cm long from the south side of the upper middle and lower canopy per plant were selected and investigated for plant morphological traits. The sampling times were arranged as follows: young leaves in early May; mature leaves in mid-June; leaf blades (main color just before leaf fall) in late October; flowers in mid-April; fruits in early October; and persistent winter fruits in mid-December, mid-January, and mid-February. We used a group data comparison analysis to compare the different traits of the new cultivar and CK cultivar via a *t* test, in which the length, diameter, and transverse and longitudinal diameters of the trunks, branches, leaves, flowers and fruits were all measured with a ruler or Vernier caliper. All references

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to color were based on the Royal Horticultural Society (RHS, 2007) color chart.

The anthocyanin content in the leaf, flower petal, and fruit was determined by high-performance liquid chromatography (Peng et al., 2019). The surface color on the leaf, flower, and fruit peel was determined by a CR400 spectrophotometer under a C/2° light source. In the CIE L*a*b* system, the lightness L* varies from 0 to 100, i.e., from darkest black to lightest white indicating the change in brightness from dark to light; the hue a* value changes from negative to positive, indicating a decrease in green, and an increase in red; the hue b* value represents a gradual decrease in blue, accompanied by an increase in yellow; and the chroma component is determined by two Cartesian coordinates a* and b* as $C^* = (a^{*2} + b^{*2})^{1/2}$. The fruit soluble solids, titratable acid and Vc content, as well as fruit hardness, across 10 samples (n = 10) were determined by refractometry, titration, spectrophotometry, and durometry, respectively (Shen et al., 2011).

Tree. *M. 'Chunmei Donghong'* exhibits a spreading habit and broad and flat crowns with strong vigor (Fig. 1A). Annual shoots are light brown (RHS 166A) with a small number of lenticels and pubescent. Perennial branches are grayish brown (RHS 200C). The shoot length and the internode length are longer in *M. 'Chunmei Donghong'* plants than in the mother *M. 'Radiant'* plants (Table 2).

Flower. Floral bud formation ability is strong in *M. 'Chunmei Donghong'*, especially for axillary buds on the long shoots, which display rose-red flower clusters similar to a feather duster (Fig. 1C). Each umbellate is composed of more than five unopened flowers (balloon stage) with a deep red color (RHS 53A). The flower petal is single and slightly overlapping at an average of 5.6 petals per flower. The petals exhibit a broad elliptical shape and bright rose-red (RHS 52B), both the inner side or outer side of the petals with an

average length of 2.57 cm and width of 1.97 cm (Fig. 2A); these values are not different between the marginal zone and middle zone of the inner side or outer side of the petals. The petal veins are not prominent. The diameter of the blooming flowers with a shallow cup shape is 3.87 cm on average. The length of the pedicel is on average 3.27 cm and the diameter of the pedicel is ≈0.1 cm. There are, on average, 105.28 flowers per branch. All of the foregoing investigations were conducted at the full blooming stage. In total, the length and width of the single petal, the average flowers per branch, the anthocyanin content, the lightness brightness and color hues are greater, but the pedicel length are shorter, in new cultivar plants than in the mother plants at the full blooming stage (Table 1, Fig. 1E and G).

Foliage. The upper side of the young leaves are bright purplish red (RHS 166A) in the early spring, and the mature leaves are reddish green (gray orange, RHS 175A); the leaves turn bright dark-green (RHS 147A) in midsummer and yellowish green (RHS 152A-B) in autumn (Fig. 2B). However, the young leaves on the top of the autumn shoots are reddish green (RHS 176B). Moreover, the glossiness on the upper side of the leaf blade is strong. The leaf shape is elliptical with an average length of 7.81 cm width of 5.93 cm (length/width ratio: 1.32), and the leaf tip is acuminate. The leaf margins are smooth curved, multiple, and crenate. The leaf petiole is of medium length with an always present blade. The anthocyanin content is significantly higher, but the leaf length, leaf length/width ratio, leaf area, leaf brightness, and leaf petiole length are smaller in the new cultivar plants than in the mother plants (Table 2).

Fruit. The fruit is ellipsoid and conical with an average longitudinal scale of 2.84 cm and transverse scale of 1.90 cm, and the average weight of a single fruit is 3.53 g (Fig. 1B). The peel of mature fruits is orange-yellow (RHS N25A) with covered 85% orange-red (RHS

Fig. 2. Dynamic characteristics of flowers (A), leaves (B), and fruits (C) from *M. 'Chunmei Donghong'*. (A) Flower characteristics of small and large flower balloon (unopened balloon), early flowers, and blooming flower, and the single flower shape and single petal traits for *M. 'Chunmei Donghong'*. (B) Leaf characteristics at the young, expanding, transverse, and stopped growth stages, as well as leaf traits in autumn before falling for *M. 'Chunmei Donghong'*. (C) Fruit characteristics at the young, fading, and transverse stage of the fruit surface, red coloring covering the whole fruit surface stage, and fruit ripening stage for *M. 'Chunmei Donghong'*.

N34A) flesh on the surface facing the sun. The fruit peel color of *M. 'Chunmei Donghong'* changed during the fruit development period. The peel of baby fruit from the embryo is purplish red. The whole peel turns green in early May then turns orange-yellow on the sunny side and greenish-yellow on the shady side in late May. Subsequently, the orange-red (RHS N34A) flesh appears on the sunny side of the fruit peel, which extends to 80% of the total fruit surface in late June and to 100% of the total fruit surface in mid-July; this color persists until late October (Fig. 2C). The length and diameter of the fruit stalk are 2.88 cm and 0.09 cm, on average, respectively. On the surface of fruit peel, there is white powder, with light fragrance and without fruit dots. The calyx is always present with a convex calyx cavity. The pedicel cavity is shallow and the width is concave. The average fruit setting rate is 4.6 per umbel inflorescence, when no thinning is applied. The soluble solid content and Vc content in the flesh at the equator of the fruit are 18.15 mg/100 g and 17.18 mg/100 g, on average, respectively. All of the investigations described were conducted at the full fruit ripening stage (180 d after flowering). The average single fruit weight, the fruit setting rate per inflorescence, the chroma C* on the peel at the equator of the fruit, and the anthocyanin content in the flesh at the equator of the fruit are higher in the new cultivar than in the mother plant (Table 1, Fig. 1F). In addition, the persistent fruit yields in winter are 1358.18,

Fig. 1. The plant habit at the full blooming stage and at the fruit ripening stage, the rose-red flower clusters at the full blooming stage, and the persistent fruit on the tree in mid-December for *M. 'Chunmei Donghong'* (A-D) and its mother plant *M. 'Radiant'* (E-H).

Table 1. Comparisons of the flower and fruit traits between *M.* ‘Chunmei Donghong’ and its mother *M.* ‘Radiant’.

Comparison items	<i>M.</i> ‘Radiant’	<i>M.</i> ‘Chunmei Donghong’
Flower		
Petal shape	Broad elliptic	Broad elliptic
Flower type	Single	Single
Flower diameter (cm)	3.54 ± 0.12	3.87 ± 0.36 NS
Flower shape	Shallow cup	Shallow cup
Petal position	Free	Slight overlapping
Petal veins	Not prominent	Not prominent
Unopened flower color	Shallow rose-red (RHS 55A)	Deep red (RHS 53A)
Lightness L*	38.02 ± 0.97	42.06 ± 1.03 s
Chroma C*	32.97 ± 0.63	39.23 ± 0.26 s
Petal color	Shallow rose-red (RHS 55A)	Bright rose-red (RHS 52B)
Petal length (cm)	1.92 ± 0.05	2.57 ± 0.11 s
Petal width (cm)	1.20 ± 0.04	1.97 ± 0.03 s
Flowers/bunch	87.17 ± 2.96	105.28 ± 5.93 HS
Anthocyanin (μg/g)	122.00 ± 1.96	143.15 ± 3.83 s
Large buds/umbel	5.59 ± 0.15	5.26 ± 0.11 NS
Number of petals/flower	5.24 ± 0.12	5.60 ± 0.17 NS
Pedicle length (cm)	4.11 ± 0.47	3.27 ± 0.23 s
Pedicle diameter (cm)	0.08 ± 0.01	0.10 ± 0.03 NS
Fruit		
Fruit size	Small	Small
Fruit hardness	27.98	21.96 NS
Fruit shape	Ellipsoid conical	Ellipsoid conical
Fruit calyx	Present	Always present
Pedicle cavity	Width concave	Width concave
Calyx cavity	Convex	Convex
Soluble solid (%)	14.43 ± 0.50	18.15 ± 0.3 s
Fruit setting rate/umbel	3.64 ± 0.12	4.60 ± 0.09 s
Vc (mg/100 g)	14.73 ± 1.67	17.18 ± 0.34 NS
Brightness L*	45.32 ± 0.73	48.86 ± 0.62 NS
Chroma C*	36.87 ± 1.20	44.11 ± 1.7 s
Peel color	Yellowish white (RHS N34B)	Orange-yellow (RHS N25A)
Cover color	Red (RHS 40B)	Orange-red (RHS N34A)
Anthocyanin (μg/g)	124.99 ± 3.23	151.91 ± 9.5 s
FP/C in Jan (per M ³)	104.71 ± 6.42	1338.08 ± 129.35 HS
Fruit longitudinal scale (cm)	2.26 ± 0.08	2.84 ± 0.06 NS
Fruit transverse scale (cm)	1.66 ± 0.03	1.90 ± 0.09 NS
Fruit shape index	1.37 ± 0.05	1.53 ± 0.07 NS
Single fruit weight (g)	3.02 ± 0.08	3.53 ± 0.2 s
Length of stalk (cm)	3.80 ± 0.10	2.88 ± 0.23 NS
Diameter of stalk (cm)	0.09 ± 0.01	0.09 ± 0.01 NS

Data are shown as means ± SE. RHS = Royal Horticulture Society color chart; FP/C = fruit persistent/per m³ canopy in January; lightness L* = the lightness from dark to light on the inner side of petals, and on the peel at the equator of the fruit, Chroma C* = the chromatic value from green to red (hue a*) and from blue to yellow (hue b*) on the inner side of petals and on the peel at the equator of the fruit, C* = (a*² + b*²)^{1/2}. The significant differences between *M.* ‘Chunmei Donghong’ and *M.* ‘Radiant’ were determined by Student’s *t* tests (*P* < 0.05, *P* < 0.01). HS = highly significant; s = significant; NS = not significant. Qualitative descriptions were conducted according to the International Union for the Protection of New Varieties of Plants (2003).

1338.08, and 1087.91 per 1 m³ canopy, on average, in December, January, and February, respectively (Table 1, Fig. 1D and H).

Phonological period. *M.* ‘Chunmei Donghong’ generally spouts buds in late March, and the time of flowering initiation is in early April, with blossoming is in late April, with ≈24 d from unopened flowers (balloon stage) to the end of flowering in Beijing. There are ≈15 d of full blooming at a more than ≈20 °C air temperature in the Northern Hemisphere, which is an excellent feature for the present rose-red-flowered cultivar. Thereafter, the leaves spread, and the shoots grow in early May. The young fruits grow in late April, turn yellow with rose-red flesh on the sunny side in late May, and mature in early October. The leaves fall in the mid-November. The persistent fruit remains until the tree sprout stage of the following year.

Cultivation and Pest Management

M. ‘Chunmei Donghong’ has strong adaptability and is suitable for cultivation in Beijing and Hebei in northern China, as well as in regions with similar climatic conditions. It is propagated using grafting onto rootstocks such as *M. robusta* and *M. hupehensis* by selecting healthy, full buds and branches from the cultivar as the scion. This also facilitates early shaping through grafting of that scions onto the perennial rootstocks. The grafted plants >3 years old with a diameter >2.5 cm were transplanted at 800 to 1000/666.67 m² in the nursery. We recommended that *M.* ‘Chunmei Donghong’ trees used for landscape construction be shaped and trained early in the nursery for future ornamental applications. Landscape trees should be pruned regularly to improve wind flow and light transmission. No

significant plant diseases or insect pests were observed in natural planting; aphids were occasionally found and controlled by spraying pesticide. *Juniperus sabina* plants should be kept away from crabapple plants to avoid rust. When ‘Chunmei Donghong’ was planted in fertile light sandy loam and at lower autumn temperatures, its excellent qualities, such as the brightly colored of leaves, flowers and fruits, the larger-sized flower petals, the increased number of flowers per shoot, the larger fruit size and higher fruit setting rate, and the high fruit persistence rate in winter, were fully visible. This variety is suitable for planting and use in garden landscapes and afforestation in northern China and for breeding the new varieties of ornamental crabapple.

Availability

M. ‘Chunmei Donghong’ is available from the Ornamental Crabapple Germplasm Resource Garden of Beijing University of Agriculture and Beijing Hengcheng Tongtai Agricultural Science and Technology Co. LTD.

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Table 2. Comparisons of plant habit and leaf traits between *M. 'Chunmei Donghong'* and its mother plant *M. 'Radiant'*.

Comparison items	<i>M. 'Radiant'</i>	<i>M. 'Chunmei Donghong'</i>
Tree		
Tree habit	Upright	Spreading
Tree vigor	Strong	Strong
Shoots		
Shoot length (cm)	11.39 ± 0.19	15.42 ± 0.24 s
Shoot diameter (cm)	0.49 ± 0.03	0.55 ± 0.02 NS
Internode length (cm)	2.05 ± 0.24	1.65 ± 0.06 s
Shoot color	Gray orange (RHS 165A)	Light brown (RHS 166A)
Leaves		
Color of leaf blade	Green (RHS 137B)	Yellow-green (RHS 147A)
Petiole length (cm)	2.02 ± 0.03	2.14 ± 0.02 NS
Leaf blade lobes	Present	Always present
Leaf margin	Obtuse serrate	Crenate
Leaf glossiness	Weak	Weak
Anthocyanin (μg/g)	66.13 ± 1.14	87.46 ± 1.84 s
Leaf length (cm)	10.26 ± 0.22	7.81 ± 0.22 s
Leaf width (cm)	5.72 ± 0.14	5.93 ± 0.09 NS
Leaf length/width ratio	1.79 ± 0.06	1.32 ± 0.05 NS
GUSL	Medium	Strong
Lightness L*	32.72 ± 0.74	5.35 ± 0.18 s
Chroma C*	9.72 ± 0.16	10.66 ± 0.34 NS
Leaf area (cm ²)	39.69 ± 1.75	31.20 ± 1.21 s
Leaf tip shape	Acuminate	Acuminate

Data are shown as means ± SE. RHS = Royal Horticulture Society color chart; lightness L* = the lightness from dark to light on the upper side of the 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 the leaf blade, $C^* = (a^{*2} + b^{*2})^{1/2}$; GUSL = the glossiness of upper side of the leaf blade. The significant differences between *M. 'Chunmei Donghong'* and *M. 'Radiant'* were determined by Student's *t* test ($P < 0.05$, $P < 0.01$). s = significant; NS = not significant, respectively. Qualitative descriptions were conducted according to the International Union for the Protection of New Varieties of Plants (2003).

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