‘Hongbaleng’, a Crabapple Cultivar with Large Fruit and Full-coverage Red Color

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Ornamental crabapple is a popular landscaping plant worldwide; it belongs to the *Malus* genus of the *Rosaceae* family. Ornamental crabapple has been used extensively in gardens, street plantings, and is an important ornamental tree due to its colorful leaves, flowers, fruits, and beautiful tree habit; it has also been used in apple cultivation as a rootstock and pollinator due to its wide adaptability and

abundant pollen production (Dudash et al., 2011; Henry, 2007). In addition, its fruits and leaves are processed and used as dried fruit, in drinks, and also medicine because of their special nutritional and medicinal ingredients (Qian and Tang, 2005; Wang, 1989). Ongoing ornamental crabapple breeding has focused on developing a diversity of new varieties (Qian, 2005), which proposes an emphasis on varieties with high ornamental value and edible large fruit.

M. Robusta is a species of *Malus* native to northern Hebei, China, and is a typical apple rootstock and ornamental plant in northern China. Through long-term natural and artificial selection, *M. Robusta* has been selected for a spreading habit with strong vigor, bright white flowers, a large number of flowers, abundant pollen, dark green leaves, high seed germination rate, and especially large fruit relative to common crabapple cultivars; it also has eight marked longitudinal convex arrises on fruit surface, appearing the irregular octagon shape, hence its name as ‘eight arrises crabapple’ in the local area. Moreover, this plant has a wide range of environmental adaptability and high cold (–37 °C), drought, and disease resistance (Li, 2001). The fruit is also used in fresh and processed foods. As an

ornamental plant, it is desirable for breeders to have red or pinkish-white flowers and full-red fruits, while maintaining high cold, drought, and disease resistance and adaptability (Zhang et al., 2020; Zhou et al., 2020).

We found a new cultivar with red flower petals at the balloon stage and pinkish-white petals at the beginning of flowering, followed by fruits with red skin. *Malus Robusta* ‘Hongbaleng’ was derived from a natural mutant of the *M. Robusta* offspring group, and its red-skin fruit and large fruit shape distinguish it from its maternal plant and other crabapple cultivars. These flower and fruit properties were found to be stable and consistent during a 3-year observation period, and they may be important traits for growers to enhance their economic income. Although there are many red-flowered and red-fruited ornamental crabapple varieties, the edible varieties with large full-red fruits are rare. In addition, ‘Hongbaleng’ is an ideal material for the study of fruit coloration and fruit development due to its full red pericarp (Lu et al., 2017; Zhang et al., 2015). The results are expected to provide a technical reference to improve directional breeding of ornamental crabapples as well as red fruit coloration in other plants.

Origins

We collected more than 1200 seeds from a 20-year-old *M. Robusta* plant and sowed them on raised beds in the field in Mar. 2000 near Bangshuiyu village, Yanqing District of Beijing, China, then a full red-skin fruit mutation in *M. Robusta* was first observed in 2004. The field is located at 40.36°N and 115.97°E, and the average annual temperature is 8 °C, and the average altitude is more than 500 m. After 4 years of observation, we selected the full red-skin fruit mutants and propagated them by bud grafting in Sept. 2004 and shoot grafting in Apr. 2005 using *M. Robusta* and *M. hupehensis* as 3-year-old rootstocks, respectively. In 2006 and 2008, 206 grafted plants showed the same flowering and fruiting characteristics as their maternal plant and were then named *M. ‘Hongbaleng’*. From 2009 to 2013, we also conducted regional experiments in Changping, Shunyi, and Yanqing districts. ‘Hongbaleng’ displayed the same tree habit and flowering and fruiting characteristics in these places. On 5 Dec. 2014, the new cultivar was designated *M. ‘Hongbaleng’* by the Beijing Forest Variety Examination and Approval Committee (accession no. S-SV-MP-029-2014).

Description

Morphological traits of *M. ‘Hongbaleng’* were evaluated according to the guidelines for the conduct of tests for Distinctness, Uniformity and Stability (DUS) (Liu, 2018; UPOV, 2003) and compared with those of the mother parent *M. Robusta* as the control (CK). 0 These plants were 10 years old and grown on the popular *M. Robusta* and *M. hupehensis* rootstock in The Ornamental Crabapple Germplasm Resource Garden of Beijing University of Agriculture, Yanqing

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Fig. 1. Phenotypic characteristics of *M. 'Hongbaleng'* crabapple cultivar. (A) Upright growth habit at fruit-ripening stage (5 Sept. 2014). (B) Balloons and opened flowers (21 Apr. 2014). (C) Full red fruits (9 Sept. 2014). The photographs were taken in Bangshuiyu, Yanqing District, Beijing, China.

District of Beijing. For the five plants tested, 30 branches ≈ 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, and fruits in late September. We used a group data comparison analysis to compare the different traits of the new cultivar and CK plant 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 to color were based on the Royal Horticultural Society (2007; RHS, fifth ed., UK) color chart. The fruit soluble solids, titratable acid, and vitamin C (Vc) content, and fruit hardness across 10 samples ($n = 10$) were determined by refractometry, titration, spectrophotometry, and durometry, respectively (Shen et al., 2011).

Tree. *M. 'Hongbaleng'* exhibits an upright habit and vertical ramose crown with strong vigor (Fig. 1A). Annual shoots are gray-orange (RHS 165A) with a moderate number of lenticels and more pubescent, relative to CK plants. Perennial branches are gray-brown (RHS N199C) with strong branching. The shoot length and the internode length are shorter in *M. 'Hongbaleng'* plants than in CK plants, suggesting that *M. 'Hongbaleng'* has a compact and dwarfed phenotype relative to its maternal parent, which is beneficial to easier management (Table 2).

Flower. *M. 'Hongbaleng'* has umbellate inflorescences with five to six single flowers (Fig. 2A). The flower petals base partly overlapping at an average of five petals per

flower, which exhibit a broad elliptical shape (Table 1). The flower balloon is a red-purple (RHS 68A) (Fig. 2A), and petals that are not fully unfolded at the first bloom are pinkish-white (RHS N57D) (Fig. 2B and C). When flowers are in full bloom, both the inner side and outer sides of the petals are white (RHS 155D) (Fig. 2D), with an average length of 1.91 cm and width of 1.52 cm, but a few petals have a basal zone on the inner side of *M. 'Hongbaleng'* that are white (RHS 155D); additionally the color of the marginal zone of the inner side of the petal is pinkish-red (RHS N57D), and that of the outer side is purple-red (RHS N57A). These values are somewhat different between the marginal and middle zones of the inner side and outer side of the petals (Fig. 1B). The diameter of the blooming flowers exhibits a shallow cup-like shape and is 4.28 cm on average, with a

nonprominent petal vein. The length of the pedicel is on average 4.67 cm, and the diameter of the pedicel is ≈ 0.7 mm (Table 1). All of these investigations were conducted at the full blooming stage, except for flower balloon coloration. These observations suggest that the petal coloration of *M. 'Hongbaleng'* in the initial opening and blooming stage differs significantly from that of its parent CK plant. Meanwhile, the filaments are more numerous, and the stamens length and the bud size are both larger, but the petal length is shorter in *M. 'Hongbaleng'* plants than in its CK plants (Table 1). These results indicate that the initial floral morphology, such as large buds, red petals, and abundant filaments, is a significant variation characteristic that distinguishes *M. Hongbaleng* from its parent, which not only strengthens the ornamental value of this new cultivar but also provides selected material for further floral color breeding.

Foliage. The upper side of the young leaves appear light green (RHS 143C) in the early spring, and the mature leaves are deep green (RHS 137B). The main color before leaf fall is yellow green (RHS 145A). The mature leaf shape is elliptical with an average length of 5.53 cm and width of 3.47 cm; the length-to-width ratio is equal to 1.59 on average, and the single leaf area is 13.43 ± 0.98 cm² on average. The glossiness on the upper side of the leaf blade is strong, and the leaf tip is acuminate, smooth, and curved with obtuse serrate margins of the leaf edge. The petiole length and diameter are 2.05 and 0.15 cm on average, respectively. The stipule is always present, with an average length of 1.27 cm and width of ≈ 0.12 cm. The length and width of the leaves and stipules, single leaf area, and leaf length/width ratio are smaller in the new cultivar plants than those in the CK plants (Table 2).

Fruit. The fruit is globose and conical with an average longitudinal scale of 2.24 cm and a transverse scale of 2.68 cm, and the average weight of a single fruit is 9.07 g (Table 1). The peel of mature fruits is yellow (RHS 8C) and 100% red (RHS 33C) on the fruit surface (Fig. 1C). The large fruit peel color of *M. 'Hongbaleng'* changed during the fruit development period. The baby fruit peel

Fig. 2. Characteristics of flower and fruit of *M. 'Hongbaleng'*. (A) Small balloon stage (15 Apr.). (B) Big balloon stage (18 Apr. 2014). (C) Beginning of flowering stage (20 Apr. 2014). (D) Full-bloom stage (23 Apr. 2014). (E) Young fruit stage (5 May 2014). (F) Color-turning stage I (green to white transition period) (15 July 2014). (G) Color-turning stage II (yellow to red transition period) (25 Aug. 2014). (H) Ripening and full red fruits (25 Sept. 2014). The photographs were all taken in Bangshuiyu, Yanqing District, Beijing, China.

Table 1. Comparisons of the flower and fruit traits between parent *M. Robusta* and offspring *M. 'Hongbaleng'*.

Comparison items	<i>M. Robusta</i>	<i>M. 'Hongbaleng'</i>
Flower		
Petal shape	Broad elliptic	Broad elliptic
Flower type	Single	Single
Flower diameter (cm)	4.15 ± 0.24	4.28 ± 0.12 ns
Flower shape	Shallow cup	Shallow cup
Petal position	Free	Overlapping
Petal veins	Not prominent	Not prominent
Unopened flower color	Red purple (RHS 63B)	Red purple (RHS N57D)
Petal color	White (RHS 155D)	White (RHS 155D)
Petal length (cm)	2.28 ± 0.12	1.91 ± 0.11 s
Petal width (cm)	1.32 ± 0.15	1.52 ± 0.14 ns
Large buds/umbel	4.1 ± 0.12	6.0 ± 0.33 s
No. of petals/flower	5 ± 0.00	5.0 ± 0.00 ns
Pedicle length (cm)	4.43 ± 0.56	4.67 ± 0.45 ns
Pedicle diameter (cm)	0.068 ± 0.04	0.07 ± 0.05 ns
Filament length (cm)	0.92 ± 0.06	0.73 ± 0.04 ns
No. of filaments	19.40 ± 2.88	21.00 ± 2.12 s
Stamen length (cm)	0.88 ± 0.03	1.07 ± 0.07 s
Fruit		
Fruit size	Large	Large
Fruit hardness (kg/cm ²)	10.24 ± 1.08	11.62 ± 0.09 s
Fruit shape	Ellipsoid conical	Globose conical
Fruit calyx	Always present	Always present
Pedicle cavity	Narrow	Wide
Calyx cavity	Shallow	Shallow
Soluble solids (%)	15.2 ± 1.09	18.3 ± 1.12 HS
Fruit setting rate/umbel	5.5 ± 0.23	6.3 ± 0.17 s
Titrateable acid (mmol/100 g) (mg/100 g)	2.8 ± 0.21	2.1 ± 0.14 s
Vc (mg/100 g)	4.0 ± 0.91	4.4 ± 0.88 ns
Baby fruit color	Yellow green (RHS 144D)	Yellow green (RHS 144D)
Peel color	Yellow (RHS 11C)	Yellow (RHS 8C)
Cover color	Orange red (RHS N34C)	Red (RHS 33C)
Fruit longitudinal scale (cm)	1.42 ± 0.21	2.24 ± 0.18 s
Fruit transverse scale (cm)	1.39 ± 0.09	2.68 ± 0.12 s
Fruit shape index	1.02 ± 0.08	0.835 ± 0.02 ns
Single fruit weight (g)	6.64 ± 1.02	9.07 ± 0.08 HS
Length of stalk (cm)	4.23 ± 0.23	3.64 ± 0.18 s
Diameter of stalk (cm)	0.085 ± 0.05	0.106 ± 0.05 s
Pulp texture	Crisp	Crisp

Data are shown as means ± SE. The significant differences between *M. Robusta* and *M. 'Hongbaleng'* were determined by Student's *t* test ($P < 0.05$, $P < 0.01$). 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 (UPOV, 2003).

is green (RHS 145A) (Fig. 2E), and the fruit peel turns whitish green (RHS 144D) in mid-July (Fig. 2F) then yellow (RHS 11A) in early August. The covering color on the fruit peel surface is red (RHS 33C) on the sunny side in late August (Fig. 2G), and then exhibits full red coverage in early September, with maturity in late September (Fig. 2H). The length and diameter of the fruit stalk are 3.64 cm and 0.106 cm on average, respectively. On the surface of the fruit peel, there is strongly expressed glossiness, covering slightly waxy powder covering, obvious ridges, and light fragrance. The flesh is yellowish-white and crispy. The calyx is always present with a shallow concave calyx cavity (Table 1). The pedicle cavity is shallow and the width is concave. The fruit-setting rate is high and fruit persistence is long until flowers bloom the following year. The fruit hardness is ≈ 11.62 kg/cm², and the soluble solid content, titrateable acid content and Vc content in the flesh at the equator of the fruit are 18.3 mg/100 g, 2.1 mmol/100 g, and 4.4 mg/100 g, on average, respectively (Table 1). All of the preceding investigations were conducted

at the full fruit ripening stage (180 d after flowering). The average single fruit weight, the fruit setting rate per inflorescence, the fruit longitudinal and transverse scale, the diameter of the stalk, the fruit hardness, the soluble solids content, and the Vc content in the flesh at the equator of the fruit are higher, but the length of the stalk and the titrateable acid content is smaller in the new cultivar than in the mother plant (Table 1). These results suggest that the large fruits, full red skin, and light-yellow flesh crabapple fruits, with high soluble solids and Vc content, and low soluble acid content are the most obvious quality characteristics of *M. 'Hongbaleng'*, which endows it with greater ornamental value and higher fresh food and processing value than its maternal parent (Fig. 3).

Phonological period. *M. 'Hongbaleng'* generally sprouts buds in late March and in early April, and flowering initiation occurs in early April with pinkish-red flower balloons. Blossoming occurs in late April and in early May on the hillside fields at altitudes greater than 1000 m. There are ≈ 20 d from unopened flowers (balloon stage) to the end of

flowering in Beijing and northern Hebei Province. Thereafter, the leaves spread, and the shoots grow in mid-May. Young fruits grow in early May, and the fruit surface is initially yellow-green, turns red on the sunny side in mid-August, and exhibits full-red coverage fruits in the early September, with maturity in late September. Then, the pale green or slightly yellow-green leaves fall in the middle of November. Compared with its parent, *M. 'Hongbaleng'* has a long, big, red floral balloon stage, an early fruit color-turning stage, and a long fruit coloring stage, as well as a long autumn-colored leaf stage, extending the ornamental time and enhancing the ornamental quality.

Cultivation and Pest Management

M. 'Hongbaleng' has strong adaptability and is suitable for cultivation in Beijing and 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 process also facilitates early shaping through the grafting of the scion onto the perennial rootstocks. The grafted plants >3 years old with a diameter >2.5 cm were transplanted at 800–1000/666.67 m² in the nursery. We recommend that *M. 'Hongbaleng'* trees be transplanted according to the American Standard for Nursery Stock (American Horticulture Industry Association, 2014). All trees should be healthy with tops of good quality (i.e., leaf color appropriate for cultivar and no apparent injury), vigorous, and well-rooted with growth normal for the species or variety (e.g., reasonably straight trunks according to the habit of growth). We also recommend that *M. 'Hongbaleng'* trees used for landscape construction be transplanted with 1 m × 2 m plant spacing (both plant and row) and shaped and trained early in the nursery for future ornamental applications. The trees used for fruits shall be transplanted at 1 m × 3 m or 1 m × 4 m plant spacing and row spacing, respectively.

For the *M. 'Hongbaleng'* root and the root ball, not less than three root branches should be present within 12.5 cm from the collar, and the root shall carry the minimum caliper of the grade for not less than 15 cm below the collar. When digging up the tree, if the trunk diameter at 15 cm interval above the ground level is 2.5 to 5 cm, a root ball of 45 to 60 cm diameter and 30 to 40 cm depth is dug out and then wrapping in a 30 to 40 cm ground fabric bag; if the tree trunk diameter is 5 to 10 cm, a root ball of 60 to 100 cm diameter and 40 to 65 cm depth is dug out, and then wrapping in a 40 to 65 cm ground fabric bag. When the tree trunk diameter is more than 10 cm, we dig out the root ball at more than 100 cm diameter and 80 cm depth, with 100 cm ground fabric bag. The center of the plant trunk should be in the center of the root ball. When these large trees are transplanted, a suitable planting hole or ditch should be prepared according to the size of the transplanted root ball above (American Horticulture

Table 2. Comparisons of plant habit and leaf traits between parent *M. Robusta* and offspring *M. 'Hongbaleng'*.

Comparison items	<i>M. Robusta</i>	<i>M. 'Hongbaleng'</i>
Tree		
Tree habit	Upright	Upright
Tree vigor	Strong	Strong
Tree crown shape	Ramose crown	Ramose crown
Shoots		
Shoot length (cm)	59.05 ± 1.03	48.30 ± 0.91 HS
Shoot diameter (cm)	1.47 ± 0.06	1.63 ± 0.07 NS
Internode length (cm)	3.16 ± 0.12	2.28 ± 0.09 s
Shoot color	Gray-orange (RHS 165A)	Gray orange (RHS 165A)
Perennial branch color	Gray-orange (RHS 165A)	Gray brown (RHS N199C)
Lenticels number	Many	Medium
Pubescence	Few	Very many
Branching	Strong	Strong
Leaves		
Color of leaf blade	Light green (RHS N144C)	Light green (RHS 143C)
Leaf color just before leaf fall	Yellow green (RHS 146C)	Yellow green (RHS 145A)
Color of leaf blade	Green (RHS 137B)	Green (RHS 137B)
Leaf shape	Elliptic	Elliptic
Petiole length (cm)	2.02 ± 0.03	2.14 ± 0.02 NS
Petiole width (cm)	0.18 ± 0.01	0.15 ± 0.01
Leaf blade lobes	Present	Always present
Leaf margin	Serrate	Obtuse serrate
Leaf glossiness	Medium	Medium
Leaf length (cm)	9.60 ± 0.26	5.53 ± 0.24 HS
Leaf width (cm)	5.51 ± 0.13	3.47 ± 0.18 HS
Leaf length/width ratio	1.74 ± 0.06	1.59 ± 0.12 NS
Stipule length (cm)	1.76 ± 0.05	1.27 ± 0.07 s
Stipule width (cm)	0.48 ± 0.02	0.12 ± 0.02 HS
GUSL	Medium	Strong
Leaf area (cm ²)	24.64 ± 1.24	13.43 ± 0.98 HS
Leaf tip shape	Acuminate	Acuminate

Data are shown as means ± SE. GUSL = glossiness of upper side of the leaf blade. The significant differences between *M. Robusta* and *M. 'Hongbaleng'* were determined by Student *t* tests ($P < 0.05$, $P < 0.01$). s = significant; NS = not significant. Qualitative descriptions were conducted according to the International Union for the Protection of New Varieties of Plants (UPOV, 2003).

Industry Association, 2014). The planting ditch or the planting hole shall be dug at least 1 m deep and 1.5 m wide for organic fertilizer and borrowed soil if there are poor conditions. The organic fertilizer should be evenly mixed with the topsoil dug out of the planting ditch, back-filled into the planting hole, and compacted to fill with sufficient water to improve the survival rate and shorten the slow seedling period (Beijing Gardening and Greening Bureau, 2008). The organic fertilizer is mixed as Farmyard manure 100 kg, *Bacillus subtilis* 0.1 kg, ABT rooting power 50 mg, urea (N) 300 g, and KH₂PO₄ 100 g for transplant.

The desired diameter and height of *M. 'Hongbaleng'* trees at 1.0, 1.5, and 2.5 cm or greater trunk diameter corresponds to a 100, 150, and 180 cm tree height, respectively. The tree at 0.8 cm and larger single trunk diameter shall be branched and those at 1.5 cm, 2 cm, and 2.5 cm single trunk diameter shall have three or more branches. We recommend that these trees shall be pruned back to multiply the branching structure and develop a more formal effect when the tree is young (American Horticulture Industry Association, 2014). It is advisable to cut lightly, retain more branches, open the branch angle,

and remove overlapping branches and cross branches to improve light conditions and promote the early formation of tree crowns in the adult stage (Fumey et al., 2008).

No significant plant diseases or insect pests were observed in natural planting of this cultivar, but early attention should be given to apple canker, protecting the wound when pruning, applying white lime aqueous solution on the tree trunk in late autumn, and to spraying a 5° BE lime sulfur mixture before germination (Sikdar et al., 2018). Aphids and spider mites were occasionally found and controlled by spraying pesticide, and sporadic *Carpocapsa niponensis* was controlled by applying a sex pheromone (Beijing Gardening and Greening Bureau, 2015). *Juniperus sabina* plants should be kept away from crabapple plants to avoid rust (Zhang et al., 2020). This variety is suitable for planting and use in garden landscapes and for afforestation, as well as apple rootstock and pollinizers for apple cultivation in northern China and for breeding the new varieties of ornamental crabapple.

Availability

M. 'Hongbaleng' is available from the Yanqing District Fruit Service Center and Beijing Hengcheng Tongtai Agricultural Science and Technology Co., Ltd., and Hebei Yutangyuan Ecological Agriculture Co., Ltd.

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Fig. 3. Comparison of the fruit traits between parent *M. Robusta* (A) and *M. 'Hongbaleng'* (B). The photographs were taken in Bangshuiyu, Yanqing District, Beijing, China, on 25 Sept. 2014.

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