Breeding of ‘Hongguan No. 1’ and ‘Shuangse No. 1’ Pitayas with Superior Quality

Canbin Chen, Pengyang Wu, Fangfang Xie, Luyang Sun, Yemiao Xing, Qingzhu Hua, Zhike Zhang, Jianye Chen, Jietang Zhao, Guibing Hu, and Yonghua Qin¹

State Key Laboratory for Conservation and Utilization of Subtropical Agro-bioresources/Guangdong Provincial Key Laboratory of Postharvest Science of Fruits and Vegetables/Key Laboratory of South China Horticultural Crop Biology and Germplasm Enhancement, Ministry of Agriculture, College of Horticulture, South China Agricultural University, Guangzhou 510642, China

Jiaqiang Li and Yaoxiong Ye

Dongguan Institute of Forest Science, Dongguan 523106, China

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We report the release of two pitaya (*Hylocereus*) cultivars, i.e., Hongguan No. 1 and Shuangse No. 1 pitayas with good quality, high self-pollination ability and long shelf life. Significant differences in stems, flowers, and fruit quality were detected among ‘Hongguan No. 1’, ‘Shuangse No. 1’, and their original line ‘Hongshuijing’. Mature stems of ‘Hongshuijing’ were significantly thicker and its spine length was significantly longer than that of ‘Hongguan No. 1’ and ‘Shuangse No. 1’. Compared with ‘Hongshuijing’, stigmas of ‘Hongguan No. 1’ and ‘Shuangse No. 1’ were lower than anthers. Fruit-setting rates by self-pollination were 83.7% ± 10.7% and 80.5% ± 9.5% for ‘Hongguan No. 1’ and ‘Shuangse No. 1’, respectively, which is significantly higher than that of ‘Hongshuijing’ (0%). ‘Hongshuijing’ and ‘Hongguan No. 1’ were red skin with red flesh whereas ‘Shuangse No. 1’ was red skin with red without and white within flesh. Heavier average fruit weight, better quality, and longer storage life of ‘Hongguan No. 1’ and ‘Shuangse No. 1’ were detected than those of ‘Hongshuijing’. The two cultivars have a competitive advantage in the marketplace in terms of stronger self-pollination ability, larger fruit size, better quality, and longer storage life.

Origin

In this study, ‘Hongguan No. 1’ (red skin with red flesh) and ‘Shuangse No. 1’ (red skin

with red without and white within flesh) were selected from ‘Hongshuijing’ pitaya (*Hylocereus monacanthus*) through seedling selection. The objective of this study was to select self-pollinated pitaya cultivars with different flesh color and good quality, which requires less labor and increases farmer income. In 2010, two pitaya seedlings (named ‘81-1’ and ‘97-3’) with big fruit, high self-pollination ability, and good fruit quality were selected from 860 seedlings of ‘Hongshuijing’ in an orchard of Dalingshan Forest Park, Dongguan City, Guangdong Province, China. In Mar. 2011, ‘81-1’, ‘97-3’, and ‘Hongshuijing’ were planted in Dafeng orchard, Jinsuinnong orchard, and Longxiang orchard, respectively. It was determined that the characteristics of the two seedlings have good quality, stable yield, and good productivity. ‘81-1’ and ‘97-3’ were registered and released as new cultivars under the name of ‘Hongguan No. 1’ and ‘Shuangse No. 1’, respectively, by the Guangdong Provincial Crops Cultivar Approval Committee on 10 Jan. 2017.

Description

The botanical and biological characteristics were investigated according to guidelines, for conducting tests for distinctness, uniformity, and stability (Dragon Fruit) (UPOV, 2011).

Fruit-setting rate by self-pollination was recorded before fruit maturity.

Stems. The main difference of stems among ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ pitayas was listed in Table 1. Young stems of ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ were strong red, red, and light red, respectively (Fig. 1). Significant difference in thickness of mature stems was observed among ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ pitayas. Thickness of mature stems of ‘Hongshuijing’ was the largest (2.2 ± 0.3 cm), followed by ‘Shuangse No. 1’ (1.2 ± 0.2 cm), and ‘Hongguan No. 1’ (1.0 ± 0.2 cm) (Table 1; Fig. 2). There were average 2.9 brown spines for ‘Hongshuijing’ compared with 2.3 and 2.1 grey spines for ‘Shuangse No. 1’ and ‘Hongguan No. 1’, respectively. Spine length of ‘Hongshuijing’ (4.3 ± 0.6 mm) was significantly longer than that of ‘Hongguan No. 1’ (3.4 ± 0.5 mm) and ‘Shuangse No. 1’ (3.9 ± 0.4 mm). Compared with ‘Hongshuijing’, thorns of ‘Hongguan No. 1’ and ‘Shuangse No. 1’ were suberized (Fig. 3).

Flowers. As shown in Table 2 and Fig. 4, significant difference was observed in flowers among ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ pitayas. Floral bud shape of ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ were oblate, elliptic, and circular, whereas their colors were purple red, red, and cream with dark red, respectively (Fig. 4A1–A3). ‘Hongshuijing’ had a purple calyx with strong red bracts. ‘Hongguan No. 1’ had a green calyx with weak red bracts compared with a green calyx with strong red bracts for ‘Shuangse No. 1’ pitaya (Table 2; Fig. 4B1–B3 and C1–C3). Stigmas were higher than anthers for ‘Hongshuijing’. As for ‘Hongguan No. 1’ and ‘Shuangse No. 1’, their stigmas were lower than anthers (Table 2; Fig. 4D1–D3). Rate of fruit setting by self-pollination of ‘Hongshuijing’ was 0% whereas fruit setting was $83.7 \pm 10.7\%$ for ‘Hongguan No. 1’ and $80.5 \pm 9.5\%$ for ‘Shuangse No. 1’ (Table 2).

Fruits. The main difference of fruits among ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ pitayas were shown in Table 3; Figs. 5 and 6. Fruit shape index of ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ were 0.9 ± 0.1 , 1.0 ± 0.1 , and 1.1 ± 0.1 , respectively (Table 3). Scales of ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ were red, red with green edges, and green, respectively.

Table 1. Main difference of stems among ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ pitayas (2014–16).

Traits	Cultivars		
	Hongshuijing	Hongguan No. 1	Shuangse No. 1
Color of young stems	Strong red	Red	Light red
Thickness of mature stems (cm)	2.2 ± 0.3 a	1.0 ± 0.2 b	1.2 ± 0.2 b
Number of spines	2.9 ± 0.02 a	2.3 ± 0.05 b	2.1 ± 0.12 c
Spine length (mm)	4.3 ± 0.6 a	3.4 ± 0.5 b	3.9 ± 0.4 b
Color of spines	Brown	Brown	Grey
Suberification of thorns	No	Yes	Yes

Different letters within the same row indicate significant differences using Duncan test at $P \leq 0.05$.

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¹Corresponding author. E-mail: qinyh@scau.edu.cn.

Fig. 1. Young stems of 'Hongshuijing', 'Hongguan No. 1', and 'Shuangse No. 1' pitayas. (A) 'Hongshuijing'; (B) 'Hongguan No. 1'; and (C) 'Shuangse No. 1'. Scale bars = 1 cm.

Fig. 2. Transverse section of one-year-old stems of 'Hongshuijing', 'Hongguan No. 1', and 'Shuangse No. 1' pitayas. (A) 'Hongshuijing'; (B) 'Hongguan No. 1'; and (C) 'Shuangse No. 1'. Scale bars = 2 cm.

Fig. 3. Spines of 'Hongshuijing', 'Hongguan No. 1', and 'Shuangse No. 1' pitayas. (A) 'Hongshuijing'; (B) 'Hongguan No. 1'; and (C) 'Shuangse No. 1'. Scale bars = 3 mm.

Table 2. Main difference of flowers among ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ pitayas (2014–16).

Traits	Cultivars		
	Hongshuijing	Hongguan No. 1	Shuangse No. 1
Shape of floral bud	Oblate	Elliptic	Circular
Color of floral bud	Purple red	Red	Cream with dark red
Color of calyx	Purple	Green	Green with purple
Color of bracts	Strong red	Weak red	Strong red
Position of anthers in relation to stigma	Below	Above	Above
Distance between stigma and anther (cm)	1.3 ± 0.2 a	–1.2 ± 0.2 c	–0.5 ± 0.1 b
Rate of fruit setting by self-pollination (%)	0 b	83.7 ± 10.7 a	80.5 ± 9.5 a

Different letters within the same row indicate significant differences using Duncan test at $P \leq 0.05$.

Fig. 4. Flowers of ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ pitayas. (A1, A2, and A3) flower bud; (B1, B2, and B3) flower bud after 12 d; (C1, C2, and C3) flowers at open stage; (D1, D2, and D3) style and anther. (A1–D1) ‘Hongshuijing’; (A2–D2) ‘Hongguan No. 1’; and (A3–D3) ‘Shuangse No. 1’. Scale bar = 0.5 cm for A, 5.0 cm for B and C, and 2.0 cm for D.

‘Shuangse No. 1’ had the widest and longest scales, followed by ‘Hongguan No. 1’ and ‘Hongshuijing’ (Table 3; Fig. 5). Flesh color of ‘Hongshuijing’ and ‘Hongguan No. 1’ were red (Fig. 6A and B) whereas ‘Shuangse No. 1’ was red without and white within (Fig. 6C). There were some thorns on peels at the bottom of ‘Hongshuijing’ (Fig. 6A, shown by arrows)

compared with no thorns on the peels for ‘Hongguan No. 1’ and ‘Shuangse No. 1’ (Fig. 6B and C). Significant difference was detected in weight per fruit, fruit flesh firmness, edible rate (ER), total soluble solids (TSS), total sugar (TS), and titratable acid (TA) among ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ pitayas. Weight per fruit,

fruit flesh firmness, ER, TSS, and TS of ‘Hongguan No. 1’ and ‘Shuangse No. 1’ were significantly higher than those of ‘Hongshuijing’. Weight per fruit of ‘Shuangse No. 1’ ranked the first (445.7 ± 42.4 g), followed by ‘Hongguan No. 1’ (390.3 ± 27.8 g) and ‘Hongshuijing’ (370.4 ± 30.9 g) pitayas. Fruit flesh firmness of ‘Shuangse No. 1’

Table 3. Main difference of fruits among ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ pitayas (2014–16).

Traits	Cultivars		
	Hongshuijing	Hongguan No. 1	Shuangse No. 1
Fruit shape index	0.9 ± 0.1	1.0 ± 0.1	1.1 ± 0.1
Thorn on the peels	Yes	No	No
Color of fruit bracts	Red	Red with green	Green
Average width of scale/fruit (cm)	2.7 ± 0.2 b	3.1 ± 0.3 a	3.2 ± 0.2 a
Average length of scale/fruit (cm)	2.1 ± 0.2 b	3.9 ± 0.4 a	4.1 ± 0.4 a
Color of fruit flesh	Red	Red	Red without and white within
Weight per fruit (g)	370.4 ± 30.9 c	390.3 ± 27.8 b	445.7 ± 42.4 a
Fruit flesh firmness (kg/cm ²)	2.55 ± 0.2 b	2.55 ± 0.2 b	3.40 ± 0.2 a
Edible rate (%)	73.6 ± 3.1 b	78.9 ± 3.2 a	79.1 ± 3.9 a
Total soluble solids (TSS) (%)	13.9 ± 1.4 c	16.5 ± 2.3 a	15.4 ± 1.3 b
Total sugar (%)	9.7 ± 1.0 b	10.9 ± 0.9 a	10.7 ± 1.1 a
Titrateable acid (%)	0.21 ± 0.04 a	0.18 ± 0.03 b	0.20 ± 0.03 a

Different letters within the same row indicate significant differences using Duncan test at $P \leq 0.05$.

Fig. 5. Fruits of ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ pitayas. (A) ‘Hongshuijing’; (B) ‘Hongguan No. 1’; and (C) ‘Shuangse No. 1’. Scale bars = 5 cm.

Fig. 6. Peel thorns of ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’ pitayas. (A), ‘Hongshuijing’; (B), ‘Hongguan No. 1’; and (C), ‘Shuangse No. 1’. Scale bars = 5 cm.

($3.40 \pm 0.2 \text{ kg/cm}^2$) is significantly higher than that of ‘Hongguan No. 1’ ($2.55 \pm 0.2 \text{ kg/cm}^2$) and ‘Hongshuijing’ ($2.55 \pm 0.2 \text{ kg/cm}^2$). Lower TA content, higher TSS contents, ER, and TS were detected in fruits of ‘Hongguan No. 1’ and ‘Shuangse No. 1’ pitaya (Table 3).

Storage quality. Storability of ‘Hongshuijing’, ‘Hongguan No. 1’, and ‘Shuangse No. 1’

harvested at maturity stages was studied under ambient conditions of $5 \pm 0.5^\circ\text{C}$ with 70% relative humidity. Significant difference was detected among the three pitaya cultivars during storage. Compared with ‘Hongguan No. 1’ and ‘Shuangse No. 1’, scales of ‘Hongshuijing’ began to wilt at 7 d and dried on 21 d after storage. Fruits of

‘Hongshuijing’ gradually rotted in combination with significant reduction in the loss of TSS contents at 28 d after storage. Fruits of ‘Hongshuijing’ lost marketability at 35 d after storage (Figs. 7A1–G1 and 8). ‘Hongguan No. 1’ and ‘Shuangse No. 1’ maintained the better marketability in terms of fruit visual appearance and TSS contents during storage

Fig. 7. Changes of fruit visual appearance of 'Hongshuijing', 'Hongguan No. 1', and 'Shuangse No. 1' pitayas during storage. (A1–A3) 0 d; (B1–B3) 7 d; (C1–C3) 14 d; (D1–D3) 21 d; (E1–E3) 28 d; (F1–F3) 35 d; and (G1–G3) 42 d. (A1–G1) 'Hongshuijing'; (A2–G2) 'Hongguan No. 1'; and (A3–G3) 'Shuangse No. 1'. Scale bars = 3 cm.

(Figs. 7A2–G2, A3–G3 and 8). TSS contents of 'Hongguan No. 1' remained to be higher than those of 'Hongshuijing' and 'Shuangse No. 1'. TSS contents of the 'Hongguan No. 1' and 'Shuangse No. 1' pitayas gradually reduced during storage (Fig. 8).

Performance

The thickness of one-year-old stems was measured as the widest section of the triangular stem (Fig. 2A). TSS, TS, TA, and ER were assessed using 30 fruits picked randomly from each cultivar at commercial maturity in the Jinsuinnong orchard. Weight per fruit was recorded as the average weight of 20 fruits sampled at random from each cultivar. TSS was determined from filtered juice of whole flesh tissues using a digital refractometer (MD35, Sartorius, China). A portion of the filtered juice was used to determine TA following the procedure of Padda et al. (2011). TS was analyzed according to the method of Li et al. (2014). Fruit flesh firmness was determined by fruit hardness tester 510-5 (Tokyo, Japan). ER was calculated as the following formula: $ER (\%) = (\text{fruit weight} - \text{peel weight}) / \text{fruit weight} \times 100\%$. Pitaya fruit with the same degree of maturity were collected from each cultivar in Aug. 2016 from a Jinsuinnong orchard. All fruits with no packaging were subjected to an artificial climate chamber at $5 \pm 0.5^\circ\text{C}$ with 70% relative humidity. A total of nine pitaya fruits were randomly sampled from each cultivar at an interval of 7 d for quality analysis. The nine sampled pitaya fruits were

divided into three groups as three replicates. Statistical analyses were performed using SPSS 17.0 software. Multiple mean comparisons were performed using Duncan's test at the 0.05 level of significance.

Two novel pitaya cultivars, i.e., Hongguan No. 1 and Shuangse No. 1, were selected from 'Hongshuijing' through seedling selection. Compared with Hongshuijing, the two cultivars meet pitaya growing requirements for strong self-pollination ability, longer shelf life, larger fruit size, and better quality. Moreover, 'Shuangse No. 1' is red skin with red without and white within flesh. There is no peel thorn at the bottom of the fruit of 'Hongguan No. 1' and 'Shuangse No. 1' (Fig. 6), which is convenient for picking. These characteristics, as well as good flavor and high TSS contents, will give fruits of the Hongguan No. 1 and Shuangse No. 1 pitaya cultivars competitive advantages in the marketplace.

Pitaya is a fast growing and perennial plant, which makes it easy to improve through traditional breeding approaches. Selection from bud mutation and seedling variation has been commonly used in conventional pitaya breeding. Recently, a red-fleshed pitaya cultivar named Qianguo 2 was selected from Zihonglong through bud mutation (Zheng et al., 2016). Fruit-setting rate of 'Zihonglong' is very low without hand-pollination because its stigma is significantly higher than the anther. Fruit-setting rate and fruit weight of 'Zihonglong' were significantly increased following hand-pollination. Compared with 'Zihonglong', stigma of 'Qianguo 2' is the same height as the

Fig. 8. Change of TSS of 'Hongshuijing', 'Hongguan No. 1', and 'Shuangse No. 1' pitayas during storage.

anthers. Fruit-setting rate and fruit weight of 'Qianguo 2' without hand-pollination was significantly higher than those of 'Zihonglong' (Zheng et al., 2016). In our study, 'Hongguan No. 1' and 'Shuangse No. 1' pitayas were selected from 'Hongshuijing' through seedling selection. Significant difference in stems, flowers, fruits, and storage life was detected among 'Hongshuijing', 'Hongguan No. 1', and 'Shuangse No. 1'. Firmness is an external quality parameter associated with flesh color in plum (Usenik et al., 2014). The highest firmness value was found in the double flesh color of 'Shuangse No. 1'. However, no difference in firmness value was detected between the two red-fleshed cultivars, i.e., Hongshuijing and Hongguan No. 1, suggesting the differences may be responsible for the double flesh color of Shuangse No. 1.

Harvest time for pitaya mainly focuses from July to Oct. in South China. Pitaya fruit easily loses its commodity value under conditions of high temperature. Many studies have been conducted to explore optimal storage condition and time to keep pitaya fruit quality (Freitas and Mitcham, 2013; Hoa et al., 2006; Obenland et al., 2016; Punitha et al., 2010). However, pitaya cultivars with different genetic backgrounds have different storage life under the given conditions. Therefore, new cultivar selection is crucial for storage life. In this study, storage life of 'Hongguan No. 1' and 'Shuangse No. 1' was significantly longer than that of 'Hongshuijing' at 5 °C (Fig. 7). The longer and wider scale size and scale color may be responsible for longer storage life of 'Hongguan No. 1' and 'Shuangse No. 1'. TSS contents of 'Hongshuijing', 'Hongguan No. 1', and 'Shuangse No. 1' pitayas gradually reduced during storage. Our results are in agreement with those findings of

the other pitaya species (Tong et al., 2013; Zhang et al., 2014).

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