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‘Summer King’: an Early Maturing Apple Cultivar in Korea

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‘Summer King’ (*Malus domestica* Borkh.) was selected in 2010 through a breeding program conducted by the Apple Research Institute of the National Institute of Horticultural and Herbal Science, under the Rural Development Administration of South Korea. It was obtained by crossing ‘Fuji’ and ‘Golden Delicious’. ‘Summer King’ is early maturing apple that can be harvested in late July, ∼100 d after full bloom in Gunwi. The fruit exhibits a blush at harvest and has a conical shape with smooth skin. With a fresh weight of 265 g, it contains 13.7% soluble solids and has a titratable acidity of 0.43% at maturity. Among the cultivars having a showing similar harvest window, it is highly regarded for its excellent taste. In South Korea, apples available in July are typically stored apples harvested in the previous year or unripe apples harvested in the current year, which often suffer from poor quality. However, ‘Summer King’, which can be harvested in late July, has been developed to provide fresh and delicious apples. The self-incompatibility genotype of ‘Summer King’ is S_3S_9, and it has cross-pollen compatibility with cultivars such as Fuji, Golden Delicious, Gala, Cripp’s Pink, and Honeycrisp. It demonstrates very low self-compatibility and displays parthenocarpy, enabling the production of seedless fruit. These characteristics are advantageous for fruit set and yield management. When stored at a 0 °C or treated with 1-MCP (1-methylcyclopropene), ‘Summer King’ retains quality for a duration of 2 to 4 months after harvest. It stands out as a promising apple cultivar with high-quality traits and the earliest harvest date among those cultivated in South Korea.

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Origin

‘Summer King’ is derived from the cross between ‘Fuji’ and ‘Golden Delicious’ cultivars (Fig. 1). The ‘Fuji’ cultivar was developed in 1962 in Japan by crossing the ‘Ralls Janet’ and ‘Delicious’ cultivars. Known for its firmness, sweetness, juiciness, and excellent storability, ‘Fuji’ has been widely used as a breeding parent (Soejima et al. 1998; Yoshida 1977). In South Korea, ‘Fuji’ and its bud sports, the fruit of which can be harvested from late October to November and distributed until the following summer, occupy 67% of the apple cultivation area due to their outstanding fruit quality (KREI 2023). ‘Golden Delicious’ is a chance seedling, and ‘Grimes Golden’ is presumed to be one of its parents. ‘Golden Delicious’ was discovered in the United States and is an important cultivar worldwide (Salvi et al. 2014). It is very low self-fertile, has a yellow peel, crunchy texture, plenty of juice, and a subtle scent (Schneider et al. 2001). This cultivar has been used in various breeding programs and is a parent of ‘Jonagold’, ‘Gala’, ‘Mutsu’, ‘Yoko’, and ‘Cripp’s Pink’. Although ‘Golden Delicious’ was cultivated in South Korea from the 1970s to the 1990s, it is not currently in commercial cultivation (RDA 2018).

In 1994, a total of 952 seeds were obtained, washed in water, dried, and stratified at 0 to 2 °C for 3 months to break their dormancy. For stratification, plastic boxes were filled with damp vermiculite, and seeds were placed inside, sealed with vinyl, and stored at 0 to 2 °C. In 1995, seeds were sown in nursery media, and in 1996, each seedling was grafted onto M.9 rootstock and cultivated in a nursery. In 1997, 661 seedlings grafted on M.9 rootstocks were planted at a spacing of 4 m × 2 m in the experimental research field (36°16′ N, 128°27′ E, elevation 71 m) of the Apple Research Institute located in Gunwi, South Korea. The soil of the test research field was clay loam with a pH of 6.5 and an organic matter content of 2.21% at a depth of 0 to 50 cm. Irrigation was applied whenever the soil water tension was close to –30 to –40 kPa using an automatic irrigation system equipped with a tensiometer (Irrometer SR; Irrometer Company Inc., Riverside, CA, USA). On the basis of the data observed

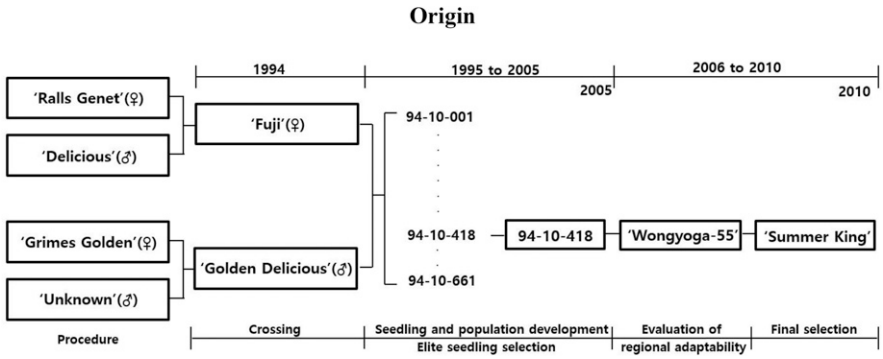

Fig. 1. Pedigree and timeline of breeding procedures used in the development of ‘Summer King’ apple cultivar.

Fig. 2. Trees (left) and fruit (right) of 'Summer King' apple cultivar.

Table 1. Physiological characteristics of tree growth performance in 'Summer King', 'Fuji', and 'Golden Delicious' apple cultivars at Gunwi, Republic of Korea.

Characteristics	Summer King	Fuji (♀)	Golden Delicious (♂)
Tree			
Vigor	Intermediate	Strong	Intermediate
Habit	Spreading	Spreading	Spreading
Bearing type	On long shoots	On long shoots	On long shoots
Flower			
Predominant color at balloon stage	Light pink	Light pink	Pink
Diameter with petals pressed into horizontal position (mm)	49.8 ± 0.45[i]	42.1 ± 0.51	48.6 ± 0.85
Petal arrangement	Overlapping	Intermediate	Overlapping
First flowering time	Late (20 Apr)	Late (19 Apr)	Late (20 Apr)
Leaf			
Leaf blade length (mm)	93.8 ± 0.49	93.4 ± 0.60	96.8 ± 0.56
Leaf blade width (mm)	48.2 ± 0.81	63.2 ± 0.73	53.5 ± 1.44

[i] Values are means ± *SD* (n = 30). Data represent the mean of 3 years of experiments (2008 to 2010).

for the past 10 years at the meteorological station closest to the experimental area, the daily average, maximum, and minimum temperatures in August were 26.2, 31.2, and 22.2 °C, respectively, and –1, 4.2, and –5.8 °C, respectively, in January. The average annual precipitation was 1200 mm.

Among 661 trees fruiting from the cross, the tree designated 94-10-418 produced early maturing fruit with excellent taste. This tree was selected in 2005 and tested further under the name Wongyoga-55. In 2006, Wongyoga-55 was grafted on M.9 rootstock and planted in the test and research fields in Gunwi and the growth was observed. From 2008 to 2010, when bearing fruit, a regional characteristic survey was conducted. Finally, Wongyoga-55 was selected in 2010 with excellent growth and fruit characteristics and named 'Summer King'. New cultivar characteristics were investigated according to the standard protocol of the International Union for the Protection of New Varieties of Plants (UPOV 1994). 'Summer King' was registered for variety protection with the Korea Seed & Variety Service in 2013 as its distinctiveness, uniformity, and stability were proven.

The self-fertility of 'Summer King' was investigated from 2017 to 2019. To obtain pollen, anthers were collected from balloon-stage flowers and used after dehiscence in a culture room at 25 °C. To assess the viability of the pollen, a 1% agar medium supplemented with 20% sucrose was placed on petri dish, and the pollen was spread evenly and germinated in an incubation room at 25 °C for 24 h. Thereafter, it was stained with cotton blue, and a 40× optical microscope was used to confirm the elongation of the pollen tube. To prevent flower-visiting insects, the entire tree was covered with an insect screen during the experiment. Self-pollination was performed exclusively on the central flower, and all lateral flowers and unpollinated flowers were removed. The number of fruits set at 60 d after full bloom and the fruits remaining at harvest were recorded as well as the number of seeds per harvested fruit. To confirm self-fertilization, seeds obtained through self-fertilization in 2019 were germinated after breaking dormancy. The self-incompatibility genotype was then analyzed using the method described by Cho et al. (2014).

Table 2. Physiological fruit characteristics in 'Summer King', 'Fuji', and 'Golden Delicious' apple cultivars at Gunwi, Republic of Korea.

Characteristics	Summer King	Fuji (♀)	Golden delicious (♂)
Size (g)	Large (265 ± 13.9[i])	Large (336 ± 16.2)	Large (298 ± 21.6)
Shape	Conic	Flat-globose	Conic
Ribbing	Absent or weak	Intermediate	Intermediate
Crowning at calyx end	Absent or weak	Intermediate	Intermediate
Ground color	Green	Yellowish green	Green
Hue of over color	Red	Red	Yellow
Pattern of over color	Only solid flush	Strong stripes	Only solid flush
Stalk length (mm)	13.1 ± 4.87 (short)	25.1 ± 2.93 (medium)	24.3 ± 3.21 (medium)
Stock thickness (mm)	2.5 ± 0.39 (medium)	3.0 ± 0.25 (medium)	3.2 ± 0.43 (medium)
SSC[ii] (%)	13.7 ± 0.58	14.5 ± 0.23	14.1 ± 0.55
TA[iii] (%)	0.43 ± 0.111	0.35 ± 0.035	0.48 ± 0.109
Firmness[iv] (N)	64.2 ± 3.83	71.8 ± 4.45	62.7 ± 5.19
Harvest time	Early (late July)	Late (early November)	Intermediate (early October)

[i] Values are means ± *SD* (n = 30). Data represent the mean of 3 years of experiments (2008–10).
[ii] Soluble solids content (SSC) was determined by squeezing flesh sample to make juice and then used a refrectometer (PAL-1, Atago, Japan) to assess SSC.
[iii] Titratable acidity (TA) was determined by titrating 5 mL juice to pH 8.1 with 0.1 N NaOH.
[iv] Firmness was determined from a texture analyzer (DFT-01; TR snc, Forli, Italy) with 11-mm probe.

Description

Trees, flowers, and leaves. 'Summer King' grows best in fertile, well-drained sandy, and loam soils, where apples generally thrive (Barden and Neilsen 2003). Tree shape is spreading (Table 2), and it has medium vigor (Fig. 2), but it is weaker than that of 'Fuji'. Therefore, when using M.9 rootstocks, it is recommended to plant and expose rootstocks 10 cm from the soil for adequate vegetative and reproductive growth of 'Summer King' (Kwon et al. 2018). The petal color is light pink before blooming compared with that of pink 'Golden Delicious' flowers and the diameter of the flower is 49.8 mm and larger than that of 'Fuji' (42.1 mm). The petals are arranged to overlapping against each other, and the flowering period is near 20 Apr in Gunwi, similar to that of its parents. The average length of the leaf is 93.8 mm, the width is 48.2 mm, and the length-to-width ratio is 1.9 and larger than that of 'Fuji' (1.5) and 'Golden Delicious' (1.8) (Table 1).

Fruit. The fruit of 'Summer King' is large (265 g) and conical but smaller than that of 'Fuji' (336 g) and 'Golden Delicious' (298 g). The shape of 'Summer King' fruit is similar to that of 'Golden Delicious' fruit. The fruitlet color of the pericarp is green, and 40% to 60% of the skin is flushed blush (Fig. 2). Unlike 'Fuji' and 'Golden Delicious', fruits of 'Summer King' do not have ribbing and crowning at the calyx end. The length of the fruit stalk is 25.1 mm for 'Fuji' and 24.3 mm

Table 3. The number of fruits and seeds obtained by self-pollination of 'Summer King' apple cultivars from 2017 to 2019.

Year	No. of self-pollinated flowers	No. of fruits (fruiting ratio %)		No. of seedless fruits (ratio %)	No. of seeds per fruit
		60 DAFB[i]	Harvest time		
2017	100	79 (79)	75 (75)	70 (93)	0.1
2018	54	29 (54)	20 (37)	12 (60)	0.6
2019	67	40 (85)	33 (49)	26 (79)	0.2

[i] DAFB = days after full blooming.

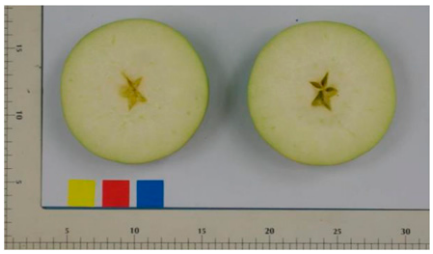

Fig. 3. Parthenocarpic fruits without seeds of 'Summer King' apple cultivar.

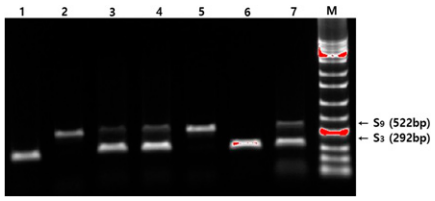

Fig. 4. Self-incompatibility genotypes of seedlings obtained by self-pollination of 'Summer King' apple cultivar. 1–6, individual seedlings; 7, 'Summer King'; M, 1 kb plus ladder.

for 'Golden Delicious,' and they are longer than that of 'Summer King' (13.1 mm). A short fruit stalk may lead to a physical fruit drop due to fruit enlargement. Therefore, young fruits with the longest fruit stalk in a cluster should be left undisturbed when thinning to prevent physical fruit dropping. The flesh of 'Summer King' is milky white, juicy, and crunchy, with a firmness of 64.2 N. The soluble solids content (SSC) of the fruit is 13.7% and titratable acidity (TA) (malic acid) is 0.43% (Table 2).

Harvest time and storability. 'Summer King' is an extremely early maturing apple cultivar that can be harvested from late July. However, it is important to note that 'Summer King' begins to experience fruit drop before harvest, typically occurring around 100 d after full bloom. As ethylene levels increase, more than 30% of the fruit may drop by 116 d after full bloom (Kweon et al. 2016). Therefore, it is recommended to start harvesting ~100 d after full bloom and complete it within 110 d after full bloom. When considering storage, 'Summer King' has certain limitations. If harvested and stored at 0 °C, the fruit can be stored for 2 months. However, if treated with 1-MCP and then stored at the same low temperature, the storage period can be extended to 4 months (Yoo and Kang 2020; Yoo et al. 2020).

Fruit setting habit. The self-incompatibility genotypes of 'Summer King' were derived from both 'Fuji' (S_1S_9) and 'Golden Delicious' (S_2S_3), resulting in an identified genotype of S_3S_9 (Cho et al. 2014). This genotype indicates that 'Summer King' exhibits cross-pollen compatibility with other apple cultivars such as Fuji (S_1S_9), Golden Delicious (S_2S_3), Gala (S_2S_5), Cripp's Pink (S_2S_{23}), and Honeycrisp (S_2S_{24}) (Broothaerts et al. 2004). As a result, these cultivars can be used for cross pollination of 'Summer King'. During 2017–19, the annual difference in fruit setting rates based on the self-pollination of 'Summer King' was significant. The fruit setting rate was 54% to 85% after 60 d of full bloom and 37% to 75% during harvest. The total number of seeds obtained from all fruits set via self-pollination was eight in 2017, 11 in 2018, and nine in 2019, and the number of seeds per fruit was 0.1, 0.6, and 0.2, respectively (Table 3). Most of the fruits that set after self-pollination normally develop without seeds (Fig. 3). Six seedlings were obtained from nine seeds harvested after self-pollination in 2019. After analyzing the self-incompatibility genotypes of six seedlings obtained after self-pollination, they were identified as S_3-, S_9-, or S_3S_9, and S_3S_9 were judged to be self-fertilized (Fig. 4). 'Summer King' has parthenocarpy and self-fertilization capabilities that are advantageous for management of fruit set and yield.

Availability. 'Summer King' was registered for variety protection by the Korea Seed & Variety Service in 2013 (Registration No. 4675). The exclusive license for the propagation and sales of certified plant material of 'Summer King' cultivar was obtained by the Rural Development Administration in Korea.

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