Breeding of Fuji Apples and Performance on JM Rootstocks

J. Soejima, H. Bessho[1], S. Tsuchiya[2], S. Komori[3], K. Abe, and N. Kotoda
Apple Research Center, National Institute of Fruit Tree Science, Shimokuriyagawa, Morioka, Iwate, 020-01 JAPAN

[1]Current address: Yamanashi Fruit Tree Experiment Station, Manriki, Yamanashi.
[2]Current address: BRAIN, Toranomon 3-18-19, Minato-ku, Tokyo.
[3]Current address: Okinawa Subtropical Station, JIRCAS, Ishigaki, Okinawa.

Breeding of Fuji and Its Offspring

The Japanese apple industry developed following the importation of 75 cultivars from America in 1871. Ralls Janet and Jonathan had been the leading cultivars until the 1960s, when those cultivars were replaced by Starking Delicious and Fuji. Starking Delicious had the greatest production in the 1970s, but its production rapidly decreased after 1980 due to short shelf life. Fuji was introduced in 1962 and continues to increase its production. Fuji is now the leading cultivar and is grown on 48% of the apple orchard area in Japan. Fuji was selected from 787 hybrid seedlings of Ralls Janet and Delicious. Fuji fruits are medium to large size, red striped, firm, crisp, very sweet and very juicy. Fruit matures in early or mid-November and often develops water core. Trees are large, spreading, vigorous and productive. The original seedling tree of Fuji still produces fruits every year in the orchard of the Apple Research Center at Morioka.

Apple breeding in Japan is popular in each apple growing prefecture. Relatively large breeding programs are located in three regions, the Apple Research Center at Morioka, the Aomori Apple Experiment Station and the Nagano Fruit Tree Experiment Station. Fuji is regarded as one of the important parents for apple breeding. Long keeping ability and sweetness of Fuji have been inherited by its children and grandchildren (first generation and second generation seedlings). Extensive use of Fuji as a parent in apple breeding has resulted in several promising offspring in Japan (Tables 1 and 2). Some of these are described below.

Akibae. Originated in Nagano by K. Odagiri. From cross of Senshu x Tsugaru made in 1981; registered in 1993. It matures in early to mid-October at Morioka. Skin color is dark red. Flesh is crisp, juicy, sweet with moderate acidity. It is recommended as a good middle-season cultivar in Nagano prefecture.

Alps Otome. Originated in Nagano. It was found as a chance seedling of Fuji and introduced by K. Hatagoshi in 1964. It is a crab apple with sweet flavor and shows scab resistance. It matures in the middle of October.

Hacnine. Now the third leading cultivar in the Hokkaido area. Hacnine originated in Hokkaido by the Hokkaido Central Agricultural Experiment Station. From the cross of Fuji x Tsugaru made in 1971. Registered in 1984. It is triploid and trees are vigorous. It matures at the end of October. Fruit is very large, oblong, juicy and sweet with a mild, subacid flavor. This variety is adapted to a cool climate.

Hokuto. Originated from the Aomori Apple Experiment Station. From the cross of Fuji x Mutsu made in 1970. Registered in 1983. Triploid cultivar. Hokuto was 3.2% of Japanese apple production in 1995. It matures at the end of October. Quality of the fruit is excellent, and water core develops when fully matured. A shortcoming is the incidence of moldy core rot.

Kitaro. Originated in Morioka, Iwate, and was introduced by the Apple Research Center, National Institute of Fruit Tree Science (NIFTS) in 1997. From the cross of Fuji x Hatsuaki made in 1976. It matures in the middle of October with Delicious. Skin color is yellow, flesh is firm with excellent flavor. This cultivar, like Fuji, keeps very well in cold storage. Problems are preharvest drop and russets around the basin.

Senshu. Originated at the Akita Fruit Tree Experiment Station. From the cross of Toko x Fuji in 1966. Registered in 1980. It matures in early to mid-October. Skin color is bright striped red, flesh is crisp, juicy and the quality is excellent. This variety was 4.5% of Japanese apple production in 1990, but is decreasing now due to the cracking around the stalk cavity.

Shinano Sweet. Originated at the Nagano Fruit Tree Experiment Station. From the cross of Fuji x Tsugaru made in 1978. Registered in 1996. It matures in the middle of October. Skin of the fruit is smooth and red striped. Flesh is juicy and sweet. This cultivar is expected to be promising in Nagano prefecture.

Shinsekai. Originated at the Gunma Horticultural Experiment Station. From the cross of Fuji x Akagi made in 1971. Registered in 1988. Shinsekai is now a fifth leading cultivar in Gunma prefecture. It matures at the end of October. Fruit, covered with solid deep red, is sweet, but immature fruits remain astringent.

Apple Rootstock Breeding and Performance of Fuji on JM Series Rootstocks

A pendulous sport of Marubakaido (*M. prunifolia* Borkh. *var. ringo* Asami) has been the standard semi-vigorous rootstock for apples and is used in approximately 75% of apple orchards in Japan (Fukuda, 1994). Major advantages of Marubakaido are very good anchorage, early and heavy

production, no burrknot production, crown rot resistance, woolly apple aphid (WAA) resistance, tolerance to wet soil conditions, and ease of propagation by hardwood cuttings. The shortcomings, however, are low virus tolerance and the formation of root suckers.

High density plantings using dwarfing rootstocks have increased since the 1970s in the less snowy areas of Japan. About 24% of apple orchards now have changed to high density plantings, mainly with M.26. Due to the troublesome problems of vegetative propagation of dwarfing rootstocks (e.g., M.9 and M.26, which do not propagate from cuttings), Japanese apple growers use these rootstocks as interstocks, grafted on rooted cuttings of Marubakaido. Trees are planted with the lower half of the interstock buried, allowing roots to grow from both stock components. This interstock system helps the trees grow well in a wide range of soils but makes Fuji trees grow too vigorously (Kikuchi, 1995).

An apple rootstock improvement program was started in 1972 at the Morioka Branch, Fruit Tree Research Station, now reorganized as the Apple Research Center, NIFTS. Main objectives of the program were: to develop excellent rootstocks that are able to 1) control tree size favorably, 2) resist diseases and pests such as violet root rot, crown rot, Valsa canker, WAA, 3) tolerate water-logged soils, and 4) propagate easily by hardwood cuttings (Bessho and Soejima, 1992).

A controlled cross of Marubakaido (Seishi) x M.9 was made in 1972. Over the next 11 years, initial screening of the seedlings continued at Morioka and 10 clones with the desirable characteristics of dwarfing (with high bark/wood ratio) and ease of propagation were selected in 1984. Beginning in 1985, these rootstock clones were distributed for field trials to several experiment stations in each apple growing district in Japan.

Based on orchard performance and observation of disease and pest resistance, JM 1, JM 7 and JM 8 were named and registered in 1996 for commercial release. JM 2 and JM 5 followed them in 1997. Application for registration under the Seeds and Seedlings Law of Japan to obtain plant breeder's right is now proceeding.

Characteristics of JM Series Rootstocks

Hardwood cutting. Over 90% of cuttings of JM 2 and JM 7, over 80% of JM 1 and JM 5, and over 70% of JM 8 survived when propagated as hardwood cuttings in the nursery. However, only 0-8% of M.9 EMLA and M.26 EMLA cuttings survived. Rooted cuttings of JM rootstocks grow 77-101 cm (30-40 inches) in height after six months in the nursery. Average trunk size of rooted cuttings was 6.1-7.0 mm (1/4 inch). This is ideal for grafting (Table 3).

Disease resistance. Five JM rootstocks were shown, in an excised twig assay, to be highly resistant to crown rot. Although JM 2 and 8 were resistant to apple chlorotic leaf spot virus (CLSV), JM 1, 5 and 7 were susceptible. Against ASPV and apple stem grooving virus (ASGV), those clones were resistant (Table 4).

Pest resistance. JM 1, 5, 7 and 8 showed resistance to woolly apple aphid. JM 2 was susceptible.

Dwarfing effect. Observations of trunk girth of Fuji trees over 15 seasons in the orchard at Morioka showed that JM 5 was very dwarfing; JM 1, 7 and 8 were dwarfing similar to M.9 EMLA; and JM 2 was semi-dwarfing (Table 5). Trees on JM 5, 7 and 8 showed typical overgrowth of the rootstocks (data not shown).

Precocity and yield. Trees of Fuji on JM 1, 7 and 8 had similar precocity to M.9 EMLA. Yield efficiency is used as a reliable predictor of productivity/unit area. Cumulative yield efficiency of Fuji was the highest with JM 7, and it was higher with JM 1, 5 and 8 than with M.9 EMLA or M.26 EMLA (Table 5).

Fruit quality. Fruit weight, red color development, soluble solids, titratable acidity as % malate, and flesh firmness were measured. Big differences were not found in these traits except for soluble solids content and flesh firmness among the fruits on selected rootstock clones. Soluble solids and flesh firmness were higher in JM 1, 5, 7 and 8 every year. Quality of Fuji fruits on JM 2 was similar to Marubakaido with slightly lower soluble solids content (Table 5).

In summary, JM series rootstock clones are very dwarfing to semi-dwarfing apple rootstocks and are propagated easily by hardwood cuttings. Our results suggest that resistance to several diseases and pests is better and the trees are more productive on the selected clones than they are on M.9 EMLA or M.26 EMLA. We regard these selected rootstocks as worthy replacements for M.9 and M.26 in Japan.

References

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Table 1. Description of major children (first generation seedlings) of Fuji bred in Japan.

Cultivar (Reg. No.[z])	Breeder (Year[y])	Parentage	Season	Remarks
4-23	Aomori AES (1975)	Fuji x Mahe 7	End Oct.	Red, juicy, slight core rot
Akita Gold (3176)	Akita FTES (1992)	Golden D. x Fuji	Mid. Oct.	Yellow, round-conical, firm
Akiyo (5018)	S. Kudo (1996)	Senshu x Fuji	End Oct.	Deep red, juicy, sweet
Alps Otome	K. Hatagoshi (1964)	Fuji x unknown	Mid. Oct.	Crab, red, sweet, short shelf life
Beninomai (1992)	T. Murakami (1989)	Fuji x unknown	End Aug.	Red stripe, rather small
Chitose Queen (4297)	T. Yamashita (1995)	Fuji x unknown	Early Sept.	Yellow, rather small
Gunma Meigetsu (2816)	Gunma HES (1991)	Akagi x Fuji	Early Nov.	Yellow, sweet, water core
Hacnine (1237)	Hokkaido CAES (1986)	Fuji x Tsugaru	Mid. Oct.	Very large, red stripe, juicy, triploid
Hida (930)	T. Sunahara (1985)	Fuji x Orin	Mid. Oct.	Red stripe, sweet
Himekami (931)	Apple RC, NIFTS (1985)	Fuji x Jonathan	End Sept.	Oblong, pinkish red, water core
Hokuto (368)	Aomori AES (1983)	Fuji x Mutsu	End Oct.	Very large, juicy, sweet, core rot, triploid
Hozuri (5019)	Fukushima FTES (1996)	Fuji x unknown	Early Nov.	Red stripe, juicy, subacid
Iwakami (932)	Apple RC, NIFTS (1985)	Fuji x Jonathan	End Sept.	Red stripe, subacid
Kitaro (applied for)	Apple RC, NIFTS	Fuji x Hatsuaki	Mid. Oct.	Yellow, firm, keeps well, preharvest drop

Kizashi (2933)	Apple RC, NIFTS (1991)	Gala x Fuji	End Aug.	Small, deep red, crisp, acid
Menkoihime (4478)	T. Murakami (1995)	Raritan x Fuji	End Aug.	Red stripe
Narihoko (926)	T. Narita (1985)	Golden D. x Fuji	Early Nov.	Green yellow, subacid
Natsunishiki (2635)	S. Sakurai (1991)	Fuji x American S.P.	End Aug.	Red stripe, sweet
Nishina (2355)	H. Ozawa (1990)	Fuji x Raritan	Mid Aug.	Deep red stripe, coarse, acid
North Queen (1864)	Hokkaido CAES (1989)	Fuji x Tsugaru	Early Oct.	Large, red, juicy
Seimei (4479)	Y. Ito (1995)	Golden D. x Fuji	Mid Oct.	Red stripe, juicy, sweet
Senshu (42)	Akita FTES (1980)	Toko x Fuji	Early Oct.	Red stripe, excellent flavor, cracking
Shinano Sweet (5139)	Nagano FTES (1996)	Fuji x Tsugaru	Mid Oct.	Red stripe, juicy, sweet
Shinsekai (1564)	Gunma HES (1988)	Fuji x Akagi	End Oct.	Deep red, sweet, slightly coarse
Slimred (4298)	Gunma HES (1995)	Fuji x Akagi	Early Nov.	Red stripe, small, juicy
Takashima (3303)	S. Komatsu (1992)	Fuji x unknown	Mid. Oct.	Red stripe, juicy, sweet

[z]Registration number under the Seeds and Seedlings Law in Japan.

[y]Year of registration or introduction.

Table 2. Description of major grandchildren (second generation seedlings) of Fuji bred in Japan.

Cultivar (Reg. No.[z])	Breeder (Year[y])	Parentage	Season	Remarks
Akibae (3411)	K. Odagiri (1993)	Senshu x Tsugaru	Mid-Oct.	Dark red, crisp, juicy, subacid
Kanki (3304)	S. Kudo (1992)	Senshu x Tsugaru	Early Oct.	Dark red, crisp, juicy, subacid
Miki Life (3231)	S. Kudo (1992)	Senshu x Tsugaru	Early Sept.	Red stripe, crisp, juicy

[z]Registration number under the Seeds and Seedlings Law in Japan.

[y]Year of registration or introduction.

Table 3. Growth of rooted cuttings after 5 months in the nursery[z].

Rootstock	Number of cuttings which survived (%)	Height (cm)	Diameter[y] (mm)
JM 1	85	102	7.1
JM 2	97	82	6.4
JM 5	82	73	6.1
JM 7	94	87	6.8
JM 8	74	76	6.7
M.9 EMLA	0	--	--
M.26 EMLA	7	29	3.1

[z]Mean of 1995 to 1996.

[y]Measured at 20 cm above the ground.

Table 4. Relative pest and disease resistance of five JM and Malling apple rootstock clones[z].

Rootstock	WAA	Crown rot *P. cactorum*	*P. cambivora*	CLSV	SPV
JM 1	VR	VR	M	S	R
JM 2	VS	M	R	R	R
JM 5	VR	R	R	S	R
JM 7	VR	VR	M	S	R
JM 8	VR	VR	M	R	R
M.9 EMLA	VS	S	VS	R	R
M.26 EMLA	VS	VS	VS	R	R

[z]Rating system: VR=very resistant; R=resistant; M=intermediate; S=susceptible; VS=very susceptible.

Table 5. Tree size, yield efficiency and selected fruit quality traits for 14-year-old Fuji with seven apple rootstock clones.

Rootstock	Trunk girth (cm)	Cumulative yield/tree (kg)	Yield efficiency (kg/cm^2 TCA)	Fruit weight[z] (g)	Soluble solids[z] (%)	Flesh firmness[z] (kg)
JM 1	41.7b[y]	338c	2.44c	264	15.3c	16.8de
JM 2	53.2d	295b	1.31a	226	14.1a	15.9bc
JM 5	30.0a	172a	2.40c	254	16.2e	17.1e
JM 7	43.1bc	401e	2.71d	267	15.9d	16.5d
JM 8	40.5b	327c	2.51c	257	15.2c	16.8de
M.9 EMLA	46.3c	337c	1.97b	256	14.4ab	15.9bc
M.26 EMLA	59.3e	373d	1.33a	262	14.3ab	15.5ab

[z]Mean of 1993 to 1996.
[y]Means followed by the same letter are not significantly different (P=0.05, n=5).