Rootstock Studies for Citrus Varieties in Japan

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Most citrus trees in Japan are grafted on trifoliate orange (*Poncirus trifoliata* Raf.) rootstocks. The merits of trifoliate as a rootstock are as follows: (1) Trifoliate is quite suitable for satsuma mandarin (*Citrus unshiu* Marc.), the leading variety in Japan. (2) Trees grafted on trifoliate produce compact canopies which facilitate cultural operations in sloped orchards. (3) Citrus trees on trifoliate show high productivity per canopy volume and the quality of their fruit is excellent. (4) Trifoliate is resistant to tristeza virus and citrus nematode, and is cold-hardy.

Although satsuma mandarin is still the most prevalent variety in the Japanese citrus industry, there is a trend of diversification of varieties in the past 15 years. In 1984, 116,400 ha (70% of all citrus area) were planted to satsuma, 13,500 ha (8%) to Natsudaidai (*C. natsudaidai* Hayata), 11,300 ha (7%) to Iyo (*C. iyo* Hort. ex Tanaka), 9,820 ha (6%) to Hassaku (*C. hassaku* Hort. ex Tanaka), and 5,060 ha (3%) to navel orange (*C. sinensis* Osbeck) followed by Ponkan (*C. reticulata* Blanco), Pummelo (*C. grandis* Osbeck), and others. The changing trends in commercial varieties resulted in the diversification of demands for rootstock varieties. Very early mutants which arose from the early ripening Wase type of satsuma mandarin are very good in flowering and fruit set but characterized by nonvigorous growth. Rootstocks which strengthen the tree vigor are required. Miyauchi Iyo and Otani Iyo, the early mutants of Iyo, have the same problem.

Tatter leaf virus infection is a problem on some selections of Ponkan and satsuma mandarin grafted on trifoliate orange. As many virus problems can be moderated by selecting suitable rootstocks, Yuzu (*C. junos* Sieb. ex Tanaka), Natsudaidai, Konejime (*C. neoaurantium* Hort. ex Tanaka), and others as well as trifoliate have been tested and used as rootstocks in Japan but many problems still remain.

We report here on a series of rootstock trials and discuss the possibilities of the candidate rootstock varieties.

Rootstocks for satsuma mandarin

Eighteen varieties in 3 genera were tested as rootstocks for satsuma mandarin (Kagoshima No. 6 strain) at Kurume Branch, National Horticultural Experiment Station.[1] The soil of the experimental field was light clay deluvium soil, deep-tilled to 100 cm depth before planting. Very light pruning and training were conducted and the trees were grown under regular cultural practices.

1) Effects on tree growth

Growth of satsuma mandarin trees on 18 rootstocks is shown in Fig. 1. The trees grafted on section Cephalocitrus, genus Poncirus, and genus Fortunella had comparatively small canopies. When the canopy volume was examined every 5 years, it was found that trees on Satsuma-kikoku, Hanayu, and Dancy tangerine were larger from the beginning until they became 15 years old. Trees on Kinkunenbo and Sudachi were slow starting and the canopy expansion was accelerated at the later bearing age. Trees on trifoliate, Rusk citrange and Tengu were larger during the first 5 years but after that canopy expansion was reduced. Trees on Kizu, Sanbokan and Marumi kumquat belonged to the smallest tree group at all times. Marumi kumquat-rooted trees were extremely small.

Leaf number per tree showed the same trend as canopy volume. Area of one leaf was larger in the

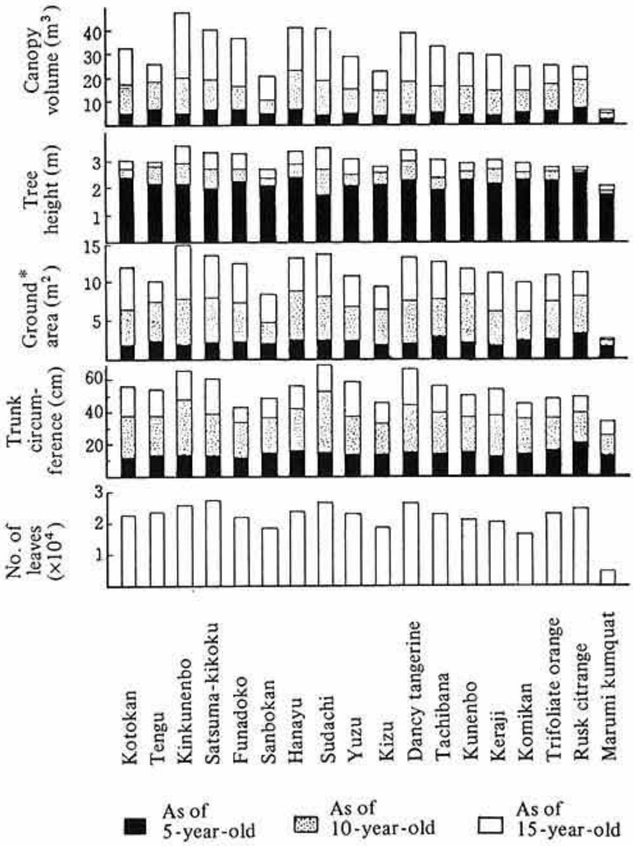

Fig. 1. Growth of satsuma mandarin trees on different rootstocks

Table 1. The budunion characteristics of satsuma mandarin grafted on different rootstocks

Types*	C+2	C+1	C	C−1	C−2
Scion/stock**	0.71−0.80	0.81−0.90	0.91−1.00	1.01−1.10	1.11−1.21
Root-stock	Funadoko	Satsuma-kikoku	Kotokan		Marumi kumquat
	Kizu	Sanbokan	Tengu		
	Trifoliate orange	Sudachi	Kinkunenbo		
	Rusk citrange	Yuzu	Hanayu		
		Dancy tangerine	Komikan		
		Tachibana			
		Kunenbo			
		Keraji			

* Types of budunion reactions by Webber (1926)
** Scion circumference/stock circumference

trees on section Osmocitrus and section Acrumen, and smaller on section Cephalocitrus, genus Poncirus, and genus Fortunella.

The budunion characteristic of every combination was classified and is shown in Table 1. Rootstocks in section Acrumen which have a close relationship to satsuma mandarin showed a high congeniality and were classified into C or C+1. Rootstocks in the genus Poncirus and genus Fortunella were classified into C+2 and C−2, respectively.

2) *Effects on yield and fruit quality*

The cumulative yield of 15 years and average fruit weight are shown in Table 2. Rootstock varieties which brought about smaller canopies such as trifoliate orange and Rusk citrange recorded higher comulative yields. This is because those rootstocks caused higher yields in the early half of the experimental period. In the last stage of the experiment, however, the larger canopy group such as Kinkunembo and Sudachi out-yielded the smaller canopy group. Fruit were thinned by hand to keep the ratio of fruit to leaves approximately 1 to 30 but the biennial bearing tendency still occurred. On the trifoliate orange rootstock this tendency was slight. Tengu, Sanbokan, Yuzu, and Kunembo showed severe biennial bearing.

Results of fruit quality investigation in 1968 when every rootstock recorded a good crop are shown in Table 3. Rind color was advanced on Kotokan, Tengu, Kizu, Kunenbo, and Rusk citrange, followed by trifoliate. Rind color of Marumi kumquat-rooted trees was most inferior. Brix was the highest on Rusk citrange and trifoliate. That on Rusk citrange was higher than that on trifoliate every year. Citric acid content was the highest on Tachibana. Rusk citrange was the highest in Brix-acid ratio and trifoliate was in the middle.

The root system, drought tolerance, cold tolerance, and microelement levels were also investigated. The relative merits of rootstocks for satsuma mandarin can be summarized as follows: Satsuma

Table 2. Yield and average fruit weight of satsuma mandarin on different rootstocks*

Rootstock		Yield (kg)	Average fruit weight (g)
Section Cephalocitrus			
Kotokan	*C. kotokan* Hayata	345.2	104.4
Tengu	*C. tengu* Hort. ex Tanaka	340.5	95.7
Section Aurantium			
Kinkunenbo	*C. sininsis* Osbeck	425.8	92.6
Satsuma-kikoku	*C. neoaurantium* Hort. ex Tanaka	329.2	96.7
Funadoko	*C. funadoko* Hort. ex Tanaka	317.0	96.9
Sanbokan	*C. sulcata* Hort. ex Tanaka	266.5	100.4
Section Osmocitrus			
Hanayu	*C. hanaju* Hort. ex Tanaka	373.5	92.7
Sudachi	*C. sudachi* Hort. ex Shirai	436.1	101.1
Yuzu	*C. junos* Sieb. ex Tanaka	260.4	95.0
Kizu	*C. inflata* Hort. ex Tanaka	324.0	97.4
Section Acrumen			
Dancy tangerine	*C. tangerina* Hort. ex Tanaka	365.7	97.1
Tachibana	*C. tachibana* Tanaka	356.5	84.6
Kunenbo	*C. nobilis* Lour	296.0	96.3
Keraji	*C. keraji* Hort. ex Tanaka	326.7	96.0
Komikan**	*C. kinokuni* Hort. ex Tanaka	336.8	101.8
Genus Poncirus			
Trifoliate orange	*P. trifoliata* Raf.	444.4	92.1
Rusk citrange	*C. sinensis* Osb. × *P. trifoliata* Raf.	452.6	95.9
Genus Fortunella			
Marumi kumquat	*F. japonica* Swingle	100.4	104.1

* Total or average of 15 years (1956—1970).
** Polyembryonic strain of *C. kinokuni* Hort. ex Tanaka.

Table 3. Ring color and fruit quality of satsuma mandarin on different rootstocks (1968)

Rootstock	Rind color* Nov.21	Rind color* Dec.11	Rind weight (%)	Brix	Acid (%)	Brix/ acid ratio
Kotokan	7.3	10.0	32.3	8.7	1.01	8.61
Tengu	7.7	10.0	30.9	8.3	1.01	8.22
Kinkunenbo	6.7	9.9	30.2	8.8	1.03	8.54
Satsuma-kikoku	5.8	9.9	31.2	8.2	0.93	8.82
Funadoko	6.7	9.9	29.6	9.0	0.98	9.18
Sanbokan	6.6	10.0	30.1	8.5	1.05	8.10
Hanayu	6.6	10.0	31.1	9.5	1.05	9.05
Sudachi	6.2	9.9	30.2	8.4	1.07	7.85
Yuzu	5.9	9.9	32.2	8.7	1.02	8.53
Kizu	7.3	10.0	31.5	9.5	1.08	8.80
Dancy tangerine	6.7	10.0	30.3	8.6	0.96	8.96
Tachibana	5.3	9.9	34.1	8.9	1.20	7.42
Kunenbo	7.2	10.0	32.4	9.6	1.05	9.14
Keraji	6.8	10.0	32.1	9.0	1.16	7.76
Komikan	6.3	9.9	30.9	8.6	1.05	8.19
Trifoliate orange	6.8	10.0	28.7	9.6	1.10	8.73
Rusk citrange	8.5	10.0	30.3	10.9	0.99	11.01
Marumi kumquat	3.7	9.5	29.8	9.5	1.06	8.96

* The degree of rind color was rated using a standard of 1 (entirely green) through 10 (orange).

mandarin trees on trifoliate rootstocks grew rapidly and yielded comparatively large crops in their first several years. The expansion of the canopy slowed down as the crop increased and the trees maintained small canopies. This scion-rootstock combination showed a less biennial bearing tendency and produced fruit of advanced rind color and higher Brix. Trifoliate proved to be one of the best rootstocks for satsuma mandarin. Rusk citrange came in the second place. It has some characteristics, such as rind color and Brix, superior to trifoliate. Recently, there have been efforts to find out rootstocks with more dwarfing effect than trifoliate. Marumi kumquat, which showed an extremely strong dwarfing effect in this trial, has some defects such as scion overgrowth, low per ground area yield, and inferior rind color. The possibility of Marumi kumquat as a dwarfing rootstock seems to be very small. It can be utilized in the future as a source for rootstock breeding.

Rootstocks for Ponkan

Many Ponkan trees in Japan are infected with citrus tatter leaf virus (CTLV). Ponkan trees grafted on CTLV-susceptible rootstocks such as trifoliate orange and citranges will have trouble at the interface between scions and rootstocks, decline and die. Consequently, CTLV resistant rootstock varieties such as Yuzu and Sunki (*C. Sunki* Hort. ex Tanaka) have been employed.

A rootstock trial for Ponkan with regard to CTLV was conducted at the Fruit Tree Research Station at Kuchinotsu.[2] In April 1975, CTLV-infected F2428 Ponkan was grafted on 2-year-old trifoliate, Shiikuwasha (*C. depressa* Hayata), and Cleopatra mandarin (*C. reshni* Hort. ex. Tanaka) seedlings. Grafted plants were planted in the experimental field in June 1976. Half of the trifoliate rooted Ponkan plants were inarched with 2-year-old Yuzu root in July 1977. In parallel with the experiment mentioned above, tatter leaf-free Yoshida Ponkan trees on trifoliate and Yuzu were planted in the same experimental field and kept under observation. The soil was derived from basalt and its texture was light clay. Trees were grown under regular cultural practices.

Effects of rootstocks on the growth and yield of Ponkan trees are shown in Table 4. Growth of canopy volume and trunk circumference of tatter leaf infected F2428 Ponkan on trifoliate were inferior to those of the Shiikuwasha and Cleopatra rooted ones. Yield of trees on trifoliate was also very small. Inarched trees with Yuzu root recorded intermediate growth and yield between susceptible and resistant rootstocks. In the case of tatter leaf-free Yoshida Ponkan trees, trifoliate showed the result

Table 4. Growth and yield of F2428 Ponkan and Yoshida Ponkan on different rootstocks

Rootstock	Canopy volume (m^3)	Trunk circumference (cm)	Yield (kg)	Average fruit weight (g)
	F2428 Ponkan (tatter leaf-infected)			
Trifoliate orange	2.2a*	16.4a	7.1a	139
Trifoliate with Yuzu inarching	5.1a	22.2a	15.4a	138
Shiikuwasha	10.5b	34.4b	24.8b	136
Cleopatra mandarin	10.1b	32.8b	26.1b	137
	Yoshida Ponkan (tatter leaf-free)			
Trifoliate orange	6.4	23.9	18.2	150
Yuzu	7.4	26.2	22.0	150

*Mean separation in columns by Duncan's multiple range test. 5% level.

Table 5. Rind color and fruit quality of F2428 Ponkan and Yoshida Ponkan on different rootstocks

Rootstock	Rind color	Brix	Acid (%)	Brix/ acid ratio
	F2428 Ponkan (tatter leaf - infected)			
Trifoliate orange	10.0	14.3a*	1.11a	12.9a
Trifoliate with Yuzu inarching	9.9	14.2a	0.88ab	16.1ab
Shiikuwasha	9.9	13.7b	0.87ab	15.7ab
Cleopatra mandarin	9.9	13.5b	0.70b	19.3b
	Yoshida Ponkan (tatter leaf - free)			
Trifoliate orange	10.0a	15.1a	0.93a	16.2a
Yuzu	9.6b	13.3b	0.67b	19.9b

*Mean separation in columns by Duncan's multiple range test. 5% level.

very close to that of Yuzu. This result supports the theory that trifoliate orange has no problem as a rootstock for tatter leaf-free Ponkan.

Fruit quality was investigated from 1982 to 1985, and the latest investigation in 1985 is shown in Table 5. Rind color of F2428 Ponkan on trifoliate rootstocks was superior to that of other rootstocks throughout the experiment. Rind color of fruit from Shiikuwasha and Cleopatra was inferior in most years. Fruit from trifoliate had a smooth rind. Brix was higher on trifoliate and trifoliate with Yuzu inarching. Shiikuwasha and Cleopatra produced lower Brix fruit. Citric acid content was also high on trifoliate. Brix-acid ratio was higher on Cleopatra, and lower on trifoliate.

Yoshida Ponkan fruit on trifoliate showed advanced rind color, higher Brix and citric acid and lower Brix-acid ratio.

As mentioned above, tatter leaf infected Ponkan trees on trifoliate rootstocks lost their vigor and fruit production was decreased. In case of tatter leaf free Ponkan trees, trifoliate can compete with Yuzu in tree growth and fruit production. Trifoliate rooted Ponkan trees produced fruit of advanced color and higher Brix. As far as tatter leaf-free scions are concerned, the superiority of trifoliate as a rootstock is obvious. Growers need tatter leaf-free Ponkan varieties and efforts to eliminate CTLV are being actively promoted at experiment stations.

Rootstocks for Iyo

Trifoliate orange is also widely used as a rootstock for Iyo, but the inferior growth of trifoliate rooted Iyo is often a problem. Using Otani Iyo, which is a less vigorous strain of Iyo, 14 rootstock varieties shown in Table 6 were tested at Kuchinotsu.[3] In April 1980, Otani Iyo scions from one source tree were grafted on glasshouse grown seedlings of the rootstock varieties. The trees were grown in a glasshouse and planted in April, 1981 in a field of light clay soil. No pruning was conducted but fruit were

Table 6. Growth, yield, and occurrence of stem pitting of Otani Iyo on different rootstocks

Rootstock	Canopy volume (m^3)	Trunk circum-ference (cm)	Fruit no.	Yield (kg)	RSP*
Rough lemon *C. jambhiri* Lush.	6.9ab	28.1a	25.6a	8.6a	0a
Natsudaidai *C. natsudaidai* Hayata	7.1ab	25.6ab	70.3b	22.3b	4.0a
Sour orange *C. aurantium* L.	7.7a	25.3ab	45.5ab	13.9ab	2.8a
Fukuhara orange *C. sinensis* Osbeck	5.8b	23.3b	43.9ab	13.6ab	3.6a
Yuzu *C. junos* Sieb. ex Tanaka	3.3cd	18.3cd	30.3a	9.5a	13.6a
Cleopatra mandarin *C. reshni* Hort. ex Tanaka	3.5cd	17.9cd	21.7a	6.2a	39.0b
Shiikwasha *C. depressa* Hayata	8.0a	26.2ab	31.3a	10.2ab	11.6a
Trifoliate orange *P. trifoliata* Raf.	4.1c	20.3c	59.0ab	17.2ab	0.8a
Hiryo (Flying Dragon) *P. trifoliata* Raf.	1.6d	14.1d	21.6a	5.3a	12.5a
BLT** *P. trifoliata* Raf.	5.0bc	20.9c	63.0ab	17.7ab	1.3a
Troyer citrange *C. sinensis×P. trifoliata*	2.7cd	18.4cd	25.7a	7.1a	22.7ab
Carrizo citrange *C. sinensis×P. trifoliata*	4.3c	19.8c	43.4ab	13.3ab	2.7a
Rusk citrange *C. sinensis×P. trifoliata*	2.8cd	17.3cd	43.3ab	12.7ab	7.3a
No. 576 *C. natsudaidai×P. trifoliata*	4.2c	20.1c	36.4ab	11.3a	6.2a

* Rate of occurrence of stem pitting

$$\text{RSP}=\frac{(\text{twig no. of }+\times 1)+(\text{twig no. of }++\times 3)+(\text{twig no. of }+++\times 5)}{\text{Total twig no.}\times 5}\times 100$$

+: Degree of occurrence of stem pitting is slight, ++: Middle, +++: Severe

** Broad-leaved-trifoliate

thinned by hand to keep the ratio of fruit to leaves as 1 to 80–100.

Tree growth measured in 1984 and 1985, and yield in Jan. 1985 (the second crop) are shown in Table 6. Shiikuwasha, sour orange, Natsudaidai, and rough lemon were grouped as producing larger canopies and trunk circumferences. Hiryo, Troyer citrange, and Rusk citrange produced smaller canopies. Trifoliate and broad-leaved-trifoliate showed intermediate growth. Natsudaidai, broad-leaved-trifoliate, and trifoliate produced much fruit. Hiryo, Cleopatra, and Troyer citrange were poor producers.

The rate of occurrence of stem pitting (RSP) was highest on Cleopatra rooted trees followed by Troyer citrange rooted trees. RSP on rough lemon, trifoliate, and broad-leaved-trifoliate rooted trees was minimal. RSP showed a positive correlation with the result of the enzyme-linked-immunosolvent assay for tristeza. The trees of higher RSP showed nonvigorous growth in most cases, but trees with no stem pitting or very low RSP sometimes showed very poor growth. Yellowish leaves, defoliation, and decline, which were identical to seedling yellows, were found on some trees on sour orange, Natsudaidai, and Fukuhara orange.

Quality of fruit harvested in Jan. 1985 is shown in Table 7. Rind was thin in the fruit on Hiryo and Troyer citrange rootstocks and thick on rough lemon, Shiikuwasha, and sour orange. The trees which produced thick rind fruit had the features of

Table 7. Rind color and fruit quality of Otani Iyo on different rootstocks

Rootstock	Rind color	Flesh weight (%)	Brix	Acid (%)	Brix/acid ratio
Rough lemon	7.7	58.9a	9.7a	1.39ab	6.96d
Natsudaidai	9.3	63.0abc	11.3b	1.32b	8.51abc
Sour orange	9.4	60.6ab	11.5b	1.42ab	8.18abc
Fukuhara orange	9.3	61.7ab	11.5b	1.55a	7.53cd
Yuzu	8.1	62.5ab	10.8b	1.39ab	7.74bcd
Cleopatra mandarin	7.7	62.8abc	10.5ab	1.31b	8.03abcd
Shiikwasha	8.7	60.3ab	11.4b	1.40ab	8.20abc
Trifoliate orange	9.3	62.2ab	11.6b	1.49ab	7.83bcd
Hiryo (Flying Dragon)	9.6	68.7c	11.9b	1.47ab	8.26abc
BLT*	9.0	62.4ab	11.4b	1.47ab	7.79bcd
Troyer citrange	8.5	64.9bc	11.7b	1.52ab	7.78bcd
Carrizo citrange	9.0	63.9abc	11.6b	1.35ab	8.66ab
Rusk citrange	9.1	63.4abc	12.3b	1.35ab	9.08a
No. 576	9.1	61.3ab	10.9b	1.39ab	7.89bcd

* Broad-leaved-trifoliate

vigorous growth and lower yield for their canopy volume. Brix was the lowest on rough lemon. Citric acid content was the highest on Fukuhara orange, and low on Cleopatra and Natsudaidai. Brix-acid ratio was high on Rusk citrange, Carrizo citrange, and low on routh lemon and Fukuhara orange.

Trifoliate, broad-leaved-trifoliate and Shiikuwasha were judged as promising from the view point of tree growth, yield, fruit quality, and resistance to tristesa virus. Iyo trees on trifoliate and broad-leaved-trifoliate were prolific and produced fruit of excellent quality. These rootstocks can be used in areas where the soil is deep and fertile and trees grow vigorously. Trees on Shiikuwasha were vigorous and productive. The ability of Shiikuwasha will be shown in the area where fruit quality is good, but trees do not grow vigorously.

Summary

Rootstocks for satsuma mandarin: Satsuma mandarin trees on trifoliate rootstocks grew rapidly and yielded comparatively large crops in their first several years. The expansion of the canopy slowed down as the crop increased and the trees maintained small canopies. This combination resulted in less biennial bearing tendency and produced fruit of advanced rind color and higher Brix. Rusk citrange gave the second best performance.

Rootstocks for Ponkan: Tatter leaf infected Ponkan trees on trifoliate rootstocks lost their vigor and fruit production was decreased. In the case of tatter leaf free Ponkan trees, trifoliate can compete with Yuzu in tree growth and fruit production. Trifoliate rooted Ponkan trees produced fruit of advanced color and higher Brix.

Rootstocks for Iyo: Otani Iyo was grafted on 14 rootstock varieties and tested for 6 years. Trifoliate, broad-leaved-trifoliate and Shiikuwasha were judged as promising from the view point of tree growth, yield, fruit quality and resistance to tristesa virus. The trees on trifoliate and broad-leaved-trifoliate were prolific and produced fruit of excellent quality. Trees on Shiikuwasha were vigorous and productive.

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