CITRUS BREEDING AND BUD SELECTION IN JAPAN

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In ancient times there was only one citrus species, *C. tachibana*,[2] indigenous in Japan. The Japanese people have known this fruit since the very beginning of their history. The widespread occurrence of it in the main Islands of Japan makes it very probable that it is in fact a wild species that has persisted since prehistoric times. The species is very similar in its characters to the mandarin orange (27).

There has undoubtedly been a migration of citrus varieties from China to Japan but historical records on these introductions are obscure. The sour orange, however, is known to have been introduced into Japan in about 50 A.D. (24). Subsequently, the 'Yuzu' (*C. junos*), trifoliate orange (*Poncirus trifoliata*), 'Kishu' (*C. kinokuni*), Kunembo (*C. nobilis*), citron (*C. medica*), shaddock (*C. grandis*), kumquat (*Fortunella japonica*), tangerine (*C. tangerina*) and others were introduced from China and other countries. Following the establishment of the Horticultural Experiment Station, Ministry of Agriculture and Forestry at Okitsu in 1902, many citrus varieties were introduced to Japan from the United States. These varieties included the 'Washington' navel, 'Joppa' and 'Valencia' sweet oranges and several varieties of grapefruit and lemons.

During the last three centuries many citrus varieties have originated in various parts of Japan by natural hybridization and bud mutation. Among these are the satsuma (*C. unshiu*) and the 'Natsudaidai' (*C. natsudaidai*). The satsuma is called Unshu-Mikan in Japan. It has long been known in Kyushu, the southern island of Japan, and it is probable that it originated there as a chance seedling from a citrus fruit from China (23).

Up until about 1880, the mandarin orange called 'Kishu' was the principal citrus variety grown commercially in Japan. Since then the satsuma, because of its superior quality, seedlessness, and early-ripening character, has largely replaced the Kishu. At present, there are approximately 250,000 acres of citrus in Japan and an annual production of 1,132,460 tons by the 1962 agricultural statistics. Satsumas comprise 80.7 percent, Natsudaidai 12.4 percent, and all other varieties 6.9 percent of this acreage.

The trifoliate orange is the most common rootstock in Japan. This rootstock is tolerant to tristeza, *Phytophthora*, and the citrus nematode, and has cold hardiness. The common trifoliate orange strain has proven most suitable and the tetraploid and diploid large leaf selections, as well as a small leaf selection, are found undesirable (3, 4, 9). The Yuzu is the second most common rootstock in Japan. Other varieties used as rootstock include Natsudaidai for common satsuma, 'Konejime' for Wase satsuma.

The first citrus breeding was done by Tanikawa in 1917 (14). He produced one hybrid, the 'Tanikawa-buntan,' and nucellar seedlings of the satsuma and the Natsudaidai. Since 1937 there has been a systematic citrus breeding program under direction of Y. Asami, former director, and M. Kajiura, present director of the Horticultural Experiment Station at Okitsu. Their work has included hybridization and the selection of new varieties through mutation (10).

SATSUMA VARIETIES IN JAPAN

As satsuma culture increased in Japan, growers soon began to distinguish differences between satsumas grown in various localities. Pomological studies of the various satsuma types by Tanaka in 1918 confirmed the existence of at least 5 varieties: 'Zairai,' 'Ikeda,' 'Ikirika,' 'Owari,' and 'Wase.' The Zairai has large, flattened, coarse, inferior quality, late-maturing fruit. The Ikeda has small spherical fruit of excellent quality and later maturing than the Bairai. The Ikiriki has very large fruits of excellent quality and has a rather dwarf growth habit. The Owari has large, flattened fruit of good quality and is early maturing. The Wase has a thin rind, earlier maturing fruit, and has a dwarf growth habit as compared with Owari (23).

Old trees of the Zairai, Ikeda, and Ikiriki varieties still exist but they are no longer propa-

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[1]The paper was presented by Mr. Nishiura at the American Society of Horticultural Science Citrus Breeding Symposium held at Boulder, Colo., August 1964. It was read by Dr. W. C. Cooper, U. S. Horticultural Field Station, Orlando, Fla., before the meeting of the Florida State Horticultural Society held at Miami Beach, Nov. 6, 1964.

[2]The binomial names given in the paper follow the classification developed by Tanaka (25, 26).

gated and are not recommended for commercial planting. The Owari variety is the most commonly grown variety. The Wase was found in 1895 as a limb sport on a tree of the common satsuma. This discovery of the Wase as a bud mutation was an epochal finding in the citrus industry of Japan. Search for limb sports has attracted citrus researchers' and growers' attention and many new bud variations were discovered among all of the satsuma varieties (16).

Development of New Satsuma Varieties through Limb Sports

A large number of limb sports from the Owari variety were found and have given rise to selections superior to the original Owari (6, 12, 20). Among the best are the 'Sugiyama,' 'Hayashi,' and 'Nankan No. 4.' Two late-maturing limb sports of the Owari are named 'Ishikawa' and 'Juman.' There are several early-maturing selections: the 'Yonezawa,' 'Nagahashi,' 'Nankan No. 20,' and 'Shiegeta.' The 'Dobashibeni' is a bud variation of the Owari carrying a deeper red-colored rind than the Owari. More recently several limb sports of the Owari have been selected for cold hardiness. These are 'Usami,' 'Fukuda,' and 'Aoshima.'

Many bud variations of the Wase character were found in trees of the Owari and Zairai varieties (23). The 'Miyagawa-Wase' appeared as a limb sport from the Zairai satsuma in 1915 and was introduced by Tanaka in 1923 (23). It is the best early-ripening variety of satsuma and now comprises about 90 percent of the acreage of early satsumas (8, 11).

Diversity Among Nucellar Seedling Selections of Satsumas

M. Kajiura, director of the Horticultural Research Station at Okitsu, has conducted research with improving satsuma varieties through selection among nucellar seedlings (10). He has postulated that mutant characters may be found more frequently in seedlings from nucellar embryos than in bud mutations. He pollinated Miyagawa-Wase flowers with trifoliate orange pollen in 1940 and produced about 200 nucellar seedlings of the Miyagawa-Wase. These were examined closely for 20 years and some distinct differences were discovered among them. Two sister nucellar seedlings, the 'Okitsu-Wase' and the 'Miho-Wase,' were registered as new varieties in 1963. Field experiments comparing the nucellar and parental Miyagawa-Wase were started in 1953. Data from these tests are shown in Table 1. The nucellar variations are more vigorous, earlier-ripening, and have higher sugar content, as compared with parental Miyagawa-Wase. The greater vigor of growth in the nucellar selections as compared to parental Miyagawa-Wase was common in almost all the nucellar and may be attributable to elimination of viruses and to a physiological rejuvenation. However, Kajiura attributes the differences in sugar content and earliness of ripening to genetical change induced by mutation. There is no way of identifying exactly when and where the mutation occurred. Moreover, these variations in nucellar seedlings occur quite frequently and the use of nucellar selections is applicable to the improvement of satsumas.

Other variations observed in nucellar seedling selections include rind color, smoothness of rind, and fruit shape. Two nucellar seedlings of 'Dobashi-beni' produce fruit with an orange-yellow rind as compared with reddish rind of the parental variety. The time of breaking rind color of nucellar seedling selections of 'Suzuki Wase' was delayed as compared with the parental variety. At present about 600 nucellar seedlings of Wase and 1,800 of common satsuma are being tested at Okitsu.

Citrus Hybridization Investigations

The satsumas have cold hardiness, seedlessness, excellent quality, and are easy peeling but they lack the fragrance characteristic of sweet oranges. In order to produce satsumas with rich aromatic fragrance, the various satsuma varieties were pollinated with the pollen of sweet orange, shaddock, and several other citrus species (18). Because of the polyembryony character of the satsuma, very few hybrids were obtained when the satsuma was used as the female parent. In these studies 3.4 percent of the seedlings were judged to be zygotic or hybrid, while the remainder were nucellar satsuma (19). The pollen parent used had no influence on the percentage of hybrids produced.

As an aid in the identification of the hybrid and nucellar seedlings, the color reaction of the Almen reagent on leaf extracts of the seedlings was used in a manner similar to that reported by Furr and Reece in 1946 (17). The color tests were made on young satsuma hybrid seedlings in 1957. Those seedlings judged to be hybrid are now being "fruited-out" in the field.

Table 1. Characteristics of nucellar and parental selections

Selection[a]	Trunk girth[b] in January 1964 cm	Yield[c] kg/ tree	Soluble solid percent[c]	Citric acid percent[c]	solid/ acid ratio[c]
Nucellar selection					
Miho-Wase	23.0	17.42x	10.47x	0.88x	12.35x
Okitsu-Wase	24.0	18.02x	10.54x	0.98y	10.96y
Okitsu No. 3	21.3	12.88xy	10.28x	0.90x	11.50xy
Parental selection					
Miyagawa-Wase	18.5	10.11y	9.71y	0.93xy	10.81y

Mean values in a column followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range Test.

a/ Each tree was budded on trifoliate orange in September 1954 and planted in May 1956.

b/ Trunk girth was measured at 5 cm above bud union.

c/ Each value is the average of the 3 years, 1961-1963 period.

Up to the present, 58 satsuma hybrids have borne fruit. Among them, a satsumelo, cross of satsuma X shaddock, has produced seedless, large-sized fruit with orange-colored rind and flesh. It is showing promise as a late-ripening variety. Another hybrid, resulting from a cross of satsuma X Joppa orange, has orange-colored flesh and peels readily. Both of these hybrids are being field-tested at the Experiment Station at Okitsu and at several prefectural experiment stations in the warmer regions of Japan.

M. Iwamasa of the Research Station at Okitsu has found male sterility common in these satsuma hybrids. Nearly half of them failed to develop their anthers and, consequently, cannot produce pollen (see Table 2). On the other hand, their female organs developed normally with production of ample seed. Those that are parthenocarpic produce seedless fruit by isolation from pollen sources. This male sterility of satsuma hybrids is a feasible method of producing completely seedless tangors and tangelos (2).

Another objective of the citrus breeding program is to produce late-maturing citrus hybrids that have superior qualities to the standard, late citrus variety in Japan, the Natsudaidai. The 'Valencia' orange is not extensively grown in Japan because of its lack of cold hardiness. The various crosses that have been made since 1944 are shown in Table 3. Some of the hybrids resulting from these crosses have borne fruit.

The 'Hassaku' shows characteristics of a grapefruit and originated as a chance seedling in 1860. It is monoembryonic and all seedlings are hybrids when used as the female parent. A population of 40 progeny of the Hassaku X 'Hirado-buntan' (a shaddock) produced a wide range in fruit sizes and forms, were very seedy, and most were highly acid when grown at Okitsu. Hybrids of Hassaku X *C. iyo* (a tangor) produced deeply orange-colored, rather sweet fruit.

The 'Hyuganatsu' originated as a chance seedling about 1820 and is a late-maturing type with tender flesh and excellent aroma. It has the defect of severe fruit drop in cold winters. A hybrid resulting from the cross of Hyuganatsu X 'Fuka-

Table 2. Number of plants without anthers and with anthers among satsuma hybrids. (1964)

Parental combination	Without anthers	Normal anthers
Satsuma X sweet orange	5	5
Satsuma X Iyo	1	2
Satsuma X shaddock	2	2
TOTAL	8	9

Table 3. Parents of citrus hybridization at the Horticultural Research Station, Okitsu, Japan

Female parent	Male parent
Monoembryonic	
Hassaku (C. hassaku)[1]	Dancy tangerine (C. tangerina)[3]
	Funadoko (C. funadoko)[2]
	Hirado shaddock (C. grandis)
	Hyuganatsu (C. tamurana)[2]
	Iyo (C. iyo)[2]
	Natsudaidai (C. natsudaidai)[1]
	Sanbokan (C. sulcata)[1]
	Sweet orange (Trovita, Fukuhara, Maltese blood)
Hirado shaddock (C. grandis)	Natsudaidai (C. natsudaidai)[1]
Hyuganatsu (C. tamurana)[2]	Funadoko (C. funadoko)[2]
	Hassaku (C. hassaku)[1]
	Iyo (C. iyo)[2]
	Natsudaidai (C. natsudaidai)[1]
	Sanbokan (C. sulcata)[1]
	Sweet orange (Trovita, Fukuhara, Maltese blood)
Kinukawa (*C. glaberima*)[1]	Natsudaidai (C. natsudaidai)[1]
Naruto (C. medioglobosa)[1]	Natsudaidai (C. natsudaidai)[1]
Polyembryonic	
Funadoko (C. funadoko)[2]	Natsudaidai (C. natsudaidai)[1]
Grapefruit (C. paradisi)	Natsudaidai (C. natsudaidai)[1]
Natsudaidai (C. natsudaidai)[1]	Duncan (C. paradisi)
	Funadoko (C. funadoko)[2]
	Kinukawa (C. glaberima)[1]
	Sweet orange (Trovita, Valencia, Maltese blood)
Washington navel orange (C. sinensis)	Hassaku (C. hassaku)[1]
	Iyo (C. iyo)[2]
	Kunembo (C. nobilis)[3]
	Natsudaidai (C. natsudaidai)[1]
	Sanbokan (C. sulcata)[1]
	Sweet orange (Trovita, Fukuhara, Parson Brown, Kanton, Kinkunenbo, Maltese blood)
	Satsuma (C. unshiu)[3]

[1]Shaddock hybrid.
[2]Sweet orange hybrid.
[3]Mandarin.

hara' sweet orange, it is promising and is under extensive field tests.

Hybrid seedlings resulting from crosses with the Natsudaidai as a female parent have not borne fruit as yet.

In 1963 a new branch station was established in Nagasaki prefecture to permit the testing of new hybrids in a warmer climate than that at Okitsu. Coincident with the acquisition of this new breeding station, the hybridization work has been expanded. The seed parents most extensively used were monoembryonic varieties such as Hirrado, Hassaku Naruto, Iyo, and Hyuganatsu in 57 different cross combinations.

In breeding for improved rootstocks the objective was to produce a vigorously growing, deeply rooted, cold-hardy type. The female parents used include Yazu, *C. tachibana*, 'Yamamikan,' Natsudaidai, Iyo, Kunembo, Kishu, and satsuma. The male parent used was the trifoliate orange. Unfortunately, most of the hybrids when budded with satsumas show inferior growth to those budded to trifoliate orange rootstock.

Search for Superior Selections of Citrus Varieties

A search for more fruitful selections of Washington navel orange has been made. Three limb sports—the 'Ukumori,' 'Suzuki' and 'Tange'—have been found, patented, and are under test.

The Natsudaidai is very adaptable to local cultural conditions but its fruit quality is inferior because of its high acid content. A selection called 'Kawano' was found as a limb sport about 60 years ago and was patented in 1950. This selection is early-ripening (March to May) and is much less acid than the standard Natsudaidai. Recently, 'Tajima Natsudaidai' was found as a limb sport. It ripens in midsummer and is very juicy.

The Iyo variety originated as a chance seedling and was introduced in 1886. It is judged to be a tangor and ripens in January to February. Recently, a limb sport of the Iyo was found that ripened earlier than the parent variety.

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