Recent Trend in Breeding Medium- and Late-Maturing Citrus in Japan

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Composition of citrus cultivars in Japan is extremely biased, with the early maturing Satsuma mandarine accounting for about 85% of the total citrus production. As a result, harvesting and consumption are limited within a short period in a year, and it is difficult to supply sufficient kinds of cultivars which satisfy consumer's demands. To improve the cultivar-composition and to extend the harvesting and marketing period, effort has been made to diversify cultivars, but the problem is that only few good cultivars are available. Therefore, it is urgently needed to breed medium- and late-maturing citrus.

Citrus breeding system in Japan

Citrus breeding is being made in three branches of the Fruit Tree Research Station, which belongs to the Ministry of Agriculture, Forestry and Fisheries, i.e. Okitsu Branch for early-maturing citrus (mainly Satsuma mandarine), Akitsu Branch for medium-maturing citrus (mainly oranges), and Kuchinotsu Branch for late-maturing citrus. In recent years, problems of cultivars attract much attention in research, so that varietal improvement has been initiated even in prefectural experiment stations.

Climatic features of citrus growing areas in Japan

Climate of citrus growing areas shows low temperature in the winter and high temperature and high humidity in the summer. Accumulated temperature during the period of fruit growth is low, and the lowest minimum temperature goes down frequently below $-4°C$, which causes cold injury of fruit. Therefore, the area which permits stable production of late-maturing citrus with overwintering fruits on trees is very limited. The area adapted to late-maturing citrus is required to have annual mean temperature higher than about 16°C and the lowest minimum temperature not lowering below $-4°C$.

Breeding objectives

The first objective is to get good quality of fruit. As kinds of fruits which appear on the market have increased recently, competition not only among citrus fruits but also with melon, strawberry, and tropical fruits has occurred. Consequently, excellent palatability, e.g. high sugar content, soft and juicy flesh, good aroma, seedless fruit, easy peeling, and attractive appearance (more than 200 g each in size, uniform shape, smooth rind with red or dark orange color, etc.) are required. As to the maturing time, many types of cultivars with different maturities from medium to late are required. With late-maturing cultivars, cold-resistance is needed. At present, cultivars with cold-resistant trees are available, but their fruit suffers from cold injury at temperatures ranging from $-4°C$ to $-5°C$. As there is no cultivar with specially high cold resistance, it seems to be not easy to breed cold-resistant cultivars. However, unless this problem is solved, a wide spread of late maturing citrus can not be expected in Japan. This is one of the important breeding objectives,

even though the solution may be difficult.

As most of the main cultivars with medium- to late-maturity in Japan are not adaptable to processing, it is also necessary to incorporate processing adaptability e.g. for making fruit juice. For medium-maturing citrus which matures in January–February, harvesting is made by early January before the lowest minimum temperature comes, and the fruit is stored before shipment. Good keeping quality is therefore needed.

As to disease resistance, varietal resistance to citrus canker is needed, because of difficulty of its control. As to virus diseases, breeding of resistant cultivars, search for mild strains of citrus Tristeza virus, and development of inoculation techniques are needed. Studies are now in progress on these problems.

Problems related to breeding techniques

Great constraints in carrying out citrus breeding are (1) a long period of time is required before fruiting, and (2) problems of polyembryony. Without the solution of these problems, the development of citrus breeding can not be expected.

1) A method to accelerate fruiting

Number of years required for the initiation of fruiting is 6–8 years with mandarine (*Citrus reticulata* Blanco) which requires relatively short period, while it takes as long as more than 10 years for oranges (*C. sinensis* Osbeck) and pummelo (*C. grandis* Osbeck) seedlings. One of the reasons is that the initial growth of seedlings is slow. There are various methods to accelerate flowering and fruiting of citrus seedlings. However, to evaluate fruit characteristics for the purpose of selection, at least some dozen fruit should be obtained. Therefore, it is necessary to accelerate plant growth to an extent sufficient to produce such number of fruit. To accelerate initial growth, top grafting by the use of intermediate stock was tested. The elongated branch was tied to a supporting pole and was grown, as a monotrunk, to more than 2 m in a year. Thus, it was made possible to get fruiting only 2 years after the grafting. At present, this method is used practically in the Kuchinotsu Branch of Fruit Tree Research Station.

The top grafting of breeding seedlings to intermediate stock has been strictly prohibited for the reason that there is a risk of virus infection from the stock. Even in case of seedlings planted to field, they are infected by Tristeza virus within a few years, causing the death of seedlings of less resistant cultivars. In recent years, however, method to produce virus-free plants was established, and there is no serious trouble unless some definite virus is concerned.

2) Increase in the rate of obtaining zygotic seedlings

The citrus shows a peculiar phenomenon, the polyembryony. Use of cultivars of monoembryony is desirable, but only few cultivars like pummelo, Hassaku (C. hassaku Hort. ex Tanaka), Iyokan (C. iyo Hort. ex Tanaka), and clementine (*C. reticulata* Blanco) are available, while many of good cultivars which we desire to use for hydridization, like Satsuma mandarine (*C. unshiu* Marc.), sweet oranges (*C. sinensis*), grapefruit (*C. paradisi* Mocf.) Natsudaidai (*C. natsudaidai* Hayata), etc. are of polyembryony, that cause low rate in obtaining zygotic seedlings. This problem is great constraint in pursuing cross breeding. Although many studies have been done to obtain efficiently hybrid seedlings from polyembryonic cultivars used as female parents, there is no reliable method yet. However, as the number of embryos per seed varies even among polyembryonic cultivars and strains, it is possible to obtain hybrid seedlings more efficiently than before by selectively using cultivars and strains with less number of embryo, that induce high rate of hybrid seedlings, for breeding parents. In addition, monoembryonic plants appear among the zygotic seedlings produced by combinations between polyembryonic parents, so that particular attention should be paid to identify them in order to develop good monoembryonic culti-

vars.

A cultivar, Kiyomi, developed from the cross, Miyagawa wase Satsuma mandarine × Trovita orange (*C. sinensis*) in the Okitsu Branch of Fruit Tree Research Station is an excellent cultivar with monoembryony and seedless fruit. This cultivar is regarded as an excellent breeding parent.

It is also important for efficient breeding to establish methods of distinguishing zygotic seedlings from nucellar seedlings, when polyembryonic cultivars are used as female parent.

Methods of breeding

1) Search for and utilization of mutations

Many bud mutants (by natural mutation) have been discovered in citrus. As desirable variations are added to established cultivars, bud mutation is highly effective, and many excellent cultivars of medium-late ripening citrus have been selected. For example, from Iyokan, an early ripening cultivar with good fruiting performance, Miyauchi Iyokan, was selected, and from which Ohtani iyokan with smooth rind was selected. With Hassaku, many mutants with deep rind color were obtained. With Natsudaidai, Kawano natsudaidai with less acidity was obtained, which is now widely grown. In addition, cultivars with smooth rind, deep color and further less acidity have appeared. With navel orange, many mutants with good fruiting habit and different maturities were found out. They are widely grown as leading cultivars at present.

2) Utilization of nucellar seedlings

Although nucellar seedlings have the same genetic constituents as their female parents, some variations are recognized. With leading cultivars, even a slight variation is very valuable in some cases depending upon characters which varied. With Satsuma mandarine, this method has been in practical use, and many excellent cultivars have been developed. But, with medium-late maturing citrus, no cultivar has been named and released yet. This method is also used to get virus-free plants.

3) Cross breeding

Although many excellent cultivars of citrus have been developed by mutation, the range of variation caused by mutation is relatively small. Therefore, to breed epochal varieties cross breeding has to be employed, and hence it is a mainstay of varietal improvement. Because of polyembryony problem and limited availability of crossing parents, attention has to be focused firstly on selection of superior monoembryonic parents. From hybrid seedlings produced by using Satsuma mandarine as a female parent, cultivars with seedless fruit and with cold resistance have been developed. Kiyomi is monoembryonic and seedless, in addition to its superior fruit quality, and is frequently used as a crossing parent.

4) Polyploidy breeding

Using tetraploid plants, produced by colchicin treatment or selected from nucellar seedlings, production of triploid plants aiming at seedless fruit is being made.

Future prospects

Reflecting the composition of citrus cultivars inclined towards Satsuma mandarine, an increasing attention to cultivars other than Satsuma mandarine, especially medium-late maturing citrus cultivars has been paid. Number of institutions dealing with citrus breeding has increased, and problems involved in breeding techniques will be solved in the near future. Epochal progress in breeding of medium-late maturing citrus is expected.

References

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