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BREEDING CITRUS FOR COLD HARDINESS

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The possibility of severe loss from cold injury is an ever-present hazard for the citrus grower in all of the major citrus-growing regions of this country. The severe freezes of 1949 and 1951 in Texas, the equally severe, but less damaging, ones in California and Arizona in 1949 and 1950, and the freezes of 1957-58 in Florida have stimulated renewed interest in research work on cold hardiness of citrus. In recognition of this need, the horticultural laboratories of the United States Department of Agriculture at Orlando, Florida; Weslaco, Texas; and Indio, California, were recently provided funds for increasing work related to cold hardiness of citrus. At these three laboratories investigations are being planned, or are already under way, with the ultimate object of reducing losses from cold injury to citrus.

One of the most obvious methods of reducing losses from frost is the production by breeding and selection of cold-hardy varieties. citrus breeding was begun in this country in 1893 by Webber and Swingle (7) just before the disastrous freezes of 1894-95 in Florida, and most of the hybrids produced were lost in the freeze. Consequently, when this work was renewed in 1896, one of the primary objectives was the production of cold-hardy varieties.

In the early work by Swingle and Webber and the later work by Swingle, Robinson, and Savage described by Traub and Robinson (6), the trifoliate orange was used as the principal source of cold resistance in crosses made for the production of cold-hardy varieties. These hybrids between various kinds of citrus and the trifoliate orange proved to be of outstanding cold hardness, but their fruits were practically inedible. These results seem to have discouraged much further use of the trifoliate orange and its hybrids in the breeding of scion varieties because of the disagreeable flavors they transmit to their progeny.

Swingle and Robinson (5) also used kumquats as sources of cold hardness in crosses made with lemons and limes. From these crosses the limequats resulted; and several of these, the Eustis and Lakeland limequats in particular, have been widely used in door yards as hardy substitutes for limes.

The current citrus-breeding work in Florida, Texas and California is being closely coordinated. The large and extremely valuable collection of citrus species, varieties and relatives at Orlando and the smaller but very useful ones at Weslaco and Indio are available for hybridization and selection work at all three stations. Also, materials from the extensive citrus collection of the University of California
Citrus Experiment Station at Riverside are available for our use. Crosses that are wanted at one station are made wherever the materials are available but mostly at Orlando and Indio.

Fig. 1. Variation in cold injury of citrus varieties in freezes of November 17 and 18, 1958, at Indio, California. A—Changsha mandarin on Cleopatra rootstock. B—Willow Leaf mandarin on Troyer rootstock. Both planted 1 year and growing 20 feet apart. C—Calamondin x Eureka lemon hybrid seedlings, 3 years old; showing segregation for cold tolerance. D—Rangpur lime x Brazil sour orange hybrid seedlings, 3 years old; showing segregation for cold tolerance.
and the seeds are sent to the places where the trees are to be grown and tested.

**Sources of Cold Hardiness in Scion Varieties**

The most critical problem in breeding for cold-hardy scion varieties is that of finding satisfactory sources of cold hardiness. The trifoliate orange seems like the most promising source from which to make large improvements in the cold tolerance of citrus, but because it and its first-generation hybrids impart disagreeable flavors to their progeny, it is likely that many years of back-crossing and selection will be required to transfer to citrus varieties a high degree of cold tolerance and to eliminate their inheritance of the factors that produce the pungent and disagreeable flavoring compounds. While it seems highly desirable to pursue such a long-term program of transferring cold tolerance from the trifoliate orange to citrus in the hope of eventually obtaining varieties with good quality and much-improved cold tolerance, other less cold-hardy varieties are of more immediate promise for producing varieties suitable for commercial production.

Possibly the most promising immediate sources from which to introduce cold hardiness into mandarins, sweet oranges, tangors, and grapefruit are the satsuma oranges, the Changsha mandarin (possibly the hardiest of the tangerines) and to a lesser extent, the Dancy tangerine. In the freezes of November 17 and 18, 1958, at Indio several young Changsha trees were only slightly injured, whereas Willow Leaf and several other tangerine varieties of the same age and growing nearby were severely injured (Fig. 1, A and B). It also seems worth while to try to introduce into citrus from the kumquat factors that contribute to early and profound winter dormancy. For breeding acid fruits some sources of cold hardiness are the Meyer, Gul-Gul, and Kusner lemons, the kumquats, lemonquats and limequats, and possibly the citrangequats.

There is also considerable possibility of reducing losses of the fruit itself by breeding and selection for earliness of ripening; that is, by producing varieties that so far as the fruit is concerned escape most of the severe freezes, which are likely to occur from late December to mid-February. Some of the varieties available for this work are the Clementine, Willow Leaf, and Honey tangerines; the Hamlin, Shamsouti, Tarocco, Moro and the navel oranges; the Orlando and Pearl tangels. The Salustiana, an early orange recently introduced to our collection from Spain, should soon come into flower and be available for breeding. This is an excellent, early, seedless, round orange that, in Spain, ripens with the navel oranges.

**Sources of Cold Hardiness in Rootstock Varieties**

In the breeding of cold-hardy citrus we are chiefly concerned with the scion variety because usually it is the dominant factor in determining the cold tolerance of a citrus tree, but the rootstock may be of considerable importance, and under some conditions, as for example, in very light sands, highly calcareous or saline soils, it may have a profound influence on the cold tolerance of the tree.

We already have some very cold-hardy rootstocks: the sour orange, the trifoliate orange and its hybrids—the citranges, citrumelos, citrandarins, citrangequats, etc. They are, however, suited neither to all scion varieties nor to all soil conditions. We need to obtain rootstocks that combine cold hardiness with other desirable traits such as that of inducing in the scion vigorous growth and high yield or high quality of fruit, tolerance to highly calcareous or saline soils, and resistance to root rot. There are fairly large numbers of rootstock varieties with special qualities that should be hybridized with the most cold-hardy varieties and selected for testing as stocks. Among these Rangpur, Cleopatra and Sunki are salt tolerant; the shaddocks, Seminole tangelo, citrumelo 4475 and a Savage seedling are resistant to foot rot; Rough lemon, Citrus macrophylla, and Rangpur produce vigorous growth and high yields on light soils; and Sour orange, Rough lemon and Shekwasha mandarin are tolerant of calcareous soils. We especially need to determine if any rootstock can be produced that will have an appreciable effect in inducing winter dormancy of the scion variety in areas where winter temperatures are relatively high for long periods. The kumquats possess the important faculty of remaining dormant through fairly long warm spells in winter. If this characteristic is heritable, perhaps it can be transferred to types more useful as stocks than the kumquats.
Relation of Physiology of Cold Hardiness to Breeding

The basic work on the physiology of cold hardiness in citrus and most of the testing for hardiness of varieties and hybrid progenies produced in the breeding work will be done at the Weslaco laboratory, where special facilities are available. It is expected that information obtained in the work on the physiology of cold hardiness in citrus will be of great value in breeding for cold hardiness.

In fact, for most effective breeding work it is essential that we know more than we now do about the nature of cold hardiness in citrus and the citrus relatives. The breeder must know what hereditary characteristics to look for and how to make tests of seedling progenies so that reliable selections of cold-tolerant individuals can be made. It is obvious that one of the factors involved in the cold tolerance of citrus is dormancy of the tree—a condition in which little or no cell division and growth occur. We need to know more about the conditions required to induce or maintain dormancy in different species and varieties. Another possible heritable factor that citrus or some hybrids of citrus and the trifoliolate orange may possess is the ability to undergo cold hardening—the process that enables some plants, for example, cabbage and wheat, after being subjected to near-freezing temperatures for a few days to withstand for some days afterwards relatively severe freezing without injury. Possibly there are other heritable factors involved in cold tolerance of citrus that should be taken into consideration. Clear definition of these factors and the development of reliable and satisfactory test methods will no doubt call for physiological investigations under carefully controlled conditions such as may be obtained at the cold-hardiness laboratory at Weslaco.

Breeding Work In California Related To Cold Hardiness

The breeding work in California is carried on at two stations. The crosses are made at Indio, where the variety collections are maintained, but most of the seedling progenies are grown at the Southwestern Irrigation Field Station at Brawley.

Much of the work related to cold hardiness has been done with rather broad objectives in view. An especial effort has been made during the last few years to collect cold-hardy varieties for use in breeding both scion and rootstock varieties. A large collection has been made of trifoliolate orange strains and hybrids and the available kumquats and kumquat hybrids. We have been much interested in collecting, selecting and testing salt-tolerant materials for use in breeding for salt tolerance in rootstocks. Results of the extensive investigations on salt tolerance of citrus rootstocks conducted during the last 10 years in Texas by Cooper and his associates (2, 3, 4) have provided us with a sound basis for breeding for salt tolerance in rootstocks. That work also showed that the degree of salt tolerance has a profound influence on the cold hardiness of citrus trees growing on highly saline soils (1).

In most of the hybridization work so far accomplished the objective was usually the combination of several desirable characteristics in the hybrid progenies. In some of these cold hardiness was a major consideration, but in many it was secondary. An account of the hybridization work on scion varieties related to cold hardiness follows.

Lemons and Limes. In the interior desert areas of Arizona and California, where summers are hot and winters are cold, the Meyer lemon has been found to be cold hardy and highly productive. With the objective of combining the hardiness of the Meyer and the high fruit quality of the commercial types, crosses were made in 1952 between the Meyer and the variety Messina, 2 strains of Eureka, and 2 strains of Lisbon. Over 700 seedlings were produced, and many of these have fruited. The Messina, Eureka and Lisbon were the seed parents, and as they produce many nucellar seedlings, it was difficult to determine whether some of the desirable seedlings are hybrids, but a few that apparently are show promise. Further study will be necessary to select the best of these. It will also be necessary to test them for cold tolerance.

With the object of producing a small hardy acid fruit of the lime type suitable for use as a dooryard fruit in cold locations, the Calamondin lime was crossed with Eureka and Lisbon lemons and with the Rangpur lime. Only a few hybrids were produced from each cross and these are not yet in bearing. In the 1958 freezes the Calamondin x lemon
hybrids showed striking segregation for cold tolerance (Fig. 1, C).

Loose-skin Types. Extensive hybridization of tangerine, tangor and tangelo varieties was accomplished in the period 1952 through 1954. The seed parents most extensively used, Clemantine, King, Wilking, Honey, Umatilla and Temple, were selected because they produce a high proportion of hybrid seedlings. Among the pollen parents were Dancy, Kinnow, Honey, Kara, Wilking and Willow Leaf tangerines; Orlando, Minneola, San Jacinto and Pearl tangelos; Umatilla and Temple tangors. These crosses were not made specifically to produce cold-hardy varieties, but in the several thousand seedlings produced it is apparent that wide variation in hardiness exists; and cold hardiness is one of the factors that will be considered in the testing and selection of seedlings for commercial trial. Many of these seedlings have fruited and about 50 have been propagated on a common rootstock for further observation at Indio. Budwood of many of them has been sent to Weslaco for observation and testing for cold hardiness.

Breeding Early Tangerines and Oranges to escape Early Frosts: With the primary object of obtaining early tangerines, tangors and oranges of high quality a series of crosses was begun in 1953 and additional ones were made each year to the present time. If, as is expected, very early ripening fruits are obtained from some of these crosses, the fruit itself should escape injury in all except the very early frosts, which usually are not severe.

Seed produced from a cross of Clementine by Owari satsuma made at Orlando by Philip Reece were received in 1953. Of the 224 seedlings produced from these seeds a few trees fruits at Brawley in 1958, and these indicate that this cross is likely to be a profitable one. Over 200 seedlings from a cross of Clementine by Hamlin were planted in 1954 at Brawley. Some of these fruited in 1958; several were quite early ripening, but the only one selected for second test was not as early as Clementine. Most of these seedlings have not yet come into bearing. An attempt was made in 1954 to obtain hybrids between several strains of navel orange as seed parents and Clementine and Honey tangerines, with the object of securing early, seedless tangors of high quality. From large numbers of flowers pollinated a few seeds were obtained and these produced only 2 or possibly 3 hybrids, and these have not yet fruited. These results suggest, however, that with sufficiently large scale pollinations of navel oranges it may be possible to obtain in a few years' time fairly large numbers of navel orange hybrids.

The Shamouti orange is not a commercial variety in this country, but in Israel it is considered to be one of the world's finest varieties. For several years we have pollinated large numbers of Shamouti flowers with Hamlin, Tarocco and Joppa pollen, in the hope of obtaining an early high-quality and nearly seedless orange. Though the yield of seeds has been small and the number of hybrids very few, it has been encouraging to obtain even a few hybrids. We hope to improve the conditions under which these crosses are made so as to obtain a higher yield of seeds. Temple orange produces some early-ripening seedlings, and as it produces only hybrids, it also has been used as seed parent in crosses with Hamlin, Tarocco and Shamouti oranges. In all of these crosses many of the hybrid seedlings are weak and worthless, so that rogueing is necessary.

Combining Cold Hardiness and Salt Tolerance in Rootstock Types: Since 1954 extensive hybridization work with rootstock varieties has been performed with the object of producing a series of rootstock types that combine various desirable traits. Special attention has been given the trifoliate orange and its hybrids because many of them are resistant to root rot, induce in the scion variety the production of high-quality fruits, and under some conditions improve the cold tolerance of the scion variety. Because of the prevalence of saline waters in many of the irrigated citrus districts the production of salt-tolerant rootstocks has been a major consideration in the hybridization work at Indio.

With the object of combining the factors for cold hardiness and salt tolerance in citrus rootstock types, crosses were made using as seed parents the salt-tolerant varieties Rangpur lime, Cleopatra and Sunki mandarins and as pollen parents several strains of the trifoliate orange, Troyer, Savage and Carrizo citranges, and the Brazil sour orange. Some of the hybrid seedlings, for example the Rangpur x Brazil sour orange hybrids, showed clear segregation for cold tolerance in the 1958 freeze (Fig. 1, D). Several hundred of these hybrids...
are now under test in salt plots. Apparently, the factors responsible for salt tolerance are heritable because the progenies of several crosses have shown striking segregation for tolerance to high salt. *Eremocitrus glauca* is hardy and highly salt-tolerant but a slow, weak grower. Some of its hybrids, however, are vigorous and salt-tolerant and are being selected and tested for salt tolerance. The best of these will be used for hybridization with other species and varieties with the object of producing a cold-hardy and exceptionally salt-tolerant rootstock variety.

**Combining Cold Hardiness with Resistance to Root Rot and Other Qualities.** In a search for plants highly resistant to injury from *Phytophthora parasitica*, the chief cause of root rot or foot rot of citrus in the warm soils of the desert citrus areas, seedlings of a large number of trifoliate orange varieties and hybrids, sour orange varieties, and mandarin and tangelo varieties have been screened for resistance to *P. parasitica*. This work has been carried out during the past 3 years by John B. Carpenter, citrus pathologist at Indio. A method that results in infection of all of the seedlings was devised. Following infection most of the seedlings die and only the highly resistant ones quickly recover and resume growth. Large numbers of resistant seedlings are now under field test. Some years will be required to complete the screening of these for cold hardiness and other qualities desirable in a rootstock.

Crosses have been made between trifoliate orange varieties and the following: Suen Kat, Cleopatra, Sunki and Shekwasha mandarins, Sunshine tangelo, several shaddocks, Iran lemon and Rough lemon, and several sweet orange varieties with the object of combining the factors in the trifoliate orange that induce high quality of fruit and cold hardiness with various qualities carried by the other parent, such as the tendency to induce high yields, vigor of growth, disease resistance, or tolerance to high-lime soils.

Most of these crosses have been made so recently that few of the seedlings have fruited. Unless the seedlings of a variety are largely nucellar, it is of limited value as a rootstock even though it has otherwise excellent qualities. Until the seedlings produced by these crosses are examined for nucellar embryony and tested in other respects, no prediction of their value can be made.

The detailed method of handling the testing of seedlings produced at Orlando and Indio in the breeding of scion varieties and rootstock varieties is yet to be worked out, but present plans are to send much of this material as seed or as budwood to Weslaco for tests of salt tolerance in the field or for tests of cold hardiness in the controlled-temperature rooms and greenhouses there.

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