Citrus Section

CITRUS BREEDING IN FLORIDA—PAST, PRESENT AND FUTURE

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INTRODUCTION

Seventy-five years ago, when the Florida State Horticultural Society was organized, citrus growing was an infant industry and Florida produced approximately 1,450,000 boxes of oranges per year, mostly from sweet orange seedling trees. The parental types for most of these sweet orange seedlings in 1887 were a very few trees that had survived the disastrous freeze of 1835 (Robinson, 1945).

Five years after the formation of this Society, the U. S. Department of Agriculture established a Subtropical Laboratory at Eustis, Florida, to study citrus diseases and citrus varieties. Walter T. Swingle and Herbert J. Webber, who had never seen an orange tree before, but who were filled with enthusiasm, were assigned to do this work. Both became outstanding authorities on citrus. Webber served as Pathologist, U. S. Department of Agriculture, 1892-1899, and as Physiologist in charge of the plant breeding work, USDA, 1900-06, during which time he was apparently in charge of the citrus breeding work. He became Professor of Experimental Plant Biology, Cornell University, in 1907, and was Professor of Plant Breeding, Cornell, 1908-1913, and Acting Director of the New York State College of Agriculture, 1909-13. In 1913 he became Director of the Citrus Experiment Station and Dean of the Graduate School of Tropical Agriculture, University of California, Riverside, California, serving there until 1935, when he became emeritus. He was largely responsible for organization and provided the stimulus which made the California Citrus Experiment Station at Riverside of world-wide reputation. After he became emeritus, he turned to writing and editing, which resulted in the important 2-volume work entitled *The Citrus Industry*. Swingle served as Pathologist, USDA, 1892-1899, and Pathologist in charge of the Laboratory of Plant Life History and Vegetable Pathological and Physiological investigations, 1900-06. In 1907 he became Physiologist in charge of the Office of Crop Physiology and Breeding; he carried the main responsibility for the USDA citrus breeding work and remained intimately associated with it until 1935.

Both Swingle and Webber were superb scientists and effective leaders. Swingle-organized teams operated all over the world. Scientists who served with Swingle included Webber, T. Ralph Robinson, Frank M. Savage, E. M. Savage, P. H. Rolfs, G. L. Taber, H. H. Hume, C. W. May, and Maude Kellerman Swingle. Although Swingle's main office was in Washington, D. C., he spent more than half of his time in Florida on breeding work and in the Phillippines, China, and other areas of the world exploring for new citrus types and wild relatives of citrus. He established test plots of citrus hybrids and varieties at the USDA Subtropical Laboratory at Eustis; at the USDA Subtropical Garden at Miami; at Glen St. Mary's Nursery in northern Florida; at Drake Point, Florida; at Little River, Florida; at Fairhope, Alabama; at Weslaco and Carrizo Springs, Texas; at Sacaton, Arizona; and at Indio and Riverside, California. Hybrid seedlings were grown in elaborate greenhouses in Washington, D. C., and the seedlings were examined carefully by Swingle before shipment to test-plot locations in Florida and elsewhere. After retirement in 1935, Swingle actively participated in citrus fruit improvement. He was the author of a 346-page chapter in *The Citrus Industry*, "The Botany of Citrus and its Wild Relatives of the Orange Subfamily (Family Rutaceae, Subfamily Aurantioideae)" (Swingle, 1943a). This is the first comprehensive review of all known citrus relatives which may have value as the industry develops.

Swingle carefully studied these wild relatives to identify heritable characters which could provide genes absent in cultivated varieties (Swingle, 1943b).

When evaluating the Swingle accomplishments in citrus breeding, it should be remembered that his work started 7 years before the rediscovery of Mendel's now famous principles of heredity and the publication of the DeVries mutation theory. Swingle developed citrus breeding from hit or miss selection to controlled crosses in which each new step could be planned. Swingle was truly a giant, who cleared the way for citrus breeders that followed him.

T. Ralph Robinson was Swingle's principal assistant (Figure 1). He came to Florida in 1901 as Plant Physiologist for the U. S. D. A. and worked at Eustis on citrus breeding until 1940, except during 1911-1918, when he was in charge of a commercial grove near Bradenton. Robinson served as the link between the citrus breeders of the past and those of the present. During his long service in citrus research, Robinson became a citrus variety expert. Probably no man in Florida could equal him in the identification of the many hundreds of types of citrus. He is now retired and lives at Terra Ceia, Florida.

After the Swingle era, systematic breeding continued at the U. S. Horticultural Station at Orlando, Florida. The work was done by H. P. Traub and Robinson during 1935-40; by F. E. Gardner and Jack Bellows in 1942; by P. C. Reece and J. R. Furr 1943-1946; and by Reece 1947-62. Closely allied programs have been conducted at Riverside, California, by H. B. Frost 1914-43, and by J. W. Cameron and R. K. Soost 1943-62; and at Indio, California, by Furr from 1948-62. The work of these men has increased our knowledge of the characteristics inherited in progeny from multiple combinations of parents. They have created new varieties which are now being planted extensively by Florida growers. Many other new hybrids are under test.

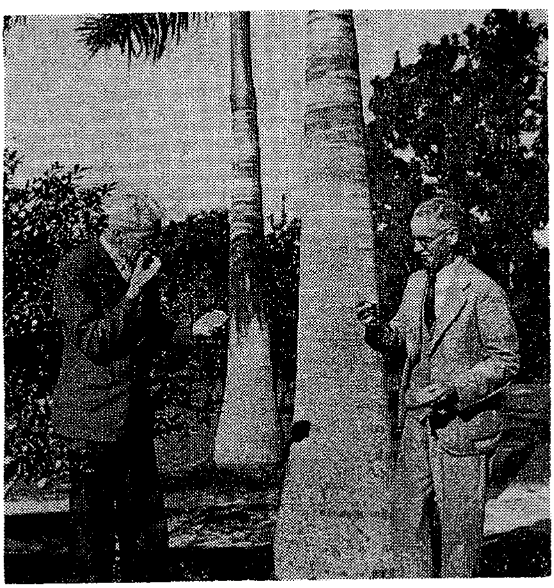

Figure 1. Walter T. Swingle and T. Ralph Robinson testing a new tangelo which had fruited at Robinson's place at Terra Ceia, Florida (about 1940).

The program in Florida was hampered by a shortage of land. The testing of the tens of thousands of new hybrids produced in the program required expanded acreage. In 1959 a group of Florida citrus industry men, recognizing that a program to improve citrus varieties requires adequating planting area, organized the Florida Citrus Research Foundation to secure land and make it available to the U. S. Horticultural Station at Orlando. The Foundation purchased a 500-acre tract of land and leased it to the government for 99 years. The staff of the U. S. Horticultural Station at Orlando are now engaged in an expanded citrus breeding program.

The purpose of this paper is to review the contributions of the citrus breeders in Florida of the past and to present current ideas on advances expected from present and future breeding work.

THE PAST

Notwithstanding their mass uniformity, enough variations occurred among sweet orange seedlings to give rise to the Parson Brown, Hamlin, Homosassa, Pineapple, Conners, Enterprise, St. Michaels, Boone's early, and other orange selections. By 1887 these selections, as well as the Valencia orange from Spain and the Washington Navel orange from Brazil, were being propagated on rootstocks by nurserymen (Webber, 1937).

Webber and Swingle thought that the prospects for improving varieties were better through breeding than through selections from seedling groves. They began their hybridization in the spring of 1893, using the Washington Navel orange and the several native sweet orange, grapefruit, and mandarin varieties as parents (Webber, 1894; Swingle, 1894). They noted that in most cases some of the offspring resembled one parent and some the other. They showed pictures of foliage of progeny of a St. Michael Blood sweet orange (female parent) x Duncan grapefruit (Swingle and Webber, 1897). Some leaves closely resembled the seed parent and some the pollen parent. They referred to both types of progeny as false hybrids and considered them worthless. They did not indicate what proportion of the false hybrids resembled each parent. Practically all seedlings from these crosses were lost in the great freeze of 1894-95.

Webber (1894) discovered that pollen was not required in the development of seedless Washington Navel fruit. At the same time, he found that emasculated unpollinated and bagged St. Michael orange flowers developed seedy fruit.

Citranges and Related Hybrids.—A second series of citrus crosses was made in 1897 with the objective of producing cold-hardy citrus varieties (Webber and Swingle, 1905). Special precautions were taken to preserve the progeny in the event of freezes before they were adequately tested. The ripe fruit resulting from cross-pollination were sent to Washington, D. C., where seed were extracted and germinated in a greenhouse. When the seedlings became 12 to 18 inches in height, they were sent to the USDA Subtropical Garden at Miami, where they were "fruited out" under the supervision of P. H. Rolfs. When the seedlings were sent south, the tops were cut back and the twigs were used to furnish budwood for budding to rootstocks to obtain trees for additional trials. These trees were tested in cooperation with a number of citrus growers in various parts of Florida. When the objective of the cross was to obtain greater cold hardiness, test hybrids were budded and grown under the supervision of G. L. Taber and H. H. Hume at Glen St. Mary in northern Florida.

In the crosses designed to produce cold-hardy varieties of citrus, one parent was a very cold-hardy and deciduous type, known as the trifoliate orange, *Poncirus trifoliata*. Although *P. trifoliata* is actually in a different genus from *Citrus*, it hybridizes with all species of *Citrus*. *P. trifoliata* ripens its fruit before frost, and the tree tends to become dormant several weeks earlier in the fall and remain dormant several weeks later in the spring than most citrus species.

In evaluating this series of crosses, Webber and Swingle were fully cognizant of the phenomenon of polyembryony and the difficulties that this phenomenon introduced in the study of citrus hybrids. Webber (1900) wrote that in the early stages the seedlings from nucellar embryos cannot be distinguished readily from true hybrids unless the parents differ markedly in some character which, combined in the hybrid, results in a distinctive character in the foliage that enables the hybrids to be recognized. In *P. trifoliata* x sweet orange crosses, Webber and Swingle (1905) noted that a single seed produced more than 13 seedlings, that all looked like the seed parent, and that all were presumably nucellar. In a cross of the unifoliate sweet orange with *P. trifoliata* pollen, 3 seedlings developed from a single seed; one had trifoliolate leaves, showing the influence of the male parent. The embryo from which it grew had developed from the egg cell; the other two seedlings had unifoliolate leaves exactly like the sweet orange seed parent and had developed from nucellar embryos.

Reciprocal crosses were made of *P. trifoliata* and Ruby sweet orange; 54 citrange hybrids were produced. Eleven different citranges—Norton, Morton, Sanford, Willitts, Phelps, Coleman, Rustic, Savage, Saunders, Cunningham, and Etonia—were grown from seeds of a single fruit of *P. trifoliata* crossed with pollen from a single flower of Ruby sweet orange (Swingle 1913). The Rusk citrange originated from another Ruby sweet orange x *P. trifoliata cross* (Webber and Swingle, 1905).

The citranges plainly showed characteristics of both parents, but they varied widely (Swingle, 1911). In all cases, most leaves were trifoliolate, but a few unifoliolate leaves occurred occasionally on some trees. All were evergreen, but fruit size, shape, and color varied greatly. The Morton fruit (Webber, 1906) was large, round, smooth, and orange-colored; the Coleman fruit (Webber, 1907) was depressed-globose, yellow, and fuzzy; the Willits fruit (Webber and Swingle, 1905) had a large percentage of fingered forms; the Rustic fruit (Webber, 1907) often were double fruits; the Phelps fruit (Swingle, 1913) was very bitter; and the Saunders fruit (Swingle, 1913) was small and less bitter than the rest. In all the hybrids the acrid flavor and cold resistance were inherited from the *P. trifoliata* parent. Because the juice is so bitter, these fruits have no prospect for commercial usefulness.

Most citranges produced only nucellar seedlings and consequently did not produce second-generation seedlings; they produced fertile pollen which could be used in further hybridization (Swingle, 1927). All pollinated citrange flowers set fruits with plump and viable seeds, but the resulting seedlings of most citranges were exactly like the seed parent. A population of 1500 Rusk citrange seedlings showed no variation in leaves or color or aroma of fruit (Swingle, 1927). It was concluded that one can propagate generation after generation of Rusk citrange from seed without any appreciable variation. This is a decided advantage in the practical utilization of these plants as rootstocks. The same was generally true for the Savage, Morton, and Rustic citranges. The Phelps and Sanford citranges produced variable segregating seedlings (Swingle, 1927).

During 1908-14, 2500 hybrids were produced from crosses of the *P. trifoliata* seed parent with various varieties of mandarin, lime, lemon, grapefruit, sour orange, and kumquat. All of the 100 citrandarins (*P. trifoliata* x. mandarin), 198 citremons (*P. trifoliata* x lemon), 14 citrines (*P. trifoliata* x lime), 299 citrumelos (*P. trifoliata* x grapefruit), 66 citrumquats (*P. trifoliata* x kumquat), 729 citradias (*P. trifoliata* x sour orange), and 81 citruvels (Washington Navel orange x *P. trifoliata*) had the objectionable acrid flavor characteristic of *P. trifoliata*, and no edible fruit was produced (Traub and Robinson, 1937). In most cases it was found that seedlings of these hybrids were nucellar; some are now being used experimentally as rootstocks (Bitters, 1960; Gardner, 1961). The Troyer citrange, actually a citruvel resulting from a cross of the Washington Navel orange x *P. trifoliata*, is a valuable rootstock for California citrus.

The citranges were back-crossed to *P. trifoliata*, producing 305 cicitranges, and to the sweet orange, producing 1109 citrangeors. Other crosses were citranges x mandarins, citranges x limes, citranges x grapefruit, citranges x calamondin, citranges x lemons, and citranges x kumquats. Today these hybrids have no commercial value because their fruits are extremely bitter. Two exceptions are the Thomasville citrangequat (Swingle and Robinson, 1923), which produced acid fruit with only a trace of bitter flavor, and the Glen citrangedin (Swingle, Robinson and Savage, 1931), which produces acid fruit with no bitter flavor. The leaves of Thomasville are usually trifoliolate; Glen leaves are usually unifoliolate. Both varieties are more cold hardy than the citranges (Frost, 1943) and are highly nucellar (Traub and Robinson, 1937).

Tangelos.—A second objective of the breeding work initiated by Webber and Swingle in 1897 was to produce new fruits having the sprightly acid flavor of the grapefruit, but reduced bitterness, and the loose, easily peeled rind of mandarin. Sampson and Thornton tangelos, hybrids of a cross between Duncan grapefruit (referred to as Bowen in the early citrus breeding literature) and Dancy tangerine, indicated great promise for this type of cross (Webber and Swingle, 1905). There is some confusion in the literature regarding the parents of this cross. Frost (1943) refers to it as a hybrid of Dancy mandarin x grapefruit; however, Webber and Swingle (1905) and Webber (1943) indicate that it is a grapefruit x Dancy mandarin. The single grapefruit which produced the Sampson tangelo had 76 seeds, from which 106 seedlings emerged. Most of the seedlings had foliage purely grapefruit in character and were nucellar. Five of the seedlings had foliage more closely resembling that of the mandarin, and one became the Sampson tangelo variety (Webber and Swingle, 1905). This instance illustrates how nucellar embryony complicates citrus breeding work. Grapefruit and tangerine foliage characteristics are distinctly different, so that many hybrids of such a cross can be recognized visually. However, when crosses are made between two genetically similar varieties, the visual detection of hybrids by foliage is more difficult.

Because Sampson and Thornton tangelos seemed to be a step forward, thousands of pollinations were made in 1911 to reproduce the cross between grapefruit and mandarin varieties. A large number of hybrids resulted. Six of these (Orlando, Minneola, Suwannee, Seminole, Pina, Sunshine) were grown from seeds of a single fruit of grapefruit crossed with pollen from a single flower of Dancy mandarin (Swingle's unpublished records). The best of these were the Orlando and Minneola varieties (Swingle, Robinson, and Savage, 1931). A backcross of grapefruit x Sampson produced the Wekiwa tangelolo, a small, very sweet, pink-fleshed fruit (Swingle and Robinson, 1921).

Tangelos were more or less intermediate in character between grapefruit and mandarin, and were neither grapefruit nor mandarin nor orange. The best were highly-colored, aromatic, richly flavored, sprightly acid, and very juicy. Their rind was usually thin, smooth, or slightly bumpy and rather easily removable like that of the mandarin. All were evergreen trees with unifoliolate leaves. The tangelo group has established itself commercially; there was an estimated production of 1,000,000 boxes in Florida in 1962.

Tangors.—Closely allied to the tangelo group were the tangors, hybrids between mandarin and sweet orange. Swingle's unpublished records on file at the U. S. Horticultural Station, Orlando, Florida, indicate that 508 apparent hybrids were produced from reciprocal crosses of sweet orange and mandarin varieties. Selections that were tested included one apparent hybrid of Clementine mandarin x King orange, one of Dancy mandarin x King, three of King x Temple orange, one of King x Ruby orange, two of Satsuma mandarin x Ruby, two of Satsuma x Temple, five Ruby x Dancy, 16 Pineapple orange x Dancy, four Ruby x Dancy, five Mediterranean sweet orange x Dancy, and others. They also made 16 selections from crosses of Clementine x Thornton tangelo. Most of these tangors and tangor-types had small-sized sweet fruits. Some potentially good selections were lost through failure to have adequate land to evaluate seedlings from the breeding program. One hybrid of King x Ruby, growing at the Little River test planting near Miami, was especially good, but it was lost in the hurricane of 1926 (correspondence with T. R. Robinson). Another tangor of good characteristics was secured from hybrid seedlings grown at Eustis. It resulted from a cross of Satsuma x Ruby and was introduced under the name Umatilla tangor. It produced large, deeply orange-colored, exceptionally attractive, late- maturing fruit (Swingle, Robinson and Savage, 1931).

Other Hybrids.—Many other combinations of parents were tested by Swingle (1910). The limequats (Key lime x kumquat) were very similar to the Key lime, but were considerably hardier. They named 3 varieties: Lakeland, Tavares, and Eustis (Swingle and Robinson, 1923; Swingle and Robinson, 1927). Some orange x lemon hybrids were secured, but none was especially good for use as either orange or lemon (Swingle's unpublished records). The Perrine lemon (Key lime x Genoa lemon) was at one time grown commercially, but it is no longer grown because of extreme susceptibility to a disease (Swingle, Robinson and Savage, 1931). Other hybrids produced included sour orange x calamondin, sour orange x grapefruit, calamondin x kumquat, calamondin x mandarin, Australian finger lime x calamondin, Australian finger lime x lime, lemon x grapefruit, lime x sour orange, lime x sweet orange, sweet orange x grapefruit, sweet orange x calamondin, sour orange x pummelo, and pummelo x calamondin (Swingle's unpublished records). None of these produced any worthwhile varieties, but they illustrate the relative ease of hybridizing the various species among the *Citrus*, *Poncirus*, *Fortunella*, and *Microcitrus* genera.

In addition, reciprocal crosses were attempted in 1908-11 between the following sweet orange varieties: Washington Navel, Ruby, St. Michael, Sanford, Boone's early, Parson Brown, Sorrento, and others (Swingle's unpublished records). Several hundred possible hybrids were selected on the basis of small variations from the parental type in the foliage characteristics and in seedling vigor; these were planted in the field at Eustis. Rootstock material was needed for field tests of 740 new tangelo types, and the sweet orange trees which had not yet borne fruit were sacrificed for that purpose (Robinson, 1962).

THE PRESENT

Hybrids among Tangors, Tangelos, Mandarins, and Sweet Orange.—The principal objective for the USDA breeding program is the production of high-quality, highly colored, seedless oranges for all seasons of the year, particularly early- and late-ripening types. For concentrate purposes, early orange types should have solids equal to or higher than those of the Valencia orange. For fresh-fruit purposes, the oranges should have easily peelable rind, as well as high quality, flavor, and large size.

In 1942 Gardner and Bellows made a series of crosses including the following: Clementine mandarin x Orlando tangelo, Clementine x Minneola tangelo, Clementine x tangor 653, Clementine x Hamlin orange, Clementine x Mott grapefruit, Mott x Hamlin, Mott x Clementine, Jaffa orange x Mott, Minneola x Clementine, tangor 653 x Valencia orange, Orlando x tangor 653, and others (See complete list in Furr and Reece, 1946.). One cross, Clementine x Orlando, yielded many promising new hybrids. A population of 327 progeny of this cross produced a wide range in forms, probably as great as the range in form of the citranges and tangelos. Most of them are predominantly mandarin in type. Some resemble sweet oranges and others tangelos. Most of them are early-maturing, large, and sweet and have an orange-red rind; but unfortunately they are rather seedy. Some of them have prominent navels.

Three of the earlier maturing mandarin types have been named and introduced (Reece and Gardner, 1959). The Robinson produces large fruit that develop a deep orange-red color and reach prime eating condition by mid-October. The Osceola ripens its fruit in November, and they are more highly colored than the fruit of the Robinson. The Lee produces fruit more closely resembling oranges in size and shape. The fruit is sweet and ripens in November. Several other selections have particularly high quality. Ten selections, including the Robinson, Osceola, and Lee, have been propagated on 8 different rootstocks, and solid-block plantings of them are being made at Foundation Farm near Leesburg, Florida.

Because of the large number of new hybrids resulting from the Clementine mandarin x Orlando tangelo cross, it appeared to Furr and Reece (1946) that the Clementine produces only hybrid seedlings. To check these conclusions, Clementine was crossed with *P. trifoliata* as male parent to introduce the dominant trifoliolate character into every hybrid embryo. Any unifoliolate plants could then with certainty be considered Clementine nucellar seedlings. Several hundred seed from this cross were planted. Every seedling had trifoliolate leaves, and no twin seedlings appeared. These facts were therefore accepted as evidence that probably no nucellar seedlings are produced when Clementine is used as the female parent.

The potentiality of hybrid production by several other parent varieties was investigated by Furr and Reece (1946). The Orlando and Minneola tangelos, tangor 653, and Temple orange were crossed with *P. trifoliata* as the male parent. Out of several hundred seedlings from each cross, Orlando produced no trifoliolate plants, Minneola two, and tangor 653 none. On the other hand, Temple produced only trifoliolate seedlings and only one per seed. This indicates that Temple, like Clementine, produces only hybrid seedlings, whereas Orlando, Minneola, and tangor 653 produce mostly nucellar seedlings.

Encouraged by the success of the Clementine mandrin x Orlando tangelo cross, Reece (1959) crossed the Robinson, Lee, and Osceola hybrids with one another, backcrossed them to Clementine, and out-crossed them to many varieties of sweet orange. Additional crosses have been made, using both the Clementine and Temple as seed parents and many varieties of sweet orange, tangelos, and tangors as pollen parents. These new crosses have not yet fruited. Many new hybrid progeny in this series of crosses were obtained by the use of monoembryonic seed parents that produce a high percentage of hybrid seedlings. This use of monoembryonic seed parents accelerates the rapid production of new hybrids, since no land is wasted in growing nucellar trees.

The present-day citrus breeders are not deterred by Swingle's results with tangors. Since the highest quality fruit is produced by mandarin and tangor types, these should be tested as parents. Probably Swingle did not grow enough seedlings to produce one that combined good size, good quality, and good color. In light of what is now known about the probability of obtaining valuable seedlings, one would not expect Swingle to have found a good tangor seedling in a single population of hybrids. Even though most of the early tangors were small-fruited, many produce hybrid seedlings and are valuable seed parents in backcrosses with sweet orange varieties. That such fine varieties as Orlando and Minneola (Swingle hybrids), Kinnow, Wilking, Kara, and Honey (Frost (1935) hybrids) were obtained from such relatively small populations of seedlings is remarkable.

Concommitently with the breeding work at Orlando, extensive hybridization of mandarin, tangor, tangelo and sweet orange varieties was accomplished by Furr at Indio, California (Furr and Armstrong, 1959). The seed parents most extensively used were Clementine, King, Wilking and Honey mandarins and Umatilla and Temple tangors. All these types produce a high proportion of hybrid seedlings when used as the seed parent. Among the pollen parents were Dancy, Kinnow, Honey, Kara, Wilking, and Willowleaf mandarins; Umatilla tangor; Orlando, San Jacinta, and Pearl tangelos; and Hamlin, Temple, Torocco, and Joppa sweet oranges. Seeds of many of these crosses were sent to Reece at Orlando, where they are now being field-tested. These additions from California to the hybridization work at Orlando have given greater depth to the Florida program and increased the chances of producing a good high-quality, seedless early orange.

Grapefruit hybrids.—There has always been a vacuum for a high-quality grapefruit in Florida that ripens in the period of September 15 to November 15. A high priority has been given to develop either an early or extremely late grapefruit that will fill this void.

Monoembryonic hybrids of a grapefruit type were produced by Reece in 1949 by a cross of Temple tangor x Nakon pummelo (unpublished data). This constituted a significant step forward in an attempt to produce superior grapefruit varieties. These new hybrid grapefruit types can be crossed to any grapefruit that produces viable pollen and a large population of grapefruit hybrids can be secured. Nearly all progeny of grapefruit x grapefruit crosses except the Sukega, Wheeny, and Triumph varieties have been nucellar grapefruit of the seed parent variety. Grapefruit breeding work in Florida is now being conducted cooperatively with Arthur Pieringer, of the University of Florida Citrus Experiment Station, Lake Alfred. Test plantings of promising grapefruit hybrids will be made at the Indian River Field Station and at Foundation Farm.

Sweet orange x Sweet orange hybrids.—The early work by Swingle with hybrids between varieties of sweet orange was unfruitful because of freezes and the difficulty of identifying the small number of hybrids among a large progeny of nucellar seedlings. Frost (1943) also reported that generally nucellar seedlings and a few weak worthless hybrids are expected from such crosses. To obtain more data on sweet orange hybrids Furr and Armstrong (1959) pollinated many flowers of Shamouti orange with Hamlin, Torocco, and Joppa orange pollen. These parent types produce very few seeds. Though the yield of seeds from the crosses was small and a high percentage of the seedlings were nucellar, some were obviously hybrids. Some of the hybrids were weaker than Shamouti and others were more vigorous. Crosses between sweet oranges, as well as crosses between sweet oranges and tangors, should be fully explored in the quest for new high-quality sweet orange varieties.

THE FUTURE

To increase information of the relative usefulness of particular parent varieties in a breeding program, the hybrid offspring from certain parents are classified into contrasting alternative categories of sugar content, acidity, time of ripening, rind and flesh colors, size, seed content, looseness of peel, and cold hardiness.

For more effective inheritance data on acidity and sweetness, more knowledge is needed about the nature of metabolism of sugars and acids in the fruit from pea size just after fruit set through enlargement and maturity. To accelerate this aspect of the work, a biochemist is now working with the citrus breeders at Orlando in an investigation of the metabolism of organic acids and sugars in the so-called acidless, low-acid, and high-acid types and the inheritance of these characteristics.

Basic work on the physiology of cold hardiness in citrus is essential to an effective breeding program for hardiness. The breeder must know what characteristics are hereditary and how to make tests of seedling progenies so that reliable selections for cold-hardy individuals can be made. Such basic work on cold hardiness is now being conducted at the USDA laboratory in Weslaco, Texas (Young and Peynado, 1961). Young and Peynado have clearly defined the role of dormancy in cold hardiness and have developed a test method for use of the citrus breeders. This involves the use of a plant growth chamber equipped with a light- and temperature-control system and a freezing chamber. Dormancy is induced in the seedlings to be tested by a two-week exposure to an 8-hour 79°F. day, and a 16-hour 50° night. The dormant seedlings are then given a 3-hour exposure to 22°, which will not cause injury to the cold-hardy individual plants but will severely injury the less hardy ones. This procedure will make it possible to screen large populations of seedling progeny for cold hardiness under standard conditions which can be reproduced at any time of the year, and year after year. It is obviously a great improvement over the usual method of testing for cold hardiness of hybrid seedlings in the field under natural freeze conditions. In the latter case, the plants will be in a different state of dormancy with each freeze and the severity of each freeze will vary in some respects.

Other systematic screening procedures are being used on rootstocks which are just being bred in Florida. Pathologists and nematologists have tested and classified various parental types for nematode tolerance (Ford, Feder, and Hutchins, 1959), *Phytophthora* tolerance (Furr and Carpenter, 1961), and tristeza tolerance (Grant, Costa, and Moreira, 1949). These tolerant types are now being used by the breeders in an attempt to combine in one rootstock variety a number of desirable traits. Seedlings from open-pollinated seeds produced by F_1 hybrid seedlings will then be screened for inheritance data on tolerance to nematodes and diseases.

The range of tolerance of observed F_1 seedlings of crosses between susceptible and tolerant parents may indicate that the inheritance of these characteristics is complex and controlled by many genes. The same may be true for inheritance of acidity and sweetness in citrus. However, as more data on the inheritance of these characteristics are accumulated on particular parental types, our information on the relative value of selected parent varieties will be augmented.

Conclusions and Summary

Swingle's work showed that generally F_1 hybrids varied greatly, indicating that an extremely heterozygous condition seems to be universal in the genus *Citrus*. The F_1 hybrids from any two parental types usually showed variability of the type expected in F_2 hybrids between varieties differing in many genes. In any particular character, such as leaf shape, hybrids from the same cross are very diverse: they may be similar to one of the parents, intermediate between the parental types, or outside the parental range.

Within the genus *Citrus*, compatibility between species is usual, and more or less fertile F_1 hybrids result. Among three other genera there is also compatability with *Citrus*: *Poncirus, Fortunella,* and *Microcitrus*. Most of the F_1 hybrids from these crosses are sterile. These genera seem to mark the limits of successful crossing.

From a practical breeding standpoint, Swingle's greatest accomplishment was the production of the Orlando and Minneola tangelos. Some of the citranges have also proved to be valuable rootstocks. He failed, however, in his attempt to produce an acceptable cold-hardy orange by the use of the cold-hardy *P. trifoliata* as a parent. The acrid flavor and cold-hardy characteristics in the *P. trifoliata* appeared in practically all hybrids. The genes that control these two characteristics are possibly closely linked in the same chromosome and the chance of breaking this linkage is not promising, but not impossible.

The most important accomplishment in citrus breeding by the more recent workers is the rapid production of tens of thousands of hybrids by the use of monoembryonic seed parents. This is a great step forward in the quest for new and superior hybrids. These workers have used many of Swingle's tangelo and tangor varieties, which are F_1 hybrids, and backcrossed, intercrossed, and outcrossed them to other varieties and produced such promising new varieties as the Robinson, Lee, and Osceola. A high-quality, early-maturing orange is more likely to be found in progenies of advanced crosses involving various intercrosses of F_1's and backcrosses than in simple F_1 progenies.

Screening of thousands of seedling progency from varieties crossed to give combinations of desirable characteristics is emphasized in the present citrus breeding program. New inheritance data will greatly enhance our information on the practical breeding prospects of particular parent varieties and will speed the day when new high-quality varieties will be available for any season of the year.

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FIELD TRIALS WITH A WIND MACHINE

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INTRODUCTION

The severely cold winter of 1957-58 served to emphasize the need for additional cold protection devices in Florida. To this end field trials with a wind machine were begun during the winter of 1958-59. The purpose of these trials was to ascertain the applicability of wind machines as cold protection devices in Florida. Since Gainesville is beyond the northern limit of the commercial citrus growing regions, due to the greater risk of cold weather, it appeared to be well suited as a site for gaining the most information in the shortest time.

PREVIOUS WORK

Field trials with wind machines have been conducted both by growers (2) and by the University of California (10) since the 1920's and 1930's. Reports of benefit obtained by wind machines vary, but it is noteworthy that growers felt the benefit great enough to continue their efforts. In 1912 McAdie (8) showed that on cold, calm, clear nights the air above the plants was warmer than among the plants, and that considerable cold protection should be obtained by mixing the air. Young (11) reported in 1929 that no machine capable of affording cold protection had been developed. Yet only 9 years later, he reported 133 wind machines in California, and by 1951 Brooks (4) reported 2,800 wind machines in California. In view of this dramatic increase in numbers, there can be little doubt that they are effective in California.

Field trials with wind machines have also been conducted in Australia (1). Angus reported that results obtained are generally similar to those obtained in California, but that meteorologic and economic conditions are sufficiently different so as to make their use somewhat limited. Ball (3) has investigated the theoretical basis of the wind machine as a device for simply mixing the lower layers of the atmosphere, and reached the rather startling conclusion that on nights which are clear and calm only ¼ horsepower per acre should be required to keep the bottom 50 feet of the atmosphere mixed. Obviously wind machines as now used do not have a very high efficiency. Much of their power is consumed in shaking trees and blowing soil.

Georg (6) has conducted field trials with wind machines in Florida and has generally concurred with the California results. Wind machines were found by Rhoades *et al.* (9) to be less effective in deciduous orchards than in citrus groves.

The results of wind machine trials both in California (5) and Australia (1) can be summarized briefly. With wind machines in the 60 to 100 horsepower class, having 12 to 15 foot diameter fans, the area of protection was circular with the wind machine at the center. Two degrees or more of protection was provided for 5 to 10 acres. On this basis approximately 10 horsepower per acre was required for protection. Protection was provided under clear, calm conditions—inversion conditions—but no measurable protection was obtained with wind-borne colds.

EXPERIMENTAL

The field trials were conducted in 2 contiguous, square, 10 acre plots planted predominantly to peaches at the Horticultural Unit of the University of Florida at Gainesville. The plot layout with the wind machine and temperature network is shown in Figure 1. The area is bounded on the north by vegetable fields and on the west by a wooded area. The south end of the plots slopes downward toward an intermittent stream. The east and south are open grass fields.

Two 55 foot inversion poles were located in the area—one in the west or test plot and one in the east or check plot. The inversion pole in the test plot was 250 feet northwest of the machine and the one in the check plot was 750 feet east of the machine. Throughout the entire three winters during which data were obtained, mini-

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