Citrus

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MAJOR ADVANCES IN THE U.S. CITRUS INDUSTRY IN THE PAST 100 YEARS

An anniversary affords the opportunity to look back and assess past achievements and failures. It is also a time to contemplate the future. Since the turn of the century, scientists and extension specialists in conjunction with citrus growers have been an integral part of the citrus industry—full partners in its growth and development. Indeed, citrus scientists have played a major role in shaping the citrus industry from its early growing pains and production difficulties to its present dominance in the global marketplace.

The U.S. citrus industry has faced many crises and challenges over the past 100 years. Devastating freezes, destructive diseases and insects, water issues, land competition from chronic urbanization, environmental pollution threats, governmental regulation, loss of pesticides, international competition, among other factors, have had complex and far-reaching impacts on citrus production. This review attempts to present major developments in the citrus industry occurring over the past 100 years.

HISTORICAL OVERVIEW

Citrus is native of subtropical and tropical regions of Asia and the Malay Archipelago. Citrus cultivation slowly spread to other parts of the world over the centuries, and highly developed cultivars naturally evolved before being first cultivated in Europe around 79 AD. The estimated dates of introduction of citrus to the United States are from 1513 to 1565 when Spanish explorers, led by Ponce de Leon, brought citrus to the St. Augustine Colony in Florida. Fruit were being produced in great quantities by 1579. Wild citrus groves were developed by Seminole Indians spreading seeds around hammocks near rivers. Records of growers first planting grapefruit in Florida date back to the early 1800s. By the mid-1800s citrus growers were developing technical horticultural methods, which were handed down to other growers.

THE DEVELOPMENT OF MODERN CITRUS TECHNOLOGY. At the beginning of the 20th century, along with the establishment of the American Society for Horticultural Science, university and federal research and extension horticulturists were actively investigating problems related to citriculture (Webber, 1967). At this time there was a rapid expansion of citrus in Florida and California. Because of an increase in population in the United States and a higher standard of living, there was a high market demand for citrus. Improvements in rail transportation, new varieties, handling methods, and the discovery of vitamin C in citrus all added to the new popularity and accessibility of citrus.

EARLY HISTORY OF RESEARCH IN CALIFORNIA. Although the University of California founded the Agricultural Experiment Station in 1874, it was not until 1907 that the Citrus Experiment Station (CES) was established in Riverside, Calif. Two University of California staff members (visiting faculty from Berkeley) were assigned to Riverside to conduct studies on soil management, fertilizer and irrigation requirements, rootstocks, and improving citrus cultivars. In 1911, J. Elliott Coit, a horticulturist, temporarily took the job of superintendent of the CES. One year later, H.J. Webber, a Cornell University plant breeder, was appointed permanent director of the CES. In 1929, Leon D. Batchelor became the second director of the CES in Riverside. Under his directorship, the facilities expanded substantially (Batchelor, 1957). The responsibilities of the station also expanded to new areas of research including all major crops of southern California. Continued emphasis was placed on fertilizers, rootstocks, cultural factors, and citrus genetics to help the citrus growers of the state. Varieties currently grown in southern San Joaquin Valley (Kern and Tulare Counties) are early 'Navels' including 'Atwood', 'Beck Newall', 'Cara Cara', Fukumoto, and 'Zimmerman' (Chao, 2000). Late 'Navel' oranges are being planted in central San Joaquin Valley (Fresno and Madera). Since 1997, thou-

sands of hectares of 'Nules' clementine mandarin have been planted in the San Joaquin Valley.

EARLY HISTORY OF CITRUS RESEARCH IN FLORIDA. At the turn of the century, citrus plantings were grown in areas near waterways accessible for transporting fruit to market. The threat of damaging freezes, however, soon induced the spread of the industry to the warmer southern locations of the state. This gradual movement was accelerated by the freeze of 1962 and the freezes of the 1980s (Attaway, 1997; Kender, 1987). In 1917, the Florida legislature authorized the establishment of an experiment station for research on problems of Florida citrus growers. In 1920, John Jeffries was appointed superintendent of the new CES located in Lake Alfred. Research was directed by scientists at the University of Florida in Gainesville who traveled to Lake Alfred to conduct field studies. Arthur F. Camp became the first resident director of the CES in 1935, a position he held until his retirement in 1956. Under his directorship, the Lake Alfred Station became one of the world's foremost citrus research facilities.

In 1941, the Florida Legislature enabled the Florida Citrus Commission to establish a scientific research department funded by a growers box tax. Starting in 1947, the new Florida Department of Citrus (FDOC) research scientists were housed at the University of Florida's Lake Alfred facility. Since then the two agencies have had close scientific interaction. L.G. MacDowell headed up the FDOC research group from 1942 to 1968. John Attaway served as its research director from 1968 to 1996 followed by Mohamad Ismail, Bill Stinson, and currently Joe Ahrens.

Horticulturist Herman J. Reitz was appointed director of the University of Florida's CES in 1957 after Camp's retirement. During his tenure, the name of the center was changed to the Agricultural Research and Education Center (AREC) although the objectives of the center remained the same. Reitz retired in 1982 and was succeeded by Walter J. Kender, horticulturist who previously was Pomology Department chairman and professor of fruit crops at Cornell University at Ithaca and Geneva, N.Y. The name of the center was again changed in 1984 to the Citrus Research and Education Center (CREC) to more appropriately depict its role. Harold Browning, Entomologist at CREC, succeeded Kender as director in 1996.

Citrus research was initiated at the University of Florida in Gainesville in the Horticulture Department in 1900s. The department separated into commodity departments in 1960, at which time Al Krezdorn assumed the chairmanship of the new Fruit Crops Department. He served in that capacity until his retirement in 1979. Michael Burke chaired the Fruit Crops Department until 1986 and Larry Jackson was Chairman from 1986 to 1991. In 1992, the Departments of Vegetable Crops and Fruit Crops merged to form the Horticultural Sciences Department chaired by Dan Cantliffe. Important research by the scientists at the Gainesville campus focused on pollination, the effect of growth regulators on flowering and fruit set, cold protection, sugar and acid metabolism, young tree care, irrigation, and climatology.

In the 1990s, in conjunction with the movement of citrus production to southwestern Florida, the Southwest Florida Research and Education Center in Immokalee was expanded substantially to include a major focus on citrus research in that region of the state. Calvin Arnold was the first director of this center. When Arnold was transferred to the Indian River Research and Education Center in Ft. Pierce, he was succeeded by Ed Hanlon.

The USDA Horticultural Research Laboratory in Florida was first established in Eustis in 1892 and moved to Orlando in 1952. The first director was Frank Gardner (1952–57) followed by L.C. Cochran (1957–59), William Cooper (1959–75), Roger Young (1975–84), and Richard Mayer (1985–99). Calvin Arnold currently serves as director at the relocated facility in Ft. Pierce. Other USDA facilities responsible for citrus research were the Citrus Rootstock Unit at Weslaco, Texas, the U.S. Date and Citrus Station at Indio, Calif., the Utilization Lab

in Pasadena, Calif., and the U.S. Citrus and Subtropical Laboratory at Winter Haven, Fla. (Cooper, 1995).

RESEARCH AND EXTENSION MILESTONES

ADVANCES IN CITRUS BREEDING AND GENETICS. Although citrus cultivars may originate as seedlings, limb sports, somatic mutations, or hybrids from breeding programs, most citrus cultivars currently grown originated as chance seedlings (Soost and Cameron, 1975). In the U.S., citrus breeding was primarily done by the USDA in Orlando, Fla., and Indio, Calif., the University of Florida at Lake Alfred, and the University of California at Riverside.

Over the past century, thousands of hybrids from the breeding programs have been continually tested. Widespread propagation of nucellar lines and varietal improvement have resulted in new citrus cultivars.

USDA. The first citrus breeding program was started in 1893 in Florida by Swingle and Webber of the USDA (Cooper et al., 1962). By 1908, they produced numerous and diverse hybrids. Among their early hybrids between grapefruit and mandarins were 'Orlando' and 'Minneola' tangelos, which still are being grown. Progeny from a cross between Clementine × Orlando gave three cultivars: 'Robinson', 'Osceola', and 'Lee', introduced in 1959. Another hybrid from that cross was 'Nova', named in 1964. The 'Page' orange, a hybrid of Minneola × Clementine, was also introduced in 1964. Thousands of seedlings from different crosses were evaluated in Florida and at the USDA Lab at Indio, Calif.

University of California. Breeding started in 1914 by H.B. Frost and was expanded after 1947 when crosses to produce triploids were emphasized. Several new nucellar seedling selections were developed. Geneticists continued research on breeding techniques and problems such as polyembryony, juvenility, incomparability, polyploidy, and induced and spontaneous mutations. Specific problem areas at that time were resistance to pests, diseases, cold, and chloride (Cameron and Soost, 1982; Cameron et al., 1982).

Citrus cultivars are grown in four major areas of California: 1) the San Joaquin Valley, 2) Ventura coastal district, 3) interior district, and 4) the desert valleys of southern California. Scion cultivars have changed over the past 100 years. The most important at present are 'Washington Navel', 'Valencia' orange, 'Eureka' and 'Lisbon' lemons, 'Marsh seedless' grapefruit, and tangelos and tangerines.

Valencia is grown in the interior and intermediate areas of southern California. Lemons are grown in the Ventura coastal area, and grapefruit does best in the hot, dry climate of the desert regions like the Coachella Valley east of Los Angeles. California's scion variety breeding program now emphasizes new mandarin, 'Valencia' orange, and grapefruit varieties suitable for California conditions (Roose and Williams, 2000). Techniques used are irradiation of budwood to produce few seeded mutants of existing varieties and hybridization between diploids and tetraploids.

Texas citrus. Texas citrus dates back to the 1880s when oranges were first planted along the Texas Gulf coast. At that time, citrus was also established in Louisiana. By the 1920s, grapefruit varieties, namely 'Foster' and 'Thompson', became commercially important. 'Ruby Red' grapefruit was discovered in 1929. The freezes of 1949, 1950, 1951, 1962, and 1963 eliminated a large portion of the industry. Before the 1951 freeze, Texas grapefruit production was primarily made up of the 'Marsh' and 'Duncan' varieties. After 1951, the pink and red varieties became prevalent. Almost all of the citrus plantings were destroyed in the freeze of 1983. 'Rio Red', now the main grapefruit variety grown in Texas, was developed by irradiation of 'Ruby Red' (Hensz, 1985).

Soils along the Rio Grande River range from sandy loams to heavy clays—most are fertile. The area is irrigated by flooding and microsprinklers.

Research and extension programs were established in the Weslaco area at the Texas A&I University Citrus Center, the Texas A&M University, and the USDA.

The new Texas A&M University Kingsville Citrus Center was established as a result of a merger between Texas A&I and Texas A&M in 1992. Center Director Jose Amador and Deputy Director John daGraca, represent the administration. Former directors were Gary McBryde and Dariusz Swietlik.

University of Florida. Important cultivars of the genus citrus

currently produced in Florida are 'Hamlin', an early, seedless sweet orange, 'Valencia', a late, seedless sweet orange, and 'Temple'. To some extent, 'Pineapple', 'Parson Brown', and 'Washington Navel' are now grown in the state as well as 'Sunburst', 'Murcott', 'Midsweet', 'Ruby Red', and others. Before 1920, Parson Brown was the leading orange variety but was too seedy for the market. 'Duncan', 'Foster', and 'Marsh' grapefruit, 'Dancy' tangerine, satsuma, and 'Tahiti' lime were also popular in the past.

Based on soil drainage, citrus trees are grown in distinct areas of Florida. Well-drained soils are found along the central ridge that extends from Clermont in the north to Lake Placid in the south. Poorly drained soils of the coastal areas (low hammocks) are found along the eastern and western coasts. The flatwood soils are found in central and south Florida and range from the Indian River area on the east coast to southwestern Florida. The Rockdale soil series is found in the very south of the state. This limestone soil is used to grow various citrus fruit, especially limes.

Starting in 1951, extensive screening and selection was started for rootstock resistance to the burrowing nematode, a debilitating problem for Florida citrus growers (Ford, 1969). Two nematode-resistant cultivars, 'Ridge Pineapple' orange and 'Milam' lemon, and one tolerant cultivar, 'Estes Rough Lemon', were introduced in 1964 (Ford and Feder, 1964). 'Carrizo Citrange' was also recommended at that time.

It was in the mid-1980s that the CREC at Lake Alfred launched a major research effort into cultivar improvement. Programs include traditional hybridization and molecular genetics and genomics. Focus is on rootstock and scion cultivar development to mitigate production problems and to expand market share through improved fruit qualities. Some of the basic research priorities are to develop genetic markers for selection and understanding the genetic control traits, clone specific genes for specific traits, and engineer genes into citrus. In the future, biotechnology techniques of genetic transformation using recombinant DNA will continue to offer novel ways to improve new germplasm.

ADVANCES IN PLANTING DENSITY, TREE SIZE, AND PRUNING. Tree density (trees per hectare) has steadily increased over the past 100 years. For example, in Florida, average orange tree density increased from 198 trees/ha in 1970 to 321 trees/ha in 2002. Plantings of 346 to 494 trees/ha have become more prevalent in the past 10 years. The trend to reduce the distance between trees in the row was based on the evaluation of a wide range of scion cultivars, rootstocks, and spacing combinations and was associated with tree vigor. Most desirable spacings currently range from 3.0 × 6.0 m for minimum spacing to 4.6 × 7.6 m for maximum spacing. Closely spaced trees produce groves in solid hedgerows. Growers found that establishment costs were higher for closely spaced groves but could be compensated for by maximum early production and returns; as labor became less available for hand picking, large-sized trees became less popular and less efficient. Conversely, smaller trees in high density plantings as a hedgerow were more effective for hand harvest because of easier access to the fruit.

CITRUS ROOTSTOCKS. Rootstocks have played an important role in determining the planting systems of choice for modern citrus groves (Wutscher, 1979). Important studies were conducted to demonstrate that the root system of the citrus tree determines its bearing potential and fruit quality. It was clear that trees of high vigor in a high-density situation resulted in excessive vegetative growth and crowding. Such trees were too large for the space allocated for the canopy volume. Allocated space and final tree size had to be in balance.

Sour orange rootstock, an important citrus rootstock since the 1930s, was found to be particularly susceptible to citrus tristeza virus. Because of the serious nature of this virus, the rootstock picture changed by the 1940s in favor of rough lemon and trifoliate orange, although Florida growers continued to plant sour orange well beyond this time. The use of rough lemon was later negated by citrus blight. In addition to scion variety and rootstock choices, research indicated that several factors affected tree vigor, specifically soil conditions, climate, nutrition, soil, water, nematodes, insects, and diseases.

In the future, because of restricted availability of water, stricter land-use regulations and conversion of citrus land to noncitrus uses, present citrus area must be used more efficiently. Large trees will continued to be phased out in favor of smaller, closer-spaced groves. Improved water-use efficiency and low-volume irrigation will be required. Fuel

consumption should be reduced because of a lower requirement of fuel, pesticides, and fertilizer in more efficient production.

PRUNING. It was shown that timely pruning was a key factor in tree size control when production efficiency was reduced because of overcrowding or shading. Trees formed into a continuous hedgerow required pruning when containment size was reached.

Citrus tree pruning studies, initiated in the 1950s in Florida, led to the development of the first mechanical hedging machine. Timing of hedging of 'Valencia' oranges that had two crops on the tree was an important issue for the grower. Removal of vegetative growth for tree size control was accomplished by mechanical hedging and/or topping and is still the major method of controlling tree vigor. When branches were cut back it was demonstrated that lateral buds were stimulated producing a more compact tree. Decisions on tree size management were based on 1) severity of pruning, 2) timing and frequency of hedging and topping, 3) angle of cutting, 4) height of topping, and 5) method of harvest.

FUTURE MANAGEMENT SYSTEMS

The rapidly growing amount of information and new technologies make it difficult for citrus growers to integrate this knowledge in an organized and meaningful way. Precision agriculture (site-specific farming) offers a method to use technological tools and decision models designed to minimize diversity to simplify management. Future research will provide decision aids to assist growers by integrating information into convenient easy-to-use computer software that will maximize efficiency.

Using GPS and GIS technology, examples of future uses of precision agriculture include weather-related decisions such as irrigation scheduling in small site-specific areas, pest and disease models, tree physiology models, etc. Yield mapping using machine vision will enable growers to develop detailed information on yield variability on a site-specific basis on areas as small as individual trees. Such systems will save time, labor and production costs, and maximize output. Future potentials for precision agriculture may include information integration of soil type and fertility level, water table depth, site-specific soil-water management, tree size sensing, coupled with variable-rate fertilizer and spray applications.

IRRIGATION. *Florida.* When water is a limiting factor for citrus production it must be used judiciously. Irrigation is required for maximum production. Urbanization, population growth, and below-normal rainfall have created demands on the water supply, which have led to regulatory restrictions on water use (Kender and Parsons, 1992).

Before the 1950s, irrigation was thought to be of little or no benefit to citrus. Citrus irrigation in Florida has been practiced to supplement rainfall since R.C.J. Koo's classic studies in the 1950s, showing irrigation increased yield by 15% to 45%. The occurrence of droughts over the years has demonstrated the importance of irrigation management. The focus of more recent research on water management has been on low-volume irrigation systems and the coverage necessary to afford adequate production. Drip and microsprinkler systems are used to improve water scheduling and precise application rates based on tree requirements and soil types.

Low-volume irrigation systems have been used for delivery of nutrients (fertigation), pesticides (chemigation), and herbicides (herbigation) and for freeze protection. Recycling of wastewater, including processing wastewater and municipal effluent, has been shown to be a valuable source of irrigation water and will become more important in the next 100 years.

Reclaimed water: Before 1980, many communities in Florida considered wastewater to be a disposal problem. When it was initially proposed to convert wastewater to reclaimed water for crop irrigation, some citrus growers refused to accept the water because of fears of heavy metals, flooding, or disease. Ultimately, several reclaimed water projects were started, and Water Conserv II west of Orlando has become one of the world's largest agricultural reclaimed water irrigation projects of its type. This project provides irrigation for more than 4,300 acres of agricultural crops and two golf courses. The water is chlorinated, is odorless and colorless, and has been used successfully for crop irrigation for 15 years (Parsons et al., 2001a). Initial fears that reclaimed water

would cause problems were unfounded. Recharge of the Floridan aquifer has been accelerated due to the application of reclaimed water to areas west of Orlando. In the sandy well-drained soil at this site, excessively high irrigation rates with reclaimed water (2500 mm/year) promoted excellent tree growth and fruit yield (Parsons et al., 2001b). Because of recent severe droughts in Florida, attitudes toward reclaimed water have changed. Once believed to be a disposal problem, reclaimed water is now considered to be a valuable resource that can meet irrigation demands. Florida and California are the two leading states in terms of reclaimed water use. In Florida, average statewide reuse flow rates increased by 119% in 11 years, and reclaimed water was being used on 40,152 acres for agricultural irrigation in 2001.

California. In California, citrus is grown on soils with widely differing textures and depths. Dry summers make irrigation vital. Irrigation has been commonly applied by furrows and low-head sprinklers. Basin and flood irrigation is used in the sandy soils of the desert. The advantage of microsprinklers is its adaptation to all soil types and terrains. Low-volume irrigation was first used to overcome high water cost and salinity problems.

COLD PROTECTION. *Florida.* Citrus is generally grown in climates where freeze damage is unlikely. Although cold events occurred intermittently throughout the years, a series of cold waves in the 1980s had a major impact on citrus production in Florida. Destructive freezes occurred in January 1981, January 1982, December 1983, January 1985, and December 1989 (Attaway, 1997). During this 10 year span the bearing acreage in Florida decreased by nearly 97,000 ha and a loss in value of an estimated \$2.4 billion. These freezes resulted in extensive fruit and tree damage and were directly responsible for causing rapid and drastic alterations in geography, economics, and management of Florida groves (Attaway, 1997).

In the past, citrus growers used a variety of methods to protect their fruit and trees from lethal low temperatures (Yelenosky, 1985). They included soil banks, trunk wraps, flooding, grove heaters, and wind machines. Heaters were effective but expensive. Wind machines were effective on calm frost nights, especially when strong temperature inversions occurred, by mixing warmer upper air with colder lower air. The use of water for freeze protection of young trees began in the 1980s. Low-volume microsprinklers with small emitters that deliver water in the range of 18 to 94 L·h⁻¹ are now the common method of freeze protection. Microsprinklers provide only partial freeze protection to large trees because emitters near the ground cannot protect fruit up in the canopy, but trees may recover for the following season. During the freeze of 1989 in Florida, an innovative development was used where microsprinklers were elevated inside the canopy of young (2- to 5-year-old) trees. These trees regrew to a height of 3 m the following year, while trees with ground-level emitters were significantly smaller, and trees without irrigation were killed to the ground (Parsons et al., 1991).

California. California experienced three very severe freezes (1913, 1937, and 1990). The most serious freeze in the history of California citrus industry occurred in December 1990. Major losses occurred in the San Joaquin Valley and other areas. Healthy trees with adequate water supply were better able to withstand the frost than weaker, dry trees. In general, the cooler nights in California induce quiescence, which allows the trees to survive lower temperatures than in Florida.

MINERAL NUTRITION. In the early 1900s, citrus production per tree was low because of a basic lack of knowledge of the soils and nutrient requirements of citrus trees. Citrus production is improved by fertilizer applications wherever it is grown. The early work of Peech and Young (1948) demonstrated that Florida's sandy soils had very low nutrient and water-holding capacity.

Soils in California, Arizona, and Texas varied from sandy loams to clay loams and had relatively high fertility compared to Florida citrus soils. In addition to N, P, and K, several serious deficiencies appeared in the field (Camp, 1938). Extensive studies were conducted to demonstrate the requirements of the essential elements for citrus production (Smith, 1966). Early horticulturists identified and controlled deficiencies of Ca, Mg, Mn, Zn, Cu, B, Fe, and Mo. Applications of Zn, Cu, and Mn was first shown by Cowart and Stearns (1941) to increase total solids, acids, sugars, and vitamin C content of fruit as opposed to only N, P, K application.

In the 1960s, citrus growers changed to high analysis fertilizers result-

ing in cost savings to the industry. Large amounts of Cu were applied to trees as foliar sprays and soil applications. Copper did not readily leach, accumulated in the organic soil layers, and restricted the uptake of Fe.

Iron deficiency was still prevalent in Florida in the late 1940s when Stewart and Leonard (1952) found that soil applications of iron chelates corrected the iron deficiency, particularly if lime was also applied. The iron deficiency was associated with excess Cu and was an important limiting factor for citrus production in early years.

Molybdenum deficiency was first observed in Florida citrus trees in 1908. The cause of the yellow spots and defoliation characteristic of the disorder was not identified until 1951, however, when Stewart and Leonard (1951) associated these symptoms to Mo deficiency.

In California, nutritional sprays containing zinc were used widely for controlling Zn deficiency. Quality and size of grapefruit were poorer on trees with Zn deficiency than on trees sprayed with a Zn spray at bloom (Parker, 1937).

The use of controlled-release fertilizers reduced leaching losses especially N and K. These fertilizer sources reduced contamination of groundwater because of lower leaching losses. Applications were made once per year rather than 5 or 6 times per year.

WEED MANAGEMENT. In the early part of the 20th century weeds were controlled by hand devices, namely scythes and hoes. Hand hoeing was generally discontinued in the 1930s because of labor costs. Weed management in citrus groves was accomplished next by mechanical means with mule or horse-drawn plows or discs for shallow cultivation. Harrows were run as close to the trunk as possible to remove weeds under the canopy. Due to the sparse labor supply and high cost of weed control, mechanical tree hoes were developed to control weeds under the tree canopy and within the row.

Starting in the 1930s, studies on herbicidal effects were conducted in California with emphasis on phytotoxic oils (Day and Jordan, 1969). The first commercial use of herbicides was in 1964 (Ryan, 1969). In the 1960s, researchers found that young trees treated with diuron and simazine had better weed control and greater tree growth than mechanically hoed trees (Ryan, 1965).

By 1960, the use of chemicals for weed control was rapidly growing due to the availability of new materials. Herbicides used in Florida since the 1960s included diuron, monuron, simazine, terbacil, and bromacil (Futch, 1997). They replaced the phytotoxic oils and by 1978 most citrus groves in California were nontilled.

ENTOMOLOGY AND CITRUS PATHOLOGY. Among the many important areas of research in the 1950s leading to the growth of the citrus industry in the United States included 1) pest biology and control by agrichemicals, 2) biologically based pest management and biological control, 3) ecological studies of pest populations showing the relationship of citrus pests with their natural enemies, 4) pathogens of mites and insects, 5) integrated pest-management using biological chemical means, 6) use of petroleum oils for pest and disease control, 7) the cause of spreading decline through the burrowing nematode, and 8) discovery of natural plant compounds.

Citrus pathologists played an important role in protecting citrus from devastating and exotic diseases. Citrus tristeza virus (CTV) first became established in California in 1925 (Webber, 1925) and later was found to be vectored by the brown citrus aphid (*Toxoptera citricidus* Kirk) (Mehta et al., 1997). CTV was first detected in Florida in 1951 (Grant and Schneider, 1953). Cooperation between Florida and USDA scientists helped develop purification methods, associated infectivity with long-filamentous particle, and produced antisera to the virus. CTV drastically affects citrus production (Garnsey, 2000) and may kill trees and reduce production. Use of molecular techniques has developed rapidly in recent years resulting in new diagnostic methods and host resistance. CTV will need long-term solutions including resistant varieties. Exocortis was first described by Fawcett and Klotz (1948). Bitters (1952) was the first to show it was a graft transmissible agent now known to be a viroid.

Citrus blight became a serious problem in Florida in the 1960s and is now widespread throughout the state. Although the disease is well characterized and easily diagnosed, the causal agent is still unknown. Timmer et al. (1992) established the infectious nature of citrus blight. Melanose, scab, postbloom fruit drop, and greasy spot fungal diseases have also been researched extensively over the years but continue to be important diseases in Florida (Knorr et al., 1957).

Citrus canker, an important invasive disease in Florida, has been a controversial issue in the attempts to eradicate the disease (Gottwald et al., 2000). The bacterial disease was first found in the southeastern U.S. in the early 1910s. It was declared eradicated in 1927. Citrus canker was rediscovered in Tampa Bay in the late 1980s and thought to be eradicated in 1994. A new outbreak was discovered in Miami in 1995. At least three genotypes have been introduced into Florida in the past 20 years.

Pesticide application has changed from high-volume to low-volume sprays over the years. Energy costs, environmental toxicology, effect on natural enemies and nontarget organisms, economics, and production efficiency have emerged as critical in developing new application strategies. Groundwater contamination and worker exposure are of concern to growers and the public.

In the future, precision agriculture will be more important, specifically variable-rate application using appropriate instrumentation. Growers will need more efficient and safer application equipment. Variable-rate applications will require an integration of spray volume, ground speed, air volume, canopy size and structure, time of application, and weather conditions.

In the 1990s, important problems facing citrus growers in the United States were related to nitrogen nutrition (best management practices and foliar application of N), water quality and management, brown citrus aphid (vector for CTV), improved rootstocks, diapaes root weevil, mechanical harvesting, integrated pest management citrus blight, cold protection, and management systems (Kender, 1995).

HARVESTING. Over the past 100 years citrus growers have faced many challenges such as declining income, higher costs of production, and potential decreases in the availability and cost of harvest labor in the future. In Florida, the cost of harvesting citrus now exceeds the total cost of production. The citrus industry supported mechanical harvesting research starting in the 1960s. When the freezes of the 1980s reduced acreage of citrus, interest in supporting such projects waned and it was not until 1994 that the Florida Department of Citrus reestablished a research and development program on mechanized harvesting. The transition from hand harvest to mechanical harvest for processing citrus is expected to evolve rapidly over the next decade. Two types of machines show exceptional promise: the trunk shake and catch and the continuous canopy shake and catch systems. Future needs to accommodate harvesters will be smaller, compact trees and an effective abscission agent to be used in conjunction with the harvesters, including air harvesters. Of particular interest for the long-term citrus harvesting needs is the development of robots for the fresh fruit market. Recent progress in the field of robotics shows promise. Changes in grove management systems will certainly be needed. Tree training to hedgerows no more than 3.6 to 4.6 m high with a narrow in-row canopy width will be required to position the fruiting zone on the outer edges of the hedgerow. Robotic harvesters with multiple arms are expected to pick all of the fruit on a tree at the rate of one fruit per second or faster.

Long-term goals of harvesting research in Florida is to 1) reduce harvest costs to be able to compete on a global basis, 2) develop management changes to accommodate machines, including robots, and 3) integrate tree spacing hedgerows, rootstocks, skirting irrigation systems, gleaning, delivery schemes to the processor for overcoming cost limitations for the grower.

ADVANCES IN POSTHARVEST HORTICULTURE. In the 1940s, it was clear that the quality of fresh fruit had to be improved to successfully compete for domestic and foreign markets. At that time, studies focused on degreening, color-add, waxes, and decay control. New fungicides, such as sodium orthophenylphenol, thiabendazole, benomyl, and imazalil, were tested, developed, and recommended to the fresh fruit citrus industry.

Research on ethylene aided in the development of degreening and storage practices. Control of temperature and humidity were studied to minimize peel injury in oranges, grapefruit, and specialty fruit. In addition, work on packaging was conducted to control fruit-keeping quality, the change from packing in wire-bound boxes to cartons and the change from field boxes to bulk handling or to pallet boxes.

Improvements were needed in degreening methods for citrus. Research was focused on redesigning degreening rooms, and large continuously operating, instrumentally controlled facilities were developed and are used to this day (Grierson et al., 1986). Research on the control of packing-house effluent gave important data for packers to meet state and

federal requirements. Sizing and grading became automated with the implementation of machine-vision systems.

Fruit fly was first controlled by fumigation. Later, cold sterilization treatments were developed in cooperation with USDA and CREC scientists. These results were responsible for opening the grapefruit export market to Japan.

The importance of fruit wax characteristics was demonstrated and fruit drying was addressed. Water loss, gas exchange, and interior quality were measured as a response to waxing. The incorporation of fungicides into commercial waxes is now commonplace in the industry. Long-term storage, with precise temperature and humidity control, became more important as citrus expanded into international markets, especially Japan.

EVOLUTION OF THE CITRUS PROCESSING INDUSTRY

The canning of citrus sections and juice products began in Florida early in the 20th century. By the 1920s, because the benefits of vitamin C in citrus juices gained public attention, the demand for citrus products soared. Early products included canned grapefruit sections followed by canned grapefruit juice and canned orange juice.

The development of frozen concentrated orange juice (FCOJ) in the 1940s was one of the most important developments in the growth of the citrus industry. The significance of FCOJ impacted all aspects of the citrus industry. In the 1948–1951 seasons, engineers designed and constructed single-stage low-temperature evaporators that could remove vapor capacities of 7.6 to 26.5 kg·h⁻¹. These evaporators were replaced in 1974 with four-stage temperature-accelerated short-time evaporation (TASTE) evaporators and subsequently by five-stage TASTE evaporators in 1991.

As the processing industry grew, new and highly efficient juice extraction equipment was developed. Other important process technologies advanced the citrus industry. Minimum quality standards were established in 1949. Also, heating methods to inactivate pectic enzymes, storage of FCOJ, improvements of sanitation methods, color grading, and flavor enhancement were developed. As innovative technologies became available, improvements were made in the quality of citrus juices. Analytical methods were developed for quantifying bitter constituents in grapefruit juice. These methods were used as a basis for state rules in Florida to improve the quality of processed citrus products. Variety and fruit color became important as the industry switched to not-from-concentrate production in the 1980s.

THE FUTURE. The citrus industry has a rich history in the United States. Past progress in developing technological advances over the past 100 years underscores the importance of increasing production efficiency and reducing costs. This results in a viable and competitive industry, which, no doubt, has been a product of effective research and extension programs. Such programs must continue to receive high priority in the future. The citrus industry has responded to diverse crises and has adapted to change. Built on a solid foundation, citrus will continue to be a dominant horticultural industry over the next 100 years.

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