Virus Diseases of Stone Fruits

L. C. Cochran, E. L. Reeves

Stone fruits have been grown in North America for some 300 years, but up to 1930 only five virus diseases were known to affect them.

Peach yellows, the first virus disease known to affect peach, may have been present around Philadelphia as early as 1750. Seven epidemics, the latest in 1920, wiped out orchards in different sections of the country. Little peach, thought to be caused by a strain of the peach yellows virus, became serious in the same geographic area as yellows in the late 1800's and now causes greater losses than yellows. Red suture, believed to be caused by another strain of the peach yellows virus, was first seen about 1910. Rosette and phony disease appeared in southeastern United States at about the same time that little peach appeared farther north. The phony disease has become the most serious virus disease of peach. More than 1,500,000 phony-affected peach trees have been removed from orchards in Georgia alone.

Since 1930, more than 40 new virus diseases have been found in North America on peach, nectarine, plum, sweet cherry, sour cherry, apricot, almond, and many ornamental and wild species of the genus *Prunus*.

It is indeed strange that so many troubles should have come upon us so suddenly. Growers and research men alike are inclined to ask why and from whence they came. They cannot be attributed to any foreign importation, because apparently only a few of those known in North America have been found in foreign countries and probably these were carried abroad from America. It appears then that most of our stone-fruit viruses are indigenous to North America and have gained access to stocks during the processes of fruit growing.

Peach yellows was recognized soon after peach culture was started in Massachusetts in 1630 or so—indicating that the causal virus was present in other hosts, from which it probably spread to peach. As peach culture spread, peach yellows went along until it reached the limit of the range of the peach yellows vector. Peach yellows may have been carried to areas outside of the vector range in nursery stock, but since yellows eventually kills peach trees and there was no vector to spread the causal virus to other trees, the disease never became established.

Little peach and red suture of peach show relationship to yellows and are generally credited to strains that have arisen from the yellows virus. Rosette, on the contrary, has a different geographic distribution than yellows and has few characters in common with yellows. Rosette appeared on peaches soon after peach culture extended into Georgia, pointing to an indigenous occurrence, possibly on wild plums. The phony disease also appears to have started in Georgia, from where it spread north and west.

Peach mosaic was already widely distributed when it was discovered in 1931. Surveys during the next few years showed it present more than 600 miles south of the border in Mexico and in various localities in the Rio Grande and Colorado River Valleys of the United States. The high incidence in several *Prunus* species in those areas indicates that it may have been present for a long time before it was discovered. Not until it escaped into the areas of intensive culture, where it produced striking effects on peach, was it seen. The distribution indicates that peach mosaic may have been centered in the vicinity of El Paso and was locally spread among the Indian villages in infected plums, which were commonly propagated by transplanting sucker shoots. It was probably introduced into the peach areas of Colorado, Utah, and southern California and Texas in infected nursery stock, which had been grown near infected plums. Sour cherry yellows appears to have been present in orchards for a number of years but was not recognized because of the presence of other disorders which caused leaf casting.

The distribution of X-disease and western X-disease is more difficult to explain. Reports of growers and the extent of occurrence indicate that both had been present in some areas for a long time before they were recognized. The variation in symptom expression in different areas indicates the presence of fairly widely varying forms. When X-disease was first seen it was limited to one locality in Connecticut, but during the next few years it spread rapidly westward in chokecherry and within 15 years was well established in the north central Midwest.

Cherry buckskin was first seen several years before X-disease was recognized on peach, and at that time its occurrence was limited to a small area in the Bay district of central California. It is now recognized that the virus causing cherry buckskin infects peach, with symptoms nearly identical with those of western X-disease. Western X-disease is rapidly becoming widely distributed in the major peach areas of central California. Western X-disease is also widely dispersed in the central valleys of Washington and Oregon east of the Cascade Range, in southern Idaho, and central Utah. The similarity of symptoms on various hosts produced by the viruses causing X-disease and western X-disease of peach, buckskin of cherry, and possibly others points to the possibility that they may have stemmed from a common source.

The origin of many of the diseases, particularly on cherries in the western United States, is something of a mystery. Stone-fruit culture in that area, particularly the nursery business, is still regarded as a relatively young industry. It seems logical that some of the viruses may have been present on native hosts and as fruit crops moved in they spread to fruit trees. The present occurrence of certain diseases with a relatively slow rate of spread would fit well into such a theory. There is good evidence to show that the cherry mottle leaf disease of sweet cherries was present in cherry trees near Wenatchee more than 20 years before it was recognized. It has been shown to be indigenous in native stands of bitter cherry near infected orchards, but spread into commercial orchards was relatively slow before 1930. Diseases with a rapid rate of natural spread, such as albino cherry in southern Oregon and little cherry of the Kootenay Lake area of British Columbia, point to either a new introduction or introduction into a host favorable to an efficient vector.

To postulate the origin of viruses is like trying to account for other kinds of life. There is no evidence to support an origin other than that they have evolved in the same way that other forms have. When they become prevalent in an area it is merely evidence that they have either been introduced into an environment favorable to them or that they were present and the environment has been changed so that it is favorable.

THE ECONOMIC IMPORTANCE of individual virus diseases affecting stone fruits is strikingly variable.

Peach yellows became so extensive in northeastern United States and the Great Lakes States in epidemic eras that it caused peach culture to disappear from certain localities for a time. Phony peach continues to be a serious threat to peach culture, particularly in Georgia and Alabama. Peach mosaic has caused the loss of more than 200,000 peach trees in southwestern United States and remains uncontrolled in many areas. Western X-disease has caused extensive losses in peach orchards in Northwestern States and is responsible for disappearance of peach culture in some localities. Surveys in several States indicate that upwards of one-third of all the sour cherries in the United States are affected with sour cherry yellows. Fruit production on thoroughly diseased sour cherry trees is reduced to 50 percent or less, thus indicating a total crop reduction of at least 15 percent. Interpreted in terms of a crop worth 45 million dollars, sour cherry yellows causes an estimated loss of more than 5 million dollars annually.

Some other virus diseases offer potential threats to stone fruits because of their ability to destroy trees or crops, but are limited in distribution and have caused only locally serious losses. Albino cherry is chiefly responsible for disappearance of cherries from the Rogue River Valley in western Oregon, where it is has spread rapidly through orchards. The disease is limited to that area, which is isolated from the more important cherry-producing areas by mountains. Sour cherry pink fruit, cherry rasp leaf, peach wart, peach yellow bud mosaic, and apricot ring pox are diseases that ruin the commercial value of their hosts and have caused serious local losses, but are still limited in occurrence to local areas.

Cherry twisted leaf, cherry mottle leaf, and cherry necrotic rusty mottle, also of only local occurrence, ruin the value of some horticultural varieties of cherries but cause only partial crop losses to others. In contrast to them is little cherry, a disease affecting sweet cherries in the Kootenay Lake area of British Columbia. Its occurrence was limited to a single orchard when first observed in 1933, but during the next 15 years it spread over an area 100 miles in diameter—despite mountainous barriers, large lakes, and the great distances between orchards. Little cherry reduces the fruit size to one-half normal size and ruins the flavor, yet causes no tree or leaf symptoms. The rapid rate of spread through the infected area and the serious effects it has on fruit make it a serious threat to sweet cherries in other districts.

A sizable number of virus diseases affecting stone fruits cause only small losses. Some have produced striking effects on a few trees but are limited in occurrence. Others are of wide distribution, but cause only minor effects. Ring spot is nearly universal in some *Prunus* species, particularly cherries, in western United States; after the initial stages of infection, however, damage appears to be limited to a possible reduction in tree vigor. While these viruses are relatively unimportant economically, their presence complicates research.

THE EXPRESSION of virus diseases in plants is usually indicated by development of some consistent off-type or abnormal change in appearance as compared to normal or healthy plants; such abnormal characters are referred to as symptoms. Demonstration that a given symptom is caused by a virus is generally accepted if that symptom is reproducible on a comparable previously healthy plant following some mode of transmission in the absence of any visible pathogen. Since plant viruses are obligate parasites which cannot be cultured outside of their hosts and are generally too small for their presence to be determined with ordinary equipment, it is necessary to depend on the symptoms they produce to indicate their presence and determine their identity.

Symptoms of virus diseases of stone fruits range from effects too mild to be recognized to various kinds of fruit and foliage abnormalities and even death of the affected trees. The most common types of symptoms are those expressed on leaves. In place of the uniform green color of normal leaves, affected ones develop patterns composed of spots, rings, blotches, or streaks of light green, yellow, or shades of red, brown, or black. Some diseases cause leaves to become uniformly chlorotic or colored. Reduction in size, deformation, death, and shedding of leaves are also common symptoms. Unfruitfulness, failure of fruit to mature or mature at the normal time, and deformation of fruits are common effects of virus diseases. It should be recognized that similar abnormalities are caused by other factors, such as insect injury, chemical spray injury, nutritional disorders, fungus and bacterial diseases, and genetic factors; thus all abnormalities in plants are not indicative of the presence of a virus.

On the basis of symptoms, virus diseases of stone fruits might be divided into groups as follows:

Mosaics: Those that cause chlorotic, mottled, or necrotic patterns in leaves. Diseases in this class are: Peach—peach mosaic, yellow bud mosaic, mottle, ring spot, asteroid spot, necrotic leaf spot, golden-net, calico, and blotch; sweet cherry—mottle leaf, rusty mottle, twisted leaf, rugose mosaic, Lambert mottle, necrotic rusty mottle, tatter leaf, and pinto leaf; sour cherry—necrotic ring spot; plum—line pattern, white spot, and Standard prune constricting mosaic; apricot—ring pox; almond—almond calico.

Yellows: Those that cause a general chlorosis of a part or all of the leaves, sometimes accompanied by defoliation and failure of fruits to mature: Peach—peach yellows, little peach, red suture, peach rosette, and X-disease; sweet cherry—buckskin, albino, little cherry, and small bitter cherry; sour cherry—sour cherry yellows, green ring mottle, pink fruit.

Stunts: Those that cause shortened internodes, resulting in stunted growth, usually accompanied by darker green color: Peach—phony, Muir dwarf, and rosette mosaic; plum—prune dwarf.

Bud failures: Those that are characterized by death and shedding of buds on the past season's growth during the dormant season, without chlorotic or necrotic patterns in leaves: Peach—willow twig; almond—Drake almond bud failure.

Excrescences: Those that cause outgrowths on plant organs: Peach—wart; sweet cherry—rasp leaf.

Cankers: Those that cause necrotic pockets in the bark, resulting as the bark gets old in large cankers: Sweet cherry—black canker; and plum—diamond canker.

Many of the virus diseases affecting stone fruits are known to spread in orchards but vary markedly in rate of spread. Insect vectors for four diseases—peach yellows, little peach, phony, and western X-disease—have been determined. It is presumed that spread of the others, which takes place independent of man, is also by insects.

All of the vectors found so far are leafhoppers; all have shown ability, once they have fed on diseased plants and acquired the virus, to retain the virus for a long time. Such vectors are easier to find than those that transfer viruses by mechanical contamination of their mouth parts and lose the virus after one or two feedings.

The ecology of insect vectors is important in the spread of viruses. Those that move about freely, especially if they travel long distances, tend to move viruses in a like manner; those that have few winged individuals tend to spread viruses in a contiguous pattern. The vectors of the phony disease of peach are long-lived, large, and rugged and can move far. Phony spreads in a random pattern; new cases occur often in the far side of an orchard away from the source of infection. In contrast, the yellow bud mosaic disease of peach appears to spread in close colonies. The vector for yellow bud mosaic is not yet known, but it should be an insect with only weak flying habits.

Viruses that affect woody plants have been transmitted experimentally by grafting tissue from the diseased plant onto the healthy plant. For some diseases transmission can be effected with any of the tissues of the diseased plant, but for others it is necessary to select tissues from twigs bearing leaves or fruits that are showing symptoms. The common procedure is to use bud shields or bark shields from the diseased plant and insert them under the bark in a T-cut in the usual manner of budding. Other tissues, such as pieces of fruit, sections of leaves, flower petals, and wood chips, have been successfully used as inoculum for some viruses. Many attempts have been made to transmit stone-fruit viruses with juice expressed from tissues of diseased trees, but none has been successful from diseased to healthy trees.

The ring spot and sour cherry yellows viruses have been shown to pass through seeds of certain species to seedlings. Ring spot was found to pass through 1 to 3 percent of peach seeds and in a higher percentage in mazzard and mahaleb cherry seeds. Sour cherry yellows has been shown to pass through mahaleb cherry seeds. Studies conducted on a number of other viruses, particularly peach mosaic, phony, peach yellows, and western X-disease, have shown that they are not seed-transmitted. Part of the world-wide geographic occurrence of both the ring spot and sour cherry yellows viruses can be attributed to distribution in seeds. If this reasoning can be used, it is further evidence that most of the other virus diseases, which have limited geographic distribution, are not transmitted through seeds of peach or cherry species commonly used for rootstocks.

THE INCUBATION PERIOD of a virus disease is generally considered to be the elapsed time between infection and symptom development. The incubation period of some stone-fruit virus diseases is long, but for most others trees infected in the fall develop symptoms during the following growing season. The length of the incubation period is strongly influenced by the season in which infection occurs. For some diseases, inoculations made early in the spring when trees are breaking dormancy may result in symptom development within 2 or 3 weeks. But, if made after growth has started, symptom development may be greatly delayed and is usually limited to tissues near the inoculation point and the terminals of strong shoots arising near the inoculation points. Symptom development can often be forced by cutting back shoots to near inoculation points and thereby producing sucker shoots. Such new rapid-growing shoots pull the virus into them and develop symptoms.

Some stone-fruit viruses require more than 1 year for development of symptoms. Expression of the phony disease of peach depends on sufficient build-up of the virus in roots and requires 18 months to 3 years. Under field conditions, sour cherry yellows, pink fruit of sour cherry, small bitter cherry, red suture of peach, and others often require more than a year for symptom development. Sweet cherry black canker, peach willow twig, and prune diamond canker do not develop characteristic symptoms on 1-year-old growth; therefore 2 years or more are needed after inoculation for infected growth to develop identifiable symptoms.

Viruses differ in their rate of translocation in infected trees. For most diseases small nursery trees inoculated in the fall are uniformly diseased when growth develops the following year, indicating that the virus has become thoroughly systemic.

On the larger trees, the viruses of stone fruit may require one or more growing seasons to become distributed thoroughly. Other viruses are slow movers in tissue but in time become thoroughly systemic. If rasp leaf virus is introduced into the main stem of a nursery tree in the fall it will usually be expressed only on leaves within a few inches of the inoculation point during the next growing season. Prune dwarf is likewise a slow mover. A few viruses appear rarely to become thoroughly distributed in their hosts.

Normal shoots are common on peach trees infected by yellow bud mosaic or X-disease. Buds taken from them fail to infect healthy trees. If either disease becomes thoroughly distributed in affected peach trees, the trees die. Western X-disease virus appears also to require a long time to become well distributed in affected sweet cherry trees, but rapidly becomes thoroughly systemic when inoculated into chokecherries. Small bitter cherry appears never to affect whole trees and it is common for affected and normal cherries to occur on adjoining spurs or even on the same spur.

The host range of stone-fruit viruses is as variable as the viruses themselves. Some appear to affect a wide variety of hosts and others a relatively few. Some affect all their hosts with the same type and severity of symptoms and others may be ruinous on one horticultural variety and infect another without the production of symptoms. Some infect a wide number of species within the *Prunus* genus and even species outside the genus, yet within a species may infect one horticultural variety but another may be immune. In general, any species of *Prunus*, until it has been proved immune, must be regarded as a possible suspect to a virus that infects a related species.

A few stone-fruit viruses affect species outside the genus *Prunus*. Ring spot has been recovered from naturally infected rose and has been inoculated into apple seedlings. Cucumber and squash have become infected following rubbing with juice containing the ring spot virus. *Kerria japonica*, Japanese Kerria, and rose were experimentally infected with yellow bud mosaic. Carrot, tomato, parsley, and periwinkle were infected with X-disease, and tomato, periwinkle, and tobacco were infected with peach rosette by use of dodder, *Cuscuta* species, a parasitic plant that formed a bridge between infected and healthy plants. These results are important because they indicate that some stone-fruit viruses can infect distantly related plants and it is therefore necessary to consider herbaceous plants as possible hosts until they have been proved otherwise.

To determine whether a plant is a host of a given virus, one has to demonstrate the presence of the virus in it naturally by indexing it or to inoculate it and then index it.

Indexing is accomplished by grafting tissue from the suspected plant onto one known to develop characteristic symptoms for the virus in question. If the suspected plant is inoculated and no symptoms develop on it, yet the presence of the virus in it is indicated by index tests, the plant is regarded as a symptomless carrier. If symptoms develop on the plant after inoculation, one must ascertain that the inoculum had only one virus in it before the symptoms can be ascribed to the virus for which the host is being tested.

Host-range studies are hampered by the lack of methods for transfer of viruses between hosts which will not intergraft. Some results have been obtained by use of the juice-rubbing technique and by use of dodder to form a bridge between plants through which the viruses can flow.

As we mentioned, for some reason the juice-rubbing method has not been successful for transmitting viruses to woody plants. Also, dodder is known not to transmit some viruses and will not grow on some plants. Insects may be useful to transmit viruses to certain plants which we now have no means of testing.

The presence of forms and strains of viruses in plants is evidence that viruses are continually changing. Changes probably take place in the formation of single new virus particles, which will survive and multiply if they have some quality that allows them to compete with the parent virus. One quality seemingly necessary is that of invading host cells, along with or in exclusion of the parent virus. Insects then can pick up the new form and transmit it to a host apart from the parent virus. Sometimes new forms get into growing points of plants and are evident because subsequent growth bears different symptoms from the remainder of the infected plant.

MOST OF THE viruses affecting stone fruits appear to exist in nature in few to many forms or strains. No variants are known for the viruses causing phony peach or peach rosette. Peach rosette kills trees so rapidly that it is entirely possible that variants have not had sufficient time to become segregated. If rosette should infect hosts which it does not kill, variants might become expressed. Peach yellows also kills peach trees, but less rapidly than peach rosette. Little peach and red suture are believed to be caused by strains of the peach yellows virus and may have arisen because of the quality that neither of them kill peach trees as rapidly as yellows. Yellows does not kill plum trees and the little peach and red suture strains may have arisen in plums and spread to peach. Both little peach and red suture appear to be stable strains and can be obtained and identified from orchards at will. Peach mosaic and ring spot, on the other hand, exist in innumerable variants, forming a gradient from one extreme of symptoms so mild that diagnosis is difficult to effects that severely damage the trees. Variations of other features, besides severity, also occur, such as type and amount of mottle, amount of dwarfing, rate of movement of virus through trees, and others. The variations are so numerous that new cultures obtained from naturally infected orchard trees, while they can be fitted into the gradient, cannot be definitely identified with previous cultures.

A number of other stone-fruit virus diseases, such as western X-disease, sweet cherry necrotic rusty mottle, and mottle leaf, are known to have variable symptoms, caused by the existence of many virus forms. As evidence accumulates it seems likely that some of the diseases that have been described separately are actually merely expressions of different forms of one virus. Certainly X-disease, western X-disease, and buckskin produce similar symptoms on peach although they produce somewhat different symptoms on sweet cherries in different areas. Lambert mottle and necrotic rusty mottle produce similar symptoms on Lambert cherry but differ on other varieties. Ring spot, as originally described on peach, appears to be very similar to necrotic ring spot described on sour cherry.

THE CONTROL of virus diseases of stone fruits is complex because of the many variable features of the diseases. Measures applicable and sufficient for one disease may not suffice for another or even for the same disease in another area. Before satisfactory control measures can be recommended, the nature of the disease, its distribution, host range, rate and manner of spread, effect on yield, and other facts should be known. In general, control procedure can be divided into two categories: Prevention by exclusion and (if already present) reduction by removal of diseased trees or application of other procedures that reduce their detrimental effects.

All evidence indicates that viruses, like other forms of life, do not arise out of nowhere but are direct descendants of preexisting forms; therefore procedures that exclude them are the most efficient means of control and should be used wherever practical.

Federal quarantines have been promulgated to prevent entrance of viruses and other pests from foreign sources. State quarantines have been established to prevent movement from infected areas in one State to another part of the same State or into other States. In general, quarantines are efficient only where areas are protected by natural barriers, such as bodies of water, deserts, and mountain ranges. Quarantines have also been used on new diseases or for outbreaks of disease in new areas while studies were being made to determine practical means of control or for slowing down spread while control or eradication was being attempted.

RECOMMENDATIONS for control of established virus diseases of fruit trees have generally been to remove infected trees from orchards. For certain diseases and in certain districts that procedure may still be generally recommended. The question as to whether removal of diseased trees, or roguing, is practical depends on the rate of spread, whether spread is originating in the orchard or from outside sources, how much damage the disease causes, and whether there are resistant host varieties or procedures to protect against infection.

Roguing coupled with isolation, use of disease-free nursery trees, and wild-host-removal programs have been the only practical means of control for some diseases, especially those that spread rapidly and severely damage all varieties of a given host. Those procedures have controlled peach yellows and reduced it from a dire threat to the peach-growing industry to the rank of a minor disease. Isolation in intensively cultivated fruit areas may be hard to achieve and may not be necessary for diseases that spread slowly.

For diseases which are generally distributed, have a rapid rate of spread, and have symptomless hosts or other features that make it impractical to remove diseased trees, other procedures of control have to be developed.

THE USE of resistant or tolerant varieties (varieties which, although infected, are not materially damaged), tolerant or resistant top and rootstock combinations, mild symptom-producing virus forms to protect against infection by more damaging ones, chemotherapy, and control of vectors are approaches which offer promise as control measures. Heat has been used to kill certain viruses in infected budwood and nursery trees, and certain chemicals have reduced infection by others in experimentally inoculated trees. No treatment with chemicals, spray materials, fertilizers, or other materials has resulted in the cure of virus-diseased fruit trees in the orchard.

There is ample evidence that stone-fruit virus diseases have been spread in infected nursery stock. Control procedures in general are ineffective unless such spread is stopped. Nursery-improvement programs are under way in several States, but because they are concerned with different diseases and different conditions, procedures and specifications which have been developed are variable. There are some general considerations that are regional in scope and there is need for consideration on a regional basis. Nurserymen need the assistance of research, regulatory, and extension men and growers. Growers need the advantages of starting orchards with better stock and can assist much in the problems by working closely in cooperation with those trying to help them.

L. C. COCHRAN *is in charge of investigations of virus diseases of deciduous fruits for the Bureau of Plant Industry, Soils, and Agricultural Engineering. He is a native of Indiana and holds degrees from Purdue University and Michigan State College. Before joining the Department of Agriculture in 1941, he was engaged in investigations of citrus and peach virus diseases at the Citrus Experiment Station of the University of California at Riverside.*

E. L. REEVES *is stationed at the United States Horticultural Laboratory at Wenatchee, Wash., and is a pioneer in investigations of stone-fruit virus diseases occurring in northwestern United States. He was born in Idaho and holds degrees from the University of California and Washington State College.*