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SOIL-BORNE PATHOGENS OF AVOCADO

G. A. Zentmyer[1]

There are several soil-borne plant pathogens that attack the avocado, but the organism of primary importance is the fungus *Phytophthora cinnamomi* Rands, which causes Phytophthora root rot. Other, usually minor problems are caused by *Armillaria mellea, Verticillium albo-atrum, Rhizoctonia solani, Phytophthora citricola* and *Phytophthora palmivora.* Several other soil-borne fungi have been reported on avocado, either as very rare or minor pathogens or as wood-rotting fungi. These will be summarized later in this paper.

Phytophthora Root Rot

The first report of this disease on the avocado was by Tucker in Puerto Rico in 1927, though there are indications that it may have been present in California and possibly other avocado-growing areas before that time. There are reports of "decline" of avocado trees in California in the 1930's and the causal fungus *P. cinnamomi* was isolated from diseased trees in California in 1942 by Wager.

Phytophthora cinnamomi was first described on cinnamon trees in Sumatra by Rands in 1922. It has been found in over 50 countries all over the world since that time, primarily in warm temperate, subtropical and tropical regions, and has caused diseases of various types on over 900 different plants (29). Victims of this devastating fungus include not only avocado but such diverse plants as pineapple, pine, cinchona, chestnut, sycamore, macadamia nut, camellia, heather, rhododendron, peach, pear, eucalyptus, acacia, many native Australian woody plants and many ornamental plants. There is some indication that it is a native fungus of northeastern Australia (13). Shepherd (15) has proposed that *P. cinnamomi* had its origins in the New Guinea-Celebes region and entered northern Australia during Pleistocene-Holocene times. All of our evidence indicates that *P. cinnamomi* is not an indigenous fungus in California—it was probably introduced from tropical America or Hawaii.

Phytophthora cinnamomi has been reported as causing this avocado disease in nearly every country where avocados are grown—in the United States (California, Florida, Hawaii and Texas), throughout Mexico, Central and South America and the Caribbean, in the Pacific (Australia, New Zealand and Fiji) and in Africa (South Africa and West Africa) (24, 29). The one avocado-producing country where Phytophthora root rot has not been found to date is Israel.

Damage from this disease has been severe in California and in many of the other avocado-producing areas. Hundreds of thousands of trees have been killed or rendered unproductive in California with estimates of 3,000-4,000 ha being involved over the years.

[1]Professor of Plant Pathology, Department of Plant Pathology, University of California, Riverside, CA.

Symptoms

The disease causes a gradual decline of the tree. Leaves of infected trees are smaller than normal and usually are pale or yellow-green instead of dark green. Leaves are often wilted, especially under conditions of moisture stress, and tend to fall, giving the diseased trees a sparse appearance. New growth is usually absent, or there may be occasional weak flushes of leaves that do not develop into full-sized, vigorous leaves. Branches die back as the disease advances and fruit set is usually light, although sometimes diseased trees will set an abnormally heavy crop of small fruit, as the loss of many roots has an effect similar to partial girdling (33).

The direct cause of the decline of the above-ground portion of the tree is the rotting of most of the small feeder roots. This rot is quite characteristic and is a good indication of the presence of *P. cinnamomi.* The small feeder roots are blackened, brittle and dead, and in advanced stages of the disease, it is difficult to find any feeder roots.

Soil moisture is closely related to the development of the disease; Phytophthora root rot is a disease primarily of soils with restricted internal drainage. Thus, essentially 2 factors are involved in disease development: the fungus *P. cinnamomi* and excess soil moisture that permits rapid fungus development and root infection.

Isolation of the Fungus

Several methods are available for the isolation of *P. cinnamomi* from infested soil and diseased roots. Corn-meal agar has been used for isolations from small roots, but with the use of selective antibiotic media (18), isolation is enhanced from tissue and from soil by incorporation of antibiotics such as pimaricin and vancomycin in the cornmeal agar.

Phytophthora cinnamomi can be isolated directly from infested soil on antibiotic agar plates by soil sieving, soil dilution plates or the soil crumb method. Populations of *P. cinnamomi* in soil are generally very low as assayed by these methods compared to some of the other species of *Phytophthora* and *Pythium.* A new chemical, hymexazol, discovered by Japanese plant pathologists may facilitate isolation of *Phytophthora,* especially from soil. Hymexazol is toxic to *Pythium,* a common soil fungus that often inhibits isolation of *Phytophthora,* and also inhibits other soil saprothytes such as *Mortierella,* as Dr. P. H. Tsao at Riverside has recently shown.

Phytophthora cinnamomi can also be isolated from soil by use of various types of baits—seedling plants or plant parts, including avocado fruit, blue lupine seedlings, seedlings of *Persea indica,* cotyledons of eucalyptus, pineapple leaves, jacaranda seedlings and pine needles. Green avocado fruit with moderately thick skin, such as 'Fuerte', are effective in detecting the presence of *P. cinnamomi* in soil. Seedlings of *P. indica,* an avocado relative very susceptible to *P. cinnamomi,* are even more effective than fruit when placed bare-root in the soil suspension. As few as 10 zoospores can cause an infection on *P. indica* and we have detected the root rot fungus in a sample as small as 0.1 g; of soil by trapping with *P. indica.*

Phytophthora cinnamomi

This fungus forms several different spore stages that are involved in disease development or survival: sporangia that form motile zoospores, chlamydospores and oospores. Zoospores can be produced in tremendous numbers and function as the primary unit causing new infections on roots. They can swim for short distances in the soil and be carried by surface water, such as rain runoff, or in irrigation water. Zoospores are attracted to avocado roots by the process of chemotaxis; they then germinate, penetrate the root, and initiate the root rot.

Chlamydospores are larger than zoospores, nonmotile and are formed in dead roots and released into the soil where they provide additional infective units. Oospores are thick-walled spores that normally are formed as the result of the fusion of the 2 mating types of fungus. One mating type can form oospores alone, as my research has show, by the stimulation of a chemical present in avocado roots. Stimulation of this spore stage can also result from a volatile chemical produced by the soil fungus *Trichoderma* (1).

Special conditions are required for the production of some of these spore stages. Sporangia are not formed on solid media in sterile culture. Production of sporangia can be stimulated in the liquid center by bacteria present in a non-sterile soil extract. We have also found that sporangia are produced in axenic culture if nutrients are removal from young mycelia by washing in a special salt solution (3). Chlamydospores and oospores can be produced in various natural and synthetic media, each depending upon a particular balance of nutrients. Production of all spore stages is stimulated by sterols. *Phytophthora cinnamomi* has a wide tolerance for various levels of oxygen and carbon dioxide (11, 12) in relation to mycelial growth and sporulation.

There are 2 mating types of *P. cinnamomi* designated as A^1 and A^2 (28). A^2 is the most common type. In taxonomy of *P. cinnamomi,* disc electrophoresis to define protein patterns appears to be of significance, in combination with morphology (7).

From our large collection of isolates of *P. cinnamomi,* we are developing evidence of variability in the fungus and the possible occurrence of strains or races. Isolates vary in their response to temperature, for example, both in relation to rate of growth at a uniform temperature and to minimum, optimum and maximum temperatures for growth (3d). We are also finding variability in pathogenicity in relation to isolates from camellia, avocado, macadamia, eucalyptus *etc.* Physiological differences have also been shown between various isolates (8).

Saprophytism

Most species of *Phytophthora* are not good saprophytes, but there is evidence that *P. cinnamomi* has considerable saprophytic ability. The fungus can invade organic matter in soil in competition with other microorganisms, particularly at high soil-moisture contents. Our tests showed also that *P. cinnamomi* can grow to a limited extent through non-sterile soil and can survive in moist soil in the absence of a host for periods up to 6 years (32).

Factors Affecting Disease Development

Temperature. Pathogenesis of *P. cinnamomi* occurs over a broad optimum range of soil temperatures of 21-30°C, with little or no infection at 33°C and little infection at 9-12°C. This corresponds well with the growth curve of the pathogen. The response of avocado seedlings to soil temperature is quite similar with the exception that they grow very well at 33°C while the fungus makes little or no growth at that soil temperature.

pH. Reducing the soil pH controls some diseases caused by *P. cinnamomi,* such as rhododendron wilt. Our tests with avocado have shown that the optimum pH for disease development is 6.5. It was necessary to reduce the pH to 3-3.5 to obtain control in nutrient solution culture; this is an impractical pi I level to attempt in soil.

Moisture. A close relation has been recognized for years between disease occurrence and soils that drain slowly. This impeded drainage can result either from the presence of shallow, impermeable stratum, or because of the high water-holding capacity of the surface soil in the case of clay soils (26, 33). Statewide surveys in California have shown a close correlation between root rot damage and soil series and soils have been classified on the basis of severe, moderate and slight hazard.

Thus, it is possible to reduce or completely avoid damage from *P. cinnamomi* by selecting soils with excellent internal drainage for avocado plantings. We have observed such soils in California in which avocado trees have been growing well in the presence of *P. cinnamomi* for over 20 years.

Control of Phytophthora

Several aspects of control are possible with a disease such as *Phytophthora* root rot of avocado. The best possibility appears to be the discovery or development of a resistant rootstock, thus much research has been done in California on this aspect. Other phases that have been explored considerably in our laboratory and elsewhere include: soil fungicides, soil fumigants, disease prevention by use of clean stock and clean seed and biological control.

Resistance

We have had a program in this area at Riverside for over 25 years, with a combination of collections in the native home of the avocado and other species of *Persea* in Latin America, as well as collections in California in areas where trees may have resisted root rot over a period of many years. I have collected many thousands of seeds and budwood samples with excellent cooperation from many people in Latin America in the course of many trips to the area and other materials have been sent in by various collaborators. We have had some fine assistance from Dr. Eugene Schieber on this rootstock collection project during the past 5 years.

Seedlings are tested for resistance in Riverside in a nutrient solution tank test and also in infested soil. High resistance was reported in several small-fruited species of *Persea* early in the development of this program, based on tests in the greenhouse and lathhouse and a few preliminary field trials (30). Since the early reports, we have additional collections of these small-fruited species that have shown high resistance, including *Persea caerulea, P. donnell-smithii, P. pachyposa* and *P. cinerascens.* Unfortunately, all of the high resistance occurs in species that are not graft-compatible with avocado (6) and thus cannot be used directly as rootstocks. Neither has it been possible to hybridize species in this small-fruited group with *P. americana,* as Dr. Bergh has shown at Riverside.

The first indications of resistance in graft-compatible types were reported by Zentmyer and Thorn in 1956 (31). This report was based on tests that showed a moderate level of resistance in 'Duke', which is a Mexican-race avocado that originated in Oroville, California, from seed possibly brought into California from the Sabinas Hidalgo area in northern Mexico. I selected 2 'Duke' seedlings that showed the most resistance and vigor in early tests in infested soil; these have been propagated by cuttings as 'Duke 6' and 'Duke 7'.

The research program in California has been expanded considerably during the past 5 years as the result of funds provided by the California Avocado Advisory Board from marketing order funds. Our research on resistance, both with collecting and testing aspects, has consequently been increased greatly. Thousands of cuttings and seedlings have been propagated from materials showing some resistance; much of this propagation was done by E. F. Frolich on the Los Angeles campus of the University of California.

During the period 1972-1975, we planted over 4,200 trees in field plots in old avocado root rot areas throughout southern California. The 'Duke 6' and 'Duke 7' cuttings are showing good resistance in most of these plots with 80-90% healthy trees compared to 10-20% healthy trees in standard rootstocks such as 'Topa Topa'.

There are some indications of less resistance when 'Duke 6' or 'Duke 7' are grafted to commercial scions such as 'Hass' and 'Fuerte'; with some other tree crops the scion has been shown to influence the resistance of the stock to diseases. This aspect is being studied further. It is apparent that the 'Duke' selections do not have as high resistance as the small-fruited species of *Persea,* but they appear to have at least moderate field resistance and would be expected to grow well in sites that are not the most severe for disease development. With very severe disease conditions, the 'Duke' cuttings will develop considerable root rot.

In addition to the 'Duke' cuttings, several newer collections and selections show appreciable resistance. These include a collection of a Mexican type from Guatemala that we are calling 'G6', a California collection, 'Huntalas', a rootstock that we recovered from a tree that had apparent resistance over many years in a root rot area and several recent Central American collections sent in by Dr. Schieber that show indications of resistance in the initial tests.

Resistant rootstocks still seem to be the best means to control Phytophthora root rot and our recent results on resistance are very encouraging.

In another interesting and potentially valuable result from the resistance program, we have found that the highly resistant, non-compatible species of *Persea,* such as *P. borbonia,* contain a unique chemical that is toxic to *Phytophthora* (21). We have isolated and characterized the chemical and are naming it borbonol. It is a long-chain hydrocarbon with a lactone ring and we feel that resistance of these species to *Phytophthora* is based on this chemical. If borbonol can be synthesized, it may be useful as a chemical control for root rot. Another possibility is to use the presence of borbonol as a test for resistance.

Soil Fungicides

One possible method of controlling or preventing the development of root rot in established trees is to apply a fungicide in the irrigation water, or in such a manner that it can be carried into the soil by rain or irrigation. We have had an extensive screening program to develop soil fungicides and have found several chemicals that are effective against *P. cinnamomi* and are not toxic to the avocado tree. One was the chemical Dexon® that gave excellent control of the disease on avocado seedlings in greenhouse tests and good results in some of our field plots (27). It was approved for use on avocado trees for several years, but has been withdrawn from use due to the change in residue requirements.

The soil fungicide ethazol, with the trade names Terrazole® and Truban®, has also been effective against *P. cinnamomi* in greenhouse and some field tests when applied around trees in early stages of disease and watered in. Repeated applications appear to be necessary, as ethazol, like Dexon®, is fungistatic rather than fungicidal. The practicality of such fungicide treatment is not yet established. The ethazol type of fungicide has not yet been registered for use on avocado, though there are indications that it should be approved soon. Several other promising possibilities are appearing in the soil fungicide line. (Ciba Geigy has new materials that give good control of *Phytophthora* in greenhouse tests and several other chemicals are available.

The possibility of applying soil fungicides via the drip irrigation system is being explored. There are also more recent developments in the field of systemic fungicides. It an effective systemic material could be developed that was translocated downward this could provide another means of controlling a root rot disease. So far there has been no success in this area with tree crops.

Several soil fumigants can be used for preplant soil treatments to drastically reduce the population of *P. cinnamomi* including methyl bromide, Vapam®, D-D and Telone®. These are possible for spot fumigation lo use prior to replanting rootstocks with higher levels of resistance.

Biological Control

Other possible approaches to control include the use of various amendments, antagonists, mycorrhizae and suppressive soils. Definite recommendations are not yet available for use in this field but there are some promising leads.

In some early work in this area (25), alfalfa meal additions to infested soil gave good control of root rot of avocado seedlings in greenhouse tests. The effect was postulated to be the result of increases in microbial populations and also to the presence of saponins in alfalfa meal that are toxic to *P. cinnamomi.* Field trials gave variable results, possibly related to the difficulty of incorporating the material into the soil around established trees.

Marx has shown that several ectotrophic mycorrhizae are effective in preventing infection of pine roots by *P. cinnamomi* (9). Unfortunately, avocados do not have ectomycorrhizae. There are endomycorrhizae in avocado roots but there is no evidence of any protection from infection.

Dr. P. H. Tsao at Riverside is studying the effects of various organic amendments on sporulation of *P. cinnamomi* in the laboratory and on infection of avocado seedlings in soil in greenhouse tests. Amendments such as chicken manure, alfalfa meal and feather meal show indications of reducing sporulation and infection (19) and are being investigated further.

Another related approach to biological control is that of suppressive soils. The first indication of suppressive soil in relation to *P. cinnamomi* was reported in 1974 from Australia by Broadbent and Baker (2). They found suppression of root rot of avocado in a grove in Queensland under conditions of a very high organic matter, high nitrogen (N) and high calcium (Ca). There are higher bacterial and actinomycete counts in suppressive soils than in conducive soils. *Phytophthora cinnamomi* produced few sporangia in extracts from suppressive soils and mycelia developed poorly. Apparently, from recent reports from Australia, some control of root rot is being obtained in areas of moderately high rainfall (1,500-1,800 mm) by additions of large amounts of chicken manure, turning under cover crops, adding inorganic N maintained in the ammoniacal form and maintaining high levels of Ca. There is a delicate balance, apparently, in soils between bacteria that stimulate production of sporangia by *P. cinnamomi* and other microorganisms that antagonize *P. cinnamomi* or affect the stimulatory bacteria.

We have looked for suppressive soils in the avocado areas in California but to date have not found any evidence of this phenomenon, aside from some lytic effect from one soil.

Other Aspects of Control

We are also investigating the possibilities of combining several control measures, *e.g.,* using the moderate resistance that we have in combination with low dosages of soil fungicides or with organic amendments. The growth of our resistant rootstocks in preliminary greenhouse tests has been considerably improved in infested soil by treating the soils with low dosages of ethazol.

In summary of control approaches, measures for preventing the development of Phytophthora root rot include: plant on well-drained soil, use disease-free nursery stock and prevent soil or water movement from infested areas.

For attempted control of disease, the following measures are available: use rootstocks with some resistance, such as 'Duke' cuttings; irrigate diseased trees and margins of diseased areas carefully as high soil moisture favors root rot development; establish a chemical or dry barrier if the diseased area is small and is below the healthy areas; treat trees in early stages of disease or healthy trees on the margin of diseased areas with soil fungicides such as ethazol when these become available for use on avocado; replant the area with resistant crops. Soil amendments to increase microbial activity in the soil are another possibility for treating trees in early disease condition or healthy trees, but details of such treatment need further research.

Other Species of *Phytophthora*

Several years ago we isolated *P. citricola* from avocado roots and trunks in California. This species is not nearly as pathogenic on roots as is *P. cinnamomi,* but can cause serious cankers on the low trunk (35). We have isolated the fungus from only a few trees in San Diego County. This species of *Phytophthora* was originally described from citrus in Asia by Sawada and has several other hosts including hops, lilac, walnut and several ornamental plants.

Phytophthora citricola is homothallic and thus is readily distinguished from *P.*

cinnamomi by the presence of oospores in single cultures on media such as V8 agar. The growth pattern is also very different from *P. cinnamomi.*

I recently isolated a different species of *Phytophthora* from cankers on trunks of young trees in a Ministry of Agriculture variety planting in Guatemala. This was shown to me by the late Dr. Wilson Popenoe (34). This species is distinct from either *P. cinnamomi* or P. *citricola* and we are in the process of identifying it.

Phytophthora cinnamomi can also cause trunk cankers on avocado trees. These cankers originate at or below ground level and may extend 180-240 cm up the trunk in some cases. Cankers have reddish-brown margins and are characterized by the exudation of considerable white avocado sugar. There have also been reports of *P. cactorum* isolated from avocado cankers. Some of these may have been confused with *P. citricola* which is quite similar to *P. cactorum.*

Two other species of *Phytophthora* have been described on avocado— *P. parasitica* and *P. palmivora.* Stevens and Piper (17) listed collar rot of avocado in Florida caused by a species of *Phytophthora* similar to *P. parasitica.* Conover in 1948 (4) described a seedling blight of avocado in a nursery near Princeton, Florida, causing leaf infections and cankers and dieback of young stems—the causal organism was identified as *P. palmivora.* I have isolated *P. palmivora* from avocado trees in Honduras, causing branch cankers in an experimental planting on Mt. Uyuca (23) and also causing a seedling blight in an avocado nursery at the Escuela Agricola Panamericana.

Armillaria Root Rot

Another disease of avocado is Armillaria root rot, caused by *Armillaria mellea,* also known as the oak root fungus (37). Avocado was thought for many years to be immune to this disease, but several cases of *Armillaria* were reported on avocado in the 1930's. Publications by Smoyer in 1949 (16) and by Darley and Zentmyer in 1957 (5) reported that some damage occurs occasionally on avocado in California. The disease has been found on a number of trees, generally not over 5-6 years old, in several counties in southern California and seedlings have been successfully inoculated with *Armillaria.* I have also observed this disease in Ecuador (23).

In contrast to *P. cinnamomi, A. mellea* invades and kills large roots and the main rootstock. Characteristic white, fan-shaped plaques of mycelia are formed just under the bark, and slender dark rhizomorphs are found on the surface of diseased roots. In addition, the mushroom stage of *Armillaria* may be produced at the base of diseased trees during rainy weather.

Armillaria does not live in the soil in the absence of large pieces of roots or other woody plant material in the soil. It may remain alive in old root pieces for many years. *Armillaria* is very sensitive to drying and in the case of infection in the upper part of the rootstock, a tree's life may be prolonged by exposing the base of the tree to air. Soil fumigation with methyl bromide will essentially eliminate the fungus and permit replanting the fumigated areas.

Verticillium Wilt

Another soil-inhabiting fungus, *Verticillium albo-atrum,* causes a disease very different from either Phytophthora root rot or Armillaria root rot. *Verticillium* enters the roots and invades the vascular system of the tree, moving in the xylem to the top of the tree and causing the disease known as Verticillium wilt. This was first described by Zentmyer in 1948 (22).

In this disease the leaves suddenly wilt on 1 or several branches or on an entire tree. The leaves rapidly turn brown, die and remain attached to the branches for several months. Originally this disease was termed apoplexy or asphyxiation in California. Brown to grey-brown streaks are found in the wood when the bark is peeled. In many cases, affected trees will send out new, vigorous shoots within a few months after the initial collapse of the tree. Many trees also recover completely and show no recurrence of the wilt.

For disease prevention, the following measures should be used: plant Mexican rather than Guatemalan rootstocks, as the former are more resistant to this disease; do not plant avocado trees on land that has been used for crops susceptible to Verticillium wilt such as tomato, pepper, eggplant, some stone fruit tress, berries and some flower crops; and do not interplant avocado trees in the early years of the grove with susceptible crops. Usually no drastic control measures are necessary. Dead branches should be pruned after dieback has stopped and new growth has begun. If the tree is severely affected or dies, the soil should be fumigated with chloropicrin before replanting.

Rhizoctonia Seed and Root Rot

The soil fungus *Rhizoctonia solani* can attack avocado seeds and seedlings, primarily under greenhouse conditions, in nursery plantings and seed beds (10). The fungus may attack the cotyledons and kill the embryo or attack the young roots causing brown lesions and reducing growth of the seedlings. *Rhizoctonia solani* attacks roots only occasionally on large trees and rapid regeneration of roots usually occurs.

In the greenhouse and nursery, the fungus can be controlled by using sand, soil and seed flats steamed for 45-60 min. To prevent seed infection, clean seeds from fruit picked from the tree would prevent introducing the fungus into seedbeds. Sanitary practices to keep contaminated soil from the seed bed and growing areas also are important.

Dematophora Root Rot

Greenhouse inoculation tests have shown that the avocado is susceptible to the soil fungus *Rosellinia necatrix* (imperfect stage: *Dematophora)* (14). In this experiment Mexican and Guatemalan seedlings were inoculated by transplanting them into soil containing inoculum of *Dematophora.* All inoculated plants were dead within 5 weeks with white mycelial plaques in the bark and cortex of the infected roots. This fungus causes a serious root disease of many fruit trees, including especially apple and it also attacks iris.

Other Fungi

Several other soil-borne fungi have been listed as occurring on avocado in Florida (20). These include *Sclerotium rolfsii,* causing a seedling blight; *Sclerotinia sclerotiorum,* causing collar rot; *Clitocybe tabescens,* the mushroom root rot fungus and several wood-rotting fungi: *Fomes geotropus, F. supinus, Polyporus hirsutus* and *P. sulphurcus.* Apparently these are very minor problems. Occasional sporophores of wood-rotting fungi in the genus *Fomes* are seen on old avocado stumps or trees in advanced stages of root rot in California.

Summary

Several soil-borne fungi can cause diseases of the avocado, including: *Phytophthora cinnamomi* (causing Phytophthora root rot and trunk canker), *Armillaria mellea* (rot of large roots), *Verticillium albo-atrum* (avocado wilt), *Rhizoctonia solani* (seed and seedling root rot), *Phytophthora citricola* (trunk cankers) and *Phytophthora palmivora* (seedling blight). There have been occasional descriptions of other soil fungi on avocado: *Sclerotium rolfsii, Sclerotinia sclerotiorum, Phytophthora parasitica, Clitocybe tabescens, Fomes geotropus, Fomes supinus, Polyporus hirsutus* and *Polyporus sulphureus.* Inoculations have shown avocado to be susceptible to the root rotting pathogen *Rosellinia necatrix (Dematophora).*

The most serious disease problem is Phytophthora root rot, causing extensive losses of avocado trees in nearly every country where avocados are grown, *Phytophthora cinnamomi* has a host list of over 900 plants including pineapple, pine, chestnut, macadamia nut, eucalyptus, camellia, heather, peach, pear and rhododendron.

Phytophthora cinnamomi can be isolated from soil and roots by using agar media containing antibiotic chemicals and by using various types of baits—seedling plants or plant parts. Four spore stages are formed by this fungus: sporangia, zoospores, chlamydospores and oospores. There is increasing evidence of variability in this species and the occurrence of strains or races.

Phytophthora cinnamomi has considerable saprophytic ability and has survived up to 6 years in moist soil in the absence of a host. There is a close relation between disease occurrence and soil moisture—Phytophthora root rot occurs most rapidly and severely on soils with restricted drainage.

An extensive testing program for developing a resistant rootstock has been carried on in California for over 25 years, with numerous collections in Latin America, the native home of the avocado *(Persea americana)* and other species of *Persea.* High resistance has been found in several small-fruited species of *Persea* that are not graft-compatible with avocado. Moderate field resistance has been found in a Mexican variety, 'Duke'. Cuttings from selected 'Duke' seedlings ('Duke 6' and 'Duke 7') show resistance in large-scale field plots in California. Several other rootstocks also show encouraging resistance. The small-fruited species of *Persea* have been found to contain a unique chemical toxic to *Phytophthora* that may be the basis for their resistance. The chemical has been isolated and characterized and we are calling it borbonol.

Several soil fungicides give some control of Phytophthora root rot when applied to established trees. These include Dexon® and Terrazole®. Dexon® has been withdrawn from registration for use on avocado and registration is pending with Terrazole®. Repeated applications are apparently necessary.

Biological control with various types of organic amendments show some promise with avocado. Soils suppressive to *P. cinnamomi* have been found in Australia and the reason for their suppressiveness is being studied. Combinations of several aspects of control, such as combining resistance and fungicides, appear feasible.

In summary of control approaches for Phytophthora root rot, measures for preventing the development of Phytophthora root rot include: plant on well-drained soil, use disease-free nursery stock and prevent soil or water movement from infested areas.

For attempted control of the disease, the following measures are available: use rootstocks with some resistance such as the 'Duke' cuttings for new plantings; irrigate diseased trees and margins of diseased areas carefully as high soil moisture favors root rot development; establish a chemical or dry barrier if the diseased area is small and is below the healthy areas; treat trees in early stages of disease or healthy trees on the margin of diseased areas with soil fungicides such as Terrazole® when these become available for use on avocado; replant the area with resistant crops. Soil amendments to increase microbial activity in the soil are another possibility for treating trees in early disease condition or healthy trees, but details of such treatment need further research.

Several other species of *Phytophthora* attack avocado: *P. citricola* that causes trunk cankers in California; another species of *Phytophthora* causing cankers in Guatemala; *P. palmivora—the* cause of seedling blight in Florida and Honduras and *P. parasitica,* described as causing collar rot in Florida.

Armillaria mellea causes a severe rot of large roots and rootstocks in California but is not common. In contrast to *P. cinnamomi* that attacks primarily small feeder roots, *Armillaria* invades large roots and forms white fan-shaped plaques of mycelia just under the bark.

Verticillium wilt is another minor disease of avocado. This is a vascular disease, with the fungus entering through the roots and moving in the xylem to the top of the tree. Severe wilts results, but affected trees commonly recover within a few months. Mexican varieties are more resistant to this disease than Guatemalan varieties. Avocados should not be planted on land that has been used for other crops susceptible to *Verticillium:* tomato, pepper, eggplant, many stone fruits and berries.

Rhizoctonia solani occasionally attacks avocado seed and seedlings under nursery conditions—in nursery plantings and in seedbeds. It can be controlled in the nursery by steaming sand, soil and seed flats and using clean seed not picked from the ground.

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