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Coffee Rust in the Western Hemisphere

Since the identification of coffee leaf rust in Ceylon (Sri Lanka) in 1867 and the description by Berkeley of the causal fungus, *Hemileia vastatrix* Berk. & Br., coffee rust has become the major problem on coffee trees (*Coffea* spp.) in all coffee-growing regions of the world (7,10,13,15). Another rust fungus, *H. coffeicola* Maubl. & Rogers, attacks the coffee plant but is of minor importance and is restricted to central and western Africa.

Coffee rust caused by *H. vastatrix* devastated the coffee plantations of Asia in the latter part of the 19th century and was largely responsible for the substitution of tea as the major social beverage of the English. Tea plantations soon replaced coffee plantations in Ceylon and many other areas of southeast Asia and India. Coffee rust is still the most important disease of coffee trees in the world, with coffee nematode attack the next most serious problem in coffee production.

In dollar value, coffee is the second most important commodity after oil in international trade, accounting for $12 billion in 1979. Coffee is produced in approximately 45 countries, one-third of which are in the western hemisphere. Latin America grows more coffee than Africa and Asia, and several countries depend almost entirely on coffee sales for their foreign exchange (13). Coffee is an extremely important source of income for millions of people in Latin America—in growing the plant, in harvesting the coffee beans, and in processing, shipping, and marketing the product.

Rust Distribution and Spread

Coffee is the only known host of *H. vastatrix*. The source of the fungus is commonly believed to be the place of origin of the host, *Coffea* spp., in the Lake Victoria region in East Africa and in Ethiopia (10). Coffee rust was discovered in 1861 in the vicinity of Lake Victoria in East Africa (10) (Fig. 1). The disease was found in Ceylon soon thereafter, then spread to much of southeast Asia. Coffee rust gradually invaded all the coffee-growing regions of Africa, to the south, then to central and western Africa, and finally to Angola on the west coast in 1966 (Fig. 1).

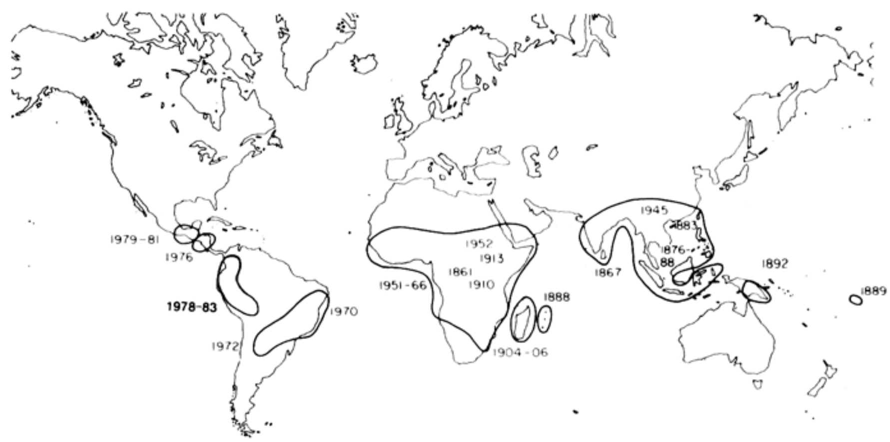

Fig. 1. World distribution of the coffee rust fungus (*Hemileia vastatrix*), with dates it was found.

D'Oliveira in 1954 (2) predicted that the western hemisphere, with its tropical environment and the genetic uniformity of its coffee varieties, would be favorable for the establishment of coffee rust. Wellman (14) expressed a similar concern about the potential danger of this disease to the Americas. For decades after establishment of the rust in Africa, however, the western hemisphere miraculously remained free from the disease. Finally, in 1970, the long-expected and dreaded disease was found in the state of Bahia in Brazil by plant pathologist Arnaldo Medeiros (5). Now, 14 years later, the disease is present in much of South and Central America and in Mexico (12,13,15).

The coffee rust fungus with its 32 different races (races I, II, III, and XV are the most disseminated worldwide) is now firmly established in 12 countries in the western hemisphere (Table 1): Brazil, Paraguay, Argentina, Bolivia, Peru, Ecuador, and Colombia in South America (Fig. 2); Nicaragua, El Salvador, Honduras, and Guatemala in Central America; and Mexico in North America. The last eight detections of coffee rust were in Bolivia in 1978, Peru and El Salvador in 1979, Honduras and Guatemala in 1980, Ecuador and Mexico in 1981, and Colombia, in Caldas Province, in 1983 (Table 1).

Much has been learned regarding dissemination of coffee rust since its detection in Bahia in 1970. The rapid spread within Brazil, from Bahia to Paraná, then into Paraguay and Argentina, following the prevailing wind currents, provided circumstantial evidence of the importance of wind. The studies of Martinez et al (4) at the Instituto Biologico in Brazil showed definitely that uredospores of *H. vastatrix* are disseminated by wind. Becker (1) in East Africa also provided good evidence of the role of wind in dissemination. Spread into other areas of Latin America, into Nicaragua, for example, was apparently not by wind but by humans (Table 1), otherwise the disease would have been found first in Panama and Costa Rica. There is also good evidence of spread of the fungus from Acre in Brazil to Beni in Bolivia by means of coffee seedlings (13) (Table 1).

Symptomatology

Coffee rust incited by *H. vastatrix* is a foliage disease (Fig. 3), but occasionally green coffee berries are attacked by the fungus, as we observed in Espírito Santo,

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Fig. 2. Spread and distribution of *H. vastatrix* in South America.

Table 1. Coffee rust (*Hemileia vastatrix*) in the Americas

Country	Date of detection	Possible factors in introduction	Races
Brazil	January 1970	Plants from Africa	II, XV, III, I, XVII, XXIV[a]
Paraguay	1972	Wind currents	II
Argentina	1972	Wind currents	II
Nicaragua	November 1976	Humans	II
Bolivia	May 1978	Coffee seedlings	II
Peru	January 1979	Coffee seedlings	II
El Salvador	December 1979	Humans	II, I
Honduras	Late 1980	Humans	II
Guatemala	December 1980	Humans and wind currents	II
Mexico	Summer 1981	Humans and wind currents	II
Ecuador	Summer 1981	Humans and wind currents	II
Colombia	September 1983	Humans	...

[a] Race II identified in 1970; races II and XV in 1972; races II, XV, and III in 1973; races II, XV, III, and I in 1974; races II, XV, III, I, and XVII in 1979; and races II, XV, III, I, XVII, and XXIV in 1980. Some new races are in the process of being identified.

Fig. 3. Coffee rust incited by *H. vastatrix*.

Brazil (9). Typical uredopustules appear on young and old leaves and even on the first leaves of young seedlings. The first symptoms are translucent chlorotic spots 1–3 mm in diameter. In a few days, these spots increase in diameter and masses of yellow-orange uredospores show on the undersurface of the leaf. The center of an old uredopustule sometimes turns necrotic while spore production continues at the edges of the pustule.

Typical pustules are pale yellow to deep orange. In certain regions, eg, Bahia in Brazil, the pustules are very pale, in contrast to our observations in Kenya, Africa, on *C. arabica*. On the Pacific coast of Guatemala, some rust pustules on coffee are the same color as that observed in Kenya, even though cultural conditions are quite different in the two areas. Coffee is grown without shade in East Africa and in the shade in Guatemala. Color differences in pustules are generally not the result of different races; inoculations with different races under controlled greenhouse conditions produce the same color of pustule.

In South America, we observed that the first pustules are often produced at the margin or tip of the leaf. Stomata are located only on the undersurface of the leaf, and infection takes place only in the presence of free moisture (dew or rain droplets). Because water droplets are suspended longer at the tip and margins of the leaf, the opportunity is greater for germination and penetration of the fungus. Rain and wind may carry the uredospores from the original pustule at the tip or margin to other areas on the undersurface of the leaf.

In Brazil, we sometimes observed that leaf rust symptoms were similar to the spots produced by *Cercospora coffeicola* Berk. & Cke. at a later stage of the disease and to the small translucent spots produced by "weak spot" disease at the early stage of pustule development. Since both diseases are present in all coffee-producing regions in Latin America, there was some misidentification of the rust while it was spreading in the Americas.

In Brazil, pustules appear on the foliage near the soil level first, then progress upward in the plant. However, as sometimes observed in Central America, the fresh new foliage at the top of a young tree also shows formation of uredopustules. Seedlings germinating under old coffee trees often show some pustules on their first leaves. During the eradication campaign in Nicaragua, these infected seedlings were a problem in certain areas.

One rust pustule can mature in 2–3 weeks (depending on ecological factors), completing its diameter. One uredopustule has up to 150,000 uredospores. These echinulated, kidney-shaped spores are in groups (Fig. 4). Uredospores can survive under dry conditions for 6 weeks. This viability period is probably important in the spread of the disease, especially by man; researchers in Viçosa, Brazil, have studied this aspect.

At the plantation level, the most striking symptom is defoliation of the trees (Fig. 5). Defoliation occurs in limited areas, and not all trees are affected at the same time within a coffee plantation.

Ecology and Epidemiology

The classical literature indicates that of the two coffee rusts, only *H. coffeicola* is found in colder regions. *H. vastatrix* is generally recognized to need high temperatures and high humidity for optimum development. Altitude in relation to temperature and rain distribution are important factors in severity of rust caused by *H. vastatrix*. During field observations in Kenya, the senior author found race II of *H. vastatrix* 1,500 and 1,600 m above sea level (9).

Some of the coffee plantings in Latin America are in relatively cool climates but still provide favorable conditions for development of *H. vastatrix*. Recent studies showed that the Rayner equation (7,10) used in Africa to predict the incubation period of the rust gave quite different results in Brazil. Under Brazilian conditions, lower temperatures resulted in higher infection rates and increased rust severity.

On the basis of epidemiologic studies in Kenya (S. M. Becker, *personal communication*) and in Brazil (6), the conclusion was reached that four factors are involved in the intensity of a rust outbreak during each rainy season: 1) the amount of residual infection at the beginning of the epidemic; 2) the distribution and intensity of the rainfall and temperature during the buildup of an outbreak; 3) the density of the foliage, which influences the leaf surface on which spores can germinate and on which inoculum can be produced; and 4) the shape of the coffee tree. Ortolani (6) found that in Brazil, in years of high yields the incidence of rust infection is also higher, demonstrating that rust is a cyclical disease and severity of infection varies from year to year. These studies are of prime importance in determining how coffee rust reduces coffee production.

Status of *H. vastatrix* Races in Latin America

Soon after coffee rust was discovered in Bahia, Brazil, in 1970, the fungus was identified as *H. vastatrix* race II. This race is now widespread in all of the Central and South American countries invaded by the rust (Table 1). Race I, recently identified in El Salvador, is the only other race found outside Brazil. Research similar to that being done in Brazil is needed to identify races of the fungus in all 12 countries with rust.

In the first decade after discovery of coffee rust in Brazil, five more races—I, III, XV, XVII, and XXIV—were found in that country (Table 1). The race situation should be monitored carefully in other countries in South and Central America and in Mexico, for, as the senior author stated in 1975 (11): "It is of prime importance to follow the appearance of new rust races in South America, because breeding programs must focus on new trends in the production of resistant varieties."

Changes in Planting Technology

The invasion of coffee rust in Latin America has stimulated a change in coffee planting technology. When rust was discovered in Brazil, the coffee plantings were too dense to permit use of chemicals for disease control.

In 1975 (11), the senior author commented on the changes in planting technology already initiated in Brazil in response to rust invasion: "Rust disease has led to the development of new planting systems in Brazil, among these, spacing mainly between plant rows, and pruning techniques. Changes in spacing have been effected to make chemical

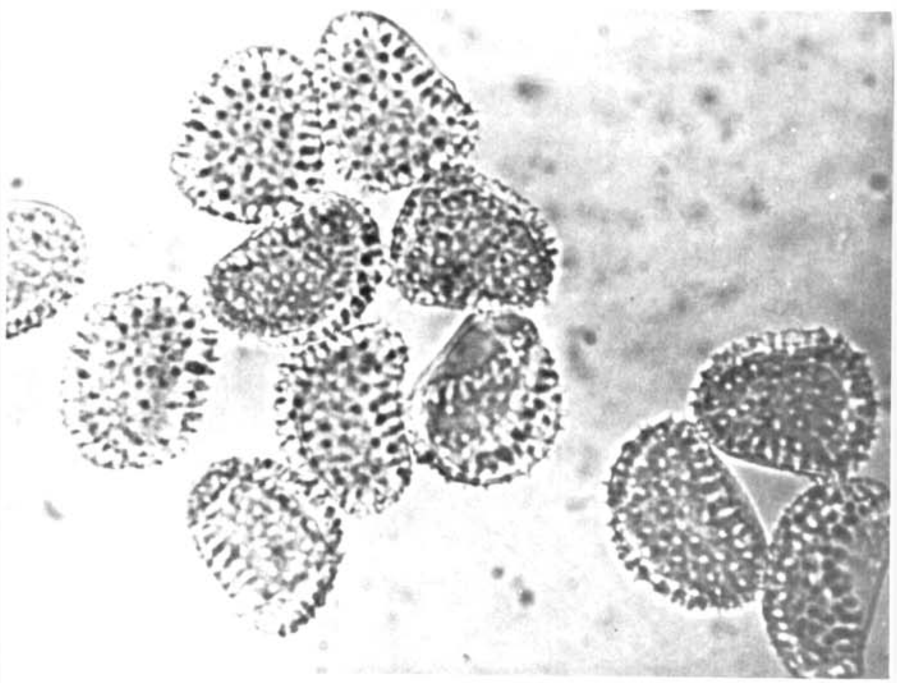

Fig. 4. Uredospores of *H. vastatrix*; echinulations aid in dissemination. (Courtesy Coffee Rust Research Center, Oeiras, Portugal)

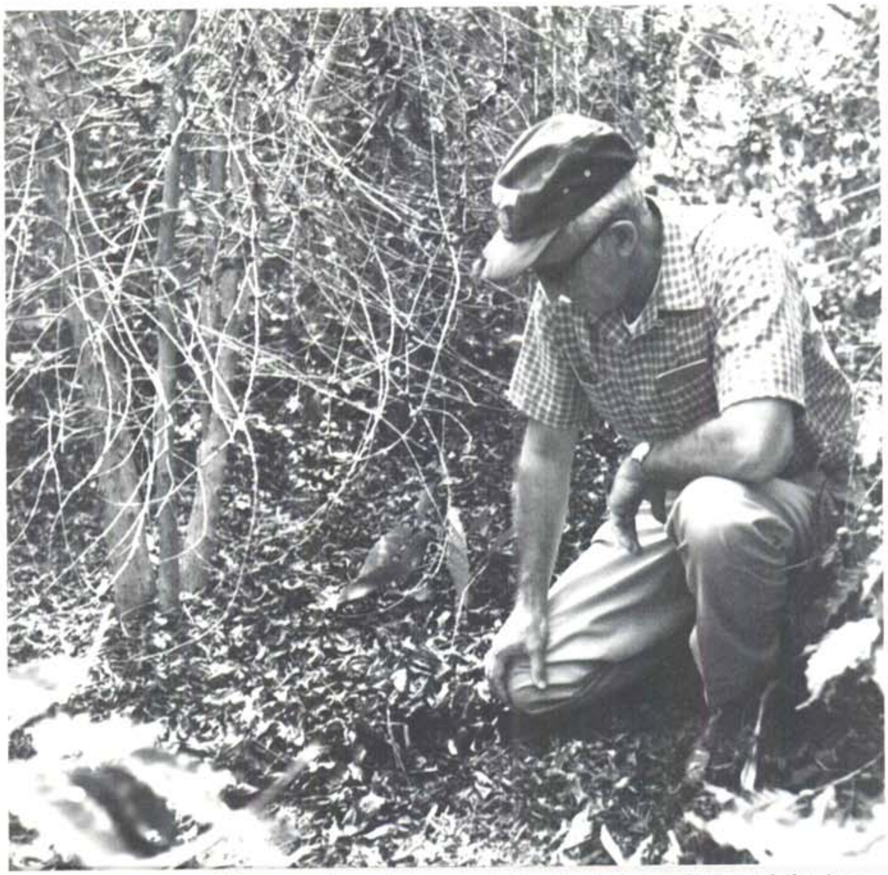

Fig. 5. The most striking symptom at the plantation level is defoliation of the trees. (Photographed in Caratinga, Brazil, in 1970)

Fig. 6. Tests of different plant densities against coffee rust in Guatemala.

Fig. 7. Catimor, produced by crossing the famous natural coffee hybrid Hibrido de Timor with Caturra, is resistant to all rust races identified in Latin America.

control feasible and to change the microecology at the plantation level. Before rust was discovered in Brazil, coffee plantation rows were closely spaced. The resultant heavy foliage affected the amount of light reaching the plants, and created an appropriate environment for rust to develop."

In Central America, while coffee rust was spreading from one country to another, some institutions and coffee growers began to test new plant densities. Figure 6 shows such a plot in Guatemala. New pruning techniques were also tested and applied. One, the so-called recepa method in which the trunk is cut back to 1 ft above soil level, has aided the renewal of old coffee plantings in South and Central America. This technique was also applied during the attempt to eradicate rust in Nicaragua (3).

Changes in Chemical Control

Since 1970 the Instituto Brasileiro do Cafe (IBC) has had an extensive program aimed at chemical control of coffee rust, including investigations of the efficiency of fungicides, dosages, timing of applications, and variations in application equipment ranging from knapsack to airplane. The GERCA (Grupo Eradicacion Cafe) division of IBC has been carrying out most of these studies under field conditions in different ecological regions. The University of Viçosa in Minas Gerais and the Instituto Biologico in São Paulo have also been active in research on chemical control. As a result of this research, Brazil has made significant advances in the field of chemical control of coffee rust and the use of fungicides by coffee growers has increased significantly.

Types of fungicides tested in Latin America have included different copper compounds as well as organics and some of the new systemics. In Brazil, copper fungicides and some of the organics have given good control of rust (11), and the new systemic fungicides, such as triadimefon (Bayleton) and pyracarbolid (Sicarol), have had a curative effect on the uredopustules. Alternate applications of copper and systemic fungicides have also been effective in field trials in Brazil. Fungicides are applied between October and April.

Since the discovery of coffee rust in Central America, similar trials of copper and systemic fungicides have been conducted there. Coppers are used alone or occasionally are alternated with systemics. Copper fungicides being used as preventive treatments include copper oxychlorides and several cuprous oxides. Two systemic fungicides being used for their "curative effect" on coffee rust are Bayleton 25WP and Sicarol. Spraying for prevention or control of rust is started just before the rainy season begins, in April or May.

Wellman and Echandi (15) recently commented on the fact that in much of the tropics, tradition is against spraying coffee but that the growers in Latin America are reluctantly including spraying in their normal procedures. They further comment: "In remarkably few years, as expensive as it is, spraying is no longer foreign to coffee growers, and in some plantations it has become an established practice."

Changes in Production of Resistant Varieties

Excellent fundamental research on resistant varieties and physiologic races of rust has been carried out for many years at the Coffee Rust Research Center in Oeíras, Portugal, by B. D'Oliveira and C. J. Rodrigues, Jr. This pioneer research has included identification of rust-resistant genes and characterization of physiologic groups of coffee and has been valuable in all coffee-producing areas of the world.

In Brazil, an excellent breeding program under the direction of A. Carvalho at Campinas (São Paulo) has been carried out for the past 30 years, with emphasis on producing varieties of coffee resistant to *H. vastatrix*. The Brazilian program cooperates with the Coffee Rust Research Center in Portugal in the search for rust resistance (8) and is directed toward the ideal combination of disease resistance, good agronomic adaptation, and good quality coffee. In recent years, efforts have been directed toward finding resistance to race II, the first race of *H. vastatrix* found in South America and still the dominant race in Latin America.

By 1973, Brazil had distributed seed of some of the new resistant varieties to farmers. One of the significant sources of resistance is found in Hibrido de Timor, the natural hybrid of *C. canephora* with *C. arabica* from the island of Timor. The finding of this natural hybrid with factors for resistance that are dominant and its subsequent use for breeding resulted from research by D'Oliveira, who was director of the Centro do Investigacao das Ferrugens do Cafeiro in Oeíras, Portugal, during the 1950s and 1960s. Hibrido de Timor has been crossed with Arabic coffees, such as Catuai, Caturra, Mundo Novo, and Geisha.

D'Oliveira first used the resistance of Hibrido de Timor in a cross with Caturra, producing Catimor (Fig. 7) in a breakthrough in the development of resistance to *H. vastatrix*. Observations in El Salvador, Brazil, Costa Rica, and some of the Caribbean islands (13) indicate that Catimor has outstanding adaptation to the ecological conditions in those Latin American countries as well as resistance to all known rust races. The discovery of Hibrido de Timor and the development of Catimor are outstanding contributions from Portugal to world-wide coffee production. These hybrids have revolutionized methods of growing coffee in Brazil by changing plant distance and density.

Two examples of good ecological adaptability of resistant varieties in the western hemisphere are Geisha in the cooler regions at higher elevations, eg, the Blue Mountains of Jamaica, reflecting Geisha's origin in the higher elevations of Ethiopia, and Catimor in the warmer regions. The adaptability of these varieties has been observed in countries with and without rust (13).

The appearance of several new races in the extensive coffee regions of Brazil creates a problem in the production of rust-resistant varieties. For example, Geisha, which has been introduced into nearly all coffee-producing countries in Latin America, is resistant to race II but susceptible to some other races. As the senior author pointed out in 1972 and 1975 (10,11), vertical resistance to race II of *H. vastatrix* is what Brazil needs in the immediate future, but horizontal resistance, as found in plants of *C. arabica* in Angola and Brazil as well as in Catimor, is desirable. Brazil has been searching for horizontal resistance for several years. Varieties developed in this process will be of great value to other coffee-producing countries in the Americas.

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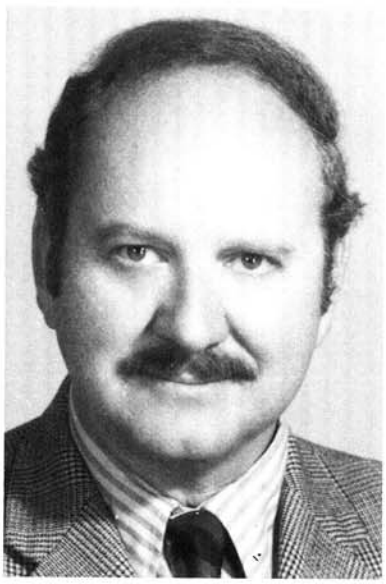

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Dr. Schieber was born on a coffee farm in the central highlands of Guatemala. He studied plant pathology and botany at the University of Wisconsin and began his interest in tropical plant diseases in 1951 at the Instituto Agropecuario Nacional in Guatemala, becoming head of the Department of Plant Pathology in 1959. He held that position until 1971. Since 1965 he has been traveling worldwide as a consultant in tropical plant pathology. He is known for his work on tropical corn rust and coffee diseases. Since 1958 he has traveled in three continents in regard to the coffee rust disease problem.

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Dr. Zentmyer is a professor of plant pathology at the University of California, Riverside, where he has been since 1944. He has worked on coffee diseases in Central America with Dr. Schieber since 1960 and has had an extensive collecting program in Latin America for over 30 years, searching among native species of *Persea* for resistance to *Phytophthora cinnamomi*.