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PLANT DISEASE LESSONS

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GLOSSARY

DISEASE: Coffee rust

PATHOGEN: *Hemileia vastatrix* - currently found in nearly all the world's coffee-growing regions.
***H. coffeicola* - restricted to central and western Africa, especially the higher and cooler regions.**

Coffee rust is the most economically important coffee disease in the world, and in monetary value, coffee is the most important agricultural product in international trade.

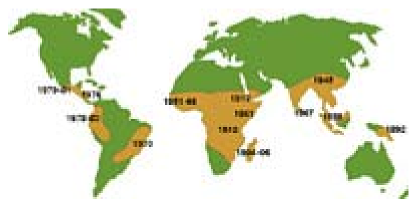
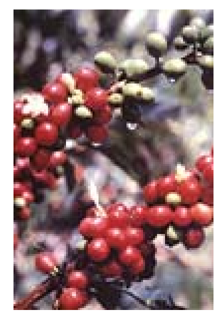


Figure 1. Click Image for more detail.

HOSTS: *Coffea arabica* (arabica coffee) and *Coffea canephora* (robusta coffee), the two most important commercial coffee species, and perhaps as many as 25 other species of *Coffea.* Existence of an alternate host has been postulated, but none have been found.



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COFFEE RUST

Symptoms and Signs

Infections occur on the coffee leaves.The first observable symptoms are small, pale yellow spots on the upper surfaces of the leaves (Figure 3). As these spots gradually increase in diameter, masses of orange urediniospores (= uredospores) appear on the undersurfaces (Figure 4). The fungus sporulates through the stomata rather than breaking through the epidermis as most rusts do, so it does not form the pustules typical of many rusts (Figure 5). The powdery lesions on the undersides of the leaves can be orange-yellow to red-orange in color, and there is considerable variation from one region to another.

Figure 3

Figure 4

Figure 5

While the lesions can develop anywhere on the leaf, they tend to be concentrated around the margins, where dew and rain droplets collect (Figure 6). The centers of the spots eventually dry and turn brown, while the margins of the lesions continue to expand and produce urediniospores. Early in the season, the first lesions usually appear on the lowermost leaves, and the infection slowly progresses upward in the tree. The infected leaves drop prematurely, leaving long expanses of twigs devoid of leaves (Figure 7).

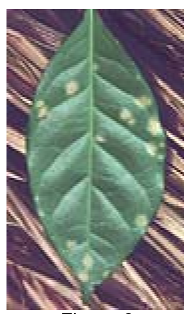

Figure 6

Figure 7

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COFFEE RUST

Pathogen Biology

The "coffee leaf disease" was first reported by an English explorer on wild *Coffea* species in the Lake Victoria region of East Africa in 1861. In 1869, the Reverend H. J. Berkeley and his assistant, Mr. Broome, reporting in the *Gardeners' Chronicle,* described the fungus they found associated with the disease on some dried coffee leaves sent from Ceylon (now Sri Lanka). They gave the name *Hemileia vastatrix* to the devastating fungus with half-smooth spores (Figure 8). Urediniospores of other rust fungi are typically round to oval, not kidney-shaped, and have fine spines over their entire surface. It belongs to the class Basidiomycetes, the order Uredinales, and the family Pucciniaceae.

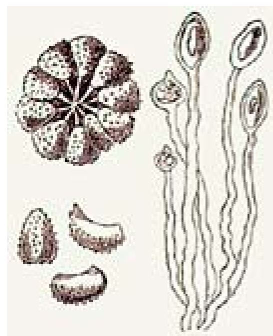

Figure 8

Hemileia vastatrix exists primarily as dikaryotic (having pairs of haploid nuclei that divide in tandem), nutrient-absorbing mycelium ramifying intercellularly within the leaves of its coffee host. Clusters of short pedicels bearing dikaryotic urediniospores protrude through the stomata on the undersides of the leaves (Figure 9). Occasionally under cool, dry conditions toward the end of the season, teliospores are produced among the urediniospores on older, attached leaves. Following karyogamy and meiosis, the teliospores germinate to produce basidia, each of which forms four haploid basidiospores (Figure 10).

Figure 9

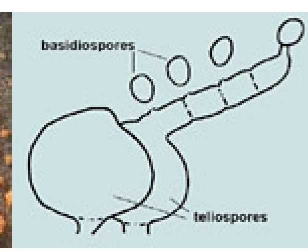

Figure 10

The basidiospores will germinate in vitro, but it is not known what plant, if any, they can infect. It is clear that they do not infect coffee. It is not known whether the basidospores are functional or are simply remnants of an ancestral, long-cycled (up to five different spore stages) rust fungus. No alternate host is necessary; *H. vastatrix* can survive and reproduce quite nicely by urediniospores alone.

Often a hyperparasitic fungus, *Verticillium hemileiae*, will colonize the coffee rust lesions. Hyperparasites are parasites that parasitize other parasites and are sometimes used as biological control agents. With coffee rust, this hyperparasitism reduces the viability of the urediniospores, but it has very little impact on overall rust development.

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Disease Cycle and Epidemiology

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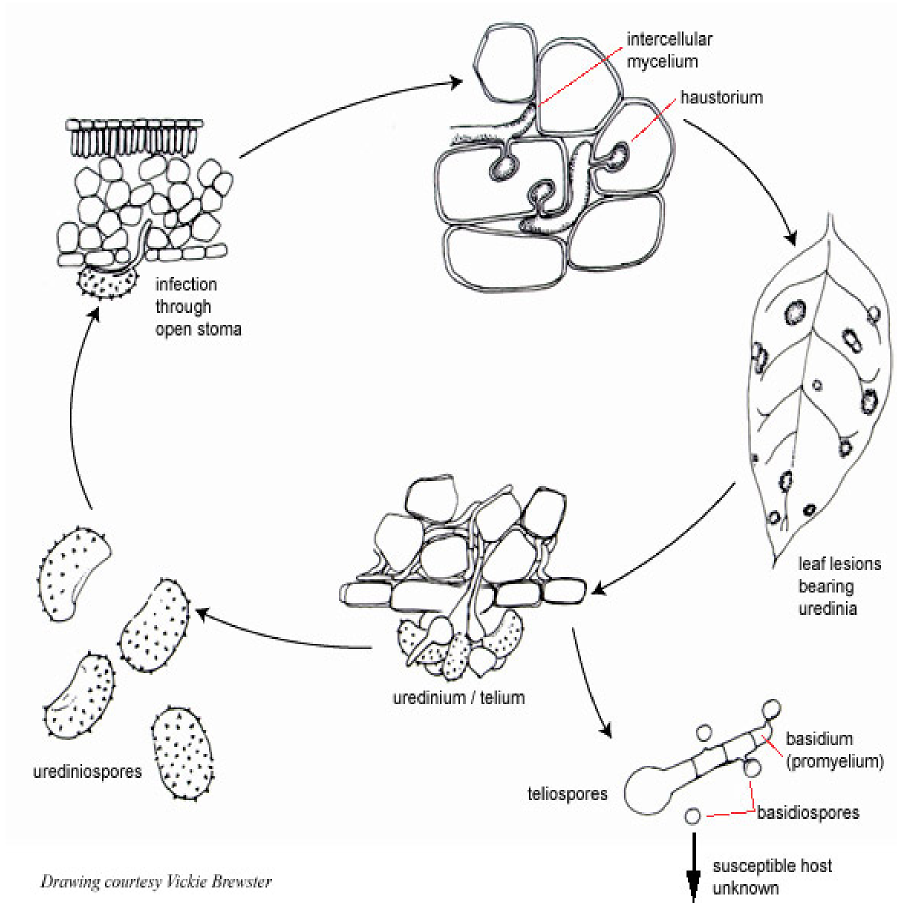

Drawing courtesy Vickie Brewster

The disease cycle is a simple one. Urediniospores initiate infections that develop into lesions that produce more urediniospores (figure 6). Since coffee is a perennial plant on which the leaves remain green throughout the year, the epidemic is continuous, with some fluctuation from season to season, depending on rainfall.


Figure 6

Survival

Hemileia vastatrix survives primarily as mycelium in the living tissues of the host, and since infected leaves drop prematurely (figures 7 and 13), this effectively removes a huge amount of potential inoculum from the epidemic. But a few green leaves always persist through the dry season, and dry urediniospores can survive about 6 weeks, so there is always some viable inoculum to infect the newly formed leaves at the start of the next rainy season.

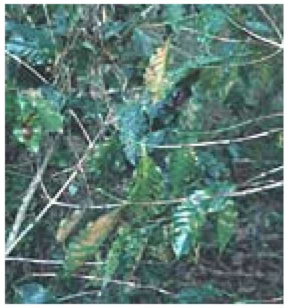
Figure 7


Figure 13


Figure 5

Spore dispersal

The urediniospores can be dispersed by both wind and rain (figure 5). By observing patterns of infection on individual leaves and among leaves within the canopy, it is clear that splashing rain is an important means of local dispersal. The patterns of infection on a regional scale, particularly in those areas where the fungus was newly introduced, have shown that the long-range dispersal is primarily by wind. A small, perhaps epidemiologically insignificant amount of urediniospore dispersal is by thrips, flies, wasps, and other insects. Movement across oceans, deserts, and mountain ranges has very likely been caused by human intervention.

Infection

Urediniospores germinate only in the presence of free water (rain or heavy dew); high humidity alone is not enough. The whole process of infection requires about 24 to 48 hours of continuous free moisture, so while heavy dew is enough to stimulate urediniospore germination, infection usually occurs only during the rainy season. The seasonal variation in disease incidence is primarily due to variation in rainfall. Where there are two rainy seasons per year, there are two peaks in severity of coffee rust. Infection occurs over a wide range of temperatures (minimum 15°C/ 59°F, optimum 22°C/ 72° F, and maximum 28°C/ 82°F). Infection only occurs through stomata on the underside of the leaf.

Sporulation

It takes 10-14 days from infection for new uredinia to develop and urediniospores to be formed (figure 4). The rust lesions continue to enlarge over a period of 2 to 3 weeks. A single lesion will produce four to six crops of spores, releasing about 300,000 urediniospores over a period of 3 to 5 months. Secondary cycles of infection occur continuously during favorable weather, and the potential for explosive epidemics is enormous.


Figure 4

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COFFEE RUST

Disease Management

Quarantine

For more than a century, strict quarantine measures kept coffee rust from invading the Americas. Some plant pathologists have speculated that urediniospores spread from Africa to Brazil on the wind, but it is far more likely that the rust was carried on coffee seedlings or perhaps that urediniospores clung to the surfaces of other plants imported into coffee-growing areas. Once the barrier of the oceans had been breached, wind dispersal came into play. Following the initial introduction into Brazil in 1970, an 80 km (50 mile)-wide "safety zone" was established by eradicating coffee in the zone, but within 18 months, coffee rust had jumped the gap in the direction of the prevailing winds.

In Central America, the new infections were eradicated by killing the infected coffee plants plus the symptomless plants in a 30-meter (yard) radius by spraying them with an herbicide mixed with diesel fuel. Initially the eradication effort seemed to be effective, but eventually, again probably because of wind dispersal, the coffee rust became too well established. There are now very few coffee-growing regions of the world where coffee rust has not yet invaded.

Cultural management

Coffee rust must be managed as a continuous epidemic on a perennial crop, and therefore, any factor that can reduce sporulation, spore dispersal, or infection, even a small amount, can mitigate the epidemic. Good cultural management is paramount, but there are no simple rules to follow. The varieties grown, the character of the soils, the amount and distribution of rainfall, and numerous other factors all interact to dictate what is required.

Figure 11

One of the key cultural management decisions is whether to produce the coffee in full sun or with some degree of shade (Figure 11). This often is more a sociopolitical decision than an agronomic one. Some say that rust is easier to control on properly spaced plants in full sun, since they dry faster and, therefore, have shorter periods of leaf wetness. (They also are easier to spray with fungicides.) Others argue that shade-grown coffee has less rust because the closed canopy of shade trees prevents dew formation on the coffee leaves and therefore reduces infection. However, dew usually does not remain long enough to support infection. It is more likely that shade reduces the susceptibility of the plant to rust because yields are reduced; production of a heavy crop depletes the tree of nutrients and makes it more susceptible to infection. In general, sun-grown coffee is produced on large, well-capitalized farms that can afford to control the rust with fungicides, the cost of which is offset by the higher yields. The small, "low-tech" producers tend to favor shade-grown coffee, which, despite its lower yields, requires less external input in the form of pesticides and fertilizers. (For a discussion of the environmental impacts of sun- and shade-grown coffee, see http://www.audubon.org/local/cn/97december/sgsoca.html

Since the susceptibility of the plant is markedly affected by its nutritional status, the depletion of nutrients by a high yield in a given season can increase the severity of rust not only in that season but in subsequent years as well, unless appropriate adjustments in nutrients are made. Fertilization with nitrogen (N) and phosphorus (P) tends to reduce the susceptibility to rust, but excessive potassium (K) increases susceptibility. In general, application of micronutrients reduces susceptibility. Since their effects can be felt over several seasons, such adjustments must be made carefully.

Proper pruning and training of the coffee plant help to prevent overcropping and maintain the vigor of the plant, thereby reducing its susceptibility to rust. These also help to improve air circulation to promote rapid drying of the foliage, and it facilitates spraying by opening up the canopy. Wider row spacing to reduce the planting density also improves air circulation and spray coverage.

Coffee is very sensitive to weed competition, so good weed control is important in maintaining plant vigor and thereby reducing susceptibility to rust. Good weed control also helps to facilitate air circulation and rapid drying of the canopy.

Fungicides
On susceptible varieties and in environments favorable for the fungus, fungicides are important tools in the management of coffee rust epidemics. In deciding when and what to spray, any given fungicide application has to be considered a long-term investment, with effects not only in the current season but in future seasons as well. Keeping inoculum levels low toward the end of one rainy season will have a major impact on reducing the level of infection at the start of the next rainy season. Preventing defoliation this season will prevent yield losses next season and maintain plant vigor well into the future.

Copper-containing fungicides are very effective in controlling coffee rust, and copper has a "tonic effect" on coffee plants, that is, it increases yields independent of its effect in rust control. One disadvantage of using copper-containing fungicides is that they must be present on the leaves before infection occurs. Another disadvantage, aside from cost, is that copper accumulates in the soil, particularly in the organic matter, and it can reach levels toxic to plants and to other organisms in the environment. To reduce the amount of copper used, copper-containing fungicides can be alternated with systemic organic fungicides, or one or two copper sprays can be applied early in the season, followed by one or occasionally two sprays of a systemic later in the season to arrest developing rust lesions.

The dithiocarbamate (organic, protective) fungicides are effective for the control of coffee rust and also sometimes have a tonic effect, but their residues do not adhere as well as those of the copper-containing, protective fungicides or the systemic fungicides under the heavy rains of many of the coffee-producing regions.

The timing of the applications and the coverage are important. As a general rule, the intervals between sprays should be less than 21 days to be sure to keep new growth covered. Forecast models exist for timing of fungicide applications according to temperature and rainfall. Since infection occurs on the undersides of the leaves, the sprays should be directed upward to cover the lower leaf surfaces.

Resistant cultivars

At the time that coffee rust first appeared in Brazil, virtually all the coffee in the Americas, and indeed nearly all the coffee in commercial production, could trace its lineage to a single tree planted in the conservatory of King Louis XIV in 1713. The resulting genetic uniformity of commercial coffee production posed (and continues to pose) an enormous potential risk of devastating epidemics.

The existence of resistance to coffee rust in wild *Coffea* species has been known for some time. So far, nine genes for resistance have been identified, mostly derived from *C. canephora* and *C. liberica* (Figure 12). One challenge to the breeders is to combine rust resistance with good agronomic characteristics and good quality coffee. The next challenge is to deploy these resistance genes in such a way that they are not immediately overcome by new races of *H. vastatrix*. So far, more that 40 different races of *H. vastatrix* have been identified, with some new ones able to attack previously resistant hybrids. New rust races continue to appear. To reduce the rate of selection of virulent races, the breeders of Cenicafé, a national coffee research center in Colombia, have created a composite cultivar with uniform agronomic characteristics and coffee quality, but with a mixture of genes for rust resistance.

Figure 12

One distressing development in coffee breeding has been the dramatic loss of genetic diversity among the wild *Coffea* species. There is very little genetic diversity in coffee outside the tropical forests in southwestern Ethiopia, where *Coffea* evolved. Because of logging, fuelwood harvest, and expanded cultivation driven by a growing human population, these forests have been reduced to less than one-tenth their original size. Ethiopia's Institute of Biodiversity Conservation and Research is struggling to hang on to what is left, and the Ethiopian government has prohibited the export of coffee plants and coffee seed from the country.

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COFFEE RUST

Significance

Losses
Coffee rust causes premature defoliation, which reduces photosynthetic capacity and weakens the tree. Since next season's berries are borne on this season's shoots, this season's rust reduces next season's yields. Depending on weather in the current season and the yield and the level of infection the previous season, yields can vary as much as 10-fold from one season to the next. Severe infection can result in dieback of twigs and can even kill trees (Figure 13).

Figure 13

Economic impact
Coffee rust is the most economically important coffee disease in the world, and in monetary value, coffee is the most important agricultural product in international trade. Even a small reduction in coffee yields or a modest increase in production costs caused by the rust has a huge impact on the coffee producers, the support services, and even the banking systems in those countries whose economies are absolutely dependent on coffee export.

History
Coffee originated as an understory plant in the forests in the mountains of Ethiopia. Its early use was as a food, in pressed cakes, often carried on camel caravans by North African traders. Its first use as a drink was probably for medicinal purposes and in religious rituals, but its stimulating and refreshing qualities made it popular. Coffeehouses were common throughout Egypt, Arabia, and Turkey by the early 1500s, and European travelers developed a taste for this exotic brew. The Dutch saw the business potential in coffee and began to plant coffee in their colonies in Ceylon, Sumatra, and Java. "Java" remains a slang term for coffee in many places.

By the early seventeenth century, coffeehouses had sprung up in all the major cities of Europe, with the Dutch being the major coffee supplier. A taste that began with the nobility and the wealthy soon drew in the common folk as well. Coffeehouses became the places where the intelligentsia gathered to discuss philosophy, religion, and politics (Figure 14). Rulers throughout history have felt threatened by this free thinking and have moved to restrict the coffeehouses (Figure 15). Coffee had taken on a political and social importance far beyond that of just another hot drink.

Figure 14

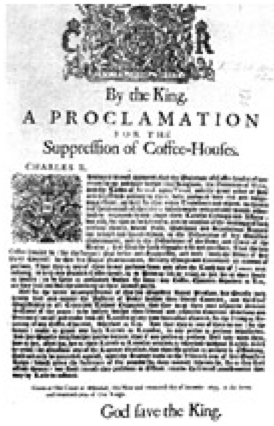
By the King.
A PROCLAMATION
FOR THE
Suppreffion of Coffee-Houfes.
CHARLES R.
God fave the King.

Figure 15

By the time the Dutch ceded it to the British in the nineteenth century, Ceylon had developed into the greatest coffee-growing region in the world. The British expanded the plantations even further, stripping the island of its forests to plant coffee in every available acre. By the 1870s, Ceylon's plantations were exporting nearly 100 million pounds of coffee a year, most of it to England.

Coffee growers in Ceylon reported the appearance of a "coffee leaf disease" in 1867, later determined by Berkeley to be caused by a rust fungus. The name "vastatrix" that Berkeley gave to the species described the devastation that he anticipated from the early disease reports. (Click here for a A scanned image of the page from the November, 1869 *Gardeners' Chronicle* in which Rev. M.J. Berleley published the first description of *Hemileia vastatrix*.) Just how the fungus made its way from its native Ethiopia to Ceylon remains a mystery. At first, perhaps, the coffee growers were hoping that it would disappear as quickly as it had appeared, but by 1879, it was clear that it was not going away, and the whole country was desperate. The Ceylon government made an appeal to send someone to investigate the disease and come up with a cure.

A young botanist, Harry Marshall Ward, who had studied Anton de Bary's work on the fungi, set off on his first assignment. His observations and recommendations were fundamentally important to the then infant science of plant pathology. Ward pointed out the risks of such widespread planting of coffee without even the benefit of windbreaks to reduce the dispersal of the rust spores. A few years before Millardet and his Bordeaux mixture, Ward proposed the use of a protective fungicide (lime-sulfur) to prevent infection.

The vigor and productivity of the coffee plantations declined to the point where they were no longer economically viable. Ward had arrived too late to save the coffee, and his warnings about the dangers of monocultures went unheeded. Following a period of severe economic and social upheaval, British planters shifted to planting tea as extensively as they had coffee, and the British coffee drinkers began drinking tea. Within a few years, coffee rust had spread to India, Sumatra, and Java, and the center of coffee production shifted to the Americas, where the rust had not yet appeared. Brazil soon became the world's major coffee supplier.

Thanks to a vigilant quarantine, the Americas remained free of coffee rust until 1970, when it was discovered in the state of Bahia, Brazil. Since virtually all of America's coffee had descended from a single rust-susceptible plant, the fungus, flying on the winds, raced through the coffee- growing areas of South America and Central America in less than a decade. *H. vastatrix* is now found in nearly all the coffee-producing areas of the world, with the exception of Hawaii.

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COFFEE RUST

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