Hemileia vastatrix Berkeley & Broome

Figure 1. Severe symptoms of *Hemileia vastatrix* in Rwanda. Courtesy of Smartse - Own work. Published under the creative commons attributions license.

Synonyms
None

Common Name(s)
Coffee leaf rust, CLR, coffee rust, orange coffee rust

Type of Pest
Fungus

Taxonomic Position
Class: Urediniomycetes, **Order:** Uredinales, **Family:** Incertae sedis

Reason for Inclusion in Manual
Suggested by CAPS community

Background Information
Hemileia vastatrix (coffee leaf rust) was first reported in 1861 by a British explorer on uncultivated coffee in the Lake Victoria region of Kenya in East Africa. The fungus is thought to originate from this region. In cultivated coffee, it was reported from Ceylon (now Sri Lanka) in 1867 (USDA-ARS SBML 2005). The disease decimated coffee production in Ceylon within 10 years (Ferreira and Boley, 1991). By the 1920's *H. vastatrix* was widespread in commercial coffee plantations in Africa and Asia (Ferreira and Boley, 1991). Because of the impact of *H. vastatrix*, tea replaced coffee as the primary cash crop in many British colonies (Christensen, 2003). *Hemileia vastatrix* was thought to be eradicated from Papua New Guinea three different times until it was reported to be widespread there in 1965 (Ferreira and Boley, 1991). In 1970, the disease was discovered in the Western Hemisphere for the first time in Bahia, Brazil (USDA-ARS SBML, 2005). From there, it quickly spread to neighboring countries, and by 1986 was reported from: Argentina, Bolivia, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Paraguay, Peru, and Venezuela (Ferreira and Boley, 1991). Currently, *H. vastatrix* is found in nearly every coffee growing region in the world, with the notable exception of Hawaii (Ferreira and Boley, 1991).

Recently, there has been increasing interest in *H. vastatrix* due to the possibility of new and more virulent strains of the pathogen affecting cultivars that were previously thought to be resistant. Although the fungus was detected for the first time in the 1980s in Puerto Rico, the reported strain was limited to certain coffee varieties at low altitude (Ramirez-Lluch, personal communication, 2015). The yield of the 2014-2015 crop was diminished; and coffee farmers attribute this to the severe attack of rust not seen before

(Ramirez-Lluch, personal communication, 2015). It is possible that the current outbreak is caused by a new fungal strain, similar to the situation that is happening in many coffee producing countries (Ramirez-Lluch, personal communication, 2015).

Pest Description

A rust fungus may produce as many as five different spore stages in its life cycle (Table 1). *Hemileia vastatrix* does not produce all five states (microcyclic). Pycnial/ spermagonial and aecial stages have not been observed. Like all rust fungi, *H. vastatrix* is an obligate parasite that requires living host cells.

Table 1. The five possible spore stages of a rust fungus.

STAGE	DESCRIPTION
0	Spermagonia bearing spermatia (n) and receptive hyphae (n)
I	Aecia bearing aeciospores (n+n)
II	Uredinia (uredia) bearing urediniospores (uredospores) (n+n)
III	Telia bearing teliospores (n+n → 2n)
IV	Basidia bearing basidiospores (n)

Hemileia vastatrix is a very unusual rust fungus. Its microcylic life cycle and urediniospore shape (Fig. 2) are very much different than the other rust fungi (Christensen, 2003). Urediniospores of other rust fungi are typically round to oval, but in *H. vastatrix* they are kidney-shaped (Fig. 4e) (Arneson, 2000). Germination occurs within 5 hours of inoculation between 21-29°C (70-84°F) in the presence of free water (Steiman, 2006). The role of the basidiospores remains uncertain. Thus, the prevailing but unproven hypothesis is that this rust species is heteroecious and that an alternate host, purportedly an orchid, exists in the center of origin or diversity of the genus *Coffea* in East-Central Africa (Carvalho et al., 2011). However, no alternate host is necessary; *H. vastatrix* can survive and reproduce by urediniospores alone (Arneson, 2000).

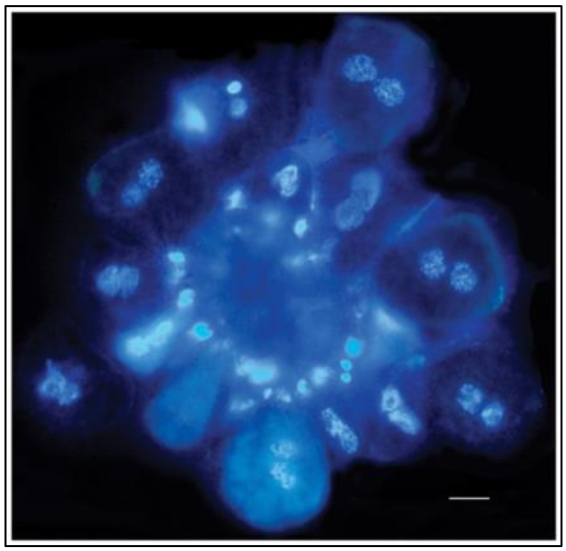

Figure 2. Uredinium of *Hemileia vastatrix* stained with DAPI. Series of nuclear events in the spore-mother cells and immature urediniospores (I–VII), prior to meiosis (bar = 10 µm). Photo from Carvalho et al. (2011), published under the creative commons attributions license.

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. 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 (Arneson, 2000).

Uredinia: "Hypophyllous, small, 0.1 mm across, dense, scattered or in rounded spots from a few mm in early infections to several cm in older infections, giving a yellowish-orange powdery appearance, then changing to pale yellowish, centers of old pustules sometimes becoming necrotic, emerging through stomata, or rarely through epidermis, composed of clavate hyphae whose tips bear numerous pedicels on which urediniospores produced in clusters; urediniospores more or less reniform, 26-40 × 18-28 μm, wall hyaline to pale yellowish, 1-2 μm thick, strongly warted on the convex side, smooth on the straight or concave side, warts frequently longer (3-7 μm) on spore edges" (USDA-ARS SBML, 2005).

Telia: "Hypophyllous, similar to uredinia, pale yellowish, teliospores often produced in uredinia; teliospores more or less spherical to limoniform, 26-40 × 20-30 μm diam., wall hyaline to yellowish, smooth, 1 μm thick, thicker at the apex, pedicel hyaline" (USDA-ARS SBML, 2005).

Spermogonia and aecia: unknown (USDA-ARS SBML, 2005).

Hemileia vastatrix exists in several races. The races arise as a result of mutation rather than genetic recombination (Christensen et al., 2003). Mutation of this pathogen has made it difficult to control.

Biology and Ecology

As described in Arneson, 2000:
"The disease cycle for *H. vastatrix* is a simple one. Urediniospores initiate infections that develop into lesions which produce more urediniospores. 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. *Hemileia vastatrix* survives primarily as mycelium in the living tissues of the host, and since infected leaves drop prematurely this effectively removes a huge amount of potential inoculum from the epidemic. However, 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".

"Temperature also influences *H. vastatrix* to the extent that normal urediniospore germination and other infection processes only occur between 15-30°C (59-86°F) (Brown et al. 1995). Brown et al. (1995) also showed that the mean minimum temperature is directly related to the severity of infection. Furthermore, as the number of days below 15°C (59°F) increases, the severity of the infection goes down."

Figure 3. Coffee leaves showing symptoms of coffee rust infection caused by *Hemileia vastatrix* in the field. Note the white growth around an old lesion caused by the hyperparasite *Lecanicillium lecanii* (b). Photo a courtesy of Cesar Calderon, USDA APHIS PPQ, Bugwood.org. Photos b, c courtesy of Howard F. Schwartz, Colorado State University, Bugwood.org.

"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. It takes 10 to 14 days from infection for new uredinia to develop and urediniospores to be formed. 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."

"Urediniospores can be dispersed by both wind and rain. 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 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."

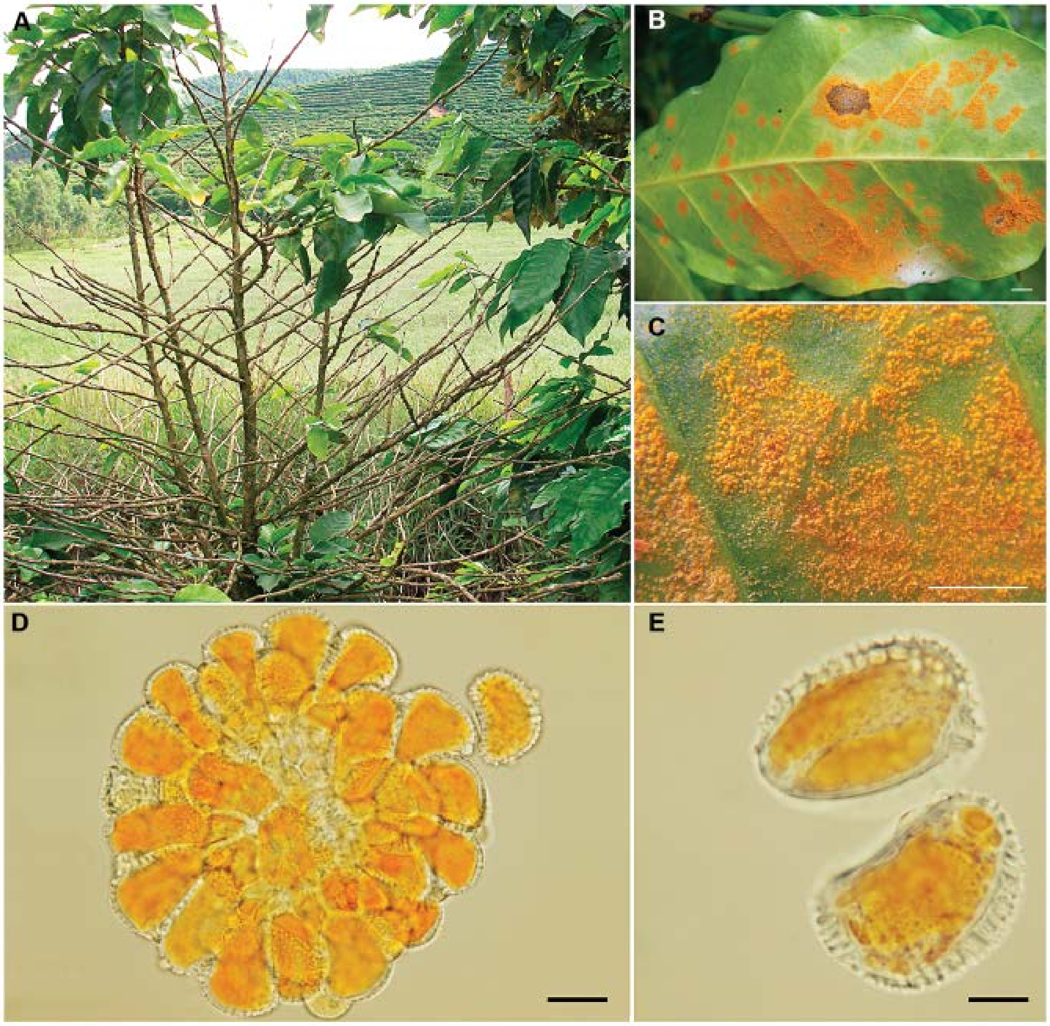

Figure 4. Symptoms and morphology of coffee leaf rust, *Hemileia vastatrix*. (**A**) Defoliation in a coffee plantation, Coimbra, Minas Gerais, Brazil; (**B**) Leaf symptoms on abaxial surface (bar = 0.5 cm); (**C**) Detail of suprastomatal uredinial pustules coalescing over lower leaf surface (bar = 0.5 cm); (**D**) Uredinium showing arrangement of spores (bar = 20 µm); (**E**) Urediniospores - showing the thickened, heavily-ornamented or verrucose upper wall – containing carotenoid lipid guttules imparting the yellow-orange color (bar = 10 µm). Photo from Carvalho et al. (2011), published under the creative commons attributions license.

Symptoms/Signs

Infections occur on the coffee leaves. The first observable symptoms are small, pale yellow spots on the upper surfaces of the leaves (Fig. 3). As these spots gradually increase in diameter, masses of orange urediniospores appear on the undersurfaces (Fig. 1, 3, 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 (Arneson, 2000). 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 (Arneson, 2000).

While the lesions can develop anywhere on the leaf, they tend to be concentrated around the margins, where dew and rain droplets collect (Fig. 3a). The centers of the spots eventually dry and turn brown (Fig. 3b,c), 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 (Fig. 4a) (Arneson, 2000).

In old lesions, a white cottony growth caused by the hyperparasite *Lecanicillium lecanii* can often be found (Fig. 3b) (Gaitán et al., 2015).

Significant reduction in photosynthetic rate can radically affect plant functions such as floral initiation and root and shoot growth. This can be followed by death of branches or even of the whole plant. Thus, yield loss is usually indirectly related to the severity of the disease (Brown et al., 1995). This reduced photosynthetic capacity and the heavy carbohydrate sink created by fruits limits the amount the growth of woody tissue that gives rise to the next season's crop. Therefore, the following season's crop is reduced. Losses due to coffee leaf rust can reach 70%, although 15 to 20% is more typical (Ferreira and Boley, 1991; Brown et al. 1995).

All *Coffea* genotypes are susceptible to *H. vastatrix* to some degree, though cultivars such as Timor and Icatu exhibit high resistance (Ferreira and Boley, 1991).

Pest Importance

"Coffee is one of the most valuable primary products in global trade, in many years second in value only to oil as a source of foreign exchange to producing nations. Cultivation, processing, trading, transportation, and marketing of coffee provide employment for hundreds of millions of people worldwide. Coffee is a crucial part of the economies and politics of many developing countries. For many of the world's least developed countries, exports of coffee account for over 50 percent of their foreign exchange earnings. Coffee is a traded commodity on major futures and commodity exchanges, most importantly in London and New York" (ICO, 2015).

Coffee rust is the most economically important coffee disease in the world (Arneson, 2000). In the 1870's and 1880's, coffee production was virtually wiped out in Asia and Africa by *H. vastatrix* (Ferreira and Boley, 1991; Christensen, 2003). The current (2014 to 2015) coffee rust outbreak in Latin America is the worst outbreak in the region since 1976 (ICO, 2015).

Coffee is grown commercially in Hawaii and several U.S. territories, including the Mariana Islands, Puerto Rico, and the U.S. Virgin Islands. In 2012, coffee was grown and harvested on 32,253 acres in Puerto Rico (USDA, 2012). In 2014, coffee was commercially harvested on a total of 7,900 acres in Hawaii, producing 8.1 million pounds of unroasted coffee beans valued at $54.2 million (USDA-NASS, 2015).

Known Hosts

Major hosts: *Coffea* spp. (coffee).

Important coffee hosts include *Coffea arabica*, *C. canephora*, and *C. liberica*.

Other hosts: *Gardenia thunbergia*, *Gardenia volkensii* (gardenia) (USDA-ARS SMML, 2005; CABI, 2015).

Known Vectors (or associated insects)

*Hemileia vastatrix*is does not have a known vector, nor is it known to vector any other organisms.

Known Distribution

Hemileia vastatrix has been reported in every coffee growing region in the world with the exception of Hawaii (Ferreira and Boley, 1991; EPPO, 2014). It is present in Africa, Asia, the Americas, and Oceania wherever coffee is grown (USDA-ARS SBML, 2005).

For a complete list of countries where *H. vastatrix* is known to be present, see USDA-ARS SMML (2005), EPPO (2014), or CABI (2015).

Pathway

Since 2005, there have been shipments of *Coffea* spp. propagative material to Hawaii from the Philippines (2) and Thailand (1) (AQAS, 2015). During the same time period, there have been shipments of *Gardenia* spp. to Hawaii (23) and Guam (6) from host countries (AQAS, 2015).

There have been 13 interceptions of *Gardenia* spp. destined for Hawaii and intended for propagation from host countries. There have also been 2 interceptions of *Coffea* spp. plant material intended for propagation from host countries (AQAS, 2015).

In addition to the shipments and interceptions of known host material, there have also been 33 interceptions of *Hemileia vastatrix* at U.S. ports of entry since 1984 (AQAS, 2015).

Potential Distribution within the United States

Coffee is not grown commercially in the continental United States. Hawaii is the most vulnerable tropical region with over 7,900 acres of total commercial production. Coffee is grown commercially on every major island of Hawaii with 2,000 acres planted in the famous Kona region (Harrington, 2011).

Hemileia vastatrix has been present in Puerto Rico since the 1980s. It has also been reported in the U.S. Virgin Islands and American Samoa (USDA-ARS SMML, 2005; Ramirez-Lluch, personal communication, 2015).

Survey

Approved Method for Pest Surveillance*:

The approved survey method is to collect symptomatic plant tissue by visual survey.

*For the most up-to-date methods for survey and identification, see Approved Methods on the CAPS Resource and Collaboration Site, at https://caps.ceris.purdue.edu/approved-methods.

Literature-Based Methods:

Visual symptoms of *Hemileia vastatrix* infection are well described (Ferreira and Boley, 1991; Arneson, 2000; USDA ARS-SBML, 2005; Carvalho et al., 2011).

This pathogen has a limited known host range. *Gardenia* spp. is reported as a host in South Africa, but the known host range of *H. vastatrix* outside of South Africa is limited to *Coffea* spp. (USDA-ARS SMML, 2005).

Key Diagnostics

Approved Method for Pest Surveillance*:

Morphological: The characteristic symptoms on coffee and the characteristics of the urediniospore can be utilized to morphologically distinguish *H. vastatrix*.

*For the most up-to-date methods for survey and identification, see Approved Methods on the CAPS Resource and Collaboration Site, at https://caps.ceris.purdue.edu/approved-methods.

Literature-Based Methods:

The characteristic rust lesions occurring as patches of yellow to orange sporulation on the undersides of leaves are diagnostic for coffee leaf rust disease (CABI, 2015). Characteristics of this fungus are described in USDA-ARS SBML (2005) and Carvalho et al. (2011).

Easily Confused Species

Hemileia vastatrix is similar to *H. coffeicola* which causes a powdery rust of *Coffea* spp; *H. coffeicola* is of minor significance and restricted to the more humid areas of Africa. It characteristically produces scattered uredinia over the entire leaf surface in contrast to the blotches produced by *H. vastatrix*; urediniospores of *H. coffeicola* also have fewer and larger spines (CABI, 2015).

Aecidium travancoricum is reported from South India and produces spermogonia and aecia on *Coffea travancorensis* (USDA-ARS SBML, 2005). Although not studied, there may be a possible connection between this rust and *Hemileia vastatrix* for which spermogonia and aecia are not known.

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