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Global rust belt: *Hemileia vastatrix* and the ecological integration of world coffee production since 1850

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Abstract

The quantitative growth of coffee production and consumption in the nineteenth and twentieth centuries produced qualitative transformations along every step of the coffee commodity chain. The economic integration of the global coffee market in this period triggered major east–west biological exchanges between the world's coffee regions. The global epidemic of coffee leaf rust, caused by the fungus **Hemileia vastatrix**, *illustrates the ecological and economic impact of such exchanges. Between 1865 and 1985, the epidemic spread from its original focus in Ceylon to engulf all of the world's coffee zones. Its economic impact varied considerably: in some places it destroyed more than 90% of the coffee crop, while in others it was little more than a minor irritant. The epidemic's origins, its diffusion, and its impacts were not accidental, but reflected specific conjunctures of local and global biological and historical processes.*

Introduction

Coffee was one of the first tropical crops to become a truly global commodity. By the early eighteenth century, coffee commodity chains spanned the globe, linking consumers in Europe (and increasingly in North America) with producers in Africa, Asia, and Latin America. This first global economy was transformed – and to a large extent re-created – by the growth of mass markets for coffee in the nineteenth and twentieth centuries. The quantitative expansion in coffee production and consumption in these two centuries produced qualitative transformations along every step of the coffee commodity chain. The global coffee market became much more tightly integrated.[1] In studying this process, historians have generally focused on the industry's economic and political structures, and on the 'north–south' connections between producers and consumers. Fewer studies have looked at the emergent 'east–west' connections *between* coffee-producing regions during this same period.

1 Steven Topik, 'The integration of the world coffee market', in William Gervase Clarence-Smith and Steven Topik, eds., *The global coffee economy in Africa, Asia, and Latin America, 1500–1989*, Cambridge: Cambridge University Press, 2003, pp. 21–49.

The integration of the global market triggered major east–west biological exchanges between the world's coffee regions. Over the nineteenth and twentieth centuries, these exchanges grew in scale and complexity, transforming coffee ecosystems around the world. They included the movement of people (coffee planters, agronomists, labourers); of plants (new varieties, and species of coffee); of ideas and techniques (monoculture, shade, chemical inputs); and of pathogens (diseases and pests). As with earlier ecological exchanges, these processes were often interconnected and self-reinforcing.[2] These movements could radically transform ecological and economic relations both within particular coffee zones, and between distant coffee zones. For example, the outbreak of a new coffee disease could swiftly eliminate an infected coffee region's comparative advantage over its competitors. As these exchanges transformed coffee ecosystems over the nineteenth and twentieth centuries, each region's comparative advantage became increasingly volatile.

The outbreak of coffee leaf rust – the first global epidemic disease of coffee – illustrates the impact of such ecological exchanges. The disease, caused by the fungus *Hemileia vastatrix*, debilitated coffee plants rather than killing them outright. Its behaviour led one British scientist to dub it the 'malaria of coffee'.[3] It first appeared as an epidemic in Ceylon and southern India in 1869. Over the next century, it spread around the globe in three waves. Between 1870 and 1920, it spread through the coffee zones of the Indian Ocean Basin and the Pacific. In the 1950s and 1960s, it broke out in the burgeoning coffee farms of West Africa. It finally crossed the Atlantic Ocean in the late 1960s, and during the 1970s and 1980s it spread throughout the coffee zones of the Americas. Its economic impact varied considerably: in some coffee zones it destroyed more than 90% of the crop, while in others it was little more than a minor irritant. This epidemic – like all epidemics in crops, livestock, and people – may have been accidental, but it was not random. Its origins, its diffusion, and its impacts all reflected specific conjunctures of local and global biological and historical processes.[4]

The coffee rust contained, 1500–1869

The coffee rust fungus is widespread in the wild coffees of Ethiopia, albeit generally in levels low enough that it does not cause much harm to the plant. Between the fifteenth and the mid-nineteenth centuries, the coffee plant was disseminated across the global tropics, but the coffee rust was contained to eastern Africa. The world's cultivated coffee remained free of the rust – or any other major diseases and pests – until the mid-nineteenth century. Given the widespread presence of rust on wild coffees, its long absence on the world's cultivated coffees requires some explanation.

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2 Alfred Crosby, *Ecological imperialism: the biological expansion of Europe, 900–1900*, Cambridge: Cambridge University Press, 1986; William Beinart and Karen Middleton, 'Plant transfers in historical perspective: a review article', *Environment and History*, 10, 2004, pp. 3–29.

3 A. Leechman, 'The story of *Hemileia vastatrix*: 'Ceylon leaf disease' and its lessons', in J. H. McDonald, *Coffee growing: with special reference to East Africa,* London: East Africa, 1930, p. 22.

4 The same was true for other tropical commodities. For bananas, see John Soluri, *Banana cultures: agriculture, consumption & environmental change in Honduras & the United States*, Austin: University of Texas Press, 2006; for sugar, see Stuart McCook, *States of nature: science, agriculture and environment in the Spanish Caribbean, 1780–1940*, Austin: University of Texas Press, 2002, pp. 77–104.

The coffee plant and the rust fungus co-evolved over many millennia in equatorial Africa. The genus *Coffea* is composed of nearly one hundred species, which grow wild in equatorial Africa and Madagascar, occupying a wide range of ecological niches. The main commercial species of coffee is arabica coffee (botanically, *Coffea arabica*). Wild arabica coffee grows in the comparatively cool and dry mountain environments of southwestern Ethiopia and northern Kenya. Other species, such as robusta coffee (*C. canephora* var. robusta), are much more widely distributed across the hot and humid tropical lowlands of central and western Africa.[5] *H. vastatrix* can survive only on plants of the genus *Coffea,* and a few closely allied genuses. All species of *Coffea* show some resistance to *H. vastatrix*, although the degree of resistance varies greatly. The rust fungus begins its life cycle as a tiny spore. The spore will germinate, if it is deposited on the underside of a coffee leaf, if the air temperature is between 15 and 28 degrees centigrade, and if liquid water is present. It then penetrates the leaf and sends shoots into the leaf tissue. Ultimately, these shoots produce spore buds that pierce back out through the underside of the leaf, forming circular orange pustules of powdery spores. Each pustule can contain as many as 100,000 spores, which can begin the cycle of infection anew. During a severe rust outbreak, the leaves of the coffee plant become covered in these pustules, causing the leaves to fall prematurely. This deprives the coffee plant of vital nutrients that it obtains through the leaves via photosynthesis. Repeated infections debilitate the plant, sometimes causing dieback of branches, and reducing the yield of coffee berries.[6]

Each rust spore contained tremendous destructive potential, but in the wild that potential was seldom realized. In the wild, rust spores can remain viable for several weeks; under laboratory conditions they can remain viable for several months. They could also be easily dispersed by winds and rain, or by the many insects, animals, and people that pass through the ecosystem. Yet while the rust was widely distributed on wild arabica, a botanical study found that it was 'common or serious in only a few localities. In most areas it is found only on a few leaves on scattered trees.'[7] The intensity of coffee rust infections in the wild was kept in check by a combination of factors, including the biological diversity of the forest, the genetic resistance of the coffee plant, the climate, and parasites that attack the rust fungus. Coffee consumption in pre-colonial Africa did little to alter the relationship between the plant and the pathogen, since most coffee was harvested from wild plants.[8]

The relationship between the plant and the rust began to change after about 1500, as coffee drinking gained popularity in the Islamic world and Europe. Coffee cultivation began on the Arabian Peninsula when the forests of eastern Africa were no longer able to produce

5 Julien Berthaud, 'L'origine et la distribution des caféiers dans le monde', in Michel Tuchscherer, ed., *Le commerce du café avant l'ère des plantations coloniales: espaces, réseaux, sociétés*, Cairo: IFAO, 2001, pp. 361–70; Gordon Wrigley, *Coffee*, Harlow: Longman, 1988, pp. 61–75, 135; Frederick L. Wellman, *Coffee: botany, cultivation, and utilization*, London: Leonard Hill, 1961, pp. 63–5, 171–3.

6 A. C. Kushalappa, 'Biology and epidemiology', in Ajjamada C. Kushalappa and Albertus B. Eskes, eds., *Coffee rust: epidemiology, resistance, and management*, Boca Raton: CRC Press, 1989, pp. 16–76; Wellman, *Coffee*, pp. 253–60.

7 C. A. Krug and R. A. de Poerck, *World coffee survey*, Rome: FAO, 1968, pp. 15–17.

8 Charles G. H. Schaefer, 'Coffee unobserved: consumption and commoditization of coffee in Ethiopia before the eighteenth century', in Tuchscherer, ed., *Le commerce du café*, pp. 23–34; Wrigley, *Coffee*, pp. 54–8.

enough wild coffee to meet demand. While the coffee plant prospered on the Arabian Peninsula, *H. vastatrix* did not. The region suffers from an acute shortage of rainfall, thus depriving the rust of the water droplets it requires to germinate and reproduce. It is arguably the driest coffee zone in the world. The Arabian Peninsula's harsh environment then, created an accidental but highly effective ecological filter against the rust. This is critical, since the Arabian Peninsula was the genetic fountainhead for all the coffee plants diffused globally between 1650 and 1850.[9] India's coffee industry was founded on coffee seeds taken from the Arabian Peninsula. The Dutch, French, and British also visited the Arabian Peninsula repeatedly to obtain coffee seeds or plants for their expanding tropical empires in Africa and Asia. The progeny of these plants also formed the genetic basis for the New World's coffee industry. Before the mid-nineteenth century, none of the coffee cultivated outside eastern Africa was descended from seeds or plants obtained directly from coffee's wild range. It all descended – directly or indirectly – from a cultivated coffee zone singularly free of rust. The health of the world's cultivated coffee had been preserved by an accident of ecology and history.[10]

Imperial epidemic: the coffee rust outbreak in Ceylon and southern India, 1869–1885

In the mid-nineteenth century the ecological *Pax Arabica*, which had preserved the health of the world's cultivated coffee until then, began to unravel. Major rust outbreaks in Ceylon and southern India were reported almost simultaneously in 1869 and 1870. The timing and location of these outbreaks were not random. Rather, they were a consequence of European – especially British – imperial expansion in the Arabian Sea. These imperial ventures produced regional and global pandemics of human diseases such as malaria, smallpox, and plague – and of animal diseases, such as rinderpest.[11] The same processes also shaped the history of crop diseases. Imperial expansion provoked epidemics in two main ways: it accelerated the spread of pathogens, and it altered colonial environments in ways that favoured epidemics. With respect to the coffee rust, British activity in the Arabian Sea accelerated the direct movement of goods and people – and by extension plants and pathogens – between eastern Africa, India, and Ceylon. British settlers in Ceylon and southern India created the ecological conditions that allowed the coffee rust to flourish.

The spores could have followed many routes across the Arabian Sea. One theory suggests that *H. vastatrix* may have been carried from eastern Africa to Ceylon on the monsoon winds. The spores may have originated in the small coffee farms then being established in

9 Michel Tuchscherer, 'Coffee in the Red Sea area from the sixteenth to the nineteenth century', in Clarence-Smith and Topik, eds., *The global coffee economy,* pp. 50–5; Krug and de Poerck, *World coffee survey*, pp. 364–8.

10 Wrigley, *Coffee*, pp. 40–50. See also F. Anthony, M. C. Combes, C. Astorga, B. Bertrand, G. Graziosi, P. Lashermes, 'The origin of cultivated *Coffea arabica* L. varieties revealed by AFLP and SSR markers', in *Theoretical and Applied Genetics*, 104, 2002, pp. 894–900.

11 See J. N. Hays, *The burdens of disease: epidemics and human response in western history*, New Brunswick: Rutgers University Press, 1998, pp. 178–211. On rinderpest, see Pule Phoofolo, 'Epidemics and revolutions: the rinderpest epidemic in late nineteenth-century Southern Africa', *Past and Present*, 138, February 1993, pp. 112–43.

Ethiopia, especially around Harar and Kaffa.[12] They may have been carried to India and Ceylon in the kit of British soldiers returning from a military expedition to Ethiopia in the late 1860s.[13] Or they may have travelled in packing material that held the ivory and other goods being shipped from eastern Africa to India. Direct trade links between the two regions had increased under British hegemony, and existing supply routes were extended deeper into the African interior. Some of these routes reached regions where the rust was endemic in the wild, such as Lake Victoria.[14] British explorers also passed through the coffee zones of Ethiopia in the 1850s.[15] It was on one of these expeditions that a European naturalist first collected samples of the rust fungus in the wild.

Ironically, a British innovation in the botanical sciences may have done the most to diffuse the disease. In the 1820s, a botanist at the Royal Botanic Gardens in Kew developed a small travelling greenhouse, known as a Wardian case.[16] This innocuous invention created new possibilities for global biological exchanges. Coffee planters around the world embraced this new technology, which unleashed an unprecedented global circulation of coffee plants. Between 1865 and 1880 alone, live coffee plants were introduced to Ceylon from Jamaica, British Guyana, Cuba, Liberia, and Java. The fungus may have been introduced to Ceylon in 1866, on a shipment of Liberian coffee plants (*Coffea liberica*). Wild coffee plants from that part of West Africa were heavily infected with a disease that may have been the rust.[17] This emergent global exchange of live coffee plants, including wild coffee plants obtained in Africa, greatly increased the opportunities for the rust to circulate. Given the variety of contacts across the Arabian Sea, it seems likely that rust spores were introduced more than once, by different routes. Most of these introductions likely had little effect, since the spores did not come into contact with susceptible coffee plants. But on one or two occasions, they did.

The coffee plantations of South Asia were, at that historical moment, especially vulnerable to rust outbreaks. As European coffee planters established coffee estates in the region during the 1830s and 1840s, they introduced new forms of coffee cultivation. Unlike the mixed gardens favoured by the local farmers, European planters tended to specialize in a single crop. In the 1840s, European coffee planters from the West Indies introduced the 'West Indian' system of cultivation, which dispensed with shade trees. This practice increased yields dramatically over the short term: between 1849 and 1869, Ceylon's coffee

12 Richard Pankhurst, *Economic history of Ethiopia, 1800-1935*, Addis Ababa: Haile Selassie I University Press, 1968, pp. 198–204.

13 Wrigley, *Coffee*, p. 314–15.

14 Abdul Sheriff, *Slaves, spices, and ivory in Zanzibar*, London: James Currey, 1987, pp. 155–90.

15 Pankhurst, *Economic history of Ethiopia*, pp. 199–200.

16 Lucile Brockway, *Science and colonial expansion: the role of the British Royal Botanic Gardens*, New Haven: Yale University Press, 2002, pp. 86–7.

17 James L. A. Webb, *Tropical pioneers: human agency and ecological change in the highlands of Sri Lanka, 1800–1900*, Athens: Ohio University Press, 2002, p. 111; H. Marshall Ward, 'Researches on the life-history of *Hemileia vastatrix*, the fungus of the "coffee-leaf disease"', *Journal of the Linnean Society of London – Botany*, 19, 1882, pp. 310–19; A. M. & J. Ferguson, *The planting directory for India and Ceylon*, Colombo, 1878; A. Crüwell, *Liberian coffee in Ceylon; the history of the introduction and progress of the cultivation up to April, 1878,* Colombo: A. M. & J. Ferguson, 1878, pp. 34, 40, 51.

exports tripled. At its height, Ceylon was the world's third-largest exporter of coffee.[18] The settlers' focus on maximizing coffee production had greatly increased the density of potentially susceptible coffee plants. By eliminating shade trees and windbreaks, they had also removed most physical obstacles to the diffusion of coffee diseases. This vulnerability was exacerbated by the region's climate. The region was visited by regular monsoons that could shower as much as 5,000 mm of rain annually, which could potentially accelerate the germination and diffusion of rust spores. Still, coffee planters at the time had little reason to recognize their vulnerability to a rust epidemic, since it had never been found in the world's cultivated coffee.

After the initial outbreak, it took several years for coffee planters to realize the epidemic's destructive potential. The severity of the outbreak varied from one year to the next, depending primarily on the rainfall. Paradoxically, the years following the initial outbreak were among the most productive in Ceylon's history. But over the longer term, it inexorably reduced yields to below the level at which coffee production was economically viable. By the mid-1870s, planters had begun to abandon infected coffee farms to open new ones in disease-free areas. Those new areas did not, however, remain free of the rust for long as the spores were carried quickly from one zone to the next. It proved impossible to contain them. Between 1870 and 1877, coffee production in Ceylon dropped by almost a third, even though the total area under coffee production had increased by 52,000 acres. Economic losses from the rust in Ceylon reached almost £2,000,000 per annum.[19] In southern India – in Wynaad, Travancore, and the Nilgiris hills – the coffee rust produced similar catastrophic losses. 'Acre after acre, mile after mile died out,' wrote one contemporary observer, 'and what were once happy valleys became valleys of dry bones and there was no hope of resurrection.'[20]

Coffee planters and the colonial governments alike struggled to understand and confront this ecological catastrophe. In Ceylon, scientists at the Royal Botanical Garden at Peradeniya conducted field studies of the disease, and recommended that infected coffee farms be destroyed. Some people argued that the fungus was a symptom of the disease, rather than its cause. Others argued that declining yields had been caused by soil exhaustion rather than the rust. To address these questions, a young botanist named Harry Marshall Ward was sent to Ceylon in 1880. Ward conducted a series of meticulous laboratory and field studies of the fungus, and showed conclusively that it was the cause of the disease. He was also the first person to prove the connection between the epidemic and the prevailing agricultural practices. 'Having provided immense quantities of suitable food [the coffee plant], carefully preserved and protected,' concluded Ward, 'man unconsciously offered just such conditions for the increase of this fungus as favour the multiplication of any organism whatever.'[21]

Ward's brilliant research offered important scientific insights into the disease, but offered coffee farmers no practical means to control it. In the absence of formal scientific research, many coffee planters conducted experiments of their own. They drew upon on

18 K. M. de Silva, *A history of Sri Lanka,* London: C. Hurst, 1981, pp. 284–6; Webb, *Tropical pioneers,* pp. 60–2, 69–70, 113.

19 D. Morris, 'Note on the structure and habit of *Hemileia vastatrix*, the coffee-leaf disease of Ceylon and Southern India 1880', *Journal of the Linnean Society – Botany*, 17, 1878–80, pp. 512–17.

20 S. Muthiah, *A planting century: the first hundred years of the United Planters' Association of Southern India, 1893–1993*, New Delhi: Affiliated East-West Press Private Ltd., 1993, p. 128.

21 H. M. Ward, 'Research on the life-history of *Hemileia vastatrix*', pp. 334–5.

their own field experience, and also on the latest agricultural ideas and technologies from Europe, North America, and elsewhere in the tropics. They experimented with new coffee seeds, sprays of sulphuric acid and other chemicals, 'rest cures', and manuring.[22] They discussed strategies for disease control in the region's many newspapers, and in a new journal, the *Tropical Agriculturist*, founded in 1881. This journal became an important vehicle for circulating new agricultural knowledge throughout the tropics. Before the 1930s, most coffee research in the Old World would be sponsored by private interests rather than the colonial state or colonial research institutions.[23]

In the end, most coffee planters in Ceylon and southern India adapted to the epidemic by abandoning coffee cultivation altogether. By the mid-1880s, the disease had run its course through the region, and most of the coffee industry was in ruins. The severity of the disease – a product both of the socially constructed coffee landscapes and the climate – made the continued cultivation of arabica coffee virtually impossible. It continued only in a few isolated areas, such as the slopes of the western Ghats, where the climate was comparatively dry, and where coffee was cultivated as a forest crop. The epidemic proved more catastrophic for some coffee growers than it did for others. Many of Ceylon's Sinhalese coffee planters went bankrupt when the colonial state began to tax them more aggressively, to compensate for its own shortfall in coffee revenues. European planters, on the other hand, borrowed from outside sources of capital and switched to new cash crops. While colonial scientific institutions had not been able to solve the epidemic, they had least offered the European settlers some alternative crops. The botanical garden at Peradeniya had introduced rubber, cinchona, cocoa, and tea to the region, and had proven that they could be cultivated profitably.[24] Tea came to dominate the landscapes of Ceylon and southern India.

From epidemic to global pandemic: coffee rust in the Old World, 1875–1920

Over the next half century, the disease spread through the coffee farms of the Indian Ocean basin and the Pacific. The initial outbreak of the disease in each coffee zone produced a crisis, which required coffee planters to adapt to the new ecological conditions of production. By the eve of the First World War, it had contributed to the dramatic collapse of the coffee industry in Africa, Asia, and the Pacific. By 1913, the region produced only 5% of the world's coffee, down from almost 30% in the mid-nineteenth century. As William Clarence-Smith has shown, there were a 'bewildering variety of responses' to the epidemic, reflecting the particular combination of ecological, economic, political, and social factors in each area.[25] The rust epidemic, however, marked a nadir in the region's coffee production.

22 'The planters suggest remedies', *Tropical Agriculturist* (Ceylon) 1 (1881–2), pp. 217, 426, 497–8, 587, 605, 733, 764, 855. Cited in J. A. Stevenson and R. Beam, *An annotated bibliography of coffee rust*, Beltsville, Maryland: USDA, 1953, p. 7.

23 This was also true for sugar. See William Kelleher Storey, *Science and power in colonial Mauritius*, Rochester: University of Rochester Press, 1997.

24 Webb, *Tropical pioneers*, pp. 117–46.

25 W. G. Clarence-Smith, 'The coffee crisis in Africa, Asia, and the Pacific', in Clarence-Smith and Topik, *The global coffee economy*, pp. 100–1, 118–19.

After about 1910, coffee producers developed strategies for managing the rust epidemic, and coffee production began to increase.

The epidemic spread first to distant regions connected to each other by trade and empire, often skipping over major coffee-growing regions between. Some British coffee planters from Ceylon and southern India migrated to other parts of the Indian Ocean Basin and established new coffee plantations. In fleeing the coffee rust, they may have helped circulate it. Two of the first places that the rust was detected beyond the Indian subcontinent were the British colonies of Natal (1878) and Fiji (1879), at the opposite poles of the British empire in the Old World. The rust spores may also have been carried to Fiji by migrant field labourers from India. They had certainly carried smallpox and cholera to Fiji in 1879, the same year that the coffee rust broke out there.[26] British coffee planters from Ceylon may also have introduced the rust to Madagascar as early as 1872,[27] and to Java, one of the world's major coffee producers, in 1876.

The rust also spread through the region by other routes, following prevailing patterns of trade, communication, and wind. The small arabica coffee farms in German and British East Africa, where arabica cultivation began between 1890 and 1920, faced the threat of rust from two fronts. One threat was the introduction of rust from an infected region of the Indian Ocean. The other was that rust might spread from stands of wild coffee, as arabica coffee cultivation expanded into *Coffea*'s native range.[28] In 1903, the rust made a dramatic leap across the globe, reaching Puerto Rico on a shipment of coffee seedlings from Java. Fortunately, an alert American scientist at the Mayagüez agricultural experiment station recognized the symptoms and destroyed all the infected plants immediately before the disease could spread to the island's coffee farms.[29] This is the only documented instance of coffee rust in the Americas before 1970; it shows just how easily the disease *could* have established itself in the Americas much earlier than it did.

In the Old World coffee zones the rust spread so rapidly that it could neither be eradicated nor contained. During the 1880s and 1890s, then, the epidemic produced a massive contraction of the Old World's arabica coffee frontiers. This ecological disaster was compounded by a sharp fall in the global price of coffee. The combination of intensive rust infections and low prices for coffee pushed many coffee producers to abandon coffee and switch to other crops. The epidemic caused the greatest losses in the warm and wet tropical lowlands – under about 1,400 metres – where the environmental conditions favoured the fungus's growth and dispersal. In the lowlands of Java and Sumatra, the rust reduced production by between 30 and 50% in a single season. Ultimately, arabica coffee in Java was abandoned at altitudes below 1,000 metres.[30] The arabica coffee zones of coastal Madagascar and Réunion suffered a similar fate. Production in Réunion's already ailing coffee

26 Hays, *The burdens of disease*, pp. 184, 187–90.

27 G. Bouriquet, *Les maladies des plantes cultivées à Madagascar*, Paris: Paul Lechevalier Éditeur, 1946, p. 139.

28 Leechman, 'The story of *Hemileia vastatrix*', p. 16; Mervyn F. Hill, *Planters' progress: the story of coffee in Kenya,* Nairobi: Coffee Board of Kenya, 1956, p. 23.

29 Frederick L. Wellman, *Hemileia vastatrix,* San Salvador: FEDECAME, 1957, pp. 9–12.

30 'Leaf disease in Netherlands India', *Tropical Agriculturist*, 5, 1 September 1885, p. 198; William H. Ukers, *All about coffee*, 2nd edn, New York; *The Tea and Coffee Trade Journal*, 1935, p. 188.

industry declined by 75% in the 1880s and 1890s.[31] The Philippines was the world's fourth-largest exporter of coffee in 1889, the year the rust was first detected there. Between 1889 and 1892, coffee exports dropped from 16 million pounds to virtually nothing.[32] By 1900, arabica coffee cultivation in the Old World had retreated to a handful of highland enclaves where cooler temperatures and distinct dry seasons kept rust levels low enough to keep arabica cultivation viable. Enclaves of arabica cultivation survived on the Western Ghats in India, and in the highlands of Java and Sumatra above 1,000 metres.[33] New arabica cultivation zones were opened in the interior highlands of Madagascar, and in eastern Africa along the slopes of Mount Kilimanjaro and the hills north and west of Nairobi. The rust became a major constraint on the opening of new pioneer fronts, foiling attempts to cultivate arabica in Uganda and in lowland regions of Kenya and Tanganyika.

The rust epidemic sparked a considerable amount of field research on rust control specifically, and coffee agriculture generally. Most of this research, however, was conducted by coffee planters – colonial research institutions devoted surprisingly little attention to coffee before the 1930s. Coffee planters in India experimented with new chemical sprays recently developed in Europe, such as the Bordeaux mixture. These sprays did help reduce levels of *H. vastatrix*, although they were only effective in places with well-defined dry seasons. They were also quite expensive, requiring added expenditures for equipment, chemicals, and labour.[34] The planters' preferred strategy was to find or to develop rust-resistant strains of coffee. Planters in India discovered one such variety in the field, which they baptized 'Coorg' coffee. This variety was widely cultivated in India until the early twentieth century, when planters discovered that it was apparently losing its resistance to rust. This field observation led to an important scientific discovery. A British scientist, Wilson Mayne, concluded that the apparent 'breakdown' of rust resistance in Coorg coffee was caused by the emergence of new varieties (known scientifically as 'races') of *H. vastatrix*. These new races had virulence genes that overcame Coorg coffee's resistance genes. This local discovery had global consequences – since Mayne's initial discovery, scientists have identified more than thirty other races of *H. vastatrix*, and new ones continue to appear.[35]

European planters in Java also searched for rust-resistant coffee, importing and acclimatizing new varieties and species from around the globe. In 1900, they imported a newly identified species of coffee known as robusta coffee (*C. canephora* var. robusta). The robusta plant was highly resistant to the rust – although not completely immune – and it flourished in the hot and humid lowlands, where the rust had devastated arabica production. It had only one significant limitation – its beans produced a drink whose taste has charitably been described as 'flat'. Consequently, robusta coffee fetched a lower price

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31 Gwyn Campbell, 'The origins and development of coffee production in Réunion and Madagascar, 1711–1972', in Clarence-Smith and Topik, *The global coffee economy*, pp. 70–1; J. Buis, *L'Hemileia et l'avenir du caféier à Madagascar et à la Réunion*, Paris: Challamel, 1907.

32 Ukers, *All about coffee*, pp. 192, 210; Benito J. Legarda, *After the galleons: foreign trade, economic change, and entrepreneurship in the nineteenth-century Philippines*, Madison: University of Wisconsin Press, 1999, pp. 115, 117, 335.

33 W. Wilson Mayne, 'Control of coffee leaf disease in southern India', *World Crops*, 23, 1971, p. 206.

34 Mayne, 'Control of coffee leaf disease', pp. 206–7; Wellman, *Coffee*, p. 260.

35 Muthiah, *A planting century*, pp. 353–7; Wellman, *Coffee*, pp. 258–9; Eskes, 'Resistance', in Kushalappa and Eskes, eds., *Coffee rust*, pp. 210–11. 'Race' is a standard term in plant pathology for describing forms of a

than arabica coffee.[36] The eminent botanist P. J. S. Cramer, director of Java's recently established coffee research station at Bangelan, saw robusta's commercial potential. Cramer's staff began experiments to breed and propagate robusta at a coffee station near Malang and the Economic Garden in Buitenzorg (Bogor). In 1906, the Dutch colonial government began promoting robusta cultivation, both as a substitute for arabica coffee, and as a catch crop in the rubber zones, to provide rubber growers with some income while their trees matured. The program was so successful that other former arabica producers in the Old World also began to cultivate robusta, using domesticated strains developed in Java.[37]

The spread of robusta coffee resurrected many of the Old World's disease-wracked arabica farms, although few coffee zones recovered their previous levels of productivity or profitability. Demand for robusta grew in the early twentieth century, initially propped up by colonial taxes and tariffs. Consumers in parts of Europe and later North America developed a taste for robusta. The global robusta market received a big boost in 1929, when the United States Department of Agriculture (USDA) authorized the importation of robusta coffee. Industrial coffee roasters there used robusta coffee as an inexpensive filler in their pre-packaged blends.[38] By 1935, robusta accounted for almost 94% of the coffee cultivated in Java and 93% of coffee cultivated in Sumatra. Between 1910 and 1930, coffee exports from Madagascar – mostly robusta – expanded from 10 tons to 6,000 tons. Robusta exports from Madagascar and other French colonies increased even further after the French government established a preferential colonial tariff and began subsidizing coffee planters in the early 1930s.[39] In the 1920s, the British administration in Uganda began to encourage African smallholders to cultivate robusta coffee, after attempts to cultivate arabica had failed. By 1939 Uganda exported a greater volume of coffee than did neighbouring Kenya, although the value of Uganda's robusta exports was less than half Kenya's arabica exports.[40]

By the eve of the Second World War, coffee producers in the eastern hemisphere had adapted to the coffee rust, using a range of strategies. Institutionalized scientific research played a surprisingly small role in this process of adaptation. Nonetheless, coffee planters produced a considerable amount of new practical agronomic knowledge about the behaviour of the coffee plant and the coffee rust, often drawing upon scientific knowledge produced elsewhere. Only in the early decades of the twentieth century, after the rust had largely run its course, did European colonial governments begin to provide sustained institutional support for research into the coffee rust specifically, and coffee agriculture more generally. The adoption of robusta coffee permitted the resurrection of former coffee zones

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pathogen that attack a particular variety of a host plant. See George N. Agrios, *Plant pathology*, 5th edn, Amsterdam: Elsevier, 2005, p. 134.

36 Wellman, *Coffee*, p. 258; Wrigley, *Coffee*, pp. 54–8; Eskes, 'Resistance', p. 225.

37 Leechman, 'The Story of *Hemileia vastatrix*', pp. 15–16; P. J. S. Cramer, *A review of literature of coffee research in Indonesia*, translated and edited by Frederick L. Wellman, Turrialba, Costa Rica: IICA, 1957, pp. 8–11.

38 Ukers, *All about coffee*, p. 188; Mark Pendergrast, *Uncommon grounds: the history of coffee and how it transformed the world*, New York: Basic Books, 1999, pp. 152–3; Wrigley, *Coffee*, p. 57.

39 Campbell, 'Coffee in Réunion and Madagascar', pp. 76–83; Ukers, *All about coffee*, p. 183.

40 J. D. Tothill, *Agriculture in Uganda*, London: Oxford University Press, 1940, pp. 289–311; J. K. Matheson and E. W. Bovill, *East African agriculture*, London: Oxford University Press, 1950, pp. 85–93; 229–30 [price and export data from p. 94]; Ukers, *All about coffee*, p. 196.

and the opening of new coffee zones. The rust epidemic produced a hemispheric specialization of the global coffee economy. It gave coffee planters in Latin America a decisive comparative advantage in arabica coffee production, while producers in Africa, Asia, and the Pacific dominated robusta production. This regional specialization persisted for most of the twentieth century.

Rust, robusta, and colonial modernization: the epidemic in West Africa, 1950–1970

Between 1920 and 1950, the coffee rust epidemic ground to a virtual standstill. It remained endemic in eastern Africa, Asia, and the Pacific, but spread no farther. The coffee zones of western Africa and Latin America remained apparently free of the rust. The epidemic was held in check in part by quarantines, in part by the geographical barriers that separated the healthy zones from the infected zones, in part by simple luck, and in part by the stagnant global coffee economy produced by the Great Depression and the Second World War. The revival of the global coffee economy after the war, however, contributed to a renewed movement of the rust in central and western Africa, although this rust pandemic did not cause the same kind of economic and social dislocations as had the previous rust outbreaks. Since the vast majority of coffee growers in the region cultivated robusta coffee, the rust's spread had only a minimal impact on production.

The postwar coffee boom led to a dramatic expansion of coffee cultivation in central and western Africa, setting the stage for the renewed circulation of the rust. The boom was fuelled by the global coffee market, reflecting a resurgence of global demand after the Second World War, and global supply shortfalls following a frost in Brazil's coffee zones in 1953. Coffee prices reached record highs in the second half of the 1950s. Political changes in the region also helped promote coffee cultivation. European colonial governments and African nationalist leaders alike saw coffee exports as a vehicle to promote economic development. Coffee cultivation expanded rapidly; between 1940 and 1965 the area under coffee cultivation in the Ivory Coast grew from 60,000 hectares to 535,000 hectares. Other countries saw proportionally similar increases. By the early 1960s, Africa produced 25% of the world's coffee, up from its nadir of 1.3% at the beginning of the century.[41] As with the coffee boom a century before, this rapid expansion of coffee cultivation in primarily hot and humid areas produced agricultural landscapes that were vulnerable to the rust.

There were so many possible avenues of infection that it would have been virtually impossible for coffee producers in central and western Africa to avoid this epidemic. The rust was first reported in British Cameroon in 1951, spreading to the Ivory Coast and Liberia in 1954 and 1955. Outbreaks were reported in Guinea and Nigeria in 1962, and finally in Angola in 1966. Cameroon's coffee farms may initially have been infected by rust spores carried from an infected region on the wind, although this would have involved a flight of at least 1,000 kilometres.[42] The rust expert Frederick Wellman discarded the possibility that the rust was circulated on infected plants or seeds, since all West African

41 Krug and de Poerck, *World coffee survey*, pp. 35–8, 112–14.

42 Wellman, *Coffee*, p. 255.

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countries had 'rigorous quarantines'.[43] Yet it is unlikely that that the quarantines were completely successful in identifying and eradicating infected plants. The expansion of coffee cultivation involved the large-scale movement of coffee plants and seed, not all of which necessarily passed under official scrutiny. Rust spores may also have travelled along newly constructed roads, or been carried in the region's expanding network of air transportation. *H. vastatrix* may also have been already present in the region's wild *Coffea* populations, and the epidemic was triggered by the introduction of relatively susceptible cultivated varieties of robusta. Rates of infection varied across the region, from a low of 19% in parts of Zaïre (Congo) to highs of 73% in the Ivory Coast.[44] Although the rates of infection were quite high, the outbreak's economic impact was limited since it did not have any appreciable impact on the yields of robusta coffee. It did, however, cause severe losses in the region's small arabica zones.[45]

In spite of this, the rust epidemic was met with a comparatively large-scale scientific response. The research was conducted by a host of new colonial, national, and international research organizations. They collected and exchanged biological material, conducted collaborative experiments, and discussed results. Scientists sponsored by the UN's Food and Agricultural Organization (FAO), by the USDA, and the Institut Français du Café et du Cacao (IFCC), searched for rust-resistant strains of coffee in the wild. The FAO-sponsored Inter-American Institute for Agricultural Science (IICA), based in Costa Rica, developed one of the world's largest collections of coffee germplasm. The USDA distributed rust-resistant coffees to coffee producers in the Americas, while the French Office de la Recherche Scientifique et Technique Outre-mer (ORSTOM) did the same in Africa. These centres for coffee research regularly cooperated with one another, exchanging plant materials and developing collaborative research programs. In 1955, an international centre for coffee rust research (Centro de Investigação das Ferrugens do Cafeeiro (CIFC)) was established near Lisbon, with funding from Portuguese and American governments. Researchers at the CIFC focused on studying the races of coffee rust and, in conjunction with Brazil's Instituto Agronômico in Campinas, collecting, breeding, and distributing rust-resistant coffees.[46]

This emergent institutional support for coffee research marks a sharp departure from the pre-war period. In part, the growing support for coffee research reflected the spread of rust and the appearance of other major coffee diseases and pests, such as the coffee wilt (*Fusarium xylarioides*) and the coffee berry disease (*Colletotrichum coffeanum*) in Africa, which caused major economic disruptions in the 1940s and 1950s.[47] However, changing disease patterns are at best a partial explanation, since earlier epidemics did not provoke a similar institutional response. In part, the growth of coffee research in Africa and Asia represented a shift from earlier *laissez-faire* models of colonialism to more developmentalist models that sought to promote broad-based colonial economic and social development. It also reflected

43 Krug and de Poerck, *World coffee survey*, pp. 39–41; Alec Ernest Haarer, *Modern coffee production*, 2nd edn, London: Leonard Hill, 1962, p. 315.

44 Eskes, 'Resistance', p. 225.

45 Wellman, *Coffee*, p. 251.

46 Eskes, 'Resistance', pp. 180–1; A. Carvalho and L. C. Monaco, 'Melhoramento do cafeeiro visando a resistência a ferrugem alaranjada', *Ciência e Cultura,* (São Paulo) 23, 1971, pp. 141–6.

47 Wellman, *Coffee*, pp. 272–3, 291–2; Wrigley, pp. 330–1, 342–4.

the growing importance of new global institutions, such as the FAO, in supporting collaborative international agricultural research in the tropics. The politics of decolonization and the Cold War also provided European colonial states and the United States with an additional incentive to fund coffee research. European and American authorities feared that catastrophic crop diseases such as the coffee rust could destabilize people's livelihoods, and could produce rural unrest and lead to anti-imperial resistance.[48] Avoiding similar foci of unrest became more of a priority for European colonial powers and the US, as well as many national governments. Still, a 1968 FAO report on the world's coffee industry concluded that 'research and experimental work [on coffee] is far from proportional to the economic importance of the crop,' and found that one-third of the coffee producing countries were conducting no coffee research at all.[49]

The spread of the epidemic to western Africa presented a significant threat to the coffee farms of Latin America, where the susceptible arabica coffees were still universally cultivated. As this threat became apparent, organizations such as the Federation of Coffee Associations of America (FEDECAME) joined in supporting international agricultural research on the coffee rust. But most coffee farmers in Latin America did little to prepare their farms for the rust's impending arrival. The stagnant global coffee economy in the 1960s discouraged any significant transformations in Latin American coffee agriculture. Global coffee prices had collapsed in 1959, as the coffee boom of the 1950s had produced a glut. A total economic catastrophe, however, was averted because of Cold War geopolitics. The International Coffee Agreement was enacted in 1962, with the support of the United States and other consuming nations, to keep coffee prices high enough to avoid rural revolts in coffee-producing nations. The ICA established production quotas for each member country, thereby ensuring that producers received a minimum price for their coffee.[50] The ICA did help stabilize coffee prices, but flat coffee prices also discouraged coffee planters from replanting their coffee trees, or adopting any new disease controls. This left the coffee farms of the Americas quite vulnerable. In 1960, the British rust expert R. W. Rayner predicted that 'the disease would certainly sweep through many areas like a fire,' and that when it did, 'there would be a disaster of the first order' (Figure 1).[51]

A pandemic foretold: coffee rust in the Americas, 1970–1989

In January 1970, a Brazilian plant pathologist working near the city of Itabuna, in the Brazilian state of Bahia, discovered rust-infected leaves on a stand of abandoned coffee

48 Such fears have a longer history. Phoofolo, 'Epidemics and revolutions'.

49 Krug and de Poerck, *World coffee survey*, p. 443.

50 John M. Talbot, *Grounds for agreement: the political economy of the coffee commodity chain*, Lanham: Rowman & Littlefield, 2004, pp. 51–60.

51 R. W. Rayner, 'Rust disease of coffee', *World Crops*, 12, June 1960, pp. 222–4.

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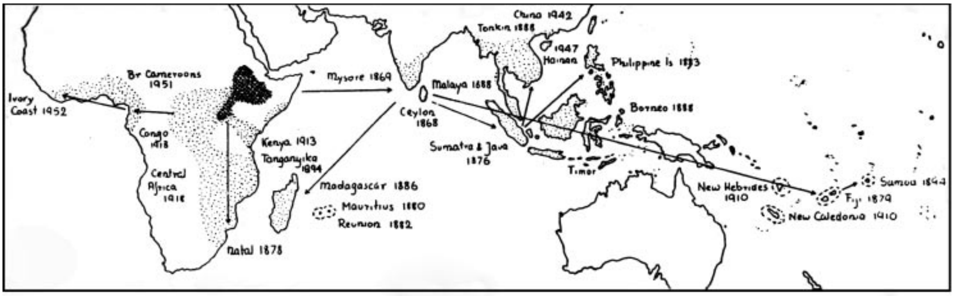
Figure 1. Spread of coffee rust to 1960. From Rayner, 'Rust Disease of Coffee' *World Crops* 12 (June 1960). Reproduced with permission from Research Information Ltd.



World distribution of coffee disease, Hemileia vastatrix, *showing the main trends of the movement, east, south and to the west. The original home is cross-hatchered and the areas subsequently invaded are stippled or ringed round*

plants.[52] Coffee planters in the Americas may have been dismayed by the news, but they were not surprised. The Brazilian government quickly sent coffee experts to the region. They discovered that the rust had infected coffee plants over an area of 500,000 square kilometres in the states of Bahia, Espírito Santo, and Minas Gerais. This outbreak marked the beginning of the third great pandemic of coffee rust. Between 1970 and 1985, the rust burned through the New World's coffee farms, spreading from its focus in eastern Brazil through the country's rich planting zones, and northward into the major coffee regions of northern Latin America – Colombia, Central America, and Mexico – producers of some of the world's finest mild arabica coffees.

As with the earlier long-distance migrations of the rust, spores may have been introduced either by the wind, or anthropogenically, or both. Wind currents may have carried spores of the rust fungus across the Atlantic from the Ivory Coast or Angola.[53] Rust spores may have been introduced accidentally in a shipment of cocoa plants, for Bahia was primarily a cocoa-growing zone, and during the 1960s there had been exchanges of planting material with the Ivory Coast. The latter was one of the few places in the world where coffee and cocoa were cultivated together, and the rust was certainly present there in the 1960s. Technological developments probably also accelerated the rust's spread to the Americas. Commercial jet travel became common during the 1960s, greatly reducing travel times between Africa and South America.[54] The outbreak of the coffee rust probably passed unnoticed in Bahia for several years, since few coffee specialists visited the region. By the time the rust was discovered, it was so widely diffused that eradication was impossible.

The outbreak in Bahia awakened fears that a large-scale epidemic could produce an economic catastrophe on the scale of Ceylon. At the time, coffee was the first or second most

52 R. A. Muller, 'La rouille du caféier (*Hemileia vastatrix*) sur le continent Américain', *Café, Cacao, Thé*, 15, 1, January–March 1971, p. 25.

53 J. Bowden, P. H. Gregory, and C. G. Johnson, 'Possible wind transport of coffee leaf rust across the Atlantic Ocean', *Nature*, 229, 1971, pp. 500–1.

54 J. M. Waller, 'Coffee rust in Latin America', *Pest Articles and News Summaries (PANS)*, 18, 4, 1972, p. 403; E. Schieber, 'Economic impact of coffee rust in Latin America', *Annual Review of Phytopathology*, 10, September 1972, p. 496.

important export for thirteen countries in Latin America, so the potential economic damage of the disease was immense. In one estimate, the Colombian Federation of Coffee Growers predicted that the rust could cause losses of up to 80% on traditional coffee farms.[55] Some leaders in the region also feared that the economic damage could, in turn, produce social unrest. M. Muyshondt, an economist and sometime Minister of Agriculture in El Salvador, warned that '[I]t has to be understood, that the importance of an economic loss caused by the rust, directly on coffee industry activity, would also affect profoundly a depression in the activities of the banking system, industry, commerce, and service institutions; consequently indirectly affecting the working class.' He concluded that 'even a 5% loss due to the rust would have a true negative impact on the economic and social development of these countries, carrying great disturbances in the internal political order in each of [these] countries . . .'.[56] Others adopted a more measured tone, noting that countries such as Kenya and India had continued to produce arabica coffee profitably, in spite of rust infestations.

In mid-1970, months after the rust was first detected, a conference was convened at the Interamerican Institute for Agricultural Science in Costa Rica. Addressing ninety-seven scientists and government officials from across the Americas, the institute's director called for a 'continental response' to the epidemic, focusing on quarantines, disease control, and the search for resistant varieties.[57] Early efforts focused on containing the disease. Brazil's military government imposed a strict quarantine on domestic movements of coffee plants, and planned a *cordon sanitaire* separating the infected regions and the major coffee zones to the southwest by uprooting all coffee trees in a band of land 50 kilometres wide and almost 400 kilometres long. Before the plan could be enacted on a large scale, prevailing winds had carried the rust spores into Brazil's coffee zones, covering more than 1,000 kilometres in less than eighteen months. In 1975, it appeared in the western Brazilian province of Acre, probably introduced in contaminated planting material. From Acre, it spread to the neighbouring coffee zones in the Andes, finally reaching Colombia's important coffee zones in 1983.[58]

A second focus of the rust appeared 1976, when it broke out near the Nicaraguan city of Carazo. It had probably been introduced to Nicaragua accidentally, by a coffee farmer who had visited an infected coffee region in Brazil. The Nicaraguan government established a quarantine around the infected zone and began an aggressive campaign to contain and eradicate the outbreak. The campaign was, however, disrupted by the Nicaraguan revolution in 1979, and soon spread beyond Carazo.[59] Between 1979 and 1984, the disease diffused to the rest of Central America and southern Mexico, frequently following the routes of migrant

55 'La roya del cafeto', *Economia cafetera*, 9, 9, September 1979, p. 4.

56 Cited in Schieber, 'Economic impact of coffee rust', p. 505.

57 IICA, *Reunión técnica sobre las royas del cafeto,* San José, CR: IICA, 1970.

58 Kushalappa and Eskes, *Coffee rust*, pp. 4–5; E. Schieber and G. A. Zentmyer, 'Distribution and spread of coffee rust in Latin America', in Robert H. Fulton, ed., *Coffee rust in the Americas*, St. Paul, MN: American Phytopathological Society, 1984, pp. 1–14.

59 H. Schuppener, J. Harr, F. Sequeira, A. Gonzales, 'First occurrence of the coffee leaf rust *Hemileia vastatrix* in Nicaragua, 1976, and its control', *Café, Cacao, Thé*, 21, 3, 1977, pp. 197–200. See also Robert A. Rice, 'Transforming agriculture: the case of coffee leaf rust and coffee renovation in southern Nicaragua', PhD Thesis, University of California, Berkeley, 1990; and GTZ (German Agency for Technical Cooperation), *Lucha contra roya del café*, Eschborn: GTZ, 1979.

coffee workers.[60] Coffee growers also faced a second major environmental threat, that of the coffee berry borer (*Hypothenemus hampei*). The borer, known locally as the *broca*, had been introduced to Brazil from Central Africa in the late 1920s. In the 1970s and 80s, it appeared in the coffee farms of northern Latin America, causing extensive damage.[61] As the strategies of eradication, containment, and quarantine successively failed in each coffee zone, planters began to look for ways to adapt to the twin threats of the rust and the borer. Few coffee planters in Latin America contemplated switching to robusta coffee, as had their counterparts elsewhere. Planters in northern Latin America were reluctant to give up high-quality mild arabicas, which fetched high prices in the global coffee markets.

In order to preserve arabica coffee, many coffee farmers in Latin America chose to 'technify' their coffee farms. Technification meant transforming coffee agriculture into an agro-industrial process, applying practices and techniques developed in the Green Revolution. These required considerably greater investments in labour and technology, but these additional costs would – at least in theory – be offset by much greater yields. Coffee farms were replanted to allow for the application of fungicides, pesticides, and chemical fertilizers. In many coffee farms, shade trees were eliminated on the theory that exposure to the sun would dry the leaves and thereby reduce the incidence of rust. Reduction in shade also helped control the *broca*.[62] New rust-resistant hybrid coffee plants were introduced, replacing the traditional arabica varieties that had been universally cultivated in Latin America since the eighteenth century. Finally, the traditional arabica varieties were cross-bred with rust-resistant hybrid coffees, themselves crosses between arabica and robusta coffee, bred with the goal of combining arabica's taste and robusta's disease resistance. Two of the most widely planted hybrids were the Catimor, produced by the CIFC in Portugal, and the 'Colombia' hybrid produced at Colombia's centre for coffee research (CENICAFÉ). Under the proper conditions, technified coffee plantations could yield as much as 300% more coffee than traditional coffee farms. Technification introduced economies of scale into coffee agriculture for the first time.

The incentive to technify was bolstered by an increase in coffee prices during the middle of the decade. It also received strong institutional support from national agencies such as the Instituto Brasileiro do Café and the Grupo Executivo de Racionalizaçao da Cafeicultura (GERCA) in Brazil, the Federation of Coffee Growers (Fedecafé) in Colombia, and PROMECAFE in Central America, Mexico, and the Dominican Republic.[63] The US Agency for International Development (USAID) also heavily promoted technification to smallholders in Central America, offering financial aid and technical assistance.[64] One study estimates that by 1990, 'almost half the area in coffee production in northern Latin America had been converted', although this conversion was not evenly distributed. Colombia had technified

60 J. M. Waller, 'Coffee rust – epidemiology and control', *Crop Protection*, 1, 4, 1982, pp. 388–9.

61 Wrigley, *Coffee*, pp. 353–60; Carlos Enrique Fernández, 'Central American coffee rust project', in Fulton, *Coffee rust in the Americas*, p. 84.

62 Instiuto Brasileiro do Café, *Cultura de café no Brasil: manual de recomendações*, 5th edn, Rio de Janeiro: IBC/GERCA, 1985, p. 343, table 1.

63 Fernández, 'Central American coffee rust project', pp. 84–92.

64 Ivette Perfecto, Robert A. Rice, Russell Greenberg, and Martha E. Van der Voort, 'Shade coffee: a disappearing refuge for biodiversity', *BioScience*, 46, 8, September 1996, p. 606.

69% of its coffee plantations by 1990, Costa Rica 40%, Honduras 35%, Nicaragua 29%, and Guatemala 20%. In spite of a program to promote technification, Mexico had only managed to technify 17% of its coffee, while war-torn El Salvador had achieved a mere 8%.[65]

The cost of technification represented a financial burden that many coffee planters – especially smallholders – could not bear. Control efforts had to be economically viable as well as technologically feasible. In Brazil, Mexico and most of Central America, technification took place primarily in the larger coffee farms, which could bear the cost of the additional labour and technical inputs, and enjoyed financial and technical support from state institutions. In Colombia and Costa Rica, the percentages of coffee lands technified suggest that technification included both large and small coffee producers. Attempts to encourage smallholders elsewhere in Central America and Mexico to technify failed, in spite of programs sponsored by the USAID and the Mexican government.[66] In Honduras, the Instituto Hondureño de Café did not provide technical aid to small farmers, 'as part of a deliberate policy to weed out inefficient producers'. In Colombia, 'fumigation can call for so large an outlay that some growers do not even adopt preventive or curative measures', even where credit was available. Peasant coffee farmers often 'let plantation diseases run their course and take their toll. They then pick[ed] what remain[ed] of their diseased and depleted harvest.'[67] Technification in most of Central America's coffee zones was also hampered by volatile coffee prices through the 1980s, and by the brutal civil conflicts that swept through the region. For many smallholders in Latin America, technification was simply not an option.

By the late 1980s, the coffee rust epidemic had transformed coffee agriculture in Latin America, although not in the way that many people had anticipated twenty years earlier. In most of Latin America, the fear of 'another Ceylon' was not realized. Losses of between 20 and 25% were reported in Brazil for the 1974–75 season, before disease control programmes were fully in effect.[68] The rust's impact in most of Central America, however, seems to have been much smaller. The highland climate of these areas – in combination with resistant varieties, chemical sprays, and cultural practices – kept rust levels low enough to continue producing coffee economically. In 1983, losses caused by rust epidemic in Honduras, El Salvador, and Guatemala were 3–4% of the total harvest.[69] In a few fortunate places, it seemed that no control measures at all were necessary. For example, the disease had little impact on the coffee farms of Chiapas.

Although the epidemic itself proved to be something of an anticlimax in Latin America, it helped to trigger the ecological transformation of Latin America's coffee farms. This was arguably the largest ecological transformation in Latin America's coffee industry since the opening of Brazil's coffee frontier in the nineteenth century. Technification caused a sharp reduction in the biodiversity of many coffee farms, although, paradoxically,

65 Perfecto *et al.*, 'Shade coffee', pp. 598–608; Robert A. Rice, 'The land use patterns and the history of coffee in eastern Chiapas, Mexico', in *Agriculture and Human Values,* 14, 1997, pp. 127–43.

66 David Nestel, 'Coffee in Mexico: international market, agricultural landscape, and ecology', *Ecological Economics*, 15, 1995, pp. 165–78; Rice, 'Coffee in eastern Chiapas', pp. 127–43.

67 Peter Nares, 'Will Colombia be able to produce high-quality Milds 10 years from now?', *Tea & Coffee Trade Journal*, 160, 5, May 1988, p. 16.

68 Figures for Brazil cited in GTZ, *Lucha contra la roya del café,* p. 13.

69 Richard Lapper, 'The coffee is mild but the politics aren't', *Coffee and Cocoa International*, 5, 1983, p. 46.

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the introduction of hybrid coffees greatly increased the biological diversity of the coffee plants themselves. It introduced new species of coffee, new chemical technologies, and tellingly, the first economies of scale. Technification also exacerbated differences between large and small coffee producers. Larger producers could, as a whole, afford to pay for the new technologies and for replanting their coffee farms, and so could also enjoy the increases in production associated with these. Small farmers, however, were often stuck in a vicious circle of declining productivity and declining income, exacerbated by the global collapse of coffee prices in the 1990s.[70]

Global rust: economy and environment in the twenty-first century

The epidemic's effects spread far beyond the direct losses in production caused by *H. vastatrix*. While the rust's epidemic phase is now largely over, its economic, political, and social repercussions continue to be felt. At best, the global coffee industry has reached a dynamic equilibrium with the rust, in which plants, pathogens and people continue to circulate globally.

The disease precipitated changes in the global distribution of the coffee plant, and in the very structure of the plant itself. The epidemic triggered a wave of coffee bioprospecting and breeding, which have increased the biological diversity of the world's cultivated coffee. The introduction of new varieties and species of coffee could have significant repercussions across the commodity chain from plantation to cup, as shown by the expansion of robusta cultivation during the twentieth century. In 2003, robusta coffee accounted for 37% of global coffee production. It has even made inroads into the Americas; Brazil is now one of the world's top robusta producers. The genetic composition of cultivated coffee has been transformed both by conventional breeding practices and, since the 1990s, by plant biotechnology. The high-yielding rust-resistant hybrid coffees introduced in the 1970s are now cultivated across the globe. Research on developing genetically modified coffees began in the 1990s.[71]

The life of the coffee ecosystem has also come to depend more on global science and technology, although the halting 'scientization' of coffee remains incomplete. Science began to gain importance as the pioneering phase of the coffee industry drew to a close. Since the mid-twentieth century, scientific institutions have played a leading role in prospecting for coffee germplasm, and in coffee breeding. 'Big science' came to coffee agriculture in the 1970s and 1980s, as governments and international organizations promoted technification. This produced significant gains in productivity for some coffee producers. For others, however, the short-term benefits of technification were undermined

70 Robert A. Rice, 'Coffee production in a time of crisis: social and environmental connections', *SAIS Review*, 23, 1, 2003, pp. 221–45.

71 Herbert A. M. Van der Vossen, 'Agronomy I: coffee breeding practices', in R. J. Clarke and O. G Vitzhum, eds., *Coffee: recent developments*, Oxford: Blackwell, 2001, pp. 185–6. On bioprospecting and genetic improvement in coffee, see Benoît Bertrand and Bruno Rapidel, eds., *Desafíos de la caficultura en Centroamérica*, San José, C.R. IICA, PROMECAFE, CIRAD, IRD, CCR, 1999, pp. 369–496.

by longer-term ecological and economic problems. Since the 1990s, many scientists have shifted from a narrow focus on productivity to a broader quest for both ecological and economic sustainability.

Global ecological exchanges continue, and coffee ecosystems will continue to be vulnerable to the rust and to other epidemic diseases. For the time being, coffee farmers worldwide have reached a grudging and fragile accommodation with the coffee rust. It can still cause losses of 20–25% of the harvest in bad years, and globally it produces economic losses of US$1–2 billion annually. Some of the supposedly 'rust-resistant' hybrid coffees have proven to be susceptible to some newly discovered races of rust.[72] Other major diseases and pests are also circulating regionally, and some may soon circulate globally. The economic and political chaos that has plagued much of central Africa since the 1990s has produced a renewed circulation of coffee plants and diseases. Diseases such as the coffee wilt (known popularly as the 'AIDS of coffee') and the coffee berry disease (CBD) have spread beyond their traditional ranges in Africa. These or other coffee diseases may, at some point, find their way into the modern transportation infrastructure and become globalized as did the coffee rust.[73] A new global coffee epidemic will remind us again how much coffee's life as a commodity depends upon its life as a plant, and vice versa.

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72 Jacques Avelino, Raoul Muller, Albertus Eskes, Rodney Santacreo, Francisco Holguín, 'La roya anaranjada del cafeto: mito y realidad', in Bertrand and Rapidez, eds., *Desafíos de la caficultura*, pp. 193–242. Van der Vossen, 'Coffee breeding practices', pp. 192–3.

73 J. F. Flood, L. F. Gil, J. M. Walker, 'Coffee diseases: a clear and present danger', in P. S. Baker, ed., *Coffee futures: a source book of some critical issues confronting the coffee industry*, Chinchiná Colombia: CABI-FEDERCAFE, USDA-ICO, 2001, pp. 66–73.