Chapter

Epidemiology and Management of South American Leaf Blight on Rubber in Brazil

Edson Luiz Furtado, Willian Bucker Moraes, Waldir Cintra de Jesus Junior, Breno Benvindo dos Anjos and Lilianne Gomes da Silva

Abstract

The rubber tree (*Hevea* spp.) is one of the main forest crops in tropical regions due commercialization of natural rubber. Brazil currently imports most rubber that is consumed. According to the International Rubber Study Group, for an annual consumption of 350,000 tons in Brazil, 135,000 tons were produced, whereas 215,000 tons were imported. This failure of rubber cultivation in Brazil is primarily due to South American leaf blight (SALB), a disease caused by the fungus *Microcyclus ulei* (P. Henn. v. Arx.). The fungus is present in all Brazilian rubber-producing regions and attacks young leaflets, causing abscission and, ultimately, death of the tree. This disease occurs in almost all areas of rubber tree plantations in Central and South America. Strategies used to manage SALB are based on the use of fungicides in nurseries and young plantations and the use of resistant clones; on phenological aspects, taking into account the leaf shedding patterns of adult rubber trees, which in certain environments provide defense in addition to resistance; and on climatic factors that are favorable or unfavorable to epidemic development. The aim of this chapter was to describe all aspects related to the epidemiology and management of leaf blight in Brazil.

Keywords: *Microcyclus ulei*, *Hevea brasiliensis*, control, evasion, damage and losses

1. Introduction

From 1914 to the 1970s, South American leaf blight (SALB) was considered one of the major causes of failure of commercial rubber cultivation in South America [1]. Today, management measures are available to ensure a minimum risk of epidemics to rubber tree crops in several regions of Brazil.

Among such measures is planting of resistant plant materials associated with evasion (choice for areas favorable to rubber cultivation and unfavorable to the pathogen). These actions have reduced injuries and losses caused by this disease and, consequently, favored large-scale production in Brazil and in other countries that aim at self-sufficient production of rubber, a strategic raw material.

This disease was described at the early twentieth century in leaves collected from native rubber trees in the surroundings of Belém, Pará State (PA); symptoms were few, not causing defoliation or other injuries to the plants since susceptible rubber trees grow naturally at a low density in forests, 3–4 trees per ha.

However, the devastating potential of this disease was detected in the first attempts to domesticate this species and establish commercial plantations in the Guianas and Brazil (Ford Crops) at the beginning of the century. Such failures are documented in the literature but were not taken into account by the Brazilian authorities responsible for the sector's policy and fiscal incentives, as well as by the former support agencies, which made some historical mistakes. One of these mistakes was the financial support by the Brazilian government to rubber cultivation at the humid Amazon region, with goals of planting rubber trees in 250,000 ha from 1970 to 1985 (PROBOR I, II, and III). Of these, only 120,000 ha were planted, of which 38,000 ha were decimated by the disease and the remaining had very low yield, discouraging new cultivation and investments in the sector [2]. Another mistake was the choice for hybrid clones of *Hevea benthamiana* and *H. brasiliensis*, which present low yield, do not have uniform leaf shedding, and do not allow breaking the pathogen's cycle.

At the end of this period, when the financial aid to the sector had finished, pressure by other Brazilian states allowed cultivation in other areas of the country, such as the central region, part of the central-west region and the southeast region, where rubber trees were grown exuberant and productive, free of leaf blight epidemics. Nowadays, these are considered areas of high productivity due to disease evasion (erroneously cited in the literature as "scape areas"), showing the way to high productivity and national self-sufficiency of such strategic raw material. Details will be addressed in this chapter.

2. Etiology of the disease

South American leaf blight, or leaf blight, is caused by the fungus Ascomycota *Microcyclus ulei* (P. Henn) v. Arx, which is found throughout cultivation areas in the American continent and is particular to the genus *Hevea*; it was already detected in six rubber tree species [3].

This fungus has two types of infective spores in its life cycle, according to the type of reproduction: conidiospores (asexual reproduction or anamorphic phase), the anamorphic reclassification of which was recently described in the literature, e.g., *Pseudocercospora ulei* [4], with cycle varying between 6 and 10 days, depending on the clone, and ascospores (sexual reproduction or teleomorphic phase), with cycle varying from 100 to 150 days (**Figure 1**).

Conidia are responsible for spreading the pathogen and causing epidemics due to their large number and rapid cycle. Ascospores take longer time and are responsible for the primary inoculum, minimally contributing to the epidemics; they can affect young plants and clonal gardens or species and hybrids that do not regularly change leaves (*H. benthamiana*). These sexual spores are produced in a small quantity and remain protected inside special structures on the leaves (pseudothecia) for several months, even in fallen leaflets, being progressively released to the air.

In nurseries at Paraíba Valley and South Bahia, weather conditions favorable to epidemics included relative humidity superior to 95% during 10 consecutive hours for 12 days a month. The disease affects specially leaflets but can also reach petioles, new branches, and even fruits [6].

Once spores come in contact with leaflets in the susceptible stage, initial symptoms appear on the inner face of the leaf as small rounded necrotic spots, under which dark green conidial sporulation of velvety aspect emerge in most clones. Under high humidity conditions, lesions grow occupying great part of the leaf limb and causing defoliation.

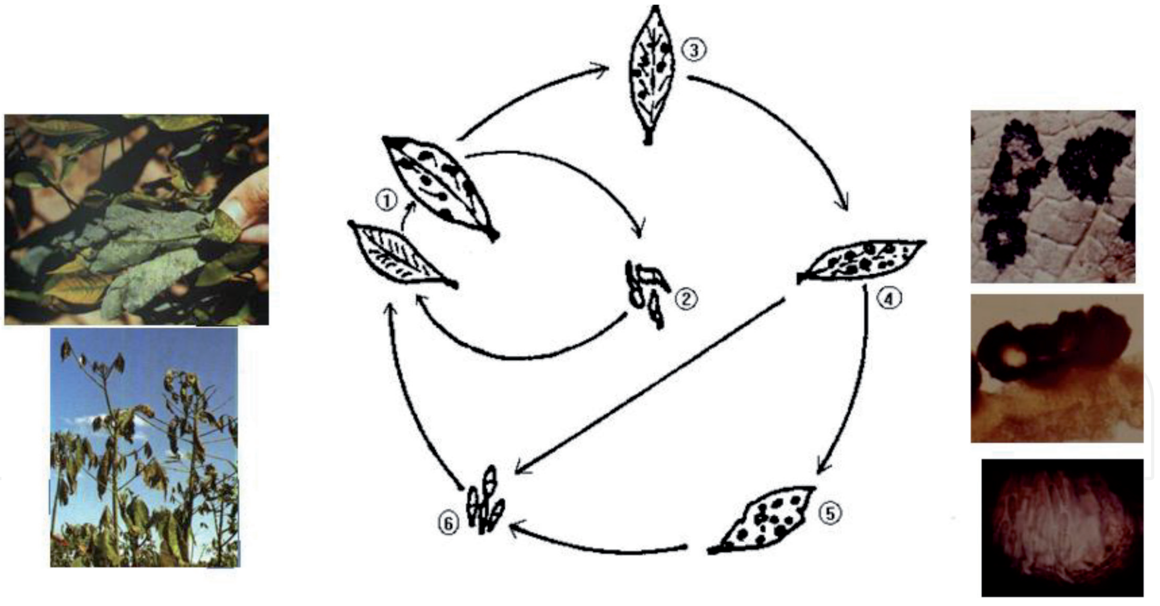

Figure 1.
Phases of Microcyclus ulei cycle, modified from [5]. (1) Wet period. Infoliation; (2) Anamorphic phase. Conidial sporulation. Leaflet shedding; (3) Teleomorphic phase. Stromata formation; (4) Mature stromata; (5) Dry period. All plants changing the leaves; ascospores released; and (6) Ascospores released by leaflets dropped. New infections occurred and beginning a new cycle.

In the remaining infected leaflets, the sexual phase develops (spermatogonia, asci, and *Ascospores*); ascospores consist in formations showing diameter of several millimeters that become massive and rough to the touch, like sandpaper (stroma). Such symptoms prevail in mature leaflets until their natural fall.

3. South American leaf blight in native rubber trees

Native rubber trees are intertwined with the Amazon forest, where they are inserted, occupying several Brazilian states and Amazon countries of South America, in which the 11 known species of *Hevea* cohabit, showing varied size (shrub to tree), variable phenology (see text below), and variable resistance to the causal agent of leaf blight. Among an enormous diversity of plant species, rubber trees are rare, i.e., they have extremely low density (2–3 plants per hectare). Such rarity and diversity protect them from herbivory and from the attack by pest insects and diseases, such as leaf blight. Based on studies conducted with native rubber trees in Acre State, Furtado [7] verified the percentage of diseased fallen leaflets per plant (incidence). In addition, diseased leaflets were evaluated for the percentage of injured leaf area (severity), according to the diagrammatic scale developed by Chee [8] and modified by Gasparotto [1]. Data were collected from native rubber trees or settings (areas of ~400 ha) containing three lots of 150 rubber trees, which were productive and aged more than 100 years ("rubber tree roads"), located at Chico Mendes Extractive Reserve, in the rubber tree plantations: São Pedro, Dois Irmãos, Nazaré, and Floresta, and at Caquetá Extractive Settlement, totaling 11 native rubber tree roads. Sampling included one out of every two individuals. Fifty trees per "road" of native and planted rubber trees were covered (**Table 1**).

There were no epidemic levels in any of the rubber tree plantations; only a greater leaf blight incidence was noticed for rubber tree plantations in Nazaré and São Pedro, evidencing a balanced situation between the native rubber trees and the fungus.

Rubber plantation	Rubber tapper's name	*Microcyclus*	*Ulei*
		Incidence	sev.
São Pedro			
Bom levar II	Raimundo Carlos	12	0.6
Vai quem Quer	Dalvo F. da Silva	12	0.1
Morada Nova	Antonio M. E. de Oliveira	9	0.15
Floresta			
Bela vista I	Domingos F. da Conceição	0	0
Maloquinha	Francisco das C. F. Marcelino	0	0
Bom Principio	Raimundo N. P. da Silva	8	0.3
Taripu (Enrascado)	Manoel da S. Oliveira	0	0
Nazaré			
Rio Branco II	Guilerme Q. de Oliveira	12	0.4
Caqueta			
Limoeiro	Ladislau do Nascimento	0	0
São Pedro	Acelino do Nascimento	0	0
Feijão Duro	Osmã A. da Silva	0	0

Table 1.
Intensity of leaf blight symptoms obtained for native rubber trees at different settings/plantations. Acre Valley [7].

4. Epidemiology of South American leaf blight

Learning the structure and the behavior of leaf blight is essential for the rational management of this disease. Thus, the dynamics of the pathogen's ascospores and conidia must be quantified, as well as the phenology of the rubber tree, the intensity, and progress of the disease, and the effects of altitude and leaf density on the production and growth of the rubber tree and leaf wetness period significantly influence the *Hevea* sp. X *M. ulei* pathosystem.

Infection by *Microcyclus ulei* occurs in young leaves of rubber trees at the optimum temperature for the disease, around 24°C. However, temperatures between 20 and 28°C are favorable to the disease, evidencing high number of foliar lesions [1].

The pathogen *M. ulei* can infect rubber trees at 16°C and the disease can evolve normally at 24°C, showing that the temperature of 16°C does not prevent the pathogen from penetrating the leaves of rubber trees but makes colonization slow or paralyzed [9].

SALB can occur in rubber trees after 6 hours of leaf wetness at 24°C since it highly depends on the aggressiveness of isolates and on whether the clone is susceptible or resistant. Localities subject to dew, fog, or light rain for prolonged periods present conditions extremely favorable to the development of leaf blight [1]. The longer the low temperature period, the minor the disease severity.

The deciduous habit of the rubber tree is considered important since it reduces the initial inoculum, located in older leaves, and standardizes the buddings, which are very important in scape areas, where refoliation coincides with the shortest leaf wetness period, unfavorable to the development of the pathogen [10].

Honorato [11] quantified the following variables: dynamics of the pathogen's ascospores and conidia; phenology of rubber trees; disease progress; and effects of altitude, disease severity, and leaf density on the production and growth of rubber trees. Experiments were conducted in rubber tree plantations at Igrapiúna, Bahia, considering three topographic conditions (top, slope, and lowland). The author detected ascospores and conidia of the fungus over the whole experimental period, but ascospore concentration was higher in the nocturnal period, while that of conidia was greater in the diurnal period. The effect of climate variables on conidial release was greater at lowland. At the top, leaf density of the rubber tree was higher and the disease severity was lower. Climate variables had a greater effect on disease severity at lowland, where the number of hours with leaf wetness was higher and relative humidity was minimal. A mean reduction of 47.7% in rubber production was detected at lowland, as well as mean severity of 15.0% and mean reduction in leaf density of 50.1%. There is evidence to propose changes in the pathogen's life cycle since ascospore and conidial production occurs all over the year in the field, under favorable environmental conditions. According to the obtained results, the author concluded that the effects of environmental variables on the disease are more evident under lowland conditions, where leaf blight, in particular, reduces the rubber production and the rubber tree growth. Under such conditions, the disease management measures should be intensified, including the planting of clones with high horizontal resistance.

An interesting phenomenon that has become frequent in the last years is the so-called South Atlantic Convergence Zone (SACZ), defined as a region of extensive cloud bands from the Amazon, Central-West, and Southeast region [12]. This climatological characteristic is associated with rainfalls that sometimes are strong, sometimes are moderate, and sometimes are intermittent, persisting for a minimum of 4 days, which can cause great disorders like floods, landslides, and overflows.

Climatologically, SACZ system is responsible for the considerable amount of summer rainfall among the Central-West, Southeast, and part of North and Northeast regions, causing humidity accumulation during the summer, which must have favored such leaf blight epidemics at the beginning of the year in São Paulo, Mato Grosso do Sul, Mato Grosso, and Goiás States. On the other hand, the absence of this system causes drastic reduction in rainfall in these regions, consequently leading to losses in agricultural production and risk of water and energy rationing [13].

As SACZ phenomenon is common in Brazil, new leaf blight epidemics are expected when a highly humid period coincides with the presence of new leaves in the rubber tree, since the pathogen is common, at low intensity, even in "scape" zones. The use of productive clones resistant to leaf blight is welcome, even for "scape" zones [13].

5. Strategies for the management of South American leaf blight in rubber tree plantations

The strategies used in the management of this disease in Brazil follow the proposals published [2, 3], based on the rubber tree-climate-*M. ulei* interaction, i.e., the phenological features of the used clones (which must have a uniform deciduous habit), on the resistance to leaf blight, and on the climate characteristics favorable or not to epidemics, in each Brazilian region, modified from Ortolani [14], shown in **Table 2**.

5.1 Phenological behavior of the rubber tree

The deciduous habit of the rubber tree is one of its most important phenological features for allowing yearly leaf renovation. Considering this character, the major species of rubber tree and their hybrids planted in Brazil present a highly important variation:

a. *Hevea brasiliensis* has the largest number of hybrids with uniform and regular deciduous habit, and their leaf shedding occurs from August to September, which corresponds to the dry period. Thus, diseased leaflets are naturally threshed and healthy growth occurs after hibernation and new budding.

I – Amazon Region:

AM1 – Marginal area, of constant super humidity and outbreaks of the disease. Annual water deficit (Da) = 0 mm; mean relative humidity of the driest month (RHs) > 85% and real evapotranspiration (RE) > 900 mm. Western Amazonas.

AM2 - Marginal area, high humidity and outbreaks. Da 0-100 mm, RHs 75-85% and RE > 900 mm. Central Amazonas.

AM3 - Marginal and preferential area with restrictions. Moderate to high disease incidence. Obligate phytosanitary control although there is a variable dry season. Da 100-200 mm, RHs 65-80% and RE > 900 mm. Eastern Amazonas.

AM4 - Preferential area with restrictions. Low incidence of *M. ulei*. Caution is required for the establishment of rubber tree plantation due to high seasonal water deficit. Da 200-300 mm, RHs 65-80%. It covers the area of transition between Central Brazil and dense Forest.

II – Non-Amazon Regions:

A - Preferential area with satisfactory thermal and water conditions and minimal risk of disease incidence. Da 0-200 mm; RHs 55-70% and RE > 900 mm.

A1 - Preferential area with restrictions. Low disease incidence. Caution is required for the establishment of rubber tree plantation due to seasonal water deficit (Da 200-300 mm).

B - Marginal area with super humid conditions. Moderate to high disease incidence. Obligate phytosanitary control. Da=0 mm, RHs > 80%, mean temperature of the coldest month (Tf) > 20°C (e.g., South Coast of Bahia).

B1 - Marginal area with super humid conditions. Moderate to high disease incidence in clonal gardens, nurseries and new plantations, or adult plantations with cultivars that do not adequately shed their leaves (hybrids of *H. benthamiana*). It differs from the previous region for presenting Tf < 20°C or longer dry period in leaf shedding (e.g., Ribeira Valley Region).

C, D and E – Marginal to inapt areas due to thermal or water limitations.

Table 2.
Brazilian climate zoning for the rubber tree, aimed at controlling South American leaf blight, modified from [14].

b. *Hevea benthamiana* and its natural hybrids, or with *H. brasiliensis*, present irregular leaf shedding, partially changing their crown every year in the dry period. Part of the diseased leaves remain in the crown and will serve as initial inoculum for new leaflets during budding.

c. *Hevea pauciflora* and its hybrids do not have a defined period for leaf shedding, being intertwined with perennial species. However, they have high resistance to leaf blight.

5.2 Resistance of rubber trees to South American leaf blight

In Brazil, breeding with rubber trees started in 1937 after outbreaks caused by the fungus *M. ulei* in crops established by Ford Company in the fields of Fordlândia in 1928 and in Belterra in 1932, both at low Amazonas, Pará State. Currently, the species of greatest interest for breeding are: (1) *H. brasiliensis*—higher productive capacity and genetic variability for resistance to *M. ulei*; (2) *H. benthamiana*—resistance to *M. ulei* and genetic variability for rubber production; (3) *H. pauciflora*—certain immunity to *M. ulei*; and (4) *H. camargoana* and *H. camporum*—small size.

Initial selections for resistance to SALB in Brazil were done by Ford Company. During 1942–1945, the program was expanded and conducted in cooperation among Ford Company itself, Agronomic Institute of the North (IAN)—newly established at that time[1], and the Department of Agriculture of the United States [15].

[1] Currently CPATU—Center for Agricultural Research in the Humid Tropics.

The first step was to select matrices that had demonstrated resistance to the disease in Fordlândia. The selected resistant clones were known as Ford clones, designated by letter F (Ford selection), such as clone FA 1639, a clone of *H. brasiliensis* originated of ungrafted plants from seeds from Acre State, and clone F 4542, originated of seeds of *H. benthamiana* at upper Rio Negro [16].

During the administration of Ford Motor Company, breedings between Ford clones resistant to *M. ulei* and productive clones from the East received the acronym FX, e.g., FX 4037, originated from the selection of a seedling resultant of the breeding between F 4542 and PB 86. Breedings conducted in 1945 and subsequent years, under the auspices of the Agronomic Institute of the North, received the acronym IAN. The materials available for the breeding program consisted of oriental clones susceptible to *M. ulei*, such as PB 86, PB 186, Tjir 1, Tjir 16, AVROS 183, and AVROS 363, considered the best producer clones of the period, as well as primary clones of *H. brasiliensis*, selected from Fordlândia and Belterra, and clones of other species of rubber trees collected all over the Amazon Basin. Having resistant and productive material, an intraspecific breeding program was developed with the aim of associating, in one same plant, the characters desirable for dry rubber production and resistance to leaf blight. However, the lack of genetic diversity between parentals led to no manifestation of the hybrid vigor for the character of resistance to the pathogen [17].

In view of the great susceptibility of genotypes obtained by intraspecific breedings, other sources of resistant germplasm had to be searched in other species of the genus *Hevea*, aiming at interspecific breeding involving productive plants of *H. brasiliensis* and other plants resistant to the pathogen. Thus, plants representing the following species were collected and taken to Belterra: *H. spruceana*, *H. microphylla*, *H. guianensis*, and *H. pauciflora*. Hybrids from the breedings *H. brasiliensis* × *H. guianensis*, *H. brasiliensis* × *H. microphylla*, and *H. brasiliensis* × *H. spruceana* were discarded for not meeting the goals of latex production and resistance. Hybrids of *H. benthamiana* (especially clones F 4542) with *H. brasiliensis*, selected in Fordlândia, started to constitute basic material of resistance in successful genetic breeding programs [18].

Since then, thousands of plants were selected as resistant, of which only a small number had a good phenotypic value (what the plant exteriorizes) for the character dry rubber production. According to [19], hybrids of *H. pauciflora* × *H. brasiliensis* presented high resistance to the fungus *M. ulei* but low production of dry rubber—material recommended, in recent years, for the genetic-horticultural control of leaf blight by means of crown grafting [20]. While Brazilian researchers searched for resistant and productive materials, the Malaysian program by the Rubber Research Institute Malaysia (RRIM) focused only on obtaining *H. brasiliensis* clones of high productivity since the disease was not a concern because the pathogen was absent. They obtained a good performance with series 500, which was subsequently supplanted with clones of series 600. The latter is known worldwide, and RRIM 600 has become one of the most cultivated clones for its high productivity and plasticity. Currently, RRIM is in series 900. Brazil has received these clones as a payment for the genetic material supplied during the last years.

Assessing the behavior of rubber tree clones to leaf blight is extremely important for the establishment and success of rubber tree plantations. Silva [21] evaluated the behavior of 18 rubber tree clones against SALB. The evaluations were performed at 15-day intervals by removing 30 leaflets per tree. The disease was quantified based on the number of leaflets that were collected and classified according to the stages of the development of the disease and the type of injury. SALB occurred during the entire experimental period; however, the intensity of the disease varied in accordance with the resistance level of the clones and the time of year. The rubber clones FX 3864, RRIM 725, RRIM 711, IAC 300, and IAN 873 exhibited the highest resistance to leaf blight (**Figure 2**).

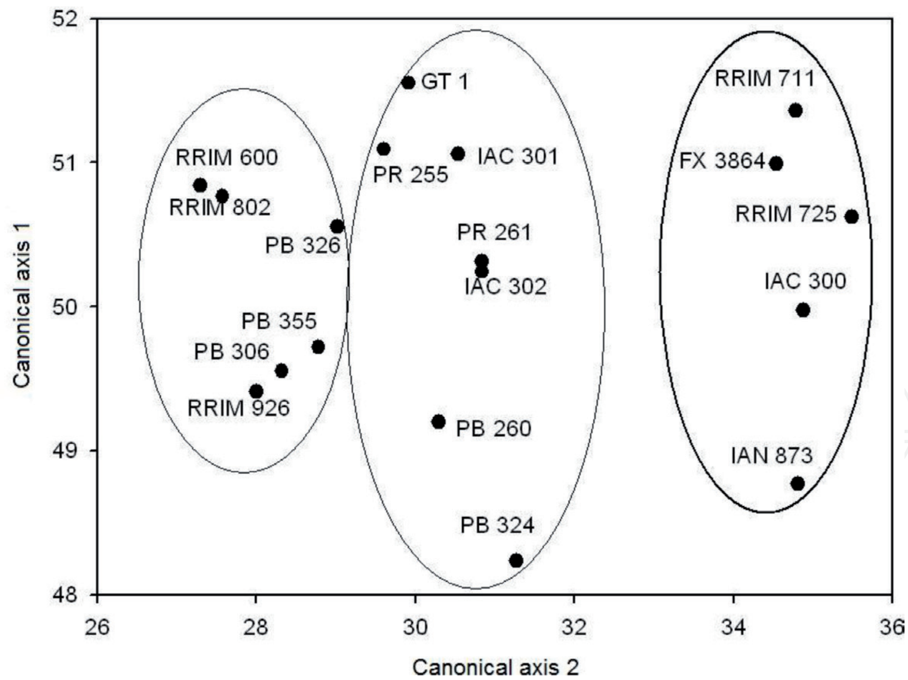

Figure 2.
Clustering of the studied rubber clones in relation to SALB (M. ulei) based on Mahalanobis distances [21].

5.3 Climate zoning

The Climatology Sector of Campinas Agronomic Institute developed a proposal of climate zoning for rubber by adopting the water balance method, that is, an accounting study involving the potential monthly values of rainfall and evapotranspiration of each region and their correlation with the intensity of leaf blight symptoms. The zoning divided the Amazon region into four distinct ecological zones, while the remaining Brazilian regions were distributed into other seven zones (**Table 2**).

5.4 Management of SALB per Brazilian climate region

5.4.1 Dry regions and spatial evasion

One of the major measures related to the management of leaf blight in Brazil includes cultivation at sites unfavorable to the development of the pathogen, using the general principle of evasion control (geographic evasion or evasion in space), popularly known as "scape areas."

According to the climate zoning (**Table 2**), a vast area in Brazil is considered preferential, with potential for rubber cultivation (region A, A1, and AM4) and well-defined dry season coinciding with the leaf shedding period of plants (clones of uniform "deciduous" habit, from *H. brasiliensis*), without risks of epidemics. This area corresponds to 2/3 São Paulo State, ¼ Mato Grosso State, ¼ Mato Grosso do Sul State, Goiás State and Minas Gerais State, besides the South of Pará, and part of Tocantins and Maranhão States. Thus, new borders were opened for rubber cultivation in the country, showing the way to self-sufficient natural rubber production. An example is the state of São Paulo, which presently counts on ~50,000 ha mostly covered with eastern clones of high productivity (e.g., RRIM 600, PB 235, and PR 255), without any concern about leaf blight, and is responsible for more than 50% of rubber produced in the country. Other examples are the south of Mato Grosso (A1), which has the largest continuous rubber tree plantation in the country, 8500 ha, and the south of Maranhão (AM4), where plantations developed very well, without leaf blight.

5.4.2 Humid regions and temporal evasion (avoidance)

In regions B and B1, with phytosanitary restrictions for cultivation, preference should be given to national clones of *H. brasiliensis* with resistance and uniform leaf shedding, which usually occurs during the period with scarce rainfall and temperature below optimal for infection by *M. ulei*. For these regions, there is great performance of clones with early leaf shedding, resulting in long hibernation periods, e.g., IAN 873, FX 4098, FX 2261, FX 985, and FX 3864. Clone MDF 180 has marked phenol production by infected leaflets. This inhibits the sexual phase of *M. ulei*, naturally breaking the pathogen's cycle, which, associated with the clone's deciduous habit, significantly reduces epidemics [22]. Using such materials favors once again the application of the evasion principle, in this case, evasion in time or avoidance, a term first proposed by [23], since local conditions favor the disease and clones should be selected for their phenological qualities [24], besides productivity.

Hybrid clones, from the breeding of *H. brasiliensis* with *H. benthamiana*, erroneously recommended in the 1970s in supporting programs (PROBOR I, II, and III), should be avoided due to their irregular habit of leaf shedding, a negative aspect for disease control, since it does not allow a break in the pathogen's life cycle and does not reconstitute vertical resistance to materials. Eastern cultivars, in general originated from *H. brasiliensis*, were selected for latex production; therefore, they are highly susceptible and consequently not recommended for these regions.

5.4.3 Super humid regions and crown grafting

In the super humid and humid Amazon region (AM1, AM2, and part of AM3), the use of resistant cultivars showing uniform leaf shedding is not sufficient to control the disease, since both leaf wetness period and temperature are high all over the year, favoring infection. Thus, plantations in continuous areas should involve crown grafting with hybrid cultivars of *H. pauciflora*, a species that has remained highly resistant to leaf blight during all these years. In this case, the adopted seedlings should be of the tricompound type or with double graft; they should also be constituted of vigorous and rustic rootstock, a first graft with productive clone, which will result in the future panel, and a third crown graft with these resistant hybrids at a height of 2.5 m, which will constitute the future crown of the tree [25].

5.4.4 Super humid regions and neoextractivism

In view of the low inoculum pressure existing in native rubber trees in the forest (see text above), besides crown grafting, the philosophy of neoextractivism can be adopted to establish plantations in these regions, i.e., extractivism with sustainability and technology, a management proposal tested in Acre State at Chico Mendes Extractive Reserve (RESEX) and Caquetá Extractive Settlement with plantations in small areas, where subsistence farming is practiced (from 1 to 1.5 ha), i.e., forest enrichment with greater density of productive rubber trees in small plantations from seeds (ungrafted) or polyclonals, associated with other species of interest such as "açai," cocoa, "cupuaçú," banana, coffee, etc., or even leaving the plants in the regenerating forest.

To constitute polyclonals, several clones of *H. brasiliensis* can be used; they should present uniform leaf shedding in the adult phase and be previously selected for resistance to different *M. ulei* races, in a larger spacing, to make up from 250 to 300 plants per hectare, surrounded by forest, which are named "highly productivity islands" (HPLs) due to the high latex production of these clones and the possibility of association with other species that allow economic use, improving the income and the rubber tappers' life condition, without leaving their activity [26]. To keep

Etiological agent	Disease	No. Products	Commercial Product	Active Ingredient (Chemical Group)
Microcyclus ulei	South American Leaf blight of rubber	9	Bravonil 750 WP	Chlorothalonil (Isophthalonitrile)
			Cercobin 700 WP	Thiophanate-methyl (Benzimidazole)
			Cobre Atar BR	Cuprous Oxide (Inorganic)
			Daconil BR	Chlorothalonil (Isophthalonitrile)
			Dacostar 750	Chlorothalonil (Isophthalonitrile)
			Metiltiofan	Thiophanate-methyl (Benzimidazole)
			Redshield 750	Cuprous Oxide (Inorganic)
			Topsin 500 SC.	Thiophanate-methyl (Benzimidazole)
			Topsin 700	Thiophanate-methyl (Benzimidazole)

Table 3.
Fungicides registered for the control of South American leaf blight in Brazil [29].

such "islands" protected from SALB epidemics, their number should not be >8, at every 400 ha, which compose a setting of native rubber trees, for RESEX, or up to two islands for every 100 ha, corresponding to one lot of the Extractive Settlement, always keeping the native forest intact in the surroundings since the native forest, in this case, acts as a natural barrier against fungal dispersion.

5.5 Additional practice to the management of South American leaf blight

5.5.1 Chemical control

As to chemical control in Brazil, there are efficient fungicides to reduce the disease intensity. Examples are the active principles thiophanate-methyl and triadimefon, which act on fungal stromata, making them sterile [27], as well as chlorothalonil, which has high residual potential while triadimefon has a healing effect. Furtado [28] found that weekly application of mancozeb and biweekly application of fenbuconazole and myclobutanil were efficient in controlling the disease. The fungicides registered for the disease control are listed below (**Table 3**).

5.5.2 Biological control

Biological control of the pathogen by the hyperparasite fungus *Dicyma pulvinata* represents a potential control measure. Studies conducted in greenhouse, nursery, clonal garden, and still young definitive plantation (4–5 years old) have shown efficient pathogen control under Amazon conditions. This hyperparasite reduces the primary inoculum since it prevents the stromatic phase of *M. ulei*, making unviable the production and the dissemination of ascospores [25]. This fungus was found parasitizing lesions in a clonal garden at the north coast of São Paulo State.

6. Potential impact of global climate changes on the spatial distribution of South American leaf blight in Brazil

The climate changes of the last decades have attracted the attention of the different segments of society, especially concerning their causes and consequences [30]. Of all economic sectors, agriculture has the greatest dependency on environmental conditions, especially climate. The impacts on plant diseases are differently expressed, and emphasis should be given to the effects of damages caused by the diseases on geographic distribution, efficiency of control methods, and remaining organisms that interact with the plant [31–36].

Among the phytosanitary problems of the country, leaf blight, caused by *M. ulei*, constitutes the major factor of productivity loss for rubber tree plantations in Brazil. Temperature and relative humidity have great influence on the rubber culture and its productivity, as well as on the geographic and temporal distribution of diseases [30]. Global climate changes constitute a serious threat to the Brazilian phytosanitary scenario since they can promote significant changes in the occurrence and severity of diseases affecting agricultural and forest plants. Based on the importance of this disease for the economic scenario of the country, the present study aimed to evaluate possible impacts of global climate changes on the spatial distribution of leaf blight in Brazil.

To elaborate spatial distribution maps of the disease, [37] regarded the monthly data for the period 1961–1990 as the current data of mean temperature and relative humidity, as indicated by the Intergovernmental Panel on Climate Changes (IPCC) and by the World Meteorological Organization, to characterize the future climate for every month, forecasts obtained from IPCC were used with the model developed by Hadley Center for Climate Prediction and Research (HadCm3). The scenarios used to obtain future projections were A2 and B2, centered in the decades of 2020 (period between 2010 and 2039), 2050 (period between 2040 and 2069), and 2080 (period between 2070 and 2099) [38]. Scenario A2 has high rates of greenhouse gas emission, i.e., it assumes the maintenance of the current emission patterns. Scenario B2 has less emission and shows more optimistic characteristics relative to scenario A2 [39].

Adopting the model HadCM3, data were interpolated by the method of inverse square of distance. Then, a mask delimitating the continents was applied on the maps and subsequently the area corresponding to Brazil was cut from the georeferenced data. For each month, maps containing data of temperature and relative humidity were generated considering the current climate situation and forecasts for the decades of 2020, 2050, and 2080, for scenarios A2 and B2.

Using the overlay techniques, maps containing the spatial distribution of areas where each climate element favors the development of the pathogen were elaborated. From the maps of mean temperature and monthly relative humidity for scenarios A2 and B2, in the current and future period, monthly distribution maps of areas favorable or not to the disease were elaborated, using classes defined based on the available epidemiological data about the effects of temperature and relative humidity on the development of the disease (**Table 4**) [8, 40–43].

The maps of risk areas for leaf blight elaborated for the future scenarios indicate that, in general, there will be a reduction in the area highly favorable and favorable to the disease in the country, relative to the current climate, for both scenario A2 and scenario B2 in **Figure 3**. Such a reduction is projected for either the period of greatest favorability to the disease (January, February, and March) or the least favorable period (July to October).

The major change in climate that is responsible for this result is probably the reduction in the mean relative humidity to levels unfavorable to the disease, i.e., values below 65%. In general, the reductions in the disease incidence were more pronounced for scenario A2 than for scenario B2. Scenario A2 predicts greater reductions in humidity than scenario B2, resulting in conditions less favorable to SALB.

Considering the current and the future scenarios, a reduction in the percentage of highly favorable and favorable areas is expected, as well as an increase in the areas relatively favorable and unfavorable to occurrence of SALB. Some regions of

Favorability Classes	Temperature (°C)	Relative Humidity (%)	Description
1	24 to 28	>90	Highly Favorable
2	20 to 24	>80	Favorable
2	24 to 28	80 to 90	Favorable
3	16 to 20	>80	Relatively Favorable
3	16 to 28	65 to 80	Relatively Favorable
4	<16 and >28	<65	Unfavorable

Table 4.
Classes of favorability to the development of SALB according to temperature and relative humidity intervals.

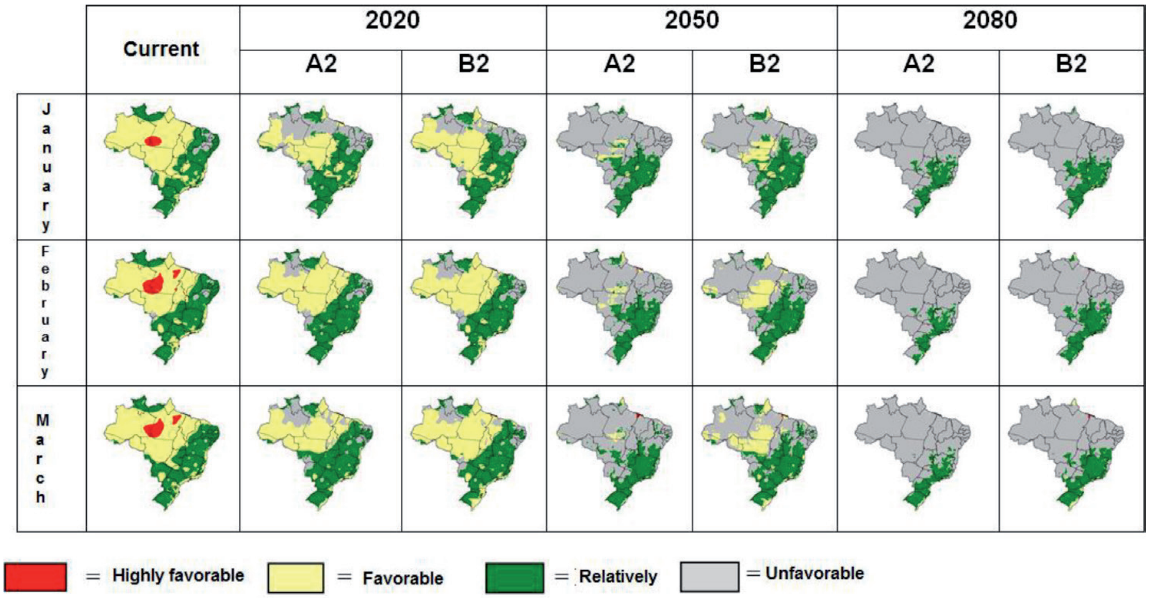

Figure 3.
Maps of climate favorability to South American leaf blight for January, February, and March in the current (1961–1990) and future scenario (years 2020, 2050, and 2080), considering scenarios A2 and B2 [36].

the country will become more apt to cultivation than others, which may trigger the emergence and/or better development of some new plantation regions. The months with higher temperatures will be more favorable to SALB; on the other hand, colder months are considered unfavorable to the development of this disease under the current climate conditions, remaining constant for future projections. The obtained knowledge associated with the development of disease prediction models can constitute important tools in the integrated management of SALB.

Author details

Edson Luiz Furtado[1], Willian Bucker Moraes[2], Waldir Cintra de Jesus Junior[3]*, Breno Benvindo dos Anjos[4] and Lilianne Gomes da Silva[4]

1 Forest Pathology, Department of Plant Protection, School of Agronomical Sciences, São Paulo State University—UNESP, Botucatu, SP, Brazil

2 Department of Agronomy, Federal University of Espírito Santo—UFES, Alegre, ES, Brazil

3 Nature Science Center, Federal University of São Carlos—UFSCar, Buri, SP, Brazil

4 Federal University of Espírito Santo—UFES, Alegre, ES, Brazil

*Address all correspondence to: wcintra@ufscar.br

References

[1] Gasparotto L. Epidemiologia do mal das folhas (*Microcyclus ulei* P. Henn. V. arx) da seringueira (*Hevea* spp) [thesis (doctorate)]. Viçosa: Universidade Federal de Viçosa; 1988. 124p

[2] Furtado EL, Trindade DR. Doenças da seringueira. In: Kimati H et al., editors. Manual de Fitopatologia: Doenças das culturas, V.II, 4. Ed. Piracicaba: Agronômica Ceres; 2005. pp. 559-569. ISBN: 85-318-0043-9

[3] Gasparotto L, JCR P, Ferreira FA, Furtado EL, Santos AF. Doenças da seringueira no Brasil. Brasilia-DF: EMBRAPA; 2012. p. 255. ISBN: 978-85-7035-097-8

[4] Hora Júnior BT, Macedo DM, Barreto RW, Evans HC, Mattos CRR, Maffia LA, et al. Erasing the past: A new identity for the Damoclean pathogen causing South American leaf blight of rubber. PLoS ONE. 2014;**9**(8):e104750. DOI: 10.1371/journal.pone.0104750

[5] Chee KH. Factors affecting discharge, germination and viability of spores of *Microcyclus ulei*. Transactions of the British Mycological Society. 1976;**66**:499-504. DOI: 10.1016/S0007-1536(76)80221-5

[6] Camargo AP, Cardoso RMG, Schmidt NC. Comportamento ecológico do mal das folhas da seringueira nas condições climáticas do Planalto Paulista. Bragantia. 1967;**26**:1-18

[7] Furtado EL, Kageyama PY, Souza AD, Costa JD. Ilhas de alta produtividade (Iap): Uma proposta para produtividade com biodiversidade nas reservas extrativistas do Acre. In: Seminário de Ciência e Desenvolvimento Sustentável. São Paulo, SP: Anais; 1997. pp. 29-31

[8] Chee KH. Assessing suceptibility of *Hevea* clones to *Microcyclus ulei*. Annals of Applied Biology. 1976;**84**:135-145. DOI: 10.1111/j.1744-7348.1976.tb01743.x

[9] Junqueira NTV. Variabilidade fisiológica de *Microcyclus ulei* (P. Henn.) v. Arx. [thesis (doctorate)]. Viçosa: Universidade Federal de Viçosa; 1985. 135p

[10] Ortolani AA. Agroclimatologia e o cultivo da seringueira. In: Simpósio sobre a cultura da seringueira no estado de São Paulo. Piracicaba, SP: Anais; 1986. pp. 11-32

[11] Honorato Júnior JJ. South American leaf blight of rubber tree: Dynamics of pathogen inoculum, progress and losses, in three topographical conditions [thesis (masters)]. Viçosa: Universidade Federal de Viçosa; 2010. 93p

[12] LMVD C, Jones C. Zona de Convergência do Atlântico Sul. In: Cavalcanti IFDA et al., editors. Tempo e Clima no Brasil. São Paulo: Oficina de Textos; 2009. p. 463

[13] Furtado EL, Cunha AR, Alvares CA, Bevenuto JAZ, Passos JR. Ocorrência de epidemia do mal das folhas em regiões de "escape" do Brasil. Arquivos do Instituto Biológico. 2015;**82**:1-6. DOI: 10.1590/1808-657000882013

[14] Ortolani AA, Pedro Junior MJ, Alfonsii RR, Camargo MBP, Brunini O. Aptidão agroclimática para a regionalização da heveicultura no Brasil. In: Seminário de Recomendação de Clones de Seringueira, Brasília, 1982. MIC/SUDHEVEA: Anais; 1983. pp. 19-28

[15] Towsend Junior CHT. Progress in developing superior *Hevea* clones in Brazil. Economic Botany. 1960;**14**:198-196

[16] Rands RD, Polhamus LG. Progress report on the cooperative rubber

development programme in Native America. Circular United States. Department of Agriculture. 1955;**976**:30

[17] Baptiste EDC. Recent progress in Malaya in the breeding annual selection clones of *Hevea brasiliensis*. In: International Horticulture Congress. London: London Proceedings; 1952. pp. 1100-11221

[18] Valois ACC. Melhoramento genético da seringueira. In: Curso de especialização em heveicultura. Belem: EMBRAPA/CNPSD/FAP; 1978. p. 24

[19] Pinheiro E, Libonati VF. O emprego da *Hevea pauciflora* M.A. como fonte genética da resistência ao mal-das-folhas. vol. 1(1). Rio de Janeiro: Polímeros; 1971. pp. 31-40

[20] Moraes VHF. Fisiologia da seringueira. In: Curso de especialização em heveicultura. Belém: SUDHEVEA/FCAP; 1985. p. 40

[21] Silva LG, Jesus Junior WC, Souza AF, Alves FR, Furtado EL. Performance of different rubber tree clones against South American leaf blight (*Microcyclus ulei*). Forest Pathology. 2014;**44**:211-218. DOI: 10.1111/efp.12084

[22] Sambugaro R, Furtado EL, Rodella RA, Mattos CRR. Anatomia foliar de seringueira (*Hevea* spp.) e desenvolvimento da infecção por *Microcyclus ulei*. Summa Phytopatothologica. 2004;**30**:44-50

[23] Evitação MJOM. Forma de defesa das plantas contra patógenos que deve ser melhor compreendida e explorada. Summa Phytopathologica. 1990;**16**:77-83

[24] Furtado ELacr [thesis (doctorate)]. Piracicaba: Escola Superior Agronomia Luiz de Queiroz, Universidade de São Paulo; 1996

[25] Gasparotto L, Trindade DR, Silva HM. Doenças da seringueira. Manaus: Embrapa-CNPSD; 1984. p. 71

[26] Kageyama PY. Extractive reserves in Brazilian Amazônia and genetic resources conservation. Tenth world Forestry Congress in Paris; September 1991. pp. 115-119

[27] Brignani Neto F, Furtado EL, Cardoso RMG, Rolim PRR, Oliveira DA. Efeito de fungicidas sistêmicos no ciclo biológico de *Microcyclus ulei*, agente da queima da folha da seringueira (*Hevea* spp.). Summa Phytopatothologica. 1991;**17**:238-246

[28] Furtado EL, Menten JOM, Carvalho JC, Godoy Junior G. Ação de fungicidas inibidores de demetilação, na síntese de ergosterol, no controle do mal das folhas da seringueira. Fitopatologia Brasileira. 1995;**20**:203-208

[29] AGROFIT. Brasília, DF: Ministério da Agricultura, Pecuária e Abastecimento; 2017. Disponível em: http://agrofit.agricultura.gov.br/agrofit_cons/!ap_praga_detalhe_cons?p_id_cultura_praga=4712 [Disponível em: 06 September 2018]

[30] Ghini R, Hamada E. Mudanças climáticas: Impactos sobre doenças de plantas no Brasil. Jaguariúna: Embrapa Meio Ambiente; 2008. p. 332

[31] Atkinson D. Global climate change: Its implication for crop protection. British Crop Protection Council Monograph No. 56; Surrey: BCPC; 1993

[32] Chakraborty S, Tiedemann AV, Teng PS. Climate change: Potential impact on plant diseases. Environmental Pollution. 2000;**108**:317-326

[33] Chakraborty S. Effects of climate change. In: Waller JML, Waller SJ, editors. Plant Pathologist's Pocketbook. Wallingford: CAB International; 2001. pp. 203-207

[34] Chakraborty S. Potential impact of climate change on plant-pathogen interactions. Australasian Plant Pathology. 2005;**34**:443-448

[35] Jesus Junior WC, Cecilio RA, Valadares Junior R, Cosmi FC, Moraes WB, Alves FR, et al. Aquecimento global e o potencial impacto na cultura e doenças do mamoeiro. In: Costa NA, Costa AFS, editors. Congresso Brasileiro de Fruticultura Tropical. Vitória: INCAPER; 2007. pp. 1-36

[36] Jesus Junior WC, Valadares Júnior R, Cecílio RA, Moraes WB, Vale FXR, Alves FR, et al. Worldwide geographical distribution of Black Sigatoka for banana: Predictions based on climate change models. Scientia Agricola. 2008;**65**:40-53. DOI: 10.1590/S0103-90162008000700008

[37] Silva LG. Comportamento de clones de seringueira ao mal das folhas e potencial impacto das mudanças climáticas globais na ocorrência da doença [thesis (másters)]. Alegre: Universidade Federal do Espírito Santo; 2010

[38] IPCC. Climate Change 2007: The Physical Science Basis: Summary for Policymakers. Geneva: IPCC. 2007. 18p. Disponível em: http://www.ipcc.ch/SPM2feb07.pdf [Acesso em: 10 June 2009]

[39] IPCC. Climate Change 2001: The Science Basis IPCC WGI, TAR. New York: Cambridge University Press; 2001. p. 881

[40] Langford MH. South American Leaf Blight of *Hevea* Rubber Trees. Washington, D.C: USDA; 1945. p. 31

[41] Holliday P. South American Leaf Blight (*Microcyclus ulei*) of *Hevea brasiliensis*. Farnham Royal: CAB; 1970. p. 31

[42] Gasparotto L, Zambolim L, Maffia L, Vale FXR, Junqueira NTV. Efeito da temperatura e da umidade sobre a infecção de seringueira por *Microcyclus ulei*. Fitopatologia Brasileira. 1989;**14**:38-41

[43] Gasparotto L, Zambolim L, Ventura JA, Costa H, Vale FXR, Maffia LA. Epidemiologia do mal das folhas da seringueira no Estado do Espírito Santo. Fitopatologia Brasileira. 1991;**16**:180-184