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REVIEW ARTICLE

Emerging and Existing Major Leaf Diseases of *Hevea brasiliensis* in Malaysia

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ABSTRACT

Hevea brasiliensis, or rubber tree, is the primary source of natural rubber, and second major commodity crop in Malaysia after oil palm. It is known that rubber trees are prone to a wide range of foliar diseases, resulting in significant yield losses. To date, a new emerging severe leaf disease epidemic tentatively termed as Pestalotiopsis secondary leaf fall was identified affecting many rubber plantations in rubber producing countries. In addition, five major leaf diseases that have been conclusively identified affecting rubber plantations nation-wide in Malaysia were also reviewed in this paper. These leaf diseases include secondary leaf falls of Oidium, Colletotrichum, and Corynespora, as well as Fusicoccum leaf blight and Phytophthora abnormal leaf fall. In general, this present paper reviews the recent epidemic and the major leaf diseases by focusing on causal pathogens, symptoms and its effects on rubber plantations. Information presented in this review would be useful in planning and initiating better control measures for rubber growing regions in an attempt to reduce or even prevent losses of latex yield.

Key words: Leaf diseases; Rubber tree; Malaysia

INTRODUCTION

Hevea brasiliensis (family Euphorbiaceae) is a tropical tree native to the Amazon Forest of South America (Noordin et al., 2012). In the 1960s, Malaysia was one of the world's leading natural rubber producers in the world. However, Malaysia was in the third ranking by only producing 8% of the total natural rubber globally, (Fox and Castella, 2013). Currently, natural rubber production is facing many challenges including fluctuations in price, lack of competent tappers and the risks of destructive epidemics (Heng and Joo, 2017).

Recently, a severe epidemic of new leaf disease on rubber plantations was reported. The disease bears a symptom of brown circular spots, that was never been reported before. Presently, the causal agent was identified as *Pestalotiopsis* sp., but it is yet to be confirmed by various on-going research collaborations. As for now, the disease is known as Pestalotiopsis secondary leaf fall.

In Malaysia, five major types of leaf diseases affecting rubber plantation nation-wide were documented. These diseases are secondary leaf falls of Oidium, Colletotrichum, and Corynespora, as well as Fusicoccum leaf blight, and Phytophthora abnormal leaf fall. Figure 1 displays the foliar symptoms of these diseases.

The diseases mentioned above have been considered important as they affect physiological processes and production of latex, ultimately affecting the economy of the producing country. The aim of the present review is to introduce a new emerging epidemic and gather comprehensive information on major leaf diseases of rubber in Malaysia.

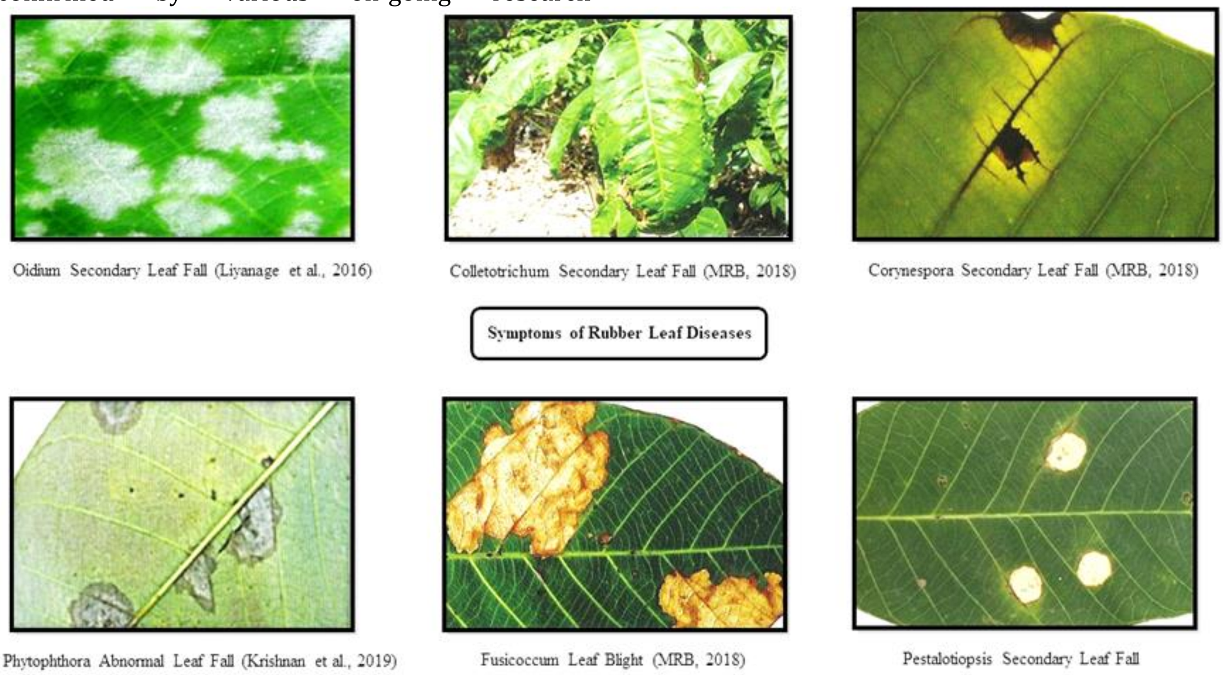

Figure 1. Symptoms of Major Rubber Leaf Diseases in Malaysia

EMERGING PESTALOTIOPSIS SECONDARY LEAF FALL

The Pathogen

A new emerging epidemic of rubber leaf disease, first reported to infect rubber plantations in Indonesia, was originally thought to be caused by *Fusicoccum* sp. Later, the causal agent was pinpointed to *Pestalotiopsis* spp. However, the factual causal pathogen is yet to be confirmed. At present, on-going research collaborations among the members of International Rubber Research Development Board (IRRDB) have been undertaken to affirm the causal agent of the outbreak.

Distribution of the Disease

The disease was initially reported by Dr. Febbiyanti from Indonesian Rubber Research Institute (IRRI) in 2016. At the end of 2017, the disease spread throughout South Sumatera (personal communication, November 5, 2019). To date, the new leaf disease has spread to four other rubber producing countries, namely India, Malaysia, Thailand and Sri Lanka. In 2017, the disease was reported by Dr. Shaji Phillip from Rubber Research Institute of India in "Meeting of Technical Committee on Plant Protection" organized by Association of Natural Rubber Producing Countries (ANRPC) on 5 November 2019 at Kuala Lumpur, Malaysia. In the same year, Dr. Murnita Mohmad Mahyudin and her team from Malaysian Rubber Board (MRB) also detected the occurrence of this disease in Johor state of Malaysia (personal communication, November 5 2019). In 2019, Dr. Arom Rodesuchit from Surat Thani Rubber Research Centre of Thailand reported the first occurrence of the disease at a rubber plantation in Narathiwat, Thailand at a "Meeting of Expert on Pestalotiopsis Leaf Disease" organized by Rubber Authority of Thailand (RAOT) from 13 - 15 January 2020 at Surat Thani, Thailand. Last but not least, in 2019, Sri Lanka stated the occurrence of the disease as confirmed by Dr. Chandra Kumara Jayasinghe from International Rubber Research and Development Board (personal communication, February 11, 2020).

According to Dr. Murnita (personal communication, November 5, 2019), in Malaysia, the disease began to infect rubber plantations in November 2017 in Johor at Labis district (2 hectare), Kulai district (1 hectare) and Setindan area (30 hectare). The affected rubber clones were RRIM 2001, RRIM 2002, RRIM 2025, RRIM 2023, RRIM 3001, RRIM 600, PB 260, PB 235, PB 347 and PB 350. In 2018, the disease has spread to other states which included Negeri Sembilan, Selangor, Perak, Pahang, Kelantan and Terengganu. In 2019, the disease was recorded in all states in Peninsular Malaysia except for Perlis and Penang. However, till to date, Sarawak and Sabah states are free from the new outbreak.

Symptoms

The symptoms of *Pestalotiopsis* secondary leaf fall were observed as circular spots with brown necrotic lesions on matured rubber leaves (Figure 2). The fungus infects matured rubber trees aged around 10 to 15 years. Most of the infected rubber plantation had low or no application of fertilizers. The disease causes defoliation up to 90% of the canopy (personal communication, November 5, 2019).

Disease Cycle

At present, no information was available on the disease cycle.

Epidemiology

Pestalotiopsis secondary leaf fall favours wet environment with high humidity. In Malaysia, wintering season begins in January to March. Young rubber leaves appear in March and April. Soon after, the leaves mature around May and June. At this stage, disease symptoms began to appear as the pathogen attack matured rubber leaves. Generally, July until October is the time for harvest (tapping) latex when yield is at its peak. Unfortunately, rainy season together with production of matured rubber leaves make it more susceptible for the outbreak to occur. The pathogen spread or transmits through rain splash and air. Favourable temperature and susceptible rubber clones transmit the disease more rapidly. In Malaysia, the epidemic began around October and November, and subsequently the yield of latex drops significantly.

Disease Management

According to Dr. Murnita, in Malaysia, the disease is currently being controlled by spraying fungicides such as chlorothalonil, mancozeb, propineb, propiconazole and hexaconazole. Spraying of fungicides are usually done on the ground and the canopy for three to six rounds. Prevention and control of the outbreak can also be done by improving good agricultural practices such as use of fertilizers, good weed control and use of resistance clones. Data from observations and surveys during advisories by MRB revealed that rubber clone RRIM 600 and PB 350 have been classified as severe to very severe towards the disease respectively. Clone RRIM 2002 was classified as moderate to severe. The severity of clones RRIM 2001, RRIM 2023, RRIM 2025, RRIM 3001 and PB 260 are moderate towards the disease. Clones that are low in severity towards the disease are PB 235 and PB 347 (personal communication, November 5, 2019).

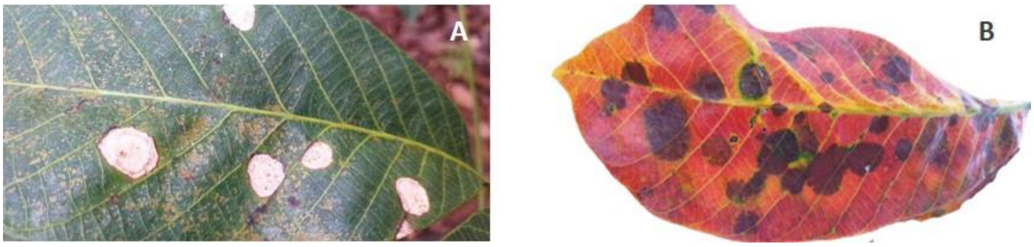

Figure 2. Circular spots with brown necrotic ring on green matured rubber leaf (A); dark green circular spots on orangey rubber leaf (B)

OIDIUM SECONDARY LEAF FALL

The Pathogen

Oidium secondary leaf fall, commonly known as powdery mildew is caused by *Oidium heveae* which is an obligate parasite requiring a living host to sustain. At present, no specific virulent strain of *O. heveae* has been reported in Malaysia.

Distribution of Disease

The first outbreak of the disease was reported in 1918 affecting rubber trees in Indonesia (Young, 1949). The outbreak spread to Malaysia, Brazil, Papua New Guinea and India (Shaw, 1967). Braun and Cook (2012) reported that *O. heveae* was detected in Asian countries including Malaysia, Thailand, Vietnam, Cambodia, Indonesia, India, and Sri Lanka. The pathogen was also detected in some African countries including Uganda, Tanzania, Ghana and Congo. Other rubber-growing regions affected by the disease included Cameroon, Brunei, Myanmar and Malawi (Liyanage et al., 2016).

Symptoms

Infected young leaves generally shrink, curl, crumple and with edges rolling inwards. Subsequently, leaves display blackened, with white mycelia on the surfaces before finally fall (Liyanage et al., 2016). White patches of mycelia generally grow on both sides of matured leaves which later turn yellow and brown, forming necrotic spots which reduce the efficiency of the processes of photosynthesis (Liyanage et al., 2016). At a later stage of infection, the whole lamina is covered by mycelia. Later, the foliar parts fall, leaving the petioles attached to the twigs. After several days, the petioles drop. The disease causes secondary leaf fall of young leaves that appear after wintering (Fernando, 1971). This causes a major defoliation leading to severe retardation of growth and extensive loss in yield up to 45% (Liyanage et al., 2016).

Disease Cycle

Conidiospores of *O. heveae* will landed on the surface of a leaf. Subsequently, conidia form germ tubes and thereafter the appressoria at the end of the tubes. The appressoria adhere spores to the surface of host tissues and start to invade the host. A feeding structure, known as haustoria develops in the cells indicating successful infection. Soon after, secondary hyphae proceed to branch out on the surface of the host. Finally, the conidiophores form at top of leaf stalks, completing a disease cycle (Sun et al., 2015).

Epidemiology

The spores of the pathogen are spread via wind. Transport of infected planting materials also contributes to the dissemination of the pathogen (Ramakrishnan and Radhakrishna, 1963). High humidity makes the environment more favourable for the spread of the pathogen (Heng and Joo, 2017). A temperature of slightly below 30°C was best for production of *O. heveae* spores (Liyanage et al., 1986). Contrarily, the release and dispersion of spore were reported to be more favourable at high temperature together with the occurrence of great air turbulence (Fernando, 1971) and low moisture (Peries, 1966a). The outbreak is notably severe in subtropical regions (Liyanage et al., 2016). Powdery mildew is said to be aggravated by climate change. For instance, fluctuations in rainfall regimes, rising temperatures, moisture and immense atmospheric humidity (97 to 100%) were reported to have increased pathogenicity of the disease (Narayanan and Mydin, 2012).

Disease Management

An effective method to reduce infection is by sulphur dusting of four to six rounds on tractor-mounted mist blower at intervals of 5 to 7 days during bud-burst (Heng and Joo, 2017). The first application was proposed to be conducted two days after bud burst (when 10-15% of leaf buds reach 5mm) and to continue for at least 80% of the susceptible period. A minimum of four applications were required within five to six weeks during a refoliation cycle. Wettable sulphur at a ratio of 1 kg in 400 L of water was proposed as suitable and efficient for rubber seedlings in nurseries (Priyadarshan et al., 2005). The employment of disease-resistant clones appears to be the simplest and most economical way of managing Oidium secondary leaf fall. Malaysian clones RRIM 929, RRIM 928, RRIM 2025, PB 350 and PB 260 have been grouped as moderately resistant clones, while RRIM 2001, RRIM 2002, RRIM 2023, RRIM 2024 and RRIM 3001 were grouped as resistant clones towards *Oidium* secondary leaf fall (Anon, 1998).

COLLETOTRICHUM SECONDARY LEAF FALL

The Pathogen

Colletotrichum gloeosporioides is the causal pathogen of Colletotrichum secondary leaf fall disease in rubber. At present, there is no virulent strain reported in Malaysia.

Distribution of Disease

Colletotrichum secondary leaf fall disease has been observed in most rubber-growing regions of Southeast Asia (Brown and Soepena, 1994), Sri Lanka (Jayasinghe et al., 1997), India (Saha et al., 2002) and China (Liu et al., 1987).

Symptoms

The disease establishes on rubber plants from the period of refoliation causing extensive damage on leaves at copper brown and light brown stages (Manju et al., 2014). Beyond light brown stage, the disease does not cause leaf fall (Manju et al., 2014). Severe deformation of leaves has been reported to occur in light green stage and beyond. As a result of leaf deformation, active leaf area is substantially reduced. The pathogen affects the development of rubber trees causing stunted growth, dieback, secondary leaf fall, dieback and death of trees at nursery stage and in the field. Moreover, the production of latex in mature rubber trees will be reduced due to the disease (Sabu et al., 2000).

Disease Cycle

C. gloeosporioides initiates interaction with rubber trees through production of melanised appressorium by spores that germinate on host surfaces penetrating the host cuticle. Soon after penetration, infection vesicles and primary hyphae are formed. Subsequently, secondary hyphae develop and colonize neighbouring cells. Eventually, visible lesions can be seen at the sites of infection (Munch et al., 2008).

Epidemiology

The main elements that influence infection rate particularly during refoliation are temperature, humidity and rainfall (Sailajadevi et al., 2005). Pathogen favours cloudy weather, more rainy days, slight sunshine and temperature of 29 °C. Pathogens persevered on and in seeds, trash and also weed hosts. Spores are spread by infected seeds, air currents, water splash and insects. Serious outbreaks make trees bare of leaves or with unhealthy foliage and retarded growth, hence lengthen the plants immaturity period (Manju et al., 2014).

Disease Management

The present method used to control Colletotrichum secondary leaf fall is by application of fungicides such as chlorothalonil and propineb, once a week until the leaves matured (MRB, 2018). The size of matured rubber trees has been noted as the limiting factor for controlling the disease. Although aerial treatment has been documented to be necessary for efficient control, the method raises environmental and health concerns. Artificial defoliation technique is another method of controlling Colletotrichum secondary leaf fall disease (Guyot et al., 2001). The process takes advantage of the time of natural wintering of the rubber trees. The technique involves the removal of entire leaves by chemical defoliation before the start of natural wintering. New leaves refoliate and mature earlier, and this coincides with the dry season where *C. gloeosporioides* is not active. Hence, secondary leaf fall is avoided. The technique accelerates leaf senescence and fall, and initiates rapid refoliation. The method was established in Asia, then in Cameroon and Gabon. In Malaysia, the technique was well-tested in 1968 and from 1974, and was adopted on large-scale to control the disease. Herbicides such as MSMA, merphos or sodium cacodylate were used in this technique. Application of the herbicides was documented to cause early refoliation, generally occurring before the rainy season, which helps rubber trees to avoid fungal infection (Guyot et al., 2001). Rubber clone PB 260 was reported as less susceptible to the disease (Guyot et al., 2001). To date, no recent literature listing the revised list of susceptible or resistant clones toward the disease.

CORYNESPORA SECONDARY LEAF FALL

The Pathogen

The disease is caused by fungus, *Corynespora cassiicola* which produces a toxin, cassiicolin. *C. cassiicola* grows very well under high humid conditions with temperature range of 28 to 30°C and long sunshine hours. The fungus is recognized as a necrotrophic pathogen that invades host through secretion of phytotoxic compounds (Breton et al., 2000). In Malaysia, there are multiple virulent strains of this fungus with different levels of virulence. Studies have shown that Strain CKT05D is virulent towards rubber tree causing severe infection, while Strains CSB16 and CLN23 showed moderate to low levels of infectivity. The least aggressive strain was recorded as Strain CKT05F which caused mild necrotic lesions (Siti Shuhada et al., 2015).

Distribution of the Disease

The fungus was first isolated from rubber trees in 1936 in Sierra Leone, later in India and in budwood nurseries in Malaysia during 1960 (Newsam, 1960). The disease has spread to most other rubber-producing countries in Asia which include Indonesia, Thailand, India and Sri Lanka. African countries were also affected by the disease at the end of 1980s (Déon et al., 2012b).

Symptoms

The disease exhibits different symptoms in over 80 host plants under wide environmental conditions (Jayasinghe, 2000a). The variety of symptoms often posed difficulties in early identification and control of the disease (Umoh and Fashoranti, 2018). The most familiar symptom was described by Jinji et al. (2007) as circular amphigenous lesions of different sizes with brown or white papery centre, encircled by brown margins and yellow halo surrounding the ring (Manju, 2011). The centre of the lesions may disintegrate, leaving holes. The shot holes effects which appear on leaves were said to be due to breakdown in the centre of the spots (Jinji et al., 2007). Frequently, the primary vein or mini veinlets adjacent to the spot becomes dark in colour giving rise to 'fishbone' or 'railway-track' appearances (Jinji et al., 2007). The fungus has been observed to cause the fall of young and old leaves. Repeated defoliations of a tree cause die-back of shoots and death of the affected tree. Under natural conditions, it was observed that the disease was more severe at the stage when a greater portion of the canopy was covered with light green leaves (Manju et al., 2014).

Disease Cycle

After the pathogen infects a rubber tree, the disease progresses rapidly. The conidia germinate and germ tubes are produced and infect leaves via wounds and extended into leaf veins. Within 24-hour period, the mycelia extend through host cells including intercellular spaces. After two days, the surfaces of lesions are covered with mycelia. Soon after, conidiophores with conidia protrude from the lesion spots (Liu et al., 2014). Toxin cassiicolin is vital in the initial phase of infection. According to Déon et al. (2012a), one or two days after inoculation, before the appearance of the first symptoms, a peak of cassiicolin transcripts occurred regardless of the susceptibility of the rubber clones. The main enzyme involved in pathogenesis of the *C. cassiicola* was reported as pectin lyase. Cellulolytic enzymes also take part in the later stage of infection (Jayasinghe et al., 1998a).

Epidemiology

The severity of the disease was reported to be aided by water stress, poor soil fertility and unbalanced or not enough nutrient supply (Rao, 1975). Spores' liberation is by wind (Jayasinghe, 2000a). The dispersion of spores has been observed to peak during mid-day. It was observed that spore dispersal was at its peak during dry season with temperatures between 25 to 30°C (Jayasinghe, 2000a). However, the disease occurs when the surface of leaf is damp (Jayasinghe, 2000a). The epidemic has been reported to be more serious during refoliation (Reshma et al., 2016). Even though the pathogen infects at all phases of leaf growth, the most vulnerable phase was reported to be at the light green phase (Umoh and Fashoranti, 2018). *C. cassiicola* causes delay in maturation of young rubber trees, dieback and yield reduction of about 45% in matured trees (Ogbebor, 2010). It was reported that Sri Lanka uprooted and withdrawn their popular high yielding rubber clone RRIC 103 as a recommended planting material due to its susceptibility and serious outbreak of Corynespora secondary leaf fall disease (Jayasinghe et al., 1997).

Disease Management

Suppression of *C. cassiicola* during its severity period is crucial to maintain well-being of trees in subsequent seasons. Control approaches have suggested efficient management of the disease to begin both in nurseries and fields. These included the application of fungicides, cultural practices and integrated management of disease, focusing on planting of resistant clones, eradication of susceptible clones, restriction for introduction of clones, multiclonal planting, and use of biological and chemical controls (Manju et al., 2019). Chemical control is commonly applied while plants are still in polybags and or in budwood nursery. Generally, most researchers suggested a combination of application of fungicides as an effective control (Umoh and Fashoranti, 2018). It is recommended to spray fungicides in nursery polybags during rainy season because all rubber clones are highly prone to the disease at young age (Jayasinghe, 2000b). Various water-based fungicides have been suggested by Joseph and Manju (2002) for control of diseases, describing that a mixture of mancozeb (0.2%), carbendazim (0.5%) and a combination of metalaxyl + mancozeb (0.2%) were normally efficient in nurseries. In addition, it was recommended to spray mancozeb weekly, as it was the most efficient fungicide available at a reasonable price. According to a study by Fernando et al. (2010) combining overhead shading and use of fungicide mancozeb was recorded as the best approach to manage Corynespora secondary leaf fall disease. The timing of sprhaying of fungicide appears to be very crucial, the best being at the stage of light green during refoliation (Manju et al., 2016). According to Chee (1988), the most promising approach of combating the disease is to prevent planting of susceptible clones. Susceptible clones need to be detected early during selection and breeding processes. Most susceptible clones in Malaysia have been identified, and these included RRIC 103, followed by KRS 21, FX 25 and RRIM 725. Clones GT 1 and RRIM 600 were classified as moderately susceptible.

FUSICOCCUM LEAF BLIGHT

The Pathogen

Fusicoccum leaf blight of rubber was first reported by Radziah and Chee (1989) in February 1987. The disease was infecting four-year-old rubber trees at FELDA Lok Heng Selatan, in Johor. The disease pathogen was identified as a *Fusicoccum* species. Based on taxonomic and sequence data, Nyaka Ngobisa et al. (2013) identified *Neofusicoccum ribis* as the primary causal agent of leaf blight disease in *H. brasiliensis* in commercial plantations in Malaysia. Study conducted by Nyaka Ngobisa et al. (2015) revealed that all isolates were pathogenic to immature leaves of rubber trees and seedlings. Nevertheless, the virulence of the fungus differs according to the rubber clones (Nyaka Ngobisa et al., 2015).

Distribution of Disease

In 2003, *Fusicoccum* leaf blight disease outbreak was reported to have spread to Perak and Selangor and was recently classified as one of the five major rubber canopy diseases in Malaysia (Hashim et al., 2010).

Symptoms

The pathogen causes large lesions with concentric brownish zones and rusty brown pin-head size spots on foliar parts of the rubber tree. Subsequently, infected young leaves drop off after four months of infection (Nyaka Ngobisa et al., 2012). The following are rubber clones that could be affected by the disease: PR 261, PB 260, PB 217, PB 255, RRIM 600, RRIM 2023, RRIM 2024, RRIM 2025, RRIM 3001 and PB 350 (Radziah and Chee, 1989; Murnita et al., 2008).

Disease Cycle

To date, no literature describing the disease cycle specifically on *Neofusicoccum ribis* is available.

Epidemiology

Infection of the genus *Neofusicoccum* was generally believed to develop via spores and through seeds. It has the capability of colonizing the host without producing any visible symptoms and remains as endophytes in the host (Slippers and Wingfield, 2007). Transition into pathogenic phase was cited to be associated with environmental stresses such as nutrient deficiencies, extreme temperature fluctuations, drought and mechanical injuries (Lopes et al., 2016).

Disease Management

The current method used to control this disease is by application of fungicides, carbendazim, propiconazole and benomyl by continuous weekly spraying until no symptoms appear (MRB, 2018). Based on Percentage of Disease Intensity (PDI), rubber clones used in the study were classified into three groups according to their capability to endure infection following artificial inoculation. Group 1 consists of susceptible clones (PDI > 10%) which comprises of clones PB 350, RRIM 2024 and RRIM 2023. Group 2 consists of moderately resistant clones (PDI > 5%) which include RRIM 2025 and PB 260 while Group 3 are resistant clones (PDI < 5%) including RRIM 2007 and RRIM 2002 (Nyaka Ngobisa et al., 2015).

PHYTOPHTHORA ABNORMAL LEAF FALL

The Pathogen

The genus *Phytophthora* causes disease in nearly all components of a rubber tree excluding roots. Abnormal leaf fall disease caused by *Phytophthora* spp. is one of the most damaging infections of a rubber tree. *P. palmivora*, *P. botryosa* and *P. meadii,* have been reported to cause abnormal leaf fall in Malaysia (Krishnan et al., 2019). Currently, there is no report describing any specific virulent strain of the pathogen infecting Malaysian rubber trees.

Distribution of the Disease

It has been reported that *Phytophthora* diseases are present in rubber growing countries including Malaysia, Costa Rica, India, Venezuela, Sri Lanka, Thailand, Myanmar, Cambodia, Liberia and Vietnam (Krishnan et al., 2019).

Symptoms

In the early stages of the disease outbreak, leaves of infected plants generally remain healthy and green. The colour of the lamina of fallen leaves gradually change colour from green to yellow. Fruits of infected rubber trees remain intact and turn dark in colour. In severe infection, the fruits rot. Falling of leaves negatively affects timber output besides reducing crop yield (Krishnan et al., 2019).

Disease Cycle

Phytophthora sp. favours tropical climate with prolonged damp conditions. The establishment and dispersal of disease occur during damp rainy season when there is enough moisture (Krishnan et al., 2019). Fundamentally, *Phytophthora* is a soil-borne organism although some species can be spread by other methods (Drenth and Guest, 2004). Epidemics begins when the environmental conditions are favourable for the germination of primary inocula. Primary inocula exist as chlamydospores and mycelia in infected soils, bark cankers, roots and mummified pods or fruits. Asexual reproduction of *Phytophthora* species may have up to three asexual spore forms, which are chlamydospores, sporangia and zoospores (Drenth and Guest, 2004). Asexual sporangia are spread either by water or wind (Krishnan et al., 2019). Sporangia germinate by establishing germtubes or invasive hyphae or evolve into biflagellate zoospores. The flagella of the zoospores play a part in the spread and epidemics of *Phytophthora* species (Cline et al., 2008). After the zoospores get attached to a host surface, they germinate and form germtubes which subsequently develop over the plant surface and finally form appressoria. Consequently, the appressoria penetrate the epidermis of the host (Latijnhouwers et al., 2003).

Epidemiology

If infection succeeds, secondary inocula are produced and trigger the disease epidemic. The sporangia can also be released and spread by wind, water and through contact with vectors (Drenth and Guest, 2004). Sexual reproduction results in the production of oospores. The germination of oospores from previous season is the beginning of an inoculum development (Drenth and Guest, 2004). The oospores live in twigs, leaves, infected dried pods and also on the soils (Drenth and Guest, 2004). Infection is more frequent on petioles of leaves often seen with an exudation of latex. Water-soaked lesions exhibited on leaf petioles turn dark brown or black in colour (Krishnan et al., 2019). A drop of coagulated latex often exudes from a lesion. Lesions could also be seen on foliar parts exhibiting dull green colour which later changes to black. The pathogen also infects young twigs and growing shoots which later cause rotting and dieback of shoots. The petioles, leaves, pods and tender shoots can also be infected causing massive defoliation and crop loss (Krishnan et al., 2019). The disease causes leaves to fall and shoots to rot leading to major dieback. Consequently, growth becomes stunted and this delays maturation of the rubber trees. Extensive defoliations of matured rubber trees cause great loss in terms of economy. The disease also reduces growth of rubber trees which results in decreased latex yield (Krishnan et al., 2019). When climatic conditions are ideal for the pathogen, leaf fall can be more extensive particularly in vulnerable clones. Leaf falls also result in fallen leaves covering the entire ground forming a carpet (Krishnan et al., 2019). Phytophthora abnormal leaf fall of rubber becomes outstanding during the monsoon season (Krishnan et al., 2019).

Disease Management

The current method used to control Phytophthora abnormal leaf fall in rubber is through the application of fungicide, copper oxychloride in mineral oil by spraying before the monsoon season begins. The method has been used widely in Malaysia, Sri Lanka and India (MRB, 2018). The best alternative method apart from chemical control is by planting tolerant or resistant clones. Formerly famous rubber clone RRIM 600 and PR 107 were susceptible to this disease in most rubber growing countries in Southeast Asia. Conversely, GT 1, PR 261, PR 255 and RRIM 712 are tolerant clones suggested for Southeast Asian regions (Anon, 1986).

CONCLUSION

There are five major leaf diseases of rubber tree in Malaysia. The diseases include secondary leaf falls of Oidium, Colletotrichum, Corynespora secondary leaf fall, Fusicoccum leaf blight and Phytophthora abnormal leaf fall. A new epidemic of leaf disease known as Pestalotiopsis secondary leaf fall also significantly affects Malaysian rubber plantations. Table 1 summarizes all the major diseases reviewed in this paper. Generally, the causal pathogens cause defoliation of leaves which eventually disrupt physiological processes such as photosynthesis, resulting in stunted growth rate and yield loss. These catastrophic leaf diseases most significantly affect smallholders as they depend solely on latex yield as their source of income. Malaysia was once the biggest producer of rubber; however, Thailand and Indonesia have over-taken the place as the leading rubber producer in the world. To curb the declining rubber production, effective management on existing and current rubber diseases is a matter of prime importance. Lack of information on the virulent strains of pathogens infecting rubber trees in Malaysia has been a constraint in developing preventive or curative measures. Recent literature updating the list of susceptible or resistant clones towards particular diseases is scarce. Researchers should also update on the distribution of the disease so that better precaution could be implemented to control the spread and movement of the pathogen particularly in international trade. For each disease discussed in the present review, much information is still lacking. Further study needs to be carried out in order to provide comprehensive information, better understanding and to develop sustainable methods to combat the diseases for a brighter future of natural rubber industry in Malaysia.

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COMPETING INTERESTS

The authors declare that they have no competing interests

DATA AVAILABILITY STATEMENT

The raw data used to support the findings of this study are available from the corresponding author upon request.

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Table 1. Summary of major leaf diseases of rubber in Malaysia

DISEASE	ASPECTS OF DISEASES				
	Distribution	Symptoms	Disease cycle	Epidemiology	Disease Management
Oidium secondary leaf fall	Malaysia, Thailand, Vietnam, Cambodia, Indonesia, India, Sri Lanka, Uganda, Tanzania, Ghana, Congo, Cameroon, China, Brunei, Myanmar, Malawi, Papua New Guinea and Brazil.	Infected young leaves will shrink, curl, crumple and edges roll inwards. White patches of mycelia grow on both side of matures leaves which later turn yellow and brown, forming necrotic spots.	1) Conidiospores reach surface of leaves and conidia form germ tubes, and thereafter appressoria at the end of tubes. 2) The appressoria adhere spores to the surface of host tissues and start to invade host. 3) Haustoria, a feeding structure, develop in host cells indicating a successful infection	1) High humidity and temperature between 25°C to 28°C are favourable for survival of pathogen. 2) Spores are spread via wind.	Sulphur dusting.
Colletotrichum secondary leaf fall	Malaysia and in most rubber growing countries of Southeast Asia, Sri Lanka, India and China.	Spots and deformation on mature leaves.	1) Spores germinate and produce melanised appressorium which penetrate host cuticle. 2) Soon after penetration, infection vesicles and primary hyphae are formed. 3) Later, secondary hyphae develop and colonize neighbouring cells.	1) Cloudy weather, rainy days, slight sunshine and temperature of 29°C favour spread of pathogen. 2) Spores are spread via infected seeds, air currents, water splash and insects.	Application of fungicides such as chlorothalonil and propineb once a week until the leaves are matured.

Corynespora secondary leaf fall	Sierra Leone, India, Malaysia, Indonesia, Thailand, Sri Lanka and African countries.	1) Circular amphigenous lesions with brown or white papery centre encircled by brown margins with yellowish halo surrounding the ring. 2) The primary veins or mini veinlets adjacent to infected spots become dark in colour giving rise to 'fishbone' or 'railway-track' appearances.	1) The conidia germinate and germ tubes produced and infect leaves via wounds and extended into the veins. 2) Within 24 hours, the mycelia extend through host cells including intercellular spaces. 3) The surface of lesions covered by mycelia after 2 days.	1) High moisture, water stress, poor soil fertility and insufficient nutrient increase severity of disease. 2) Spores are spread via wind.	Fungicide combination is an effective control; mixture of mancozeb (0.2%), carbendazim (0.5%) and a combination of metalaxyl and mancozeb (0.2%).
Fusicoccum leaf blight	Malaysia	Large lesions with concentric brownish zones and rusty brown pin head size spots on rubber leaves.	To date, no literature describing the disease cycle specifically on *Neofusicoccum ribis* available.	1) Infection via spores and through seeds. 2) *Neofusicoccum ribis* may remain as endophytees in host and transit into pathogenic phase when triggered by environmental stress, nutrient deficiencies, extreme temperature fluctuations, drought and mechanical injuries.	Application of fungicides carbendazim, propiconazole and benomyl by spraying continuously once a week until no symptom appears.

Phytophthora abnormal leaf fall	Malaysia, Costa Rica, India, Venezuela, Sri Lanka, Thailand, Myanmar, Cambodia, Liberia and Vietnam	1) The colour of lamina of fallen leaves gradually change from green to yellow. 2) The fruits of rubber persist on tree and turn to dark in colour. In severe case, the fruits rotted.	1) Sporangia germinate by establishing germtubes or invasive hyphae or evolve into biflagellate zoospores. 2) Zoospores become attached	1) Spread by wind, water and other vectors. 2) Severe during monsoon seasons.	Application of fungicide copper oxychloride in mineral oil by spraying before a monsoon season begins.
Pestalotiopsis secondary leaf fall	Indonesia, Malaysia, India, Thailand, Sri Lanka	Circular spots with brown necrotic lesions on matured rubber leaves	No information available on disease cycle of pathogen.	1) Wet, high humidity and rainy season favour spread of pathogen. 2) Spread through water and air.	Spraying with fungicides such as chlorothalonil, mancozeb, propineb, propiconazole and hexaconazole.

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