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Significant Oil Palm Diseases Impeding Global Industry: A Review

(Penyakit Penting Sawit yang Menghalang Industri Global: Satu Ulasan)

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ABSTRACT

Oil palm is the most well-known high yielding and versatile oil crop grown. In 2019, Malaysia ranked as the world's second largest producer of palm oil products (28%) after Indonesia (57%), contributing around USD 9.07 billion to the country's Gross Domestic Product (GDP) and has been the main economic contributor in the agriculture sector. In recent years, increase in demand has paralleled production. However, pests and diseases have been the major constraints in production causing reduction in palm oil quality and yield. This paper reviews a current status of oil palm diseases of significant economic importance affecting the global oil palm industry. Plant diseases such as basal stem rot (BSR), *Fusarium* wilt, *Phytophthora* bud rot, *Pestalotiopsis* leaf spot, common spear rot, orange spotting and upper stem rot (USR) have been classified as the major diseases of oil palm in terms of economic importance. This paper discusses on the damages caused by the diseases, the causal pathogens and pathogenicity, symptoms as well as treatments or control in the view of developing measures to manage occurrences.

Keywords: Disease control; oil palm diseases; pathogen

ABSTRAK

Kelapa sawit terkenal sebagai tanaman yang menghasilkan minyak yang tinggi dan versatil. Pada tahun 2019, Malaysia merupakan pengeluar produk minyak sawit kedua terbesar di dunia (28%) selepas Indonesia (57%) dengan menyumbang sebanyak USD9.07 bilion kepada Keluaran Dalam Negara Kasar (KDNK), sekaligus menjadi penyumbang ekonomi utama dalam sektor pertanian negara. Beberapa tahun kebelakangan ini, peningkatan permintaan adalah selari dengan pengeluaran. Namun begitu, serangan perosak dan penyakit menjadi kekangan utama dalam pengeluaran yang menyebabkan kemerosotan kuantiti serta kualiti minyak sawit. Kertas ini mengulas status semasa penyakit tanaman sawit yang mempunyai kepentingan ekonomi yang ketara serta mempengaruhi industri sawit secara global. Penyakit seperti reput pangkal batang (BSR), layu *Fusarium*, reput tunas *Phytophthora*, bintik daun *Pestalotiopsis*, reput daun muda biasa, bintikan oren dan reput batang atas (USR) telah dikelaskan sebagai penyakit utama sawit. Kertas ini membincangkan kerosakan yang disebabkan oleh penyakit pada sawit, patogen penyebab, keupayaan patogen menyebabkan penyakit, simptom serta rawatan atau kawalan dengan tujuan untuk membangunkan langkah bagi menguruskan kejadian jangkitan.

Kata kunci: Kawalan penyakit; patogen; penyakit kelapa sawit

INTRODUCTION

Literature has it that the 2020/2021 global oilseed production was recorded at 209.62 million metric tons of which 35.9% was contributed by palm oil (USDA 2020). In 2019/2020, the main producers of palm oil products were Indonesia (57%), Malaysia (28%), Thailand (3.9%), Colombia (2.2%) and Nigeria (1.3%). At present, palm oil is the world's largest domestically consumed oil with 74.57 million metric tons followed by soybean oil (59.22 million metric tons) (USDA 2020). Malaysia ranked as the second largest palm oil supplier and distributor in the world with 22.28 million metric tons in 2020/21, following behind Indonesia with 49.43 million metric tons (USDA 2020). In recent years, demand for palm oil has increased compared to a few decades ago due to increased global production and oil consumption in food and industrial products (Khatiwada et al. 2018; Prokurat 2013). Oil palm plantations in Indonesia covered more than 11.9 million hectares in 2017 and were estimated at 13 million hectares in 2020 (Woittiez 2018). Malaysia's oil palm plantations covered more than 5.39 million hectares in 2014. As of December 2018, the acreage was almost 5.9 million hectares across the country (MPOB 2018).

In the cultivation of crops, pests and diseases are bound to invade and cause significant impact on healthy plants. Without exception, oil palm is susceptible to a variety of pathogen attacks, which include pathogenic fungi, bacteria, viroids, and viruses (Monge Pérez et al. 1993; Pornsuriya et al. 2013; Poromarto 2020; Sheong et al. 2018; Widiastuti et al. 2018). Generally, diseases affecting oil palm reduce yield and retard healthy growth of palms (Chung 2012). Around 32 diseases and disorders affecting oil palm in Southeast Asia, Africa and South America have been recorded (Aderungboye 1977). To date, the major oil palm diseases have been documented to be economically imperative for the palm's survival. The present paper reviews major oil palm diseases of economic importance including basal stem rot (BSR) (Khaled et al. 2018; Rakib et al. 2015), *Fusarium* wilt (Gogbe et al. 2017; Koussinou et al. 2019; Tengoua & Bakoumé 2008), *Phytophthora* bud rot (Moreno-Chacón et al. 2013; Torres et al. 2016), *Pestalotiopsis* leaf spot (Barrios-Trilleras et al. 2015; Lekete et al. 2019), common spear rot (Hafizi et al. 2013; Monge Pérez et al. 1994; Sumi et al. 2017) and Cadang cadang viroid (Randles & Rodriguez 2003; Rodriguez et al. 2017; Vadamalai et al. 2006) described as follows:

BASAL STEM ROT (BSR) DISEASE

Basal stem rot (BSR) disease has been documented as the major and most devastating disease of oil palm in Southeast Asia, particularly in Indonesia and Malaysia (Assis et al. 2016; Muniroh et al. 2014; Munthe & Dahang 2018; Susanto et al. 2005). The estimated loss due to the disease was more than 40% and could reach 80% of the potential yield which greatly increased the total yield loss by reducing the weight or the number of fresh fruit bunch (FFB) (Assis et al. 2016; Priwiratama & Susanto 2014). In Malaysia, the expected loss of potential yield caused by BSR was anticipated to be more than 400,000 hectares of matured oil palm (Roslan & Idris 2012).

BSR is caused by white-rot fungi, *Ganoderma* spp. (Munthe & Dahang 2018; Purba et al. 2019). The genus *Ganoderma* belongs to *Ganodermataceae* family. Generally, it causes white rots in woody plants. The fungus degrades and decomposes lignin, cellulose, and related polysaccharides (Sun et al. 2013). The causal pathogen was first identified as *Ganoderma lucidum* Karst in West Africa (Wakefield 1920). *Ganoderma* causing BSR has been recorded in several countries including Malaysia (Ho & Nawawi 1986; Idris et al. 2001), Indonesia (Susanto et al. 2013; Wiratmoko et al. 2018), Thailand (Preecha et al. 2017), Africa (Mih & Kinge 2015), Colombia (Arango et al. 2016), Papua New Guinea (Pilotti et al. 2018) and Solomon Islands (Gorea et al. 2019). Some of the common species are *G. applanatum, G. boninense, G. chalceum, G. lucidum, G. miniatocinctum, G. phillipii,* and *G. tornatum*. The species *G. boninense, G. zonatum,* and *G. miniatocinctum* have also been proven to be pathogenic to oil palm (Idris et al. 2001; Rakib et al. 2015), in which the main pathogenic species that was identified as the most vigorous pathogen causing BSR was *G. boninense* (Jameel et al. 2017; Munthe & Dahang 2018; Rakib et al. 2015).

The initial mechanism employed by this devastating pathogen in the penetration step is the degradation of lignin, the most important structural component in woody and non-woody plants which play a role in giving strength and rigidity to plant cells (Musa et al. 2018). Lignin, linked to cellulose and hemicelluloses, also plays a role as a first-line of defence barrier against attacks from microbes (Sun et al. 2013). *Ganoderma* has the capability of degrading lignin. It also has the capability of showing celluloses and hemicelluloses to be consumed as accessible hydrolysable nutrients, subsequently causing lignin to be mineralized (Paterson 2007). Ariffin et al. (2000) and Hanum and Tantawi (2016) documented that BSR disease begins with the decaying of the root system as well as the lower stem which subsequently induces the appearance of disease symptoms. Some of the symptoms of this disease prior to collapse of a standing palm include mottling of the lower fronds, growth retardation, unopened spear leaves, pale leaf canopy, presence of basidiocarp on the stem (Figure 1) and water stress. The disease progresses gradually at a very slow pace and eventually kills the palm. Records indicate that early detection of the disease is almost impossible as visible symptoms only occur at later stages of the disease infestation. Mottling (blotchiness) in young palms lead to necrosis. At this stage, more than 50% of the stem base area is already rotting, and the basidiocarp could be detected. Without any control measures taken at early stages of infection, the affected palm generally dies within 6 to 12 months after the development of the visible symptoms (Roslan & Idris 2012).

To date, there is no effective treatment for the disease. Naher et al. (2013) and Priwiritama and Susanto (2014) stated that the only treatment accessible to control the disease is to prolong the lifespan of the palm. Early detection of BSR is of primary importance in order to work on the curative measures (Ahmadi et al. 2017; Fowotade et al. 2019; Khaled et al. 2018). Early detection methods have been carried out with reliable methods such as *Ganoderma* selective medium (GSM) (Ariffin et al. 1996), Polymerase Chain Reaction (PCR) (Chong et al. 2011; Idris et al. 2010; Mandal et al. 2014), and enzyme-linked immunosorbent assays (ELISA) (Kandan et al. 2010; Madihah et al. 2014).

FIGURE 1. Basidiocarps of *Ganoderma boninense* growing on oil palm basal stem (Photo courtesy of Tuan Muhammad Syafiq Tuan Hassan 2020)

Muniroh et al. (2014) developed a novel protocol which was robust and reliable where ergosterol extraction from infected oil palms tissue was used as a benchmark to demonstrate the degree of infection. The protocol enables an efficient analysis with large number of samples while providing a simple and rapid detection method. Profiling of secondary metabolites has also been used in the detection of BSR. Metabolites have been proven to be involved in early oil palm defence against pathogenic attack (Chong et al. 2012; Nusaibah et al. 2016; Sahebi et al. 2017). However, the stated techniques are said to be laborious and unsuitable for large scale samples. Recently, remote system has been developed to detect and assess the occurrence of the disease with much reduced labour and time. Remote sensing and geospatial technologies have been used with high efficiency and applicable for early detection of BSR (Ahmadi et al. 2017; Azuan et al. 2019; Khaled et al. 2018; Santoso et al. 2017).

FUSARIUM WILT DISEASE

Fusarium wilt or *Fusarium* vascular wilt is a devastating disease of oil palm and has caused severe losses to plantations in Africa (Cooper & Rusli 2014; Corley & Tinker 2003; Gogbe et al. 2017; Paterson et al. 2013; Tengoua & Bakoumé 2008). *Fusarium* wilt was first described in the Democratic Republic of Congo (Wardlaw 1946). The disease was also reported in Cameroon, Ghana, Nigeria, Ivory Coast and other West African regions (Omamor et al. 2007; Tagoe 1999; Tengoua & Bekoumé 2005; Wardlaw 1946). Localized outbreaks in Brazil and Ecuador have also been recorded (Renard & de Franqueville 1989; Van de Lande 1984). The incidence of the disease was recorded in Ivory Coast with the affected regions including Sassandra (5.13%), La Mé (1.80%), Dabou (0.87%), and Anguédédou (0.60%) (Gogbe et al. 2017). To date, there has been no report on *Fusarium* wilt disease occurring in Southeast Asia where most of the oil palms are grown.

Fusarium wilt is caused by *Fusarium oxysporum* f. sp. *elaeidis*. The disease was reported as an endemic to several countries in Africa (Corley & Tinker 2003) where thousands of standing palms had been severely damaged and yield remarkably reduced (Tengoua & Bakoumé 2008; Waller & Brayford 1990). Cooper (2011) and Rusli et al. (2013) reported that the mortality rate caused by this disease could go up to 70%. The pathogen is a soil-borne fungus that produces macroconidia and microconidia, and has long-living chlamydospore with the potential of surviving in soil and debris. The pathogen infects roots with lesions and migrates into the xylem vessels of a palm that causes hormonal imbalance in the root system and subsequently lead to water stress (Flood 2006). Apart from infecting roots with lesions, it could also infect an intact root (Cooper 2011; Cooper & Rusli 2014). Cooper (2011) cited that systemic colonisation subsequently occurs via xylem vessels. Tengoua and Bakoumé (2008) reported that physiological imbalance of the palms causes a decrease in total yield, while in some, causes the plants to die.

Gogbe et al. (2017) reported that symptoms of *Fusarium* wilt include yellowing of one or two crown leaves of young palms (1 to 4 years old) and drying out of older leaves. Internal symptoms of the disease include browning of the sap conductive fibres which could be seen in the cross-section of the yellowing leaves' petiole. They further elaborated that in palms of 5 years and above, the first group of symptoms are the yellowing and drying of one or two crown leaves, while older leaves in the lower part of the stem are dried and broken. This could be due to acute wilting or the first syndrome where the palm retains its erect position until broken off (Flood 2006). Some palms in the second group exhibit stunting in growth while some have medium height with narrowed stems. However, the palms may have green leaves, but none bears fruits as well as no browning of fibres could be observed in petiole although it could be seen in stipe level (Gogbe 2017). In the third group, symptoms of drying out or de-coating of crown suggest that the palm is affected by *Fusarium* (Gogbe 2017). Flood (2006) cited that this is related to the second syndrome which is the chronic wilting where the palm remains alive for many months or years but become progressively stunted. The youngest erect fronds remain but often chlorotic in nature and have stunted growth subsequently flattening the crown. The diameter of the trunk apex is also reduced. The stunting of the palm was due to a decrease in petiole size and leaf lamina where it was caused by the reduction in cell division (Ekhorutomwen et al. 2018; Mepsted et al. 1995a). Changes in the level or activity of the host's gibberellins could also be involved. Further research found that the stunted leaves were correlated with prolonged mild water stress (Mepsted et al. 1995b). They suggested that the stunted leaves were a way of adapting to prolonged mild water stress. Failing to produce smaller leaves, the palms were theorized to face acute wilt.

Cultural practices have included planting of new palms at distance from old diseased stumps (Flood 2006), changing of types of cover crops (Renard & de Franqueville 1989), avoiding use of spent bunch stalks as mulch to reduce incidence of disease (Renard & de Franqueville 1989), and the application of potassium (Renard & Quillec 1983). However, due to long survival nature of chlamydospores in soil and debris, the cultural methods proposed had their limitations and made management of the disease even more challenging. Cooper (2011) suggested that the only practical way to control *Fusarium* wilt was by breeding lines of disease resistant palms. de Franqueville and Renard (1990) reported that breeding program in Ivory Coast was a success where the introduction of resistant varieties reduced the total yield loss from 30% to 3%. Since the breeding programme involved partners from several countries, seeds needed to go through intermediate quarantine with inspection and chemical seed treatments (Flood et al. 1994). Nevertheless, the breeding programme took more than 7 years involving selection of desired material in field trials. Cooper and Rusli (2014) developed a non-destructive method of controlling the disease involving core sample extraction to detect *Fusarium* in the xylem vessels. *Trichoderma* spp. has also shown to be antagonistic against *Fusarium* species (Babychan & Simon 2017; Naher et al. 2019; Papavizas et al. 1984; Rusli et al. 2019a, 2019b, 2016).

PHYTOPHTHORA BUD ROT DISEASE

Phytophthora bud rot is a disease that has caused devastating economic losses on oil palm worldwide, besides bringing environmental damage with different levels of aggressiveness in the natural ecosystems. Malaguti (1953) first reported on bud rot in oil palm destroying 27% of palms in Suriname in 1920s and has caused major losses. Another incidence was reported in 1928 in Panama by Reinking (Benítez & García 2014). In 1990s, the disease has affected palms in Latin America which covered Peru and Brazil as well as parts of Africa (de Franqueville 2003). In 2004 to 2009, more than 30,000 hectares of oil palm plantations in Western Colombia were destroyed by this pathogen while more than 35,000 hectares were destroyed in

2013 in Eastern Colombia (Martínez & Plata-Rueda 2013; Martínez et al. 2010). To date, there has been no lethal or outbreak report on this disease in Malaysia (Latifah et al. 2017) or any other Southeast Asian countries although *P. palmovira* was commonly found in the regions with other host plants (Latifah et al. 2018).

Phytophthora bud rot is caused by a genus of plant-damaging oomycetes. The genus name itself is a Greek word with the meaning 'the plant destroyer'. *Phytophthora palmivora* Butler causes bud rot disease and may take in 2 forms: a lethal form; and a non-lethal form where recovery rate is high (de Franqueville 2003; Torres et al. 2010). The disease has become the most devastating threat in Latin America, especially in Colombia where 35,000 hectares or 90% of productive oil palms were affected resulting in the death of the palms (Moreno-Chacón et al. 2013). Sarria et al. (2008) reported that many plantations in Colombia, Brazil, and Ecuador suffered deterioration by the disease and faced major losses. The losses had caused decline in rural investments in the affected regions, thus creating tremendous job losses while losing local support (Sarria et al. 2008).

This plant-damaging oomycete is one of the most important plant pathogens in agriculture due to its global destructive threat (Torres et al. 2016). This is due to its capability of attacking a wide range of plant tissues from stems, flowers, roots and fruits of individual plants species, making it an irritating plant pathogen specifically in the tropics (Mohamed Azni et al. 2019; O'Brien et al. 2009; Torres et al. 2016). *Phytophthora* spp. produces a variety of propagules such as hyphal swellings, oospores, zoospores, chlamydospores, and sporangia that spread via air, water, soil, and vector (Drenth & Guest 2013). The pathogen spreads through infested soil, water and infected plants as well as debris (Cahill et al. 2008; Van de Lande 1993). The disease is characterized by having infection in the soft tissue of the spear leaves in the elongation and maturation zones of the upper third of the bud, and eventually spreads to neighbouring spear leaves. The rotting of spear leaves is generally accompanied by frond chlorosis on the younger ones. The white leaf tissues provide an ideal condition for the pathogen to colonize, sporulate and cause repeated infections. Subsequently, colonization of the bud by *P. palmivora* takes place. Emergence of new leaves is a sign of an attempt to recover growth by severely affected palms (de Franqueville 2003).

Torres et al. (2016) reported that once the pathogen has infected a palm, the observable symptoms included lesions in spear leaves. Under environmental conditions of high rainfall and high humidity, increasing number of larger lesions subsequently caused secondary infections. Lesions could also be seen in the meristematic zones of the affected palm's developing leaflets. New infections affected other tissues on the nearby leaflets if favourable conditions assist the development of disease. In advanced stages of the disease, the external leaflets of complete spear leaf appeared dry. The necrotic tissues dropped, and released sporangia and zoospores carried by droplets of water down to the base of the spear leaf once it opened (Drenth & Guest 2013). The visibly expressed symptoms indicated the early stage of bud rot infection and commonly referred by growers as spear rot.

Biological control agents (BCAs) have been used due to their minimal environmental impact as well as providing sustainable and target specific approaches in managing any disease. Studies involving BCA on other *Phytophthora* with different host species have been well-discussed (Biju et al. 2018; de Oliveira et al. 2018; Phung et al. 2015; Segarra et al. 2013; Woo et al. 2014). However, there was no study on BCA in controlling *Phytophthora* in oil palm. The use of chemical control is found to be one of the viable methods to control the disease caused by *P. palmivora* (Moreno-Chacón et al. 2013; Opoku et al. 2007; Yousaf et al. 2018). Although the pathogen may develop resistance to many fungicides, a fungicide of Bordeux mixture with copper oxychloride generally inhibits mycelia growth completely under *in vitro* screening (Neeraja et al. 2019). Plants use chemical mechanism in their cells in response to pathogenic attack. Oil palm regulates its enzymes of the antioxidant system to block the progression of pathogen, maintaining low levels of disease severity (Ávila-Méndez et al. 2019). The method on inoculation assay of *P. palmivora* could provide a beneficial use as a screening tool for breeding programme due to the understanding of the infection processes (Sarria et al. 2016). By understanding the processes of how *P. palmivora* infects oil palm, researchers could obtain information to comprehend the development of the disease.

PESTALOTIOPSIS LEAF SPOT DISEASE

Pestalotiopsis leaf spot or grey leaf blight is a devastating disease of oil palm particularly in Venezuela's plantations that had caused significant yield losses (Escalante et al. 2010). Crop loss was recorded at around 40% with the reduction of bunch by as much as 18 to 20 t ha^{-1} (Jollands 1983). The disease was reported in Colombia, Honduras, Columbia, Venezuela, and Peru (Genty et al. 1983; Howard et al. 2001). There were also reports of

Pestalotiopsis in China, Ghana and Thailand (Lekete et al. 2019; Shen et al. 2014; Suwannarach et al. 2013), where Ghana was reported to have 85% of disease incidence.

Lepidoptera larvae have been known to be the main insect vector that spread this disease. The disease is a complex of virulent fungi include; *Colletotrichum, Curvularia, Gloeosporium helminthosporium,* and *Pestalotia* on oil palm leaves (Escalante et al. 2010). The conditions of the leaves turning grey and brittle caused by the disease could occur at any stage of growth of the palm. The disease gets more severe in plantations of more than five years' old which later reduces production up to 36% due to plummeting of photosynthetic capacity of the leaflets (Barrios-Trilleras et al. 2015).

The fungus *Pestalotiopsis* causes leaf spots, and blights on the petiole or rachis (Suwannarach et al. 2013). Unlike other leaf spot or petiole blight pathogens, this disease infects all parts of the leaf from its tip to the base (Figure 2). The insect vector from the genus Lepidoptera, *Leptopharsa gibbicarina*, feeds and defoliates along oil palm leaflets and is necessary for disease destablishment (Turner 1981). Due to the feeding wounds caused by the lace bugs, invasion by fungal pathogen *Pestalotiopsis* may be facilitated. *Pestalotiopsis*' pathogenicity may be influenced from the interaction of multiple conditions where environmental conditions, host and pathogen's virulence susceptibility play a role (Gehlot et al. 2008). The disease within adult palms is considered in optimal conditions when the development of the disease is aided by the density of the leaves (Gehlot et al. 2008). The density of the palm leaves may be the cause of the increase in insect population and disease onset.

FIGURE 2. Symptoms of leaf spot caused by *Pestalotiopsis microspora* on oil palm leaflets (Photo: Nusaibah Syd Ali, 2015)

Pestalotiopsis leaf spots develop either only on the leaf blade, or only on the petiole and rachis. Spots could also develop on both parts simultaneously (Elliott 2009). Symptoms of the disease normally begin with a very small yellow, brown or dark spots from circular to elliptical lesions that gradually increase in diameter (Escalante et al. 2010; Lekete et al. 2019). Leaf spots are usually dark brown to black, with yellow to rust brown zones surrounding the spots. If the disease is restricted, Elliott (2009) reported that the spots were never more than 1/4 inch (0.6 cm) in size. In humid environment, the disease will be more severe, black, sessile and discoid conidiomata developed and exuded conidial masses that later turned to black was documented (Suwannarach et al. 2013). Palms that have undergone severe defoliation on the upper part of the canopy usually take up to two years to get their foliage recovered (Corley & Donough 1995). The pygmy date palm (*Phoenix roebelenii*) was affected quite often by the disease in Florida during winter months. Dark lesions were found on the base of young palms emerging from buds (Eliott 2009).

Control of the disease could begin with the removal of severely infected leaves (Elliott et al. 2004). Cultural methods including increase in air flow could reduce humidity. Moreover, increased planting distance could also reduce disease spread and removal of weeds or trimming surrounding vegetation is essential. Timed irrigation is also vital to avoid excess water and wetness in the soil (Elliott et al. 2004). Insectidal fungicide could be used to control insect vector, *Leptopharsa gibbicarina* by root absorption. Martinez et al. (2013) found that insecticide have long time protection time while providing toxicity cause to the insect with about 99.99% mortality. Lekete et al. (2019) discovered that most fungicides used to control the disease did not demonstrate promising outcome while neglecting the more important fungicide, Carbendazim which have more adverse effect in just low concentration. The common fungicide used by farmers was found to be Mancozeb did not suppress growth and spread of leaf spot disease even in high concentration.

COMMON SPEAR ROT DISEASE

Common spear rot, also known as the crown disease, commonly attacks young oil palms between 1 and 3 years old (Breure & Soebagjo 1991; Chinchilla-López et al. 1997; Monge Pérez et al. 1994). It has been reported to be a destructive disease in Suriname and Indonesia particularly in Northern Sumatra (Breure & Soebagjo 1991; de Lande 1999; Turner 1981). The disease was also reported in India and tropical America (de Lande 1999; Monge Pérez et al. 1994; Sumi et al. 2017). This disease reduces oil palm yield per palm by 4% (Breure & Soebagjo 1991). Literature indicated that leaf expansion and petiole cross-section were also hindered by the disease although disease incidences were rarely more than 5%. However, more than 50% of highly susceptible progenies had been affected (Breure & Soebagjo 1991; Monge Pérez et al. 1994).

Spear rot infects oil palm at early stages of growth. *Fusarium solani* and *F. oxysporum* have been reported to be associated with spear rot disease of oil palm in Malaysia and Indonesia (Hafizi et al. 2013; Monge Pérez et al. 1994). *Ceratocytis paradoxa* and *F. sacchari,* dominated by a group of weak virulent of *Fusarium* spp. were cited to be associated with spear rot in Indonesia (Akino & Kondo 2012). *C. paradoxa* has been reported to cause spear rot even before the leaf tissues were wounded (Akino & Kondo 2012). *Fusarium* species was reported to be able to recover from environmental stresses such as drought and salt stress (Suwandi et al. 2018). They suggested that there was an association between osmotic stress and the plant pathogenic *Fusarium* species, where osmotic stress was observed to facilitate in *Fusarium* spp. virulence enhancement.

Symptoms of this disease are observable during the juvenile growth of oil palm especially during the first two years after transferring to the field. The symptoms may be observed even at the nursery stage, and in many cases, symptoms only appear after seven years or more. The first symptom of this disease is the appearance of small, brown, watery lesions on leaflets of the unexpended spear leaves (Pornsuriya et al. 2013). Once the lesions grow, they get contagious and affect the leaflets prior to the emergence of spear leaf. The other common symptoms include bending of rachis, breaking, rotting of some spear and emerging leaves (Chinchilla 2008). *C. paradoxa* was reported to cause rotting symptoms; however, it did not cause bending of rachis (Akino & Kondo 2012). Extensive yellowing and rotting at the tip of the young leaves caused 30% loss or more of the leaves prematurely. In advanced spear rot disease infestations, rotting could be quite immense and this affects meristem which subsequently kills the palm. During the recovery phase, emergence of short and distorted leaves can be seen. Unfortunately, only a proportion of affected palms undergo total or partial recovery (Henry et al. 2015).

Proper agronomic practices which improve soil properties to allow better root development was proposed in order to reduce symptom severity as well as to increase the recovery of affected palm (Henry et al. 2015). Root system of oil palm needs to be regenerated to allow the recovery of aerial growth and thus, reducing disease incidence and severity while increasing the productivity and yield (Albertazzi & Ramirez 2009). The identification of *Fusarium* species on the common spear rot has been mainly based on the distinctive macroconidia and microconidia's shapes and sizes (Leslie & Summerell 2008). The presence and absence of chlamydospores, colony appearances, pigmentations, as well as growth rate of *Fusarium* on agar media could also depict the characterization of the species (Leslie & Summerell 2008). PCR has been utilized to differentiate strains of intraspecific level in *Fusarium* taxonomic studies (Hafizi et al. 2013). Breeding of less susceptible materials could be carried out as it may be the most appropriate control measure. The screening of materials should be focused on area with known high incidence where the crossing scheme should consider sufficient connections between families (Breure & Soebagjo 1991).

ORANGE SPOTTING DISEASE

Orange spotting (OS) disease was recognized as a disorder in Africa in the 19th century (Forde & Leyritz 1968). Coconut Cadang-Cadang Viroid (CCCVd) was identified as the causal agent of the disease in coconut (*Cocos nucifera* L.) (Hanold & Randles 1991a), causing an estimated total loss of 40 million palms in the Philippines (Hanold & Randles 1991a; Imperial & Rodriguez 1983). In African, CCCVd variants were identified as the causal pathogen of OS disease on palm leaves (Thanarajoo et al. 2017; Vadamalai et al. 2006; Wu et al. 2013). In Philippines, disease incidence of 700,000 was reported (Philippines Coconut Authority 2014) with yield of about 25% to 50% lower than healthy palms (Rodriguez et al. 2017). CCCVd variants of oil palm have more than 90% sequence similarity with CCCVd of coconut (Rodriguez et al. 2017; Vadamalai et al. 2006; Wu et al. 2013).

The OS is a well-known disease in oil palm (Rodriguez et al. 2017). It has been observed in commercial oil palm plantations in Malaysia, Thailand, Indonesia, Papua New Guinea, Solomon Islands, Latin America, and West Africa (Genty & Reyes 1977; Pornsuriya et al. 2013; Randles et al. 1980; Rodriguez et al. 2017; Selvaraja et al. 2012; Wu et al. 2013). It is transmitted by vegetative multiplication of infected hosts, by seeds or pollens, with still unknown vector(s) (EFSA 2017). The European Food Safety Authority (EFSA) stressed that the OS disease has the potential of spreading via planting materials produced for trade purposes. There are three classes of CCCVd described to consist of 297, 293, and 270 nucleotides (Vadamalai et al. 2006). The authors noted that the concentrations of CCCVd were found to be low, below the threshold amount of detection.

Observable symptoms of this disease in oil palm include no inflorescences produced, broken pinnae, and reduced number and size of fronds. Numerous pinnae of older fronds were seen to have large bright orange spots, while the younger fronds were chlorotic and possessed smaller spots (Randles et al. 1980). As the frond ages, the small yellow spots expand into non-necrotic orange spots (Randles & Rodriguez 2003; Randles et al. 1980). Palms with OS were found to be shorter and have smaller fruit brunches compared to non-infected palms (Hanold & Randles 1991a). The inflorescences became necrotic and infertile where nut production subsequently ceased (Hanold & Randles 1998; Randles & Rodriguez 2003). The production of frond and size were reduced, leaflets became brittle, followed by death of crown (Randles et al. 1977).

At present, CCCVd mode of natural transmission in oil palm is still unclear with no control measures available. In depth research on the causal agent and disease transmission are crucial as unexpected outbreak is possible with climate change issues faced by the world. Oil palm CCCVd variants are difficult to detect since they exist in very low concentrations in oil palm tissues (Vadamalai et al. 2009, 2006). Polyacrylamide gel-electrophoresis (PAGE), hybridization assay, and conventional RT-PCR are some of the reliable molecular techniques in detecting CCCVd variants in oil palm (Hanold & Randles 1991b; Vadamalai et al. 2006). A robust and liquid-hybridisation-based method which is ribonuclease protection assay (RPA) was also found to be reliable; however, it requires radioactive probes (Vadamalai et al. 2009). Nevertheless, a reverse transcription loop-mediated isothermal amplification (RT-LAMP) was reported to be rapid and sensitive in detecting viroids where it was used to detect Potato spindle tuber viroid, Peach latent mosaic virus and CCCVd (Boubourakas et al. 2010; Lenarčič et al. 2013; Thanarajoo et al. 2014). Recently, a non-destructive method using spectral screening for rapid disease diagnosis was used to detect CCCVd variants in diseased palms (Golhani et al. 2019a, 2019b; Selvaraja et al. 2012).

UPPER STEM ROT (USR) DISEASE

Upper stem rot (USR) disease has been detected in oil palm (Hasan et al. 2005; Pilotti et al. 2003; Rakib et al. 2014). The causal pathogen of USR disease is similar as the fungal pathogens associated with oil palm BSR disease. Similar field symptoms to BSR was also noted in USR incidences, with the key distinction being the invasion site on the oil palm tree (Pilotti 2005; Rakib et al. 2014; Utomo et al. 2005). USR was defined as an infection on oil palm caused by *Ganoderma* spp. at one meter from the ground level while BSR at the base level (Rakib et al. 2014). In multiple areas, the ratio of USR to BSR varies between 1:10 and 1:1, particularly where a susceptible palm variety was planted; the incidence of USR was above BSR incidence in some fields (Hasan et al. 2005). *Ganoderma zonatum* was identified as the most dominant causal species of USR followed by *G. boninense* and *G. miniatocinctum* (Rakib et al. 2017). More than 80 years ago, data and report on USR disease was still sparse as it was regarded as a minor disease of oil palm (Thompson 1937). At present, USR is only reported in Sabah, Malaysia (Abdullah et al. 1999; Rakib et al. 2017, 2014), Papua New Guinea (Pilotti 2005) and Indonesia (Rees et al. 2012). To this date, there were no records of USR disease in Peninsular Malaysia.

Symptoms of spear rot, bud rot, bunch rot, and BSR caused by root diseases are close to those of USR (Hasan et al. 2005). Initially, the lower leaves turn yellow and wilt from the tips to the base. The USR disease advances to the middle of the crown, and eventually affects the leaves of the spear. The stem tissues turn brown even though the palm roots are not affected (Hasan et al. 2005). The USR disease exhibits stem decay and basidiocarp production at higher parts of the stem, followed by a fracture or toppling of stem above the point of infection (Flood et al. 2002). Infection could occur only after a sufficiently large *Ganoderma* inoculum is made of dead materials, which in turn provide a source of nutrients for *Ganoderma* (Hasan et al. 2005). The authors stated that the causal factor in the propagation of this disease could be due to the controlled pollination (which requires manual bending of the fronds). Harvesting at higher heights particularly in older palms causes trunk wounds that may facilitate in disease infestation. With extensive wounds caused by regular harvesting (severing the fruit bunch peduncle) and pruning (from the fruit base to free the fruit bunch), the capability for infection sites in plantation palms is substantial (Rees et al. 2012). The expansion of USR disease is largely contributed by the artificial wounding of the palm tissues that was made mechanically (e.g. during controlled pollination) and from insects (Hasan et al. 2005). These ready-made wounds facilitated pathogenic *Ganoderma's* basidiospores to germinate, penetrate and subsequently colonize the upper stem parts of the palm. Basidiospore dispersal plays a significant role in BSR and USR epidemiology as basidiospores develop infectious through the production of the parent inoculum source (Hasan et al. 2005; Rakib et al. 2017). Inappropriate sanitation could lead to the spread of *Ganoderma* spp. inoculum in oil palm plantations (Rakib et al. 2014). Preventive action should be taken in order to minimize spore spread. Rakib et al. (2017) stated that less incidence of USR was probably due to closer canopy in older palms. This will restrict the movement of basidiospores upward hence, most of them settle on the ground.

Management of disease, including removal of inoculum sources (infected tissues from fell or collapsed logs) in and around the seedlings is of prime importance, which later may form basidiocarp (that could spread more basidiospores) and removal of existing basidiocarp. Study of USR occurrence via spatial distributions using geostatistic tools was carried out to show the disease density (Rakib et al. 2014). These graphical data could be helpful in determining areas that require priority in disease management. Unfortunately, less focus was given to the detection and control measures of USR disease and its major causal pathogen *G. zonatum*.

Conclusion

A review on updated information on major diseases of economic importance affecting global oil palm industry is presented. Many extensive studies have been conducted and published on various disease detection and identification. Though, the advancement could only be seen in the detection method and neither in the curtive nor the preventive measure. The diseases discussed in the current review still require further research in order to address the limitations, such as the identity of the causal pathogen strains, mode of transmission, applicable preventive and curative measures using cost effective yet environmental friendly approaches. Nevertheless, research on the development of disease resistant palms should be of the highest priority.

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