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INVITED ARTICLE

Panoramic Over View of Advancements in the Arena of Detection and Management of Basal Stem Rot of Oil palm caused by *Ganoderma sp.*

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ABSTRACT

Basal stem rot (BSR) caused by *Ganoderma sp* is a major economic constraint that is increasing at alarming rate in oil palm. It has become imperative to save each palm instead of new one to sustain productivity and profitability among oil palm growers. The persistence as well as asymptomatic nature of disease and perennial monocropping of host pose a hurdle to implement prompt and effective management strategies. The alarming surges in BSR incidence necessitate precise, early, and timely detection for effective management of the disease. Adoption of integrated BSR disease management employing all successful cultural practices control, chemical control, and biological agents is essential for managing this dreadful pathogen.

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Oil palm is the most efficient oil-bearing crop in the world as it produces 4-10 times more oil than any other oil crops per hectare **(**Barcelos *et al*., 2015). This paradigmatic palm can yield up to 20-25 MTs Fresh Fruit Bunches (FFB) and in turn to 4-6 MTs of Palm Oil and 0.4-0.6 MT Palm Kernel Oil (PKO). The unique specialty of this crop is that it requires only 0.26 hectares of land to produce 1 ton of oil **(**Idris *et al*., 2004**).** Palm oil contributes one-third of the world's vegetable and fat supply, and thus plays an important role in supporting global population and food demand (Bharudin *et al*., 2022). The demand for palm oil is expanding globally. The lion share of palm oil production is mainly from five countries such as Malaysia, Indonesia, Thailand, Nigeria and Columbia of which South East Asia alone accounts for more than 90% of global oil production. Particularly, Malaysia contributes 25.93% of worlds palm oil supply with export revenue of RM73.5 billion in the year 2020. Being a major oil-consuming and importing country, palm oil contributes significantly to India's total edible oil imports, amounting to 56% in 2020–21. For securing self-sufficiency, there is no way but to record a substantial increase in the area of oil palm cultivation and production in India.

Basal Stem Rot of Oil palm: Occurrence and Economic consequences

Oil palm has undergone a remarkable transformation from ornamental status to the most oil yielding crop. As crop plantation areas have expanded, there have been serious outbreaks of oil palm diseases in different parts of the world jeopardises the productivity and sustainability of the oil palm industry. Basal Stem Rot (BSR), vascular wilt, spear rot-bud rot, sudden wither and red ring are the major economic constrains in oil palm (Corley and Tinker, 2008).

BSR incited by the basidiomycetous fungi *Ganoderma sp* is annihilating pathogen in oil palm that has potential to have an incidence of up to 80% at 50% of the economic life span (20 years). The disease is critically destructive, causing substantial yield losses of 50-80% due to a reduction in the number of standing oil palm trees per hectare and productivity of the fresh fruit bunches and the tree may be dead within 2 years (Turner and Gillbanks, 2003; Sustano *et al*., 2009; Hushiarian *et al*., 2013; Corley and Tinker, 2015). In monetary terms, BSR causes losses of USD 50 to 350 million per annum accounting for 0.1 to 0.7% of the total value of the industry (Ommelna *et al*., 2012; Paterson, 2019b). One percent BSR disease incidence in oil palm may lead to loss of palm oil export to the tune of 38.20 million US$ in Indonesia (Darmono, 2000). In Malaysia, 68.73% yield reduction was estimated in 12 months amounting to USD4112.78 per year (Assis, *et al*., 2020). Evidently, Paterson (2019a) reported a scenario of 3% surge in Ganoderma infected trees and their economic impact due to increased virulence from Climate change. This is corroborated by the fact that in Malaysia, the incidence of BSR has significantly increased over the previous 30 years (1995-2017), rising from 1.5% to 7.4%, with expectations of an additional increase in years to come. recent decades have witnessed. By 2020, 4.44 lakh ha (equivalent to 65.6 million oil palms) were estimated to have BSR infection (Roslan and Idris, 2012). Management of BSR is highly toiling as infected palms remains asymptomatic until advanced stage and recalcitrant to any kind of curing measures.

Occurrence

Although the fungus was previously thought to cause severe damage only on oil palms older than ten years, the incidence is also seen in young and seedling stages (Corley and Tinker 2015). One of the major diseases causing losses in the oil palm industry is the (BSR) which was recognized in Malaya since 1928 when the disease was reported to attack mainly palms aging 30 years and above. Infections in younger palms of 10-15 years become more apparent after 1957, followed by spreading of the disease in oil palms at nursery stage. This trend demonstrates the ability of the pathogens to adapt to the environmental conditions and food source from plantations to nursery and from old oil palms to its seedlings. The damage caused is becoming increasingly serious and occurs increasingly early from one planting cycle to the next.

Disease progression and symptomatology

The main hurdle in the early diagnosis of disease is its delayed expression of external symptoms. The onset of visual symptoms is seen only after 60-70% vascular blocking. The typical aerial BSR symptoms are chlorosis, multiple unopened spears, snapping of petiole, skirting, necrosis of lower leaves and production of brackets or fruiting bodies on the bottom of the trunk. The foliar symptoms resemble moisture stress condition due to clogging and lignolytic degradation of xylem vessels. Ganoderma root colonisation reduces water absorption, resulting in chlorosis. As disease progress, the shoot of palm gets affected and results in formation of multiple unopened spears. Upon complete invasion, restricted water uptake by the host which causes the lower leaves to collapse and hanging downwards termed as skirting. Later, the lower leaves get necrotic and while the younger leaves begin to droop, turn yellow, and die back from the tip. Eventually, all of the dried leaves fall off, leaving dried twigs that look like stag horns. Under extreme xylem decay, blackening of trunk base and stem bleeding symptoms are observed. The cross-sectional view of infected trunk exhibits severe rotting with irregular zones and cavities. White mycelial mat can be observed in these cavities. On the other hand, non-hollow type rotting also seen. Root system is reduced considerably and infected roots become friable and dry, emitting a chocolate odour. Cortical tissues develop brown discoloration and easily peel off, whilst stele turn black

(Singh,1991). Basidiocarp formation at the stem or leaf base or roots especially during rainy season is considered and realised as in *situ* typical BSR diagnosis (Paterson, 2007) in fact it is penultimate stage of infection. Ultimately, the crown of the oil palm falls off and the foundation of the tree becomes fractured leading to collapse of palm marking end of its life (Siddiqui *et al*., 2021) (Figure 1). It is noteworthy that Ganoderma takes at least 2-3 years to kill mature palms, whereas young palms are killed within a short span of 6-24 months (Paterson, 2007).

Pathogenesis

Ganoderma hypha penetrates in to oil palm root surface from infected soil and plant debris and extends to inner and thin-wall cortex and colonises to trunk base. Decline of starch grains in host cytoplasm is observed at this stage (Rees *et al*., 2009). The BSR pathogenesis happen in two distinctive developmental shifts-biotrophy followed by necrotrophy. The first phase is invasion which is characterised by intracellular colonisation of root cortex or basal stem and later shifts to second phase ie. aggressive necrotrophic phase. At this stage, the pathogen secretes a multitude of cell wall degrading enzymes for recalcitrant polymers, cellulose, suberin and lignin cell wall degradation for facilitating easy penetration. It is worth noting that Ganoderma, as a white rot fungus, targets lignin, which acts as a preexisting structural defence barrier against microbial attack. Lignin degradation results in carbon dioxide (CO_2) and water and damages vascular circulation there by preventing absorption of water and nutrients to the upper parts of the tree, including the leaves. It employs plethora of ligninolytic enzymatic systems such as laccase, lignin peroxidase (LiP), manganese peroxidase (MnP) (Silva *et al*., 2005) and versatile peroxidase (Paterson, 2007) to to degrade lignin under the presence of free radicals through oxidative process (Paterson, 2007). Lignin degradation in particular can happen at the distant areas from the site of infection due to reactive oxygen species and phenoxyl radicals during lignin oxidation (Kirk and Farrell, 1987). Finally, recalcitrant melanised mycelium within oil palm tissues and pseudo sclerotia on external roots (Rees *et al*., 2009).

Etiology

Ganoderma is a white-rot fungus that belongs to the family Ganodermataceae and the class Agaricomycetes that is capable of exposing the white cellulose of wood by degrading the lignin component (Paterson, 2007). Despite the fact that the first report on the occurence and etiology of BSR Malaysia was reported in 1930 as *G. lucidum* (W. Curt.: Fr.) Karst. (Thompson, 1931), plethora of species were later included. Importantly, *boninense*, *zonatum* and *Ganoderma miniatocinctum* were reported to incite BSR disease in oil palm in Malaysia and Indonesia (Idris *et al*., 2001). Amongst all, *G. boninense* is considered as the most prominent causal agent of BSR in oil palm of South East Asia countries (Moncalvo, 2000) as it has got potential to turn down the yield 20 to 40% (Hisham, 1993) or even up to 46 to 67% in infected oil palm after 15 years of planting (Singh, 1991). Moreover, the species has got broad host specificity, inflicting other palms and hardwoods (Miller, 1995). Where as *G. zonatum is* mainly associated with Ganoderma trunk rot in Nigeria and regarded to be weakly pathogenic to oil palm, when compared to *G. boninense* (Pilotti, 2005). In India, *G. lucidum* and *G. applanatum* are known to cause BSR disease in oil palm as well as coconut (Mandal *et al*., 2003). Presently, there is no general consensus regarding the identity of the dominant species of Ganoderma causing basal stem rots in different countries. As different species of Ganoderma exhibit differential nutritional requirement, infection rates and aggressiveness, the current ambiguity in pathogenic and non-pathogenic species need to be clarified for determining the appropriate disease management strategies. In addition, there is conflicting information regarding the host range of Ganoderma species that occur on oil palm and their relationship to species associated with previous cropping or vegetation.

Epidemiology

There are several factors that influence the occurrence, build up and ramification of BSR

- **Age of the palm**: The recent past has proven that Ganoderma infection is not specific to plant growth stage. The fungi can infect oil palm in all of stages, starting from seedlings to old plants (Priwiratama and Sustano, 2014). BSR is not only seen in ill managed mature plantation but also in younger plantations Reports on BSR occurrence in four- or five-year-old trees in replanted areas (Singh, 1990) and one-year-old seedlings in nurseries in coconut plantation areas (Susanto, 2009) support its non-specificity with regard to palm growth stage. Surprisingly, the most aggressive isolates are found in younger palms alarming the oil palm growers (Nur-Rashyeda *et al*.2021).

- **Soil factors**: As BSR is a soil borne pathogen, various soil factors such as soil type, moisture, pH, The incidence of BSR is seen more in red sandy soils or sandy loam soil in coastal tracts and peat soil. This disease is more severe in hard black loamy acid soils containing higher iron and low calcium (Lalithakumari, 1969). However, it is occurring in all oil palm growing soils (Idris, 1999). Ill-drained soil and water-logged soil during rainy season are more prone to disease perpetuation. The pH extremes high or low is not congenial for fungal growth (Parthiban *et al*., 2016; Chong *et al.*, 2017). Ganoderma prefers acidic pH ranging from 3.7-5.0 at temperature range of 27-30 ^{0}C (Nawawi and Ho,1990). It is a surprising fact that the pathogen is able to manipulate surrounding host tissue in favour of them (Vylkova, 2017).
- **Season**: Disease incidence more in March to August months.
- **Previous crop**: Whenever, there is coconut as previous crop, early infection and rapid disease progression (40-50%) was observed in 1–2-year-old palms (Singh,1991). Similarly, In India, incidence of BSR is seen in major oil palm growing belt of Andhra Pradesh where Ganoderma disease on coconut and palmyra palms is known to be prevalent. Similar observations were also seen with respect to rubber and pineapple (Ariffin *et al.*, 1989)
- **Number of generations**: The disease intensity will increase and can reach 40% on the second and third generation of oil palm plantation.
- **Inoculum load**: It is the high disease inoculum load in the form of organic debris and stumps left by previous crop is the actual deciding factor.
- **Irrigation**: Unlike drip or sprinkler irrigation, flood irrigation facilitates dissemination of infected propagules from infected to healthy palms. Soil moisture stress during summer can aggravate the diseases.

Disease Cycle

The infection of oil palm is caused by the presence of the basidioma of the pathogen on the stem base, frond base or roots (Idris *et al*.,2004). The main modes of transmission for Ganoderma are root-to-root contact, basidiospores and free secondary inoculum (infected plant debris, mulching material) in the soil (Turner, 1965; Flood *et al*., 2000; Chong *et al*., 2017). Root infection of BSR initiates on proximity to soil inocula or diseased plant debris buried in the soil (Rees *et al*., 2009, 2012). Often, infected dead logs kept unremoved without sanitation act as main hub for Ganoderma propagation to healthy palms. Similarly, Ganoderma sporophores present on stumps of coconut and palmyra is considered to source of inoculum. The partially decomposed FYM can also aggravates the inoculum build up. Irrigation water and rain water help in the spread of the fungus from one field to others. Basidiospore mediated dissemination is of major concern that it can 14,000 spores/min can be propelled from 10 cm^2 of fruiting body (Rees *et al.*, 2012) and can travel long distance by wind, rain and insect Oryctes beetle (Turner,1981) and larvae of the *Safetula* spp (Genty *et al*., 1976). Wounds as a result of routine harvesting and fronds pruning act as entry points. Basidiospores can be sucked in to a height of 10 cm in to xylem by negative tension (Rees *et al*., 2012) as well as can germinate and grow on any non-living tissues (Pilotti *et al.*, 2003; Sanderson, 2005). Xylem residing basidiospores are well protected from solar radiation, dehydration and microbial competition (Cooper, *et al*., 2011). Formation of melanised mycelium, pseudosclerotia and chlamydospores helps in spread and survival of pathogen.

Detection

The detection of Ganoderma, a destructive pathogenic fungus, in oil palm plantations is of paramount importance for sustaining the global palm oil industry. Various detection techniques, including conventional, molecular, and remote-based approaches, play a pivotal role in identifying early infections, enabling timely interventions, and ensuring the longevity of oil palm trees.

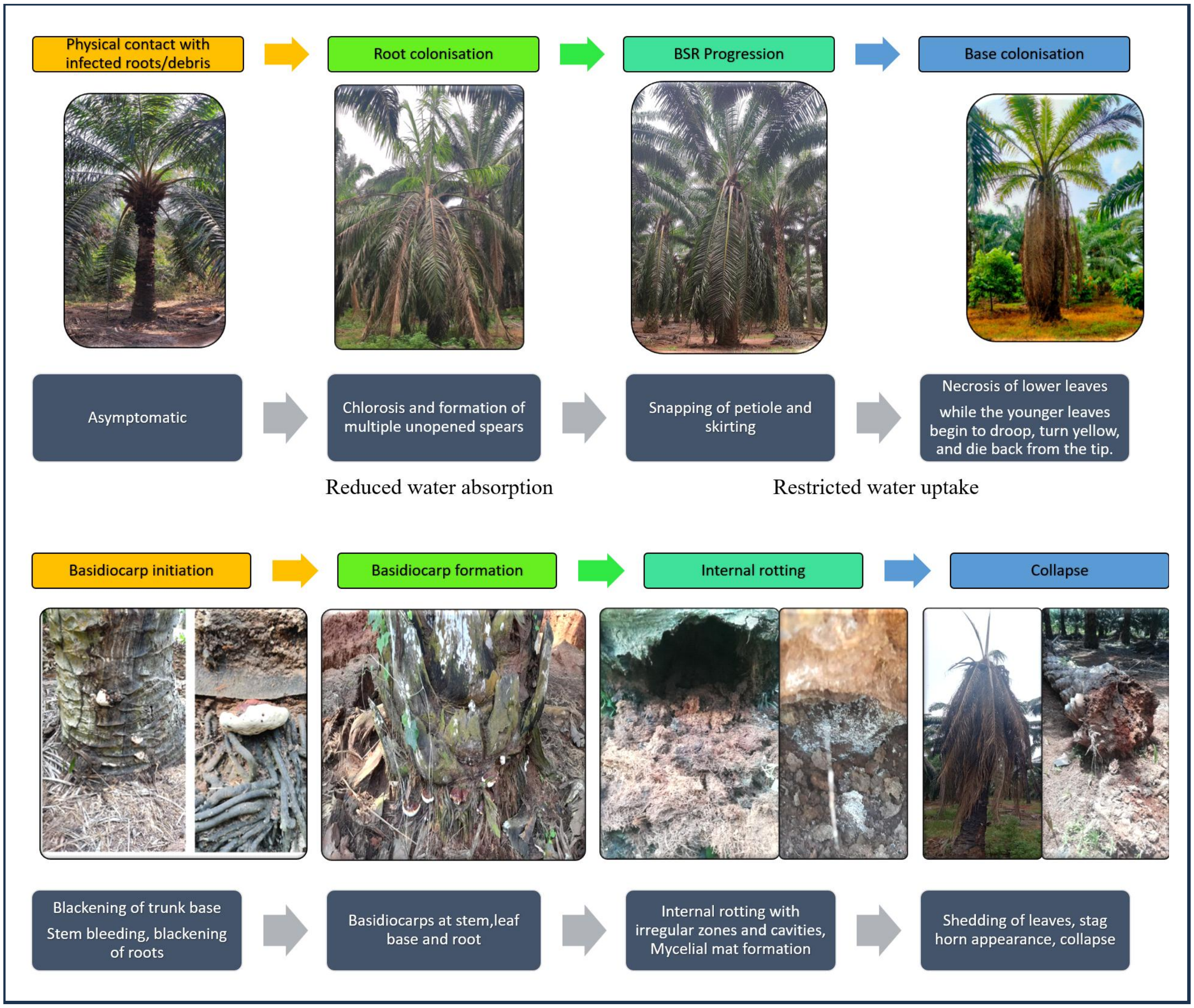

Figure 1: Disease progression and Symptomatology of Basal Stem Rot in oil palm

Conventional Techniques: Conventional detection methods serve as the foundation for Ganoderma identification. Visual observations by trained field personnel are the initial steps in recognizing external signs of infection. The presence of unopened spear leaves and basidiocarps near the soil level, on the tree trunk, or primary roots serves as telltale signs of Ganoderma infection in oil palm (Mohd As'wad *et al*., 2011). Another approach of Ganoderma detection is based on the cultural characteristics upon incubating the infected tissues on Ganoderma selective medium (Ariffin and Idris, 1991). However, these techniques primarily diagnose advanced infections, limiting their applicability in early detection. Additionally, conventional techniques are subjective and rely heavily on the expertise of observers. Nonetheless, they form a crucial starting point for identifying areas warranting further investigation.

Biochemical and Physiological Methods: Spectroscopic detection of Ganoderma induced biochemical compounds is used as a measure to indicate the presence of pathogen in suspected palms. KOH test, iodine staining technique, EDTA method, orthophenanthroline reagent method, alkaline CuSO4 test, TTC test are the different methods to estimate the phenolics accumulation in palms (Utomo and Niepold, 2000; Karthikeyan *et al.*, 2002; Raju *et al.*, 2015; Snehalatharani *et al.*, 2016). The presence of lignolytic enzymes like laccase can be validated on ABTS [2,2(prm1)-azinobis(3-ethylbenzathiazoline-6-sulfonic acid)] medium (Kandan, 2003; Murugesan *et al.*, 2007; Goh *et al.*, 2014). The deviations from the normal electrical conductivity, relative water content, photosynthesis and transpiration rate of the suspected palm also gives an estimation of Ganoderma infection (Karthikeyan *et al.*, 2002; Liaghat *et al.*, 2014). But all these techniques are inconclusive since the other wood rotting fungi also give similar biochemical and physiological responses and hence can be performed as an indicative measure.

Protein based Methods: The presence of specific mycelial proteins as well as isoenzymes are employed as a rapid diagnostic tool for Ganoderma detection. The distinct pectinase zymograms generated by palm-associated Ganoderma isolates serve as a species level identification tool (Bridge *et al.,* 2000; Smith, 2000). The fungal antigens produced during infection are the focal point for the serological approach. Immunoassay techniques like Indirect ELISA and dot immuno-binding are effective in large scale identification of Ganoderma (Idris, 2008; Rajendran, 2009). Even though these techniques are simple and require less instrumentation as compared to nucleic acid-based detection, the reliability is less due to the cross reactivity and accuracy limitations.

Molecular Techniques: The advent of molecular techniques, particularly Polymerase Chain Reaction (PCR), Restriction Fragment Length Polymorphism (RFLP), Random Amplified Polymorphic DNA (RAPD), Loop-mediated isothermal amplification (LAMP), DNA microarray, and DNA biosensors has revolutionized Ganoderma detection in oil palm plantations. PCR allows for the amplification of specific Ganoderma DNA fragments, offering heightened sensitivity and accuracy (Moncalvo *et al*., 1995; Idris *et al*., 2003). Through DNA sequencing, researchers can differentiate between Ganoderma species and trace their origins, facilitating targeted control strategies. RFLP and RAPD approaches offer valuable insights into the genetic variation present within *Ganoderma* species. RFLP enables species level differentiation by making use of the variability present in highly conserved and variable regions of the Internal Transcribed Spacer (ITS) or rDNA sequences (Nusaibah *et al*., 2011). RAPD is particularly useful in cases where lower taxonomic levels cannot be resolved using ITS sequence data alone (Moncalvo and Buchanan, 2008). RAPD analysis has successfully revealed distinct differences across different *G. boninense* isolates (Zakaria *et al*., 2009) which are crucial for identifying and characterizing isolates that possess identical ITS sequences.

The isothermal technique, LAMP can be used as a field level detection tool (Madihah *et al.,* 2018). The positive samples of *G. boninense* targeted for regulatory genes like Manganese superoxide gene (MnSOD) and Laccase gene (lac) generated bioluminescence even at lesser quantities (Madihah *et al.,* 2018; Akul and Chong, 2018). The Real-time PCR is another advanced technique that quantifies the pathogen in tissue while generating fluorescence signals. But the high sensitivity of these assays, will detect even small amounts of contamination in reagents or biological samples, leads to false positives.

Remote-Based Techniques: Various remote sensing technologies *viz.,* VOC profiling, tomography, Microfocus X-Ray Fluorescence (ìXRF), Electrical Resistance, RGB cameras, Terrestrial laser scanning, Hyperspectral imaging, and Multispectral imaging, have ushered in a new era of Ganoderma detection efficiency and coverage. Different tomography methods including Electrical Capacitance Volume Tomography, Gamma Scorpion, X-ray computed tomography, Sonic Tomography uses several quantity measurements of ray transmission over the object cross section to locate Ganoderma in oil palm (Wang, 2015). Microfocus X-Ray Fluorescence could potentially identify changes in elemental concentrations caused by Ganoderma infection. Ganoderma-infected palms contained fewer inorganic elements than healthy palms (Khosrokhani *et al.,* 2016). Hyperspectral imaging, often mounted on drones, captures intricate spectral signatures from oil palm canopies. The altered reflectance patterns in infected trees, attributed to changes in chlorophyll content and water stress, aid in identifying potential Ganoderma-infested areas. Hyperspectral imaging in the visible-near infrared (VIS-NIR) range has been utilized to detect early *boninense* infections in oil palm trees even before visible symptoms of BSR become apparent (Azmi, 2020). Multispectral imaging captures data from multiple narrow and predefined spectral bands across the electromagnetic spectrum and identifies spectral signatures associated with disease-related changes in the plant's physiological and biochemical properties (Jensen, 2006). Ground-based LIDAR obtains high-resolution point clouds of trees, terrestrial laser scanning measures the tree trunk diameter and height, and visible cameras capture the color and texture of the tree bark to detect Ganoderma infection in oil palms (Zheng *et al.*, 2012, Husin *et al.*, 2020, Wiratmoko *et al.*, 2020). Machine learning techniques are then applied to these techniques to classify the point clouds and images into Ganoderma-infected and healthy trees. Remote sensing data, when combined with ground observations, offers a comprehensive understanding of infection dynamics. This approach enhances the ability to respond swiftly and implement targeted interventions. However, the successful implementation of remote-based techniques hinges on advanced technology, data processing expertise, and collaboration between researchers and technicians.

Integration and Holistic Approach: The synergy of conventional, molecular, and remote-based techniques holds the promise of a comprehensive Ganoderma detection strategy in oil palm plantations (Fig2). The strengths of each technique compensate for the limitations of others, providing a well-rounded and robust approach. Visual inspections set the stage for further investigation, while molecular techniques unearth hidden infections, and remote-based methods provide valuable spatial insights. Integrating these techniques enhances the accuracy of detection and aids in prioritizing management efforts.

Management

Controlling soil pathogens like Ganoderma demand a good management system consisting of integrated diseases management strategies to maintain healthy field stands. As early detection of the disease is challenging in field, due to long gestational period.The palms may not respond well to the treatments given after the symptom expression (Sapak *et al.*, 2008). The reasons for incompetent performance of the currently followed practices could be the soil borne and systemic nature of pathogen, melanised mycelium, resting structures, pseudosclerotia, basidiospores and pathogen's ability for deep penetration inside palm (Bivi *et al*., 2010). Besides, the sources of resistance against the pathogen are constrained and the curative methods are not economically sound to save the affected trees (Chong *et al*., 2012a). So proactive steps to reduce the incidence and delay disease progression are the needs of current scenario.

A variety of cultural methods have been practiced to manage BSR disease such as sanitation (Turner, 1965; Singh, 1990; Flood *et al*., 2000; Chung 2011), windrows (Hashim 1991; Flood *et al*. 2000), soil mounding (Ho and Khairudin, 1997; George *et al*., 2000), isolation trenches (Hasan and Turner, 1998; Lim and Udin, 2010; Chung 2011), surgical removal of infected tissues (Singh, 1991; Turner, 1981; Hasan and Turner, 1998; Priwiratama *et al*., 2020), fallowing (Virdiana *et al*., 2010), soil amendments (Prakasam *et al*., 1997; Bhaskaran *et al*., 1994) and planting legume cover crops (Chung, 2011). However, cultural practices could only promise the extension of economic life of the palm, rather than controlling the disease completely. Also, practices like burning the infected parts create environmental concerns. Nutritional management to boost the plant defence is another method to be integrated with the cultural practices. Experimental results showed some effect nutrient management (Dordas, 2008; Chong, 2011; Sariah and Zakaria, 2000; Nur Sabrina *et al*. 2012; Bivi *et al*., 2014; Tengoua *et al*., 2014; beneficial elements- Najihah *et al*., 2015) on disease levels in terms of increase in defense related response or augmenting the soil microbes. Besides, a combination of calcium chloride + copper-EDTA + salicylic acid was evaluated and validated as a beneficial mixture to supress the disease symptoms in oil palm (Bivi *et al*. 2014). Recently, a new technology formulated by Rebitanim (2020) introduces a combination fertilizer containing powdered empty fruit bunches and beneficial elements. Soil pH is increased by the Application of liming materials on the soil surface can reduce BSR incidence (Rahman *et al*., 2020).

Various fungicides have been tested and studied against *Ganoderma* and among which the triazole group of fungicides were shown to have high detrimental effect on growth of Ganoderma (Gurmit ,1991; Idris *et al*., 2010; Said *et al*., 2019). One of the widely tested fungicide, hexaconazole could reduce the intensity of BSR disease in treated palms (Idris *et al*., 2004a; Idris *et al*., 2010; Mohammed *et al*., 2014). In a study, the trunk injection of hexaconazole was demonstrated as an effective delivery method to suppress the spread of the pathogen in the palm trunk (Idris *et al*., 2004a; Mohammed *et al*., 2014). The trunk injection of fungicides such as cyproconazole and carboxin-quintozene mixture were effective in holding up the infected palms, when given through trunk injection (George *et al*., 1996). Another potential chemical as a preventive treatment against Ganoderma is a soil fumigant, dazomet which eradicate the pathogen inoculum and limit the growth of the fungus (Idris and Maizatul, 2012). Nano fungicides are a breakthrough technology in improving the fungicide application efficacy (Duhan *et al.*, 2017). Chitosan-hexaconazole/dazomet nanoparticles have shown enhanced efficacy in controlling the disease over a long period along with added advantage of residue free palm oil matrices (Maluin *et al.*, 2019; 2020). A recent study found out a new generation fungicide, pyraclostrobin which has shown dual function as a potent fungicidal agent against Ganoderma. It is able to inhibit *G. boninense* while simultaneously enhancing plant growth (Said *et al.*, 2019). Though, the effect of continuous use of the fungicides on environment and biodiversity of soil microorganisms and the residue effect are a matter of concern.

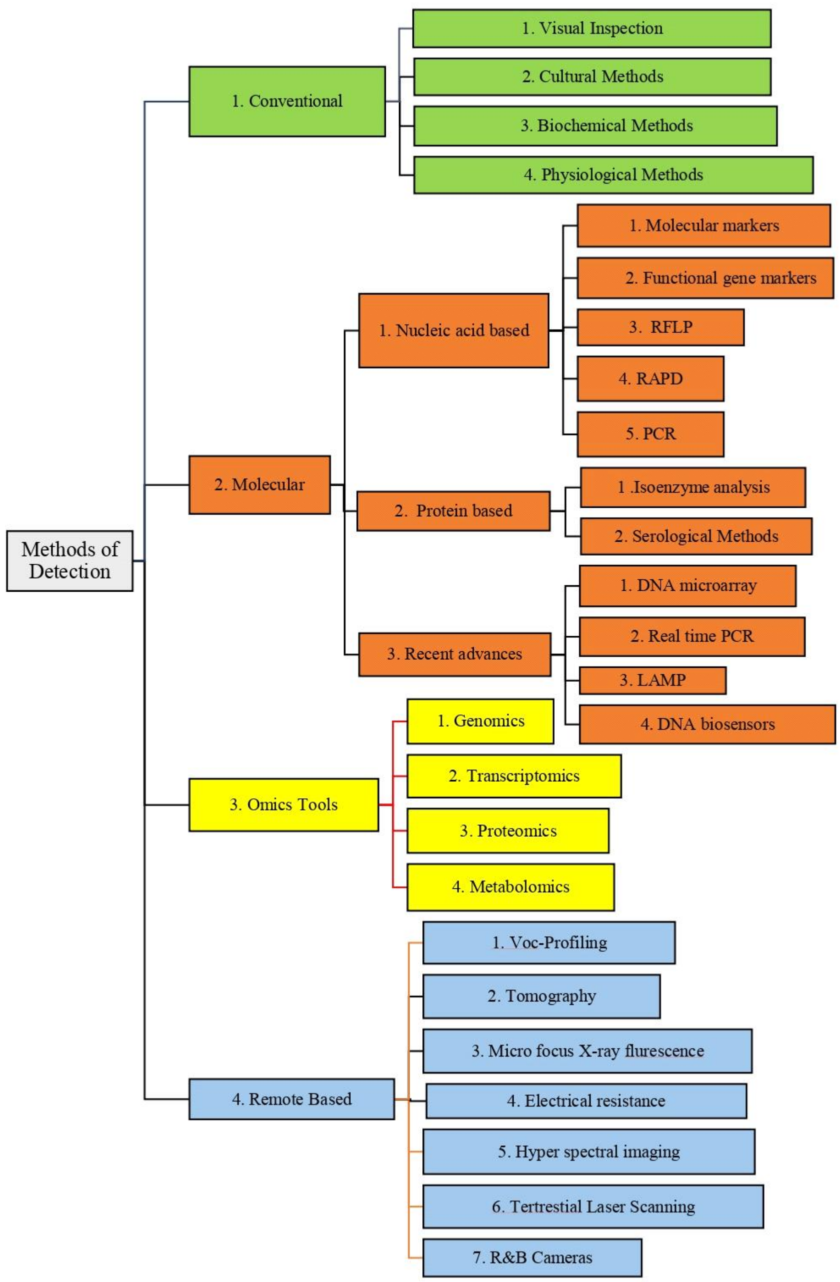

Fig.2: Overview of detection techniques for Ganoderma

The unsatisfactory results of the conventional practices and increasing concern over the use of fungicides necessitated finding an alternate technology which is now mainly focused on green tools like biocontrol agents. Numerous microbes were studied for their antagonistic activities against *G. boninense* (Ilias, 2000; Susanto *et al*., 2005; Sariah *et al*., 2005, Nur Ain Izzati and Abdullah, 2008; Buana *et al*., 2014; Sustano *et al*. 2016; Goh *et al*., 2020) which resulted in identification of effective bioagents for the management of BSR. Particularly, endophytic bacteria as a solo agent (*S. marcescens*- Zaiton *et al*., 2006; *Pseudomonas aeruginosa*- Bivi *et al.* 2010; *Bacillus* spp.- Azizah *et al*. 2015; *Burkholderia cepacia*- Ramli *et al*., 2016) or consortia having multiple bioagents (*P. aeruginosa* and *Burkholderia cepacia* -Sapak *et al*., 2008) were found efficient in its antagonistic action against the BSR pathogen. Among the endophytic fungi, most popularly studied fungus was *Trichoderma* spp. The potency of this free living fungus in reducing the BSR disease incidence has been demonstrated in both green house and field conditions (Ilias 2000; Susanto *et al*. 2005). Different Trichoderma species have shown to increase plant defense responses and suppress the growth of Ganoderma (Siswanto and Darmono 1998; Sariah and Zakaria 2000; Naher *et al*. 2012; Sundaram *et al*., 2014, 2016; Haryadi *et al*., 2021). In addition, many other endophytic fungi like *Glomus intraradices* (Sundram *et al*., 2015), *Diaporthe miriciae (Sim et al. 2019)*, *Penicillium citrinum* (Cheong *et al*., 2017), *Scytalidium parasiticum* (Goh *et al*., 2016), basidiomycetes (*Neonothopanus nambi* -Naidu *et al*., 2016; *Pycnoporus sanguineus*, *Trametes lactinea*, *Grammothele fuligo*- Naidu *et al*., 2018) were studied and shown to be combat the infection by *G. boninense* in oil palm. Other possibilities were exploited by researchers and the biocontrol traits and plant growth promotion of a consortium of *Clonostachys rosea* and *Talaromyces apiculatus* were established in nursery conditions (Goh *et al*., 2020). Apart from antagonism, the plant growth promoting activities and defense inducing properties of *Trichoderma asperellum* and *P. aeruginosa* (Muniroh *et al*., 2019) and *Bacillus subtilis* (Puspita *et al*., 2020) were also proved. Different actinomycetes like Streptomyces have identified as antagonists of *G. boninense* (Tan *et al*., 2002; Ting *et al*., 2014; Sujarit *et al*., 2020) and could be utilised as potential agents to manage the disease. In a recent study, a biofertilizer GanoEF1 containing an ascomycetous fungus, *Hedersonia* has shown potential to hinder the development of *G. boninense* in oil palm seedlings (Nurrashyeda *et al*., 2018). Nevertheless, the tetrapolar mating system in G. boninense leading to variation in genomic composition can hinder with the efficiency of the biocontrol agents. A bioagent showing high percentage radial growth inhibition against one strain may not exhibit same values towards another dikaryotic strain. Besides, high rate of evolving in biocontrol agents could cause some non-target effects. Thus, further studies and monitoring are needed to assess the performance and reliability of the biocontrol agents in the field conditions outside the laboratory settings.

Disease resistance as a promising management strategy, efforts have also been made to enhance the resistance in the planting materials by employing available genetic sources. Palms of different origin have identified to be resistant to *G. boninense* (Franqueville *et al*., 2001; Idris *et al*., 2004b; Durand-Gasselin *et al*., 2005). Breeding and selection for palms having higher lignin might be a promising approach for imparting resistance in palms (Casler *et al*., 2002; Rees *et al*., 2009). Advanced tools like genetic engineering were exploited by Rashdan and Abdullah, (2000) in attempt to transform the palm by transferring *chitinase* gene against *G. boninenese*. Omics technologies including transcriptomics (Tee *et al*., 2013; Chong *et al*., 2012b; Wulandari *et al*. 2018; Faizah *et al*. 2020), proteomics (Al-Obaidi *et al*., 2014; Daim *et al*., 2015) and metabolomics (Nusaibah *et al*. 2011; Chong *et al*., 2012b; Dzulkafli *et al*., 2019) were employed in different studies, which would assist in designing markers for the resistance source selection or phenotyping of plants.

Ganoderma is a fascinating pathogen which is known for century that has been detrimental in palmaceous crops and forest trees without proper remedies. A limiting factor in controlling the BSR disease is the lack of reliable diagnostic method(s) for early diagnosis. Integration of of conventional, molecular, and remote-based techniques holds the promise of a comprehensive Ganoderma detection strategy in oil palm plantations. Similarly, adoption of integrated BSR disease management employing all successful cultural practices control, chemical control, and biological agents is essential for managing this dreadful pathogen. Studies on species diversity and delimitation in palmaceous species and forest trees need to be explored. Omics approaches can be exploited for development of biomarkers for early diagnosis and understanding molecular mechanism underpinning host-pathogen interactions. Research by integrating phytopathology, genomics and plant genetics toward marker assisted selection of high yielding and Ganoderma resistant oil palm need to be taken up. Application of metagenomic analysis to study interaction of microbiome at phyllosphere, endosphere and rhizosphere for exploitation of novel unexplored beneficial organism and antimicrobial substances for plant health management can be strengthened.

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