Australian Journal of Crop Science
AJCS
AJCS 7(11):1723-1727 (2013) ISSN:1835-2707

Review Article

Ecological status of *Ganoderma* and basal stem rot disease of oil palms (*Elaeis guineensis* Jacq.)

Laila Naher[1]*, Umi Kalsom Yusuf[1], Ahmad Ismail[1], Soon Guan Tan[2] and M.M.A. Mondal[3]

[1]**Department of Biology, Faculty of Science, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia**
[2]**Department of Cell and Molecular Biology, Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia**
[3]**Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia**

***Corresponding author address: laila_islam@yahoo.com**

Abstract

The bracket fungus, *Ganoderma boninense* Pat., causes basal stem rot (BSR) disease in oil palm plants. Previously the disease was reported only in older age palms and currently found on young stages palms as well. Therefore, *Ganoderma* can infect all stages of oil palm plants. Disease symptoms only appear at the late stage of the disease and usually called a silent killer of oil palm. Progression of the disease is slow; however, it can destroy thousands of hectares of oil palm plantations. Basal stem rot shortens the productive life of oil palms and causes serious economic losses to the oil palm industry. Hence, BSR is considered a serious threat to the oil palm industry in South East Asian countries. To date, there is high demand for sustainable detection and control of this disease. This review paper is elaborated on the detection and ecological impact of *Ganoderma* and BSR disease in oil palms plantation.

Keywords: Basal stem rot disease, diagnostic, Ecological impact, *Ganoderma*, oil palm.

Introduction

Elaeis guineensis Jacquin, which is originated from the Gulf of Guinea in West Africa is known as the African oil palm. It was first introduced to Brazil and other tropical countries in the 15th century by the Portuguese (Corley, 1976). In the 18th century, the Dutch brought oil palm seeds from Africa to Indonesia. In 1878, the oil palm was introduced as an ornamental plant to Malaya, and the first commercial planting occurred in 1917 in Malaya (Williams and Hsu, 1970). The oil palm fruit is a drupe.

The pericarp consists of three layers: the exocarp (skin), mesocarp (outer pulp containing palm oil), and the endocarp (a hard shell enclosing the kernel or endosperm, which contains oil known as kernel oil). Currently, palm oil is the world largest edible oil. In 2009, around 33% of total edible oil is obtained from palm oil, while 28% is from soybean (www.cmegroup.com). Besides, the palm oil is also used for biofuels and some manufactured products. However, one major problem in oil palm is basal stem rot (BSR) disease, caused by *Ganoderma boninense* Pat., which is a serious threat to the oil palm industry in South East Asian countries, especially Malaysia and Indonesia. The disease is lethal and in the past few decades has been spreading rapidly. The disease spreads through root to root contact. During planting any little piece of rotting trunk is removed as this could be a potential source of *G. boninense* in the current stand (Hasan and Turner, 1998). The disease progresses slowly, but eventually all infected plants become dead. This is because the disease cannot be detected at the early stages, and when the disease symptoms do appear more than 50% of internal tissues are already rotten (Kandan et al., 2010). There are various methods applied to control BSR disease, including culture practices, good land preparation, fungicide treatment, biological control and the use of genetic resistance. The uses of resistant cultivars are becoming important management strategy for BSR control in oil palm (Idris et al., 2004; Breton et al., 2006; Flood et al., 2010). This review paper demonstrates the BSR disease and detection, and ecological impact of the causal organism of *Ganoderma* in oil palm plantation.

Ganoderma spp.

The genus *Ganoderma* belongs to the family of Ganodermataceae, which causes white rots of hardwoods in many woody plants by decomposing lignin as well as cellulose and related polysaccharides (Hepting, 1971). *Ganoderma* sp. is an economically important plant pathogen especially in oil palm, causing basal stem rot disease. The distributions of *Ganoderma* species are worldwide in green ecosystem both to tropical and temperate regions (Pilotti, 2005). The causal pathogen was originally identified as *Ganoderma lucidum* Karst in West Africa (Wakefield, 1920). In Malaysia, this causal pathogen was first recognised as *G. lucidum* by Thompson (1931) (Arrifin et al., 2000). The species *Ganoderma* has a wide host range, where more than 44 species from 34 genera of plants have been identified as potential hosts (Venkatarayan, 1936). This includes the coconut and oil palms as the main hosts for BSR (Hasan and Turner, 1998). Turner (1981) reported fifteen species of *Ganoderma* from various parts of the world such as North America, Africa, India, Malaysia, Indonesia, Papua New Guinea and Thailand as being associated with BSR, including for example, *G. applanatum*, *G. boninense*, *G. chalceum*, *G. cochlear*, *G. lucidum*, *G. miniatocinctum*, *G. pseudoferreum*, *G. tornatum*, *G. tropicum* and *G. zonatum*. Within these species *G. boninense*, *G. chalceum*, *G. lucidum*, *G. miniatocinctum*, *G. pseudoferreum*, *G. tornatum* in isolates of diseased oil palms from different areas of Peninsular Malaysia, *G. boninense* is the most aggressive pathogen to caused the basal stem rot in oil palm (Wong et al., 2012; Turner 1981).

The morphological shape of *Ganoderma* sporophores depends on the species while the body contained stalk or stipe and usually brackets produced form the stalk (Turner 1981). The upper side of sporophores colour is light to dark brown depends on the species and the lower side is white in colour. The upper surface called laccate which form a shiny appearance at the young stage and become brown when spore are produced. Usually, different species of *Ganoderma* produced different feature and pathogenecity (Wong et al., 2012). The species identification or differentiation of *Ganoderma* is still limited; thus, this lack of information causes crucial problem for disease management. However, very limited documents have been reported in previous studies to differentiate between the species of *Ganoderma* using basidioma's size, shape and habit, basidiospore, laccate or non-laccate, pillus surface colour, and mating behavior (Steyaert, 1977; Adaskaveg et al., 1986; 1988; Pilotti et al., 2005).

Ecological status of BSR disease

BSR disease in oil palm is adversely found in Malaysia and Indonesia and in other South East Asian countries, including Papua New Guinea, Ghana, Nigeria, Africa, Central America, Cameroon, Tanzania, Zimbabwe, and Thailand (Arrifin et al., 2000). The disease was first introduced in the Republic of Congo, West Africa in 1915 (Wakefield, 1920) and successively, in 1931, the disease was found on 25 year old oil palms (Arrifin et al., 2000). At that time the disease was not economically important, but after a few years the disease was found in 10-15 year old palms and today the disease can be found in one year old or immature palms (Wong et al., 2012; Azahar et al., 2008).

Hence, BSR has become a serious disease of oil palms with severe economic losses in the oil palm industry especially in Malaysia and Indonesia. In Malaysia, a higher incidence of BSR disease has been reported in the coastal areas (Navarantnam, 1964; Turner, 1965). Similarly, Khairudin (1990) reported that most of the soils tested in the coastal areas of the western part of Peninsular Malaysia are prone to BSR disease. Subsequent reports indicated a high incidence of BSR on oil palms in inland areas, including soils of Holyrood, Sungai Buloh, Rasau, and Bungor series (Khairudin, 1990), Batu Anam/Burian series and Munchong series (Benjamin and Chee, 1995), peat soils (Rao, 1990), and lateritic soils, especially Malacca series (Benjamin and Chee, 1995). Over the last decade Malaysia is the world's largest producer of palm oil. Around 50% of palm oil in the world market is bagged by Malaysia. The second largest producer of palm oil with around 32% production is from Indonesia. Besides, the highest economic losses due to BSR also occur in Malaysia and Indonesia compared to Africa, Papua New Guinea and Thailand (Idris et al., 2004). In Papua New Guinea, the disease introduced in 1994 and disease level is still low around 3.5 to 5.5 % (Pillotti, 2005). In Peninsular Malaysia, high disease incidence is found in the coastal areas, especially in Seberang Prai, Sungai Kerian, Teluk Intan, Bantingm Gemencheh, Segamat and Pontian (Ariffin, 2003). Lower disease incidence is reported around Peninsular Malaysia in Pahang, Kelantan, and Terengganu. In Sabah and Sarawak, the disease incidence is considered low, except in a few plantations at Kota Marudu and Sandakan in Sabah as well as Miri in Sarawak (Ariffin, 2003). A survey carried out at four year intervals in Malaysian oil palm plantations showed that every four years the disease incidence was double (Azahar et al., 2011). A similar situation is also observed in Indonesia (Flood et al., 2010).

Ecological impact and Economic importance

The *Ganoderma* fungus is a facultative parasite that can live as a saprophyte on rotting stumps and roots, but when a suitable host (e.g., an oil palm) becomes available, it will colonize the host and establish a parasitic relationship (Turner, 1981). Many surveys indicated that the disease incidence of BSR is highest in coastal areas and in areas previously planted with coconuts (Turner, 1981). High incidence is recorded in locales where an old stand of oil palm had been felled but with the stumps left in the ground. It is a characteristic of basidiomycete fungi which cause root diseases and require wounded or dead roots for infection of the host plant. Subsequently, the disease spreads from plant to plant by roots or by spores (Sanderson et al., 2005; Paterson, 2007).

Thus, BSR results in significant economic losses in Southeast Asian countries, especially Indonesia and Malaysia. Sumatra in Indonesia thousands of hectares of oil palm plantation are facing by this disease. The disease can cause 50% losses of palm in oil palm plantation as the result observed in the national plantation PT[1] Perkebunan Nusantara IV in simalangan, North Sumatra Indonesia (Santoso *et al.*, 2011). The losses recorded 45% yield in fresh fruit bunches in Malaysian oil palm plantation (www.nakedeye.view.com.my). In Peninsular Malaysia, around 400,00 hectares of oil palm plantation have been infected by *Ganoderma* basal stem rot disease (www. the star.com.my). If the owners of oil palm plantation are not made aware to control this disease then the feature of this situation may escalate to grate economic threat in oil palm industry (www. the star.com.my).

BSR symptoms and disease development

Ganoderma spp. can infect oil palm at all stages, from seedlings to old plants. Disease symptoms progress slowly, but usually every infected plant eventually dies. Usually, the disease develops from the roots but the external symptoms of BSR that appear on young palm shown as one-sided yellowing or molting of lower fronds, followed by necrosis (Singh, 1991; Kandan et al., 2010). The newly unfolded leaves are shorter and chlorotic, and sometimes the tips are necrotic. Infected older plants produced several unopened spear leaves that are usually white in color. By the time the foliar symptoms are apparent, the fungus has already killed half of the plant's tissues (Arrifin et al., 2000). The roots of the infected palms are very friable, and their internal tissues become very dry and powdery. The cortical tissue is brown and disintegrates easily, and the stele becomes black in color (Singh, 1991). Normally, infected young palms die within 6–

24 months after these symptoms appeared, whereas mature palms take 2–3 years to die (Arrifin et al., 2000). A glass house trial study found that the disease severity was 8.3% in roots on six-month-old oil palm seedlings but the leaves showed no symptoms (Naher et al., 2012a). For this reason BSR is called a silent killer of oil palm plant. The basal tissues in cross section appeared as brown areas of rotting tissues, whereas the leaves are still alive. Turner (1981) and Ariffin et al. (1989) mentioned that areas of rotting tissues or darker yellow zones defined as 'reaction zones' are the result of some defence mechanism of the palm to infection. Similarity, in our previous study, we observed the defence response, where the chitinase gene in oil palm is higher in root tissues compared to leaf tissues (Naher et al., 2011).

Subsequently, other studies also found some defence response genes such as glucanase or stearoyl-acyl carrier protein desaturase (SAD) and type 3 metallothionein expressions are increased in root tissues when oil palms were infected with *G. boninense* (Yeoh et. al., 2012; Alizadeh et al., 2011). These studies have mentioned that plant's growth and metabolism are initially decreased during advanced disease development, but later the expression of defence response genes lead to enhance disease resistance. However, the expression level is finally decreased, showing the susceptible situation of oil palm to the pathogen.

Control strategy of BSR disease

Basal stem rot disease caused by *Ganoderma* considered most destructive disease in oil palm. This is because the disease escaped the early disease symptoms. In addition, resistant mycelium, basidiospores, chlamydospores, and pseudosclerotia at these resistance stages present in *G. boninense* which are influence to inhibit control of *Ganoderma* (Susanto et al., 2005; Naher et al., 2012b). When a suitable food like dead or felled oil palm is introduced then they can grow for entrance into the host plant causing disease spread by spore or root to root contact (Sanderson, 2005; Paterson, 2007). Hence, to date no satisfactory method exists to control BSR in the field condition.

However, some previous studies using various methods such as the trench system of control, replanting techniques, and chemical control had taken somewhat different paths with great potential. Digging trenches around infected palms to prevent mycelium spread by root contact with neighboring healthy palms has been recommended as a controlling method. The digging depends on type of the soil and; therefore, cost of digging and maintenance of trenches is high. BSR infection is assumed to occur by mycelial development through root contact; thus, sanitation during replanting regarded as an important practice for controlling BSR. The result showed that this method lower the disease incidence but not reduced BSR with satisfactory (Singh, 1991). On the other hand, the chemical treatment result showed significant reduction in BSR incidence when the oil palm trunk was injected with a combination of the fungicides carboxin and quintozene fungicides (George et al., 1996). However, chemical control agents are not good for the environment since they inhibit the growth of good microbes. Hence, growing concerns about the environment and the high cost of chemicals have encouraged farmers and researchers to find out the alternative way to control BSR, such as the use of biological control agents and pathogen-resistant cultivars. Biological control of BSR disease or *Ganoderma* spp. achieved notable attention. *In vitro* studies have shown that the fungi *Trichoderma* spp., *Aspergillus* spp., and *Penicillum* spp. are antagonistic agents towards *Ganoderma* (Bruce and Highley, 1991; Badalyan et al., 2004). When mass produced by antagonistic activity, these antagonists, especially *Trichoderma* spp., are good bio-control agents for *Ganoderma* (Susanto et al., 2005; Bruce and Highley, 1991). It is noted that *Trichoderma* can only protect the plants at the very early stages of the disease, and is not able to cure highly infected palms (Abdullah et al., 2003). Even though, bio-control agents have not provided a complete solution for BSR control, but the technique has become a notable approach compared to others. Hence, numerous bio-fungicides are currently available in the market for BSR control. The use of chemical fungicide caused environmental pollution such as Methyl bromide used for controlling *Rhizoctonia* diseases, while the fungicide affects an ozone layer resulting effect in greenhouse climate change (Chung et al., 2005). Using bio-fungicide is a good agricultural practice for management of plant diseases. The most benefits of bio-fungicide reside in their biocompatibility and biodegradability that it controls the disease without causing any damage to the plant and leaving any toxic elements which are harmful for microoranism and soil environment (Chung et al., 2005; Pepeljnjak et al., 1988; Takka and Acarturk, 1999).

Diagnostics tools for *Ganoderma*

BSR is like a 'cancer' in oil palm which is very difficult to detect at the early stages of the disease. The limiting factor in the control of BSR is the lack of early disease detection. Some conventional diagnostic tools have been developed for early diagnosis of BSR such as (i) the colorimetric method, using ethylenediamine-tetraacetic acid (EDTA), which is used to detect *G. licidum* in coconut (Natarajan et al., 1986), (ii) semi-selective media for *Ganoderma* cultures from oil palms (Darus et al., 1993), and (iii) *Ganoderma*-selective media (GSM) which can detect the pathogen from any infected tissues. According to Ariffin et al. (1996), GSM can detect *Ganoderma* in oil palms that are infected but have not shown any external symptoms. Due to the low accuracy these conventional methods are not recommended for large scale application. Currently, advance molecular techniques have been innovated with more accuracy of detection and fungal identification. Two diagnostic methods used to detect *Ganoderma*, such as (i) the use of polyclonal antibodies (PAbs) in the pathogen using enzyme-linked immunosorbent assay (ELISA), and (ii) the use of polymerase chain reaction (PCR) methods using specific deoxyribose nucleic acid sequences of the pathogen (Kandan et al., 2009; Utomo and Niepold, 2000; Priestley et al., 1994; Fox and Hahne, 1989). The above mentioned methods all are laboratory base techniques and suitable for small scale samples which are not for field condition. Currently, development of device system in agriculture technology such as remote sense system or e-nose system is being used to detect real-time disease monitoring. Thus, e-nose system has been conducted in limited study for BSR detection. The results showed that the e-nose system can discriminate the *Ganoderma* infected plant in field condition but not able to detect the stages of infection levels or early infection of the disease (Santoso et al., 2011; Azahar et al., 2011; Markom et al., 2009; Md Shakaff et al., 2009). Several studies have shown that fluorescence or spectroscopic imaging (Chaerly et al., 2007; infrared spectroscopy (Spinelli et al., 2006); visible/multiband spectroscopy (Choi et al., 2004) were used to detect any biotic or abiotic stress related symptoms in plants. These techniques are convenient and non time consuming which also can be developed to detect BRS or *Ganoderma* infection in oil palm.

Conclusion

There is no doubt that *Ganoderma* is the most important disease of oil palm. The ecological environment is an importance factor which influences disease advancement. Till date, *Ganoderma* selective media, enzyme linked immunosorbent assay (ELISA), PCR, Real-time PCR or DNA array methods or electronic device system have been used for detecting BSR. At present, there is considerable demand for a fast, accurate, and sensitive method for the early detection of BSR disease or real-time disease monitoring in oil palm in field condition. Based on our limited knowledge spectroscopie or flurorescence imaging technology can be developed for rapid detection of BSR in large scale which is not time consuming and laborious. This will enable considerable savings in terms of economic benefits and productivity.

Acknowledgements

The authors would like to thank the reviewers for critically review this paper and their useful comments.

References

Abdullah F, Ilias GNM, Nelson M, Izzati NAMZ, Yusuf KU (2003) Disease assessment and the efficacy of *Trichoderma* as a biocontrol agent of basal stem rot of oil palms. Science Putra. 12: 31–33

Adaskaveg JE, Gilbertson RL (1986) Cultural studies and genetics of sexuality of *Ganoderma lucidum* and *G. tsugae* in relation to the taxonomy of the *G. lucidum* complex. Mycologia. 78: 694–705

Adaskaveg JE, Gilbertson RL (1988) Basidiospores, pilocystidia and other basidiocarp characters in several species of the *Ganoderma lucidum* complex. Mycologia. 80: 493–507

Alizadeh F, Abdullah ANS, Khodavandi A, Abdullah F, Yusuf KU, Chong PP (2011) Differential expression of oil palm pathology genes during interactions with *Ganoderma boninense* and *Trichoderma harzianum*. J Plant Physiol. 168: 1106-1113

Ariffin D, Idris AS, Abdul HH (1989) Significance of the black line within oil palm tissue decay by *Ganoderma boninense*. Elaeis. 1: 11-16.

Ariffin D, Idris AS, MArzuki A (1996) Spread of *Ganoderma boninense* and vegetative compatibility studies of a single field palm isolates. In: Ariffin, D (ed) PORIM International Palm oil Congress (Agriculture). Palm oil Research Institute of Malaysia Bangi, Malaysia, p 317-329

Arrifin D, Idris AS, Singh G (2000) Status of *Ganoderma* in oil palm. In Flood J, Bridge PD, Holderness M (eds) *Ganoderm* diseases of perennial crops. CABI Publishing: Wallingford

Idris AS, Ariffin D (2003) *Ganoderma*: Basal stem rot disease and disease control. Oil Palm Bull. 11: 1-10

Azahar TM, Boursier P, Seman IA (2008) Spatial analysis of basal stem rot disease using geographical information system. GIS Develop. p 1–6

Azahar TM, Mustapha CJ, Mazliham S, Patrice B (2011) Temporal analysis of basal stem rot disease in oil palm plantations: An analysis on peat soil. Int J Eng Tech. 3:96-101

Badalyan MS, Innocenti G, Garibyan GN (2004) Interactions between Xylotrophic mushrooms and mycoparasitic fungi in dual-culture experiments. Phytopathol Mediterr. 43: 44–48

Benjamin M, Chee KH (1995) Basal stem rot of oil palm- a serious problem on inland soils. MAPPS Newslet. 19: 3

Breton F, Hansan Y, Hariadi S, Lubis Z, de Franqueville H (2006) Characterization of parameters for the development of an early screening test for basal stem rot tolerance in oil palm progenies. J Oil Palm Res. p 24-36

Bruce A, Highley LT (1991) Control of growth of wood decay Basidiomycetes by *Trichoderma* spp. and other potentially antagonistic fungi. Forest Product J. 41: 63–76

Chung WC, Huang JW, Huang HC (2005) Formulation of a soil biofungicide for control of damping-off of Chinese cabbage (*Brassica chinesis*) caused by *Rhizoctonia solani*. Biol Control. 32: 287-294

Chaerle L, Lenk S, Hagenbeek D, Buschmann C, Van Der Straeten, D (2007) Multicolor fluorescence imaging for early detection of the hypersensitive reaction to tobacco mosaic virus. J Plant Physiol. 164: 253–262

Choi YH, Tapias EC, Kim HK, Lefeber AWM, Erkelens C, Verhoeven JTJ, Brzin J, Zel J, Verpoorte R (2004) Metabolic discrimination of *Catharanthus roseus leaves* infected by phytoplasma using 1H-NMR spectroscopy and multivariate data analysis. Plant Physiol. 135: 2398–2410

Corley RHV (1976) The genus *Elaeis*. In: Corley RHV, Hardon JJ, Wood BJ (eds) Oil Palm Research. Elsevier Scientific Publisher, Netherlands

Darus A, Seman A, Khairudin H (1993) Confirmation of *Ganoderma* infected palm by drilling technique. PORIM international palm oil congress: Update and Vision (Agriculture). PORIM, Malaysia, p 735-738

Flood J, Copper R, Rees R, Potter U, Hasan Y (2010) Some latest R&D on *Ganoderma* disease in oil palm. Paper presented at MPOB seminar on the advances in the controlling of devastating disease of oil palm (*Ganoderma*), In South East Asia. Jogjakarta, May 2010

Fox RTV, Hahne K (1989) Prospects for the rapid diagnosis of *Armillaria* by monoclonal antibody ELISA. In: Morrison DJ (ed) proceeding of the seventh international conference on root and butt rots. Pacific Forestry centre, Columbia, p 458-469

George ST, Chung GF, Zakaria K (1996) Updated results (1990–1995) on trunk injection of fungicides for the control of *Ganoderma* basal stem rot. In: Ariffin D et al., (eds) PORIM International palm oil congress (Agriculture). Palm Oil Research Institute of Malaysia, Bangi, p 508-515

Hasan Y, Turner PD (1998) The comparative importance of different oil palms tissues as infection sources for basal stem rot in replanting. The Planter. 74:119-135

Hepting GH (1971) Diseases of forest and shade trees of the United States. In: Flood J, Bridge PD Holderness M (eds) *Ganoderma* diseases of perennial crops. CABI Publisher, UK

Idris AS, Ariffin D (2003) *Ganoderma*: Basal stem rot disease and disease control. Malaysia Palm Oil Board Bulletin. 11: 1-12

Idris AS, Kushairi A, Arrifin D (2004) Selection for partial resistance in oil palm progenies to *Ganoderma* basal stem rot. J Oil Palm Res. 16: 12-8

Kandan A, Bhaskaran R, Samiyappan R (2010) *Ganoderma*-a basal stem rot disease of coconut palm in South Asia and Asia Pacific regions. Arch Phytopathol Plant Protect. 43: 1445–1149

Kandan A, Radjacommare R, Ramanathan A, Ragachander T, Balasubramanian P, Samiyappan R (2009) Molecular biology of *Ganoderma* pathogenicity and diagnosis in coconut seedling. Folia Microbiol. 54: 147-152

Khairudin H (1990) Basal stem rot of oil palm: incidence, etiology and control. MSc thesis. Universiti Pertanian Malaysia, Selamgor, Malaysia.

Markom MA, Shakaff AY, Adom AH, Ahmad MN, Hidayat W, Abdullah AH, Fikri AN (2009) Intelligent electronic nose system for basal stem rot disease detect. Com Electron Agri. 66: 140-146

Md Shakaff AY, Ahmad MN, Markom MA, Adom, AH, Hidayar W, Abdullah AH and Fikri NA (2009) E-nose for basal stem rot detection. Explore Article. p 1-3

Naher L, Ho CL, Tan SG, Yusuf UK, Abdullah F (2011) Cloning of transcripts encoding chitinases from *Elaeis guineensis* Jacq. and their expression profiles in response to fungal infections. Physiol Mol Plant Pathol. 76: 96–103

Naher L, Tan SG, Yusuf KU, Ho CL, Abdullah F (2012a) Biocontrol agent *Trichoderma* strain FA 1132 as an enhancer for oil palm growth. Pertanika J Tropical Agri Sci. 35: 173-182

Naher L, Tan SG, Yusuf UK, Ho CL, Siddiquee S (2012b) Activities of chitinase enzyme in oil palm (*Elaeis guineensis* Jacq.) in interaction with pathogenic and non-pathogenic fungi. Plant Omics. 5: 333-336

Natarajan S, Bhaskaran R, Shanmugam N (1986) Preliminary studies to develop techniques for \early detection of Thanjavur wilt in coconut. Indian Coconut J. 17: 3-6

Navaratnam SJ (1964) Basal stem rot of oil palm on ex-coconut states. The Planter. 40: 256–259

Paterson RRM (2007) *Ganoderma* disease of oil palm- a white rot perspective necessary for integrated control. Crop Protect. 26: 1369–1376

Pepeljnjak S, Penovski S, Jalsenjak D (1988) Influence of microencapsulated propolis extract on Bacillus subtilis strain IP-5832. Pharmazic. 43: 728-732

Pillotti CA (2005) Stem rots of oil palm caused by *Ganoderma boninense*: Pathogen biology and epidemiology. Mycopathol. 159: 129-137

Priestley R, Mohammed C, Dewey FM (1994) The development of monoclonal antibody-based ELISA and dipstick assays for the detection and identification of Armillaria species in infected wood. In: Schots A, Dewey FM, Oliver UR (eds) Modern assays for plant pathogenic fungi: Identification, detection and Quantification, CAB internaltional: Wallingford, UK, p. 149-156

Rao AK (1990) Basal stem rot (*Ganoderma*) in oil palm smallholdings- IADP Johore Barat experience. In: Ariffin D, Jalani S (eds), Proceedings of the *Ganoderma* Workshop. Palm Oil Resrearch Institute of Malaysia, Malaysia, p 113-131

Sanderson FR (2005) An insight into spore dispersal of *Ganoderma boninense* on oil palm. Mycopathol. 19: 193-141.

Sankaran S, Mishra A, Ehsani R, Davis C (2010) A review of advanced techniques for detecting plant diseases. Com Electron Agri, 72: 1-13

Santoso H, Gunawan T, Jatmiko HR, Darmosarkoro W, Minasny B (2011) Mapping and identifying basal stem rot disease in oil palms in North Sumatra with QuickBird image. Precision Agri. 12:233-248

Singh G (1991) *Ganoderma*- the scourge of oil palms in the coastal areas. The Planter. 67: 421–444

Spinelli F, Noferini M, Costa G (2006) Near infrared spectroscopy (NIRs): Perspective of fire blight detection in asymptomatic plant material. Acta Horticul. 704: 87–90

Steyaert RL (1977) Basidiospores of two *Ganoderma* species and others of two related genera under the scanning electron microscope. Kew Bull. 31: 437–442

Susanto A, Sudharto PS, Purba RY (2005) Enhancing biological control of basal stem rot diseases (*Ganoderma boninense*) in oil palm plantations. Mycopathol. 159: 153–157

Takka S, Acarturk F (1999) Calcium alginate microparticles for oral administration I: effect of sodium alginate type on drug release and drug entrapment efficiency. J Microencapsul. 16: 275-90

Turner PD (1981) Oil Palm Diseases and Disorders. Oxford University Press, UK

Turner PD (1965). The incidence of *Ganoderma* disease of oil palm in Malaysia and its relation to previous crop. Ann Appl Biol. 55: 417–423

Venkatarayan SV (1936) The biology of *Ganoderma lucidum* on areca and coconut palms. Phytopathol. 26: 153–175

Utomo C, Niepold F (2000) The development of diagnostic tools of *Ganoderma* in oil palm. Phytopathol. 148: 507-514

Wakefield EM (1920) Diseases of the oil palm in West Africa. In: Flood J, Bridge PD, Holderness M (eds) *Ganoderma* diseases of perennial crops. CABI Publisher, UK

Wong CL, Bong JFC, Idris AS (2012) *Ganoderma* species associated with basal stem rot disease of oil palm. Amer J Appl Sci. 9: 879-885

Williams CN, Hsu YC (1970) Oil palm cultivation in Malaysia. Universiti of Malaya Press, Malaysia

Yeoh KA, Othman A, Meon S, Abdullah F, Ho CL (2012) Sequence analysis and gene expression of putative exo- and endo-glucanases from oil palm (*Elaeis guineensis*) during fungal infection. J Plant Physiol. 169: 1565-1570