A REVIEW OF CURRENT MANAGEMENT STRATEGIES FOR CONTROLLING BLACK POD DISEASE IN MALAYSIA

Siti Nur Arifah Binti Ibrahim
Faculty of Plantation and Agrotechnology,
Universiti Teknologi MARA, Melaka Branch,
Jasin Campus, 77300 Merlimau, Melaka, Malaysia

Mohd Zafri Ab Wahab
Faculty of Plantation and Agrotechnology,
Universiti Teknologi MARA, Melaka Branch,
Jasin Campus, 77300 Merlimau, Melaka, Malaysia
Email: zafri2238@uitm.edu.my

ABSTRACT

Black pod is a major destructive disease for the cocoa plantation in Malaysia. The symptoms on the cocoa pod were necrotic lesions of black or brown colour on the pod. It became severe when the growing area of cocoa had high rainfall intensity and high humidity. Hence, these studies aim to discuss the current management controls that can be used to manage the black pod disease in Malaysia, and their impact for both biological and chemical control. This review found the use of synthetic fungicides based on copper and metalaxyl was successful to control black pod disease, but it gave a bad impact to the environment such as high toxicity level residue in the soil. Meanwhile, biological control agent, Trichoderma spp. and endophytic bacteria were successful and effective in inhibiting the Phytophthora palmivora and Phytophthora megakarya on cocoa pod, based on previous studies. This control can be the alternative way to reduce the losses in yield due to disease infection and improve the condition of the environment compared to the chemical control, which produced high toxicity levels and the resistance of the disease which could lead to the disease outbreak. The issue with biological control is that it is difficult to commercialise owing to the long amount of time required to generate high-rate successful inhibition, but it can produce positive long-term side effects on the development of the cocoa plant and on the environment. For recommendation, this strategy should be improved and encouraged as one of the main strategies for reducing the rate of black pod cocoa.

Keywords: *Black pod disease, Phytophthora palmivora, Phytophthora megakarya, biocontrol agent, chemical control, cocoa pod.*

INTRODUCTION

Cocoa (*Theobrama cocoa L.*) is a tropical evergreen tree from the Malvacee family with edible seeds that has evolved as an understorey forest species in the Amazon. The crop is widely farmed in a number of humid tropical nations (Arshad et al., 2015). It is also known as a tropical wood species that thrives in areas with significant yearly rainfall in the rainforest and is utilised as a shade resistant plant because its seedlings develop effectively under a mill shade and experience minimal water and low nutrient stress (Ávila-Lovera et al., 2016). This plant was grown throughout Mexico and Central America.

Cocoa has been commercially introduced in Malaysia since the 1960s and is currently ranked fourth in the Malaysian agriculture industry. Cocoa, also known as the third most important commodity product in Malaysia after oil palm and rubber, and was referred as a crop that involved in agricultural diversification in the Second Malaysia Plan, which ran from 1971 to 1975 (Arshad et al., 2015). Total cocoa grind production in 2014 was 244,423 tonnes, providing farmers with the possibility to raise raw cocoa bean output for supply to the cocoa industry (Fadzim et al., 2016).

There are various issues that could hinder the cocoa production, which are cocoa disease, a lack of and high cost of arm labour, inadequate state input subsidies, small-scale farmers with limited field knowledge, fertiliser use, ageing cocoa tall trees, and bad access roads in important production zones (Sowunmi et al., 2019). The black pod disease, which is frequent in cocoa fields can damage the entire pod if not controlled, is among of the devastating cocoa diseases. The common causal agent fungi that attack cocoa are *Phytophthora palmivora* and *Phytophthora megakarya*. *Phytophthora palmivora* is broaden distributed pathogen in the global, causing the output losses ranging from 20% to 30% and tree fatalities can up to 10% per year. This disease can be avoided or overcome by implementing a variety of strategies, including chemical control, biological control, cultural methods, genetic resistance, and phytosanitary measures (Acebo-Guerrero et al., 2012).

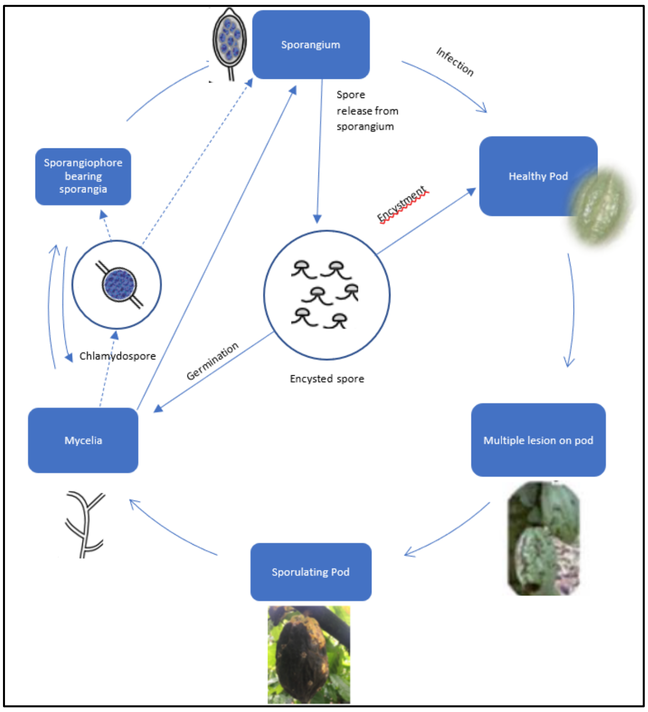
Fungicides have been one of the common strategies used by farmers to manage the black pod disease of cocoa throughout the centuries (Akrofi, 2015). Systemic and copper-based contact fungicides are often used active ingredient chemicals to control the disease. They have been using a protective spray and trunk injection to apply the fungicide (Acebo-Guerrero et al., 2012) . The effectiveness of some chemical controls is determined by a variety of elements such as temperature, climate, and life cycle. Aside from that, the effectiveness of chemical control is higher since it can withstand high disease pressure during the wet season (Bowers et al., 2001), but it can have a negative impact on the environment in the long run. However, for the biological control strategy, they employed beneficial fungi, Trichoderma, because it is inherently antagonistic to *Phytophthora spp.* and it has been reported that the microorganisms from genus Trichoderma are helpful in suppressing the fungal plant pathogen (Bowers et al., 2001). Nonchemical management methods have been shown in some research to be equally effective as chemical application (Promwee et al., 2017). Cocoa diseases treated biologically by *Trichoderma spp.* are also extensively utilised in disease management for other crops (Akrofi et al., 2017). Therefore, this review further contributes by providing the information on the current management controls that will be implemented in Malaysia to control black pod disease or black pod rot.

BLACK POD ROT DISEASE AND CAUSAL AGENT

Definition: As a result of black pod rot, cocoa production might be reduced up to 44 percent (Bailey & Meinhardt, 2016). This disease could attack the stem, flower cushion, leaves and the whole portion of cocoa pod. BPR may cause 100 percent crop loss in the tropics when the environmental circumstances encourage the disease growth and poor management techniques. The cocoa plant is vulnerable to BPR at all stages of growth, including the vegetative stage. Black Pods contain sporangia that can infect healthy pods, causing them to become sick. The visible symptoms develop as a brown patch on the pod's surface two days after infection. Development of Sporangia normally begins on the second night after the 1st night (Thorold, 1959). The researchers describe the symptoms as grizzly-coloured necrotic spots in seedlings, formation of foliage spots in plants grown, necrotic brown patches on the pod surface, and rot beans where it can reduce the cocoa production and affect the quality of the cocoa (Rodríguez-Polanco et al., 2020). Farms are adding a great deal of resources to manage the sickness and limit the number of occurrences (Mboussi et al., 2016).

The occurrence of causal pathogen black pod disease on cocoa pod: Phytophthora species are responsible for the pathogen that causes black pod disease. Phytophthora has more than 60 species in its genus and is one of the most destructive plant diseases because it led to crop production losses (Perrine-Walker, 2020). *Phytophthora palmivora* can shed its zoospores earlier and is double same as like the *Phytophthora megakarya*. The pathogen that infects the cocoa pod and its life cycle are shown based on (Figure 1). Appressoria are enlarged and thickened the tip of a hyphal branch to allow the host plant to penetrate. Water splashes can disseminate secondary inoculums, resulting in secondary infections (Nembot et al., 2018). These diseases are transferred either directly from the cocoa pod to cocoa pod or indirectly from an environment reservoir to a healthier pod (Tchameni et al., 2012) and both are caused by pathogen-infection disorders. The management of the disease is effective which are based on chemical and biological methods (Wakam Nana et al., 2016; Enoch, 2015).

Figure 1: The Life Cycle of *Phytophthora megakarya* infected the cocoa pod (Nembot et al., 2018).



CHEMICAL CONTROL

Definition: When it comes to plant disease management, chemicals play an important role in efficient integrated pest management (IPM) systems. Chemical control began with the introduction of lime sulphide and Bordeaux mixes in the mid-1800s (Wyenandt, 2020). Many fungicides have defensive and restorative characteristics with systematic intervention, enabling consumers flexible application windows, until recently (Thind, 2017). The following table (Table 1) is the descriptions of previous studies that shows chemical control was successful in inhibiting the *Phytophthora palmivora* and *Phytophthora megakarya*. They found that the active components in both fungicides inhibited the infection. Metalaxyl is a copper and phosphorus compound that is used as a systemic fungicide. A metalaxyl can be absorbed slowly through the leaf cuticle and then instantly transmitted into the plant (Durio et al., 2021). Metalaxyl's penetration capacity will be increased by adding surfactant. Plants that are not infected with a disease are protected by metalaxyl (phosphorus acid), which would also prevent any symptoms from developing when field application were followed on a regular healing basis. It also facilitates the development of asymptomatic plants.

Table 1 List of previous studies that shows the chemical control was successful in inhibiting the *Phytophthora palmivora* and *Phytophthora megakarya*

No	Author(s)	Topics	Type of Chemical
01	(Enoch, 2015)	This paper was studies about the application of fungicide which is Ridomil Gold in the 1000 mL molten Campbell Vegetable juice agar. The result shows the *Phytophthora spp.* can be reduced but the side effect can give harmful impact toward the environment and high cost if frequently used.	*Fungicide (Ridomil Gold)*
02	(McMahon et al., 2010)	This paper was studies about the application of phosphonate chemical to inhibit the black pod disease through the trunk injection on the cocoa tree. The result was effective in reduce the lesion on the cocoa pod.	Phosphonate chemical application

FUNGICIDE APPLICATION

Fungicides are organic substances that are applied to plants for treating and managing the plant fungal diseases. Fungicides have been prevalent in agriculture in recent decades as fungal infections are anticipated to reduce the agricultural production by roughly 20 percent worldwide (Palareti et al., 2016). Due to their low cost, ease of use, and efficiency, fungicides have become the most widely used means of controlling fungal disease (Xia et al., 2006). There are a lot of factors that determine the effectiveness of fungicide applications which are the efficacy of various fungicide active ingredients, the optimum timing of fungicides, the number of applications to control plant disease, and the impact of fungicides on plant yield response (Carmona et al., 2020).The use of synthetic fungicides based on copper and metalaxyl is the mainstay of chemical management (Matthews et al., 2003). For cocoa black pod disease, the amount of fungicide used is depending on the recommended dosage (Lin Marcellin et al., 2018). For each fungicide, the concentration was adjusted to the prescribed field application dose in g/L as stated in the (Table 2) to manage cocoa black pod disease.

Table 2 The list of fungicide with their recommendation field application of dosage for controlling cocoa black pods (Lin Marcellin et al., 2018).

Fungicide	**Active Ingredient (%)**	**Mode and site of action**	**Recommended field dose (X)**
Ridomil Gold Plus 66 (WP)	6% Metalaxyl 60% Copper oxide	Systemic 1	3.33 g/L
Penncozeb 80 (WP)	4 % Metalaxyl 80% Mancozeb	Systemic 1 + M	3.33 g/L
Beauchamp 72% (WP)	8 % Metalaxyl 64% Mancozeb	Systemic 1 + M	3.33 g/L
Kocide 2000 (WP)	53.8% Copper hydroxide	Contact M	4 g/L
Golden-Blue pentahydrate coppersulphate 98% (SG)	98.5% Copper sulphate	Contact M	6 g/L
Nordox 75 (WG)	86% Copper oxide	Contact M	2.66 g/L

(WP: Wet-table powder; SG: Soluble granules; WG: Water-dispersible granules; 1: single site fungicide; M: multi sites fungicide.)

Meanwhile, the other study by, Enoch (2015) who has studied two Phytophthora species: *Phytophthora palmivora* and *Phytophthora megakarya* from six different cocoa growing regions. He found that the oomycetes were particularly sensitive to the higher temperature, and the Ridomil Gold used in his study is very efficient against the causative agent of black pod disease. The zoospores have been inhibited by the fungicide in this way because certain or more specific steps of metabolism have been prevented. Double acting fungicide prevents inoculum germination and penetration (Rhouma et al., 2016). Based on other studies , *Phytophthora palmivora* was inhibited at a higher rate when phosphonate was injected into the trunk of the cocoa tree but these trends may be different in certain situation due to changes in rainfall pattern, in which the normal life span of sporulation and infection of the black pod disease may occur again (McMahon et al., 2010).

THE ADVANTAGE AND DISADVANTAGE CHEMICAL CONTROL

Advantage: Severals contact fungicides such as Metiram 70 percent WG and Mancozeb 75 percent WP and systemic fungicides such as Dimethomorph 50 % WP, Fenamidone 50 percent WP, Curzate (cymoxanil 8 per cent + mancozeb 64 per cent) and Ridomyl M2 72% WP (metalaxyl 8 per cent + mancozeb 64 per cent) were found to be extremely selective can inhibit the occurrence of Phytophthora infestations (Elliott et al., 2015). Other studies state that the fungicide application can boost more the crop performance and yield (Mani et al., 2016). The plant, which was sprayed with fungicide, was greater towards stress tolerance, wider leaf-sized and dense and had a greater uptake of nitrogen use (Zhang et al., 2017).

Disadvantage: The usage of fungicides was not cost-effective, and they had to be reapplied frequently where it contributes to high toxicity residue in the soil (Deberdt et al., 2008). Land and water contamination will also result from the heavy and chronic application of synthetic fungicides (Hegde, 2020).

Cocoa farmers sometimes abuse the recommendation uses of the copper-based fungicide. Consequently, it has been reported that copper sulphate has attributable a harm to fish and marine invertebrates such as lobster, shrimp, and oysters, and that constitutes a possible risk to the ecosystem that involves water sources such as sea and rivers (Sowunmi et al., 2019). Humans can also be susceptible to higher copper doses. Long-term exposure to copper dust can irritate the nose, throat, and eyes, triggering headaches, dizziness, sores, and nausea where can lower their healthy rate (Kawser Ahmed et al., 2016).

Many fungicides, however, have hazardous effects that are not limited to their target species and could have a negative impact on certain living organisms that support the large agro-ecosystem (Kwodaga et al., 2017). Fungicides are absorbed into the soil as a result of runoff or drifting sprays (Miles et al., 2017). The cost of reapplying the fungicide has also been questioned among researchers. It would be useful to know more about the dosage of fungicides used and the effects on the environment in this study (Enoch, 2015). (Bowers & Bailey 2001) offered biological control as a second option. For example, as a biological control agent,Trichoderma has been shown to be efficient in controlling *Phytophthora spp.* and it has been proven that *Trichoderma spp.* is efficient in managing the fungal plant pathogen.

BIOLOGICAL CONTROL

Definition: Biological control is the ecological management of living organism. The uses of pathogenic microbes to boost plant health is included. Plants (hosts), pathogens, biocontrol agents (antagonists), the physical environment, the environment around the plant, and the microbial community are all involved in eliminating disease is utilise through the biological agents (O'Brien, 2017). Depending on the conditions in which they occur, these types of interactions might take on different features. It is based on exploiting mutualism between microorganisms and their plant hosts, or exploiting antagonistic interactions between bacteria and disease pathogens (Bull et al., 2002). *Phytophthora megakarya* and *Phytophthora palmivora* are inhibited successfully by the biocontrol agent that were described in the following table (Table 3). Researchers have employed a variety of ways to inhibit Phytophthora species in a biological way.

Table 3 List of previous studies that shows the biocontrol agent successful in inhibiting the *Phytophthora palmivora* and *Phytophthora megakarya*

No	Author(s)	Topics	Biocontrol agent
01	(Junaid et al., 2020)	This paper was studies about the capacity of *Trichoderma spp.* isolates from South Sulawesi whether it can develop the cutinase to aid spore survival in pod and flower surfaces until penetration to suppress the cocoa disease.	*Trichoderma spp.*
02	(Nurlaila et al., 2020)	This paper was being carried out to determine the potency of the *Trichoderma asperellum* in inhibiting the pathogen growth. Results showed *Trichoderma asperellum* was successful in reducing the rate of growth of the pathogen but depend on its clone variety and the lowest resistant clone.	*Trichoderma spp.*
03	(Angraeni et al., 2020)	This paper studied on another way to inhibit the *Phytophthora palmivora* by composting the husk pod by *Trichoderma spp.* The result show that there are no presence of *Phytophthora palmivora* but the *Trichoderma* was not survived in the compost.	*Trichoderma spp.*
04	(Miguelez-Sierra et al., 2019)	This paper was carried out some studies about the effect of *Pseudomonas chlororaphis* (CP07) against towards the *Phytophthora palmivora* that has being isolated from *Theobroma cacao*. They invented plant growth promoting bacteria (PG07PB) as one new solution to control the plant disease. The result shows the *Pseudomonas chlororaphis* (CP07) was efficient in reducing the disease symptom compared to other treatment.	*Pseudomonas chlororaphis*
05	(Zubir et al., 2019)	This paper was doing some studies about the ability of the endophytic bacteria in inhibiting the development of *Phytophthora palmivora*. The result shown four different endophytic bacterial has being isolates to the reduce the occurrence of the pathogen. Among the four endophytic bacteria, *Bacillus subtilis* has showed the high rate of inhibition towards the *Phytophthora palmivora* where it has good potential that can be the option for biological control uses.	*Bacillus subtilis*

06	(Pakora et al., 2018)	This paper was studies about 3 different *Trichoderma spp.* against 3 different kind of *Phytophthora spp*. The result shows the most effective to control the pathogen is *Trichoderma viride* where it can produce 2 active metabolites which are viridin and glovirin where they are known as good active metabolites for plants development.	*Trichoderma viride*
07	(de OLIVEIRA et al., 2018)	The study uses 4 different of antagonist *Trichoderma spp.* to inhibit the *Phytophthora palmivora*. The frequency and seriousness of disease is substantially decreased by both *Trichoderma*s. The *T. longibrachiatum* was the strongest *P. palmivora* post-harvest control agent.	*Trichoderma spp.*
08	(Ndoungue et al., 2018)	This paper was study about the effectiveness soil treatment application that use *Trichoderma* asperellum (PR11) as the biocontrol agent to against the *Phytophthora megakarya*in Cameroon. The result show that, although it cannot reduce the disease, but it can delay the spread of the disease because the pathogen spores was started first in the soil.	*Trichoderma asperellum*
09	(Villamizar-Gallardo et al., 2017)	This paper was study in about the *Trichoderma viride* against towards the *Phytophthora palmivora* and *Moniliophtora roreri.* It was the causal agent for black pod disease and frosty cocoa pod. This study show that these strains can be used to effectively biological control against the cocoa phytopathogens in the area.	*Trichoderma viride*
10	(Promwee et al., 2017)	This paper studied about how to enhance more the efficient of controlling the *Phytophthora* leaf fall disease. It shows that the use of the *Trichoderma harzanium* was success in controlling the disease where it also has no significant different compare with the metaxly fungicide application.	*Trichoderma harzanium*
11	(Tchameni et al., 2017)	This paper studies about 4 different *Trichoderma asperellum* to control the *Phytophthora megakarya*. The result show that, beside it can inhibit the occurrence of the pathogen, it also can enhance more the development of the cacao plants.	*Trichoderma asperellum*
12	(Sriwati et al., 2015)	This paper was studied on about 3 different type of *Trichoderma spp.* which are *Trichoderma virens*, *Trichoderma longibrachiatum*, and *Trichoderma asperellum*. The *Trichoderma virens* is one of the fungi that can exhibits antibiotics against *Phytophthora spp.* where it indicates that many modes of action aid to minimize *Phytophthora spp.* expansion in cocoa pots and plants.	*Trichoderma virens*
13	(Mbarga et al., 2014)	This paper was carried out some new formula of controlled method which are the combination of *Trichoderma asperellum* with soybean oil-based dispersion which more effective than in the powder form. As a result, *Trichoderma asperellum* prepared in oil dispersion has a strong potential to manage cocoa black pod disease with lesser usage of synthetic fungicides.	*Trichoderma asperellum*

Trichoderma spp. as a biocontrol agent

Definition: A biocontrol agent is a microbe found naturally in the plant environment that can help to reduce the incidence of disease or disease disruption, but only if allowed to flourish abundantly (James, 2019). They do this by competing with food pathogens, generating compounds that inhibit pathogen growth, and physically removing pathogens from the plant by first devouring room and locations (James, 2019). (Baker, 1987). Bacterial, fungal inoculum, or biochemical extracts, as well as herbal extracts, have been identified as biological antagonists that capable of inhibiting the infection. This entails biological controls that remove or minimise illness by enhancing the plant quality. *Trichoderma spp.* is a species that is usually utilized in biological management of black pod disease (Peter & Chandramohanan, 2014). The *Trichoderma spp.* fungus family is a diverse community of microorganisms that play a big role in environmental aspect. It can be used to improve agricultural plant health or to boost some plant's natural ability to digest harmful chemicals in soil and water.

They were also employing a number of techniques to colonise various environmental zones. Numerous *Trichoderma spp.* are plant growth stimulants that protect plants against bacterial and fungal diseases. They were also utilised in biological plant defence as bio-fungicides and bioremediation (Baszczyk et al., 2014). It is possible to accomplish this by using organic goods that naturally contain microbial communities, such as manure, or natural microbial populations, such as natural organic fertilisers with microbial supplements (Bonapace et al., 2004). Furthermore, they are preventative rather than curative, they must be used prior to the commencement of the disease. Parts of the Trichoderma family are still utilised in various industries, especially in carbohydrates, antibiotics, and other metabolites, but also in biofuels. Some Trichoderma species, particularly *Trichoderma harzianum* strain T22 and *Trichoderma atroviride* strain P1, interacts with plants and soil-borne fungal diseases (Woo et al., 2006).

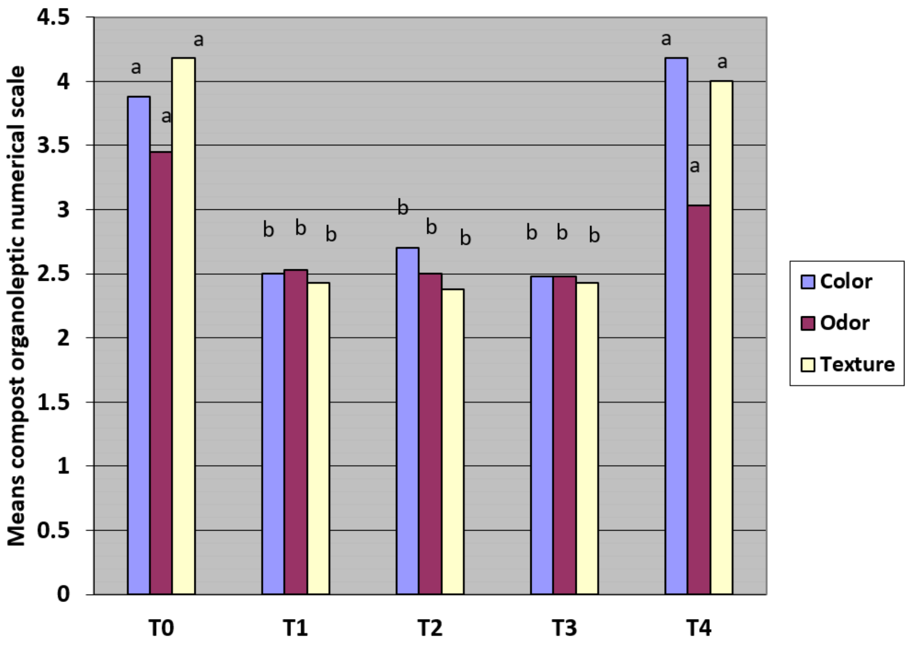
The several species of these organisms have often been known for their ability to increase and improve plant growth, their ability to alter the rhizosphere and the capacity to expand under adverse conditions which are nutrient competence, high phytopathogenic aggressiveness, and effectiveness to encourage plant growth and strengthened the defensive mechanisms (Keswani et al., 2014).

Phytophthora palmivora isolates from (Sundram & Ainni 2018) revealed the aggressiveness of mycoparasitism based on how they overlapped, coiling the Phytophthora parasites. Phytophthora spp. has been successfully controlled with its mycoparasitic approach through the Trichoderma-based biological control system. This has been demonstrated by a variety of dual culture tests using Trichoderma virens strains T7b and T159c (Sundram & Ainni, 2018). The level virulence inhibition of *Phytophthora palmivora* is dependent on Trichoderma species.

Another study has been conducted that uses *Trichoderma asperellum* as a biocontrol agent to suppress the growth of Phytophthora tropicalis on cocoa pods. *Trichoderma spp.* treatment resulted in a lower percentage of severity and less necrotic lesions on cocoa pods (Sriwati et al., 2015). Another report the *Trichoderma spp.* isolate, *Trichoderma longibrachiatum*, was found can reduce the lesion region for treatments when the biocontrol agent was applied 1 hour and 24 hours before the pathogen. In comparison to the untreated control, the isolates of *Trichoderma spp.* have considerably reduced the severity of disease and enhanced disease prevention (de OLIVEIRA et al., 2018). When it sprayed to cocoa pods in the field, the endophyte *Trichoderma martiale* strain ALF 247 could minimise the black-pod rot disease caused by *Phytophthora palmivora* (Falcäo et al., 2014).

Aside from that, another technique to suppress *Phytophthora palmivora* is to compost the infected husk of cocoa pod with Trichoderma virens, because the pathogen-affected cocoa pod is usually discarded on the ground, which can enable the spore of *Phytophthora palmivora* inoculum disseminate to other cocoa trees (Angraeni et al., 2020).Based on (Figure 2), *T. harzianum*, *T. virens*, and *T. asperellum* (T1, T2, and T3) compost organoleptic tests revealed that the cocoa pod husk was well decomposed by *T. harzianum*, *T. virens*, and *T. asperellum* (T1, T2, and T3) in comparison to Control and *T. longibraciatum* (T0 and T4).A relatively blackish compost, smelling as deteriorated litter, crumb textured and particles bonded into the soil visually generated by *T. harzianum*, *T. virens* and *T. asperellum*. It was characterized with the appearance of mature compost which is blackish, scented as humid littered and crumb texture, was marked as the successful result. The possibility of producing the type of cellulase compounds that matched the decomposition of cellulose into cocoa pod husk to efficiently degraded, the *T. harzianum*, *T. virens*, and *T. asperellum* was probably produced by this circumstance. Some microorganisms have the capacity to create abundantly in nature cellulose-degrading enzyme derivatives.

Figure 2 Organoleptic test of compost (Angraeni et al., 2020).



ENDOPHYTIC BACTERIA AS BIOCONTROL AGENT

Pseudomonas spp. is a commonly used endophytic bacteria. It has vast metabolic and physiological diversities and can withstand harsh conditions, making them potential bacterial cell cellulose host resources (Nikel et al., 2014). In agriculture and biopesticide development, *Pseudomonas chlororaphis* strains without virulence determinants are well developed plant rhizobacteria that promote growth. Moreover, the genus Pseudomonas has a range of natural environments that can be colonized and adapted because of their metabolism and ubiquity. Other than that, they are also recognised for their capacity to interact with others bacteria, fungus, and multicellular creatures (Sitaraman, 2015). Since a well-researched biocontrol agent, *Pseudomonas spp.* has showed their efficiency in biological control, the establishment of numeral secondary metabolites produced by them have become extremely relevant (Zohara et al., 2016).

Numerous properties of Pseudomonas species make them ideal biocontrol and growth promoters. It includes the ability to colonise and propagate in the rhizosphere and sperm habitats, as well as synthesise a wide range of bioactive compounds that are antibiotics within the plant. In contrast, pseudomonads are also involved for the natural control of soil pathogens in specific soils (Weller, 2007). As a plant growth promoting rhizobacteria, *Pseudomonas spp.* can limit the growth of *Phytophthora palmivora*. Plant-growth promoting rhizobacteria (PGPR) is a huge soil bacterium, such as Pseudomonas strains, that effectively colonise the root plant and boost plant development through the manufacturing of numerous plant growth hormones, P-solubilizing action, N_2 fixation, and biological activity. They are also recognised as strains that can produce a different growth hormone in plants (Ehab and Heba, 2014). *Pseudomonas spp.* can also produce antibiotics such as phenazine, an electron transfer inhibitor, membrane damage caused by phloroglucinols, pyrrolnitrin, fungicidal compounds, cyclic lipopeptides with surfactant qualities to prevent fungi, and hydrogen cyanide (HCN), a potent metal enzyme inhibitor. They could also produces enzymes such as chitinases, cellulases, glucanases and lipases, which are utilised to kill phytopathogens (Miguelez-Sierra et al., 2019). In addition, it can induce systemic resistance by activating pathogen protection mechanisms and promoting the manufacture of biochemical substances that are involved in plant immune responses in order to protect plants.

Furthermore, according to Ouattara et al., (2020), the isolates of the seven bacteria were particularly effective against *Phytophthora palmivora*, with a mycelial growth inhibition rate ranging from 70.54 to 62.20 percent or 24.75 to 31.75 mm in diameter. Seven bacterium isolates were particularly effective against *Phytophthora megakarya*, with percentage inhibition of mycelial development ranging from 64.29 to 60.13 percent, or between 30 and 33.5 mm of mycelial growth in diameter. A total of four bacterial isolates, 18N, 42P, 47P, and 60P, showed significant antagonistic behaviour against these two Phytophthora spp. strains, with a percentage inhibition of mycelial development more than 60%.

THE ADVANTAGE AND DISADVANTAGE BIOLOGICAL CONTROL

Advantage: Biological control has shown to be effective against a broad range of crop diseases in greenhouses and on the field (Wakam Nana et al., 2016). Biocontrol agents consist of antagonistic bacteria and fungi that are not pathogenic are routinely utilised by farmers. After implementing the control, a lot of advantages can be gained, such as the members of the Bacillus genus. Beneficial qualities of this bacterium include the ability for the plant growth being stimulated through the production of phytohormones, gaining nutrients and to protect plants from abiotic stresses (Saxena et al., 2020). Other than that, earlier research has shown that biocontrol agents supply amino acids and phenolic compounds that are crucial for rebuilding the plant's defensive mechanism (Tchameni et al., 2017).

Biological antagonists can have a variety of potential modes of function. These include exuding chemical compounds that inhibit pathogen growth, such as antibiotics, acting as a parasite that penetrates and feeds the pathogen, or acting as an endophyte symbiont through systemic resistance in the plant, such as defensive enzymes and phenolics, as stated in previous research that *Trichoderma spp.* has many mode actions to colonise and inhibit Phytophthora spp. on the pod (Sriwati et al., 2015).

Regeneration of endangered ecosystems and long-term benefits to plant ecosystems are other one of good environmental results that can be attributed to this control. Some bio-agents and nanoparticles have been effectively used to enhance development and growth in several plants under various stresses and natural circumstances, such as *Trichoderma spp.* which can generate several volatile organic compounds (VOC) that can encourage plant growth and avoid phytopathogens from forming (Silva et al., 2021). The application of *Trichoderma asperellum*, a biocontrol agent against *Phytophthora megakarya* was also contributed to the development of cocoa (Tchameni et al., 2017). It is possible that biological control agents can be used as efficient agronomic tools to improve crop stress resistance, minimise pesticide application, and reduce the impact of crops on the ecosystems (Passera et al., 2020). The other benefit of this control is that it has a high potential and is ideal for the types of sprayers used by farmers in Cameroon to control the cacao black pod disease without relying on expensive synthetic fungicides that are harmful to the environment (Mbarga et al., 2014).

Disadvantage: The most common issue with biological control is a lack of coherence in plant resistance by a biocontrol agent, where changes in host genotype contribute to variations in responses to a biocontrol agent, which can modify the secondary metabolites of the endophytic organism (Sood et al., 2020).It can be concluded that biological management is more effective in managing the disease, but less commercially viable due to its high cost and extended procedure time (Bélanger et al., 2012).
This biological control is essential for further research in order to improve their effectiveness in disease control.

THE POSSIBLE MANAGEMENT STRATEGIES FOR CONTROLLING BLACK POD DISEASE IN MALAYSIA

This review has provides a valuable information and discussion for the agriculture sector and farmers who grow cocoa as their sole source of income, as well as future researchers in Malaysia. These results and approaches allow farmers or agricultural workers to make an informed decision on whether chemical control is more effective than biological control by referring to the content provided in this review. In general, a biocontrol agent is not commonly used in Malaysia to manage black pod disease. *Phytophthora palmivora* is commonly controlled with fungicides, which are metalaxyl and copper as the active ingredients where it is easier to apply and has a rapid result compared to the biocontrol agent (Kwodaga et al., 2017).

As a results, toxicity and water pollution are becoming a significant issue, with prior studies indicating that it can raise input costs since fungicide application needs to be applied regularly, with some studies recommending a maximum interval of 3 to 4 weeks (Bowers et al., 2001). Instead of focusing just on crop productivity, the government is encouraging Malaysian farmers to adopt sustainable agriculture, the environment also must be sustained because nowadays a growing number of consumers are opting for organic foods to maintain a healthier lifestyle. To ensure sustainable agriculture production, this review finds that biological management is one technique to manage plant diseases .Based on previous studies by (Mani et al. 2016) , although the successful rate is faster when using chemical control to lower the occurrence of the disease compare to biological control, there are negative side effects associated with frequent use of chemical control, including soil toxicity and other negative effects on the environment (Mani et al.2016). According to (Eteng, 2020), heavy metals from chemical control could give a negative impact on plant development. If the plant's nutrient requirements are exceeded, the toxicity can be transmitted to the consumer who consumes the plant.

Biocontrol agents are still being developed by researcher for a greater yield and early disease prevention (Soh et al., 2013). *Trichoderma spp.* is one of the common biocontrol agents. There are a few advantages and a few disadvantages to the implementation of the control of *Trichoderma spp.* Researchers have found that using Trichoderma species to control *Phytophthora palmivora* is similar to using metalaxyl fungicides to suppress the infection. (Promwee et al., 2017). Thus, there is high possibility for the biocontrol agent to be used in controlling the black pod disease. Unfortunately, biocontrol consumes a lot of money to construct a biological control framework. A significant degree of financial planning is required to build a successful strategy. Based on the review above, biological control is effective in controlling the black pod disease in Malaysia under certain conditions, and it should be improved to be more efficient, environmentally friendly, and good for long term effect.

CONCLUSION

Since we have heavy rainfall of roughly 2000 millimeters per year, black pod disease or black pod rot caused by *Phytophthora spp.* is a major issue for cocoa plantation. The disease incidence can exceed 50% in ripe pods, mostly during the wet season, and some crops can occur from 70% up to 80% incidence of Phytophthora pod rot. On the basis of research published in the journals indicated in this review, this review has identified and discovered a lot of research investigations being carried out more by researchers about biological controls than chemical controls for managing black pod disease. Researchers thought that biological control has a better long-term effect than chemical controls whereas fungicides are one of the most prevalent treatments used by farmers to prevent the black pod disease of cocoa. Synthetic fungicides are used intensively that they develop resistance towards the strains of the pathogen. They also pollute the land and water through soil application, runoffs from the treated regions, or drifting sprays. Fungicides that are reapplied in accordance with dosage recommendations will also increase the production costs. So, in terms of strategies for overcoming this problem, biological control is suggested as a solution to chemical control, where *Trichoderma spp.* and endophytic bacteria can be used and resulted in a successful result in inhibiting the growth of the *Phytophthora palmivora* and *Phytophthora megakarya*, the causal agent of black pod. Although the preparation of biological control takes a long time and expensive but it is more sustainable and environmentally friendly than chemical control, which could pollute the environment and lead to the emergence of resistance pathogens in the future. Nevertheless, this strategy should be improved and encouraged as one of the major methods in managing black pod disease in Malaysia in order to boost the agriculture industry.

REFERENCES

Adeniyi, D., Adeji, A., Kolawole, O., Ogundeji, B., & Fadara, A. (2018). Comparative Toxicity of Copper – Based Fungicides against *Phytophthora megakarya*; a Causal Agent of Black Pod Disease of Cocoa. *Current Journal of Applied Science and Technology*, *28*(4), 1–6. https://doi.org/10.9734/cjast/2018/26120

Alex, P. G., Elisée, A. L.-N. D. G., Kouabenan, A., Nakpalo, S., Edwige, C. A., & Daouda, K. (2018). Valorisation of Cassava Wastewater as Substrate for *Trichoderma* virens Production, Bio-control Agent Cocoa Black Pod Disease. *Current Journal of Applied Science and Technology*, *30*(5), 1–8. https://doi.org/10.9734/cjast/2018/45488

Altomare, C., Norvell, W. A., Björkman, T., & Harman, G. E. (1999). Solubilization of phosphates and micronutrients by the plant-growth- promoting and biocontrol fungus *Trichoderma* harzianum Rifai 1295-22. *Applied and Environmental Microbiology*, *65*(7), 2926–2933. https://doi.org/10.1128/aem.65.7.2926-2933.1999

Angraeni, L., Sriwati, R., & Susanna. (2020). Application of Various Species of *Trichoderma spp.* in Composting Cocoa Pod Husk Contaminated *Phytophthora palmivora*. *IOP Conference Series: Earth and Environmental Science*, *515*(1). https://doi.org/10.1088/1755-1315/515/1/012069

Arshad, F. M., & Abdulla, I. (2015). Malaysia's cocoa beans decline: A prognosis. *International Journal of Agriculture, Forestry, and Plantation*, *1*(1), 1–14.

Awad, A., Hameed, A., Dewi, S., Arshad, F. M., & Nasir, M. (2010). *an Econometric Model of the Malaysian Cocoa Market*. 1–15.

Bailey, B. A., & Meinhardt, L. W. (2016). Cacao diseases: A history of old enemies and new encounters. In *Cacao Diseases: A History of Old Enemies and New Encounters*. https://doi.org/10.1007/978-3-319-24789-2

Bélanger, R. R., Labbé, C., Lefebvre, F., & Teichmann, B. (2012). Mode of action of biocontrol agents: All that glitters is not gold. *Canadian Journal of Plant Pathology*, *34*(4), 469–478. https://doi.org/10.1080/07060661.2012.726649

Błaszczyk, L., Siwulski, M., Sobieralski, K., Lisiecka, J., & Jędryczka, M. (2014). *Trichoderma spp.* - Application and prospects for use in organic farming and industry. *Journal of Plant Protection Research*, *54*(4), 309–317. https://doi.org/10.2478/jppr-2014-0047

Bonapace, G., Waheed, A., Shah, G. N., & Sly, W. S. (2004). Chemical chaperones protect from effects of apoptosis-inducing mutation in carbonic anhydrase IV identified in retinitis pigmentosa 17. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(33), 12300–12305. https://doi.org/10.1073/pnas.0404764101

Bowers, J. H., Bailey, B. A., Hebbar, P. K., Sanogo, S., & Lumsden, R. D. (2001). The Impact of Plant Diseases on World Chocolate Production. *Plant Health Progress*, *2*(1), 12. https://doi.org/10.1094/php-2001-0709-01-rv

Bull, C. T., Shetty, K. G., & Subbarao, K. V. (2002). Interactions between myxobacteria, plant pathogenic fungi, and biocontrol agents. *Plant Disease*, *86*(8), 889–896. https://doi.org/10.1094/PDIS.2002.86.8.889

Carmona, M., Sautua, F., Pérez-Hérnandez, O., & Reis, E. M. (2020). Role of Fungicide Applications on the Integrated Management of Wheat Stripe Rust. *Frontiers in Plant Science*, *11*(June). https://doi.org/10.3389/fpls.2020.00733

Chizari, A., Mohamed, Z., Shamsudin, M. N., & Seng, K. W. K. (2017). The Effects of Climate Change Phenomena on Cocoa Production in Malaysia. *International Journal of Environment, Agriculture and Biotechnology*, *2*(5), 2599–2604. https://doi.org/10.22161/ijeab/2.5.42

de OLIVEIRA, T. A. S., Blum, L. E. B., Duarte, E. A. A., & Luz, E. D. M. N. (2018). Control of *Phytophthora palmivora* on postharvest Papaya with *Trichoderma* asperellum, T. Virens, T. harzianum and T. longibrachiatum. *Bioscience Journal*, *34*(6), 1513–1521. https://doi.org/10.14393/bj-v34n6a2018-39548

Durio, D., Leaf, L., Chromatography, H. L., & Technique, H. (2021). *The Study of the Kinetics of Metalaxyl Accumulation and*.

Ehab A.D. Sarhan. (2014). *Bacillus Against Alfa Lfa To Control Damping Off.Pdf*.

Elliott, M., Shamoun, S. F., & Sumampong, G. (2015). Effects of systemic and contact fungicides on life stages and symptom expression of *Phytophthora* ramorum invitro and in planta. *Crop Protection*, *67*(January), 136–144. https://doi.org/10.1016/j.cropro.2014.10.008

Enoch, K. (2015). *Phytophthora megakarya and P. palmivora on Theobroma cacao: Aspects of virulence and the effecte of temperature on growth and resistance to fungicides*. 81. http://curis.ku.dk/ws/files/141769966/MASTER_THESIS_2015_ENOCH_N._KUDJORDJIE.pdf

Eteng, E. U. (2020). Distribution of heavy metals in cocoa bean and soils along toposequence of cocoa plantations. *Nigeria Agricultural Journal*, *51*(1), 181–188.

Falcäo, L. L., Silva-Werneck, J. O., Vilarinho, B. R., da Silva, J. P., Pomella, A. W. V., & Marcellino, L. H. (2014). Antimicrobial and plant growth-promoting properties of the cacao endophyte Bacillus subtilis ALB629. *Journal of Applied Microbiology*, *116*(6), 1584–1592. https://doi.org/10.1111/jam.12485

Harman, G. E., Howell, C. R., Viterbo, A., Chet, I., & Lorito, M. (2004). *Trichoderma* species - Opportunistic, avirulent plant symbionts. *Nature Reviews Microbiology*, *2*(1), 43–56. https://doi.org/10.1038/nrmicro797

Hegde, G. M. (2020). *Integrated management of pod rot disease of cocoa in hilly tracts of Karnataka*. *48*(1), 21–26. https://doi.org/10.25081/jpc.2020.v48.i1.6213

Howell, C. R., Stipanovic, R. D., & Lumsden, R. D. (1993). Antibiotic Production by Strains of Gliocladium virens and its Relation to the Biocontrol of Cotton Seedling Diseases. *Biocontrol Science and Technology*, *3*(4), 435–441. https://doi.org/10.1080/09583159309355298

James, R. (2019). MAKING GREATER USE OF INTRODUCED MICROORGANISMS FOR BIOLOGICAL CONTROL OF PLANT PATHOGENS. *European Approaches to International Management*, 257–260. https://doi.org/10.1515/9783110849844-019

Junaid, M., Rosmana, A., & Firman. (2020). Testing cutinase produced by native *Trichoderma* isolate and its persistence in pod and flower surfaces on cocoa tree in South Sulawesi. *IOP Conference Series: Earth and Environmental Science*, *486*(1). https://doi.org/10.1088/1755-1315/486/1/012160

Kawser Ahmed, M., Baki, M. A., Kundu, G. K., Saiful Islam, M., Monirul Islam, M., & Muzammel Hossain, M. (2016). Human health risks from heavy metals in fish of Buriganga river, Bangladesh. *SpringerPlus*, *5*(1). https://doi.org/10.1186/s40064-016-3357-0

Keswani, C., Mishra, S., Sarma, B. K., Singh, S. P., & Singh, H. B. (2014). Unraveling the efficient applications of secondary metabolites of various *Trichoderma spp. Applied Microbiology and Biotechnology*, *98*(2), 533–544. https://doi.org/10.1007/s00253-013-5344-5

Kumar Deshwal, V., & Kumar, P. (2013). Plant groawth promoting activity of Pseudomonads in Rice crop. *Int.J.Curr.Microbiol.App.Sci*, *2*(11), 152–157. http://www.ijcmas.com

Kwodaga, J. K., Odamtten, G. T., Owusu, E., & Akrofi, A. Y. (2017). Effect of Four Copper-Based Fungicides on Soil Fungi in A Cocoa Farm at Tafo, Eastern Region, Ghana. *Scientia Agriculturae*, *17*(2). https://doi.org/10.15192/pscp.sa.2017.17.2.5576

Lin Marcellin, M., Essouma François, M., Audrey Valteri, V., Marie-Josephe Endali, E., & Begoude, B. (2018). In vitro study of the compatibility of six fungicides with two strains of *Trichoderma* asperellum, biocontrol agents used against cacao black pod disease in Cameroon. *International Journal of Innovation and Applied Studies*, *24*(4), 1834–1848. http://www.ijias.issr-journals.org/

Mahmoud, A. F. (2016). Genetic variation and biological control of Fusarium graminearum isolated from wheat in Assiut-Egypt. *Plant Pathology Journal*, *32*(2), 145–156. https://doi.org/10.5423/PPJ.OA.09.2015.0201

Mani, K. K., Hollier, C. A., & Groth, D. E. (2016). Effect of planting date, fungicide timing and cultivar susceptibility on severity of narrow brown leaf spot and yield of rice. *Crop Protection*, *90*(June 2018), 186–190. https://doi.org/10.1016/j.cropro.2016.07.029

Matthews, G., Wiles, T., & Baleguel, P. (2003). A survey of pesticide application in Cameroon. *Crop Protection*, *22*(5), 707–714. https://doi.org/10.1016/s0261-2194(03)00008-5

Mbarga, J. B., Begoude, B. A. D., Ambang, Z., Meboma, M., Kuate, J., Schiffers, B., Ewbank, W., Dedieu, L., & Hoopen, G. M. (2014). A new oil-based formulation of *Trichoderma* asperellum for the biological control of cacao black pod disease caused by *Phytophthora megakarya*. *BIOLOGICAL CONTROL*, *77*, 15–22. https://doi.org/10.1016/j.biocontrol.2014.06.004

Mboussi, S., Ambang, Z., Ndogho, A., Dooh, J., & Essouma, F. (2016). In vitro Antifungal Potential of Aqueous Seeds Extracts of Azadirachta indica and Thevetia peruviana against *Phytophthora megakarya* in Cameroon. *Journal of Applied Life Sciences International*, *4*(4), 1–12. https://doi.org/10.9734/jalsi/2016/23710

McMahon, P. J., Purwantara, A., Wahab, A., Imron, M., Lambert, S., Keane, P. J., & Guest, D. I. (2010). Phosphonate applied by trunk injection controls stem canker and decreases *Phytophthora* pod rot (black pod) incidence in cocoa in sulawesi. *Australasian Plant Pathology*, *39*(2), 170–175. https://doi.org/10.1071/AP09078

Miguelez-Sierra, Y., Acebo-Guerrero, Y., El Jaziri, M., Bertin, P., & Hernández-Rodríguez, A. (2019). Pseudomonas chlororaphis CP07 strain reduces disease severity caused by *Phytophthora palmivora* in genotypes of Theobroma cacao. *European*

Journal of Plant Pathology, *155*(4), 1133–1143. https://doi.org/10.1007/s10658-019-01842-8
Miles, A. K., C., W., Tran, N. T., Shuey, T. A., Drénth, A., & Dewdney, M. M. (2017). Does Fungicide Run-off From Citrus Delay Leaf Litter Decomposition? *Citrus Research & Technology*, *38*(1). https://doi.org/10.4322/crt.icc044
Ndoungue, M., Petchayo, S., Techou, Z., Nana, W. G., Nembot, C., Fontem, D., & Hoopen, G. M. T. (2018). The impact of soil treatments on black pod rot (caused by *Phytophthora megakarya*) of cacao in Cameroon. *Biological Control*, *123*(April), 9–17. https://doi.org/10.1016/j.biocontrol.2018.04.016
Nembot, C., Takam Soh, P., ten Hoopen, G. M., & Dumont, Y. (2018a). Modeling the temporal evolution of cocoa black pod rot disease caused by *Phytophthora megakarya*. *Mathematical Methods in the Applied Sciences*, *41*(18), 8816–8843. https://doi.org/10.1002/mma.5206
Nembot, C., Takam Soh, P., ten Hoopen, G. M., & Dumont, Y. (2018b). Modeling the temporal evolution of cocoa black pod rot disease caused by *Phytophthora megakarya*. *Mathematical Methods in the Applied Sciences*, *41*(18), 8816–8843. https://doi.org/10.1002/mma.5206
Nikel, P. I., Martínez-García, E., & De Lorenzo, V. (2014). Biotechnological domestication of pseudomonads using synthetic biology. *Nature Reviews Microbiology*, *12*(5), 368–379. https://doi.org/10.1038/nrmicro3253
Nurlaila, N., Rosmana, A., & Dewi, V. S. (2020). The capability of *Trichoderma* asperellum in suppressing vascular streak diseases on five different cocoa clones. *IOP Conference Series: Earth and Environmental Science*, *486*(1). https://doi.org/10.1088/1755-1315/486/1/012158
O'Brien, P. A. (2017). Biological control of plant diseases. *Australasian Plant Pathology*, *46*(4), 293–304. https://doi.org/10.1007/s13313-017-0481-4
Of, E. C., Control, B., & Plant, O. F. (1987). *EVOLVING CONCEPTS OF BIOLOGICAL CONTROL OF PLANT PATHOGENS*. 67–85.
Ouattara, A., Coulibaly, K., Konate, I., Kebe, B. I., Beugré Grah, A. M., Tidou, A. S., & Filali-Maltouf, A. (2020). Screening and Selection in vitro and in vivo of Cocoa Tree (Theobroma Cacao Linn) Endophytic Bacteria Having Antagonistic Effects against *Phytophthora* Spp . Fungal Agents Responsible of Black Pod Disease in Côte d ' Ivoire. *Journal of Applied and Environmental Microbiology*, *8*(1), 25–31. https://doi.org/10.12691/jaem-8-1-4
Pakora, G. A., Mpika, J., Kone, D., Ducamp, M., Kebe, I., Nay, B., & Buisson, D. (2018). Inhibition of *Phytophthora* species, agents of cocoa black pod disease, by secondary metabolites of *Trichoderma* species. *Environmental Science and Pollution Research*, *25*(30), 29901–29909. https://doi.org/10.1007/s11356-017-0283-9
Palareti, G., Legnani, C., Cosmi, B., Antonucci, E., Erba, N., Poli, D., Testa, S., & Tosetto, A. (2016). Comparison between different D-Dimer cutoff values to assess the individual risk of recurrent venous thromboembolism: Analysis of results obtained in the DULCIS study. *International Journal of Laboratory Hematology*, *38*(1), 42–49. https://doi.org/10.1111/ijlh.12426
Passera, A., Vacchini, V., Cocetta, G., Shahzad, G. I. R., Arpanahi, A. A., Casati, P., Ferrante, A., & Piazza, L. (2020). Towards Nutrition-Sensitive Agriculture: An evaluation of biocontrol effects, nutritional value, and ecological impact of bacterial inoculants. *Science of the Total Environment*, *724*, 138127. https://doi.org/10.1016/j.scitotenv.2020.138127
Peter, P., & Chandramohanan, R. (2014). Integrated management of black pod disease of cocoa caused by *Phytophthora palmivora*. *International Journal of Plant …*, *7*(1), 1983–1986. http://www.cabdirect.org/abstracts/20153017782.html
Peterson, P. G., Merrett, M. F., Fowler, S. V., Barrett, D. P., & Paynter, Q. (2020). Comparing biocontrol and herbicide for managing an invasive non-native plant species: Efficacy, non-target effects and secondary invasion. *Journal of Applied Ecology*, *57*(10), 1876–1884. https://doi.org/10.1111/1365-2664.13691
Promwee, A., Yenjit, P., Issarakraisila, M., Intana, W., & Chamswarng, C. (2017). Efficacy of indigenous *Trichoderma* harzianum in controlling *Phytophthora* leaf fall (*Phytophthora palmivora*) in Thai rubber trees. *Journal of Plant Diseases and Protection*, *124*(1), 41–50. https://doi.org/10.1007/s41348-016-0051-y
Rhouma, A., Salem, I. Ben, & Gomez, D. G. (2016). Efficacy of Two Fungicides for the Management of Phytophthora Infestans on Potato Through Different Applications Methods Adopted in Controlled Conditions. *International Journal of Applied Science and Agriculture*, *02*(December), 39–45.
Sabetta, W., Vandelle, E., Locato, V., Costa, A., Cimini, S., Bittencourt Moura, A., Luoni, L., Graf, A., Viggiano, L., De Gara, L., Bellin, D., Blanco, E., & de Pinto, M. C. (2019). Genetic buffering of cyclic AMP in Arabidopsis thaliana compromises the plant immune response triggered by an avirulent strain of Pseudomonas syringae pv. tomato. *Plant Journal*, *98*(4), 590–606. https://doi.org/10.1111/tpj.14275
Saxena, A. K., Kumar, M., Chakdar, H., Anuroopa, N., & Bagyaraj, D. J. (2020). Bacillus species in soil as a natural resource for plant health and nutrition. *Journal of Applied Microbiology*, *128*(6), 1583–1594. https://doi.org/10.1111/jam.14506
Shafique, S., Shafique, S., Javed, A., Akhtar, N., & Bibi, S. (2019). Analysis of antagonistic potential of secondary metabolites and organic fractions of *Trichoderma* species against alternaria alternata. *Biocontrol Science*, *24*(2), 81–88. https://doi.org/10.4265/BIO.24.81
Sherkhane, P. D., Bansal, R., Banerjee, K., Chatterjee, S., Oulkar, D., Jain, P., Rosenfelder, L., Elgavish, S., Horwitz, B. A., & Mukherjee, P. K. (2017). Genomics-Driven Discovery of the Gliovirin Biosynthesis Gene Cluster in the Plant Beneficial Fungus *Trichoderma* Virens. *ChemistrySelect*, *2*(11), 3347–3352. https://doi.org/10.1002/slct.201700262
Silva, L. R. da, Valadares-Inglis, M. C., Peixoto, G. H. S., Luccas, B. E. G. de, Muniz, P. H. P. C., Magalhães, D. M., Moraes, M. C. B., & Mello, S. C. M. de. (2021). Volatile organic compounds emitted by *Trichoderma* azevedoi promote the growth of lettuce plants and delay the symptoms of white mold. *Biological Control*, *152*(July 2020), 104447. https://doi.org/10.1016/j.biocontrol.2020.104447
Singh, U. B., Malviya, D., Wasiullah, Singh, S., Pradhan, J. K., Singh, B. P., Roy, M., Imram, M., Pathak, N., Baisyal, B. M., Rai, J. P., Sarma, B. K., Singh, R. K., Sharma, P. K., Kaur, S. D., Manna, M. C., Sharma, S. K., & Sharma, A. K. (2016). Bio-protective microbial agents from rhizosphere eco-systems trigger plant defense responses provide protection against sheath blight disease in rice (Oryza sativa L.). *Microbiological Research*, *192*, 300–312. https://doi.org/10.1016/j.micres.2016.08.007

Sitaraman, R. (2015). Pseudomonas *spp.* as models for plant-microbe interactions. *Frontiers in Plant Science*, *6*(SEPTEMBER), 1–4. https://doi.org/10.3389/fpls.2015.00787

Soh, P. T., Ndoumbè-Nkeng, M., Sache, I., Nguema, E. P. N., Gwet, H., & Chadœuf, J. (2013). Development stage-dependent susceptibility of cocoa fruit to pod rot caused by *Phytophthora megakarya*. *European Journal of Plant Pathology*, *135*(2), 363–370. https://doi.org/10.1007/s10658-012-0092-4

Sood, M., Kapoor, D., Kumar, V., & Sheteiwy, M. S. (2020). *Trichoderma* : The " Secrets " of a Multitalented. *Plants*, *9*, 762.

Sowunmi, F. A., Famuyiwa, G. T., Oluyole, K. A., Aroyeun, S. O., & Obasoro, O. A. (2019). Environmental burden of fungicide application among cocoa farmers in Ondo state, Nigeria. *Scientific African*, *6*. https://doi.org/10.1016/j.sciaf.2019.e00207

Sriwati, R., Melnick, R. L., Muarif, R., Strem, M. D., Samuels, G. J., & Bailey, B. A. (2015a). *Trichoderma* from Aceh Sumatra reduce *Phytophthora* lesions on pods and cacao seedlings. *Biological Control*, *89*(November 2017), 33–41. https://doi.org/10.1016/j.biocontrol.2015.04.018

Sriwati, R., Melnick, R. L., Muarif, R., Strem, M. D., Samuels, G. J., & Bailey, B. A. (2015b). *Trichoderma* from Aceh Sumatra reduce *Phytophthora* lesions on pods and cacao seedlings. *Biological Control*, *89*, 33–41. https://doi.org/10.1016/j.biocontrol.2015.04.018

Sundram, S., & Ainni, M. A. I. N. (2018). *The Use of Indigenous Trichoderma in Controlling Phytophthora palmivora – An In Vitro Investigation*. *76*(May), 22–27.

Tchameni, S. N., Sameza, M. L., O'donovan, A., Fokom, R., Mangaptche Ngonkeu, E. L., Wakam Nana, L., Etoa, F., & Nwaga, D. (2017). Antagonism of *Trichoderma* asperellum against *Phytophthora megakarya* and its potential to promote cacao growth and induce biochemical defence. *Mycology*, *8*(2), 84–92. https://doi.org/10.1080/21501203.2017.1300199

Tchameni, S. N., Nwaga, D., Wakam, L. N., Mangaptche Ngonkeu, E. L., Fokom, R., Kuaté, J., & Etoa, F. X. (2012). Growth Enhancement, Amino Acid Synthesis and Reduction in Susceptibility Towards *Phytophthora megakarya* by Arbuscular Mycorrhizal Fungi Inoculation in Cocoa Plants. *Journal of Phytopathology*, *160*(5), 220–228. https://doi.org/10.1111/j.1439-0434.2012.01888.x

Thind, T. S. (2017). Role of fungicides in crop health management: Prospects and challenges. *Developments in Fungal Biology and Applied Mycology*, 433–447. https://doi.org/10.1007/978-981-10-4768-8_22

THOROLD, C. A. (1959). Methods of Controlling Black-Pod Disease (Caused By *Phytophthora palmivora*) of Theobroma Cacao in Nigeria. *Annals of Applied Biology*, *47*(4), 708–715. https://doi.org/10.1111/j.1744-7348.1959.tb03487.x

Türkölmez, Ş., & Derviş, S. (2017). Activity of metalaxyl-M+mancozeb, fosetyl-Al, and phosphorous acid against phytophthora crown and root rot of apricot and cherry caused by *Phytophthora palmivora*. *Plant Protection Science*, *53*(4), 216–225. https://doi.org/10.17221/38/2016-PPS

Villamizar-Gallardo, R. A., Ortíz-Rodriguez, O. O., & Escobar, J. W. (2017). Fungos simbióticos e endofíticos como biocontroles de fitopatógenos de cacau (Theobroma cacao L.). *Summa Phytopathologica*, *43*(2), 87–93. https://doi.org/10.1590/0100-5405/2175

Wakam Nana, L., Thérèse Ekounda, V., Mkounga, P., Eke, P., Ephraïm Nkengfack, A., & Nwaga, D. (2016). Potentialisation of the biocontrol efficacy of arbuscular mycorrhizas fungi against cocoa black pod rot causing *Phytophthora megakarya* with natural flavonoid. *International Journal of Agronomy and Agricultural Research*, *9*(1), 165–181. http://www.innspub.net

Wan, J. S. H., & Liew, E. C. Y. (2020). Efficacy of chemical and biological agents against pepper blight (*Phytophthora* capsici Leonion) in East Asia: a meta-analysis of laboratory and field trial data. *Journal of Plant Pathology*, *102*(3), 835–842. https://doi.org/10.1007/s42161-020-00519-0

Wang, W., Xu, M., Wang, G., & Galili, G. (2018). New insights into the metabolism of aspartate-family amino acids in plant seeds. *Plant Reproduction*, *31*(3), 203–211. https://doi.org/10.1007/s00497-018-0322-9

Weller, D. M. (2007). Pseudomonas biocontrol agents of soilborne pathogens: Looking back over 30 years. *Phytopathology*, *97*(2), 250–256. https://doi.org/10.1094/PHYTO-97-2-0250

Woo, S. L., Scala, F., Ruocco, M., & Lorito, M. (2006). The molecular biology of the interactions between *Trichoderma spp.*, phytopathogenic fungi, and plants. *Phytopathology*, *96*(2), 181–185. https://doi.org/10.1094/PHYTO-96-0181

Wyenandt, A. (2020). *Volume 49 Number 3 Article Number 3FEA8 Evaluating Fungicide Recommendations for Vegetable Crop in the United States : Should More Be Done to Limit the Risk of Fungicide Resistance Development ? Development of Fungicide Resistance Risks and Use of FRAC Co*. *October*.

Xia, X. J., Huang, Y. Y., Wang, L., Huang, L. F., Yu, Y. L., Zhou, Y. H., & Yu, J. Q. (2006). Pesticides-induced depression of photosynthesis was alleviated by 24-epibrassinolide pretreatment in Cucumis sativus L. *Pesticide Biochemistry and Physiology*, *86*(1), 42–48. https://doi.org/10.1016/j.pestbp.2006.01.005

Zhang, S., Zheng, X., Reiter, R. J., Feng, S., Wang, Y., Liu, S., Jin, L., Li, Z., Datla, R., & Ren, M. (2017). Melatonin attenuates potato late blight by disrupting cell growth, stress tolerance, fungicide susceptibility and homeostasis of gene expression in *Phytophthora* infestans. *Frontiers in Plant Science*, *8*(November), 1–19. https://doi.org/10.3389/fpls.2017.01993

Zhao, K., Penttinen, P., Zhang, X., Ao, X., Liu, M., Yu, X., & Chen, Q. (2014). Maize rhizosphere in Sichuan, China, hosts plant growth promoting Burkholderia cepacia with phosphate solubilizing and antifungal abilities. *Microbiological Research*, *169*(1), 76–82. https://doi.org/10.1016/j.micres.2013.07.003

Zohara, F., Akanda, M. A. M., Paul, N. C., Rahman, M., & Islam, M. T. (2016). Inhibitory effects of Pseudomonas *spp.* on plant pathogen *Phytophthora* capsici in vitro and in planta. *Biocatalysis and Agricultural Biotechnology*, *5*, 69–77. https://doi.org/10.1016/j.bcab.2015.12.009

Zubir, I., Ross, E. E. R., Hamzah, A., & Aqma, W. S. (2019). Endophytic bacteria from Theobroma cacao L. with antifungal activities against *Phytophthora palmivora*. *Asian Journal of Agriculture and Biology*, *7*(3), 404–411.