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Article

Soil Microbiome and Banana Plant Diseases: A Review

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***Abstract*— Soil microbiomes not only benefits the ecosystem, such as facilitating nitrogen cycling, but they can also cause unhealthy plant or even death since some of the microbes are pathogens. The crops yield will significantly decrease if the pathogens are still assembled in the soil, which could cause losses to farmers. Previous studies have acknowledged several aspects of the roles of soil microbiome and how soil variations can affect the availability and functions of the microbes. Banana is one of the most popular, commonly consumed, and essential fruit crops worldwide. Nevertheless, the accumulation of pathogenic microorganisms as primary inhabitants in the soil become a main limiting factor in banana crops production. With current studies and technologies, the disease caused by pathogenic microbes in the soil can be controlled. The scope of this review is on soil microbiomes that contribute to banana plant diseases and the methods to control the disease.**

***Keywords*— Soil microbiome; Banana plant disease.**

I. INTRODUCTION

Soil is an essential part of life on Earth and a valuable resource that influences our ecosystems in countless aspects [1]. Soil is defined as a natural source composed of solids, liquids, and gases that exist on the Earth's surface and occupy space [2]. Predominantly, soil contained a diversity of microorganisms as natural inhabitants, known as soil microbiome [3]. The existence of soil microbiome could affect the growth of particular plants, either promoting plant growth and production or demoting and damaging the host plant [4].

Banana (*Musa* spp.) comes from the Musaceae family. It is one of the fruit crops from tropical and subtropical regions and can be the world's oldest cultivated crop [5]. Banana plants only produce fruit once in a lifetime and usually take ten to twelve months from planting to harvest [6]. Despite its deliciousness and nutrition, the plantation of this herbaceous plant is quite challenging as soil-borne pathogens become the main hindrance in the production of healthy plants. Though, using biocontrol agents as biofertilisation with the appropriate application could prevent the dissemination of diseases.

II. SOIL

Soil formation is slow because it takes hundreds of years to form the topsoil. It consists of individual components that give the specific characteristic and structure [1]. According to Abdulkadir (2017), the soil is divided into solid and pore spaces. The solid area comprises organic matter and mineral matter; air and water are part of the pore space [7]. Also, the living things that contribute direct or indirectly to soil formation are humans, plants, animals such as earthworms, and the most important is the soil microbiome [1]. Soil bacteria and fungi are the main soil microbiome found in the mass or the root system [3]. Apart from that, the soil has many functions that help maintain the ecosystem. Nutrient cycle, physical stability and plant support system, water dynamics, filter and buffer, as well as the encouragement of ecosystem and environment are the biophysical elements of soil roles [7, 8]. Moreover, gas exchange and carbon storage also occurred in the soil [1]. Besides, the presence of soil microorganisms enhances the utility of the soil mainly in the agricultural system by promoting plant growth, the disintegration of the pesticide and inhibiting the growth of pathogens [9].

Notwithstanding the beneficial functions of soil, some shifts can cause changes to the soil properties, affecting soil fertility and the growth of plants and organisms accumulated in the soil. One of the common environmental changes that interrupt the ecosystem service is climate change, which can alter the soil growth processes and significantly impact the growth of crops [10]. According to Rasmussen *et al.* (2020), climate change can switch species populations, which will lead to a new interaction within the latest range of plants and the soil microbes, therefore will either promote plant growth or cause damage to the plant [4]. Jansson & Hofmockel (2018) marked those variations in soil, especially the formation of precipitations, soil depletion, and unethical land management practices, can risk the fundamental functions of soil microbes in the soil [11]. The use of fertiliser can also affect soil quality, although it is known for helping plants grow healthy and improve soil fertility. However, the malpractices such as high dose consumption can adversely affect the soil. Yang *et al.* (2016) reported that the unethical application of fertiliser in plantations could cause leaching in soil nutrients [12]. Additionally, eutrophication of water and acidification in soil are some of the adverse effects when the fertiliser is used for an extended period in sequence, leading to a decrease in crop production [13]. Besides, the existing variation of the microbial community is one of the consequences when using fertiliser, and these microbes can change nutrient intake by the plant [14].

Insecticides, fungicides, herbicides and other pesticides are examples of the wide range of synthetic chemicals used in present agriculture [15]. A study by Wang et al. (2020) stated that pesticides are commonly used to increase economic benefits. However, circa 85% of overall global emissions are nitrogen by utilising pesticides in their agricultural practices [16]. Another study by Wang et al. (2020) emphasised that around 55-80% of pesticides can remain in the soil, altering the soil microbial community and environmental behaviour [17].

III. SOIL MICROBIOME

The microbiome is a modern development field that explores the interaction of microbiota community and the ecosystem in which they survived and usually incorporates various types of microorganisms [18]. Microbiome acts as an observable identifier to the biological content and discovery of environmental factors in which they define the microbiome as a bioindicator [19]. Besides, another definition of the microbiome is a community of microbes in a particular environment such as soil, rhizosphere, gut, and others, including their genes and transcripts, metabolites, and proteins [20]. Recently, Berg et al. (2020) defined a microbiome as a population of pathogenic, commensal and mutualist microorganisms that assemble and interact with each other [21]. Millions of the microorganisms, specifically 10^9 to 10^{10} per gram, are present in the soil [22]. Generally, 10^7 mainly represents the bacteria, while 10^5 to 10^6 are fungi species [23]. The high density of microbes present in the soil is stated to be near the roots of the plants' [24]. Accordingly, one cubic meter obtained from the topsoil possibly contained millions of microbes, with nearly ten times more bacteria and actinomycetes than fungi species, substantially fewer nematodes, earthworms and uncountable algae and protozoa [25]. Soil microbe is deemed a sensitive benchmark in determining the quality and health of the soil, although it comprises only approximately 0.5-6.0% of soil organic matter [26].

A study by Schlatter *et al.* (2020) stated that the diversity of accumulated soil microbiome is related to the depth of the soil [9]. The presence of bacteria is predominantly the highest in the top 10 cm of the layer [27]. The carbon cycle and the formation of healthy soil play the prominent role of soil microbiomes in the deeper layer [9]. Their structures and functions differentiate the diversity of microbes present in the ground. Two main factors contribute to the structure and function of the microbes: biotic and abiotic factors [28]. Genotypes of the host, the cultivars, the development process, and proximity to the root are biotic factors. Meanwhile, the abiotic factors are commonly related to the pH of the soil, temperature, seasonal changes and the availability of rhizosphere sediments which give the chemical stimuli, therefore impacting the structure and function of the microbes. Parasites coupled with abiotic variations have relatively influenced the structure and function of the soil microbiome [3]. Also, the formation of bacteria and fungi communities are significantly affected by biotic factors.

Moreover, some of the microbial activity is regulated by the chemical and physical characteristics of the soil [9]. The changes to the structure of soil microbes will increase the availability of beneficial microbes [29]. Thus, several diseases in the plant can be prevented by valuable microbes. The type of farming system also contributes to the variety and composition of the soil microbes, influencing soil health [30]. Besides, the presence of soil microbiome aids in the nutrient uptake for plants. Nitrogen, phosphorus and sulphur are the nutrients incorporated with organic compounds in the soil and thus absorbable to plants. However, the plant itself is not accessible to the nutrients unless, with the help of the soil microbes, for instance, bacteria and some fungi break the molecules, and therefore can be used by the plants [31].

The productivity of plants resulting from soil microbes has become a significant concern in the ecosystem as they help resist diseases and encounter abiotic stress [26, 32]. Anzuay *et al.* (2015) added that soil microbes are the core aspect of ecosystem functioning since they can break the organic materials and preserve the biogeochemical processes [15].

Despite giving beneficial functions to the ecosystem, some of the soil microbes served as pathogens, mutualists and decomposers to control macro-organism formation and release greenhouse gases which could trigger global climate change [33]. Nevertheless, having many soil bacteria and fungi is not a severe problem as they contribute to carbon capturing and nutrient mineralising [3]. In addition, soil microorganisms are also known as an indicator of soil quality [34]. Thus, the sustainability of all agricultural production is primarily driven by soil microbial species, which are the key players of ecological systems [35]. However, the availability and the presence of pathogenic microbes in the soil should not be neglected as they become a significant source of soil-borne diseases.

Jansson & Hofmockel (2018) mentioned that one gram of soil could harbour up to 10 billion species of microorganisms, categorised as bacteria, fungi, protozoa, actinomycetes, viruses and algae [11, 35]. The presence of these organisms contributes to the different functions of soil as they have their unique features, and these microbes communicate with each other, which then impact soil productivity. Another research by Lladó *et al.* (2017) revealed that five phyla of bacteria that usually appear in soils are *Acidobacteria*, *Actinobacteria*, *Proteobacteria*, *Bacteroidetes* and *Firmicutes* [36]. The availability of bacteria as the most microbes present in the soil becomes the main highlight. This organism helps function the ecosystem, such as nitrogen and carbon cycling and contributes to plant health [30]. Furthermore, fungi also represent the majority of soil microbes as both fungi and bacteria exist in bulk in the soil rhizosphere [3].

One of the common beneficial soil microbes is actinomycetes, anaerobic spore-forming bacteria which contain high guanine and cytosine content in the genome. They usually embedded in the top layer and are gradually decrease through the depth of the soil [25, 37]. This microorganism plays a vital role in organic matter cycling and prevents the growth of plant pathogenic microorganisms either by producing the antimicrobial compound or competing with those microbes [37-38]. Actinomycetes can decompose complex soil compounds such as cellulose, lignocellulose, and xylene. Thus, actinomycetes are recently being recognised as saprophytes [25]. They are also capable of secreting some enzymes that retain soil health, for example, chitinases, proteases and other agro-biochemicals.

On the contrary, fungi are known to cause problems in crop production, but some can benefit the plants. Fungi can be widely found in all terrestrial environments, and they are among the most common groups of microorganisms on the Earth [39]. They can be beneficial due to their ability to break down the nutrients that others cannot degrade or are detrimental to the soil community. They are parasites and stick to plants or other organisms to get their food [35]. Plant diseases that lead to decreased crop production and its quality are due to fungi producing mycotoxins [40]. Polyak *et al.* (2020) mark out several examples of toxin-producing fungi, for instance, *Aspergillus*, *Penicillium*, *Fusarium* and *Botrytis* that accumulated in the soil and caused toxicosis, then decreased plant productivity. In agriculture, this phenomenon is known as soil sickness [41].

IV. BANANA PLANT

One of the major fruit crops becoming a staple food source in most tropical areas is bananas, known as *Musa* spp. [30]. According to Dadrasnia *et al.* (2020), Food and Agriculture Organisation (FAO) stated bananas are the eighth most important food crop in the world [42]. The global production of this climacteric fruit is approximately around 114 million tons [43]. However, the production of bananas is affected by several factors such as cultivar and soil type, agro-climatic conditions and risk of the diseases [44]. This herbaceous plant also needs favourable soil conditions to increase its production [45]. Banana is not only be consumed for its tastiness, but it also can have many beneficial effects when consuming it. A report by Qamar & Shaikh (2018) clarified that bananas could give anti-diarrheal, antimicrobial, antioxidant, anti-ulcer, anti-lithic, and wound healing effects to their consumers [46]. For instance, the antioxidant effect from banana consumption can protect the body from oxidative stress [47]. Ripe banana is proved to have antimicrobial properties by showing positive results against selected Gram-positive and Gram-negative bacteria, including *Staphylococcus aureus*, *Streptococcus pneumonia*, *Escherichia coli* and *Haemophilus influenza* respectively [48]. Besides, banana also gives consumers anti-cancer, anti-diabetic and anti-atherosclerosis effects [49].

V. STUDIES ON BANANA PLANT DISEASE

Although banana is the highest crop production, it is vulnerable to several diseases caused by fungi, bacteria, and viruses [43]. These biotic stresses, including pests, will decrease banana production [50].

Mathew *et al*. (2020) mentioned disease caused by fungi becoming one of the biggest declines in banana crop production [43]. In the East and Central Africa region, bunchy top disease (BBTD) and banana *Xanthomonas* wilt (BXW) are diseases related to a banana plantation [50], while in India, soft rot or rhizome rot or tip rot disease is caused by *Pectobacterium carotovorum* subsp. *carotovorum* [52]. Another banana plant disease is banana bract mosaic virus (BBrMD) which is caused by banana bract mosaic virus (genus Potyvirus) [53], and banana blood disease caused by *Ralstonia syzygii* subsp. *celebesensis* [54]. Meanwhile, Moko and Panama diseases rank the most banana diseases in Malaysia, followed by Black Sigatoka and Yellow Sigatoka [51].

According to Blomme *et al*. (2017), several diseases are associated with bananas, and the most common is Moko disease. In some countries, it is known as Bugtok disease, Xanthomonas wilt disease, bacteria head rot or tip-over disease and bacterial rhizome and pseudostem wet rot disease [55]. In addition, banana blood diseases caused by *R. syzygii* subsp. *celebesensis* shows yellowing and necrotic leaf as the disease spread, thus becoming wilt, collapse and drop from the petiole [56]. They also described other diseases in banana plants caused by bacteria, for example, Javanese vascular wilt, bacterial wilt of abaca, and bacterial finger-tip rot are not widely spread. In addition, Panama diseases caused by fungi are also one of the major diseases that decline banana crops production.

A. Ralstonia-associated Disease

Ralstonia solanacearum is the bacteria known to cause Moko disease, and in some countries, it is known as Bugtok disease [55]. The colonisation of this bacterium and then clog the vascular system result in the wilting and ultimately caused death to the plant [57]. The wilting usually starts with the youngest leaf and necrosis of the flat-leaf, spreading towards the mature leaf. Yellow and hollow immature fruit and red spot or brown line in the vascular bundle (Figure 1A) due to degradation of the tissues are also the symptoms of this disease [56]. Khaledian et al. (2017) reported that *R. solanacearum* is a phytopathogenic soil-borne bacteria that can live in the soil for many years [58]. This bacterium also can be readily spread by dirt, water surface and irrigation, farming tools and contaminated biological material [59].

B. Xanthomonas-associated Disease

Xanthomonas wilt of banana and onset disease is due to *Xanthomonas campestris* pv. *musacearum* [55]. This disease can rapidly infect banana plants and thus become harmful to a banana plantation [60]. Usually, *Xanthomonas* wilt of banana can be detected by the wilting and yellowing of leaf. The ripe or unripe fruits will also show yellow (Figure 1B), indicating that they are already affected by the bacteria [56].

C. Erwinia-associated Disease

Erwinia-associated disease, known as bacterial head rot or tip over the condition (Figure 1C), is caused by *Erwinia carotovora* spp. *carotovora* and *Erwinia chrysanthemi* [55]. This disease can be detected in the initial three to four months after planting [52]. The condition becomes a severe crop loss, especially in cultured tissue plantations, as this bacteria species can contaminate during the tissue culture development [61].

D. Fusarium Wilt Disease

Fusarium oxysporum f. sp. *cubense* (Foc) is the famous soil-borne fungi that caused the disease to many crops, especially bananas. *Fusarium* wilt disease, also known as Panama, is the most dangerous disease and causes many agricultural losses [62-63]. This pathogen can survive in the soil for many years and give the infection to the xylem (Figure 1D), which promotes the plant's wilting and finally kills the plant [64]. Fungi can quickly spread by air and water, and they are active in hot and humid environments with frequent rainfall [43]. Thus, the probability of the pathogenic fungi spreading rapidly in the closely banana planted field is high. Many control practices have been done to prevent the disease. However, it is difficult to stop the infection when they accumulate in the soil. One of the significant factors is that they can live in the ground for a long time as chlamydospores or live as a saprophyte on the non-host plants [62, 65, 66].

Disease-associated with banana plants is becoming a significant concern in agriculture as this can affect the production of the crops and thus bring losses to the farmer. Therefore, many strategies have been developed to decrease the diseases, including using chemical agents such as soil fungicides, pesticides, crop rotation and fumigation. This method is proven to be effective in controlling plant diseases. However, it left its residues unhealthy to humans, animals, and the environment.

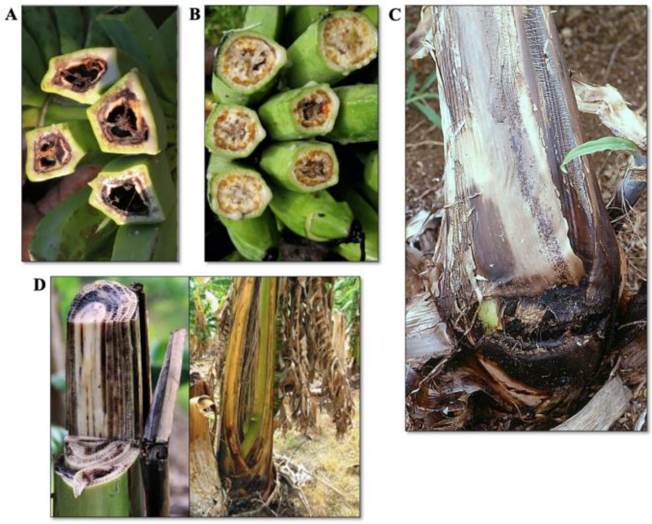

Figure 1 The Banana diseases: (A) *Ralstonia*-associated disease, (B) *Xanthomonas*-associated disease, (C) *Erwinia*-associated disease, and (D) *Fusarium* wilt disease (adapted from internet source).

Biocontrol agents with the addition of crop rotation and organic material amendment have been introduced and proved to give a positive result in controlling the soil-borne plant disease [67]. A biocontrol agent is the most effective way to suppress the disease as it offers safety, longevity, environmental save and low cost but can give a good yield [68]. According to Raymaekers *et al*. (2020), biocontrol indicates the uses of microorganisms that are available in nature, such as bacteria, fungi, viruses, protozoans and yeasts, which directly or indirectly control plant disease [69]. This organism helps the plant respond quickly and effectively to the pathogen infection by inducing the plant-mediated responses.

Biocontrol agent is an environmentally sustainable solution to pesticides as pesticides will alter soil's physicochemical properties and interfere with the function and nature of soil microbial species [70]. Some examples of biocontrol agents that have been used for particular diseases are *Pseudomonas* spp., *Sphingobium* spp., *Penicillium* spp., *Chaetomium* spp., and *Mortierella* spp [29]. Another biocontrol agent is *Bacillus subtilis* Tpb55, isolated from the tobacco phyllosphere to inhibit the tobacco black shank pathogen [70]. Meanwhile, for banana plant disease, rhizobacteria from *Bacillus* genera are reported to have the ability to control the conditions by inhibiting the growth of pathogenic microorganisms and promoting plant growth [42]. A study by Wang *et al*. (2015) demonstrated that *Bacillus amyloliquefaciens* with four different strains (isolated from different rhizosphere soils of healthy banana plants that are grown in diseased fields) in combination with organic fertiliser are proved to reduce the banana *Fusarium* disease [71]. Apart from that, another study verified that *B. amyloliquefaciens* strain W19 could promote the growth of the banana plant by producing indoleacetic acid (IAA) and reducing the Foc population in the rhizosphere soil [72]. Later, a further study reported on the application of fumigation followed by biofertilisation could reduce the presence of the most harmful microbes, which is *F. oxysporum*, in the soil [73]. The study stated that lime and ammonium bicarbonate fumigation significantly decreased the accumulation of *F. oxysporum* as it is toxic to ammonium; moreover, the use of biofertiliser can further decline it. This method could enhance soil quality and fertility by altering the soil characteristics and reshaping the microbial population. The changes in the composition of the microbial population due to the lime and ammonium bicarbonate fumigation lead to the high probability of biofertiliser to control the disease.

Though, the application of soil fumigation without biofertilisation could result in microbial biomass, activity, and diversity being declined, which later could derive an unstable soil ecosystem [66]. Notably, the decrease in soil microbial diversity could enhance the development of soil-borne disease [73]. Therefore, biofertilisation after the fumigation is essential to increase soil biodiversity and health. The biofertiliser could manipulate the soil microbiome in banana plants and stimulate beneficial microbes such as Actinobacteria, Firmicutes and Bradyrhizobium [66]. Furthermore, one example of a biofertiliser that can be used is actinomycetes. A study by Hozzein *et al*. (2019) claimed that the availability of actinomycetes could alter the soil properties and enhance the nutrient content in the soil [38]. The actinomycetes not only increased soil fertility but also improved soil health. Another study by Qiu *et al.* (2020) reported that actinomycetes could secrete different plant hormones such as indoleacetic acid (IAA), which is crucial for the growth of the plant [25]. Hence, biocontrol agents as biofertilisers combined with fumigation and crop rotation could prevent the diseases from affecting the banana plant.

VI. CONCLUSIONS

In conclusion, soil microbiomes play a significant role in maintaining the ecosystem and promoting the growth of plants. However, the availability of pathogenic microbes in the soil could diminish the production of crops. The banana plant is one of the crops that has been affected by different types of pathogenic soil microbes and result in several categories of diseases. However, with the recent advancement of technology, banana plant diseases can be overcome. Applying biocontrol agents combined with fumigation and crop rotation is recommended as it is the best way to control banana plant diseases.

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