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Potential use of Bacillus genus to control of bananas diseases: Approaches toward high yield production and sustainable management

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Bananas and plantains are perennial crops that grow quickly and can be harvested all year round. According to the FAO, bananas are the eighth most important food crop in the world and the fourth most important food crop among the world's least-developed countries with production of over 105 million tons per year. Through trade and supply, bananas make up a global $8.9 billion trade industry. This popular crop is now threatened with different diseases. Statistics illustrated that banana disease could potentially spread up to 1.6 million ha by 2040 if no significant interventions are instituted and consequently cause major yield losses, and emerging diseases pose new threats to global food security. Potential losses of this crop could have substantial socio economic impacts on livelihoods along the banana value chain. Currently the application of chemicals against pathogens is considered highly effective, but the continuous use of pesticides could potentially threat the environment. Thus, there is increasing need to find a sustainable alternative to using synthetic pesticides in order to improve profitable agricultural yield. One strategy for the control of plant diseases is that of biological control using natural enemies of these pests, such as rhizobacteria of the *Bacillus* and *Pseudomonas* genera. Bacillus species have proved to be effective and play a crucial role in the field of bioagents. They have been illustrated as systemic resistance inducer and plant growth promoter. They could produce a broad range of competitors for growth factors and antimicrobial compounds such as enzymes, lipopeptides, and antibiotics. At this point, we focus on details on the versatile application of bacillus-based products. In this context, biocontrol utilizing bacillus species against banana diseases will be presented and verify to serve as a promising alternate to the use of chemicals.

1. Introduction

Basically, crop wastage is mainly as a result of plant diseases which pose a major danger to yield productivity as well as food security. It has been reported that about 20–25 percent of banana fruits harvested are decomposed due fungi during postharvest management and everyday 1.6 million banana fruits are thrown in developing nations (Kuyu and Tola, 2018). This is a universal problem and the impact is losses a wide range of corps production and in some cases the results in plant death. Many measures have been taken to control or prevent such pathogenic organisms, including modification of genetically resistant plants, the development of resistant plant breeding or combat chemicals such as fungicides. It is argued that the use of chemicals has limited efficiency and severe negative environmental impact. Many of these diseases are difficult to combat because they could survive in soil for long periods of times in the form of resting structures. Ecological strategies were also available and aimed at reducing initial soil inoculums such as solarisation, crop rotation and the use of resistant plant species. However, conventional chemicals, pesticides and fungicides strategies have only limited efficiency and have its own limitations and have strong correlation with environmental contamination in addition to social and economic problems.

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Moreover, bioaccumulations of fungicide, chemicals and pesticide remains on food products have a detrimental impact on human well-being, which as well raised significant fears recently. A study conducted in Burundi Rwanda on pesticide use practice on some crops, including banana by smallholder farmers reported a substantial case of death in the previous 12 months as a result of accidental- or self-poisoning among humans and domestic animals (Okonya et al., 2019). From scientific stand point developing of a resistant plant breed is time consuming and in addition, the resistance is non-permanent or universal due to the fact that, pathogen often changes in order to overcome host plant resistance (Khan et al., 2007). Therefore, the need for an effective biological method to control crop disease toward a sustainable agricultural method is obvious. The banana production was endangered by a damaging soil-borne fungus worldwide (Bubici et al., 2019). Owing to the simplicity with which the fungal disease spreads, the worldwide banana industry is a facing serious risk from this soil-borne fungal ailment (Siamak and Zheng, 2018). The fungal diseases have always been regarded as the most significant banana diseases worldwide and have therefore acknowledged more consideration. Nevertheless, bacterial diseases generate substantial effects on produce globally and management practices are not at all times well identified (Blomme et al., 2017). Hence the need to establish sustainable Bacillus-based approaches towards banana diseases management is necessary.

2. Banana fruit

Bananas, as the most popular fruit in the world, are produced in 135 countries and territories with a total production capacity of 144 million metric tonnes cultivated in an area covering 3.8 million hectares (Chai et al., 2012). According to the FAO report, 70–80 percent of production in Africa is local bananas that have been present on the continent for over 1000 years. These are mostly cooking bananas that are a popular and important staple food. Available data indicate that between 2000 and 2017, global production of bananas grew at a compound annual rate of 3.2 percent, reaching a record of 114 million tonnes in 2017, up from around 67 million tonnes in 2000. Bananas are predominantly produced in Asia, Latin America and Africa. The biggest producers are India, which produced 29 million tonnes per year on average between 2010 and 2017, and China at 11 million tonnes. Production in both countries mostly serves the domestic market. Other large producers are the Philippines with an annual average of 7.5 million tonnes between 2010 and 2017, and Ecuador and Brazil both at an average of 7 million tonnes (Fig. 1) (FAO, 2019).

In Malaysia it is the second most commonly grown fruit crops, covering approximately 26,000 ha with 530,000 metric tonnes as a total production capacity (Anem, 2015). Around 50 per cent of the banana growing land is cultivated with Pisang Berangan and the

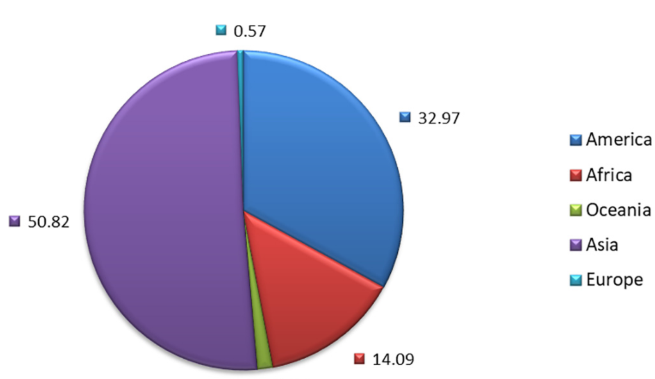

Fig. 1. Banana production by region according to the FAO (FOA, 2019).

Cavendish type, and the remaining popular cultivars are Pisang Nangka, Pisang Tanduk, Pisang Awak Pisang and Pisang Raja. Approximately 12% of the entire production is exported to the Middle East, Brunei and Singapore. Indeed, banana production in Malaysia has decreased due to high labor costs, an increasing threat of diseases and marketing issues (Chai et al., 2012; Mia et al., 2010). Banana cultivation demands high quantity of fertilizers, which is expensive and could be unsafe to the environment, when used inordinately (Mia and Abdul, 2002).

3. Plant growth promoting rhizobacteria (PGPR)

Microbial inoculants and bio fertilizers (free-living nitrogen-fixing bacteria) have been revealed to promote productivity and plant growth; it is accepted globally as an alternate source of N-fertilizer (Mia and Shamsuddin, 2010). It is an economical and environmental-friendly which can be utilized towards workable banana production. Plant growth promoting rhizobacteria (PGPR) would be used as an alternative source of fertilizer for non-leguminous crops and also for improving the nutrient uptake by banana. In fact, PGPR strains could improve the colonizing ability of bacteria on the bananas root surfaces, a location where more microbial cells were present in the root hair propagation zone (Mia et al., 2010). Significant increase of banana yield (69.15 t/ha) and reduced sugar content were recorded in inoculation with *Azospirillum* (Tiwary et al., 1998). While, combination application of *Azospirillum* and *Azotobacter* along with inorganic nitrogen fertilizer, did not show root development and yield improvmnet in bananas compared to un-inoculated control (Wange and Patil, 1994).

Amir et al. (2001) observed the ability of *Bacillus sphaericus* strain UPMB 10, isolated from oil palm, to produce beneficial effects on plantation crops such as oil palm, banana and coconut (Shamsuddin et al., 2001; Shamsuddin et al., 1999). PGPR properties between *Pseudomonas aeruginosa* and *Bacillus subtilis* shows that in terms of performances there was no significant difference at $p < 0.05$ in respect to these two bacteria. The results illustrated that in case of *Bacillus* viability was retained for long periods in soil as PGPR because of the ability to form endospores than *Pseudomonas* (Adesemoye et al., 2008).

Evidently, PGPR improves indole acetic acid (IAA) which is playing a significant function in rhizobacteria-plant contacts (Spaepen and Vanderleyden, 2011). Yasmin et al. (Yasmin et al., 2009) conducted a research in Malaysia on potato, they screened 15 PGPR strains for IAA production and found that all isolates grew in N-free media and produced IAA (Yasmin et al., 2009). Generally, IAA affects root surface area, extension and plant cell division and thereby improves root development and increases the rate of xylem. Moreover, rhizobacterial provides additional nutrients to support the growth of rhizosphere bacteria (Glick, 2012). Mobility of bacterial would contribute to survival in soil and the initial phase of colonization. Root colonization is considered as an important factor in the successful inoculation of beneficial bacteria (Ahemad and Mulugeta, 2014). Colonization includes the bacterial movement to the root surface of plant, following adsorption and/or interactive contact among the bacterium and the host plant, which cause analysis of bacterial gene expression (Mia et al., 2010). Variable types of root colonizations were recorded by PGPR strains, which can colonize a broad kind of plant species. However, many plant roots are not colonized by bacteria. Puente et al. (1999) reported, *A. halopraeferens* produced heavy colonization of the root surface than *A brasilense* for root of black mangrove seedlings. Recently, PGPR have been found to provoke systemic resistance against viruses and fungi and also to improve plant growth. Increased ethylene concentration can results to plant growth inhibition. While, the 1-aminocyclopropnae-1-carboxlyic acid formed by PGPR led to decrease in the concentration of ethylene due to break down the ethylene precursor. This is resulting stimulated plant growth by decreasing environmental salt and drought stress (Lim and Kim, 2009).

The mechanism involved in growth enhancement can be achieved via direct interactions of beneficial microbes and the host plant or inderectely via its antagonistic capability against plant pathogens. The mechanisms by which PGPR enhance plant growth include the ability to generate hormones like auxins, cytokinins, gibberellins as well as ethylene, that make the PGPR assist further propagation of root hairs thereby increasing the level nutrients (nitrogen, iron and phosphorus) absorption (Gamez et al., 2019).

4. Banana diseases

4.1. Moko and Bugtok diseases

Ralstonia solanacearum is currently found on all continents and act as the main factor of bacterial wilt. This bacterium is counted as one of the significant detrimental phytopathogenic bacteria because of its wide host range, widespread geographic distribution and lethality (Mansfield et al., 2012). *Pseudomonas solanacearums'* (syn. *R. solanacearum*) have grown in broadly different areas and have diverse abilities with both natural flora and introduced hosts and apparently with different soils and environmental conditions. This versatility results in various disease potentials and expression for each host/parasite genotype interaction (Buddenhagen, 2009; Blomme et al., 2017). Schomburgk is the first person who reported a reference to a bacterial wilt disease on bananas during his journeys in British Guyanab in 1844 (Sequeira, 1998).

4.2. Pseudostem and rhizome rot

Dickeya paradisiaca is identified as the main causes of Pseudostem and Rhizome Rot and was reported first in the Colombia. It caused a serious loss of over 2000 (Fernández and López, 1970). It is reported that this disease is extensively distributed in banana plantain in Venezuela, Colombia, Jamaica, Haiti, Peru, and Cuba. For instance, in the 1970s, this disease seriously affects plantations of over 75% of fields in Cuba, Panama, and Nicaragua, where losses reported up to 50% of banana yield. *Pectobacterium carotovorum* has been also another bacterium in humid tropic areas that affect rhizome rot or head rot. This is another disease commonly affecting plantain and banana; it leads to a soft rot of the rhizome of plantain and banana grown in cool damp humid soils or in suckers (Buddenhagen, 1994). Infected plants are usually detected in soils with poor drainage following heavy rainfall periods (Blomme et al., 2017).

4.3. Blood disease

Ralstonia syzygii (Subsp. *Celebesensis*) is identified as the main causes of banana blood disease. This disease was first reported in 1900s, and it is believed to have initiated on Salayar Island (Thwaites R.). Because of the strict regulatory quarantine measures applied by the Dutch this disease was bounded to Salayar. However, it had become widespread throughout the island and then found in Java in the late 1980s (Thwaites et al., 2000). Currently, in peninsular Malaysia the banana blood disease is spreading (noticed in the province of Selangor and Perak) coexists with the Fusarium wilt diseases and Moko (Kogeethavani et al., 2013). In Malaysia, blood disease has been detected first in the province of Perak and more recently in Selangor province (Kogeethavani et al., 2013). It has been reported that banana worth a value of US$1 million (more than 20,000 tons) was lost as a result of banana blood disease in Lampung Province (Nurhadi and Harlion, 1994). About 70–80% of the plantations were lost in South Sulawesi due to banana blood disease (Roesmiyanto and Hutagalung, 1989), also in West Java 36% plantation were lost due blood disease (Subijanto, 1991). In fact, the rate of losses would likely increase with disease spread.

4.4. Fungal diseases

Fungus Fusarium oxysporum f. sp. cubense race 4 is a pathogenic organism that causes Fusarium wilt disease, which is currently threatens global banana production (Shen et al., 2019). Banana production is extremely threatened by the soil-borne fungus Fusarium wilt disease (Shen et al., 2013). This disease is regarded as one of the most damaging diseases affecting banana in history (Dita et al., 2018). In a block of Grand Naine in the Faizabad district in Uttar Pradesh India, the banana plants affected with Fusarium wilt exhibited distinct yellowing signs of mature leaves persisting toward the younger leaves. The laminae of the emerging leaves were noticeably decreased and wrinkled. The gradual collapsed of leaves was observed (Damodaran et al., 2019). Fusarium wilt disease was first informed in Australia, which later has been spreading worldwide through movement of spore-bearing soil as well as informal exchange of planting matter (Dita et al., 2018). The mechanisms through which microorganisms exhibit antifungal effects include blockage, interference and holes formation in the cell wall and cell membranes of the fungi. Similarly, some peptides are taking part in the breakdown of fungal intracellular nucleic acid and mitochondria (Zhao et al., 2013), Fig. 2 shows various types of banana diseases.

5. Disease management: chemical and biological control

In recent years, the biological control of plant diseases becomes an admired environmental friendly disease management approach as other conventional approaches are not effective and the use of chemical fungicides pose environmental worries (Raza et al., 2017). Due to the negative impacts of some chemicals on environment, human health and other living organisms, investigators are concentrating on potential biocontrol microbes as workable substitutes toward management of plant pathogens (Syed et al., 2018). Fungicides have importantly contributed towards protecting a variety of crops from fungal infections. Nevertheless, such crops produced are often threatened by the manifestation of pathogenic fungicide-resistant strains (Ishii, 2006) Therefore, use of biological agents is advantageous in that it has the low risk of adverse effects on both human health and environment with low cost technology (Cavero et al., 2015). Bacillus species are used as biological control agents with several advantages as they can produce endospores, which are forbearing to heat and dehydration. In addition, some Bacillus-derived secondary metabolites exhibit broad-spectrum actions against pathogens (Sun et al., 2011).

6. Microbial biocontrol: biocontrol attributes of various Bacillus species

Advantageous bacteria belonging mainly to Bacillus and Paenibacillus (the closely associated genus), which are closely associated with plant roots are of particular attention due their plant protecting and antifungal futures (Khan et al., 2007)). *Bacillus amyloliquefaciens* strain NJN-6 can produce antagonistic secondary metabolites to numerous soil-borne pathogens. In an attempt to study the effect of *B. amyloliquefaciens* strain NJN-6 containing biofertilizer to encourage the growth and defeat Fusarium wilt of

Fig. 2. Banana diseases, A) moko, B) blood disease, C) Pseudostem and rhizome rot, D) Fusarium Wilt, E) fungal diseases, F) black Sigatoka.

banana plants, result from this study revealed that application results showed biofertilizer meaningfully reduced the incidence the disease and encouraged the growth of the plants (Yuan et al., 2013). Another attribute which enhances plant growth is achieved via production Siderophore by bacteria, this is achieved either by providing iron to the plants and by depriving essential nutrient to the fungal pathogens (Heidarzadeh and Sareh, 2015).

Siderophores are lower molecular compounds capable of chelating iron that whose most famous role is to sequester iron from the host, thereby providing this essential metallic nutrient to microbes (Behnsen and Manuela, 2016). A wide range of antifungal agents (which can destroy fungal cell wall) such as bacilysin, mycobacillin, subtilin, subtilosin, TasA and some enzymes are produced by Bacillus subtilis which qualified it as a known potential biological control agent (Thangavelu and Mustaffa, 2012). Bacillus subtilis is widely distributed in nature with non-pathogenic effects; it can produce quite a few types of small antibiotic peptides like fengymycin, iturin, acillomycin none ribosomally (with molecular weight of <2000 Da) that exhibits antifungal properties. In addition, it also releases plenty of protein (Tan et al., 2013). Antibiotic production was suggested to play a key function in suppressing plant disease (Thangavelu and Mustaffa, 2012).

In a study involving 57 strains of microbial (antagonistic in nature) obtained from the rhizospheres of fit banana grown in a severely wilt-diseased area, six bacterial strains were selected for further study due to best survival capabilities. *Bacillus amyloliquefaciens* W19 strain noticeably reduce the incidence of *Fusarium* wilt and enhanced the banana plant growth in combination with the organic fertilizer when compared with the control. Based on 16S rRNA molecule and other analysis the strain was recognized as *B. amyloliquefaciens*. Further analysis revealed that W19 strain produced lipopeptides iturin, bacillomycin D, and surfactin that are antifungal in nature. In addition, 18 antifungal (volatile compounds) with significant antagonistic consequence against *F. oxysporum* were noticed and identified (Wang et al., 2013). Table 1 illustrated a list name of some commercial biocontrol products of Bacillus spices used for control of banana diseases.

Xu et al. (2017) selected one isolate from Bacillus spp. as a potential biocontrol agent which plays an important role in the management of banana disease. They reported that *Bacillus amyloliquefaciens* strain NJN-6 is an important PGPR which can produce secondary metabolites antagonistic to several soil-borne pathogens. Thus, application of PGPR strain NJN-6 significantly suppressed the incidence of Fusarium wilt disease and promoted the growth of banana plants. Some active compounds produced by NJN-6 also showed the initial protection of the plants against soil-borne pathogens (Yuan et al., 2013; Fu et al., 2017). Fu et al. proposed a novel idea for solving this problem is the continuous application of bioorganic fertilizer, which should be practiced from the beginning of banana planting. The results showed that BIO application significantly reduced disease incidences and increased crop yields, respectively after four years. And the stabilized general bacterial metabolic potential, especially for the utilization of carbohydrates, carboxylic acids and phenolic compounds, was induced by BIO application. This study revealed a new method to control Fusarium wilt of banana for long term banana cultivation (Fu et al., 2016).

Cao et al also reported that the application of B. *subtilis* SQR 9 as bio-organic fertilizer (BIO), on the control of Fusairium wilt could significantly reduce the disease (49–61% reduction) in comparison with the control. The rhizosphere population of F. *oxysporum* f. sp. *cucumerinum*, as detected both by selective plating and real-time PCR, was significantly lower in BIO-treated plants than the control (Cao et al., 2011). Similarly, (Zhang et al., 2014; Zhang et al., 2011) reported that the suppression ability of bioorganic fertilizers containing B. *subtilis* N11 against banana Fusarium wilt was associated with soil microbial community regulation, with increased densities of bacteria and actinomycetes but decreased numbers of fungi in the rhizosphere soil. Generally, susceptibility of the rhizosphere to invasion by soil pathogens is inversely related to the diversity

Table 1
Commercial biocontrol products of Bacillus spp. used for control of banana diseases.

Agents	Application	Control obtained result (%)	Remarks	Reference
B. *subtilis N11*	Colonized bioorgains fertilizer	82	Enhanced root elongation	(Zhang et al., 2011)
B. *amyloliquefaciens W19*	Colonized bioorgains fertilizer	77	Antifungal lipopeptides	(Wang et al., 2013)
B. *amyloliquefaciens WJ22*	Colonized bioorgains fertilizer	75	Antifungal lipopeptides	(Wang et al., 2015)
B. amyloliquefaciens NJN-6	Colonized bioorgains fertilizer	85	Isolated from suppressive soil	(Xue et al., 2015)
Bacillus spp. (PHC Biopak)	Soil inoculation in the nursery	50	reduced Fusarium colony forming: 6% in Rhodic Ferralsol and 50% in Vertisol	(Mukhongo et al., 2015)
B. *subtilis TRC 54*	Combined with *pseudomonas fluorescens Pf1*	75	64% and 75% Fusarium dieses reduction under greenhouse and field conditions, respectively	(Akila et al., 2011)
B. *amyloliquefaciens W19*	Colonized bioorgains fertilizer	44	Enhanced root elongation	(Wang et al., 2016)

Bacillus products/ Commercial products	Mode of action	Carrier formulation	Percentage effectiveness	References
Bacillus subtilis EA-CB0015	The effectiveness against black Sigatoka disease depends mainly on the metabolites (Fengycin C, surfactin, iturin A) and in reduced extent to B. subtilis EA-CB0015 cells	Aqueous solution	In the field, when applied in solution with water at 0.15 L/ha and 1.5 L/ha every 11 days during 10 weeks black Sigatoka disease severity reduced in 20.2% and 28.1% respectively;	(Gutierrez-Monsalve et al., 2015)
Bacillus subtilis N11	Biofilm formed around the zones of elongation and differentiation of banana root will be pursued as a possible mechanism underlying the biocontrol of Fusarium wilt disease	Integrated with novel bio-organic fertilizer (BIO2) and mature composts	Incidence of wilt disease, decreased by 64–82%	(Zhang et al., 2011)
B. *amyloliquefaciens W19*	Fermentation of broth and precipitated lipopeptides significantly inhibited the growth of FOC	Biofertilizer	The antifungal activity of the VOCs produced by W19 strain was 21% compared to the control	(Wang et al., 2013)
Bacillus spp. (PHC Biopak)	Suppression of FOC	PHC Biopak in combination with vertisol	PHC Biopak reduced Fusarium colony forming units per gram of soil by 50% in clay-rich soil	(Mukhongo et al., 2015)
The *Bacillus amyloliquefaciens* strain W19	Production of metabolites iturin and bacillomycin D that effectively act against *Fusarium oxysporum* f. sp. *cubense* (*FOC*)	The *Bacillus amyloliquefaciens* strain W19 with bio-organic fertilizer (BIO)	The utilization of BIO decreased the incidence of banana *Fusarium* wilt by 42.86% in a field experiment	(Beibei et al.,2016)

of the rhizosphere microbiome (Matos et al., 2005; Wang et al., 2018), whereby increased diversity can result in decreased pathogen virulence.

7. Genetic engineering and conventional breeding

Transfer of beneficial agronomic characters across species is facilitated through genetic engineering tool. This can complement conventional breeding approach of banana by permitting the bottlenecks associated with breeding be overcome (Tripathi et al., 2017). Since the greatest important damage to banana production is triggered by fungal pathogens, the incorporation of desirable genes conferring resistance to fungal pathogens is a main research goal. Transformation genetically make available the prospect for a single gene or combined genes that are linked with disease resistance to be isolated from the genome of the causative organism and moved directly into the chosen variety. This permits addition of the desired trait into the variety in question and all its original characteristics retained (Sági et al., 1997). Chitinases are enzymes that break down chitin (a polysaccharide found in fungi). Chitinases are gaining great value considering their biotechnological applications, particularly the chitinases utilised in agricultural grounds for pathogens control (Hamid et al., 2013). In an attempt to study the effect of chitinase on the antifungal capability of *B. subtilis* F29-3, a DNA fragment (2.4-kb) comprising the chiA gene of *B. circulans* WL-12 was introduced into a carrier vector (pHY300PLK) which was later transformed into *B. subtilis F29-3*. An assay carried out on the supernatant obtained from stain culture indicated that, the strain expressing the chiA gene showed a superior inhibition of spore germination of *Botrytis elliptica*, when compared to the control strain (*B. subtilis*) signifying that chitinase could serve as a booster of antifungal conferred by *B. subtilis* F29-3 (Chen et al., 2004). Another study revealed that transgenic bananas expressed the plant ferredoxin-like protein (*Pflp*) gene which bring about improved resistance to Banana Xanthomonas wilt. This transgenic approach can offer a sensible solution to the Banana Xanthomonas wilt disease (Namukwaya et al., 2012). Tripathi et al. reported that indicate constitutive expression of the rice *Xa21* gene in banana resulted in heightened resistance against *Xanthomonas campestris* pv. *Musacearum* (Tripathi et al., 2014). Since the 1920s, the conventional breeding approach of banana for enhanced resistance to pathogens has been tried (Jones, 2007). Disease-resistant banana cultivars can be established via conventional and non-conventional breeding approach, depending upon available sources of resistance in banana (Viljoen, 2008). Improvement of banana genetically is difficult, contrasting most other major food crops. The encounter is that almost all banana cultivars and landraces are triploids having high infertility levels of male and female (Dale et al., 2017).

8. Conclusions

Chemicals have been the key approach toward managements of banana pathogens with effectiveness. However, demand for the safe control measures that are environmental-friendly has promoted the attention in finding non-chemical substitutes like biological agents for the management of banana pathogens. Useful stains of Bacillus rank high for their potentiality due to their ability to synthesize variety of secondary metabolites which decrease pathogenic attack and enhance growth. Biocontrol should not be considered as an independent tool, but adequately implemented in an integrated management framework. Moreover, combined breeding and biocontrol strategies maintaining diversity and ecosystem health are required. These systemic approaches are required in order to avoid further losses of our biodiversity and to ensure sustainable agricultural practices. Targeted microbiome engineering for crops is a future trend. Biodiversity should be a biomarker for these microbiome modulations. Higher plant-associated diversity can be achieved not only through the implementation of biological control agents which shifts the microbiome, but also by the application of microbial consortia. In this context, crop-specific biological consortia can be taken together from a pool of selected biocontrol agents. Unfortunately, the application of several microbial strains for biocontrol reasons is currently limited. Current and future progress in our understanding of Bacillus strains colonization ability, mechanisms of action, and application could facilitate its development as a reliable management component of sustainable agricultural systems. This literature study highlights the need for more economical and environmentally friendly Bacillus-based approached towards management of banana pathogenic epidemics.

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