Chapter

Fusarium Wilt: A Destructive Disease of Banana and Their Sustainable Management

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Abstract

Banana is one of the most important fruit crops. The major losses in banana mainly due to the fungal wilt disease which is caused by *Fusarium oxysporum* f. sp. *cubense.* The pathogen is mainly soil bone and saprotrophic in nature that's why its management is very difficult. The yearly losses of banana by this disease in the world is ranging from 60 to 90% and in India 30–40%. Sustainable management of panama wilt is must to overcome these losses occur in banana. The management strategies for longer duration through crop rotation, organic amendment, application of micronutrient like silicon (Si), borax, host-pathogen interaction, hormonal induction of defence response, biological control, transgenic approach, disease resistance developed by somaclonal variation. These approaches are mainly emphasized for long term management of the panama wilt disease.

Keywords: *Fusarium oxysporum* f. sp. *cubense*, Fusarium wilt, banana, sustainable management

1. Introduction

Banana crops is as old as Indian culture and known to be one of the earliest fruit crops produced by humankind from ancient times in India with extraordinary socio-economic significance, interlink in the social and cultural legacy of the country. It is likewise the fourth most significant food crop after paddy, wheat and maize and forms an important crop for survival of farmers. Considering the wholesome importance of banana, it is so noticeable and well known among the Indians so that it is loved by both poor and rich individuals. It is otherwise called 'poor man's apple' since it is that the most economical among fruit grown up within the country with healthy qualities and wholesome values. The yearly losses of banana in the world are 60–90% [1] and in India 30–40% [2]. The most economically significant pathogen of banana is *Fusarium oxysporum* species. Fusarium wilt disease was earlier reported from Panama canal of Australia. In India, this disease was first reported by Stover [3] from West Bengal. The Fusarium wilt pathogen survives in soil and penetrates into the roots with the assistance of nematodes, from where it gradually spreads until it achieves the centre of the corm that is the reason the plant showed quick wilting. Purplish darker shading shows up in the xylem vessels and are blocked, external leaves turn yellow and finally breakdown. Soon, only a few of the youngest leaves remain functional. Later the older leaves and pseudostem show yellow and longitudinal part with patches at the leaf edge. The symptoms become evident after 5–6 months of planting and are expressed both externally and internally.

2. Symptoms

The first internal symptoms develop in feeder roots at the primary sites of infection. They progress toward rhizome and are most noticeable where the stele joins the cortex. As the infection in pseudostem is colonized, blackout dark coloured streaks or flecks become apparent on and inside more seasoned leaf sheaths. Eventually, enormous segments of the xylem turn a black red to darker shading. The first external symptoms of Panama disease are a yellowing of the most seasoned leaves or a longitudinal splitting of the lower part of the external leaf sheaths on the pseudostem (**Figure 1**). This is further trailed by wilting and collapsing of leaves from the petiole base. At initial phases of infection, these leaves stay green. As the disease advances, more tender and young leaves breakdown until the whole plant covering comprises with dead leaves.

At the point when external symptoms are obvious on banana plants, however internal symptoms are missing from the pseudostem, it winds up for critically examine the rhizome. The plant sliced open at soil level to uncover the pseudostem base, and after that pushed over. Diseased plants have a trademark yellow to dim dark discolouration of the internal rhizome, which for the most part begins at the edges and advances inwards. Regularly some parts of the inward rhizome is influenced, yet with movement of the disease the whole internal rhizome winds up influenced. The external rhizome is rarely influenced. The piece of the rhizome that had been pushed over will show yellow strands of the rhizome which are appended

Figure 1.
External and internal symptoms of Panama wilt of banana.

to both the top and base portions of the rhizome. At the point when no discolouration is seen inside the rhizome, the outside symptoms are brought about by an option that is other than Foc. In such cases, the internal rhizome may show dark spots rather than the consistent yellow to reddish darker discolouration related with panama wilt.

3. Causal organism

Panama disease is brought about by the soilborne hyphomycete, *Fusarium oxysporum* Schlect. f. sp. *cubense*. It is one of more than 100 special forms of *F. oxysporum* that reason vascular wilt of flowering plants. It contains pathogenic and saprophytic strains that cannot be recognized morphologically. Fungus grow 4–7 mm/day on Potato Dextrose Agar medium at 24°C, with slight to significant fluffy mycelium, and have white to pink pigmentation. Sporodochia are tan to orange, and sclerotia are blue and submerged. Conidia and macroconidia are delivered on extended and unbranched monophialides. Microconidia are 5–16 × 2.4–3.5 μm, one or twocelled, oval to kidney shaped, and are borne in false heads. Macroconidia are 27–55 × 3.3–5.5 μm, four to eight sickle celled formed with foot shaped basal cells. Terminal and intercalary chlamydospores are 7–11 μm size, normally globose and formed independently or two by two in hyphae or conidia (**Figure 2**). Atypically for the species, chlamydospores are not distributed by isolates of *F. oxysporum* f. sp. *cubense* in vegetative compatibility group (VCG) 01214.

Four races of *F. oxysporum* f. sp. *cubense* have been revealed, just three of which affect banana (race 3 is a pathogen of Banana). Race 1 caused the pandemics on Gros Michel and furthermore affects the cultivars Maqueño, Silk, Pome, Pisang Awak. Race 2 affects cooking bananas *viz.*, Bluggoe, and some reared tetraploids. Race 4 is most dangerous since it affects race 1 and race 2 powerless clones just as the Cavendish cultivars. Up to this point, it had been accounted for just in subtropical regions where cold weather during winter are believed to be a predisposing factor. In any case, inside the most recent decade, remarkable harm was observed in Cavendish monocultures in tropical South-East Asia. A particular populace of the pathogen, VCG 01213-01216, is responsible for these flareups. Despite the fact that it is as of now limited to Asia and northern Australia, it caused critical disease in the western exchanges because of their dependence on the Cavendish clones. Vegetative or substantial similarity has been utilized widely to describe overall populaces of this pathogen. More than 20 VCGs have been accounted which is a pointer for the incredible genetic diversity that happens inside this taxon.

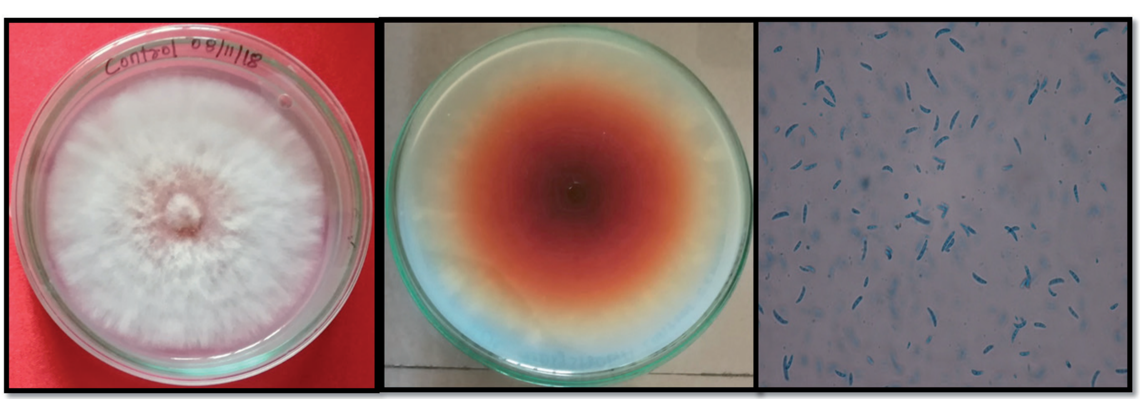

Figure 2.
Pure culture and spore of Fusarium oxysporium *f. sp.* cubense.

4. Disease cycle and epidemiology

Beckman and his colleagues considered the internal responses for susceptible banana cultivars to infection by *F. oxysporum* f. sp. *cubense*. They observed that race 1 strain of the pathogen produced rich microconidia in xylem vessels of cultivar Gros Michel. These propagules move acropetally in vessels by means of the plant transpirational change which caught at the scalariform parts of the bargains. As the fungus develops, it colonizes inside vessel end within 2–3 days, delivered microconidia on its adaxial side, along these lines empowering the pathogen to travel through another vessel (**Figure 3**). This procedure proceeded with unabated in Gros Michel, yet stopped in a race1 safe Cavendish cultivar not long after was it immunized. In the later case, gels formed in infected vessels in 24–48 h, followed by the development of vascular parenchyma into vessels after 48–96 h. These pathogen-incited exercises in the host caught spores of the pathogen and precluded it further colonization from claiming the host. At last, the host discharged phenolic aggravates that infused and lignified the blocking structures. Consequently, in a safe cultivar, there is a reasonable and quick coordination of host defences to ensure the systemic colonization of the xylem does not happen.

Rhizomes (suckers) are utilized generally as vegetative seed pieces for banana cultivation. Since they are generally free of symptoms when they are early infected by *F. oxysporum* f. sp. *cubense*, are a typical methods by which this pathogen is spread. The pathogen spreads in soil, running water, farm executes and apparatus. Work in the early trade estates showed that susceptible clones could not be successfully replanted in an infested site for as long as 30 years due to the long term survival of *F. oxysporum* f. sp. *cubense* in soil and as a parasite of nonhost weed species. Root tips are the characteristic, starting locales of infection; injured rhizome surfaces are evidently minor infection courts. Much of the time, root-tip infections are halted soon after the pathogen arrives at the xylem, and responsible for the formation of gels, tyloses and vascular breakdown. Macroconidia and chlamydospores

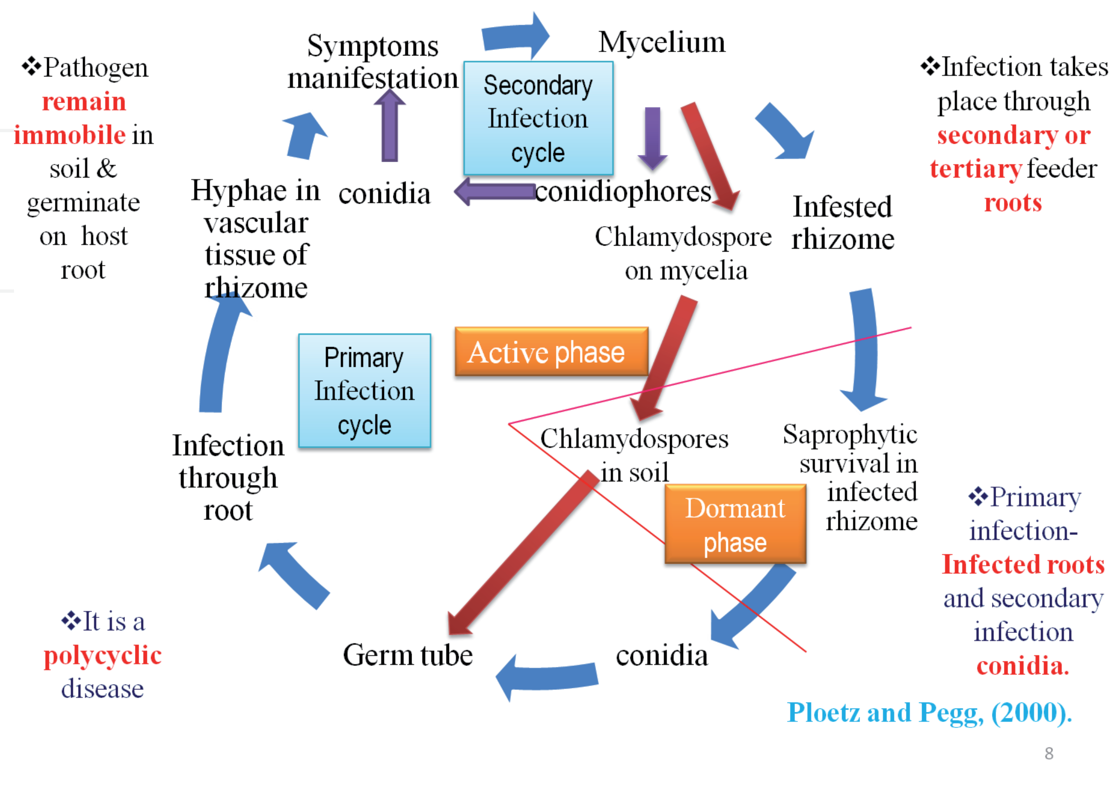

Figure 3.
Disease cycle of Fusarium oxysporum *f. sp.* cubense.

are formed on dead or passing on plants. The last propagules are the most significant survival structures of pathogen.

Weather factors like prolonged wet or dry conditions, extremes in temperatures, storm damage and soil conditions like poor soil drainage, aeration, unfavourable chemical or physical conditions also play a major role in influence on the wilt disease [4]. An internal water deficit due to dry conditions or waterlogging promotes expression of symptoms [5]. Temperature is a critical factor in panama wilt development [6]. Peng et al. [7] reported that the growth of Fusarium wilt pathogen is usually maximum at 28°C, and reduced above 33°C and below 17°C.

5. Management strategies for the Panama wilt disease of banana

5.1 Crop rotation

Continuous cultivation of bananas in the field compounds Foc event in the dirt. The spread and survival of this pathogen is mainly depend in the soil and also it can persist in the soil for long term, at the time of conducive environment causes of Fusarium wilt in bananas in severe form [5]. Yield turn as an administration practice, as a rule, is a profoundly effective and naturally friendly methods for control soil-borne diseases. In China, particularly in Panyu, Guangzhou, a region intensely infested by Foc, banana is turned with 2–3 years of economically developed Chinese leek (*Allium tuberosum*) to control Fusarium wilt [8]. Therefore, Chinese leek becomes a possible way for an ecologically friendly treatment to control Fusarium wilt of banana. Crop rotation is one of the most important cultural practices for reducing the plant pathogens in the soil. Crop rotation like pineapple-banana revolution was found more effective than maize-banana by reducing the Foc incidence in the banana fields.

5.2 Organic amendments

Organic matter management is basic for soil wellbeing and suppressiveness of the pathogens [9]. Albeit natural issues are included through yield buildups and spread harvests, offfield sources eq natural alterations (OAs) are especially significant as they are advanced with specific microorganisms. Yogev et al. [10] demonstrated that fertilizers dependent on plant squander buildups stifled diseases brought about by four different formae speciales of *F. oxysporum melonis*, *basilici*, *radicis lycopersici*, and *radicis cucumerinum*. Nonetheless, there are significant differences among banana and these yearly crops, regarding trimming cycle, yet in addition in the measure of auxiliary inoculum created per territory. An infected banana plant may created significantly more auxiliary inoculum than these yearly crops. Therefore, the degree of intercession to smother Foc inoculum with use of OAs may be more noteworthy and incorporated with other administration practices like utilization of beneficial and opponent microorganisms. In this sense, the helplessness of *F. oxysporum* to rivalry for supplements in the dirt may facilitate its concealment if great contenders are set up. For example, Fu et al. [11] revealed the concealment of FW in banana by the nonstop utilization of natural fertilizer. In any case, the effect of OAs on disease concealment may likewise be connected to natural control.

5.3 Application of silicon (Si) and borax (H_3BO_3): reduce the severity of Panama wilt of banana

Silicon (Si) helps in reducing the severity of a range of infections in specific crops [12]. In addition to the other strategies mentioned for managing banana panama wilt, silicon (Si) application shows potential as part of a novel disease management strategy to avoid Foc infection and assist maintain enough banana output in the future [13]. It has been also reported that Si application suppressed disease in cucurbits caused by foliar and soil-borne pathogens. The obtained resistance of Si amended plants against the fungal pathogen might be due to accumulation of Si in the leaves, thereby, interfering with the pathogen's penetration as a result of a mechanical barrier. Niwas et al. [14] tested seven micronutrients *viz*., Calcium nitrate, Ammonium sulphate, Copper sulphate, Potassium chloride, Borax, Ferrous sulphate and Zinc sulphate. Borax @ 500 ppm completely inhibited the growth of *F. oxysporum* f. sp. *cubense* followed by zinc sulphate. Johnson et al. [15] also reported similar results on stem rot of groundnut. The micronutrients were used to manage the disease as well as it provided the healthiness of plant and increase the fertility of the soil that's why the plant was free from the disease or less infected. The mycelial growth of *F. oxysporum* f. sp. *cubense* was found low against different micronutrients and finally, it is concluded the borax completely inhibited the growth of *F. oxysporum* f. sp. *cubense in vitro* and used for the management of the Fusarium wilt disease of Banana under field conditions.

5.4 Application of phyto-hormones for the induction of resistance against Panama wilt

Plant hormones act as an important regulators in plant-microbe interactions. The impact of key plant hormones on the interaction between Fusarium wilt and host plants was also examined for suppressing the pathogens. Methyl jasmonate (MeJA) activates host defence against a wide range of infections as well as control host defence responses to biotic and abiotic challenges. Reglinski et al. [16] reported that application of MeJA to *Pinus radiata* seedlings resulted in induced resistance to subsequent wound inoculation with *Diplodia pinea*. Sun et al. [17] reported that the application of MeJA activated enzymes and reduced the level of H_2O_2 and malondialdehyde (MDA) in banana plantlets following inoculation with Foc TR4.

5.5 Application of bio-control agent for managing Fusarium wilt of banana

Considering the urgency of Panama disease, biological control offers a complementary disease management approach. However, there has been very little long-term biocontrol effectiveness studies for Fusarium wilt of banana in the field. In recent years, the usage of biocontrol agents (BCAs) has been shown to be an ecofriendly disease management technique. Xue et al. [18] identified one *Bacillus* spp. isolate as a possible biocontrol agent that plays a key role in the management of banana wilt disease. Despite the limitation of published scientific research on biocontrol, particularly with practical field findings, techniques that may be used to predict biocontrol failures in the field would necessitate a deeper knowledge of these interactions as well as pragmatic assessments of their usefulness. Biological control's success is determined not just by production techniques, but also by the expenses involved and the presence of effective antagonists. Furthermore, these antagonists must be dry preparations that may be stored for a long term. As field trials reports, soil application of *Trichoderma harzianum* effectively controlled Fusarium wilt with an efficacy comparable to that of the fungicide carbendazim. Previous reports have also demonstrated that siderophore producing endophytic *streptomycetes* from banana roots are effective against the Fusarium wilt pathogen and which developed as BCAs against the banana Fusarium disease. Successful inoculation of tissue cultured banana plants with fungal endophytes has been reported by Paparu et al. [19]. Addition of artificial inoculation to tissue cultured banana plantlets resulted in a substantial reduction in the infection and severity of Fusarium wilt disease, as well as increased the plant growth parameters [20]. Application of plant growth promoting rhizobacteria (PGPR) to induce resistance against Fusarium wilt of banana plants. PGPR are considered as the most promising agent for cash crop production and managing soil-borne disease. Several substances produced by PGPR such as antibiotics have been related to pathogen control and indirect promotion of growth in many ways. Considering the employment of elicitors in crop protection is still in the very early stages for the use as a new control method, further research in this area is needed to demonstrate elicitors' effectiveness in banana wilt disease control.

5.6 Transgenic approaches for developing Fusarium wilt resistant banana

There are Fusarium wilt-resistant banana cultivars, and some have been conventionally developed through various breeding programmes. Now using techniques like particle bombardment or sonication assisted vacuum infiltration of the apical meristem, or using multiple bud clumps followed by Agrobacterium mediated gene transformation, genetic transformation of elite banana cultivars for resistance to Fusarium appears to be a more promising approach to improve disease resistance or tolerance. Testing the efficacy of the altered proteins against the target pathogen, which includes exposing the plants to the pathogen in an appropriate infective unit such as spores, is one of the most important phases in banana genetic engineering for disease resistance. Based on the antifungal activities of thaumatin like proteins are reported as a good candidate for genetic engineering toward production of disease resistant banana plants [21].

5.7 Breeding programme for the development of Fusarium wilt resistant banana

The most common, economical, successful and long-term Foc management method is universally recognized breeding and selection programme for disease tolerance or resistance [22]. Currently, Foc-TR4 resistance screening is mostly done on farmed bananas, but there is not much information on wild banana species. Li et al. [23] used a two step process comprising a combination of greenhouse and field studies which provided a comprehensive and reliable information regarding disease reaction on the evaluated genotypes of banana. To develop a global screening and evaluation protocol is critical for the selection of reliable resistant materials against the Fusarium wilt.

5.8 Somaclonal variations for development of Fusarium wilt resistant banana

Promising Foc resistant or tolerant clones acquired through nonconventional breeding techniques have been proposed as an aid in banana breeding programmes. Shoot tip cultures from banana clones are sensitive and resistant to Foc races 1 and 4 cultivated *in vitro* in the presence of fusaric acid and fungal crude filtrates to examine under *in vivo* and *in vitro* condition. Peroxidase activity was employed as a measure to distinguish between susceptibility and tolerance which was shown to correspond well with the host plant's field response to infections. At present, attempts to develop new banana genotypes resistant to Fusarium wilt using conventional breeding techniques face significant obstacles mainly because most cultivars of Musa AAA Cavendish subgroup are totally sterile and seedless. Whilst, several resistant clones has been also acquired through somaclonal variation. Wu et al. [24] investigated the utility of *in vitro* inoculation of rooted banana plantlets grown on modified medium as a reliable and rapid bioassay for resistance to Foc.

6. Conclusions

Fusarium wilt is a destructive disease worldwide. It is a soil borne and saprophytic in nature. Once a banana growing area is infected by Foc, it is very difficult for banana cultivation. Sustainable management requires proper know how of disease cycle and impact of weather factors for reducing the impact of Fusarium wilt. Combating the spread of Fusarium wilt is a race against time. To prevent and contain Fusarium wilt, a complementary approach such as exclusion and surveillance must be considered as significant components of integrated disease management strategies [25]. Thus, preventing the spread of Fusarium infection is very decisive for ensuring the continuity of banana production as well as securing the nutritional supply. Management strategies include crop rotation, organic amendments of soil, application of micronutrients like Si and Borax, plant-microbe interaction, induction of systemic resistance MeJA, treatment with bio-control agents like *Trichoderma harzianum* and PGPR to overcome the threat. Screening of banana genotypes for resistance to Fusarium wilt using in vitro evaluation, mutation and selection along with somaclonal variation which improve breeding efficiency for resistance against Foc. In addition to the these management strategies, various recent technologies introduced may shed some light into the development of Fusarium-resistant banana varieties which finally manage this venerable menace.

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References

[1] Bhuvanendra HK, Udaya Shankar AC, Chandra NS, Ramachandra KK, Shetty HS, Prakash HS. Biochemical characterization of *Fusarium oxysporum* f. sp. *cubense* isolates from India. African Journal Biotechnology. 2010;**9**:523-530

[2] Thangavelu R, Sundararaju P, Sathiamoorthy S, Reghuchander T, Velazhahan R, Nakkeeran S, et al. Status of Fusarium wilt of banana in India. In: Proceedings of the International Workshop on Banana Fusarium Wilt Disease; 18-20 October; Malaysia. 1999. pp. 58-63

[3] Stover RH. Fusarial wilt (Panama Disease) of bananas and other Musa species. Fusarial wilt (Panama disease) of bananas and other Musa species. 1962

[4] Brake VM, Pegg KG, Irwin JAG, Chaseling J. The influence of temperature, inoculum level and race of *Fusarium oxysporum* f. sp. *cubense* on the disease reaction of the banana cv. 'Cavendish'. Australian Journal of Agricultural Research. 1995;**46**:673-685

[5] Pattison AB, Wright CL, Kukulies TL, Molina AB. Ground cover management alters development of Fusarium wilt symptoms in Ducasse bananas. Australasian Plant Pathology. 2014;**43**:465-476

[6] Rishbeth J. Fusarium wilt of bananas in Jamaica: I. Some observations on the epidemiology of the disease. Annals of Botany. 1955;**19**(3):293-328

[7] Peng HX, Sivasithamparam K, Turner DW. Chlamydospore germination and Fusarium wilt of banana plantlets in suppressive and conducive soils are affected by physical and chemical factors. Soil Biology and Biochemistry. 1999;**31**:1363-1374

[8] Zhang N, Wu K, He X, Li SQ, Zhang ZH, Shen B, et al. A new bioorganic fertilizer can effectively control banana wilt by strong colonization with *Bacillus subtilis* N11. Plant and Soil. 2011;**344**(1):87-97

[9] Noble R. Risks and benefits of soil amendment with composts in relation to plant pathogens. Australasian Plant Pathology. 2011;**40**:157-167

[10] Yogev A, Raviv M, Hadar Y, Cohen R, Katan J. Plant waste-based composts suppressive to diseases caused by pathogenic Fusarium oxysporum. European Journal of Plant Pathology. 2006;**116**(4):267-278

[11] Fu L, Penton CY, Ruan YZ, Shen ZZ, Shen QR. Inducing the rhizosphere microbiome by biofertilizer application to suppress banana Fusarium wilt disease. Soil Biology and Biochemistry. 2017;**104**:39-48

[12] Debona D, Rodrigues FA, Datnoff LE. Silicon's role in abiotic and biotic plant stresses. Annual Review of Phytopathology. 2017;**55**:85-107

[13] Fortunato AA, Rodrigues FA, Baroni JCP, Soares GCB, Rodriguez MAD, Pereira OL. Silicon suppresses Fusarium wilt development in banana plants. Journal of Phytopathology. 2012;**160**:674-679

[14] Niwas R, Chand G, Azad CS. Evaluation of micronutrients for inhibition of Panama wilt disease pathogen (*Fusarium oxysporum* f. sp. *cubense*) of Banana. Annals of Plant Protection Sciences. 2019;**27**(1):81-83

[15] Johnson M, Subramanyam K, Balaguravaiah D, Sudheer MJ. Management of stem rot in groundnut through soil amendments. Annals of Plant Protection Sciences. 2003;**11**(1): 83-85

[16] Reglinski T, Taylor JT, Chee AA, Northcott G, Spiers M. Biochemical

responses to ultraviolet-C radiation and methyl jas- monate in *Pinus radiate* seedlings that accompany induced resis- tance to *Diplodia pinea*. Plant Pathology. 2012;**62**:851-858

[17] Sun D, Lu X, Hu Y, Li W, Hong K, Mo Y, et al. Methyl jasmonate induced defense responses increase resistance to *Fusarium oxysporum* f. sp. *cubense* race 4 in banana. Scientia Horticulturae. 2013;**164**:484-491

[18] Xue C, Penton CR, Shen Z, Zhang R, Huang Q, Li R, et al. Manipulating the banana rhizosphere microbiome for biological control of Panama disease. Scientific Reports. 2015;**5**(1):1-11

[19] Paparu P, Dubois T, Gold CS, Adipala E, Niere B, Coyne D. Inoculation, colonization and distribution of fungal endophytes in Musa tissue culture plants. Uganda Journal of Agricultural Sciences. 2004;**9**(1):583-589

[20] Jie L, Zifeng W, Lixiang C, Hongming T, Patrik I, Zide J, et al. Artificial inoculation of banana tissue culture plantlets with indigenous endophytes originally derived from native banana plants. Biological Control. 2009;**51**:427-434

[21] Mahdavi F, Sariah M, Maziah M. Expression of rice thaumatin-like protein gene in transgenic banana plants enhances resistance to Fusarium wilt. Applied Biochemistry and Biotechnology. 2012;**166**(4):1008-1019

[22] Buddenhagen I. Understanding strain diversity in *Fusarium oxysporum* f. sp. *cubense* and history of introduction of “Tropical Race 4” to better manage banana production. Acta Horticulture. 2009;**828**:193-204

[23] Li C, Shao J, Wang Y, Li W, Guo D, Yan B. Analysis of banana transcriptome and global gene expression profiles in banana roots in response to infection by race 1 and tropical race 4 of *Fusarium oxysporum* f. sp. *cubense*. BMC Genomics. 2013;**14**(1):1-16

[24] Wu Y, Yi G, Peng X, Huang B, Liu E, Zhang J. Systemic acquired resistance in Cavendish banana induced by infection with an incompatible strain of *Fusarium oxysporum* f. sp. *cubense*. Journal of Plant Physiology. 2013;**170**(11):1039-1046

[25] Ploetz RC. Panama disease: A classic and destructive disease of banana. Plant Health Progress. 2000;**1**(1):10