Chapter

Fusarium Disease of Maize and Its Management through Sustainable Approach

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Abstract

Fusarium causing disease in maize is probably the one of the most serious diseases among the crop plants all over the world. It not only damages the maize plant, reduces its potential yield and its nutritional values but imposes threatening to the human life through the induction of mycotoxin development. *F. graminearum* and *F. moniliforme* syn. *Fusarium verticillioides* are two important maize pathogens that cause substantial damage to its ear, stalk and foliage, causing contamination of grains with mycotoxins. Since conventional methods of controlling the diseases including the chemical methods proved not enough for total control of the disease with creating situation even worse for our surroundings, the application of PGPR and PGPF can play significant role to control the damage caused by *Fusarium*.

Keywords: mycotoxin, PGPR, PGPF, *Fusarium verticillioides*, *F. graminearum*, pathogens

1. Introduction

Maize is one of the most important cereal crop cultivated worldwide. It is popularly known as queen of cereals because it has highest population yield among the cereals [1]. Maize is the crop of diverse environmental conditions and now considered as one of the fastest growing cash crops in the world [2] and may play significant role to satisfy the ever increasing demand of world population. It is a multi-utility crop with major source of food, feed, fodder and industrial raw material which also provides huge opportunity to various stakeholders for crop diversification, value addition and employment generation [3, 4]. Maize plant is often induced by various types of naturally occurring pathogens like bacteria, virus, fungi and nematodes etc. and are detrimental to the yield and quality of grains and thereby subsequently affect the economy and threaten the food security around the globe [5]. Diseases are one of major obstacle in understanding the yield potential of maize. Among the disease causing pathogen in maize, fungal diseases caused by *Fusarium* spp. are most threatening not only to the plant but both animal and human's life are also equally intimidating. The contamination of human food and animal feed with mycotoxins produced by the *Fusarium* spp. incur various health issues in human and various livestock, such as equine leukoencephalomalacia, human esophageal and liver cancer etc. [6]. Despite of all these issues, the maize productivity over the years has been increased due to green revolutionized availability of resistant variety and various synthetic fertilizers [7]. However, extensive and indiscriminate use of synthetic chemicals such as fertilizers and fungicides in order to improve the crop productivity has been very damaging not only to plant, man and animal but resulted adversely to many beneficial organism which includes rhizospheric microbial communities, pollinators, and competitors etc. [7, 8]. Therefore, application of microbes both PGPF and PGPR as biofertilizers is the only way out solve the problems which can play significant role in sustainable agriculture of maize plant without disturbing the surrounding environment. Along with application of biocontrol agent, diagnosis of the disease for proper identification is also very important part of eradication of pathogen. The proper identification of pathogen ensures the proper application of biocontrol agents. These microbes introduced to the soil in various form and by different techniques, interact with host plant and initiate cascade of reactions promoting the plant growth and impart defense responses [9]. Recently both PGPF and PGPR have attracted worldwide attention because of its eco-friendly nature, low cost and easy application. It is reported that many species of *Trichoderma*, *Penicillium*, *Phoma*, *Burkholderi*a, *Bacillus*, *Pseudomonas cepacia* are effective against *Fusarium* spp. through the production of various defense enzyme such as chitinase, peroxidase, phenylalanine ammonia lyase and β-1,3-glucanase etc. [9–12]. In addition, the plant growth promoting fungi and plant promoting bacteria are well known for plant growth promoting activity through the production of plant growth hormone like IAA, cytokinins, gibberelins; siderophore secretion, hydrocyanic acid (HCN) production, phosphate solubilization and nutrient uptake which indirectly boost the host plant for the defense against pathogen [13].

2. Fusarium disease of maize

Fusarium is considered as a most devastating agent among prevalent fungus on maize, particularly in USA, Europe, Africa, Asia and Australia [14]. It damages the host plant severely causing decrease in quality and productivity. *Fusarium* spp. are ubiquitous mostly soil borne pathogen which affect the plant development throughout the cultivation period. Infection of maize plant with *Fusarium* spp. such as *F. monilifrme* J. Sheld. (=*Fusarium verticillioides* (Sacc.) Nirenberg), and *F. roseum* f. sp. *Cerealis* "Graminearum" (Syn. *F. graminearum* Schwabe, group II), are believed to be responsible for the diseases like stalk rot, ear rot, seed rot, root rot and seedling blight of maize [15–17]. The different strain of *Fusarium* such as *F. verticillioides*, *F. proliferatum*, *F. subglutinans*, *F. graminearum*, *F. oxysporum* and *F. temperatum* are important pathogens involved in seedling diseases which interfere the seed germination and emergence and hence affect the seedling development [18, 19]. Brown discolouration of the seedlings, light yellowish discolored and stunted seedlings are major symptoms of seedlings [20]. Seed rot is another important disease occurs in weak and damaged seed which become easily susceptible to the attack of soil and seed borne *Fusarium* spp. Stalk rot is one of the most common and dominated diseases in maize characterized by tan to pink or salmon discoloration and disintegration of the pith caused by many species of *Fusarium* such as *F. graminearum*, *F. culmorum*, *F. verticillioides*, *F. proliferatum*, *F. equiseti*, *F. avenaceum*, *F. cerealis*, *F. poae*, *F. subglutinans* and *F. temperatum* [18, 21]. *The Fusarium spp.* belonging to the *Gibberella fujikuroi* species complex (GFSC) and *F. graminearum* (*Gibberella zeae*) like *F. moniliforme*, *F. temperatum* and *F. subglutinans* are very much associated with stalk rot disease in maize [22]. The common symptoms of stalk rot disease of maize include reduced growth, rotted leaf sheaths and internal stalk tissue and brown streaks in the lower internodes whereas at its maturity, it develops pink to salmon discoloration of the internal stalk pith tissues [23]. The *Fusarium* stalk rot disease may cause premature death of host plant hampering the nutrients and water translocation to leaves and ears. The infected maize plant often wilt and appear from a light to a dull color and lower stalk dries (**Figure 1A**) with pith tissues disintegrating to a shredded appearance [24]. Tan to dark brown discolouration of the lower internodes and pink to reddish discolouration of the pith tissue are the distinct symptoms of stalk rot caused by *F. graminearum* whereas for *F. verticillioides*, brown streaks appear on the lower internodes and the rotted pith tissue may be whitish-pink to salmon in color [24]. The systematic and successful infection of seed and root gradually extends towards the internodes, stalk and ear contributing more and more diseases in plant [15]. Among *Fusarium* maize diseases, ear rots significantly contribute in loss of both quality and quality of the yield. Ear rot disease is basically concerned with corn ears and *F. moniliforme* which predominantly now known as *F. verticillioides*, has been reported as causal organism of the disease [25]. *Fusarium* ear rot has been reported as most common disease of maize in United States [25]. *F. temperatum*, a closely related species to *F. subglutinans* and reported form maize in different countries, was recently identified and described as a new pathogen causing ear rot in European maize [26, 27]. *F. graminearum* causing ear rot disease is characterized by a pinkish colored mold [24]. Typical symptoms of *Fusarium* ear rot caused by *F. verticillioides* include [28, 29]: (1) tan to brown discolouration or white or light pink mold on random kernels; (2) limited ear areas or groups of kernels scattered over the ear (**Figure 1B**). Symptomless kernel infection was also observed through systemic growth of *Fusarium verticillioides* from infected seed, roots or stalks through ear with peduncles maize [20]. Kernel and stalk are not only the susceptible parts of the maize plant to the *Fusarium* spp. but infections may also occur on foliar parts like leaf sheaths and around the blade-sheath boundary and husks, whereas the leaf blades appear visually unaffected throughout the vegetation period [20]. Comparative analysis of leaf sheath and leaf blade contamination with DON (mycotoxin) showed that higher concentrations of DON was in leaf sheath indicating that leaf infection by *Fusarium* spp. may move from primarily infected leaf sheath into the leaf blades [30]. The airborne spores of the fungus during its reproductive stage contributes its richness to maize field [31]. Further, *Fusarium* spp. also infect the husks, leaf sheaths and around the blade-sheath boundary with appearance of whitish mycelium and/or pink spore layers, reddish discoloration zones and necrotic lesions on husk, Leaf sheath and blade/sheath boundary [20].

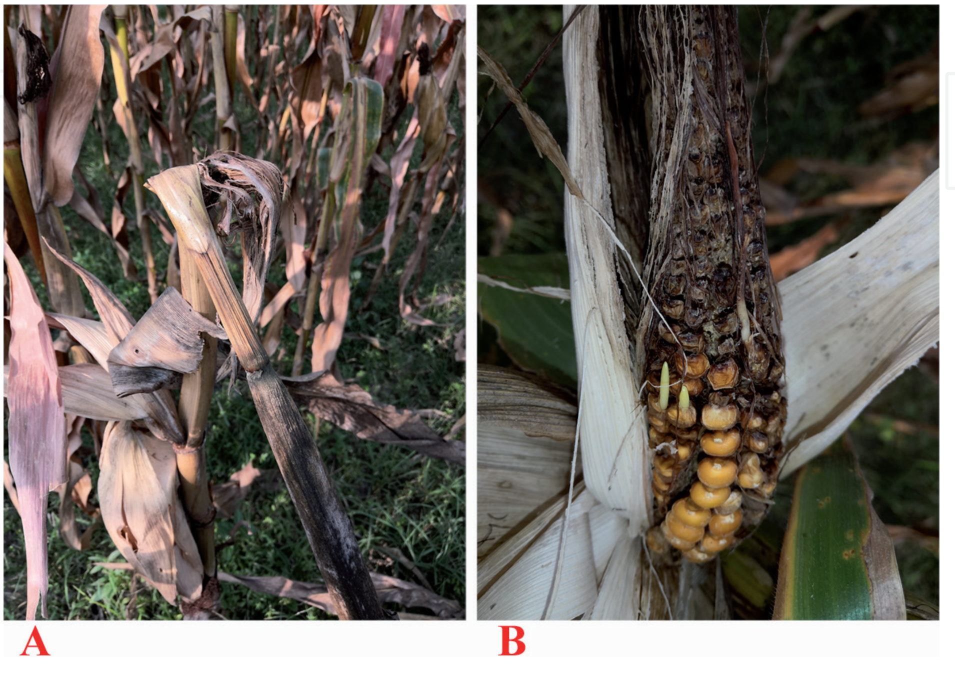

Figure 1.
Major diseases of maize caused by Fusarium *spp.; (A) stalk rot disease and (B) ear rot disease.*

3. Source of inoculum and infection pathway

Many *Fusarium* spp. have been reported to cause the various diseases in maize but the most devastating fungal agent for ear rot and stalk rot diseases is *F. verticillioides* [32, 33]. Ear rot and stalk rot diseases are two most important *Fusarium* disease of maize occurs worldwide. The significance of these diseases has been witnessed by the world for many decades. Maize plant residues present in nearby fields is the primary and important source of inoculums for infections of maize plant [34]. Many *Fusarium* spp. successfully survive on maize crop residue or in the soil as mycelium or other structures like *F. graminearum* produces chlamydospores and *F. verticillioides* (reported as *F. moniliforme*) can produce thickened hyphae capable of colonizing senescent tissues of the host plant [24, 35]. *F. verticillioides*, *F. subglutinans* and *F. proliferatum* produce large numbers of microconidia and macroconidia on crop residues, and may act as the most important inoculum for *Fusarium* ear rot and symptomless kernel infection [25]. Though *Fusarium* spp. are commonly seed borne but the role of seed as an inoculum source for further infection has always been a matter of controversy [36]. According to Cotten and Munkvold, the surface residues may be the potential reservoir of recolonization and spore production for airborne inoculums contributing significantly in spreading of the disease into the next vegetation period [16]. *Fusarium* spp. can enter the host plant through different pathways and starts primarily from root infection, through stalk nodes or through injuries in the stalk made by various biotic agents, silk infection and systematic spread after root penetration [24, 37, 38]. In stalk rot disease, the *Fusarium* spp. enter the stalk systematically after the successful colonization of root through various ways such as seed transmission, young leaf sheath and via wounds created by hail or insects [33, 39]. At maturity, both root and lower stalk lose their metabolic activities weakening the plant defense system against infection [40]. The other factors such as drought, high plant density, leaf diseases, and corn borer attacks decreases photosynthesis rate in the host plant and may contribute in stalk rot disease development [40]. The major infection pathways taken up by most *Fusarium* spp. for maize ears infection is via silk which occurs severely at early stage of silk development [41]. There are three major entry points for ear infection: (1) landing and germination of fungal spores on the silk and moving down the silk to infect the kernels and rachis; (2) through injuries made by biotic agents and hail; (3) through systematic infection of *F. verticillioides* [24]. The important factors which appears to be affecting the range of different species of both ear and stalk rot infection are temperature and moisture [42]. However, the timing and significance of infection pathways may vary from one geographical region to another depending upon the weather conditions and occurrence of biotic agents. *F. graminearum* and *F. culmorum* are reported to cause the ear rot infection at low temperatures and high precipitation whereas *F. verticillioides*, *F. subglutinans* and *F. proliferatum* are responsible at high temperatures and dry conditions [25, 43].

4. Fusarium associated mycotoxin and its toxicity

Mycotoxins are low-molecular-weight secondary metabolites produced by various fungal group specially *Fusarium* spp. and are not only toxic to plant causing serious diseases in them but also significantly harmful to human and animals [44]. *Fusarium* is one of the most important plant-pathogenic fungi producing most important mycotoxin. Some of the emerging mycotoxin produced by the *Fusarium* includes: trichothecenes, zearalenones, fumonisins, and moniliformin. These mycotoxins are naturally found to occur in plants and its products all over the world. The mycotoxins namely: fumonisins, beauvericin, fusaproliferin, and moniliformin produced by the strains of *F. verticillioides*, *F. proliferatum*, and *F. subglutinans* are commonly associated with maize ear rot disease [45].

Fumonisins (FUMs), especially FUM B1 (FB1) produced by *F. fujikuroi* species complex in warm climate are extremely toxic and carcinogenic to human causing liver cancers and human esophageal [46–48]. FB1 is also reported to have toxic effects in animals and several organs like kidney, liver, lungs, and nervous and cardiovascular systems [44, 49]. FUMs also exert its toxicity by causing wilting, chlorosis, and necrosis in maize and also interfere with shoot and root growth of the plant [44, 50]. It is evident that FUM phytotoxicity induced some symptomatic diseases in maize seedlings when inoculated with *Fusarium verticillioides* [51]. Trichothecenes (TRIs) are sesquiterpenoids with a tetracyclic ring system, categorized into type A to type D inhibits protein synthesis in eukaryotes and suppress or stimulate immune system [49]. They also produce some common effects on livestock like changes in neuroendocrine, hepatological and gastrointestinal systems; gaining of weight and feeding reduction [52]. Most TRIs have also been reported to produce phytotoxic effects. Reduced seed germination; stunting of coleoptiles, roots, and shoots; chlorosis; wilting; and necrosis are the most common toxic effect of TRIs [52]. Zearalenone (ZEA) produced by the *F. graminearum* and the *F. incarnatum-equiseti* in maize is effectly contaminated to its product and produce severity in their various consumers [44, 53]. Various species of *Fusarium* infecting maize have been reported with some of the emerging mycotoxin (**Figure 2** and **Table 1**).

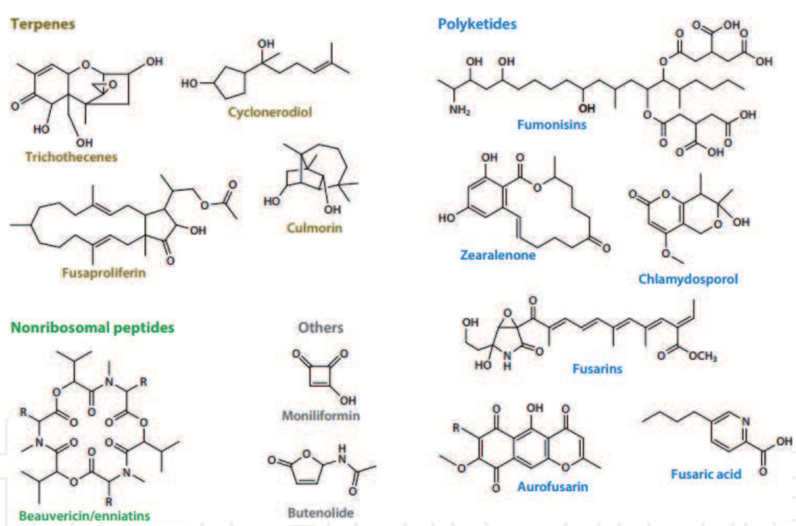

Figure 2.
Chemical structure of some important mycotoxin produced by Fusarium *spp. [44].*

Mycotoxin	Pathogen	Host	Reference
Beauvericin	*F. moniliforme*, *F. subglutinan* and *F. proliferatum*	Maize	[54, 55]
Moniliformin	*F. subglutinans*, *F. proliferatum*, *F. avenaceum* and *F. verticillioides*	Maize	[17]
Nivalenol	*F. graminearum*, *F. culmorum* and *F. crookwellense*	Maize	[56]
Fusaproliferin	*F. subglutinans* and *F. proliferatum*	Maize	[17]
Fusarin and fusaric acid	*F. graminearum* and *F. verticillioides*	Maize	[57]

Table 1.
Some of the emerging mycotoxin produced by Fusarium *spp. in maize.*

5. Diagnosis of pathogen

Earlier detection of plant pathogens is very important for plant health certification and to conduct the disease management appropriately [58]. The detection and enumeration of disease causing pathogen have always been challenging issues over the years. The environment form which they are originated, pose difficulties in identification, isolation and quantification of pathogen. Developing the accurate and effective detection methods and assay is very challenging for the pathogen like *Fusarium* spp. as they exists as multiple species complex, different pathogenic profiles and virulence levels to the host [59]. Over the years, several techniques and methods have been developed in order to detect and identify disease causing pathogen in crop plants. Some of the techniques widely used in identification of pathogen are morphological based identification; Immunological assay and PCR base methods. The morphology based identification of any plant pathogen is the first and one of most difficult steps in the direction of proper identification of disease causing pathogen in plants. The identification of fungal pathogen isolates based on morphological characteristics of culture is still in use for many laboratories. Since many *Fusarium* spp. offer species complex instead of single species and look similar in many aspects, it is always challenging for proper identification of the pathogen and hence mere morphology based identification may not work good for complete identification and may lead to wrong identification for sure. It is very difficult, time consuming method and requires experts [60]. Although morphological identification is not sufficient for proper identification of the pathogen, the observable morphological characters may give us great amount of information from the culture they grow [61]. Immunoassays technique for early detection and precise identification of pathogen has been significantly increased following the development of enzyme-linked immunosorbent assay (ELISA) and monoclonal antibodies with greater sensitivity and specificity compared to morphological based methods [62]. Serology-based technique can be used to detect fungi present even in low quantities on plant tissues at an earlier stage of disease development. The earliest serological techniques used, were polyclonal antisera from immunized animals by centrifugation of clotted blood [63]. This method is further refined to a serum fraction in classical enzyme-linked immunosorbent assay (ELISA) with IgG as dominant which is obtained by ammonium sulphate precipitation, then passage over an ion exchange cellulose column is followed [64]. Now monoclonal antibodies in plant pathology are more routinely used but polyclonal antisera are also in use in this kind of techniques. Detection or quantification of binding of the diagnostic antibody with the target antigen is the principal aim of all the serological techniques used in plant pathology and double immunodiffusion techniques, indirect immunofluorescence assays and ELISA are most common used techniques. Techniques using antibodies are now suitable for both laboratory and field conditions and can identify pathogenic strains within species in very short span of time. In recent years, the PCR based identification techniques is most preferred and widely used technique among others due to its greater speed, specificity, sensitivity and reliable reproducibility. Polymerase chain reaction (PCR) is one of the greatest achievements of molecular biology. PCR synthesizes DNA and nucleic acid fragments can be specifically replicated in a semiconservative way. Currently, with the help of PCR-based technique, the taxonomic status of any fungal isolates can easily be determined. This technique has the ability to differentiate fungi species which are very closely related and morphologically similar in nature e.g. *F. proliferatum*, *F. temperatum*, and *F. verticillioides* belonged to *Fusarium fujikuroi* species complex (FFSC) [61]. PCR-based molecular methods along with sequencing of ribosomal DNA is now being successfully used to detect and identify the richness of the species from different environments [65]. The ribosomal internal transcribed spacer (ITS) region of nuclear rDNA from gDNA of the *Fusarium* isolates is amplified through PCR by using ITS1 and ITS4 primers followed by analysis of ITS sequences based on a ClustalW Multiple alignment using suitable BioEdit software [66, 67]. The search for homologous sequences is then conducted using Basic Local Alignment Search Tool (BLAST) at the National Center for Biotechnology Information (NCBI) for exact identification of fungal pathogen [68].

6. Disease control through sustainable approach

The significant problems caused by *Fusarium* spp. in maize crop production worldwide include reduce in crop quality, decrease in yield, and higher production costs. Once soilborne *Fusarium* spread in the field, it is very difficult to control. The one of the major reason for not being able to control the *Fusarium* diseases of maize including ear and stalk rot diseases is, its nature of being survived in crop residue for longer period of time and being endophytic, many *Fusarium* spp. remain away from the contact of chemical control [16]. Currently, in order to control the soilborne pathogens the conventional methods of controlling like soil disinfection using fumigants, hot water, or solarization, or using resistant cultivars are very popular and even the chemical fertilizers are in great use [69]. However, the efficacy obtained with these treatments is not up to the mark and found less effective than expected. Many of these methods have been found to be very harmful not only to the plants only but man; animal and associated beneficial microbial communities are severely affected. Therefore, there is an urgent need of finding such an alternative option which could be eco-friendly and sustainable. There are many microorganisms dwelling in the rhizospheric zone of the host plant which significant not only in controlling the soilborne diseases causing pathogen but their role in plant growth promotion is quite commendable. These biocontrol agents have been proved to be eco-friendly, less expensive and more sustainable tools for disease management. Biocontrol agent use different mode of action in order to control the disease which include nutrient competition, antagonism, and production of toxic metabolites and induced systemic resistance (ISR) through the production of defense enzymes. Many microorganism like *Trichoderma* spp., *Penicillium*, *Bacillus* spp., *Rhizobium* and *Pseudomonas* spp. have been reported to function as plant growth promoting fungi (PGPF) and plant growth promoting rhizobacteria (PGPR) in addition to their potentiality to boost defense mechanism [70, 71]. Among the fungi, *Trichoderma* is often considered as universal biocontrol agent due to it extra ordinary function such as mycoparsitism, antibiosis, production of extracellular enzyme, competition for space and nutrients etc. [72].

6.1 Antibiotic production

Antibiosis, a kind of interaction takes place between two organisms when one produces antimicrobial metabolites called antibiotics that directly check the growth and metabolism of the other organism. Antibiotics are low molecular weight toxic organic compound produced by many organisms in order control the growth of pathogen. It is assumed to be one of most effective measures having antagonistic activity against wide range of phytopathogen. Bacteria can either produce single antibiotic and toxin or can produce them in multiple numbers. The antibiotic and toxin produce by bacteria include pioluteorin, pyrrolnitrin, hydrogen cyanide (HCN), oomycins, polymyxin, circulin, colistin and tensin etc. [73]. Bacteria and fungi of various genera, such as *Bacillus* spp. *Microsphaeropsis* sp. *Trichoderma* *harzianum* and nonpathogenic *Fusarium* spp. have been identified as microbial antagonists of *Fusarium* spp. through the mechanism of antibiosis elicited by a wide range of antifungal metabolites, including antibiotics [74]. The ability to produce multiple classes of antibiotics by various group of microorganism enhances the biocontrol activities against the phytopathogen. Microbiotacontaining fungi belonging to genus *Trichoderma* are found eliminate plant pathogens by producing specific and nonspecific antibiotics such as trichodemin, trichodermol, harzianun and harzianolide etc. [75].

6.2 Production of extracellular enzyme

Cell wall-degrading enzymes produced by biocontrol strains of bacteria and fungi have a definite role in restricting the growth of various pathogenic fungi including *Fusarium*. The exracellular enzyme such as chitinase and β-1,4-glucanase etc. interferes with fungal growth by lysing and degrading the cell and cell wall of the pathogenic fungi. *Trichoderma* spp. are very effective biocontrol agents because of their powerful extracellular lytic enzymes activity against fungi through lysis of cell walls [10]. Chitinases from bacteria and fungi are reported with fungicidal and insecticidal activities against *Fusarium* spp. showing extraordinary role in bio-control mechanism include *Streptomyces*, *Pseudomonas*, *Bacillus*, *Trichoderma* spp. and *Penicillium* spp. [71]. Various strains of *Bacillus* has been found to produce chitinase and glucanase for biocontrol mechanism against *Fusarium verticilloides* [76]. There is a report that *Trichoderma asperellum* along with other extracellular enzymes like chitinase and protease, produced β-glucanases against *F. graminearum* causing stalk rot of maize [77].

6.3 Competition for root niche and nutrient

Competition between pathogens and non-pathogens for nutrient resources is important for limiting disease incidence and severity. Rhizosphere is hotspot zone of microorganism and nutrient rich environment which provide a suitable platform for the interaction. Competition for these nutrients and niches is a fundamental mechanism by which beneficial microorganism both bacteria and fungi protect plants from phytopathogens. The interaction between them brings the beneficial microbes to control the disease causing pathogen. Soilborne pathogens, such as species of *Fusarium*, that infect through mycelial contact are more susceptible to competition from other soil and plant-associated microbes [78]. The nonpathogenic microorganisms extremely dependent on exogenous nutrient make them highly competitive with pathogenic microorganism. Competition for nutrient like carbohydrates in the nutrient rich environment in combination with competition for the limited amounts of nitrogen sources such as amino acids play the key roles in the antagonistic interaction [79]. Mycorrhizal fungi are also potential candidates for biocontrol through competition for space and nutrients by virtue of their ecologically obligate association with roots [80].

6.4 Siderophore production

Iron is one of the most common trace elements in nature required by almost all the living organism for their growth and metabolism. Siderophores are low molecular weight extracellular chelating compounds and have a great affinity for ferric iron that are produced by many microorganism like *Trichoderma* spp., *Penicillium* spp., *Bacillus* and *Pseudomonas* etc. in response to iron deficiency. They are secreted into the surrounding environment to dissolve iron minerals and hold it in a soluble form so that they can acquire them by diffusion and consequently enhance plant development by increased uptake of iron [81, 82]. Solubilization and the competitive acquisition of iron under limiting conditions restrict the availability of iron to soilborne pathogen, subsequently limiting their growth [83]. Many *Fusarium* spp. are found to be inhibited by both PGPF i.e. *Trichoderma* spp. and PGPR i.e. *Pseudomonas* through siderophore mediating competition. PGPR such as *Bacillus amyloliquefaciens* and *Microbacterium oleovorans* have been found to protect maize against *Fusarium verticillioides* [84]. Siderophores produced by *Pseudomonas* species (pyoverdine, pyochelin) has shown siderophore-mediated competition for iron and in the control of *Fusarium* [85].

6.5 Induced resistance

Rhizospheric microbes protect the plant not only through their antagonistic properties but also help the plant to defend itself from the pathogenic attack. The term induced resistance is meant for the induced state of resistance in plants triggered by various biological inducers and subsequent protection of non-exposed plant parts against future attack by pathogenic microbes of any kind. Induction of resistance can be local and/or systemic in nature depending on various factor such as types, source, and stimuli. There are two types of induced resistance namely SAR and ISR which provide long-lasting resistance against plant pathogens. Systemic acquired resistance (SAR) is mediated by salicylic acid (SA) and produced following pathogen infection and leads to the expression of pathogenesis-related (PR) proteins. PR proteins include enzymes which may act directly to lyse invading cells, reinforce cell wall boundaries to resist infections, or induce localized cell death [78]. Induced systemic resistance is the process of active resistance against pathogen and is induced upon by colonization of beneficial microbes like PGPF and PGPR or infection by some specific pathogen. It does not rely on SA but depends on the pathways regulated by jasmonate and ethylene [86]. Pathogenic microorganisms trigger a wide range of defense mechanisms in plants through ISR. The major changes occurs in root of the host pant through ISR are: (1) Strengthening of epidermal and cortical cell wall; (2) increase in levels of defense enzyme such as chitinase, polyphenol oxidase, peroxidase, phenylalanine; (3) increase in phytoalexin production and (4) expression of stress related genes [80]. ISR extending up to the shoots from roots protects the unexposed parts of plants against pathogenic attacks by microorganisms in future [87]. The induced resistance is elicited by various beneficial and non-beneficial organisms and regulated by signal pathways, where plant hormones for example play a vital role in inducing the resistance which is regulated by networks of interconnected signaling pathways [88]. Several *Pseudomonas* spp. and *Bacillus* spp. participate in induced systemic resistance (ISR) in a wide range of plants against different pathogens [89]. The PGPR like *Pseudomonas aurantiaca* has been reported to induce the immunity in maize apart from growth promotional activities [90]. Many fungal biocontrol agents such as *Trichoderma* spp., *Penicilliumn simlicissmum* and *Phoma* spp. have also been found to elicit the induced systemic resistance [91].

7. Bioformulation

Pseudomonas spp. and *Trichoderma* spp. have many success stories as a part of bioformulation inducing disease resistance and plant growth promotional activities. Different organic and inorganic carrier materials may function for effective delivery of biocontrol agents. However, the concentrated formulation with potential biocontrol agents provided an extra advantage of smaller packaging with respect to storage and transportation, and low product cost as compared to other carrier materials such as charcoal, vermiculite, sawdust and cow dung [92]. A talc-based formulation with *T. harzianum* was developed aiming at supply of concentrated conidial biomass of the biocontrol agent with high colony forming units (CFU) and long shelf life which significant increased the plant growth promotion [93]. The application of seed based bioformulation using *Pseudomonas fluorescens* not only reduced the disease incidence of *F. verticillioides* causing disease of maize but helped the plant to achieve the plant's growth [93].

8. Conclusions and future prospects

Maize is one of the main contributors to the economy and food security of the world. A Suffering of maize plant by the *Fusarium* is immense only to the plant but entire biotic community. World has witnessed the effect of *Fusarium* on maize plant and subsequent role in causing the diseases in man and animal. Complete control over the *Fusarium* causing disease in maize has not been possible till date and some of control mechanism like chemical control has made the situation even more critical by creating unhealthy environment. Therefore world must look and emphasize on biocontrol mechanism to ensure the security and healthy environment for the next generation. There is a huge existence of unknown microbes in the soil and therefore we must not rely on limited and known microbes but investigate sustainable potentiality of others which could play significant role in this regard. It is also very important to commercialize their production for mass application through sustainable way.

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