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Biocontrol of Some Fungal Pathogen that Cause Plant Diseases by Some Bio Agents

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Abstract

Fungal plant pathogens are among the most important factors that cause serious losses to agricultural products every year. Biological control of plant diseases including fungal pathogens has been considered a viable alternative method to chemical control. In plant pathology, biocontrol applied some microbes to suppress soil borne and airborne pathogens in an attempt to replace existing methods of chemical control byfungicides, which often lead to resistance in plant pathogens. In this review, we present the effect of mycorrhizae, actinomycetes and *Trichoderma* on plant growth and biocontrol of some fungal pathogens under stress conditions. The biological performance of mycorrhizae and Actinomycetes in soil is important for plant growth and development in stressed environments. In agriculture, plant growth promoting Actinomycetes can be used as biocontrol microorganisms and they had a big role in antibiotic production. They arewell- known as active producers of a wide range of secondary metabolites, antibiotics and volatile organic compounds that can inhibit the growth of phytopathogenic fungi and bacteria. In particular, mycorrhizae and *Trichoderma* spores are found in soil and enhance both plant growth and decrease fungal infections. These antagonistic microorganisms are abundant in soils around the roots of economically and nutritionally valuable crops. Their interactions with plant pathogens can significantly affect plant health in various ways. Different mode of actions of biocontrol-active microorganisms in controlling fungal plant diseases include hyper parasitism, predation, antibiosis, cross protection, competition for site and nutrient and induced resistance. In conclusion, some microorganisms can used to suppress some phytopathogens and improve plant growth.

Keywords: Streptomyces, Antibiotics, Antibacterial, mycorrhizae, *Trichoderma*, actinomycetes

Introduction

Plants are very important as a primary source of food and have benefit for our planet because they cover most of the earth and are the main nutritional supplements for animals and humans. Moreover, wild or cultivated plants are a powerful biological fertilizer for soil, as plant debris after death and degradation in soil provides sufficient organicmatter. Accordingly, plants are very important in our lives because they use carbon dioxide and provide us with the essential fresh oxygen which is necessary to human survival and live (Dean et al 2012; Mandadi et al 2013, FAO, 2013). Every year, world population was increased and the great challenge facing the world today is to find food, place, or work (Tapwal et al., 2011, Glick 2012). With the limitations of land availability for agriculture, the demand for sustainable food is increased through increasing plant production and biocontrol of different plant pathogens. The pesticides, Aldrin, Benomyl, Diazinon, and Metoxuron had dangerous impacts on ecological sustainability and human health (Naher et al., 2015). It is desirable to replace many of the present commercial fertilizers, pesticides, fungicides, insecticides, and herbicides with bacterial growth promoter and biocontrol agents. Biocontrol mean control of the pathogen growth by very effective living organism. Living organisms are used in this method to control some bacterial and fungal pathogens and insects without damaging the environment. The eco-friendly antagonistic microorganism appears as a potential, nonchemical and safely agents for crops against several pathogens **Biocontrol Methods** are easy to use, environment friendly and with no side effects, cost-effective, reduces the use of chemicals and other pesticides (Kamble et al., 2021).

Biological control can be categorized into two types: classical biocontrol (Importation) and **Inductive biocontrol (Augmentation. C**lassical biocontrol uses the natural enemy of the pest as a biocontrol agent while **inductive biocontrol (Augmentation) use** a large number of natural enemies are released to kill the target pest. Bio-Control Agents may be microorganisms such as coccobacillus bacteria which used to kill insects by affecting their digestive and/or fungi *Entomophaga* is used against green peach aphids (Kour et al., 2020).

Materials and methods

In the biological sciences, the importance of review articles is rising to update the knowledge of student and researchers and generate guidelines about a topic. They frequently use reviews as a starting point. The value of a review is associated with what has been done, what has been found and how these findings are presented. The main and fundamental purpose of writing a review is to create a readable synthesis of the best resources available in the literature for an important research question or a current area of research. Although the idea of writing a review is attractive, it is important to spend time identifying the important questions. Good review methods are critical because they provide an unbiased point of view for the reader regarding the current literature. There is a consensus that a review should be written in a systematic fashion, a notion that is usually followed. In a systematic review with a focused question.

The research methods

They must be clearly described and a 'methodological filter' is the best method for identifying the best working style for a research question which reduced the workload when surveying the literature. An essential part of the review process is differentiating good research from bad and leaning on the results of the better studies. The ideal way to synthesize studies is to perform a meta-analysis and is best to clearly focus on fixed ideas, to use a procedural and critical approach to the literature and to express your findings in an attractive way.

The studied items

There are different points to be discussed in this review like phytopathogens and their related diseases, Biological control of some plat diseases, the endophytic mycorrhizal fungi as a biocontrol agent for some plant pathogens, plant growth promoting microbes and actinomycetes for plant pathogen biocontrol and finally the interaction between actinomycetes and mycorrhizae for plant pathogen biocontrol. Also, the biocontrol of some plant pathogens by *Trichoderma* was also discussed**.**

Results

Phytopathogens and their related diseases

Plant pathogens are two types either biotic factors like microbes and parasitic plants or abiotic factors, which include all environmental factors. The plant pathogens, diseases and their causes especially microbes are the main topic of this review. As well know, plants are infected by various pathogens including viruses, bacteria, nematodes, vascular plants and fungi (Dean et al., 2012; Mandadi et al., 2013), causing damages to the plants and the severity of attack varies due to host age and environmental factors. Also, some fungi can infect a wide range of vegetables. Until now, out of 99.000 known fungal species more than 8,000 fungal isolates infect wide range of plants whereas 70% of the plant diseases are caused by fungi. Plant pathogenic fungi are parasites, but not all plant parasitic fungi are pathogens and the most common fungal diseases are Anthracnose; Botrytis rots; Downy mildews; Fusarium rots; Powdery mildews; Rusts; Rhizoctonia rots; Sclerotinia rots and Sclerotium rots (Table 1).

Most plant pathogenic fungi belong to Ascomycetes and Basidiomycetes. The fungi reproduce both sexually and asexually via the production of spores which spread for long distances by air or water, or they may be soil borne. Fungal diseases may be controlled through the use of fungicides and other practices but new strains of fungi are resistant to the used fungicides. Fungal pathogens colonize living plant tissue to obtain their nutrients from host living cells but Necrotrophic fungal pathogens infect and kill host tissue and extract nutrients from the dead host cell (Bastos et al., 2021).

Table 1. The most important phytopathogenic fungi that infect plants a and cause some diseases

Diseases	Causative agent	Hosts
Damping off, collar rot, root rot, wire stem	*Rhizoctonia solani*	Various plants diseases
Root rot, damping off.	*Pythium* spp	Wheat, Barley, Rice, Maize
Beach leaf cruel.	*Taphrania sp*	Beach
Head blight	*Fusarium graminearum*	Wheat, Barley.
late blight of potato	*Phytophthora infestans*	Potato
Black stem rust of wheat	*Puccinia graminis*	Wheat; Many Grasses
Coffee rust	*Hemileia vastatrix*	Coffee
White-pine blister rust	*Cronartium ribicola*	White Pine Tree
Corn smut	*Ustilago maydis*	Corn
loose smut	*Ustilago nuda*	Barley, Oats, Wheat
Downy mildew	Species of family Peronosporaceae	Grapes, Grasses, Vegetables
Powdery mildew	Species of family Erysiphaceae	Grasses, Vegetables
Apple scab	*Venturia inaequalis*	Apple
Black spot of rose	*Diplocarpon rosae*	Rose
Anthracnose of grape	*Elsinae ampelina*	Grape
Black knot of plum and cherry	*Plowrightia morbosum*	Plum And Cherry

Fungal diseases had aggressiveness and destructive behavior and have emerged as a global problem having serious effects on economically crop yield and may even lead to complete crop failure. Among these diseases Potato blight is caused by *Phytophthora infestans*, an extremely virulent pathogen. Root rot is another infectious disease caused by *Phytophthora*. Many diseases produced from fungi cause a significant loss of many economic crops worldwide. Heavy attacks of powdery and downy mildew, rusts, *Fusarium* and *Verticillium* wilt, late and early blight cause plant and crop damage including cotton, tomatoes, potato and tobacco (Dean et al., 2012; Doehlemann et al., 2017). Management of these pathogens is required as at least 10% of essential food is lost due to plant diseases (Strange and Scott, 2005). Therefore, some cultural practices including the crop rotation, sanitation, and soil solarization are not sufficiently effective means of control. The application of chemical pesticides, mainly, methyl bromide fumigation, has been a reliable method to control *R. solani* (Vinale et al., 2008; Manganiello et al., 2018).

About 90% of the total global crops are obtained from seeds which may be infected by many diseases like seed rot, seedling blight, root rot, wilt caused by *Rhizoctonia solani*, *Sclerotinia sclerotium*, *Sclerotium rolfsii*, and *Fusarium oxysporum* are among the various kinds of plant diseases which are dangerous than others as they decrease the quantity and quality of the crops leading to 10 – 20 % crop yield losses (Ray et al., 2017, Pandey et al., 2018). Moreover, treatment of these diseases is also difficult due to inefficient chemicals. Moreover, due to national as well as international exchange of seeds, several seedborne plant pathogens are transmitted to the unaffected regions. Soilborne pathogens attack a specific organs and tissues causing the mortality of young seedlings and damage the adult trees and the disease severity depends on time of attack, stage of the plants growth and the efficacy of fungal infection (Kim et al., 2011, Singh et al., 2011, Bhattacharyya and Jha, 2012, Ge et al., 2015). Fungi, bacteria and actinomycetes were known to inhibit the pathogenic plant pathogens and bacteria producing plant toxins.

Biological control of some plat diseases

Biological control has gained increasing attention in recent decades as one of the alternativesto chemical pesticides in the field of plant disease control, especially after the increasing awarenessof the pesticide risks to the environment in general and human health in particular and the appearance of the pesticide resistance in some of the causes. Biological control agents could be available alternative way over chemicals treatments in management of fungal crop diseases. Biological control has the ability to combat plant diseases and at the same time does not causeharm to the environment by using of natural or genetically improved microorganisms to resistor eliminate pathogenic microorganisms, and is carried out by using objects directly from the environment or to cause a change in their properties, which leads to their spread and increase theireffectiveness or use of one of their products.

Biological control includes the selection of resistance varieties, crossbreeding, genetic mutations, or genetic engineering. Stimulating systemic resistance using a living organism or its products stimulate the work of genes of self resistance in the plant. Cross protection is intended to pollinate a particular plant with a weak strain from a specific pathogen that protects the plant from infection with strong strains of the pathogen and possibly from other causes. Parasitism and antagonism mean the use of microorganisms that possess the property of parasitism and antibiotic with plant pathogens, and usually these organisms are used before or after infection, which we try to focus on in this article. The most important organisms used in the biological control of plant diseases.

The endophytic mycorrhizae as a biocontrol agent for some plant pathogens

In nature, plants had different kinds of positive effects on human health and growth. These plants may be infected with some endophytes which increase nutrient availability (biofertilization), the ability to compete, eliminate or reduce the effect of potential pathogens (biocontrol), and the ability to chemically stimulate the growth and/or tolerance of the host to abiotic stress (phytostimulation) and the ability to inactivate or degrade existing toxic substances in the soil (Linderman et al., 1994, Moronta Barrios et al. 2018). Mycorrhizae are classified as a member of subkingdom *Mucoromyceta* and the phylum *Glomeromycota* including three classes *Glomeromycetes*, *Archaeosporomycetes*, and *Paraglomeromycetes* (Tedersoo et al., 2018). Mycorrhizae belong to 11 families, 25 genera, and nearly 250 species (Spatafora et al., 2016). In return, the fungi improve the supply of water and nutrients, such as phosphate and nitrogen to the host plant through extraradical and intraradical hyphae, arbuscules. *Glomus* is the largest genus of Arbuscular mycorrhizal fungi, and all species form symbiotic relationship with plant roots. Mycorrhiza may be Ectomycorrhiza and Endomycorrhiza and 95% of all plants form mycorrhizal relationships. Few of plant such as, Brassicaceae, Cyperaceae, and Juncaceae do not have mycorrhizal associations (Walitang et al., 2017, 2018).

According to Backman et al. (1997), the effectiveness of endophytes as biological control agents is dependent on many factors, such as the production of various antibiotic compounds and exoenzymes, such as proteases, lipases, chitinases, and glucanases as well as competitive root colonization, and induced resistance in the host plant. Plant root symbiosis with fungi occurs in several different forms and is referred to as mycorrhizae. Arbuscular mycorrhizal fungi are main component of the soil microbiota in most agro-ecosystems and form symbiotic association with most of the plants. They depend on the host plant for carbon source and 4- 20 % net photosynthates of host are transferred to the fungus to complete their life cycle (Vigo et al., 2000, Smith and Read 2008).

Mycorrhizal fungi have been known to form a symbiotic relationship with 80% of vascular plants. They are obligate symbionts and they also provide the plant with many benefits, including enhancement of plant growth, germination rates, increasing supplement of water and nutrients especially phosphorous (P^{+++}), and increase resistance to a wide range of fungal and bacterial pathogens, especially pathogens causing rots (Smith et al., 2003; Jacott et al., 2017). They found that infection of tomato and cucumber by *Fusarium* wilt might slow down by VAM due to the morphological changes in the root cells of the endodermis including lignification incensement which protect the roots from penetration by other pathogens. The colonization of tomato root by *Glomus mosseae* lead to a bigger root size and more branches which increase the number of root tips, length, surface area and root volume (Tahat et al 2008, 2010). Other mechanisms of action against plant pathogens are include structural functional compensation in the roots of diseased plants and the maintenance of the redox equilibrium during Oxidative Stress promoted by the pathogenic fungal attack.

In return, the AM fungi are completely affected the nutrients exuded from living root system and nutrient cycling (Jacott et al., 2017). It also increases the tolerance of plants to biotic and abiotic stresses, as pathogens, drought and high salinity (Oztekin et al., 2013). VAM fungi can efficiently absorb mineral nutrients from the soil and deliver them to their host plants in exchange for carbohydrates. Arbuscular mycorrhizal fungi play a key role in facilitating nutrient uptake by crops in low-input farming systems (Lugtenberg and Dekkers, 1999).

There is an exchange of nutrients between fungus and plant where the fungus provides the plant with minerals like phosphorus (P) and nitrogen (N). In addition, they increase tolerance to water stress, induce greater resistance to pathogens and reduce sensitivity to toxic substances present in the soil. Application of these fungi is generally useful to overcome heavy metal problems and to alleviate soil stress, and ultimately increases agricultural production. Depend upon the plant species and AM fungal species, AM fungi can increase or decrease the P^{+++} uptake and other mineral nutrients like Ca, Cu, Mn and Zn (Harrier and Watson 2004). It was also favored the increase in surface area and development of root hairs, enhanced the absorptive capacity of roots also one of the compensatory mechanisms (Tahat et al., 2010). The AMF have higher shoot concentrations of copper (Cu) and zinc (Zn) when grown in soil with low concentration of these elements. Copper and zinc concentrations increased in leaves of AM soybean plants compared to non mycorrhizal plants. Sulfur acquisition was enhanced in sorghum colonized by *Glomus fasciculatum* compared to non-colonized plants (Raju et al., 1990). The efficient use of AM fungi may allow for acceptable yield levels with minimum fertilizer dose, while also reducing costs and environmental pollution risk (Gryndler, 2000, Hajiboland et al., 2019).

Use of mycorrhizal fungi as biocontrol agent gained importance in integrated disease management programs (Harrier and Watson 2004, Smith et al., 2003; Jacott et al., 2017, Oztekin et al., 2013). AM fungi which result in more vigorous growth of plants and increased in tolerance or resistanceof plants to pathogens attack (Singh et al., 2011). AMF inoculation may affect selenium uptake from soil and the level of antioxidant compounds in vegetable crops such as the green asparagus *Asparagus officinalis* (Conversa et al., 2019, Luo et al., 2019, Watts-Williams and Gilbert, 2020). The colonization of plantroot by *Glomus mosseae* lead to a bigger root size and branches which increase the numberof root tips, length, surface area and root volume (Tahat et al. 2008, Al-Hmoud and Al-Momany, 2017, Parihar and Bora, 2018). Similar results were obtained in mycorrhizal tomato plants with an increase in the concentrations of sugars, organic acids, and vitamin C in fruits (Bona et al., 2017). There are many beneficial effects of AMF on tomato tolerance to water stress and in several otherplant species such as *Lactuca sativa* (Ruiz-Lozano et al., 2016), *Triticum aestivum* (Allen and Boosalis, 1983), *Lavandula spica* L. (Marulanda et al., 2007), *Allium cepa, Trifolium repens* (Ortiz et al., 2015), *Pistacia vera* L. (Ouledali et al., 2019).

Plant growth promoting microbes and actinomycetes for plant pathogen biocontrol

Plants are extensively colonized by arrange of beneficial microorganisms and acquire a variety of plant-microbe interactions. Some of these interactions are beneficial, whereas some are dangerous to the plant. The plant growth promoting microbes provide the additional benefit of being a biofungicides with inorganic or as a replacement to manage the fungicide resistance among plant pathogens and to reduce the number of fungicide applications per year (Walitang et al., 1978, Gopalakrishnan et al., 2015) which may otherwise cause serious deterioration of soil health. They also exhibit an endophytic association with the plant and benefits for growth and development of the host. Also, actinomycetes play a vital role in control of plant pathogens (Hoster et al., 2005) and plant growth promotion (Nassar et al., 2003). This is due to their capability to act and exhibit production of antibiotics, siderophores, antimicrobial enzymes, plant growth promoting substances, phosphate solubilization, and competition with plant pathogens for food and space. Actinomyces are Gram-positive bacteria with high G+C (>55%) content in their DNA and they are originally considered as an intermediate group between bacteria and fungi. They are free living, saprophytic, filamentous bacteria, among which some genera produce spores (Ludwig et al. 2012). A large number of actinomycetes have been isolated and screened from soil in the past several decades, accounting for 70-80% of relevant secondary metabolites available commercially (Baltz 2008). Unexplored extreme habitats can be used as sources of novel and rare actinomycetes which considered as a big factory to many useful products.

The filamentous and sporulating nature of *Streptomyces* allowed them to survive during unfavorable environmental conditions. Therefore, they appear to compete more efficiently against many other microorganisms present in the rhizosphere. *Streptomyces* produce various lytic enzymes during their metabolic processes which degrade insoluble organic polymers, such as chitin and cellulose, breaking them to substituent sugars (Bertram et al., 2006; Seipke et al. 2012). *Streptomyces* spp. had the ability to act as plant growth promoters which influenced soil fertility through production of siderophores, solubilizing phosphate and various enzymes including chitinase, cellulase, phytase and xylanase (Jog et al., 2016).

Many scientific reports have explained the ability of actinobacteria to stimulate seed germination and the secretion of plant growth hormones and enhance their growth promoting activity. In soil, most of known actinomycetes have been used under for various agricultural purposes, mainly due to their production of antifungal and antibacterial metabolites and number of plant growth – promoting traits (Goodfellow et al., 1987). Actinobacteria provide the additional benefit of being a biofungicides for plant pathogens and to reduce the number of fungicide applications per year (Gopalakrishnan et al., 2015) which may improve soil health.

Streptomyces produce various lytic enzymesduring their metabolic processes. Such enzymes are able to degrade insoluble organic polymers, such as chitin and cellulose, breaking them to substituent sugars for binding and uptake by multipleABC transporters (Bertram et al., 2006, Seipke et al., 2012). Actinomycetes provide the additional benefit of being a biofungicides and act as a replacement tomanage the fungicide resistance among plant pathogens and to reduce the number of fungicide applications per year (Gopalakrishnan et al., 2015), which may otherwise cause serious deterioration of soil health. The role of actinomycetes in the plant growth promotion like siderophore production, indole aceticacid (IAA) production, P solubilization and biocontrol activity against various pathogens such as *Fusarium* sp. (Lu et al., 2008, Gopalakrishnan et al., 2015, Sreevidya et al., 2016) *Rhizoctonia* sp. (Goudjal et al., 2014), *Pythium* sp. (Hamdali et al., 2008), *Sclerotium* sp. (Karthikeyan et al., 2018) and *Colletotrichum* sp. (Prapagdee et al., 2008).

Streptomyces also exhibit immense biocontrol action against a range of phytopathogens (Wang et al., 2013). Azalomycin, an antibiotic, when treated with soil as culture filtrate resulted in more than 80% decrease in fungal population after 14 days of treatment days of treatment and found to be stable over a broad range of pH and temperature and exhibited antagonism against *Fusarium oxysporum*, *Rhizoctonia solani*, *Sladosporium cladosporioides*, *F. chlamydosporum*, *Alternariasolani* and *Colletotrichum gloeosporioides* (Jinhua et al., 2010).

Interaction between actinomycetes and mycorrhizae for plant pathogen biocontrol

Actinobacteria were often found to be associated with AMF spores. Mugnier and Mosse (1987) reported that *G. mosseae* spores germinated in vitro only in the presence of microorganisms, including *Streptomyces orientalis*. Ames and coworkers (1989) found that out of 190 spores examined, 100 were colonized by one or more chitin-decomposing microorganisms; 82% were colonized by Actinomycetes, 17% by bacteria, and 1% by fungi. Treatments with co-inoculation of AMF and actinomycetes demonstrated diminishing on wilt diminution, this suggesting a possible synergetic relationship between both microorganisms in bioprotection against *P. capsici*. The capacity of AMF to control soil disease would be strongly related with their capacity to promote the establishment of rhizobacteria antagonistic to plant pathogens, as in the particular case of actinomycetes in which some of the species of the genus *Streptomyces* bacteria are even considered mycorrhizal assistants (Lynch and Whipps, 1991).

The microorganisms grow on plants as a source of nutrients in one of the symbiotic interaction, the roots of many plants are infected by specific mycorrhizae and/ or actinobacteria (particularly *Streptomyces*) that help the plant to acquire nutrients from the soil and to protect it from fungal infections (Smith et al. 1997; Smith et al., 2003). Many researches are trying to identify effective natural products for controlling diseases therapy replacing synthetic pesticides and fungicides (Kim et al., 2005). Microbial biological control agents protect crops from damage by diseases via different modes of action. Actinomycetes are widely distributed in terrestrial and aquatic ecosystem, especially in soil forming as aerial mycelia (Yoshida et al. 2008). The role of actinomycetes in the plant growth promotion like siderophore production, indole acetic acid production, P solubilization and biocontrol activity against various pathogens such as *Fusarium* sp. (Gopalakrishnan et al., 2013; Sreevidya et al., 2016), *Rhizoctonia* sp. (Goudjal et al., 2014), *Pythium* sp. (Hamdali et al., 2008), *Sclerotium* sp. (Prapagdee et al., 2008; Pattanapipitsai and Kamlandharn, 2012) and *Colletotrichum* sp. The bioactive secondary metabolites produced by actinomycetes include antibiotics, enzymes and antifungal compounds which are recognized as important factors for controlling some plant diseases. Generally, the use of mycorrhizal fungi and/or actinomycetes enhanced plant growth and has been shown to be effective against plant pathogen and eco-friendly to the environment (Latha et al., 2009). *Streptomyces* is the most prolific antibiotic producers as well as industrially important enzymes. Thus, there is an urgent need to discover new classes of antimicrobial agents effective against resistant pathogenic bacteria and fungi with minimum or no toxicity.

Biocontrol of plant pathogens by Trichoderma

All members of genus *Trichoderma* are free living and known as imperfect fungi or Deuteromycetes, fast growing in culture and have the ability to produce several types of spores. These occur worldwide and are commonly found in the soil and associated with roots of plants and debris (Howell, 2003). The potential effect of *Trichoderma* as biological control agents in plant disease control was introduced and the mycoparasitic activity of the *Trichoderma* against wide range of microorganisms like soil born fungal and bacterial pathogens was reported. Biological control by *Trichoderma* species results either from competition activity for nutrients and area, on the other side *Trichoderma* species have ability to produce several compounds as a resist metabolite that either inhibit spore germination, kill the pathogen or decrease pH of the rhizosphere soil, in the end all these mechanisms lead to lysis of the plant pathogens. It had parasitism/predation activity through production of some types of cell-wall-degrading enzymes, toxic compounds and secondary compounds, antibiotics that act synergistically with some lytic enzymes (Druzhinina et al., 2011, Vinale et al., 2008).

Some isolates of *Trichoderma* spp. had asignificant reducing powers on some pathogenic fungi due to secretion of some bio-agents are known as biocontrol agents from increased localized and systemic resistance to plant diseases (inducing the defensive mechanisms of host plant) as well as overall plant growth, such as several soil borne fungal plant pathogens including(*Magnaporthe grisea*) *pyricularia oryzae*, *Rhizoctonia solani* and *Macrophomina phasolina* (Nadarajah, 2016, Ali and Nadarajah, 2014). Also, *Trichoderma* and *Gliocladium* have antagonistic activity on many soilborne pathogens (including *Verticillium, Sclerotinia, Rhizoctonia, Fusarium, Pythium*) due to a variety of mechanisms, including: parasitism, competition for nutrients andspace, antibiosis, and production of lytic enzymes, as well as the ability to trigger the induction of systemic resistance (Nawrocka et al., 2018). Furthermore, tomato plants subjected to biotic and/or abiotic stresses release specific root exudates that act as chemo- attractants for *Trichoderma*, which are able to recognize “help” signals and grow toward the stressed plants (Lombardi et al., 2018).

Colonization by *Trichoderma*, prior to infection by biotrophic or necrotrophic phytopathogens, activated a priming status that was able to systemically enhance resistance (Hermosa et al., 2013). Moreover, some *Trichoderma* strains can produce microbe-associated molecular patterns that induce plant defense response by production of xylanase in tomato and tobacco, an endopolygalacturonase in *Arabidopsis thaliana*, and a swollen in cucumber (Morán-Diez et al., 2009). Harzianic and tetramic acids produced by *Trichoderma harzianum*, demonstratedremarkable biological properties, including plant growth promotion, antimicrobial activity against different pathogens such as *Pythium irregulare, Sclerotinia sclerotiorum,* and *Rhizoctonia solani*, plus an ability to chelate soil iron ($Fe3^{+}$), thus facilitating its uptake by the plant (Vinale et al., 2008, 2013). The use of these naturally-derived compounds in alternative to, or incombination with the living microbe may contribute to developing novel plant protection products and biofertilizers that may be more effective and reliable when applied to a variety of crops and environment conditions.

Conclusion

Plants are infected by various pathogens including viruses, bacteria and fungi which reduced the crop productivity or post-harvest losses and leads to a huge loss to mankind. Biocontrol of these pathogens using chemical pesticides have a negative impact on the human health and environment. Both mycorrhizae and actinomycetes live in close association with plants and can be used as biological control agents for many plant pathogens where they become important components of disease management and improve crop production and food safety. Mycorrhizal fungi played an important role in improving soil nutrition and enhancing crop disease resistance, which have great application potentials in overcoming crop replant problems. Many paper reported the biological control of plant fungal pathogens using Mycorrhizae, actinomycetes, plant extracts or their interaction. Increasing biocontrol **process** using more environmentally friendly alternatives microbes, biofertilizers and biopesticides **is** encouraged to enhance the growth and plant health. Some endophytes like mycorrhizae and/or Actinomycetes could be new approaches that are needed to improve plant growth and agricultural yields and also reduce consumption of harmful chemical products and fungal infection.

References

Alexander, M. (1978). Introduction to soil microbiology. Soil Science, 125**,** 331.

Al-Hmoud, G. and Al-Momany, A. (2017). Effect of four mycorrhizal products on squash plant growth andits effect on physiological plant elements. Adv. Crop. Sci. Tech, 5**,** 273-280.

Ali, M, Ali Q, Sohail MA, Ashraf MF, Saleem MH, Hussain S, Zhou L. Ali M, et al. (20210. Diversity and Taxonomic Distribution of Endophytic Bacterial Community in the Rice Plant and Its Prospective. Int J Mol Sci., 22(18):10165.

Ali, H. and Nadarajah, K. (2014). Evaluating the efficacy of *Trichoderma*' spp and *Bacillus substilis*' as biocontrol agent's against *'Magnaporthe grisea* 'in rice. Australian Journal of Crop Science, 8**,** 1324-1335.

Allen, M. F. and Boosalis, M. G. (1983). Effects of two species of VA mycorrhizal fungi on drought tolerance of winter wheat. New Phytologist, 93**,** 67-76.

Ames, R. N., Mihara K. L. and Bayne H. G. (1989). Chitin-decomposing *Actinomycetes* associated with a vesicular arbuscular mycorrhizal fungus from a calcareous soil. New Phytol. 111**:**67-71.

Backman, B. , Bodis D., Lahermo P., Rapant S., Tarvainen T. (1997). Application of a groundwater contamination index in Finland and Slovakia. Environ. Geol., 36, pp. 55-64.

Bastos, RW, Rossato L, Goldman GH, Santos DA. (2021). Fungicide effects on human fungal pathogens: Cross-resistance to medical drugs and beyond. PLoS Pathog., 17(12):e1010073.

Bertram, H. C., Wu, Z., Van Den Berg, F. and Andersen, H. J. (2006). NMR relaxometry and differentialscanning calorimetry during meat cooking. Meat Science, 74**,** 684-689.

Bhattacharyya, P.N., Jha D.K. Plant growth-promoting rhizobacteria (PGPR): Emergence in agriculture. World J. Microbiol. Biotechnol. 2012;28:1327–1350.

Conversa, G., Lazzizera, C., Chiaravalle, A. E., Miedico, O., Bonasia, A., La Rotonda, P. and Elia, A. (2019). Selenium fern application and arbuscular mycorrhizal fungi soil inoculation enhance Se content and antioxidant properties of green asparagus (*Asparagus officinalis* L.) spears. Scientia Horticulturae, 252**,** 176-191.

Dean R. , van Kan J.A.L., Pretorius Z.A., Hammond-Kosack K.E., Pirtro A.D. , Spanu P.D. et al. (2012). The top 10 fungal pathogens in molecular plant pathology. Mol Plant Pathol, 13: 414-430.

Doehlemann G, Ökmen B, Zhu W Sharon A (2017). Plant Pathogenic Fungi. Microbiol Spectr., 5(1)111-119.

Druzhinina, I. S., Seidl-Seiboth, V., Herrera-Estrella, A., Horwitz, B. A., Kenerley, C. M., Monte, E., Mukherjee, P. K., Zeilinger, S., Grigoriev, I. V. and Kubicek, C. P. (2011). Trichoderma: the genomics of opportunistic success. Nature Reviews Microbiology, 9**,** 749-759.

FAO (2013). Food and Agriculture Organization of the United Nations. FAO Statistical Yearbook: World Food and Agriculture. Rome, Italy: 2013. 307p.

Ge, H., Li Y., Fu H., Long G., Luo L., Li R., Deng Z. (2015) Production of sweet orange somaclones tolerance to citrus canker disease by in vitro mutagenesis with EMS. Plant Cell Tiss. Org., 123, pp. 29-38.

Glick, B.R. (2010). Using soil bacteria to facilitate phytoremediation Biotechnol Adv, 28 pp. 367-374

Goodfellow, M. and Williams, S. (1983). Ecology of actinomycetes. Annual review of microbiology, 37**,**189-216.

Gopalakrishnan, S., Srinivas, V., Alekhya, G., Prakash, B., Kudapa, H., Rathore, A. and Varshney, R. K. (2015). The extent of grain yield and plant growth enhancement by plant growth-promotingbroad-spectrum Streptomyces sp. in chickpea. Springer Plus, 4**,** 1-10.

Goudjal, Y., Toumatia, O., Yekkour, A., Sabaou, N., Mathieu, F. and Zitouni, A. (2014). Biocontrol of damping-off and promotion of tomato plant growth by endophytic actinomycetes isolated from native plants of Algerian Sahara. Microbiological Research, 169**,** 59-65.

Gryndler, M. (2000). Interactions of arbuscular mycorrhizal fungi with other soil organisms. *Arbuscular mycorrhizas:* Physiology and function. Springer.

Hajiboland, R., Joudmand, A., Aliasgharzad, N., Tolrá, R. and Poschenrieder, C. (2019). Arbuscular mycorrhizal fungi alleviate low-temperature stress and increase freezing resistance as asubstitute for acclimation treatment in barley. Crop and Pasture Science, 70**,** 218-233.

Hamdali, H., Hafidi, M., Virolle, M. J. and Ouhdouch, Y. (2008). Rock phosphate-solubilizing Actinomycetes: screening for plant growth-promoting activities. World Journal of Microbiology and Biotechnology, 24**,** 2565-2575.

Harrier, LA, Watson CA. (2004). The potential role of Arbuscular Mycorrhizal (AM) fungi in the bioprotection of plants against soil-borne pathogens in organic and/or other sustainable farmingsystems. Pest Manage. Sci.; 60:149-157.

Jacott C N., Murray J D. and Ridout C J. (2017) Trade-Offs in Arbuscular Mycorrhizal Symbiosis: Disease Resistance, Growth Responses and Perspectives for Crop Breeding. ***Agronomy***, ***7***(4), 75;

Jana, SK, Islam MM, Mandal S. Jana SK, et al. (2022). Endophytic Microbiota of Rice and Their Collective Impact on Host Fitness. Curr Microbiol.,79(2):37.

Jinhua, W., Xiang, Z., Bing, Z., Yafei, Z., Rui, Z., Jindun, L. and Rongfeng, C. (2010). Rapid adsorption of Cr (VI) on modified halloysite nanotubes. Desalination, 259**,** 22-28.

Jog, A., Kayiran, O., Pattnaik, A., Kandemir, M. T., Mutlu, O., Iyer, R. and Das, C. R. (2016) Exploiting core criticality for enhanced GPU performance. Proceedings of the ACM SIGMETRICS International Conference on Measurement and Modeling of Computer Science, 2016. 351-363.

Kamble V., Joshi S M., Hadimani S, Jogaiah S (2021). Biopriming with rhizosphere Trichoderma harzianum elicit protection against grapevine downy mildew disease by triggering histopathological and biochemical defense responses. Rhizosphere,Vol. 19,112-119.

Karthikeyan, N., Pandiyan, K., Sahu, P. K., Srinivasan, R. and Singh, U. B. (2018). Actinomycetes: a promising tool for plant growth promotion and disease control. Int J Curr Microbiol App Sci, 7**,**2418-2429.

Kim Y.C., Leveau J., Gardener B.B.M., Pierson E.A., Pierson L.S., Ryu C.M. (2011).The multifactorial basis for plant health promotion by plant-associated bacteria. Appl. Environ. Microbiol.; 77:1548–1555.

Kour D, Rana K Lata, Kaur T, Neelam Y , Halder SK et al. (2020). Chapter 11 - Potassium solubilizing and mobilizing microbes: Biodiversity, mechanisms of solubilization, and biotechnological implication for alleviations of abiotic stress. Editor(s): Ali Asghar Rastegari, Ajar

Nath Yadav, Neelam Yadav. In New and Future Developments in Microbial Biotechnology and Bioengineering, Elsevier, Pages 177-202.

Kumar M, Kumar A, Sahu KP, Patel A, Reddy B, Sheoran N, Krishnappa C, Rajashekara H, Bhagat S, Rathour R. Kumar M, et al. (2021). Deciphering core-microbiome of rice leaf endosphere: Revelation by metagenomic and microbiological analysis of aromatic and non-aromatic genotypes grown in three geographical zones. Microbiol Res. May;246:126704.

Latha, G. M. and Somwanshi, A. (2009). Effect of reinforcement form on the bearing capacity of squarefootings on sand. Geotextiles and Geomembranes, 27**,** 409-422.

Linderman, RG (1994). Role of VAM Fungi in Biocontrol. In: Mycorrhizae and Plant Health, Pfleger, F.L. and R.G. Linderman (Eds.). The American Phyto pathological Society, St. Paul, MN., USA., ISBN: 0-89054-158-2, , 1-27.

Ludwig, G. 2012. Foundations of quantum mechanics, Springer Science and Business Media.

Lugtenberg, B. J., Dekkers J. (1999). Microbial stimulation of plant growth andprotection from disease. Current Opinion in Biotechnology, 2**,** 457-464.

Luo, W., Li, J., Ma, X., Niu, H., Hou, S. and Wu, F. (2019). Effect of arbuscular mycorrhizal fungi on uptake of selenate, selenite, and selenomethionine by roots of winter wheat. Plant and Soil, 438**,** 71-83.

Lynch, J. M. and Whipps. J. M. **(**1991). Substrate flow in the rhizosphere, p. 15-24 *In* D. L. Keister and P. B. Cregan (ed.), The rhizosphere and plant growth. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Mandadi KK, Karen-Beth G and Scholthof L (2013). Plant immune responses against viruses: how does a virus cause disease? Plant Cell, 25(5):1489-505.

Manganiello G., Sacco A., Ercolano M. R., Vinale F., Lanzuise S., Pascale A., et al.. (2018). Modulation of tomato response to *Rhizoctonia solani* by *Trichoderma harzianum* and its secondary metabolite harzianic acid. Front. Microbiol. 9:1966.

Marulanda, A., Porcel, R., Barea, J. M. and Azcón, R. (2007). Drought tolerance and antioxidant activities in lavender plants colonized by native drought-tolerant or drought-sensitive Glomusspecies. Microbial ecology, 54**,** 543.

Morán-Diez, E., Hermosa, R., Ambrosino, P., Cardoza, R. E., Gutierrez, S., Lorito, M. and Monte, E. (2009). The ThPG1 endopolygalacturonase is required for the Trichoderma harzianum–plantbeneficial interaction. Molecular plant-microbe interactions, 22**,** 1021-1031.

Moronta-Barrios, ID , Gionechetti, F, Pallavicini, A, Marys, E and Venturi, V (2008). Bacterial Microbiota of Rice Roots: 16S-Based Taxonomic Profiling of Endophytic and Rhizospheric Diversity, Endophytes Isolation and Simplified Endophytic Community Felix. microorganisms , 6, 14:1-20.

Mugnier, J and Mosse B (1987). Spore germination and viability of a vesicular arbuscular mycorrhizal fungus, *Glomus mosseae*. Transactions of the British Mycological Society. Vol. 88: 411-413.

Nadarajah, K. K. (2016). Induced systemic resistance in rice. Microbial-mediated induced systemic resistance in plants. Springer.

Naher, U.A., Othman R., Panhwar Q.A., Ismail M.R (2015). Crop Production and Global Environmental Issues. Springer; Berlin, Germany:. Biofertilizer for sustainable rice production and reduction of environmental pollution; pp. 283–291.

Nassar, S. (2003). Improving the inertial navigation system (INS) error model for INS and INS/DGPSapplications, Citeseer.

Nawrocka, J., Małolepsza, U., Szymczak, K. and Szczech, M. 2018. Involvement of metabolic components, volatile compounds, PR proteins, and mechanical strengthening in multilayer protection of cucumber plants against Rhizoctonia solani activated by *Trichoderma atroviride* TRS25. Protoplasma, 255**,** 359-373.

Ortiz, N., Armada, E., Duque, E., Roldán, A. and Azcón, R. 2015. Contribution of arbuscular mycorrhizal fungi and/or bacteria to enhancing plant drought tolerance under natural soil conditions: effectiveness of autochthonous or allochthonous strains. Journal of plant physiology, 174**,** 87-96.

Ouledali, S., Ennajeh, M., Ferrandino, A., Khemira, H., Schubert, A. and Secchi, F. (2019). Influence of arbuscular mycorrhizal fungi inoculation on the control of stomata functioning by abscisic acid (ABA) in drought-stressed olive plants. *South* African Journal of Botany, 121**,** 152-158.

Oztekin S, Funda Karbancioglu-Guler, Moore H (2013). Bioprospection of Metschnikowia sp. isolates as biocontrol agents against postharvest fungal decays on lemons with their potential modes of action. Postharvest Biology and Technology, Volume 181, 202- 221.

Pandey, Pr, Verma, Mahendra & De, Nirmal. (2018). Chitosan in agricultural context - A review. Crop production 7. 87-96.

Parihar, P. and Bora, M. (2018). Effect of mycorrhiza (Glomus mosseae) on morphological and biochemical properties of Ashwagandha (Withania somnifera)(L.) Dunal. Journal of Applied and Natural Science, 10, 1115-1123.

Prapagdee, B., Kuekulvong, C. and Mongkolsuk, S. 2008. Antifungal potential of extracellular metabolites produced by *Streptomyces hygroscopicus* against phytopathogenic fungi. International Journal of Biological Sciences, 4**,** 330.

Ray, R L., Fares, A, Risch (2018). Effects of Drought on Crop Production and Cropping Areas in Texas. Agricultural & Environmental Letters 3(1)11-22.

Ruiz-Lozano, J. M., Aroca, R., Zamarreño, Á. M., Molina, S., Andreo-Jimenez, B., Porcel, R.,García-Mina, J. M., Ruyter-Spira, C. and López-Ráez, J. A. (2016). Arbuscular mycorrhizal symbiosis induces strigolactone biosynthesis under drought and improves drought tolerance inlettuce and tomato. Plant, cell and environment, 39, 441-452.

Seipke, R. F., Kaltenpoth, M. and Hutchings, M. I. (2012). *Streptomyces* as symbionts: an emerging andwidespread theme? FEMS microbiology reviews, 36**,** 862-876.

Singh, J.S., Pandey, V.C., Singh, D.P. (2011). Efficient soil microorganisms: A new dimension for sustainable agriculture and environmental development. Agric. Ecosyst. Environ.;140:339–353.

Smith, SE, Read, DJ. , Moore, J (1997). Mycorrhizal symbiosis, 2nd edn , Cambridge, UK: Academic Press Ltd.

Smith SE, Smith FA, Jakobsen I. (2003). Mycorrhizal fungi can dominate phosphate supply to plants irrespective of growth responses. *Plant Physiology* 133: 16– 20.

Smith, S.E. and Read, D.J. (2008) Mycorrhizal Symbiosis. 3rd Edition, Academic Press, London.

Spatafora, J. W., Chang, Y., Benny, G. L., Lazarus, K., Smith, M. E., Berbee, M. L., Bonito, G., Corradi, N., Grigoriev, I. and Gryganskyi, A. 2016. A phylum-level phylogenetic classificationof zygomycete fungi based on genome-scale data. Mycologia, 108**,** 1028-1046.

Sreevidya, M., Gopalakrishnan, S., Kudapa, H. and Varshney, R. (2016). Exploring plant growth-promotion actinomycetes from vermicompost and rhizosphere soil for yield enhancement in chickpea. Brazilian Journal Of Microbiology, 47**,** 85-95.

Tahat, MM, Kamaruzaman, S, Radziah, O, Kadir, J, Masdek, HN. (2008), Response of (*Lycopersicum esculentum* Mill.) to different arbuscular mycorrhizal fungi species. Asian J Plant Sci.; 7:479-484.

Tahat, MM, Kamaruzaman, Sijam, Othman, R. (2010). Mycorrhizal Fungi as a Biocontrol agent. Plant pathologyjournal.; 9:198-207.

Tapwal, A., Garg, S., Gautam, N. and Kumar, R. (2011). In vitro antifungal potency of plant extracts against five phytopathogens. Brazilian archives of biology and technology, 54**,** 1093-1098.

Tedersoo, L., Sánchez-Ramírez, S., Koljalg, U., Bahram, M., Döring, M., Schigel, D., May, T., Ryberg, M. and Abarenkov, K. (2018). High-level classification of the Fungi and a tool forevolutionary ecological analyses. Fungal Diversity, 90**,** 135-159.

Vigo J, Norman J, Hooker J. (2000). Biocontrol of the pathogen Phytophthora parasitica by arbuscular mycorrhizal fungi is a consequence of effects on infection loci Plant Pathology; 49:509-514.

Vinale, F., Nigro, M., Sivasithamparam, K., Flematti, G., Ghisalberti, E. L., Ruocco, M., Varlese, R., Marra, R., Lanzuise, S. and Eid, A. (2013). Harzianic acid: a novel siderophore fromTrichoderma harzianum. FEMS microbiology letters, 347**,** 123-129.

Vinale, F., Sivasithamparam, K., Ghisalberti, E. L., Marra, R., Woo, S. L. and Lorito, M. (2008). Trichoderma–plant–pathogen interactions. Soil Biology and Biochemistry, 40**,** 1-10.

Walitang DI, Kim CG, Kim K, Kang Y, Kim YK, Sa T. Walitang DI et al. (2018). The influence of host genotype and salt stress on the seed endophytic community of salt-sensitive and salt-tolerant rice cultivars. BMC Plant Biol., 27;18(1):51.

Walitang DI, Kim K, Madhaiyan M, Kim YK, Kang Y, Sa T. Walitang DI et al. (2017). Characterizing endophytic competence and plant growth promotion of bacterial endophytes inhabiting the seed endosphere of Rice. Microbiol Res., 223-229.

Wang, X.-J., Zhang, J., Wang, J.-D., Qian, P.-T., Liu, C X and Xiang, W. S. (2013). Novel cyclopentenone derivatives produced by a rare actinobacterial strain Actinoalloteichus nanshanensis sp. nov.NEAU 119. Natural product research, 27**,** 1863-1869.

Watts-Williams, S. J. and Gilbert, S. E. (2020). Arbuscular mycorrhizal fungi affect the concentration anddistribution of nutrients in the grain differently in barley compared with wheat. Plant Crops, 15:22-29.