Chapter 6
Exploitation of Fungi and Actinobacteria for Sustainable Agriculture

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6.1 Introduction

Soil microorganisms presents a connecting link with plants and mineral nutrients in soil. Thus, they are amassing accruing interest as biofertilizers. They form symbiotic association with approximately 80% of crop species (Araujo et al. 2009). They provide minerals, nutrients and water to the host plant in return for photosynthetic products. These microorganisms can acquire nutrients from soil volumes that are inaccessible to roots of the crop plants. Thus, these organisms can mitigate the limitation in plant growth caused by an inadequate nutrient supply. Far more than nutritional supply, these association also benefits the plants with add on benefits like drought resistance, tolerance to salinity and disease suppression. Metals like Zn, Cu and Fe play prominent roles in the subcellular compartments of the plants, but they are toxic at higher concentrations. The microorganisms associated with the plant rhizosphere play a role in alleviating toxicity caused by heavy metal in the host plants and those plants are also capable in tolerating high metal concentrations in the soil (Nihorimbere et al. 2011) Fungi and actinomycetes play an unequivocal role on the ecosystem, as they augment the structure of soil and its aggregation and drive the structure of plant communities and productivity. Thus, soil microorganisms are prime biotic soil components lacking of which, can lead to an inefficient functioning of the ecosystem.

Restoring the existing level of microorganism luxuriance can prove as a substitute to ordinary fertilization procedures for tenable agriculture, a crucial objective for farmers meeting the global recession. The crucial approach endorsed to accomplish this target is the open reenrichment of propagules into a particular soil. Nonetheless, the discovery of these actinomycetes and fungi in the level of

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application needs the understanding of how they suit and proceed to the respective ecosystem and soil management and of the processes that pave to the formulation of a functional symbiosis, including the mechanisms associated with nutrient transfer. In this chapter, various applications of fungi and actinomycetes in agriculture are discussed with main emphasis on their use in sustainable agriculture.

6.2 Vesicular Arbuscular Mycorrhiza (VAM)

The symbiotic VAM fungi that colonize and settle the roots and soils of crop and weed plants form an element of the ecology of agricultural systems since they have a considerable impact on the functioning, strength and stability of any ecosystem. They include significant soil biota that commit essentially to the fertility and durability of the man- made ecosystems (Mobasser and Tavassoli 2013). Fungi form a close symbiotic association with most of the terrestrial greens. Most of the deciduous or evergreen trees have ectomycorrhizas- in this case the roots are externally surrounded by the hyphae of some fungi such as Boletus Phallus, Scleroderma, Amantia, Tricholoma etc. Those fungi decompose soil organic matter and the leaf litter in the soil. Ectomycorrhiza stimulates the growth of the used-seedlings, easily absorb nutrients like phosphorous, calcium, nitrogen, potassium etc. and then passed to the tissues of roots (Ramanankierana et al. 2007). Being saprophytes they decompose the organic matter and augment the fertility of the soil. In this way a symbiotic relationship is established between the fungi and roots. In a sustainable agricultural system characterized by low levels of disturbance, the significance of mycorrhizae will be similar to that in natural ecosystems at advanced successional stages. In such systems, the role of mycorrhizae may be expressed not only by the procurement of nutrients by one host plant, but also by a redistribution of nutrients between many host plants and between host plants and soil.

Today's agriculture highlight on maximum production of commodities for consumption. This approach has induced the germplasm selection favouring translocation of Carbon compounds to different portions of crop plants. The proper allocation of Carbon to the roots is desired to maintain soil structure and safeguard subsequent harvests. The general loss of Carbon from the plant to its sorroundings is mediated by exudation. As it is lost, the population density of soil microbiota fumble steepily with increasing distance from root. The mycelia of VAM fungi, in particular, not only control the composition and rate of flow of root exudates, but contain a massive portion of Carbon that are derived from roots. These fungal biomass is also accessible as a substrate to microbial metabolism (Harrier 2001).

6.2.1 *Impact of Cultural Practices and Agro Chemicals on VAM*

The level of cultural stress in soil is a magnitude of the sustainability of agriculture in the soil. Just as it is, the degree of impoverishment of VAM microflora is a symbol of decreased stability of plant-soil system. Soil disturbances alter root and soil colonization by VAM fungi. The disruption of mycorrhiza formation conclude in decreased phosphorous uptake by plants. Tillage effects upset the density of infective propagules required to re-establish VAM colonization differently. Hence, the roots become more naive to pathogen attack by infectious organisms. Crop rotation demonstrate to be an effective solution to this problem, but the exact reason is not well known. Enhanced VAM colonization and spore production were established in different crops, as a result of rotation (Abbasi et al. 2015). It also influence the species composition of VAM microflora growing with different crop plants. A better perspective of rotation effects would help in selecting more effective VAM fungi for use in agriculture. In intercrop systems, VAM fungi colonize and link the roots of adjacent plants and thereby mutual enhancement of productivity by both plants is observed. They are also engaged in transfer and distribution of nutrients in such plant communities. They indirectly affect the nitrogen inputs in a legume intercropping system by increasing the phosphorous availability of plants. Mycorrhiza formation may also build upon grazing intensity. This depends on the capability of the host plant to provide the symbionts with photosynthetic products.

Agro-chemicals are profitable in controlling pests and pathogens, but their application also results in aimless killing of beneficial microorganisms, such as VAM fungi. These fungi are integral parts of both the plant and population of soil microbes. Biocides, may therefore influence VAM fungi either directly or in an indirect manner through their effects on host plant or through the soil organisms associated with the plant. These complex interactions are of precise interest in sustainable agriculture, because the retardation induced by biocide in VAM hyphae, the subsequent stoppage of root colonization by them, and an alteration in species combinations in soil are significant for soil stability and production by plants. The use of agrochemicals have varied effects on VAM. They embellish or hinder VAM colonization and sporulation, improve mycorrhiza formation by controlling hyperparasites and VAM in turn revamp host plant resistance to pesticide stress. It is important to have a thorough understanding of using biocides based on its effects on VAM fungi and on pathogens and pests since it affects the potentiality of VAM's biocontrol ability (Sukarno et al. 1993). The fungi in the mycorrhizal symbiosis are major elements affecting plant and soil health. They have a dominant role in agriculture as agents of plant productivity and soil conservation. As of now, we do not have much knowledge on the effects of specific VAM-fungal isolates on specific plant or soil problems. This information have to be gathered before these fungi can be fully integrated into agricultural practice as a management tool. Research on the VAM plant-soil system is vital on many fronts to achieve this goal: (a) Elucidation of the conditions for large scale production of host-free inocula (b) Choice of effective isolates from naturally occurring populations or by artificial, directional selection methods; and (c) Identification of specific cultural and environmental conditions which can be pacified by mycorrhizae (d) provide the field user with specific product-use recommendations.

6.3 Myco-bio Control of Insect Pests

Biopesticides are biological substances that manage pests without posing a toxic threat to environment. They include natural enemies of pests, phytochemicals produced by them and their byproducts which effectively regulate the pests that are harmful to plant crops (Gupta and Dikshit 2010). Biopesticides have a significant role in protecting crops although most commonly used in conjunction with other aids like chemical pesticides as part of concerted Integrated Pest Management. These microbial pesticides prove to be a substitute to chemical insecticides for enhancing target specificity as well as ecological safety lest they are used uniquely or merging with other pest management programmes. For instance there are fungi that can control weeds as well as insects.

Approximately about US $ 10,000 million has estimated to be a loss in the agricultural production in India in relation to the pest associated damages in the field and during storage. The application of fungi to minimize the frequency of insects and reducing its pathogenesis thereby resulting in a reduced crop loss is referred to as Mycobiocontrol (Chet et al. 1993). About 700 species of fungi are listed as pathogens. Few of these fungi are having confined host ranges, for instance, *Aschersonia aleyrodes* affects scale insects and whiteflies, whereas other species of fungi have an expanded host range, with particular isolates being extra specific to distinct pests. Species like Aspegillus and Penicillium are facultative pathogens whereas species like Cordyceps are obligate pathogens.

Pathogenic fungi that infects the fungi are found as spores in the environment. When an insect comes in contact with a spore either on the surface of a plant or from soil or from air or from the dead insects, spores stick to the body of the insect. These spores penetrate the insect cuticle (often at joints or creases where its protective lining is thin), and grows throughout its body. Most of the insects also produce toxins in the host body which reduces its time of killing and also prevent entry of other microbes (Faria and Wraight 2001). After the insect death, fungus exits through the exoskeleton of insect, usually from the above mentioned thinner areas and once again begins spore production. The spores are liberated and scattered by the action of wind, rain or contact in the surroundings. The insect victims often have a “fuzzy” appearance, because the fungi protrude out of the exoskeleton to produce spores. Most commercial fungal strains produce green or white spores, although the colour of fungi can vary overtime.

Most of the fungi which is used to manage pets belong to hyphomycetes. Some of the species can be mass multiplied, hence used for commercial production. Some of the fungi in this group cause natural outbreaks in the soil when conditions are favourable. Their host range are broad. Commercial fungal strains often target aphids, ants, caterpillars, grasshoppers, thrips, whiteflies, weevils, Colorado potato beetle, and mealybugs. One of the most widely used fungal biopesticide include the hyphomycete fungus, *Beauveria bassiana*.

6.3.1 Entomopathogenic Fungi

Entomopathogenic fungi are natural managers of insect populations and are potent mycoinsecticide agents against various insect pests in agriculture. These fungi penetrate host cuticle, facilitating its entry into the hemolymph, produce toxins, and utilize the maximum available nutrients in the haemocoel therby avoiding immune response of the insects. The conidia of these fungi is applied since they sporulate after application. Fungal entomopathogens serves as an alternative to insecticide and the combined application of insecticide with fungal entomopathogens can turn out to be very useful for management of insecticide resistance. Table 6.1 showing some bioactive products derived from Entomopathogenic fungi commercially used for agricultural field applications.

Fungi belonging to this group cause outbreaks in natural population but are difficult to produce by mass multiplication, hence not used commercially. They are host specific, certain species affects aphids. Inspite of the adversities in commercial production, they have a large impact on the infecting pest populations. Using fungi as biocontrol agents have an added advantage of controlling even sucking insects since they infect the host tissues by invading directly through the cuticle rather than the hosts ingesting them. Insects in the orders Coleoptera Hemiptera, Orthoptera, Thysanoptera, and Lepidoptera, comprise most of the targets. Chinese caterpillar fungus controls insect pests of crop plants, the spores being applied to (Florez 2002). The other widely used fungi include those that control Colorado potato beetles, Citrus rust mites, leaf hoppers and Spittlebugs. This method is cheap and less detrimental than chemical pesticides.

6.3.2 Bio-Management of Insect-Pests by Different Entomopathogenic Fungi

6.3.2.1 *Beauveria sp. Beauveria bassiana*

A filamentous fungus, also named as imperfect fungus belonging to a class of insect pathogenic deuteromycete. Particular strains of Beauveria act only against specific hosts. A wide variety of *B. bassiana* spp. have been obtained from a variety of medicinal or agriculturally important insects worldwide. These fungi is found in soil naturally all around the world and is pathogenic to many insects causing physiological disease such as white muscardine disease. *Beauveria* sp. is the highly host

Table 6.1 Bioactive products derived from Entomopathogenic fungi commercially used for field application

Product	Fungus	Biological action (Sandhu et al. 2000)
Mycotal	*Verticillum lecanii*	Fungal pesticide
Pfr 21	*Paecilomyces fumosoroscus*	Fungal pesticide
Verelac	*Verticillum lecanii*	Sucking pests
Beevicide	*Beauveria bassiana*	Borer type pests
Grubkill	Selected fungus and bacteria	Borers and sucking pests
Pelicide	*Paecilomyces lilacinus*	Effective against nematode
Biologic Bio 1020	*Metarhizium anizopliae*	Mycelium granules as pesticide
Bioter	*Verticillum lecanii*	Effective against termites
Brocaril	*Beauveria bassiana*	Wetteble powder used as pesticide
Ostrinil	*Beauveria bassiana*	Microgranules of mycelium used as pesticide
Boverol	*Beauveria bassiana*	Dry pellets as pesticide
Naturalis	*Beauveria bassiana*	Liquid formation as pesticide
Mycontrol- WP	*Beauveria bassiana*	Wetteble powder used as pesticide
Betel	*Beauveria brongniartii*	Microgranules of mycelium used as pesticide
Engerlingspilz	*Beauveria brongniartii*	Barley kernels colonized with fungus used as pesticide
Biopath	*Metarhizium anizopliae*	Conidia on a medium used as pesticide
Biomite	*Verticillum lecanii* and other entomopathogenic organisms	Effective against mites
Biogreen	*Metarhizium anizopliae*	Conidia produced on grain used as pesticide
Naturalis-O and BotaniGard	*Beauveria bassiana*	Effective against whiteflies
Trypae Mix	*Trichoderma* and *Paecilomyces*	Effective against fungal pathogens and nematodes in soil

specific (Sandhu et al. 1993). The hosts of medicinal significance include vectors for agents of tropical infectious diseases such as *Glossina morsitans,* tsetse fly, and sand fly *Phlebotomus* that transmits *Leishmania* and bugs belonging to genera *Triatoma* and *Rhodnius*, that transmits Chagas disease. The most important agricultural hosts include Coloradopotato beetle, American bollworm *Helicoverpa armigera*, *Hyblaeapara* and *Eutectona machaeralis* and other termites.

The long term effects of entomopathogenic fungi on pest suppression in case of an epizootic is attributed to the high level of its persistence in the host population. It is a good bioinsecticide to manage a number of pests such as whitefly, termites, and in malaria-transmitting mosquitoes. It is the asexually reproducing form (anamorph) of *Cordyceps bassiana* (Sandhu et al. 2001). The teleomorphic form has been found only in eastern Asia. This fungus, ubiquitously found is the most frequent causative agent of disease associated with dead and obsolescent insects in nature and has been scrutinized worldwide as a control agent of hypogeous species. The sub-terranean level of Curculionidae weevils are highly vulnerable to white muscardine disease.

B. bassiana comprise of geographically and genetically distinct variants as hosts which differ in their ability to cause pathogenesis, the spores of which are sprayed on infected crops as an emulsified suspension or wettable powder. *B. Bassiana* targets a large number of arthropod hosts and hence regarded as a nonselective biological insecticide. *B. bassiana* is also applied against the, pine caterpillars *Dendrolimus* spp., European corn borer *Ostrinia Mubilalis* and green leafhoppers *Nephotettix* spp (Thakur et al. 2005).

6.3.2.2 *Verticillium lecanii*

Verticillium lecanii is widely seen fungi which cause large epizootic in tropical and subtropical regions, as well as in warm and humid environments. In south Korean greenhouses, *V. Lecanii* is used as effective bio agent against *Trialeurodes vaporariorum*. This fungus invade nymphs and adults and get cemented to the leaf underside by means of a filamentous mycelium (Nunez et al. 2008). *Verticillium lecanii* has been instrumental in manging whitefly, many aphids, including *Myzus persicae*. The cereal cyst nematodes showed an enormous drop in population when treated with *V.lecanii*. *Verticillium chlamydosporium* has a broad host range among cyst and root-knot nematodes but is highly variable and only some isolates proved to be potent commercial biological control agents (Kim et al. 2002).

6.3.2.3 *Metarhizium spp. Metarhizium anisopliae*

A major pathogen affecting pests and is probed for mycobiocontrol of injurious insect pests. A thorough bioactivity of *M. anisopliae* has been investigated on teak skeletonizer *Eutectona machaeralis* and it has been reported to be a potential mycobiocontrol agent of teak pest. The spore production of *M. anisopliae* by solid state fermentation makes its production easier (Sandhu et al. 2000).

6.3.2.4 *Nomuraea sp. Nomuraea rileyi*

It is a dimorphic hyphomycete that leads to death in insect pests. *N. rileyi* kills Lepidoptera class insects like Spodoptera litura and some insects belonging to Coleoptera. The fungi being environmental friendly and host specific, are used in insect pest management (Mathew et al. 1998). The mode of infection and development of *N.rileyi* have been reported for various insect hosts such as *Heliothis zea*, *Trichoplusia ni*, *Plathypena scabra*, *Pseudoplusia includes, Bombyx mori*, and *Anticarsia gemmatalis*, now *Spilosoma* was found to be severely attacked by *Nomuraea rileyi*, hence studied in detail for its mycobiocontrol. Similarly an epizootic of *Nomuraea rileyi* on the hedge plant eater *Junonia orithya* proved to be the best alternative to manage the same.

6.3.2.5 *Paecilomyces sp. Paecilomyces*

It belongs to a genus of nematophagous fungus which is detrimental to harmful nematodes. Hence this is used as a bionematicide to control nematodes by its application onto soil. *Paecilomyces lilacinus* attacks root- knot nematodes and assimilates eggs of cyst nematodes. After its discovery in 1979, this fungus turned out to be the subject of appreciable biological control research *Paecilomyces fumosoroseus* (Hyphomycetes) is one among the crucial natural enemies of whiteflies worldwide, and causes the sickness "Yellow Muscardine". The capability of this fungus to grow largely over the leaf surface under humid conditions is a feature that enhances its ability to spread briskly through whitefly populations (Wraight et al. 2000).

The fungi suppress and kills *Bemisia tabaci* multitudes. Epizootics by *Paecilomyces fumosoroseus* also result in considerable reductions in *B. tabaci* populations during or shortly following rainy seasons and in prolonged periods of humid conditions in the field or greenhouse (Faria and Wraight 2001). But, epizootics of naturally occurring fungi cannot be confided upon for control. Many fungi have the capacity to cause remarkable mortality, and advancement of natural epizootics is not only dependent on the climatic conditions, but also determined by many crop production practices. Epizootics often occur after acute injury has previously been inflicted by whiteflies. *P. fumosoroseus* is perfect for controlling the nymphs of whitefly. The nymphs exhibit "feathery" form and are enclosed by mycelia and conidia. *P. furiosus* is also used to control mosquito sp. *Culex pipiens*.

Advantages of using fungi as biopesticide include: (1) Non-toxic and non-pathogenic to wildlife, humans, and other organisms not closely related to target (2) Mass production of spores of these fungi is relatively easy, so comparably priced with other biocontrol agents (3) Application can be done with spray rigs, hence easily adapted to existing application technology (4) broad host range, so can achieve control of multiple pests with the same product (5) persistence of seasonal infection tends to be low for most fungi (6) most microbial insecticides can be used in combination with artificial chemical insecticides/ pesticides since the microbial product is not deactivated by residues of conventional insecticides (7) Enhance the root and plant growth by increasing the beneficial soil microflora. By this way they take a part in the increase of the crop yield.

Disadvantages of fungal biopesticide includes: (1) High concentration of spores needed to get adequate control of pests (2) Time required by fungi to get rid of the pests is too long (3) Non-target mortality of beneficial insects (4) Environmental factors also can affect the fungal activity which limit their effectiveness as biocontrol agents of pests (5) Each application of the microbial insecticide is specific to only a certain class of insects (6) Special formulation and storage procedures are necessary for some microbial pesticides. Even though these procedures may obstruct the production and distribution of few products, storage requirements need not vigorously limit the management of microbial insecticides that are broadly available. (Store all pesticides, inclusive of microbial insecticides, in accordance with label directions).

6.4 Integrated Pest Management

Integrated Pest Management is a method used to control pests in an environmentally culpable manner. Biological control is a doctrine of cultural control of plant pathogens that chiefly involves the change of biotic and abiotic environments from one that devours disease/pathogen to one that dispirits the accumulation of infective or parasitic material and curtails the activity of the pathogen (Kalra 2007). These potential biocontrol fungi are mostly saprophytic in nature and proliferate abundantly in various natural soils. The most important fungi used as biocontrol agents against plant pathogens are – *Trichoderma*, *Gliocladium*, *Aspergillus*, *Penicillium*, *Neurospora*, *Chaetomium, Dactylella, Arthrobotrys, Catenaria, Paecilomyces, Glomus* etc.

Isolates of *Beauveria bassiana* (Balsamo) Vuillemin has been used in conjunction with conventional insecticides for biological control of rice stink bug, Oebalus pugnax (F.) in the laboratory and in small-plot field experiments. Entomopathogens (like Verticillium lecani) have shown promise for augmentative biological control of Scirtothrips dorsalis, and there was scope for identifying more adapted and virulent strains of the entomopathogens. The commercial mycoinsecticide ‘Boverin’ formulated on *B. bassiana* with low doses of trichlorophon have been employed to weaken the second-generation outbreaks of *Cydia pomonella.* Higher insect mortality was also observed when *B. bassiana* and sublethal doses of insecticides were tested to control Colorado potato beetle (*Leptinotarsa decemlineata*), resulting in higher rates of synergism among two agents. The combination treatment of fungi *Beauveria bassiana* and *Metarrhizium* along with new generation pesticides have showed higher dose mortality response of disease causing insects than their sole treatment (Hajeck 1994).

6.5 Fungi in the Conversion of Agricultural Wastes to Compost

The residues from crop plants are produced abundantly butis an underutilized renewable resource in agriculture. The approximate amount of residues is estimated to be 620 million tons. Half of the quantity is used for roofing purposes, animal feeds, fuel and packing stuffs. Burning of these residues is an easy way of disposing them but tends to air pollution, cause soil erosion and reduces the efficiency of herbicides in soil. It also causes respiratory problems and fog issues. The application of agro residues in soil, eventhough increase soil health, decrease subsequent crop yields due to the production of phytotoxins, allelochemicals etc. (Singh and Nain 2014).

Lignocellulose is composed of polymers like cellulose, hemicelluloses and lignin. Hence the microorganisms which can breakdown these polymers with their enzymes are efficiently used in their breakdown. The more complicated is the polymer, the more elaborate network of enzymes required for its breakdown. There are mainly three types of fungi which lives on dead wood that preferentially degrade one or more wood components *viz.* soft rot fungi, brown rot fungi and white rot fungi. Soft rot fungi decompose cellulose but degrade lignin slowly and incompletely. The brown rot fungi exhibit preference for lignin, hence largely focussed on demethylation. White rot fungi are capable of degrading both lignin and cellulose. In majority of soils, 80% of the fungal population belongs to the genera *Aspergillus* and *Penicillium.*

6.6 Fungi in Humus Formation

Once the plants and animals die, there is a generation of large amount of organic wastes. Agricultural wastage, forest litter, etc. also plays a vital role in organic or bio-waste formation. The fungi and bacteria play the key roles for degradation of these. When fungi degrades such organic wastes, these generates a kind of organic nutrient for plants called humus. Humus is none other than degenerated plant and animal bodies. During the formation of humus, Carbondioxide gas (CO2) is formed, which is utilised by green plants during photosynthesis. Humus is hence a degenerative product of cellulose, hemicellulose, lignin, proteins, nucleic acid, etc. The major part of the humus consists of Humic acid, Humins, Fulvic acid, etc. It maintains physical and chemical properties of soils supporting various biological activities. During humus formation, all those complex organic molecules are degraded in steps. Mentioned below are some of the complex organic molecules along with the fungi degrading them:

- *Cellulose: Aspergillus, Penicillium*, *Chaetomium*, *Fusarium*, *Trichoderma*, *Cladosporium, Alternaria, Humicola, Phoma*, etc.
- Hemicellulose: *Aspergillus, Penicillium, Fusarium, Chaetomium, Glomerella*, etc.
- Pectin: *Aspergillus, Penicillium, Fusarium, Rhizopus, Monilia*, etc.
- Lignin: Many white rod fungi of Basidiomycotina and many *Agaricus* spp.

And thus fungi upgrades minerals and other nutrients in soil, increasing fertility.

6.7 Fungal Enzymes in Agriculture

Soil is an important component of all terrestrial ecosystems as well as a main source of production in agriculture. The functioning of an ecosystem and its biochemical functions are influenced by soil. The overall enzyme activity in soil consists of various intracellular and extracellular enzymes that originate from microorganisms and from plants and animals.

Soil enzymes are significant in soil functioning due to the following features: (1) they play a critical role in the decomposition of organic materials and the transformation of organic matter, (2) they release available nutrients to plants, (3) they participate in N2 fixation, nitrification and denitrification processes, and (4) they take part in the detoxification of xenobiotics, such as pesticides, industrial wastes, etc.

Amylase: An alpha amylase enzyme produced by *Aspergillus niger* and *Aspergillus oryzae.* Rapid acting hydrolase enzyme particularly active in the mildly acidic pH range and degrades a variety of starch containing substrates. It can also be used as feed additives to increase the utilization of feedstuffs by hydrolyzing the starch contained in feeds to dextrins and sugars.

Cellulase: Cellulases are inducible enzymes produced by a wide variety of microorganisms which includes both fungi and bacteria. *Trichoderma*, and *Aspergillus* are the most widely employed cellulose producers. Many enzyme preparations comprising of various combinations of cellulases, hemicellulases, and pectinases have immense applications in the field of agriculture for stimulating growth of crops and managing plant diseases.

Pectinase: Pectin is a polymer of carbohydrate group esterifying with methanol. It is an important component of plant cell wall. The maximum amount of pectin is present in middle lamella of cells. Plant pathogens attack target cells by producing number of cell degrading enzyme which facilitates the entry and expansion of pathogen in the host tissue. *Aspergillus niger, Aspergillus japonicus, Chaetomium globosum* and *Aspergillus flavus* are potent pectinase producers.

Invertase: Invertase acts on 1, 4 glycoside linkage of sucrose and splits it into D-glucose and D-fructose. It is intracellular as well as extracellular enzyme. Invertase is also referred as β- fructofuranosidase as it catalyses hydrolysis of the terminal non-reducing residue of β –fructofuranoside. *Thermomyces lanuginosus, Candida utilis, Penicillium chrisogenum, Saccharomyces cerevisiae* and *S. Carlsbergensis* are examples of invertase producing fungi.

6.8 Phytohormone Production by Fungi

A phytohormone is an organic substance manufactured in defined organs of the plant that can be transported to other sites, where it brings about specific morphological, physiological and biochemical responses. Nevertheless, phytohormones are also effective in tissues where they are created. In addition, various soil bacteria and fungi are also phytohormone producers. The most commonly accepted classes of phytohormones, known as the "classical five", are: the auxins, cytokinins, gibberellins, ethylene and abscisic acid,. The capacity to synthesize cytokinins, Gas and IAA, is common among soil and plant-associated bacteria and fungi responsible for plant growth promotion, symbiotic associations and also pathogenesis. *Aspergillus niger, Penicillium citrinum, Trichoderma harzianum* are major exogenous phytohormone producers in the plants.

6.8.1 Auxins From Fungi Play a Positive Role in Plant–Fungus Interactions

The hormones derived from indole capable of plant development is termed as auxin. The processes such as cell division, differentiation and organ formation needs auxins (Barker and Tagu 2000). Auxins also control biotic and abiotic stress responses in plants. Auxins are involved in symbiotic interactions between plants and bacteria or fungi. They are required for the initiation of nodule formation in the nitrogen-fixative bacterial symbiosis and for the invasion of mycorrhizal fungi. They are also involved in plant–pathogen interactions (Benjamins and Scheres 2008).

6.8.2 Cytokinins

Cytokinins are plant hormones derived from ATP/ADP/AMP or from the tRNA degradation pathway. They have a decisive role in plant developmental processes, such as root and shoot formation, through the regulation of cell cycle and cell differentiation. They are also involved in the delay of senescence and in source–sink nutrient distribution. CKs are probably involved in 'green island' formation, a photosynthetically active zone often found around lesions caused by biotrophic fungi (Chanclud et al. 2016).

6.8.3 Gibberelic Acid

GAs are terpenoid hormonal compounds identified for the first time as being produced by Gibberella fujikuroi. GAs are involved in the control of germination, flowering, cell division and internode elongation. In mycorrhizal interaction, the GA content is increased in plants (Brian and Elson 1954).

6.8.4 Abscissic Acid (ABA)

ABA is the key hormone for plant abiotic stress responses (Peleg and Blumwald 2011) and it is also involved in seed dormancy by acting antagonistically with the GA pathway. In plants, ABA is well known to induce stomatal closure and thus to contribute to plant drought tolerance (Crocoli et al. 1991).

6.8.5 Ethylene

A gaseous hormone involved in plant physiology and defence which also affects fungal development. Ethylene is a gaseous compound first discovered for its role in fruit maturation. ET was later shown to be involved in senescence, germination, flowering and the inhibition of root and shoot growth (Bleecker and Kende 2000).

6.9 Actinobacteria in Agriculture

One of the most fascinating group of organisms' actinobacteria or actinomycetes comes under largest taxonomic units within the domain bacteria. The word "Actinomycetes" are originated from "atkis" (a ray) and "mykes" (fungus), Greek words, because they having the features of both bacteria and fungi. But with satisfactory unique features delineate them into 'Kingdom bacteria'. These are aerobic, sporulaing, gram positive bacteria comes under the order actinomycetales, especially with guanine and cytosine rich DNA. Although they are unicellular, they do not possess cell wall and characterized with slender, nonseptate distinct substrate and aerial mycelium. Most actinobmycetes produce powdery colonies and firmly sticking to agar surface and producing fungi like hyphae and conidia/sporangia in culture media. They are the potential producers of several secondary metabolites, include antibiotics, immunosuppressive agents, antitumor agents, and enzymes (Chaudhary et al. 2013).

Actinomycetes displays a range of unique prokaryotic life cycle and play an important role in organic matter recycling of soil ecosystem (Veiga et al. 1983). They are the most abundant soil organisms, produces a characteristic "earthy smell" because the existence of metabolite "geosmin" and grows as thread-like filaments in the soil (Sprusansky et al. 2005). The Actinomycetes are ubiquitous group of microbes extensively distributed in nature all around the world (Srinivasan et al. 1991). They are largely soil occupants (Kuster 1968) but widely distributed in diverse habitats including sediments collected from deep sea vents (Colquhoun et al. 1998), from the deepest depth of Mariana Trench (Pathom-aree et al. 2006), cryophilic soil taken from Antarctica (Moncheva et al. 2002) and also has been reported from desert soil (Diraviyam et al. 2011). A comparative survey on Actinomycete population has been demonstrated that it is greatly found in surface layer of soils and decreases gradually when the depth increased (Takahashi and Omura 2003) (Fig. 6.1).

Actinobacteria are characterized by the development of branching filaments or rods with nonseptate hyphae (Fig. 6.2). Several special conditions, septa may be visualized in different forms. The sporulating mycelium may be straight, branching or nonbranching or spiral shaped. The spores are cylindrical, spherical or oval. The cell wall has a rigid structure that helps for maintaining the shape of the cell also prevents from breaking of the cells under high osmotic pressure. The wall contains

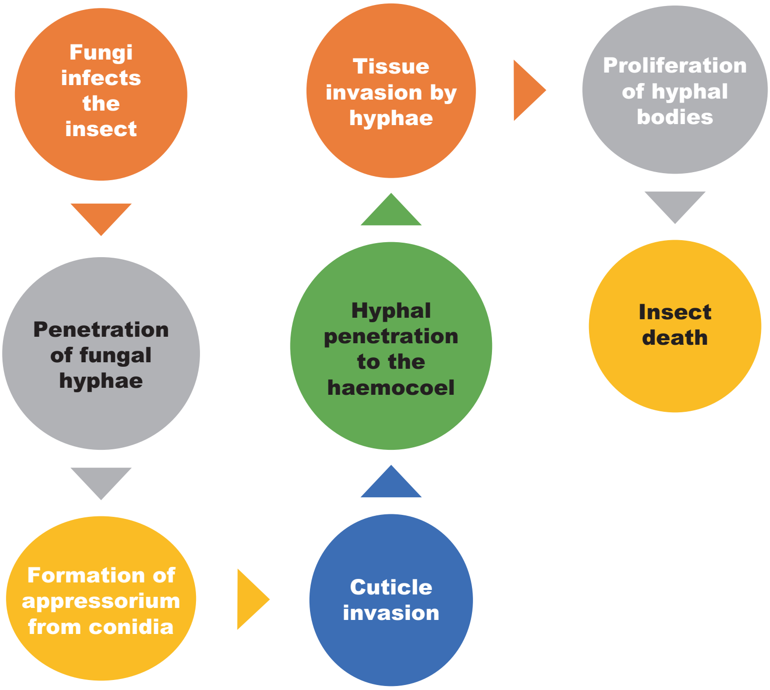

Fig. 6.1 Depiction of infection process by Entomopathogenic fungi

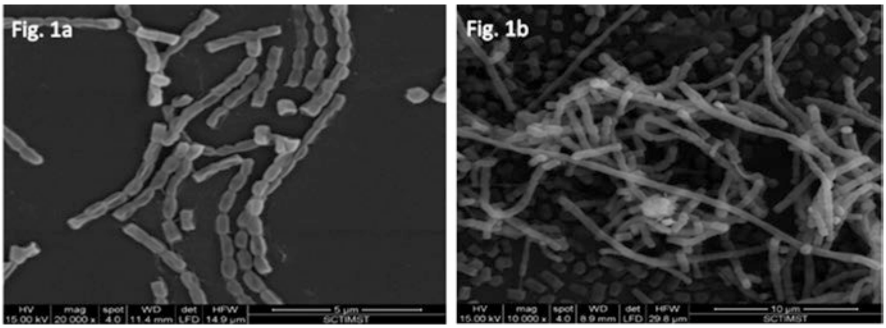

Fig. 6.2 Scanning electron microscopy images of Actinobacteria showing branching rods (Fig. 1a: Streptomyces sp. TBG-AL19) or filaments (Fig. 1b: Streptomyces sp. TBG-AL13)

variety of composite compounds like peptidoglycan [glycan chains with alternating N-acetyl-d-muramic acid (NAM), N-acetyl-d-glucosamine (NAG) and diaminopimelic acid (DAP)], teichoic and teichuronic acids and some polysaccharides (Manuselis and Mahon 2007). They shows similar cell wall chemical composition like in gram positive bacteria but their well-developed cultural and morphological characteristics, finely separated Actinomycetes from all other common bacteria

(Das et al. 2008). They are included volume four of Bergey's Manual of Determinative Bacteriology, comes under the order Actinomycetales. It is separated in to four families- Streptomycetaceae, Actinomycetaceae, Mycobacteriaceae, and Actinoplanaceae (Williams et al. 1989). Streptomyces and Micromonospora are the two generally defined actinobacterial genus. Although the Streptomyces genus is recognized as the largest reservoir of natural bioactive products (Terkina et al. 2006). About 75% of available natural antibiotics are produced in the members of genus Streptomyces (Jimenez-Esquilin and Roane 2005).

6.10 Plant Growth Promotion by Actinobacteria

The popular soil actinobacteria indicated their optimal development in neutral or alkaline conditions. The filamentous sporulating actinobacteria have fascinated superior interest because of their ability to flourish in extremely diverse soil circumstances and also due to their significant ecological role in nutrient cycling. Furthermore, these are existent widely in the plant rhizosphere and secrete innumerable agro active compounds. In the last few years, Actinobacteria gained much attention are also included in the category of plant growth promoting rhizobacteria (PGPR), free living agriculturally important bacteria, due to its robust antimicrobial potential, and dominant soil saprophytic nature (Franco-Correa et al. 2010). These bacteria have voluminous beneficial properties on agricultural production by overwhelming microbial plant pathogens, improving nutrient availability and increasing assimilation. Hence, the use of plant growth promoting Actinobacteria (PGPA) diminishes the negative impact of inorganic fertilizers, thus by improving crop quality, fertility and yield. Actinomycetes are actively involved agricultural productivity by production of plant growth promoting substances such as plant hormones, siderophores etc. and actively involved in increasing soil fertility and in stress alleviation. Figure 6.3 representing the roles of actinobacteria that helps maintaining sustainable agriculture.

6.10.1 Actinobacterial "Geosmin" as Soil Fertility Indicator

Actinobacteria are well-known producers of organic compound "geosmin", is responsible for the earthy odour of soil mostly after the rain. Among the actinomycetes, the *Streptomyces* strains are the most common producers of this volatile compound and released into the soil after the death of these microorganisms. The geosmin biosynthesis in *Streptomyces coelicolor* was has been showed (Jiang et al. 2006, 2007). During geosmin biosynthesis, the substrate farnesyl diphosphate is converts to geosmin by a single enzyme, geosmin synthase, in a two-step reaction. It is a bicyclic alcohol ($C_{12}H_{22}O$) and a derivative of decalin, frequently used for soil biological fertility. The soil intense "geosmin in soil are the major indicator of its

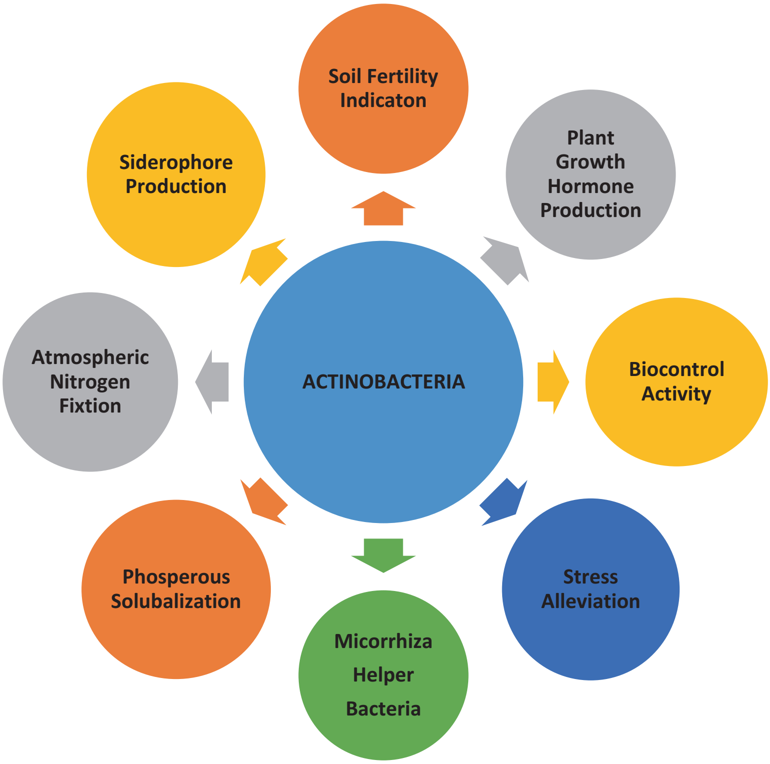

Fig. 6.3 Actinobacteria in sustainable agriculture

fertility status. Soils with this earthy smell are considered as more fertile. The geosmin smell can be detected by human nose up to five parts per trillion. Besides to execute the role as soil fertility indicator, actinobacteria can also be involved in the nutrients biogeocycling particularly of phosphorous, nitrogen and iron.

6.10.2 Plant Growth Hormone Production by Actinobacteria

A known plant growth regulator, Indole acetic acid (IAA), an active form of auxins, plays a vibrant role in plant development. It promotes lateral roots and apical meristem development along with roots elongation (López et al. 2004). IAA are produced by several Actinobacteria in substantial quantities (Ghosh et al. 2011). In Streptomyces IAA production is tryptophan dependent (Lin and Xu 2013). A significant quantity of IAA (52.3 μg.ml^{-1}) was made by *Streptomyces* sp. obtained from the medicinal plants rhizosphere region. *Streptomyces filipinensis* no. 26 isolate produced IAA stimulated the growth of tomato under greenhouse environments (Khamna et al. 2009). 29 Actinobacterial isolates studied in soil from yam rhizosphere region found that 28 isolates produced IAA and there 11 were stimulated in vitro growth of Arabidopsis (Palaniyandi et al. 2013a, b). Similarly, many IAA produced Actinobacteria has been reported to increase plant shoot and root lengths. *Streptomyces* genus (Da Silva Sousa et al. 2008; Shrivastava et al. 2008), *Frankia* sp. (Sivasithamparam et al. 2003), *Nocardia* sp. (El-Tarabily and Sivasithamparam 2006), *Kitasatospora* sp. (Shrivastava et al. 2008) have been broadly considered as IAA producers. IAA helps for the germination of *Streptomyces atroolivacezlz* spore by acting as an endogen regulator and also involved in the actinobacteria differentiation. Three actinobacterial species, *Streptomyces olivaceoviridis*, *S. rochei* and *S. rimosus* cultures, not only produces IAA, but the studies indicated that they are excellent producers of cytokinin and gibberellins -like substances, also showed enhanced the growths in wheat plants (Aldesuquy et al. 1998).

The reports that supporting cytokinin producion by actinobacteria are very few when compared with IAA production. According to Joshi and Loria 2007, cytokinin producing Actinomycetes like *Streptomyces turgidiscabies* and *Rhodococcus fascians* are pathogenic to plants and causes tobacco leafy galls. *Streptomyces hygroscopicus*, an endophytic actinobacterium synthesised pteridic acids A and B along with auxin-like activity, promoted the hypocotyls of kidney beans adventitious roots formation (Ortı´z-Castro et al. 2008). *Streptomyces turgidiscabies* Car8 have a gene cluster for cytokinin biosynthesis and produces the leafy galls (Joshi and Loria 2007). An actinobacterium, *Arthrobacter globiformis*, was found to produce small amounts of a gibberellin-like substance.

6.10.3 Actinobacterial Siderophores in Crop Protection

Siderophores are low molecular weight, organic molecules chelating ferric ion produced by various microorganisms surviving under iron-limiting conditions, increases the uptake of iron in microorganism's compounds. The function of siderophore is to scavenge environmental ferric iron, which are inaccessible to microorganisms at physiological pH (7.35–7.40) and converted as mineral, which is virtually always essential and accessible to the microbial cell (Saha et al. 2015). In agriculture, siderophores promotes plant growth and can used equally as an eco-friendly biocontrol agent that substitute to harmful chemical pesticides. Iron is a micronutrient, in plants it is essential for redox reactions, chlorophyll biosynthesis and some other physiological activities. Iron limitation in soil significantly decreases the yield in agriculture sector. Microbial siderophores can be used as an efficient and easily available iron source in plants. Siderophore can also use as a prospective biocontrol representative against phyto-pathogens. Siderophores strongly bind with the iron, thus limits the availability of iron plant pathogens and enabling the killing of phytopathogens due to iron limitation (Ahmed and Holmstrom 2014). Numerous studies have been conducted to demonstrate the biocontrol role of siderophores in crop protection.

Actinobacteria is one the supreme group of microorganism involved in siderophores production. An endophytic Streptomyces sp obtained from the rhizosphere of a Thai jasmine rice plant produced considerable amount of Siderophore prompted plant growth and evidently raised root- shoot lengths and biomass (Rungin et al. 2012). Actinobacterial strains such as Thermobifida and Streptomyces MCR3 synthesis a great amount of hydroxamate-type siderophores using the glucose as the sole carbon source. The plants also have a mechanism to increasing the structure of microbial community around the root soil areas. They synthesize certain phenolic exudates from roots that enhances the development of additional siderophore-secreting microbes. This improves the iron solubility and moreover enhances iron uptake in plants (Jin et al. 2010).

6.10.4 Atmospheric Nitrogen Fixation by Actinobacteria

Nitrogen fixation in plants is referred as the assimilation of gaseous N into amino acids. Nitrogen fixation by actinobacteria have been broadly reported (Clawson and Benson 1999; Tjepkema et al. 2002). The heterotrophic actinobacteria necessitate carbon sources to acquire the energy essential for nitrogen fixation. Each bacteria varies in the ability of nitrogen fixation and carbon metabolism, showing dissimilar units in acetylene reduction assay (ARA). It is centred on distinguishing the existence nitrogenase enzyme, which reduces nitrogen (N2) to ammonium. This essay also estimates the enzymatic reduction of acetylene to ethylene. Most extensively studied actinobacterial nitrogen fixation is in *Frankia*, mostly it lives in symbiotic relationship with dicotyledons. It has an exceptional feature, the vesicles specialized for nitrogen fixation. The *Frankia* infected with plants through symbiosis are known as actinorhizal plants and produces root nitrogen-fixing nodules (Yamaura et al. 2010). Apart from Frankia, *Streptomyces thermoautotrophicus*, a thermophilic Actinobacteria can fix atmospheric nitrogen. The nitrogenase enzyme in *S. thermoautotrophicus* is O_2 insensitive, and also utilizes N_2 as nitrogen source, is exclusive in biological nitrogen fixation (Gadkari et al. 1992).

Several PGPA creates a symbiosis relationship between other nitrogen-fixing microorganisms. For example, *Streptomyces lydicus* WYEC108 induces root nodulation only after inoculating with *Rhizobium* sp in cow pea plant. It works as a nodule colonizes on the cell surface layers of the nodules, which increases nodule size and bacteriods vigour by enhancing iron and other nutrients assimilation. *Streptomyces kanamyceticus* revealed a negative effect in the nodule formation when they are inoculated with *Bradyrhizobium japonicum*. Though, the co-inoculation of *Streptomyces kanamyceticus* with *Bradyrhizobium japonicum,* an antibiotic-resistant strain, showed a positive effect in increasing root nodule vigour and number. This a very important observation specifies that Streptomyces producing antimicrobial substances masked the facilitate nodulation. The symbiosis with *Frankia* sp. actinobacteria such as *Micromonospora, Streptomyces* and *Actinoplanes* were capable to stimulating root nodule formation in *Discaria trinervis*. However, studies indicated that co-inoculation of *Frankia* mycelia did not encourage root nodulation. But, *Frankia* culture filtrates promoted root nodulation, suggesting the occurrence of nodule-inducing substances in culture filtrate (Solans et al. 2009). In addition, actinobacteria were described to stimulate symbiosis between plants and mycorrhizal fungi (Frey-Klett et al. 2007).

6.10.5 Phosphorus Solubilization by Actinobacteria

Phosphorus (P) is a key vital macronutrients for plants. Phosphorus deficiencies are wide spectrum because major phosphorus portion in soil is unavailable to plants, and mainly it is applied as phosphatic manure in soil. However, a major percentage of the used phosphorus is promptly immobilized and becoming inaccessible for plants due to the formation of metal complexes with Al, Fe and Si. Many soil microorganisms involved phosphorus transformation processes of soil, solubilizing soil phosphorus and accessible it for plants growth. Phosphate solubilization is widely exhibited in actinobacteria such as *Streptomyces, Micromonospora, Micrococcus, Thermobifida* and *Kitasatospora*. Although the mechanism behind actinobacterial phosphorus solubilisation is not fully understood. Actinobacteria with ability to solubilizing rock phosphate were reported that it promotes the wheat plants growth in vitro and in vivo conditions (Hamdali et al. 2008). Actinobacterial P-solubilizing strains have a dual benefit, they are revealed to suppress damping off affected by Pythium ultimum and also increased wheat growth in P-deficient soil. This dual assistance is advantageous in cumulative agricultural production (Oliveira et al. 2009). PGPA solubilize P by the producing organic acid and by acidification of rhizosphere. Furthermore, phosphorus availability is recognised by the chelating cations such as Fe^{+2}, Al^{+3} or Ca^{+2} helps in the solubilization of phosphate. Actinobacteria secretes phosphatases such as phytases and acidic/alkaline phosphatases which can hydrolyse phytate, constitutes up to 60% of soil organic phosphorus (Palaniyandi et al. 2013a, b). Actinobacteria such as *Nocardia* sp*., Micromonospora* sp*., Actinomadura* sp*., Actinoplanes* sp*., Rhodococcus* sp*., Microbispora sp. and Streptosporangium sp*. produce alkaline or acidic phosphatase enzymes, depending on reaction conditions.

6.10.6 Actinobacteria in Plant Biotic Stress Alleviation

Abiotic stresses like salinity, drought, heavy metal contamination and nutrient stress reduced agricultural productivity at a significant level. These stresses often cause the production of gaseous hormone ethylene in plants which negatively affects plant growth. Some PGPA have the ability to produce stress alleviating compound thus by enhancing plant growth by several mechanisms. One well studied mechanism is ACC deaminase production by actinobacteria. Enzyme ACC deaminase converts

ACC, an ethylene precursor in plants, to α- ketobutyrate and ammonia, in that way dropping stress at ethylene level and enlightening plant growth (Glick 2005). ACC deaminase activities were reported from some halotolerant actinobacteria such as *Corynebacterium variabile, Micrococcus yunnanensis,* and *Arthrobacter nicotianae*, promots canola plants growth under salt stress conditions (Siddiqui et al. 2010). ACC deaminase activity reported in Arthrobacter sp. EZB4 from pepper plants significantly reduced some osmotic stress-inducible gene expressions. ACC activity was also detected in Streptomyces filipinensis no. 15 strain. When this strain was co-inoculated with tomato plants, it significantly reduces ACC deaminase levels in roots and shoots and promotes plant growth (Sziderics et al. 2007). Recent studies on 29 actinobacterial strains from yam rhizosphere revealed only 6 were showed ACC deaminase activity, belonged to the genus Streptomyces (Palaniyandi et al. 2013a, b). Recently a novel type Actinobacterial drought stress tolerance was also reported. Inoculation of mountain laurel tissue-cultured seedlings with Streptomyces padanus AOK-30, an endophyte, showed callose accumulation in cell wall, which enhanced drought tolerance in seedlings.

6.10.7 Antagonistic Activity against Plant Pathogens

Actinobacteria have been recognised as one of the chief antagonistic microbe against some plant pathogens based on their ability to secrete metabolic compounds, which inhibit the pathogens growth by competing for nutrients. Antibiotics produces actinobacteria in rhizosphere region thus helps for inhibiting the growth of fungal pathogens, which in turn promots effective rhizosphere colonization. For example, antibiotics methyl vinyl ketone produced by actinobacteria alters pathogenic fungal morphology and finally kill them. Streptomyces genus have widely exploited for antibiotic production and have revealed antagonistic activity against *Pythium aphanidermatum, Alternaria* sp., *Colletotrichum higginsianum, Fusarium oxysporum and Acremonium lactucum* (Hong et al. 2002). According to Molano et al. an antibiotic actinomycin, synthesized by *Nocardia* sp. showed in vitro inhibition contrary to Fusarium oxysporum isolated from rhizosphere soil sample. Antifungal agents produced by Actinomycetes shows wide spectrum activity against plant fungal pathogens. An antifungal metabolite Mildiomycin, isolated from *Streptoverticillium rimofaciens* inhibits fungal protein biosynthesis and is intensely active against powdery mildews on various crops. The main site of action of these fungicide are the location of chitin synthesis in fungal cell walls. Examples of some actinobacterial antifungal agents and their functions are showing in Table 6.2. *Streptomyces lydicus* WYEC 108 producing water soluble biofungicide was permitted by Natural Industries Inc., TX, USA and registered as Actinovate soluble in 2004 and it effectively controls some common soilborne and foliar diseases.

Actinomycetes frequently produces hydrolytic enzymes against enormous spectrum of pathogenic fungi. Production of certain cell wall-degrading enzymes like glucanase and chitinase also causes fungal cell wall degradation and hinder the

Table 6.2 Actinobacterial antifungal agents and mode of actions

Antifungal agent	Producing Actinomycetes	Mode of action	References
Actinomycins	*Streptomyces anulatus*	Protein synthesis inhibition	Bister et al. (2004)
Validamycin	*Streptomyces hygroscopicus*	It inhibits enzyme trehalase	Iwasa et al. (1970)
Tetracenomycin	*Streptomyces canus*	Inhibits DNA replication	Zhang et al. (2013)
Resistomycin	*Streptomyces canus*	Inhibits DNA and RNA synthesis	Zhang et al. (2013)
Polyoxin B	*Streptomyces cacaoi*	Inhibits chitin synthesis	Isono et al. (1965)
Nikkomycin	*Streptomyces tendae*	Inhibits chitin synthesis	Bormann et al. (1985)
Streptothricin	*Streptomyces lavendulae*	Protein synthesis inhibition	Waksman and Woodruff (1942).
Natamycin	*Streptomyces natalensis*	Targets ergosterol in fungal membrane	Struyk et al. (1958)
Oligomycin	*Streptomyces diastatochromogenes*	Inhibitor for ATP synthase	Smith et al. (1954)
Fungichromin	*Streptomyces padanus*	Prevents oospore induction	Shih et al. (2003)
Kasugamycin	*Streptomyces kasugaensis*	Inhibits protein synthesis	Umezawa et al. (1965)
Amphotericin B	*Streptomyces nodosus*	Targets ergosterol in fungal membrane	Linke et al. (1974)
Transvalencin	*Nocardia transvalensis*	Squalene epoxidase inhibition	Hoshino et al. (2004)
Blasticidin	*Streptomyces griseochromogenes*	Inhibits protein synthesis	Takeuchi et al. (1958)
Galbonolides	*Streptomyces galbus*	Inhibits sphingolipid biosynthesis	Fauth et al. (1986)
Chloramphenicol	*Streptomyces venezuelae*	Prevents protein chain elongation	Matsuoka et al. (1953)
Candicidin	*Streptomyces griseus*	Targets ergosterol in fungal membrane	Acker and Lechevalier (1954)

growth. Chitin is an important structural component of fungal cell wall, composed by residues of N-acetyl-D-Glucosamine, which can hydrolysed by chitinase enzymes. Actinobacteria have been reported as the dominant organisms involved in the production of chitinase enzyme. *Streptomyces* species are the chief chitinolytic microbial group and promising fungal antagonist (Asha poorna and Pradeep 2016). Numerous chitinolytic enzymes have been recognised in some actinobacterial species such as *Streptomyces aureofaciens*, *Streptomyces antibioticus*, *Streptomyces lividens*, *Streptomyces halsteii* AJ-7, *Streptomyces plicatus*, and *Streptomyces lydicus* WYEC108.

Actinomycetes fungus antagonism is also related with the production of β-glucanase enzymess. A best effective fungal antagonist against *Phytophthora* spp is *Streptomyces* sp. EF-14 secreted β-1,3 glucanase and β-1,6 glucanase. Soil added *Streptomyces nigellus* strain NRC 10 reduced damping off diseases affected by *Pythium ultimum* in tomato plants. Studies designated that these strains are tremendous producers of β-1,4 glucanases and β-1,3 glucanases (Helmy et al. 2010). β-1,4, β-1,3, and β-1,6 glucanases produced from *Actinoplanes philippinesis, Micromonospora chalcea* and *Microbispora rosea* caused *Pythium aphanidermatum* hyphae lysis and thereby reduces cucumber damping- off disease (El-Tarabily 2006). Some *Streptomyces* strains produced β-1,3-glucanase such as CAI-24, CAI-127, CAI-121, KAI-32 and KAI-90 demonstrated significant *Fusarium oxysporum* f. sp. Cicero biocontrol activity causes Fusarium wilt of chickpea (Gopalakrishnan et al. 2013). According to Lekshmi et al. (2017) exo- β-1,4- glucanase activities in Streptomyces sp. are also considered as an indicator of environmental and soil quality changes.

6.10.8 Actinobacteria as Mycorrhiza (MA) Helper Bacteria

Bacteria also present inside mycorrhizas as colonies, hence the plants takes these strains as beneficial for the symbiosis. Microorganisms encourage the formation mycorrhiza through several activities, like fungal propagules stimulation in pre-symbiotic infective stages, enable the formation of inputs points in the roots and also increasing growth rate. Actinomycetes have the ability to promote mycelial growth that is correlated with their influence on mycorrhizal formation predominantly in hyphal growth promotion. Streptomyces also evolved in mechanisms to facilitate mycorrhiza formation by stimulating fungal growth and by reducing plant defence responses. At the time of rhizobacterial infection, plants attain a high resistance against plant pathogen attack. Later, the investigations revealed that such disease resistance have been induced by some endophytic *Streptomyces* sp. Based on the studies of Carpenter-Boggs et al. 1995, an actinobacteria, *Streptomyces orientalis*, have the ability to secrete volatile compounds, have an advantageous effect on *Gigaspora margarita* spore germination. An Auxofuran compound released by mycorrhiza helper *Streptomyces* spp. AcH 505 influences fungal metabolism and helps mycorrhizal formation by improving root colonization and also prompts a systemic defense response against mycorrhizal fungus (Schrey et al. 2007).

6.11 Conclusion

The current farming interest is predominantly placed in eco-friendly and sustainable agricultural practices. Efficient microorganisms and their products may improve plant growth in many ways compared to synthetic fertilizers, pesticide and insecticides and help in sustainability of environment and crop productivity. Nowadays sustainable agriculture is vital as it compromises the prospective to meet our agricultural necessities. This kind of agriculture fully utilized environmental resources through special farming technique and at the same time it is environment friendly and warrants healthy and safe agricultural foodstuffs. The practice of plant growth-promoting microorganisms, for improving fertility of soils, increasing crop yield and reducing the worst deleterious impact of chemical fertilizers, has developed as a most attractive strategies for emerging sustainable agriculture. The use of fungi and actinobacteria in agriculture offers an environmentally sustainable approach for agricultural production and overall global health. Hence, agro active natural compounds, effective for sustainable farming practices from fungi and actinobacteria are not fully illustrated and that are currently considered as a foremost research area in the field of agriculture, biotechnology and microbiology. Current and future advances in our knowledge about of diversity, mechanisms, applications and formulations of plant growth promoting microorganisms facilitating reliable development and management of sustainable agricultural systems.

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