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# Preface

The growth rate of the global population demands increasing food production. However, the increase in agricultural productivity is in many circumstances largely dependent on the use of chemical fertilizers that many farmers around the world do not have economic provision and can have a negative effect on the climate. Environmental stresses may also impede plant growth and yield, causing low crop productivity, which can impact global food safety. There must also be less use of chemical fertilizers and an increased plant tolerance for abiotic stresses in order to increase global agricultural production economically, ecologically, and sustainably. Plant growth-promoting microorganisms (PGPM) have a potential benefit to improve crop production, food, and safety in sustainable and more environmentally friendly agricultural systems. The use of beneficial microbes like fungi, bacteria, algae, cyanobacteria, and actinomycetes, those microbes which enhance the growth of plants under abiotic stressors including drought, salinity, waterlog, temperature extremes, mineral nutrients, heavy metal, and biotic stress conditions including plant diseases, nematodes, viruses, and diseases. The achievement of sustainable agriculture while maintaining environmental, agroecosystem functions and biodiversity is a major challenge to current agricultural practices and also poses serious risks for crop productivity, soil fertility, and nutritional value of agricultural production through the conventional use of chemical inputs (fertilizer, pesticides, nutrients, etc.). Given these threats, the management of pests and diseases, the preservation of the health of the agroecosystems, and the avoidance of public and animal health problems now become key priorities. Researchers, scientists, agriculturists, farmers, and policymakers have been very aware of PGPM as biofertilizers, plant growth promoters, biopesticides, and managers of soil and plant health. PGPM are receiving increasing attention from agronomists and environmentalists as candidates to develop an effective, eco-friendly, and sustainable alternative to conventional agricultural (e.g., chemical fertilizers and pesticide) and remediation (e.g., chelators-enhanced phytoremediation) methods employed to deal with climate change-induced stresses. Using PGPM will help satisfy the demand for global agricultural productivity, which is projected to hit approximately nine billion by 2050 to feed the world's growing population. To achieve this goal, however, PGPM strains must be environmentally friendly, be compatible with useful soil rhizobacteria, give considerable plant growth promotion and biocontrol potential, and can withstand different biotic and abiotic stresses.

This book provides up-to-date knowledge on biofertilizers and the roles of microorganisms in plant health, with specific emphasis on the mitigating strategies to combat plant stresses. The application of microorganisms for quicker, more cost-effective, and precise diagnostic procedures of plant disease control and antimicrobial mechanisms has been discussed in detail.

The first chapter by Shah et al. reviews Cyanobacteria and Algae as Biocontrol Agents Against Fungal and Bacterial Plant Pathogens. Chapter 2 by Monteiro et al. highlights Plant Growth Promoting Rhizobacteria in Amelioration of Abiotic Stresses: A Functional Interplay and Prospective. In Chap. 3, Jampílek and Kráľová describe Seaweeds as Indicators and Potential Remediators of Metal Pollution. The Role of Microorganisms in Managing Soil Fertility and Plant Nutrition in Sustainable Agriculture is described by Mohamed et al. in Chap. 4. In Chap. 5, Prasher and Sharma highlight the Role of Endophytic Bacteria in the Alleviation of Heavy Metals from an Ecosystem. Chapter 6 by Silva et al. provides insights into Microbial Enzymes and Soil Health. In Chap. 7, Yasmeen et al. state *Pseudomonas* as Plant Growth-Promoting Bacteria and Its Role in Alleviation of Abiotic Stress. In Chap. 8, Basit et al. highlight Plant Growth-Promoting Rhizobacteria (PGPR) as Biocontrol Agents for Viral Protection. Chapter 9 by Lonkar and Bodade describes the Potential Role of Endophytes in Weeds and Herbicide Tolerance in Plants. Almoneafy et al. in Chap. 10 detail the Auspicious Role of Plant Growth Promoting Rhizobacteria in the Sustainable Management of Plant Diseases. Chapter 11 by Basit et al. gives an overview of Microbial Bioactive Compounds Produced by Endophytes (Bacteria and Fungi) and Their Uses in Plant Health. Biosynthesis of Nanoparticles by Microorganisms and Applications in Plant Stress Control are discussed in Chap. 12 by Ramadan and El-Beltagi. Chapter 13 by Padhi and Behera explains Nano-enabled Approaches for the Suitable Delivery of Fertilizer and Pesticide for Plant Growth. Shanab and Shalaby give information about the Production of Plant Hormones from Algae and Its Relation to Plant Growth in Chap. 14. In Chap. 15, Misra and Ansari state the Role of Trichoderma in Agriculture and Disease Management. The Production of Antibiotics from PGPR and Their Role in Biocontrol of Plant Diseases are highlighted in Chap. 16 by Hamid et al. In Chap. 17, Jilani et al. describe the Role of Phosphate-Solubilising Microorganisms in Agricultural Development. Gören-Sağlam in Chap. 18 gives an overview of Cyanobacteria as Biofertilizer and Their Effect Under Biotic Stress. Shah et al. in Chap. 19 describe Microorganism: A Potent Biological Tool to Combat Insects and Herbivores. In Chap. 20, Ahmad et al. focus on Eco-Friendly Approaches for the Alleviation of Root-Knot Nematodes. In Chap. 21, Sharma et al. write on Rhizosphere, Rhizosphere Biology, and Rhizospheric Engineering. Finally, Siddiqua et al. explain Microbial Enzymes and Their Role in Phytoremediation in Chap. 22.

We wish to thank Springer officials, particularly C. Aishwarya and Shanthini Kamaraj, for their generous support and efforts in accomplishing this volume. We are highly delighted and thankful to all our contributing authors for their vigorous support and outstanding cooperation to write altruistically these authoritative and valuable chapters. We specially thank our families for consistent support and encouragement.

With a bouquet of information on the role of plant growth-promoting microorganisms for sustainable biotic and abiotic stress management, the editors hope that this book will be a valuable resource for students of different divisions; researchers and academicians, working in the field of nanoscience, nanotechnology, plant sciences, agriculture microbiology, and fungal biology; and scholars interested in strengthening their knowledge in the area of environmental microbiology.

Cairo, Egypt — Heba I. Mohamed
Al-Ahsa, Saudi Arabia — Hossam El-Din Saad El-Beltagi
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# About the Editors

**Heba I. Mohamed** is a Professor of Plant Physiology, Faculty of Education, Biological and Geological Sciences Department, Ain Shams University. Dr. Heba completed her M.Sc and Ph.D in Plant Physiology, Faculty of Education, Ain Shams University. Dr. Heba's research interests include biotic and abiotic stresses, plant biochemistry, use of eco-friendly compounds to alleviate plant stress, plant secondary metabolites, and genetic differences between different genotypes. She has published 8 book chapters, 1 review article, and more than 57 research articles in international peer-reviewed journals including *Agronomy*, *Plants*, *Molecules*, *Sustainability*, *Plant Physiology and Biochemistry*, *Biological Trace Element Research*, *Photosynthetica*, *European Journal of Plant Pathology*, and other journals. Dr. Heba is a reviewer of journals including *Plant Physiology and Biochemistry*, *Scientific Reports*, *The Journal of Horticultural Science & Biotechnology*, and *Journal of Soil Science and Plant Nutrition*. She also is editor of the *Microbial Biosystems* journal. Dr. Heba is a member of the project titled Genome wide association study (GWAS) of dodder tolerance in the model plant *Medicago truncatula* to detect key genetic factors and accelerate MAS in fodder legumes. Belonging to PHC IMHOTEP bilateral Egypt France cooperation in science and technology program 2019. Dr. Heba has obtained certificate of recognition in honor of achievement in international publication that supports Ain Shams University World Ranking 25/6/2012, 2017, 2018. Dr. Heba has obtained country encouragement prize in Cairo 2018.

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**Hossam El-Din Saad El-Beltagi, Ph.D.** is a Professor of Agricultural Biotechnology, College of Agriculture and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia, and a Professor of Biochemistry, Faculty of Agriculture, Cairo University, Giza, Egypt. Dr. Hossam's research interests include plant biotic and abiotic stresses, plant biochemistry, biotechnology, and plant secondary metabolites.He has published 5 book chapters, 1 review article, and more than 102 research articles in international peer-reviewed journals including *Food Chemistry*, *PLoS One*, *International Journal of Food Science and Nutrition*, *Food Biochemistry*, *Molecules*, *Sustainability*, *Animals*, *Antioxidants*, *Radiation Physics and Chemistry*, *Physiological and Molecular Plant Pathology*, *Grasas y acetes*, *Gesunde Pflanzen*, *Journal of Biotechnology*, *Notulae Botanicae Horti Agrobotanici cluj napoca*, *Fresenius Environmental Bulletin*, and *Journal of Medicinal Plants Research*. He is Associate Editor of many international journals by different publishers including *Journal of Advanced Research* from Elsevier and *Notulae Scientia Biologicae*. Dr. Hoosam attended more than 25 international conferences and workshops. He is a member of more than 8 international scientific societies. Dr. Hossam is a reviewer of more than 30 international peer-reviewed journals from many publishing houses. He received many Prizes including Ministry of Higher Education Prize for International Publishing Award in top Eigenfactor Score journal 2012; Country Encouragement Prize for Agriculture Sciences, 2013; Cairo University Encouragement Prize in advanced technological sciences 2013; and Cairo University scientific excellence Prize in the field of interdisciplinary environmental science 2015. Dr. Hossam served as visiting professor in Biochemistry Department at College of Science in Granada University, Spain 2017. He served as Consultant in Deanship of Scientific Research in King Faisal University since 2019 to date.

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# Chapter 1
# Cyanobacteria and Algae as Biocontrol Agents Against Fungal and Bacterial Plant Pathogens

**Syed Tanveer Shah, Abdul Basit, Izhar Ullah, and Heba I. Mohamed**

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# 1 Introduction

Present sustainable agricultural farming is severely reliant on an intensive use of tillages, excessive fertilizer use and irrigation, and chemical pesticides; with no doubt, the food requirement of the majority of countries has been fulfilled, even though this raised many health and environmental problems. Now the question of enhancing the crop production in agriculture sector without deteriorating the environment and harming water resources and land/soil fertility has arisen (Singh and Strong 2016). The need of quality environment and food crops production can be fulfilled with sustainable practices of agriculture (Singh and Strong 2016); this philosophy of sustainable agricultural production includes environmentally friendly farming with low cost through natural techniques of resources conservation, i.e. water and soil, maintaining the crop profitability and productivity and also making the agricultural ecosystem self-regulating and resilient (Koller et al. 2012). For the last few decades, green energy production of various processes of microbes has attained great attention as a sustainable technique for biofuel generation, namely, ethanol, butanol, methane (CH4), syngas and $H_2$. Recent studies reported remarkable growth in cyanobacterial biomass production for biofertilizers; a different supplement of foods, i.e. superfoods; and biofuels for farming of safe agricultural production (Benson et al. 2014).

A highly diversified group of various microorganisms have been found in association to different plant species in the endosphere, rhizosphere and phyllosphere. These microorganisms associated to plants and known for metabolite production may have a neutral, beneficial or harmful impact on crop productivity (Mendes et al. 2013). Ever since, the approach of sustainable crop protection can be characterized by synthetic pesticide alternatives, i.e. derived compounds and microorganisms of plants (Gwinn 2018). Amongst all the alternatives, cyanobacteria and algae are distinguished bioactive agents which have gained a remarkable consideration by scientists globally.

Phytopathogenic biocontrol agents (Fig. 1.1) in the very wide-ranging sense encompass the methods for utilization of organisms except for human. Remarkable research literature can be found as a result of this long-lasting present strategy, with an impetus principle of the enhanced activity and limitations to the application of chemical pesticides. This also included high costs of purchase, concerns to the environment and the highly increased regulations and restrictions of governments. Cyanobacteria, autotrophic blue-green algae which are known to be the most diverse, largest and abundantly distributed group of small, prokaryotic, unicellular and photosynthetic organism, found specifically in fresh and marine water, all together with eukaryotic algae ‘could have been the world’s largest biomass’. As a promising biocontrol agent growing in huge colonies and causing plant diseases, no great attention has been attained by cyanobacteria (Pisciotta et al. 2010). Cyanobacteria with diversified sizes and shapes have covered 150 identified genera with the features of oldest-ever fossils of 3.5 billion years, approximately, and are responsible for the oxygenic environment of the current days (Hoekman et al. 2012).

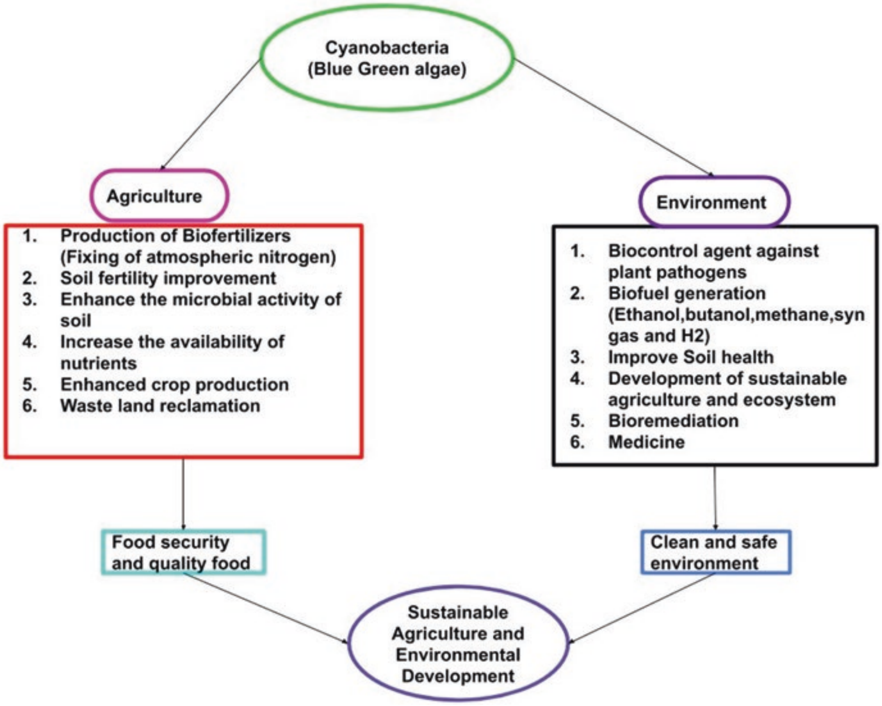


**Fig. 1.1** The theoretical framework shows potential cyanobacterial functions in the environment or sustainable agriculture

A proposed classification of cyanobacteria since 1985, with four bacterial orders, has been recognized, namely, *Oscillatoriales*, *Chroococcales*, *Stigonematales* and *Nostocales*, with their phyla *Gloeobacterales*, *Pleurocapsales* and *Chroococcales*. Cyanobacteria are associated with the periods of origin of plants. The cyanobacteria are immensely important in determining the path of evolution and ecological changes all over the earth's history. In the late Proterozoic or the early Cambrian period, cyanobacteria began to take up residence within certain eukaryote cells, this event is called endosymbiosis, for the origin of the eukaryotes. They have the potential to fix atmospheric nitrogen, so that could be used as a biofertilizer for the cultivation of economically important crops such as rice and beans (El-sohaimy 2012; Meena et al. 2019; Koller 2015) (Fig. 1.1). Mostly, the eukaryotic algae have been categorized in 18 different taxonomic classes (Wainwright et al. 1993), where a majority of the algae can be found either in marine or in freshwater habitats and almost 147 genera have a large number of species found in soil. They are mostly photosynthetic; however, a great number are heterotrophic facultative species while few are non-photosynthetic (heterotrophic obligates). These are largely untapped and rich sources of a varied wide collection of naturally active products. This chapter is aimed to understand cyanobacteria as an alternative for sustainable development without the harmful effect of chemicals, synthetic fertilizers and other pesticides/insecticides, to elaborate the antifungal and antibacterial activities of cyanobacterial extract against pathogenic colonial growth and to study the role of Cyanobacteria as a source of exopolysaccharides to improve soil structure and microbial growth.

## 2 Cyanobacteria and Algae Against Phytopathogens

Since a long time, cyanobacteria and algae have been used scarcely as beneficial extracts against pathogenic fungus because of their stimulation effect for plant productivity and vigour. They have also been used as media substrates for microbial cultures and biofuel production (Fig. 1.1). A fungal pathogen may be responsible for causing infection in cultivated cropping systems, severe postharvest losses and fruit decay. *Schlerotinia sclerotiorum* and various other species of *Fusarium*, *Rhizoctonia*, *Verticillium*, *Pythium* and *Phytopthora* are known to be the most significant polyphagous fungi found in soil (Pastrana et al. 2016). While hindering water absorption and nutrients in the soil, they directly attack root structures and cause wilting, damping off, yellowing, root rot and color rot. Amongst leaf-related pathogens, fungus of Erysiphales order are strong mediators of the disease powdery mildew causing huge economic losses, thus the need for various applications of chemicals (Romero et al. 2007; Jarvis et al. 2002). *Colletotrichum* spp. and *Botrytis cinerea* are the vectors for anthracnose and grey mould, respectively, and many other *Rhizopus*, *Mucor* and *Penicillium* species are the fungal pathogens which are responsible for postharvest losses and fruit decay (Husaini and Neri 2016). Such fungal pathogens could be controlled normally by the fungicidal applications during the time of growing crop cycle from the time of flowering to harvest time.

### *2.1 Cyanobacteria: A Prevalent Evolutionary Phylum*

The most successfully emerged phyla of prokaryotes which were sustained during the evolutionary course were cyanobacteria. They are known to be the most primitive forms of life on the Earth planet, and their evidence reported chloroplasts with eukaryotic photosynthesis have their origin from cyanobacteria, bringing about the evolutionary aerobic respiration as long time ago (2.22–2.45 billion years) (Dixit and Suseela 2013; Gothalwal and Bajpai 2012). Even though the autotrophic nutritional mode is more dominant while some of the species of cyanobacteria can grow well in dark and anaerobic environments including *Oscillatoria* and *Nostoc*, few cyanobacterial species, i.e. *Nostoc*, can also function in atmospheric nitrogen fixation (Yadav et al. 2011; Uzair et al. 2012). However, cyanobacteria can be included in those phyla where simple and unicellular structures have developed complex and multicellular structures during the evolutionary era (Schirrmeister et al. 2011). Extending from a range of unicellular gram-negative to colonial and multicellular filamentous forms (Singh et al. 2011), being the principal phytoplankton constituent, this provides sufficient opportunity to exploit them as a secondary metabolite producer. Along with so many applications in nutraceuticals, pharmaceuticals, food and feed industries, the ecological, morphological and genetic cyanobacterial diversity has led to the wide array of compound production (Tan 2007).

### 2.1.1 Antifungal Activity

Cyanobacteria have been found to be the most significant source of naturally occurring bioactive compound with antiprotozoal, antimicrobial, antibacterial, antiviral, anti-proliferative and anticancer activities (Dixit and Suseela 2013; Russo and Cesario 2012; Simmons et al. 2008). Many authors revealed efficiency against the growth of the fungal colony of various phytopathogens is among the different activities of cyanobacteria (Table 1.1). Many studies have observed numerous species of *Nostoc*, *Microcystis* and *Anabaena*. Crude source of ethanol extracted from *Anabaena laxa* reported an inhibitory effect and a counter to various fungi, namely,

**Table 1.1** Antifungal activity of cyanobacterial extracts on plant pathogenic colonial growth

| Cyanobacteria | Pathogen | References |
|---|---|---|
| *Anabaena* sp. | *Alternaria alternata, Botrytis cinerea, Colletotrichum gloeosporioides, Fusarium oxysporum* | Kim (2006) |
| *Anabaena* sp. | *Macrophomina phaseolina, Fusarium moniliforme, Alternaria solani, Pythium aphanidermatum, Fusarium solani* | Prasanna et al. (2008) |
| *A. laxa* | *F. moniliforme, F. oxysporum* f. sp. *lycopersici* | Prasanna et al. (2015) |
| *Anabaena variabilis* | *F. moniliforme, F. oxysporum* f. sp. *lycopersici* | Prasanna et al. (2015) |
| *A. variabilis* | *Aspergillus Niger, A. solani* | Tiwari and Kaur (2014) |
| *Calothrix* sp. | *A. alternata, B. cinerea, C. gloeosporioides, F. oxysporum, Phytophthora capsici, Pythium ultimum* | Kim (2006) |
| *Microcystis aeruginosa* | *F. Oxysporum, M. phaseolina, P. aphanidermatum, Pythium oedochilum, Rhizoctonia solani* | Khalid et al. (2010) |
| *Microcystis aeruginosa* | *Aspergillus flavus, Fusarium verticillioides, Fusarium proliferatum* | Marrez and Sultan (2016) |
| *Nostoc* sp. | *A. alternata, B. cinerea, C. gloeosporioides, F. oxysporum, P. capsici, P. ultimum, Rhizopus stolonifer* | Kim (2006) |
| *Nostoc commune* | *F. oxysporum* f. sp. *lycopersici* | Kim and Kim (2008) |
| *Nostoc entophytum* | *R. solani* | Osman et al. (2011) |
| *N. muscorum* | *R. solani* | Osman et al. (2011) |
| *Chlorella* sp. *Halopithys* sp. | *R. solani* | Righini et al. (2020) |
| *Anabaena* sp. *Ecklonia* sp. *Jania* sp. | *Botrytis cinerea* | Righini et al. (2019) |

*Candida albicans*, *Aspergillus oryzae*, *Saccharomyces cerevisiae*, *Trichophyton mentagrophytes* and *Penicillium notatum*. The colony growth of *Fusarium moniliforme* was reduced by 23 different Anabaena strains observed in a screening (Prasanna et al. 2008), whereas *Alternaria solani* and *Nostoc muscorum* were observed as an effective counter to *R. solani*, inhibited by 17 several strains. Different *Anabaena* and *Calothrix* strains carried action countering to various species of *Rhizoctonia* and *Pythium* (Manjunath et al. 2010). *Nostoc muscorum* is known to be effective against *R. solani*, and was effective and inhibited the colony growth more than *N. entophytum* (Osman et al. 2011). Among all the compounds synthetized by cyanobacteria, chitosanase homologues, endoglucanase and benzoic acid were detected, and their presence was correlated to the activity against fungi (Gupta et al. 2011). The terpenoid noscomin, as an extract of *N. commune*, was tested to function against *Escherichia coli*, *Bacillus cereus* and *Staphylococcus epidermidis* (Jaki et al. 2000). Methanolic extract taken from *M. aeruginosa* exhibited an activity of fungus contrary to seven different pathogens of human and eight saprophytic and five phytopathogens (Khalid et al. 2010). *M. aeruginosa* strain revealed the growth inhibition of *Aspergillus flavus* and *A. niger* and *Fusarium verticillioides* (Marrez and Sultan 2016).

### 2.1.2 Antibacterial Activity

Recently, nosocomial infections (Enterococci and *Staphylococcus aureus* resistant to vancomycin and methyicillin, respectively, Amp C β-lactamase produced by Enterobacteriaceae) showing a big threat worldwide and a challenge to therapeutic studies are caused by bacteria resistant to multidrug (Reinert et al. 2007). Cyanobacteria having antibacterial activity and possibly energetic against bacteria are of great importance to scientists to produce new antibiotics (Biondi et al. 2008). Noscomin shows antibacterial activity against *Escherichia coli*, *Staphylococcus epidermidis* and *Bacillus cereus* taken from *Nostoc commune* (Jaki et al. 2000). Furthermore, stronger inhibition of green algea as compared to cyanobacteria was observed from isolated Nostocine A from *Nostoc spongiaeforme* (Hirata et al. 2003), while the growth of other cyanobacteria and green algae was introverted by *Nostoc*-isolated nostocarboline (Blom et al. 2006). Growth of *Salmonella typhi* MTCC3216, *E. coli* ATCC25992, *Mycobacterium tuberculosis* H37Rv, *Enterobacter aerogenes* MTCC2822, *Staphylococcus aureus* ATCC25923 and *Pseudomonas aeruginosa* ATCC27853 was inhibited by hapalindole isolated from *Fischerella* sp. and *Nostoc* CCC537, thus showing antimicrobial activity (Asthana et al. 2009).

### 2.1.3 Control of Diseases

Some studies are carried out on cynobacterial activity on the suppression of plant pathogen both in plant (especially leaf portion) and soil. The activity of *R. solina* was significantly reduced by *N. entophytum* and *Nostoc muscorum*, which also increased the survival rate, plant height, dry weight of root and shoot of soybean (Osman et al. 2011). Wilt disease of tomato caused by *F. oxysporum* was significantly controlled by *Nostoc linckia* when applied in soil (Alwathnani and Perveen (2012). Powdery mildew caused by *P. xanthii* in zucchini was significantly reduced by application of *Anabaena* sp. which also enhanced the defense enzyme activities (Roberti et al. 2015) which were also confirmed by Prasanna et al. (2015) in maize.

## *2.2 Algae*

A varied assemblage of photosynthetic species mostly aquatic is known as algae. Algae mostly include green algae which are unicellular organisms (*Chlorella*) and seaweeds which are marine multicellular algae (*Sargassum*). Table 1.2 shows the

**Table 1.2** Classification of algae

| Phylum/class | Alga species |
|---|---|
| Chlorophyta | *Caulerpa sertularioides* |
| | *Chlorella* |
| | *Ulva lactuca* |
| | *Zygnema czurdae* |
| | *Zygnema stellinum* |
| | *Zygnema tenue* |
| Phaeophyceae | *Ascophyllum nodosum* |
| | *Cystoseira myriophylloides* |
| | *Ecklonia* sp. |
| | *Ecklonia kurome* |
| | *Durvillaea potatorum* |
| | *Fucus spiralis* |
| | *Laminaria digitata* |
| | *Leathesia nana* |
| | *Padina gymnospora* |
| | *Pelvetia canaliculata* |
| | *Sargassum* |
| | *Sargassum filipendula* |
| | *Sargassum liebmannii* |
| | *Stypopodium zonale* |
| | *Undaria pinnatifida* |
| Rhodophyta | *Corallina* sp. |
| | *Eucheuma denticulatum* |
| | *Gelidium pusillum* |
| | *Gracilaria edulis* |
| | *Halopithys* sp. |
| | *Kappaphycus alvarezii* |
| | *Porphyra umbilicalis* |
| | *Rhodomela confervoides* |

different phyla that include red algae (Rhodophyta), chlorophyta (green algae) and Ochrophyta (brown algae) (Guiry 2012). Algal composition is effected by harvest season, compounds such as polysaccharides and geographic location (Schiener et al. 2015), essential nutrients (Cu, Zn, Mn, Co, Mo etc.) and plant hormones (auxins, abscisic acid and cytokinins (Craigie 2011). Furthermore, algae also show antiviral, antioxidant, antimicrobial and antifungal activities which have many applications in cosmetics, bioactive substances, pharmaceuticals and pigments production (Sharma and Sharma 2017). Due to all these properties, algal application plays an important role in soil fertility and crop productivity (Arioli et al. 2015) in different agronomic and horticultural crops (Alam et al. 2013). The increment in postharvest life, disease control and resistance to biotic and abiotic stresses was reported in fruits due to the application of various algal extracts (Esserti et al. 2017).

### 2.2.1 Antifungal Activity

Several studies have shown the direct importance of pathogen resistance by algal extract (brown algae) having antifungal activity. Mycelial growth of *Aspergillus* spp. and *Penicillum* spp. and *Fusarium oxysporum* was significantly reduced by cyclohexanic and aqueous extracts from *Sargassum* sp. (Khallil et al. 2015). Colonies of *Rhizoctonia* and *Fusarium solani* were inhibited by *Padina gymnospora* and *Sargassum laftifolium* which contain methanolic extract (Ibraheem et al. 2017). *Ascophyllum nodosum*, *stypopodium zonale*, *Fucus spiralis*, *Pelvetia canaliculata* and *Sargassum muticum* extracts contain terpenes and phenols which can suppress the growth of *Colletotrichum lagenarium* (Fernandes Peres et al. 2012). De Corato et al. (2017) reported that the mycelial growth and germination of spores of *Botrytis cinerea* were completely inhibited by *Undaria Pinnatifida* and *Laminaria digitata*. Furthermore, *Gracilaria edulis* that contains methanolic extract significantly inhibits the mycelial growth of *Macrophomina phaseolina* (Ambika and Sujatha 2015) while water extract obtained from *Gracilaria edulis* minimized infections of *Corallina* sp. and *Halopithys* in zucchini (Roberti et al. 2016). Brown algae (*Leathesia nana*) and red algae (*Rhodomela confervoides*) contain bromophenol bis(2,3 dibrom-4,5- dihydroxybenzyl) ether which is an antifungal substance which reduced *B. cinerea* growth and *Colletotrichum gloeosporioides* (Liu et al. 2014). An extract acquired from *Chlorella vulgaris* (green microalgae) by process of enzymatic digestion can reduce the growth of *B. cinerea* (El-ghanam et al. 2015) and showed antifungal activity associated with flavonoids and phenols. These antioxidant compounds are found abundant in alga (Ahmed 2016).

### 2.2.2 Antibacterial Activities

Active metabolites such as alkaloids, sterols, peptides and phlorotannins produced by marine macroalgae have a wide range of biocontrol activities against different pathogens in the ecosystem (Abdel-Raouf et al. 2015) which have attained much consideration due to their antibacterial, antioxidant and cytotoxic properties (Moubayed et al. 2017). For example, leaf spot disease of *Gymnema sylvestre* (a precious medicinal plant) caused by *Pseudomonas syringae* can be minimized by methanolic extract obtained by *Sargassum wightii* (Kumar et al. 2008) but the little effect has been shown by ethyl acetate extract. Several other studies have shown that other taxa (*Turbinaria conoides*, *Ulva lactuca*, *G. verrucosa*, *Chaetomorpha antennina* and *Halimeda tuna*) have less effective antibacterial activities against *P. syringae* though an evident effect was recorded by acetonic extract from *Sargassum polyceratium* (brown macroalga) against *Erwinia carotovora*, *Escherichia colia*, etc. (Kumar et al. 2008). Now ethanolic extract acquired from *Caulerpa racemosa* and *S. polyceratium* can work actively against *Staphylococcus aureus* (Arunkumar et al. 2005). Esserti et al. (2017) reported a reduction of crown gall disease of tomato caused by *Agrobacterium tumefaciens* by foliar application of aqueous macroalgal solution obtained from *Fucus spiralis* and *Cystoseira myriophylloides*.

### 2.2.3 Control of Diseases

The effectiveness of algal extract through soil or foliar application against different diseases has been reported in different crops in which disease control ability of brown algal extract is extensively reported (Righini et al. 2018). *E. maxima* algal extract applied through soil minimized the incidence of *Verticillium* wilt of pepper (Rekanović et al. 2010), while *Ecklonia* sp. algal extract applied as foliar spray was effective against powdery mildew in zucchini caused by *P. xanthii* (Roberti et al. 2016). This fungal activity is due to the antioxidant activities of secondary metabolites especially phenols that work both against plant and human pathogens. Moreover, Nagayama et al. (2002) reported the effectiveness of phlorotannins (algal phenols) acquired from *Ecklonia kurome* against methicillin-resistant *Staphylococcus aureus*. Athukorala et al. (2006) described the anticancer and antioxidant activity of *Ecklonia cava* phenols which was effective against murine colon cancer cell line CT-26.

In a 2-year experiment, Pugliese et al. (2018) reported minimizing powdery mildew (causal agent: *Erysiphe necator*) in grapevine by applying laminarin which also controlled powdery mildew and leaf spot in several strawberry cultivars which were caused by *B. cinerea* and *M. fragariae*, respectively (Meszka and Bielenin 2011). Furthermore, the application of laminarin can be used as an alternative against grey mould in raspberry (Krawiec et al. 2016) and disease severity in strawberry caused by (Feliziani et al. 2015). *B. cinerea* hence can reduce *B. cinerea* resistance to fungicide (Krawiec et al. 2016). Bromophenol (BDDE), a compound extracted from brown algae and red algae, can be used to treat strawberry for disease control caused by *B. cinerea* (Liu et al. 2014).

As previously mentioned, algal extracts can work directly (antifungal activity) or indirectly (induce plant resistance) against a fungal pathogen. In particular, it has been shown that cell wall and storage polysaccharides from green, brown and red seaweeds (marine macroalgae) corresponding to ulvans, alginates, fucans, laminarin and carrageenans can trigger defense responses in plants enhancing protection against pathogens (Vera et al. 2011). Extracts obtained from brown algae (*A. nodosum*) is successfully investigated on many plant species especially in carrot against *Alternaria radicina* (Jayaraj et al. 2008) and cucumber against *F. oxysporum*, *Alternaria cucumerinum* and *B. cinerea* (Jayaraman et al. 2011). This might be due to their role to enhance enzymatic activities and synthesis of pathogenesis-related proteins (PRs) by brown algal extract (Abkhoo and Sabbagh 2016). *Sargassum filipendula* extract (Ramkissoon et al. 2017) and polysaccharide-enriched extract from green algae *Ulva lactuca* (Hernández-Herrera et al. 2014) are effectively used to control disease symptoms in tomato caused by *Xanthomonas campestris* and *A. solani*, respectively.

## 3 Role of Algae in the Agriculture Sector

A diversified class of microbes that can perform photosynthesis is known as algae, which play a vital role in agriculture, used as a soil stabilizer and biofertilizer. Seaweeds from algal source can be grown on arid, desert and waste lands with very low demand of water and are used as a fertilizer and more effective to reduce runoff of phosphorus and nitrogen as compared to seaweed obtained from manures of livestock producing a carbon-less and healthy food. These are produced around the world which can be consumed as food supplements. These are an essential source of iodine, and levels of iodine in milk depend upon the feeding mechanism of a cow which is increased by application of seaweeds. Feed seasonings with algae enhanced the rate of egg-laying in hen (Abdel-Raouf et al. 2012).

## 4 Biocontrol Strategy of Phytopathogen

The protection of plants by using precise and directed components of an ecosystem is termed as biocontrol. Similarly, biological control is the regulation of pests' population by use of biotic organisms, i.e. parasites, predators, and pathogens. It is also the use of organisms that live inside the host cells or utilization of introduced organisms other than host plants resistant to the diseases for combating multiplication in their populations. They are classified based on their contribution to controlling phytopathogen attacks like facultative symbionts of plants and hyperparasites, and saprophytes. The use of environmentally friendly methods like biological control is of great importance in maintaining the natural balance of pest population and is a slow process, acquiring few quick profits, but their effect is long-lasting and environmentally friendly.

### *4.1 Biological Control of Phytopathogen by Cyanobacteria*

Different alternative methods of synthetic pesticides by natural microbial sources and light components have been used for controlling the attack of the pathogen in different ways as agents of insecticides, fungicides, and acaricide (Hassan 2007; Safonova and Reisser 2005; Amer et al. 2000; Ibraheem and Abdel-Raouf 2007; Duke 2002). These environmentally friendly methods despite their lethal effect on pests are widely used for maintaining the health of the environment and fauna distribution without effecting beneficial organisms. Biological agents like fungi and bacteria have been used for control of soil-borne pathogens. Various concentrations of nitrogen-fixing cyanobacterium (*N. muscorum* Ag) were used against damping-off disease. It was observed that the growth of damping causal agents like *Sclerotinia sclerotiorum* and *Rhizoctonia solani growth was inhibited by the use of* extracts from cells of *N. muscorum* or by extracellular products of this cyanobacterium (Caire et al. 1997). The usage of biological control agents like different algal taxa of different habitats was found effective against different plants or animal diseases and also against some plant pests. Some other studies were reported about the residual effect of algal sources against insect pests (Nassar et al. 1999). They also reported the larval development inhibition and the development and survival delay of adult female mosquitoes by cyanobacteria- and green algae-producing substances. The production of some potential substances by blue-green algae is of great importance quantitatively which acts as an approach to integrated pest management, and also a suitable environmental system of disease control revealing the significance of biological control agent as a basic component of techniques for the management of pests (Hassan 2007).

### *4.2 Exopolysaccharide*

Cyanobacteria can be counted as the most significant source of exopolysaccharides, the extracellular polymers with changed chemical composition improving microbial growth and soil structure, as well as exoenzymes activity (Hamed 2007; Ibraheem 2007). Sustainable agricultural farming to yield high crop production could be achieved by maintaining an adequate quantity of organic matters available in the soil. Cultivation of crops on soil with adequate nutrient changes the structural characteristics of soil and causes reduction of nitrogen amount and organic matter. Reduction in organic matter availability in the soil disturbs the soil aggregate stability. Some cyanobacteria increase the availability of nutrients and improve soil structure by excreting mucilage or slime which spread all around the organism to an extent of dissolution in the soil solution or culture medium partially. The reclamation of uncultivated soil such as saline and calcareous soil could be made suitable for agricultural operations by application of algal biofertilizers (Hedge et al. 1999). *N. muscorum is* one of the cyanobacteria that excrete exopolysaccharides and enhance the overall saline soil stability (Caire et al. 1997).

## 5 Role of Cyanobacterial Products on Antagonistic Activity of Fungal and Bacterial Agents

Wide-ranging mechanisms have been used as defensive agents against pathogen development and disease incidence by showing different responses, i.e. to prevent, combat or control plant disease. For achieving maximum productivity and quality products, most of the growers depend on inorganic fertilizer and pesticides. However, the excessive use of agrochemicals for controlling disease and pest attack causes environmental pollution, adversely affecting the health of the environment, and also fear-mongering by some challengers of pesticides which significantly changed the attitude of people towards chemical pesticide use in the agriculture sector. Many plant diseases could be successfully controlled with the application of biocontrol agents, i.e. antagonistic microorganisms. However, their effect is very slow and costly, but its effect is time lasting and acts as the best control method of disease in greenhouse farming. The concern of people towards pesticide use as a preventive measure against pest and disease problems has brought the increasing interest in using alternatives to inorganic pesticides. Currently, few eco-friendly biological control vectors were used to control plant pathogenic fungi causing soil-borne disease. The biologically active compound produced by cyanobacteria (blue-green algae) and eukaryotic algae exhibiting antifungal, antibiotic and toxic activity counters to phytopathogens (Schlegel et al. 1998). *Anabaena* spp., *Scytonema* spp. and *Nostoc* spp. were found active against the growth of *Cunninghamella blakesleeana* (soil-borne fungus) and damping-off (Bloor and England 1989). Seeds were treated with culture filtrates, or extracts produced by cyanobacteria and algae performed better against damping-off fungi, i.e. *Pythium* spp., *Rhizoctonia solani* and *Furarium* spp. (Kulik 1995).

## 6 Mechanism of Interaction Between Pathogenic and Plant Diseases Biocontrol Agent

A combination of different types of interaction between organisms results in biological control under different experimental conditions; many mechanisms are operated during the characterization of mechanism followed in the biocontrol process. Almost in all conditions, the presence and activities of other organisms encounter the antagonistic effect of pathogens. Therefore, the adaptation of different antagonistic mechanisms produced by the directional spectrum associated with the specificity of interactions and the interspecies contact quantity has been focused in this study (Fig. 1.2).

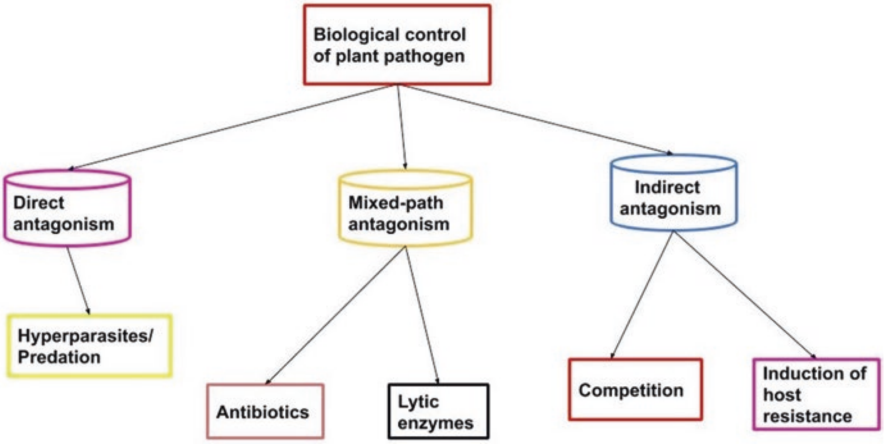


**Fig. 1.2** Mechanism of interaction between pathogenic and plant diseases biocontrol agent

### *6.1 Hyperparasites and Predation*

In hyperparasitism, biological control agents (BCA) are used to kill directly the pathogen or its propagules. Generally, hyperparasites are classified into major four classes, i.e. hypoviruses, obligate bacterial pathogens, facultative predators and parasites. An obligate bacterial pathogen of root-knot nematode, i.e. *Pasteuria penetrans*, was used as an agent of biological control. Hyperparasites such as hypoviruses (a fungus, i.e. *Cryphonectria parasitica*) that cause chest nut diseases were infected by virus that shows the effective result in reducing the disease-producing ability of the pathogen (hypovirulence) (Milgroom and Cortesi 2004). However, the success or failure of hypovirulence is dependent on the interaction of viruses, fungus, trees and the environment. A number of plant pathogenic fungal parasites have been specified where some of them like *Coniothyrium minitans* attack on sclerotia and others like *Pythium oligandrum* attack on living hyphae, whereas hyperparasites attack on the individual fungal pathogen, e.g. pathogens of powdery mildew were parasitized by a small fungal group, i.e. *Acrodontium crateriforme*, *Acremonium alternatum*, *Ampelomyces quisqualis*, *Cladosporium oxysporum* and *Gliocladium virens* (Kiss 2003). Some other attack on different developmental stages of phytopathogenic nematodes (e.g. *Dactylella oviparasitica*, and *Paecilomyces lilacinus*). Microbial predation compared to hyperparasitism gives less predictable results of disease control and is more general and pathogen nonspecific. However, some under limited availability of nutrients show predatory behaviour compared to typical growing conditions. Some species of *Trichoderma* show differential response by activating the chitinase genes that are helpful against the cell wall of fungi to parasitize *R. saloni*.

### 6.2 Antibiotic-Mediated Suppression

Antibiotics are known as microbial toxins which damage or kill different other organisms a minute quantity. Some of the microbes are considered as an important source of producing and secreting either single or many compounds with an antibiotic action which play an effective role in suppressing disease-causing plant pathogens. The growth of the target pathogens has been significantly suppressed by using antibiotics in vitro/in situ. Different biocontrol agents are important means of in situ antibiotics production (Pal and McSpadden 2006); moreover, estimated effective quantities are hard to measure because of their small quantity products as compared to other less toxic organic compounds available in the phytosphere. The suppression of diverse microbial competitors could be resolved by the production of antibiotics. Biological control could be enhanced by the production of antibiotics that inhibit the activity of different pathogens differentially. Phenazine and DAPG were produced by genetically engineered strains of *Pseudomonas putida* WCS358r and have been found effective by suppressing phyto-disease in wheat grown in the field (Glandorf et al. 2001).

### 6.3 Lytic Enzymes and Other By-Products of Microbial Life

The activity and growth of pathogen were significantly effective in the production of metabolites of a diverse group of microorganisms. Many microbes are used in suppressing plant pathogen activity directly by secreting lytic enzymes which hydrolyze several polymeric compounds, i.e. chitin, proteins, cellulose, hemicellulose and DNA. Biocontrol activities of *Lysobacter enzymogenes* strain C3 significantly show a positive response by a b-1,3-glucanase (Palumbo et al. 2005). The fungal plant pathogen is suppressed by *Lysobacter* and *Myxobacteria* that produce a significantly large number of lytic enzymes (Bull et al. 2002). In addition to these, indirect suppression of disease could be achieved by the activity of some products of the lytic enzyme. Oligosaccharides obtained from the cell wall of fungus are identified as an important source of plant host defense induction. Plant host resistance against diseases was achieved by a strain of *Lysobacter enzymogenes* (C3) (Kilic-Ekici and Yuen 2003), though induction of these activities is not clearly understood. The ratio and composition of C:N of organic matter in the soil is mostly dependent on the activity of any and above compounds in disease suppression of phytopathogens that play a major role in providing a nutrient-rich environment in the soil and rhizosphere. Sometimes maximum disease suppression could be achieved by the improvement of these activities. The use of chitosan as a postharvest biocontrol agent can stimulate the damage of microbial activity similar to that of using hyperparasites (Benhamou 2004) and also found effective against root rot caused by *Fusarium oxysporum* f. sp. *radices lycopersici* in tomato plant.

# 7 Role of Cyanobacteria in Crop Protection

## *7.1 Cyanobacteria and Allelopathy*

Biologically active metabolites used by single species are effectively used in inhibiting sympatric species growth which may act as a potential competitor for controlling annual variability and resources in the communities of phytoplankton (Vardi et al. 2002). Several heterocystous cyanophycean genera such as *Anabaena sp., Nostoc sp., Cylindrospermum, Scytonema, Calothrix, Rivularia, Chlorogloea, Gloeotrichia, and Nostochopsis* have been shown to fix atmospheric nitrogen efficiently, which improve the nutritional status of soil. *Fischerella* produce fischerellins (A and B), and play role as alternative approach of allelopathy (Ganter et al. 2008) but also play a role as alternative approach of allelopathy. The pentacyclic calothrixins produced by *Calothrix* strains act in allelopathic interactions in inhibiting RNA polymerase and DNA synthesis (Doan et al. 2000). Nostoc 78-12A produced nostocarboline (a carboline alkaloid) that helps in inhibition of the toxin produced by cyanobacterium. *Microcystis aeruginosa* acts as an allelopathic agent and has significant effects on photosynthesis (Shao et al. 2009).

## *7.2 Application of Cyanobacterial Secondary Metabolites*

Cyanobacteria are a major source of bioactive metabolites or compounds that contain a varied range of nitrogen-rich alkaloids and peptides (Gervick et al. 2001). The significance of such microbes, which are known as the source of cyano-toxins and different other newly found biologically active compounds, is accepted and recognized worldwide (Mundt et al. 2001; Kumar et al. 2005); however, their role as a chemical potential agent like biocontrol agents or in crop protection is less explored in agriculture. The attack of a disease-causing organism like bacteria, fungi, zooplankton and eukaryotic microalgae could be reduced possibly by using cyanobacteria as a potential defense option of synthesis of highly active toxins.

## *7.3 Biological Control Perspective of Cyanobacteria Against Diseases*

Cyanobacteria produce various secondary metabolites having hormonal, toxic, antimicrobial and antineoplastic effects (Jaki et al. 2000) and are targeting prokaryotic as well as eukaryotic microorganism. Selected microorganisms show bioassays of aqueous and organic solvent extracts of antimicrobial compounds. Bioactive compounds showed fungal activity against important fungi that act as a synthesis of antibiotics by lead production and open a gateway in the agriculture sector (Nagle

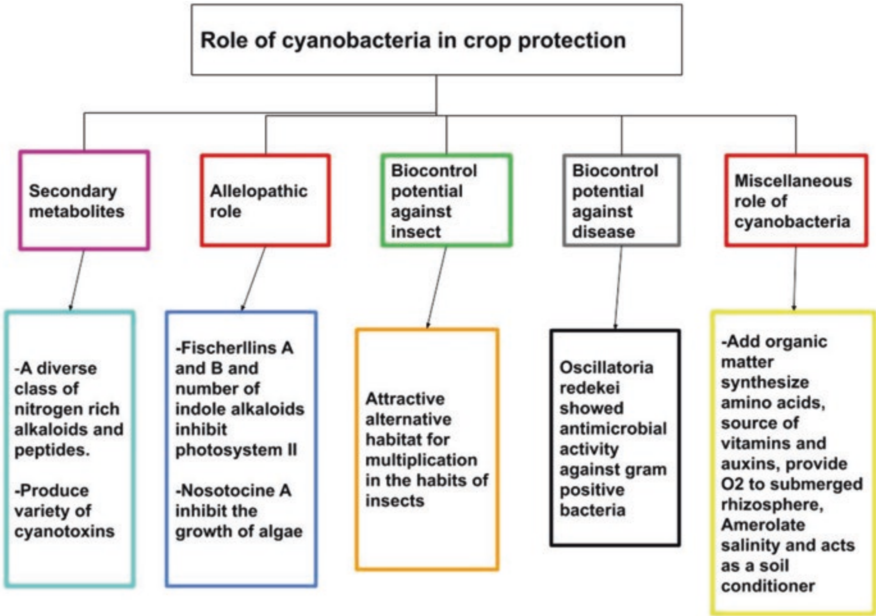


**Fig. 1.3** Biological control perspective of cyanobacteria against diseases

and Wedge 2002; Volk and Furkert 2006). *Tolypothrix tjipanensis*, cyanobacterium that produced tjipanazoles, revealed an effective response of showing fungicidal activity against *Aspergillus flavus* (Ozdemir et al. 2004). Several pathogenic fungi activities were reduced by fischerellin-A from *Fischerella*. Gram-positive bacteria showed antimicrobial activity by an unsaturated mixture of fatty acids from *Oscillatoria redekei* (Sabin et al. 2003). Gram-positive bacteria showed positive activity in a sample of 22 different strains of cyanobacteria obtained either from terrestrial or freshwater environments while reported minute activity counters to gram-negative bacteria (Fig. 1.3).

## 7.4 *Multiple Significant Roles of Cyanobacteria*

Cyanobacteria can be considered as an excellent source of organic matter to the soil, synthesis of amino acid, auxins and vitamins, and oxygen supply in submerged conditions, increase phosphate solubility and enhance fertilizer efficiency in plants, while decreasing the contents of oxidizable matter and salinity (Kaushik 2004). They are also considered as an important agent of soil conditioner and nitrogen that represent renewable biomass resource which is increasing as a source of the novelty of bioactive molecules. They promote the production of plant hormones, and their antibiotics or toxic compounds have been observed in enzymes inhibiting the activities of phytopathogen (Sergeeva et al. 2002). Besides toxins, cyanobacterial biomass is also a source of a large number of active substances having fungicide, cytotoxic, algicidal, antibacterial and antiviral activities (Jaki et al. 1999). Green algae in paddy fields were controlled by the use of algicides obtained from cyanobacteria, and their better growth was also observed. The major component of Nostoc 31 was nostocyclamide that has antibiotic and algicide activities. Mundt et al. (2002) observed the response of lipophilic and hydrophilic extracts for antibiotic, immunomodulating, antiviral and inhibiting activity of various enzymes in in vitro systems reporting various interesting effects.

## 8 Conclusion

For sustainable environmentally friendly farming, the reduction of synthetic fertilizers application and pesticides use is an interesting topic of the recent time. There has been mproved progress in cyanobacterial and algal biofertilizer products. On the other hand, application of cyanobacteria and algae use in controlling fungal and bacterial diseases is an innovative concept in sustainable agriculture. Recent studies reported remarkable growth in cyanobacterial biomass production for biofertilizers; a different supplement of foods, i.e. superfoods; and biofuels for farming of safe agricultural production. The most successfully emerged phyla of prokaryotes which were sustained during the evolutionary course were cyanobacteria. Along with so many applications in nutraceuticals, pharmaceuticals, food and feed industries, the ecological, morphological and genetic cyanobacterial diversity has led to the wide array of compounds production. The autotrophic nutritional mode is more dominant while some of the species of cyanobacteria can grow well in dark and anaerobic environments including *Oscillatoria* and *Nostoc*, while few cyanobacterial species, i.e. *Nostoc*, can also function in atmospheric nitrogen fixation. The cyanobacterial activity against phytopathogens has been studied both through their applications on leaves and soil surfaces. Green algae being unicellular and photosynthetic organisms, i.e. seaweeds (multicellular marine algae), and *Chlorella*, such as a brown alga named *Sargassum* can reach up to a length of 1–3 m. Cyclohexane and aqueous extracts from *Sargassum* sp. inhibit mycelial growth of *Aspergillus* spp. by 37–54.5%. Marine microalgae with an enormous spectrum production of synthetically vigorous metabolites, i.e. polysaccharides, cyclic peptides, sterols, polyketides, diterpenoids, alkaloids, quinones, glycerols and lipids, have a wide-ranging capability of bacterial/biological activitity function against many other organisms. Both cyanobacteria and algae play a key role in sustainable agricultural farming as biological control agents. They also play a vital role as allelopathic sources and are eco-friendly for safe sustainable crop production.