12

Secondary Metabolites from Cyanobacteria: A Potential Source for Plant Growth Promotion and Disease Management

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12.1 Introduction

Cyanobacteria belong to the most diverse group of Gram-negative photosynthetic prokaryotes in terms of their morphology, physiology, and metabolism (Codd 1995). Due to its aerobic as well as anaerobic nature, cyanobacteria show rapid growths in different habitats. In eutrophic surface water, cyanobacteria are able to form intense blooms. This bloom-forming process can be caused by increased levels of nutrients, like phosphorus and nitrogen due to anthropogenic influence. Cyanobacteria have a number of special properties, like their ability to fix nitrogen using the enzyme nitrogenase (Ressom et al. 1994), and many of them also have the ability to form several toxic metabolites. Cyanobacteria contain five functional groups of toxins named cytotoxins, neurotoxins, hepatotoxins, dermatotoxins, and irritant toxins (lipopolysaccharides). In the aquatic ecosystem, with exception of the cytotoxic cylindrospermopsin, these toxins are mainly present within cyanobacterial cells but can be released in high concentrations during cell lysis (Saker and Grifiths 2000).

Cyanobacteria belong to the Gram-negative group of bacteria having properties of photolysis mediated evolving of oxygen. These are cosmopolitan prokaryotes that have been survived and boomed on the earth for over two billion years with the formation of oxygenic environment (Sergeeva et al. 2002). The most common cyanobacterial structures in the fossil record include stromatolites and oncolites (Herrero and Flores 2008). The fossil of oxygen producing stromatolites has been reported around 2.8 billion years ago (Olson 2006). Cyanobacteria can survive in almost every habitat such as from oceans to freshwater, soil to bare rocks, deserts to ice shelves, and hot springs to Arctic and Antarctic lakes as well as in the form of endosymbionts in plants, lichens, and several protists (Baracaldo et al. 2005). In some of these habitats, they form dominant microflora in terms of total biomass and

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productivity. Because of persistent survival in varied habitats, cyanobacteria display a range of secondary metabolites, each with specific purpose to compete successfully for their sustenance on the planet. Several species of cyanobacteria produce photoprotective metabolites such as scytonemin and mycosporine-like amino acids (MAAs) that play significant role in screening of ultraviolet radiation (Sinha and Häder 2008). It produces various enzymes such as superoxide dismutase, catalase, and peroxidases. The production of scavengers such as vitamins B, C, and E as well as cysteine and glutathione is also observed which quench or scavenge UV-induced excited states and reactive oxygen species (ROS) (Vincent and Quesada 1994). Biochemically active (bioactive) metabolites have been also studied in marine and freshwater as well as in extensive and intensive aquaculture systems. In diverse array of cyanobacterial secondary metabolites, there are certain groups which cause undesirable tastes and odors (Smith et al. 2008). The odorous metabolites are produced by certain cyanobacteria from marine and freshwater habitats. These are harmful for several organisms including humans by means of alliterating the quality of drinking water and recreational activities (Dittmann and Wiegand 2006). The examples of toxic metabolites include compounds such as microcystin, anatoxin, and saxitoxin, which exhibit hepatotoxicity and neurotoxicity (Karl and Cyril 2008). Cyanobacterial toxins also show allelochemical properties, and their applications such as algaecides, herbicides, and insecticides have been also investigated. These allelochemicals (e.g., microcystin, lyngbyatoxin A, cyanobacterin, etc.) could also involve in defense against potential predators and grazers (Berry et al. 2008). The ability of cyanobacteria to synthesize numerous complex secondary metabolites such as peptides, depsipeptides, polyketides, alkaloids, etc. has fascinated the researchers for their pharmaceutical and biotechnological exploitations (Thajuddin and Subramanian 2005; Sielaff et al. 2006; Spolaore et al. 2006). These compounds may be exploited as drug leads, mainly formed through large multimodular nonribosomal peptide synthetase (NRPS), polyketide synthase (PKS), and mixed NRPS-PKS enzymatic systems (Wase and Wright 2008). Several indole alkaloids have been reported, from simple carbolines such asbauerines and nostocarboline as well as from complex polycyclic structures such as hapalindole, welwitindolinone, and ambiguine in cyanobacteria (Van Wagoner et al. 2007). Few cyanobacteria also lead to the production of iron chelators (siderophores) such as schizokinen, synechobactin, and anachelin. The protease inhibitors such as cyanopeptolins, micropeptin, and oscillapeptin from certain cyanobacteria and their selectivity for trypsin/chymotrypsin have also been described. In the present scenario, cyanobacteria are recognized as a potential source of toxins as well as novel bioactive compounds with pharmaceutical applications (Raja et al. 2008; Abed et al. 2009) as several compounds are demonstrated to have antibacterial, antiviral, antifungal, algicide, and cytotoxic activities (Rao 1994; Issa 1999; Schlegel et al. 1999; Schaeffer and Krylov 2000).

Research activities involving investigations on plant metabolites and metabolites from other groups of organisms were undertaken not only for a better understanding of their nature but also to discover new metabolites for possible use in humans for different fields of interest. And the common way to discover biologically active metabolites is to screen the extracts or isolate compounds from different natural sources. In the context of these research activities, microalgae, for example, cyanobacteria, were regarded to be a rich source for various metabolites of pharmaceutical or toxicological interests like primary metabolites such as proteins, fatty acids, vitamins, or pigments (Borowitzka 1995) and secondary metabolites with different bioactivities (antifungal, antiviral, antibiotic, and others) or cyanotoxins like the hepatotoxic nodularins and microcystins or the neurotoxic like saxitoxins and anatoxins (Carmichael 1992; Rinehart et al. 1994). Most of the cyanobacterial metabolites are accumulated in the cyanobacterial biomass. Moreover, cyanobacteria too excrete various organic compounds into their environment.

12.2 Cyanobacterial Secondary Metabolites

Cyanobacteria secondary metabolites are low molecular weight organic molecules which are not essential for normal growth, development, and reproduction of organism. They facilitate to face stress environment and reproductive process. Tremendous increase in the discovery of secondary metabolites is due to the use of analytical techniques like advanced ultra-performance liquid chromatography, which can be a better option than high-performance liquid chromatography. These secondary metabolites are associated with toxic, hormonal, and antimicrobial effects (Patterson et al. 1994). Some of these too take part in the treatment or prevention of multitude biological disorders. Many of the deadly diseases did not have any cure until these products were discovered. Secondary metabolites are commonly divided into structural classes related to their biosynthesis. This classification has its limitations because a number of compounds have building blocks from more than one biosynthetic pathway and some compounds that appear closely related can have completely different biosynthetic origins. The important classes of cyanobacterial secondary metabolites are the polyketides and non-ribosomal peptides. The other structural classes are alkaloids, terpenoids, shikimate-derived molecules, and amino glycosides (Davies and Ryan 2011). Secondary metabolites in cyanobacteria confer an evolutionary benefit to the producing organism. In the simplified environment of the laboratory, cyanobacteria often do not depend on the entire capabilities of their secondary metabolome, and thus the products of most of the biosynthetic gene clusters could not be observed. Improvements in de novo genome sequence technologies have resulted in a dramatic increase in the number of complete genomes available for well-known producers of natural products. These data have revealed that many members of these groups produce only a small fraction of the natural products encoded by their genomes under the standards of laboratory conditions. The biosynthetic pathways of natural product that are not often expressed are referred to as the “silent metabolome,” therefore, potentially representing a vast reservoir of undiscovered small molecules. Epigenetic enzymes like histone deacetylases (HDACs) and DNA methyl transferases (DNMTs) play a crucial role in gene regulation of biosynthesis clusters (Schmitt et al. 2011). A recently studied approach is genome mining which is used to discover natural product, while it is also possible to recognize the biosynthetic gene cluster from genome sequence data for a known compound produced by a microorganism. But, the converse approach of predicting the exact structure of a natural product from sequence data is often not possible. The factors which lead to this problem are complexity in forecast of post-assembly, modification, ambiguous cyclization patterns, biosynthetic domain skipping, and non-colinearity of few biosynthetic enzymes. Although bioinformatics tools are available to analyze genome data, identify biosynthetic clusters of natural product with a low level of accuracy, to predict the structure of the encoded compound which concludes that there is room for significant advancement in this field. There are possibilities to identify silent gene clusters in natural product produced by microorganisms through subtractive analysis by comparing the observed compounds to predicted biosynthetic pathways using existing bioinformatics tools (Schmitt et al. 2011). In recent time, mass spectrometry based on metabolomics has come forward as an efficient tool for the recognition of metabolites in complex biological systems as well as identification of novel metabolites.

12.3 Role of Cyanobacterial Secondary Metabolites in Plant Diseases Management

Ethanol extracts of the blue green alga *Anabaena circinalis* exhibit antimicrobial activity against the fungus *Aspergillus flavus*. The other blue green algae *Nostoc muscorum* has wide range of activities on both Gram-positive and Gram-negative bacteria in addition to the fungus *A. flavus* (Shaieb et al. 2014). Aqueous, methanol, n-propanol, and petroleum ether extracts of 40 cyanobacterial isolates belonging to 9 genera had been earlier examined showing inhibitory activities against five fungal plant pathogens, *Aspergillus flavus*, *Aspergillus niger*, *Colletotrichum musae*, *Fusarium oxysporum*, and *Paecilomyces lilacinus* (Pawar and Puranik 2008). In an experiment, it has been reported that the aqueous extract of one of the dominant species of cyanobacteria *Spirulina platensis* demonstrates antifungal activity against the fungus *A. flavus* (Shaieb et al. 2014). In vitro and in vivo fungal growth, spore sporulation, and fungal infection of the wilt pathogen in tomato seeds were significantly inhibited by cyanobacterial extracts. *Nostoc commune* FA-103 extracts showed the potential to suppress *Fusarium oxysporum* f. sp. *lycopersici* (Kim 2006). Algae are one of the chief biological agents that have been studied for the control of plant pathogenic fungi, particularly soilborne pathogens (Hewedy et al. 2000). *Anabaena* spp. (Moore et al. 1986; Frankmolle et al. 1992), *Scytonema* spp. (Chetsumon et al. 1993), and *Nostoc* spp. (Bloor and England 1989) were shown to be efficient in the control of damping-off as well as the growth of the soil fungus *Cunninghamella blakesleeana*. The aqueous extract from cyanobacteria and algae cells when applied to seeds showed protection from damping-off fungi such as *Fusarium* sp., *Pythium* sp., and *Rhizoctonia solani* (Kulik 1995). In a previous study, Kim (2006) reported antifungal activities in 29 strains of the 298 microalgal strains tested. *Nostoc commune* FA-103 was selected as the subject of this study because of its broad-spectrum antifungal activity on plant pathogenic fungi, especially *F. oxysporum* f. sp. *lycopersici* (Borowitzka 1995). They reported that the extracts of *Nostoc muscorum* significantly inhibit the growth of *Candida albicans* and *Sclerotinia sclerotiorum*. Nonetheless, Kulik (1995) reported that the growth of *R. solani* on PDA was significantly inhibited by using *N. muscorum* extract. The maximum inhibition of *Fusarium* growth in soil was 81% with *Anabaena flosaquae*. In addition, the growth activities of *F. oxysporum* f. sp. *betae*, *F. oxysporum* f. sp. *lycopersici*, and *F. oxysporum* f. sp. *vasinfectum* were strongly inhibited with increasing concentration of cyanobacterial extracts (Moussa and Shanab 2001). In vitro and in vivo growth, sporulation, and sclerotial production were significantly inhibited with *Nostoc muscorum*. In vivo studies showed that *F. oxysporum* was very sensitive to cyanobacteria species *Nostoc muscorum* filtrates. They have potential for the suppression of phytopathogenic fungi such as the sugar beet pathogens *Fusarium verticillioides*, *Rhizoctonia solani*, and *Sclerotium rolfsii* (Rizk 2006). Abo-Shady et al. (2007) also reported that cyanobacteria filtrates strongly inhibit the phytopathogenic fungi isolated from leaves, stems, and roots of Faba bean. Mycelial growth of several plant pathogenic fungi such as *Fusarium oxysporum*, *Penicillium expansum*, *Phytophthora cinnamomi*, *Rhizoctonia solani*, *Sclerotinia sclerotiorum*, and *Verticillium albo-atrum* was inhibited by the methanol extracts of the cyanobacterium *Nostoc* strain ATCC 53789 (Biondi et al. 2004). The reduced disease severity coupled with improved plant growth elicited by cyanobacterium *Anabaena* spp. treatments illustrated the utility of such novel formulations in integrated pest and nutrient management strategies for *Fusarium* wilt challenged tomato crop (Prasanna et al. 2013). Biological control of *Fusarium oxysporum* f. sp. *lycopersici* (FOL) causing wilt disease in tomato was studied in vitro as well as under pot conditions. Methanol extract of *Nostoc linckia* and *Phormidium autumnale* showed moderate and minor zone of inhibition (33.3% growth inhibition). In spite of all these investigations and researches, more efforts are required in search of more strains of cyanobacteria including genetically modified strains to ensure maximum production of the desired products (Table 12.1).

12.4 Role of Cyanobacterial Secondary Metabolites in Plant Growth Promotion

Cyanobacteria generally known as BGA (blue-green algae) is not a true eukaryotic algae; it is a Gram-negative prokaryotes that are able to perform nitrogen fixation and oxygenic photosynthesis. It can easily grow in ponds, lakes, rivers, and any other wetlands. This BGA has the quality to improve soil fertility and enhance plant growth. Cyanobacteria are a rich source of enzymes, fibers, carbohydrates, proteins, vitamins, etc. Among all vitamins, the most abundant are vitamins A, C, B1, B2, and B6 and niacin, and the minerals like iron, magnesium, iodine, potassium, and calcium are commonly found in BGA. The proper use of particular cyanobacterial strain in agriculture purpose shows beneficial effect on crop production (Higa and Wididana 1991). Cyanobacteria enhance plant growth by some different mechanisms such as fixing atmospheric nitrogen and producing plant beneficial hormones,

Table 12.1 Biocidal activity of cyanobacteria against plant pathogens

Sl. No.	Cyanobacteria	Extract	Plant pathogens	References
1.	*Fischerella muscicola*	Fischerellin	*Uromyces appendiculatus* (brown rust), *Erysiphe graminis* (powdery mildew), *Phytophthora infestans*, and *Pyricularia oryzae* (rice blast)	Hagmann and Juttner (1996)
2.	*Nostoc muscorum*	aBis (2, 3-dibromo-4, 5-dihydroxybenzyl) – BDDE	*Sclerotinia sclerotiorum* (cottony rot of vegetables and flowers) and *Rhizoctonia solani* and *Candida albicans*	Borowitzka (1995)
3.	*Tolypothrix byssoidea*	Antifungal peptides dehydrohomoalanine (Dhha)	Antifungal activity against the yeast *Candida albicans*	Jaki et al. (2001)
4.	*Oscillatoria redekei* syn. *Limnothrix redekei* HUB 051	Antibacterial fatty acids a-dimorphecolic acid, a 9-hydroxy-10E, 12Z-octadecadienoic acid (9-HODE), and coriolic acid	Inhibited the growth of the Gram-positive bacteria *Bacillus subtilis* SBUG 14, *Micrococcus flavus* SBUG 16, and *Staphylococcus aureus* SBUG 11 and ATCC 25923	Mundt et al. (2003)
5.	*Nostoc* sp.	Cryptophycin	Natural pesticides against the fungi, insects, and nematodes	Biondi et al. (2004)
6.	*Anabaena subcylindrica*, *Nostoc muscorum*, and *Oscillatoria angusta*	Efficient algal filtrate concentration (EAFC)	*Alternaria alternata*, *M. phaseolina*, and *F. solani*	Abo-Shady et al. (2007)
7.	*Spirulina platensis*, *Oscillatoria* sp., and *Nostoc muscorum*		*Cercospora beticola* causing leaf spot of sugar beet	Mostafa et al. (2009)
8.	*Calothrix elenkenii*	Ethyl acetate extract	*Pythium aphanidermatum*	Manjunath et al. (2010)

(continued)

Table 12.1 (continued)

Sl. No.	Cyanobacteria	Extract	Plant pathogens	References
9.	*Lessonia trabeculata*	Ethanolic extracts	Reduced number and size of the necrotic lesion in tomato leaves following infection with *Botrytis cinerea*	Jimenez et al. (2011)
10.	*Gracilaria chilensis* (red algae)	Aqueous or ethanolic extracts	*Phytophthora cinnamomi*	
11.	*Durvillaea antarctica*	Crude extracts	Tobacco mosaic virus (TMV) in tobacco leaves	
12.	*Anabaena variabilis* RPAN59 and *A. oscillarioides* RPAN69	Antifungal	*Pythium debaryanum*, *Fusarium oxysporum lycopersici*, *F. moniliforme*, and *Rhizoctonia solani*	Chaudhary et al. (2012)
13.	*Anabaena variabilis*, *S. platensis*, and *Synechococcus elongatus*	Butanol extract	*Aspergillus niger* and *Alternaria solani*	Tiwari and Kaur (2014)
14.	*Nostoc muscorum* and *Oscillatoria* sp.	Norharmane and α-iso-methyl ionone	*Alternaria porri* (purple blotch of onion)	Abdel-Hafez et al. (2015)

vitamins, and enzymes (Higa 1991). The fixed nitrogen may release in the form of polypeptides, auxin-like substances, ammonia, free amino acids, or vitamins (Subramanian and Sundaram 1986). More particularly, the hormones that are released by cyanobacteria are abscisic acid (Marsalek et al. 1992), auxin (Ahmad and Winter 1968), cytokinin (Rodgers et al. 1979), gibberellins (Singh and Trehan 1973), and vitamin B in particular (Grieco and Desrochers 1978). Most studied cyanobacterial effect on plant growth was paddy and wheat, where the use of BGA helped in increasing the germination rate, root and shoot growth, and chlorophyll content in both crops' growth (Misra and Kaushik 1989a, b; Obreht et al. 1993). Plant growth promotion activities of cyanobacteria were first observed in rice and wheat crops. In 1995, Likhitkar and Tarar observed that the total length of plants, seedlings, radicals, and dry weight was significantly increased in *N. muscorum*-treated cotton seed. Similar results were observed by Adam in 1999 when lentil, maize, sorghum, and wheat seeds were soaked in live inoculums, and boiled algal extract or filtrate extract of *N. muscorum*, *N. calcicola*, and *Anabaena vaginicola* from Iranian terrestrial helped in promoting growth in several herbaceous plants, vegetables including *Satureia hortensis*, *Cucumis sativus*, *Mentha spicata*, *Cucurbita maxima*, and *Solanum lycopersicum* (Shariatmadari et al. 2013; Hashtroudi et al. 2013). Another morphological and biochemical parameters were tested by Haroun and Hussein (2003) in *Lupinus termis* when treated with *A. oryzae* and *Cylindrospermum muscicola* extracts. Culture filtrates of *Cylindrospermum* increase nitrogenous compound contents, photosynthetic activity, and carbohydrate in plants. Some cyanobacteria secrete some components that were attributed to gibberellic acid. It was also known to inhibit chlorophyllase activity, and for this reason, both chlorophyll a and b and total chlorophyll and total pigments increased (Martinez et al. 1996). Osman et al. (2010) analyzed some protein bands through sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE), and it was observed that there was a change in the gene expression pattern after cyanobacterial treatment in plants. A huge number of cyanobacterial species like *Nostoc muscorum*, *Anabaena variabilis*, *Tolypothrix tenuis*, and *Aulosira fertilissima* are considered as an efficient biofertilizers. Some cyanobacterial strains like *Nostoc* and *Anabaena* are able to colonize in rocks and soil and have nitrogen fixation capability of up to 20–25 kg/ha, and *Aulosira*, *Anabaena*, *Tolypothrix*, etc. are also used as inoculums for rice crop. The second most important macronutrient for plant growth is phosphorus. Cyanobacteria can produce phosphatise enzymes that help in solubilization of the organic phosphorus and help in plant growth. After death of cyanobacteria, the phosphate present in cell wall is released in soil and easily serves as a nutrient for the plants. Fuller and Roger (1952) observed that phosphorus uptake was significantly increased in the algal-treated plant compared to untreated plants. A study of Rogers and Burns (1994) showed that the cyanobacteria inoculums improved the water holding capacity and aeration of soil that helped in improving soil fertility and increasing plant growth (Table 12.2).

12.5 Cyanobacterial Extract in Defense Activation Against Biotic and Abiotic Stresses

Cyanobacteria are ubiquitous in nature as they are found in saline water, marine water, and freshwater and terrestrial environments and having symbiotic association with plants, animals, protista, etc. (Gupta et al. 2013). They are known to produce various bioactive compounds, and their utilization as biological agents showed them as best antiviral, antifungal, antibacterial, and anti-inflammatory properties which have promising application in agriculture, food, and various industries. The role of cyanobacterial extract of *Calothrix elenkenii* was tested against *Pythium aphanidermatum* and found potential inhibitor of pathogenic fungi by treating seeds of some vegetable crops with ethyl acetate extract (Manjunath et al. 2010). Some other researchers also shed their ideas in improving nutrient uptake that leads to enhancing defense enzyme activities in plants. Various cyanobacterial strains such as *Anabaena variabilis* RPAN59 and *A. laxa* RPAN8 are good in defense enzyme expression and fungicidal and hydrolytic enzymatic activities (Prasanna et al. 2013). Defense enzymes, viz., polyphenol oxidase (PPO) and phenylalanine ammonia lyase (PAL), and pathogenesis-related enzymes like β-1,3 glucanase and chitosanase were observed to be highest in the roots of a 14-day-old tomato seedlings under the action of cyanobacterial strains. And they further stated that the highest correlation of defense enzymes and hydrolytic enzymes is associated with

Table 12.2 Cyanobacterial metabolites and their mechanism in plant growth promotion

Secondary metabolites	Cyanobacteria	Mechanism	Reference
Cytokinins	*Chroococcidiopsis*, *Anabaena*, *Anabaenopsis*, *Cylindromum*, etc.	Nitrogen fixation	Hussain and Hasnain (2011)
6-benzyl adenine (6-BA) Thidiazuron (TDZ) Kinetin (KIN)	*Anabaena*	Increase the organic matter of the soil and nitrogen fixation	El-Bahbohy et al. (2014)
Phytohormones	*Acutodesmus*	Enhanced plant growth, biostimulant, nitrogen fixation	Garcia-Gonzalez and Sommerfeld (2016)
IAA	*Anabaena*, *Oscillatoria*, *Synechocystis*	Nitrogen fixation	Bergman et al. (1997)
Auxin	*Anabaena*, *Plactonema*, *Chlorogloeopsis*, *Cylindrospermum*, *Glactothece*, *Synechocystis*, *Anabaenopsis*, *Calothrix*, *Nostoc*, etc.	Plant growth promotion	Ahmad and Winter (1968), Mohan and Mukherji (1978), Selykh and Semenova (2000), Sergeeva et al. (2002)
Gibberellins	*Anabaenopsis*, *Cylindromum*	Plant growth promotion	Mohan and Mukherji (1978)
Vitamin B12	*Cylindrospermum*, *Tolypothrix*, *Nostoc*, *Hapalosiphon*, etc.	Plant growth promotion	Venkataraman and Neelakantan (1967), Okuda and Yamaguchi (1960), Misra and Kaushik (1989a)

phosphorus uptake, whereas the nitrogen uptake was highly correlated with hydrolytic enzyme production (Prasanna et al. 2013). Priya et al. (2015) showed utilization of cyanobacterial strain *Calothrix elenkenii* in flooded rice field which resulted increase in plant growth as well as enhancement in some plant defense enzyme expression levels. The tropical spray and root application of such strains also resulted in increased accumulation of phytochemicals such as glucosinolates, alkaloids, terpens, polyphenols, etc. Cyanobacteria not only act against biotic stress, but their association in salt- affected soils is also well studied (Apte and Bhagwat 1989; Singh and Dhar 2010). Multiple approaches are made by cyanobacteria in the regulation of immune responses against salt stress (Pandhal et al. 2009; Nikkinen et al. 2012). Their colonization in association with plant helps them to act against stressed soil condition by producing diverse biologically active metabolites in soil and thereby inducing systemic acquired responses by combating abiotic stresses. In order to maintain physiological properties of plants in salt stress condition, the application of cyanobacteria upregulates the phytohormone producing genes associated with cytokinin, indole-3-acetic acid (IAA), and gibberellic acid (GA) production which plays a major role in stabilizing the growth (Singh 2014). The cytokinin and IAA production were observed in rice roots under the influence of the endophytic *Nostoc* (Hussain et al. 2013). The *Oscillatoria angustissima*, *Cylindrospermum* sp., and *Anabaenopsis* sp. produce gibberellin-like substances and provide the phytohormonal signaling under stress conditions (Tsavkelova et al. 2006). The production of salicylic acid, jasmonic acid, and its various metabolites plays effective role in regulation of immune responses to abiotic and biotic stresses (Khan et al. 2012). The antioxidant production, viz., superoxide dismutase and peroxidase, by the application of cyanobacterial extract in rapeseed and rice was demonstrated by Chen et al. (2004). Because of its ability to promote growth and production of defense response (Grzesik et al. 2017) assessed the application of *Microcystis aeruginosa* MKR 0105, *Anabaena* sp. PCC 7120 (cyanobacteria), and *Chlorella* sp. (green algae) singly for their utilization as foliar biofertilizers in order to improve plant growth and yield through enhanced physiological performance of the plants.

12.6 Conclusion

The use of cyanobacterial products can provide us a better future by limiting the use of inorganic chemical products for the management of plant pathogens which are causing prominent diseases in agriculture crops. These cyanobacterial extracts are having more potential in battling against the biotic and abiotic stress responses by activating the defense enzymes to provide resistance response in plants to withstand various stresses.

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