RESEARCH ARTICLE

Cyanobacterial Richness in Paddy fields of Saidabad Block, Prayagraj District, UP, India

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Abstract

Cyanobacteria are the common microbial population present in paddy fields. Their presence and diversity indicate the health of the soil and also give an idea of the types of fertilizers used in the field. This study on isolation and identification of cyanobacterial strains was carried out for the first time from ten paddy fields in Saidabad block, Prayagraj district, to identify the local and dominant strains for future preparation and application of biofertilizer in different crop fields. These strains also have the prospect of being utilized as liquid trees for the purification of the environment at the study site. In the present work, a total of 37 cyanobacterial species belonging to 26 genera and ten families were recorded. Data indicates the dominance of filamentous heterocystous types like *Nostoc, Anabaena, Aulosira,* and *Gloeotrichia* in paddy fields. However, the frequency of occurrence and species diversity were the maximum of non-heterocystous form *Oscillatoria*. Nostocales was the most dominant order with representatives of all its five families, i.e., Oscillatoriaceae, Microchaetaceae, Nostocaceae, Scytonemataceae, and Rivulariaceae.

Highlights

- Cyanobacteria are ubiquitous, prokaryotic organisms that commonly inhabit paddy fields. Their occurrence in soil improves soil characteristics and adds nutrients and growth substances to the soil that enhance plant productivity.
- The study isolated and identified the region-specific cyanobacterial strains from paddy fields of Saidabad block, Prayagraj district. It is important as indigenous strains are well adapted in their local niche and give optimum benefits to plants, soil, and environment when utilized as biofertilizers.
- The study area showed the dominance of filamentous heterocystous types like *Nostoc, Anabaena, Aulosira,* and *Gloeotrichia* in paddy fields.
- Heterocystous forms were more in overall species diversity, but the frequency of occurrence and number of species was found to be the maximum of a non-heterocystous form *Oscillatoria*.
- Nostocales was the most dominant order with representatives of all its five families i.e. Oscillatoriaceae, Microchaetaceae, Nostocaceae, Scytonemataceae, and Rivulariaceae.

Keywords: Cyanobacteria, Species diversity, Nitrogen fixation, Saidabad block.

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Introduction

Cyanobacteria are photosynthetic prokaryotes that are ubiquitous and can grow at any place and in any environment where air, sunlight and moisture are available. The paddy field is one such ecosystem that supports the luxuriant growth of cyanobacteria. Their abundance and diversity in terms of number and species, particularly in paddy fields, is due to the unique ecological environment of paddy wetlands. The occurrence of cyanobacteria in paddy fields shows a type of symbiotic relationship in which paddy fields provide appropriate niches to cyanobacteria, the plant provides food and space while cyanobacteria give nitrogen, phosphorus, other minerals and growth-promoting substances such as hormones, vitamins and amino acids to the plants besides improving soil health (Song *et al.,* 2022). Cyanobacteria or BGA are multipurpose organisms that require minimal conditions for growth. They are used as biofertilizers as they enrich the soil with nutrients and growth-promoting substances, reclaim the salt-affected soil, improve the physical and chemical properties of soil and bioremediate the waste in the environment (Usharani and Naik, 2019; Kumar and Rai, 2020; Jan *et al.,* 2023). Their role in the purification of the environment in the form of liquid tree is the current field of research (Dhar *et al.,* 2023). Cyanobacteria can also boost agricultural practices in arid regions by overcoming challenges such as water shortage, high temperatures, high salinity, and infertile soil (Bibi *et al.*, 2024). Saidabad block of Prayagraj district is an agricultural area with unexplored ecology and diversity of cyanobacteria. The documentation on cyanobacteria helps in understanding the nutrient status of the field and might be applied for sustainable agricultural practices by controlling the application of chemical fertilizers. Furthermore the information

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on dominant strains could be utilized in the preparation of area-specific biofertilizers for enhancing productivity in other crops. Experiments conducted using cyanobacterial biofertilizers or inoculants on growth performance, yield and nutritional status showed positive results in the improvement of plants like *Lupinus termis* (Haroun *et al.,* 2003), pea (Osman *et al.,* 2010), wheat (Rana *et al.,* 2012), cotton (Prasanna, 2015), maize crop (Prasanna, 2016), and *L. luteus* (Shedeed *et al.,*2022).In the present study, an attempt has been made to isolate and identify the local cyanobacterial strains for the first time from Saidabad block (Prayagraj dstrict, Uttar Pradesh, India). These strains will be utilized in the production of biofertilizers and as a prospect in the purification of the environment in the form of liquid trees.

Materials And Methods

Soil Sampling Site

Soil samples were collected from paddy fields of Saidabad block, Prayagraj district (Uttar Pradesh), during the rice cultivation period at the panicle initiation stage. The block, having a geographical area of 191.42 km^2 is situated at latitude and longitude coordinates of 25.370766 and 82.109756, respectively. The major souce of income in the block is agriculture. Here rice is grown as a kharif crop with a sowing and harvesting period between June - July to November - December.

Collection of Soil Samples

Soil samples were collected at the panicle initiation stage from paddy fields of ten villages: Amora, Bajaha Mishran, Beerpur, Binda, Dhokari Holagarh, Garaghanpur, Kaithwal, Mahuwa Diha, Sarai Mansoor and Saidabad. Five soil samples were taken from randomly selected spots of each of the ten fields by scraping the upper soil layer having green patches. These soil samples were collected in sterilized air-tight polythene bags and transported to the botany laboratory of DDU Government PG College, Saidabad, Prayagraj, for analysis. Soil samples of each field were homogenized and mixed thoroughly to make ten composite soil samples.

Taxonomic identification of Cyanobacteria

A suspension of each of the composite soil samples of ten fields was prepared by dissolution of one gram of soil in 10ml sterilized distilled water. A few drops of this suspension were observed under the research microscope Magnus MX21i Tr for identification of dominant cyanobacterial species by observing characteristics like the shape of cells, presence or absence of heterocyst, akinete and trichome sheath. The growth pattern, color and texture of the colony were also observed in culture media as an identification source. The identification of cyanobacterial species was made using standard monographs suggested by Halder (2015).

Isolation, Purification and Culture Maintenance of Cyanobacterial strains

Serial dilution of 10^{-1} until 10^{-6} was carried out for each of the ten composite soil samples. Each dilution was plated on nitrogen-free BG-11 medium at 25 ± 2°C in a culture room under continuous light intensity of 1200 to 1400 lux for 10 to 12 days. After the growth of cyanobacterial colonies, a dilution factor of 10^{-5} was found suitable for CFU (Colony Forming Units) calculation. Individual strains were transferred to fresh medium for unialgal culture. These cultures were used for morphological identification and kept for future preparation and application of biofertilizers. Pure cultures were maintained by renewing the unialgal strains after a definite time interval to avoid contamination.

Data Analysis

$$\text{Frequency of Occurrence (\%)} = \frac{\text{Number of samples containing the species}}{\text{Total number of samples studied}} \times 100$$

$$\text{CFU (/ml)} = \frac{\text{No. of visible colonies on petriplate X Total dilution factor}}{\text{Volume of culture plated in ml}}$$

Results and Discussion

About 50 soil samples collected from 10 independent fields located at a distance of about 5 to 10 km from each other showed 26 genera and 37 species of cyanobacteria belonging to 10 families. Among them, family Nostocaceae and Oscillatoriaceae showed maximum number of species (Fig. 1). On comparison of structural forms 19 species were filamentous heterocystous, 09 were filamentous non-heterocystous and 09 were unicellular (Table 1). Thus in the study area, filamentous heterocystous form was found to be more prevalent in distribution (Fig. 2). Order Nostocales was represented by all the five families, i.e., Oscillatoriaceae, Microchaetaceae, Nostocaceae, Scytonemataceae and Rivulariaceae showing better survival ability.

The maximum frequency of occurrence (90–100%) was of *Anabaena oryzae*, *Aphanocapsa biformis, Gloeocapsa punctata, Lyngbya spiralis, Nostoc muscorum, Oscillatoria limosa, Oscillatoria princeps* and *Oscillatoria tenuis* while minimum frequency of occurrence (10–20%) was that of *Nodularia* sp, *Tolypothrix tenuis*, *Trichormus* sp., *Nostochopsis* sp., *Haplosiphon* sp., *Pleurocapsa microbewiki, Rivularia aquatica, Schizothrix calcicola* and *Scytonema* sp. The maximum species diversity was of *Oscillatoria* represented by four species (Table 2).

Earlier nitrogen fixation ability was considered as an attribute of heterocystous cyanobacteria. The study on variety of non-heterocystous BGA present in paddy field soil has revealed their ability to fix atmospheric nitrogen (Berrendero *et al.,* 2016). Paddy fields with stagnant water provide appropriate conditions to non-heterocystous cyanobacteria to fix atmospheric nitrogen in anoxic or micro-oxic conditions (Rajasekaran and Raja, 2021). *Oscillatoria* is a non-heterocystous alga that uses a temporal strategy in which the cells reduce nitrogen into ammonium during night with a halt in photosynthesis (Hendrayanti *et al.,* 2018). Aerobic nitrogen fixation in other non-heterocystous cyanobacteria has also been discussed by Fredriksson *et al.,* (1998) and Misra *et al.* (2003). Similar dominance of BGA has been observed in rice field surveys of other localities (Dey *et al.,* 2010; Choudhary, 2011; Srinivas and Aruna, 2016; Sebastian, 2017; Ghadage and Karande, 2019; Petkar *et al.,* 2020).

Native cyanobacterial species flourish in paddy fields as they can utilize optimum conditions of temperature, light and water needed for their growth. The isolation of region-specific strains is important as indigenous strains are well adapted in

Table 1: Structural forms of cyanobacteria observed in the study area

S. No.	*Structure*	*Family*	*Number of genus*	*Number of species*
1.	Filamentous heterocystous forms	07	15	19
2.	Filamentous non-heterocystous forms	01	04	09
3.	Unicellular forms	02	07	09

Table 2: FO (%) of identified cyanobacterial sp. in studied samples of different paddy fields of Saidabaad block, Prayagraj district.

S. No.	*Family of Species*	*Name of Species*	*Structure*	*FO (%)*
1.	Chroococcaceae	*Aphanocapsa biformis*	Unicellular	90
		Aphanothece stagnina	Unicellular	60
		Chroococcus montanus	Unicellular	60
		Chroococcus pallidus	Unicellular	70
		Gloeocapsa atrata	Unicellular	80
		Gloeocapsa punctata	Unicellular	90
		Microcystis aeruginosa	Unicellular	70
		Synechococcus aeruginosus	Unicellular	40
2.	Mastigocladaceae	*Mastigocladus laminosus*	Filamentous heterocystous	40
3.	Microchaetaceae	*Microchaete aequalis*	Filamentous heterocystous	30
4.	Nostocaceae	*Aulosira prolifica*	Filamentous heterocystous	80
		Anabaena cylindrica	Filamentous heterocystous	80
		Anabaena oryzae	Filamentous heterocystous	90
		Cylindrospermum muscicola	Filamentous heterocystous	30
		Nodularia sp.	Filamentous heterocystous	10
		Nostoc commune	Filamentous heterocystous	80
		Nostoc muscorum	Filamentous heterocystous	90
		Nostoc sphaericum	Filamentous heterocystous	70
		Trichormus sp.	Filamentous heterocystous	10
5.	Nostochopsidaceae	*Nostochopsis* sp.	Filamentous heterocystous	20
6.	Oscillatoriaceae	*Lyngbya rubida*	Filamentous non-heterocystous	70
		Lyngbya spiralis	Filamentous non-heterocystous	90
		Oscillatoria tenuis	Filamentous non-heterocystous	90
		Oscillatoria limosa	Filamentous non-heterocystous	100
		Oscillatoria princeps	Filamentous non-heterocystous	90
		Oscillatoria sancta	Filamentous non-heterocystous	80
		Phormidium mucosum	Filamentous non-heterocystous	60
		Schizothrix tenuis	Filamentous non-heterocystous	30
		Schizothrix calcicola	Filamentous non-heterocystous	20
7.	Pleurocapsaceae	*Pleurocapsa microbewiki*	Unicellular	20
8.	Rivulariaceae	*Calothrix braunii*	Filamentous heterocystous	50
		Gloeotrichia indica	Filamentous heterocystous	60
		Gloeotrichia natans	Filamentous heterocystous	70
		Rivularia aquatica	Filamentous heterocystous	20

9.	Stigonemataceae	*Haplosiphon* sp.	Filamentous heterocystous	20
10.	Scytonemataceae	*Scytonema* sp.	Filamentous heterocystous	20
		Tolypothrix tenuis	Filamentous heterocystous	10

Table 3: Colony Forming Units (CFU/ml) of identified Cyanobacterial strains at ten different sites of Saidabad Block, Prayagraj District, UP

Sites	*Localities*	*CFU/ml*
1	Amora	48 X 10^6
2	Bajaha Mishran	35 X 10^6
3	Beerpur	29 X 10^6
4	Binda	65 X 10^6
5	Dhokari Holagarh	68 X 10^6
6	Garaghanpur	28 X 10^6
7	Kaithwal	72 X 10^6
8	Mahuwa Diha	40 X 10^6
9	Sarai Mansoor	76 X 10^6
10	Saidabad	36 X 10^6

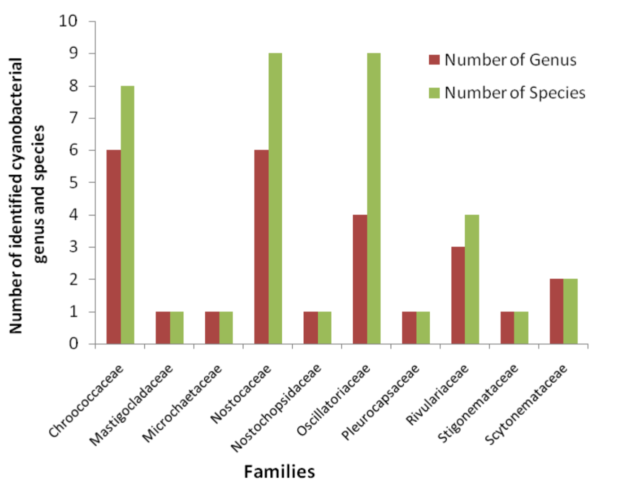

Fig. 1: Diversity of genus and species in different families indentified from saidabad block, Prayagraj district

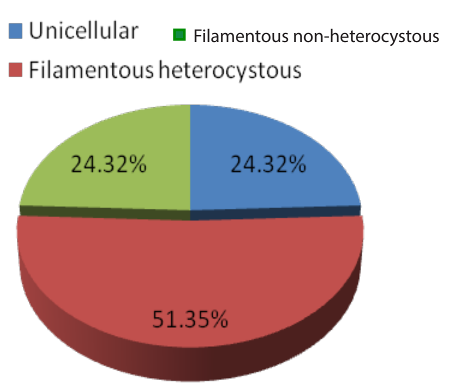

Fig. 2: Prevalence of structural forms of BGA in the study area

their local niche and give optimum benefits to plant, soil and environment when utilized as biofertilizers (Abdelaziz *et al.*, 2014). Their nitrogen-fixing ability makes them an important microbial component in paddy fields that also contributes to its fertilization (Song *et al.*, 2005). As compared to different growth stages of paddy cultivation, panicle initiation stage has been chosen as during this period occurrence of a broad rice canopy and high phosphorus content in soil provides more favorable environment for the growth of cyanobacteria (Hendrayanti *et al.*, 2018).

The CFU/ml of soil solution calculated from each of the study site revealed the highest CFU index at sites 7 and 9 (above 70 colonies at 10^{-5} diluton), while the minimum CFU index was at 3 and 6 (below 30 colonies at 10^{-5} diluton) (Table 3).

The innumerous microbial community of soil ecosystem maintains the natural texture and fertility of soil. Excessive use of pesticides, fungicides and insecticides disturbs the community structure and productivity of soil and has an adverse impact on growth and enzyme activity in cyanobacteria (Liu *et al.*, 2006; Rajendran *et al.*, 2007; Debnath *et al.*, 2012). They also express a negative effect on growth, production and nitrogen-fixing ability of BGA (Mazlan *et al.*, 2017). In some studies insecticides are found to inhibit the phycocyanin, chlorophyll a, and carotenoids of some strains (Prasad *et al.*, 2005). Less diversity (below 30 colonies at 10^{-5} diluton) indicates the indiscriminate application of chemical fertilizers and biocides in the paddy fields of III and VI while the fields that used organic fertilizers supported the growth of cyanobacteria that acted as soil conditioners, enhancing crop productivity (Saadatnia and Riahi, 2009; Prasanna *et al.*, 2013; Chittora *et al.*, 2020; Nascimento *et al.*, 2019; Iniesta-Pallarés *et al.*, 2021). These observations coincide with the experimental result of the ecotoxicological impact of higher doses of pesticides and chemical fertilizers on the growth structure and function of native cyanobacterial species present in the paddy field ecosystem (Singh *et al.*, 2018; Singh *et al.*, 2020).

Conclusion

In an agriculturally dependent community, cyanobacterial biofertilizers will save money and provide nutrient-rich, safe and healthy food for the growth and welfare of population. Besides this, cyanobacteria are well documented as biocontrol agents and in bioremediaton of pollutants. Therefore, for sustainable agriculture and balance of the soil ecosystem, there is an urgent need to focus on the use of biofertilizers. The present work pioneered the study of the distribution and diversity of cyanobacterial strains in the Saidabad block of Prayagraj district (Uttar Pradesh, India). This study documented a wide range of cyanobacterial diversity in rice fields. *Anabaena oryzae*, *Aphanocapsa biformis*, *Gloeocapsa punctata*, *Lyngbya spiralis*, *Nostoc muscorum*, *Na commune*, *O. limosa*, *O. princeps* and *O. tenuis* are the species that occurred in maximum frequency. *Oscillatoria* was the most dominant genera in paddy fields of

Saidabad.

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Authors Contribution

Dr. Swati Chaurasia has written the manuscript. Dr Rahul Soni helped in data compilation and Dr Amita Pandey contributed to the final version of the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

References

Abdelaziz, A.E.M., Ghosh, D., & Hallenbeck, P.C. (2014). Characterization of growth and lipid production by *Chlorella* sp. PCH90, a microalga native to Quebec. *Bioresource Technology,* 156, 20–28. https://doi.org/10.1016/j.biortech.2014.01.004.

Berrendero, E., Valiente, E.F., Perona, E., Gómez, C.L., Loza, V., Muñoz-Martín, M.Á., & Mateo, P. (2016). Nitrogen fixation in a non-heterocystous cyanobacterial mat from a mountain river. *Scientific Reports*, 6, 30920. https://doi.org/10.1038/srep30920.

Bibi, S., Saadaoui, I., Bibi, A., Al-Ghouti,M., & Abu-Dieyeh, M.H. (2024). Applications, advancements, and challenges of cyanobacteria-based biofertilizers for sustainable agro and ecosystems in arid climates. *Bioresource Technology Reports*, 25, 101789. https://doi.org/10.1016/j.biteb.2024.101789.

Chittora, D., Meena, M., Barupal, T., Swapnil, P., & Sharma, K. (2020). Cyanobacteria as a source of biofertilizers for sustainable agriculture. *Biochemistry and Biophysics Reports,* 22, 100737. https://doi.org/10.1016/j.bbrep.2020.100737.

Choudhary, K. (2011). Occurrence of nitrogen-fixing cyanobacteria during different stages of paddy cultivation. *Bangladesh Journal of Plant Taxonomy*, 18(1), 73-76. https://doi.org/10.3329/bjpt.v18i1.7842.

Debnath, M., Mandal, N.C., & Ray, S. (2012). Effect of fungicides and insecticides on growth and enzyme activity of four cyanobacteria. *Indian Journal of Microbiology*, 52(2), 275-280. https://doi.org/10.1007/s12088-011-0212-4.

Dey, H., Tayung, K.N., & Bastia, A. (2010). Occurrence of nitrogen-fixing cyanobacteria in local rice fields of Orissa, India. *Ecoprint: An International Journal of Ecology*, 17, 77-85. https://doi.org/10.3126/eco.v17i0.4120.

Dhar, A., Dey, S., & Sarkar, S. (2023). Liquid Trees: A novel approach for air pollution mitigation. *Vigyan Varta*, 4(11), 193-196. https://www.researchgate.net/publication/375769507.

Fredriksson, C., Malin, G., Siddiqui, P.J.A., & Bergman, B. (1998). Aerobic nitrogen fixation is confined to a subset of cells in the non-heterocystous cyanobacterium *Symploca* PCC 8002. *New Phytologist*, 140(3), 531–538. http://doi.org/10.1046/j.1469-8137.1998.00284.x.

Ghadage, S.J., & Karande, V.C. (2019). The distribution of blue-green algae (Cyanobacteria) from the paddy fields of Patan and Karad tehsils of Satara District, Maharashtra, India. Journal of Threatened Taxa, 11(14), 14862–14869. http://doi.org/10.11609/jott.

Halder, N. (2015). Nitrogen fixing cyanobacterial flora of Nadia District in West Bengal, India. *International Journal of Experimental Research and Review*, 1, 8-16. https://doi.org/10.52756/ijerr.2015.v01.002.

Haroun S.A., & Hussein M.H. (2003). The promotive effect of algal biofertilizers on growth, protein pattern and some metabolic activities of *Lupinus termis* plants grown in siliceous soil. *Asian Journal of Plant Sciences,* 2, 944–951. https://doi.org/10.3923/ajps.2003.944.951.

Hendrayanti, D., Khoiriyaha, I., Fadilah, N., & Salamah, A. (2018). Diversity of N_2 – fixing cyanobacteria in organic rice field during the cycle of rice crops. In *AP Conf. Proc*. 2002, 020011. https://doi.org/10.1063/1.5050107.

Iniesta-Pallarés, M., Álvarez, C., Gordillo-Cantón, F. M., Ramírez-Moncayo, C., Alves-Martínez, P., Molina-Heredia, F.P., & Mariscal, V. (2021). Sustaining Rice Production through Biofertilization with N2 -Fixing Cyanobacteria. *Applied Sciences*, 11, 4628. https://doi.org/10.3390/app11104628.

Jan, Z., Ali, S., Rahim, H.U., Ali Akbar, W., Sehrish, A.K., Taj, A., Rahim, T., & Iqbal, M. (2023). Cyanobacterial strains reclaimed induced-salinity stress attributes and improved the physicochemical properties of induced-saline soil. *Acta Ecologica Sinica*, 43(6), 1074-1079. https://doi.org/10.1016/j.chnaes.2023.03.003.

Kumar, N., & Rai, L.C. (2020). Cyanobacterial diversity: Molecular insights under multifarious environmental conditions. In: Singh, P. K., Kumar, A., Singh, V. K., & Shrivastava, A.K. (Eds.) *Advances in Cyanobacterial Biology*. Academic Press, pp. 17-33.https://doi.org/10.1016/B978-0-12-819311-2.00002-4.

Liu, W.X., Chen, J.L., Lin, X.M., & Tao, S. (2006). Distribution and characteristics of organic micro pollutants in surface sediments from Bohai Sea. *Environmental Pollution*, 140, 4-8. https://doi.org/10.1016/j.envpol.2005.08.074.

Mazlan, N., Ahmed, M., Muharam, F.M., & Alam, M.A. (2017). Status of persistent organic pesticide residues in water and food and their effects on environment and farmers: A comprehensive review in Nigeria. *Semina: Cieˆncias Agra´rias,* 38, 2221-2236. https://doi.org/10.5433/1679-0359.2017v38n4p2221.

Misra, H.S., Khairnar, N.P., & Mahajan, S.K. (2003). An alternate photosynthetic electron donor system for PSI supports light dependent nitrogen fixation in a non-heterocystous cyanobacterium, *Plectonema boryanum*. *Journal of plant physiology*, 160(1), 33-39. https://doi.org/10.1078/0176-1617-00846.

Nascimento, M.D., Battaglia, L.S.R., Ambrosia, R., Palma, A.A.D., & Curatti, L., (2019). Prospects of using biomass of N_2- fixing cyanobacteria as an organic fertilizer and soil conditioner. *Algal Research*, 43, 101652. https://doi.org/10.1016/j.algal.2019.101652.

Osman, M.E.H., El-Sheekh, M.M., El-Naggar, A.H., & Gheda, S.F. (2010). Effect of two species of cyanobacteria as biofertilizers on some metabolic activities, growth, and yield of pea plant. *Biol Fertil Soils,* 46, 861–875. https://doi.org/10.1007/s00374-010-0491-7.

Petkar, S.D., Wadhawe, N.S., & Dahegaonkar, R.R. (2020). Diversity of blue green algae in rice fields of Nagbhid tehsil, dist. Chandrapur, Maharashtra, India. *InternationalJournal of Advances in Engineering and Management*, 2(5), 355-356. https://doi.org/10.35629/5252-0205353356.

Prasad, S.M., Kumar, D., & Zeeshan, M. (2005). Growth, photosynthesis, active oxygen species and antioxidants responses of paddy field cyanobacterium *Plectonema boryanum* to endosulfan stress. *The Journal* of *General* and *Applied Microbiology*, 51, 115-123. https://doi.org/10.2323/jgam.51.115.

Prasanna, R., Chaudhary, V., Gupta, V., Babu, S., Kumar, A., Singh, R., & Nain, L. (2013). Cyanobacteria mediated plant growth promotion and bioprotection against *Fusarium* wilt in tomato. *European Journal* of *Plant Pathology*, 136(2), 337-353. https://doi.org/10.1007/s10658-013-0167-x.

Prasanna, R., Babu, S., Bidyarani, N., Kumar, A., Triveni, S., Monga, D., Mukherjee, A.K., Kranthi, S., Gokte-Narkhedkar, N., Adaki, A., Yadav, K., Nain, L., & Saxena, A.K. (2015). Prospecting cyanobacteria-fortified composts as plant growth promoting and biocontrol agents in cotton. *Experimental agriculture*, 51(1), 42-65. https://doi.org/10.1017/S0014479714000143

Prasanna, R., Kanchan, A., Ramakrishnan, B., Ranjan, K., Venkatachalam, S., Hossain, F., Shivay, Y.S., Krishnan, P., & Nain, L. (2016). Cyanobacteria-based bioinoculants influence growth and yields by modulating the microbial communities favourably in the rhizospheres of maize hybrids. *European Journal of Soil Biology*, 75, 15-23. https://doi.

org/10.1016/j.ejsobi.2016.04.001.

Rajasekaran, A., & Raja, U. (2021). Diversity of non-heterocystous cyanobacteria in paddy field soil. *Bhartiya Krishi Anusandhan Patrika*, 36(2), 153-155. https://doi.org/10.18805/BKAP338.

Rajendran, U.M., Elango, K., & Anand, N. (2007). Effects of a fungicide, an insecticide, and a biopesticide on *Tolypothrix scytonemoides*. *Pesticide Biochemistry and Physiology,* 87, 164–171. https://doi.org/10.1016/j.pestbp.2006.07.006.

Rana, A., Joshi, M., Prasanna, R., Shivay, Y. S., & Nain, L. (2012). Biofortification of wheat through inoculation of plant growth promoting rhizobacteria and cyanobacteria. *European Journal of Soil Biology*, *50*, 118-126. https://doi.org/10.1016/j.ejsobi.2012.01.005.

Saadatnia, H., & Riahi, H. (2009). Cyanobacteria from paddy fields in Iran as a biofertilizer in rice plants. *Plant Soil and Environment*, 55(5), 207-212. https://doi.org/10.17221/384-PSE.

Sebastian, S. (2017). Filamentous algal diversity in Kole wetland paddy fields. *International Journal of Advanced Research*, 5(6), 361-366. https://doi.org/10.21474/IJAR01/4420.

Shedeed, Z.A., Gheda, S., Elsanadily, S., Alharbi, K., & Osman, M.E.H. (2022). *Spirulina platensis* biofertilization for enhancing growth, photosynthetic capacity and yield of *Lupinus luteus*. *Agriculture*, 12(6),781. https://doi.org/10.3390/agriculture12060781.

Singh, A.K., Singh, R.P., Tripathi, V., Verma, H., Singh, S.K., Srivastava, A.K., & Kumar, A. (2018). Distribution of cyanobacteria and their interactions with pesticides in a paddy field: A comprehensive review. *Journal of Environment Management*, 224, 361-375. https://doi.org/ 10.1016/j.jenvman.2018.07.039.

Singh, V.K., Singh, S.K., Singh, P.K., Verma, H., Pandey, K.D., Singh, P.K., & Kumar, A. (2020). Impact of pesticides applications on the growth and function of cyanobacteria. In: Singh, P.K., Kumar, A., Singh, V.K., & Srivastava, A.K. (Eds) Advances in Cyanobacterial biology. Academic press, pp. 151-162. https://doi.org/10.1016/B978-0-12-819311-2.00010-3.

Song, J., He, X., Wang, S., Yang, X., Wu, L., Li, S., Wang, D., Yang, M., & Wu, Z. (2022). Community composition specificities of cyanobacteria in paddy soil under different ecological conditions. *Agronomy*, 12(12), 3090. https://doi.org/10.3390/agronomy12123090.

Song, T., Martensson, L., Eriksson, T., Zheng, W., & Rasmussen, U. (2005). Biodiversity of seasonal variation of the cyanobacterial assemblage in a rice paddy field in Fujian, China. *FEMS Microbiology Ecology*, 54(1), 131-140.https://doi.org/10.1016/j.femsec.2005.03.008.

Srinivas, M, & Aruna, M. (2016). Diversity of blue green algae from paddy fields. *International Journal of Sciences*, 2, 27-30. https://doi.org/10.18483/ijSci.1010 .

Usharani, K.V., & Naik, D. (2019). Cyanobacteria: Role in agriculture- a review. *Trends in Biosciences,* 12(1), 15-26. https://doi.org/10.1016/j.trac.2014.07.007.