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DISTRIBUTIONAL PATTERN OF CYANOBACTERIA IN RICE FIELDS OF MANIPUR, INDIA

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The present investigation deals with the 550 algal and soil samples which were collected from the rice fields of Manipur, India falling under Indo-Burma Biodiversity hotspots during 2010-2014. One hundred twelve (112) unialgal cyanobacteria (non-heterocystous and heterocystous both) were encountered, successfully cultured, purified and deposited to the National fresh water cyanobacterial and Microalgal repository of IBSD, Imphal, Manipur with accession numbers. These strains belong to sixteen genera namely; *Myxosarcina* (01), *Spirulina* (01), *Oscillatoria* (01), *Phormidium* (15), *Lyngbya* (08), *Limnothrix* (04), *Cylindrospermum* (04), *Nostoc* (13), *Anabaena* (32), *Aulosira* (02), *Plectonema* (10), *Scytonema* (03), *Westiellopsis* (01), *Microchaete* (06), *Calothrix* (09) and *Dichothrix* (02). All these strains were morphologically characterized by classical method.

Keywords: Accession, Cyanobacteria, Heterocystous, Manipur, Repository

Manipur is landlocked, hilly and mountainous state within the north eastern part of India. It has 22,327 sq. km area, which constitutes 0.7 per cent of the total land surface of India. The state has a valley area of about 1,843 sq. km, which is 8 per cent of the total area of the state with two main seasons separated by two transitions; the winter season and the monsoon season. The ability of cyanobacteria to survive through 3.5 billion years was the consequence of wide spread compatibility and adaptability to the extremes of temperature, desiccation, illumination, radiation, salinity, pH, toxin and nutrient availability. In the cultivated fields, algae occur even upto 20 cm depth with pronounced effect on the surface soil layer. They have recently gained importance in agriculture as an input, which help in better crop nutrient management (Goyal 1996, 1998). The ability of cyanobacteria to fix atmospheric dinitrogen is implicated in maintaining the spontaneous fertility of tropical rice field soil (Singh 1961, Venkataraman 1972, 1981, Goyal 1993, 1995). Cyanobacteria not only act as essential for human, but also play an important role in paddy field ecosystem which is directly related with the ability of certain forms to fix nitrogen. The role of cyanobacteria in the sustained fertility of flooded and irrigated rice field soil is well established (Singh 1961, Venkataraman 1975, Roger 1996). Cyanobacteria as bio-inoculants have found to reduce the chemical fertilizers consumption by about 30%. The amount of nitrogen contributed by cyanobacteria to rice crop varies from 20-30 kg/ha (Kaushik 1994). Singh (1961) reported that rice fields in highest elevations were dominated by members of oscillatoriaceae while those at lower elevation contained a mixed population of oscillatoriaceae and nostocaceae. Singh (1976) observed that species of *Aulosira*, *Wollea, Gloeotrichia* and *Anabaena* were mostly found in waterlogged rice fields.

MATERIALS AND METHODS

Sample collection: Total 550 algal and soil samples were collected from rice fields of Manipur during the study period. The collection sites of sampling shown in Fig-1. The algal samples along with soils were collected on sunny, cloudy and rainy days

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Map of study site

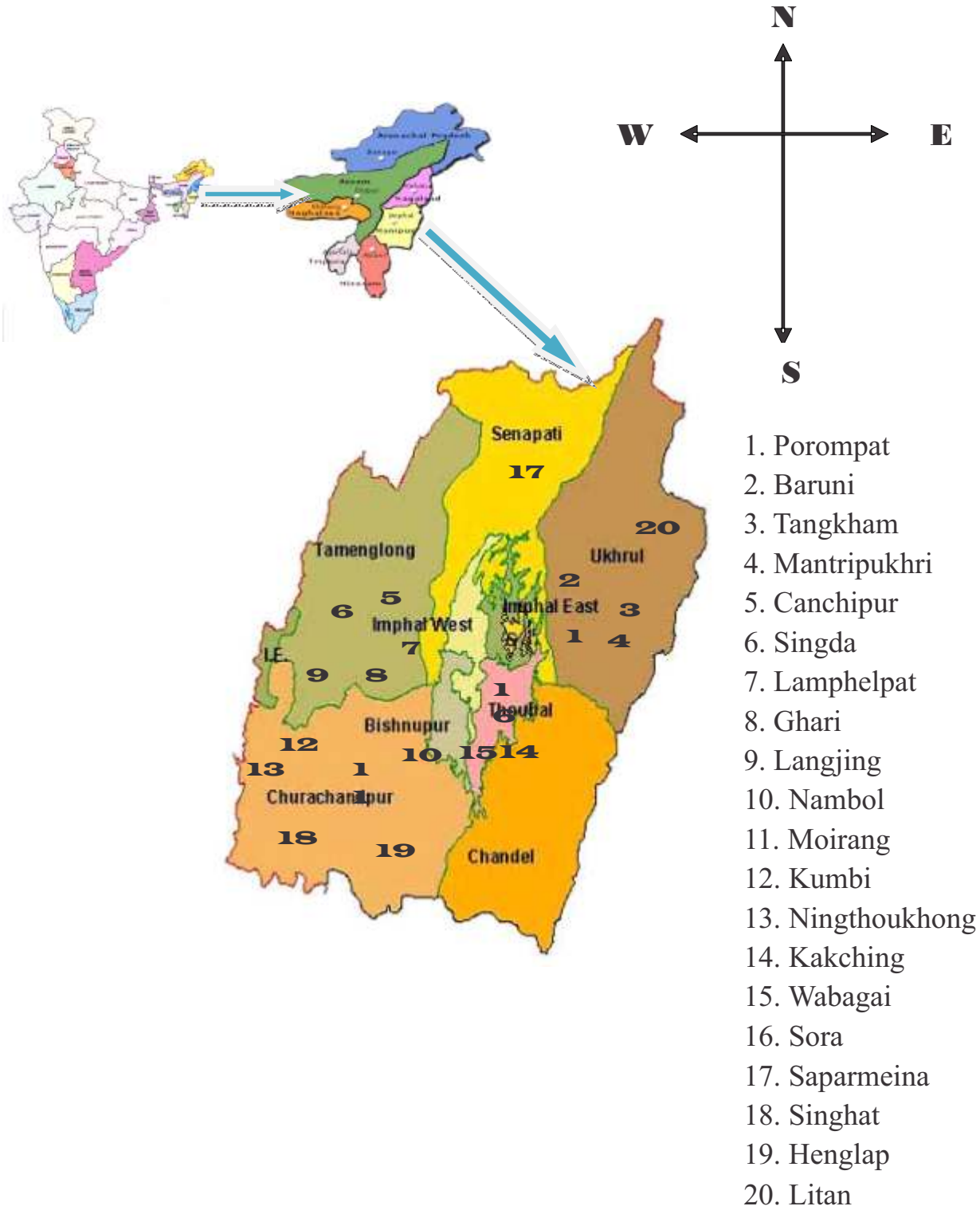

Figure -1: Location of study site in different sub districts of Manipur, India

List-1: Classical identification of non heterocystous cyanobacterial strains of rice fields of Manipur and their distribution

SN	Cyanobacterial strains with accession no.	Location of strains	GPS location of strains	Taxonomical enumeration of strains				
				Colony characteristic	Cell colour/ Filaments	Sheath	Cell constriction	Trichome ends
1	*Phormidium mucosum* Gardner BTA002	Porompat, Imphal East, Manipur	Alt: 775 m N24°49'26.4" E093°57'52.0"	Colony firm and thick	Bright light green, many	Fine colourless	Cross wall	Slight rounded
2	*Limmothrix vacuolifera* (Skuja) Komarek *et al*. BTA005	Porompat, Imphal East, Manipur	Alt: 775 m N24°49'26.4" E093°57'52.0"	Dark blue green spreaded	Light green, solitary	Fine colourless	Cross wall	Rounded
3	*Plectonema radiosum* Schiederm BTA009	Porompat, Imphal East, Manipur	Alt: 782 m N24°52'09.0" E094°01'12.9"	Irregular flattened colony	Dull green, irregular	Thick	Cross wall	Rounded
4	*Plectonema boryanum* Gomont BTA010	Porompat, Imphal East, Manipur	Alt: 782 m N24°52'09.0" E094°01'12.9"	Colonies dense dark blue green	Olive green, sparsely branched	Hyaline	Cross wall	Rounded
5	*Phormidium tenue* (Meneghini) Gomont BTA013	Porompat, Imphal East, Manipur	Alt: 775 m N24°49'26.4" E093°57'52.0"	Colony thin weakly layered mat	Yellowish, entangled	Diffluent	Distinct	Attenuated
6	*Plectonema boryanum* Gomont BTA016	Canchipur, Imphal West, Manipur	Alt: 769 m N24°46'06.7" E093°54'14.5"	Flattened colonies on the soil surface	Olive green, false branched	Hyaline	Cross wall	Rounded
7	*Phormidium faveolarum* Mont. BTA020	Canchipur, Imphal West, Manipur	Alt: 769 m N24°46'06.7" E093°54'14.5"	Colony very slippery	Dark green, solitary	Very thin	Cross wall	Rounded
8	*Plectonema radiosum* Schiederm BTA032	Langjing, Imphal West, Manipur	Alt: 780 m N24°43'15.5" E093°53'25.5"	Forming thick mat, dark green	Dull green, irregular curved	Lamellated	Distinct	Rounded
9	*Plectonema litorale* Anand BTA033	Nambol, Bishnupur, Manipur	Alt: 776 m N24°43'15.5" E093°50'27.5"	Small colony mixed with other algal	Blue green, long	Thin	Not constriction	Rounded
10	*Myxosarcina burmensis* Skuja BTA040	Moirang, Bishnupur, Manipur	Alt: 769 m N24°30'12.3" E093°41'46.4"	Dense packing in cubical colonies	Pale blue green	Individually thin	Unicellular	Unicellular
11	*Phormidium arthurensis* Novis & Visnovsky BTA042	Kumbi, Bishnupur, Manipur	Alt: 764 m N24°32'21.4" E093°45'27.6"	Colony leathery, thin pale blue green	Pale blue green, Entangled	Thin colourless	Cross wall	Rounded
12	*Plectonema nostocorum* Bornet ex Gomont BTA047	Ningthoukhong, Bishnupur, Manipur	Alt: 767 m N24°33'39.0" E093°45'42.3"	Intermingled gelatinous colonies	Pale blue green, nearly straight	Thin	Cross wall	Rounded
13	*Phormidium fragile* Meneghini Gomont BTA048	Ningthoukhong, Bishnupur, Manipur	Alt: 767 m N24°33'39.0" E093°45'42.3"	Gelatinous colonies	Yellowish blue green, entangled	Diffluent	Distinct	Attenuated
14	*Phormidium purpurascens* (Ag) Gomont BTA081	Kakching, Thoubal, Manipur	Alt: 776 m N24°29'25.1" E094°00'23.7"	Colony firm, thick dark pale green	Yellowish blue green, entangled	Diffluent	Distinct	Attenuated
15	*Limnothrix redekei* (Van Goor) Meffert BTA082	Kakching, Thoubal, Manipur	Alt: 763 m N24°29'25.1" E094°00'40.4"	Spreaded with dark green	Pale blue green, solitary	Indistinct	Slightly	Pointed

SN	Cyanobacterial strains with accession no.	Location of strains	GPS location of strains	Taxonomical enumeration of strains				
				Colony characteristic	Cell colour/ Filaments	Sheath	Cell constriction	Trichome ends
16	*Phormidium kuetzingianum* Kirchner Anagnostidis et Komarek BTA083	Kakching, Thoubal, Manipur	Alt: 759 m N24°29'25.1" E094°00'42.7"	Colony thin, leathery like	Bright blue green, curved	Thin	At apical part	Rounded
17	*Lyngbya laxespiralis* Skuja BTA085	Kakching, Thoubal, Manipur	Alt: 769 m N24°29'25.1" E094°00'43.7"	Mass leathery like colonies	Blue green, intermixed	Firm	Not distinct	Rotund
18	*Phormidium tenue* Menegh. Gomont BTA086	Kakching, Thoubal, Manipur	Alt: 769 m N24°29'25.1" E094°00'43.7"	Colony leathery mat like	Pale blue green, slightly bent	Thin	Slightly	Acute conical
19	*Plectonema notatum* Schmidle BTA088	Takyelpat, Imphal West, Manipur	Alt: 782 m N24°48'14.3" E093°54'18.3"	Leathery stratum colony	Pale blue green, variously bent	Thin colourless	Not distinct	Rounded
20	*Plectonema notatum* Schmidle BTA108	Henglap, Churachandpur Manipur	Alt: 835 m N24°20'36.7" E093°41'50.3"	Thick mat like colony	Pale blue green, variously bent	Thin colourless	Not distinct	Rounded
21	*Phormidium incrustatum* (Nag.) Gomont BTA118	Henglap, Churachandpur Manipur	Alt: 835 m N24°20'36.7" E093°41'50.3"	Colony calcified forming oncoids	Yellowish blue green, entangled	Diffluent	Distinct	Attenuated
22	*Limnothrix redekei* (Van Goor) Meffert BTA123	Henglap, Churachandpur Manipur	Alt: 835 m N24°20'36.7" E093°41'50.3"	Thin spreaded	Pale blue green, solitary	Indistinct	Slightly	Pointed
23	*Phormidium valderianum* (Delp.) Gomont BTA162	Nambol, Bishnupur, Manipur	Alt: 764 m N24°32'21.9" E093°45'27.6"	Colony very slippery, spreaded out	Pale blue green, slightly bent	Thin	Slightly	Acute conical
24	*Oscillatoria agardhii* Gomont BTA170	Henglap, Churachandpur Manipur	Alt: 835 m N24°20'36.7" E093°41'50.3"	Arranged in mats	Brilliant blue green, straight	Absent	Not constricted	Gradually tapering
25	*Spirulina platensis* Nordst. Gomont BTA174	Moirang, Bishnupur, Manipur	Alt: 764 m N24°32'21.9" E093°45'27.6"	Forming fine slime mat like	Blue green, spiral	Absent	Slightly	Broadly rounded
26	*Lyngbya connectens* Bruhl et Biswas BTA178	Baruni, Imphal East, Manipur	Alt: 812 m N24°46'42.6" E094°00'09.6"	Colonies mucilaginous spreaded out	Brown, single	Thick and firm	Absent	Slight rounded broad
27	*Lyngbya nordgardhii* Wille BTA184	Baruni, Imphal East, Manipur	Alt: 778 m N24°52'19.6" E093°58'37.2"	Colony rounded and later spreaded	Grey brown, long and straight	Thin and delicate	Cross walls	Rounded
28	*Phormidium tenue* Menegh Gomont BTA189	Henglap, Churachandpur, Manipur	Alt: 835 m N24°20'36.7" E093°41'50.3"	Colony membranaceous dark blue green	Pale blue green, slightly bent	Thin	Slightly	Acute conical
29	*Plectonema notatum* Schmidle BTA194	Henglap, Churachandpur, Manipur	Alt: 835 m N24°20'36.7" E093°41'50.3"	Colonies form thick mat, dark blue green	Pale blue green, variously bent	Thin colourless	Notdistinct	Rounded
30	*Limnothrix mirabilis* (Bocher) Anagnostidis BTA199	Henglap, Churachandpur, Manipur	Alt: 835 m N24°20'36.7" E093°41'50.3"	Cell evenly spread colonies	Blue grey, solitary	Hyaline	Slightly	Rounded

SN	Cyanobacterial strains with accession no.	Location of strains	GPS location of strains	Taxonomical enumeration of strains				
				Colony characteristic	Cell colour/ Filaments	Sheath	Cell constriction	Trichome ends
31	*Phormidium tenue* Menegh Gomont BTA 222	Sora, Thoubal, Manipur	Alt: 795 m N24°45'01.3" E093°52'40.2"	Colony membranous, dark blue green	Pale blue green, slightly bent	Thin	Slightly	Acute conical
32	*Lyngbya martensiana* Menegh. ex Gomont BTA436	Tangkham, Imphal East, Manipur	Alt: 780 m N24°53'54.9" E093°59'03.8"	Forming extensive masses	Blue green, long	Thick	Absent	Rotund
33	*Lyngbya digueti* Gomont BTA475	Ghari, Imphal West, Manipur	Alt: 795 m N24°45'01.3" E093°52'40.2"	Colony mat like slimy patches	Light green, long	Lamellated	Slightly constricted	Rounded
34	*Phormidium fragile* Meneghini Gomont BTA521	Litan, Ukhrul, Manipur	Alt: 950 m N24°57'53.4" E094°13'16.9"	Colony gelatinous layered	Light blue green, many	Firm	Firm	Calyptra
35	*Plectonema nostocorum* Bornet ex Gomont BTA565	Tangkham, Imphal East, Manipur	Alt: 700 m N24°53'54.9" E093°59'03.8"	Small colony surrounded	Pale blue green, highly entangled	Thin	Cross walls	Rounded
36	*Phormidium autumnale* (Ag.) Gomont BTA587	Tangkham, Imphal East, Manipur	Alt: 780 m N24°53'54.9" E093°59'03.8"	Colony expanded dark blue green	Light blue green, many	Firm	Firm	Calyptra
37	*Lyngbya aestuarii* Liedm. ex Gomont BTA597	Saparmeina, Senapati, Manipur	Alt: 933 m N24°02'20.2" E093°55'36.0"	Colony forming thick masses	Dull blue green and long	Lamellated	Absent	Rotund
38	*Lyngbya allorgei* Fremy BTA606	Thingbungjang, Senapati, Manipur	Alt: 933 m N25°01'19.2" E093°55'23.8"	Brownish thick masses colony	Pale violet, solitary	Very thin	Not constricted	Rotund
39	*Lyngbya martensiana* Menegh. ex Gomont BTA640	Wabagai, Thoubal, Manipur	Alt: 796 m N24°31'20.3" E093°56'11.1"	Flakes like free floating attached to substrata	Blue green, long	Thick	Not constricted	Rotund
40	*Phormidium stagnina* Rao, C. B. BTA855	Ghari, Imphal West, Manipur	Alt: 783 m N24°45'32.9" E093°53'16.3"	Colony thin dirty green patches	Pale blue green, slightly bent	Thin	Slightly	Acute conical

List-2: Classical identification of heterocystous cyanobacterial strains of rice fields of Manipur and their distribution

SN	Cyanobacteria strains with accession no.	Location of strains	GPS location of strains	Taxonomical enumeration of strains				
				Colony characteristic	Cell colour / Filaments	Sheath	Heterocyst/ Akinetes	Trichome ends
1	*Microchaete uberrima* Carter, N BTA001	Porompat, Imphal East, Manipur	Alt: 775 m N24°49'26.4" E093°57'52.0"	Creeping to substrate	Brownish green, solitary	Firm	Basal	Broad end
2	*Anabaena variabilis* Kutzing ex Born. et Flah. BTA003	Porompat, Imphal East, Manipur	Alt: 775 m N24°49'26.4" E093°57'52.0"	Colonies composed of filaments, gelatinous	Dark green, flexuous	Absent	Barrel shaped, akinete adjacent	Conical
3	*Anabaena dolionum* Bharadwaja BTA004	Porompat, Imphal East, Manipur	Alt: 773 m N24°15'11.1" E093°57'50.5"	Mass mucilaginous colonies	Pale blue green, single	Absent	Barrel shaped, scattered all around	Tapering ends

SN	Cyanobacterial strains with accession no.	Location of strains	GPS location of strains	Taxonomical enumeration of strains				
				Colony characteristic	Cell colour / Filaments	Sheath	Heterocyst/ Akinete	Trichome ends
4	*Anabaena variabilis* Kutzing ex Born. et Flah BTA006	Porompat, Imphal East, Manipur	Alt: 775 m N24°49'26.4" E093°57'52.0"	Gelatinous dark green mucilaginous	Dark green, flexuous	Absent	Spherical	Conical
5	*Microchaete grisea* Thuret ex Born. et BTA007	Porompat, Imphal East, Manipur	Alt: 775 m N24°49'26.4" E093°57'52.0"	Colony attached to substrate	Dull-green, entangled	Thin	Basal	Broad ends
6	*Anabaena circinalis* Rabenhorst ex Born. et Flah. BTA008	Porompat, Imphal East, Manipur	Alt: 775 m N24°49'26.4" E093°57'52.0"	Clump colonies	Light green, circinate	Absent	Subspherical prominent heterocyst	Rounded
7	*Nostoc hatei* Dixit BTA012	Porompat, Imphal East, Manipur	Alt: 782 m N24°52'09.0" E094°01'12.9"	Moniliform cells in a gelatinous	Brownish green, entangled	Very thin	Single in barrel shaped	Broad rounded
8	*Anabaena oryzae* Fritsch BTA014	Porompat, Imphal East, Manipur	Alt: 775 m N24°49'26.4" E093°57'52.0"	Huge colonies rapid growing	Deep green, aggregated	Absent	Terminal and intercalary	Conical
9	*Calothrix wembaerensis* Hieron. et Schmidle BTA015	Porompat, Imphal East, Manipur	Alt: 775 m N24°49'26.4" E093°57'52.0"	Colonies brown, incrustrated by carbonates	Deep green, separated	Very thick	Basal	Cylindrical
10	*Anabaena oryzae* Fritsch BTA017	Canchipur, Imphal West, Manipur	Alt: 745 m N24°46'06.7" E093°54'14.5"	Colonies grow in filamentous clumps	Deep green, aggregated	Absent	Terminal and intercalary	Conical
11	*Anabaena oryzae* Fritsch BTA018	Canchipur, Imphal West, Manipur	Alt: 769 m N24°46'06.7" E093°54'26.5"	Colonies grow in filamentous clumps	Deep green, aggregated	Absent	Terminal and intercalary	Conical
12	*Anabaena spiroides* Klebahn BTA019	Canchipur, Imphal West, Manipur	Alt: 772 m N24°46'06.7" E093°54'11.5"	Mucilaginous colonies	Deep green, aggregated	Absent	Terminal and intercalary	Conical
13	*Anabaena ambigua* Rao, C. B. BTA021	Canchipur, Imphal West, Manipur	Alt: 789 m N24°49'37.0" E093°43'35.2"	Colonies form mat like	Dark green, dense cluster	Hyaline	Spherical	Slightly tapering rounded
14	*Anabaena anomala* Fritsch BTA023	Singda, Imphal West, Manipur	Alt: 780 m N24°49'36.0" E093°53'25.5"	Dark green colour colonies attached on moist soil	Light green, single	Absent	Barrel-shaped	Conical
15	*Calothrix javanica* de Wilde BTA024	Singda, Imphal West, Manipur	Alt: 780 m N24°49'36.0" E093°53'25.5"	Mucilaginous colonies	Light green, single	Unlamellated	Basal	Pointed
16	*Calothrix geitonos* Skuja BTA025	Singda, Imphal West, Manipur	Alt: 780 m N24°49'36.0" E093°53'25.5"	Colonies olive green	Dark green, aggregated	Colourless	Basal	Cylindrical
17	*Calothrix marchica* Lemmermann BTA026	Singda, Imphal West, Manipur	Alt: 792 m N24°50'33.6" E093°56'23.4"	Colonies dry brownish colour	Olive green, straight	Thin colourless	Basal and spherical	Conical
18	*Nostoc muscorum* Ag. ex Born. et Flah. BTA027	Lamphelpat, Imphal West, Manipur	Alt: 786 m N24°50'31.0" E093°66'23.0"	Colonies form a jelly like mess	Light green, densely entangled	Distinct at periphery	Spherical	Broad rounded
19	*Dichothrix orsiniana* Kutz. Born. et Flah. BTA028	Lamphelpat, Imphal West, Manipur	Alt: 792 m N24°50'33.6" E093°56'23.4"	Colonies spreaded out and mixed with other algal species	Green, flexuous	Close to the trichome	Basal	Broad rounded

SN	Cyanobacterial strains with accession no.	Location of strains	GPS location of strains	Taxonomical enumeration of strains				
				Colony characteristic	Cell colour / Filaments	Sheath	Heterocyst/ Akinetes	Trichome ends
20	*Nostoc parmelioides* Kutz. ex Born. et Flah. BTA029	Takyelpat, Imphal West, Manipur	Alt: 782 m N24°48'14.3" E093°54'18.3"	Moniliform cells and mucilaginous	Green, entangled	Distinct	Spherical	Rounded
21	*Anabaena fertilissima* Rao, C. B. BTA030	Takyelpat, Imphal West, Manipur	Alt: 782 m N24°48'14.3" E093°54'18.3"	Loose colony indistinct mucilage	Yellowish green, single	Absent	Spherical	Rounded
22	*Anabaena oryzae* Fritsch BTA031	Takyelpat, Imphal West, Manipur	Alt: 782 m N24°48'14.3" E093°54'18.3"	Dark green colour form small colonies	Deep green, aggregated	Absent	Terminal and intercalary	Conical
23	*Anabaena ambigua* Rao, C. B. BTA034	Nambol, Bishnupur, Manipur	Alt: 776 m N24°43'15.5" E093°50'27.5"	Mat like colony clump and form thick patches	Dark green, dense cluster	Hyaline	Spherical	Slightly tapering rounded
24	*Anabaena fertilissima* Prasad BTA035	Nambol, Bishnupur, Manipur	Alt: 776 m N24°43'15.5" E093°50'27.5"	Very dark green small patches make colony	Green, single	Absent	Spherical	Rounded
25	*Anabaena variabilis* Kutzing ex Born. et Flah. BTA036	Nambol, Bishnupur, Manipur	Alt: 776 m N24°43'15.5" E093°50'27.5"	Colonies mucilaginous and dark green color	Green, single	Absent	Spherical	Rounded
26	*Nostoc hatei* Dixit BTA037	Moirang, Bishnupur, Manipur	Alt: 761 m N24°30'12.3" E093°46'46.4"	Confluent with colonial mucilage	Yellowish green, coil	Absent	Single	Flattened board
27	*Nostoc carneum* Ag. ex Born. et Flah. BTA038	Moirang, Bishnupur, Manipur	Alt: 767 m N24°30'12.3" E093°46'46.4"	Colonies formed a gelatinous	Olive green, loosely contorted	Indistinct	Oblong	Rounded
28	*Anabaena iyengarii* Bharadwaja BTA041	Moirang, Bishnupur, Manipur	Alt: 765 m N24°30'12.3" E093°46'46.4"	Well developed colonies mat	Light green, single	Absent	Barrel-shaped	Conical
29	*Anabaena variabilis* Kutzing ex Born. et Flah. BTA043	Kumbi, Bishnupur, Manipur	Alt: 764 m N24°32'21.4" E093°45'27.6"	Mucilaginous colonies with thick patches	Dark green, single	Absent	Barrel-shaped	Conical
30	*Microchaete loktakensis* Bruhl et Biswas BTA044	Kumbi, Bishnupur, Manipur	Alt: 764 m N24°32'21.4" E093°45'27.6"	Colonies forming a turf	Green, aggregated	Thick	Basal	Cylindrical
31	*Microchaete uberrima* Carter, N. BTA045	Kumbi, Bishnupur, Manipur	Alt: 764 m N24°32'21.4" E093°45'27.6"	Colonies of many filaments	Greenish blue solitary	Firm	Basal	Broad end
32	*Calothrix marchica* Lemmermann BTA046	Kumbi, Bishnupur, Manipur	Alt: 764 m N24°32'21.4" E093°45'27.6"	Colonies dark brown, mat form and firm substrate	Olive green, straight	Thin colourless	Basal and spherical	Conical
33	*Microchaete tenera* Thuret ex Born.et Flah. BTA049	Kakching, Thoubal, Manipur	Alt: 772 m N24°29'25.1" E094°00'47.7"	Colonies	Greenish blue solitary	Firm	Basal	Broad end
34	*Anabaena oryzae* Fritsch BTA050	Kakching, Thoubal, Manipur	Alt: 769 m N24°29'25.1" E094°00'43.7"	Colonies loosely arranged spreaded	Deep green, aggregated	Absent	Terminal and intercalary	Conical
35	*Anabaena spiroides* Klebahn BTA084	Kakching, Thoubal, Manipur	Alt: 769 m N24°29'25.1" E094°00'43.7"	Colonies form mat like	Deep green, slight spiral	Thick	Subspherical	Rounded
36	*Nostoc muscorum* Ag. ex Born.et Flah. BTA087	Takyelpat, Imphal West,	Alt: 782 m N24°48'14.3" E093°54'18.3"	Forming large colonies	Olive green, loosely contorted	Indistinct	Oblong	Broad rounded

SN	Cyanobacterial strains with accession no.	Location of strains	GPS location of strains	Taxonomical enumeration of strains				
				Colony characteristic	Cell colour/ Filaments	Sheath	Heterocyst/ Akinetes	Trichome ends
37	*Scytonema bohneri* Schmidle BTA106	Takyelpat, Imphal West, Manipur	Alt: 782 m N24°48'14.3" E093°54'18.3"	Slimy matrix colony forming dense tufts	Bluish green, long, branch	Colourless	Rectangular	Broad and rounded
38	*Scytonema guyanense* Mont Bornet et Flahault BTA167	Henglap, Churachandpur, Manipur	Alt: 835 m N24°20'36.7" E093°41'50.3"	Semi spherical colonies attached	Blackish green, united in bundle, branch	Firm	Compressed	Quadrate
39	*Nostoc commune* Vaucher ex Born. et Flah. BTA168	Henglap, Churachandpur Manipur	Alt: 835 m N24°20'36.7" E093°41'50.3"	Distinct periderm on colonial surface	Blue green, entangled	Distinct	Spherical	Rounded
40	*Calothrix castellii* (Massal.) Born. et Flah. BTA177	Baruni, Imphal East, Manipur	Alt: 812 m N24°46'42.0" E094°00'09.6"	Colony clathrate, mucilaginous	Dull blue green, bent	Thin	Basal	Attenuated
41	*Scytonema schmidtii* Gom BTA186	Henglap, Churachandpur, Manipur	Alt: 835 m N24°20'36.7" E093°41'50.3"	Colony flat, spreading sparsely	Brownish green, irregular, branch	Thin	Quadrate and compressed	Broad
42	*Aulosira aenigmatica* Fremy BTA188	Henglap, Churachandpur, Manipur	Alt: 835 m N24°20'36.7" E093°41'50.3"	Colonies irregular	Dark blue green, intricate	Colourless	Rectangular	Attenuated
43	*Aulosira bombayensis* Gonzalves BTA190	Baruni, Imphal East, Manipur	Alt: 752 m N24°52'31.8" E094°00'56.3"	Form partial mat like	Yellowish blue green, board	Firm	Intercalary	Rounded
44	*Calothrix marchica* Lammermann BTA195	Henglap, Churachandpur, Manipur	Alt: 835 m N24°20'36.7" E093°41'50.3"	Spherical mucilage colonies	Yellowish, irregular	Thin	Basal	Tapered
45	*Nostoc calcicola* Brebi son ex Born. et Flah. BTA204	Singhat, Churachandpur, Manipur	Alt: 796 m N24°31'20.3" E093°56'11.1"	Gelatinous colonies	Blue green, loosely entangled	Indistinct	Subspherical	Broad rounded
46	*Anabaena circinalis* Rabenhorst ex Born. et Flah. BTA205	Singhat, Churachandpur, Manipur	Alt: 776 m N24°43'15.5" E093°50'27.5"	Colonies grow in filamentous clumps	Light green, circinate	Absent	Subspherical	Rounded
47	*Calothrix marchica* Lammermann BTA206	Henglap, Churachandpur, Manipur	Alt: 835 m N24°20'36.7" E093°41'50.3"	Colony form attached firmly to the substrate	Yellowish, irregular	Thin	Basal	Tapered
48	*Calothrix clavata* West G.S. BTA218	Singhat, Churachandpur, Manipur	Alt: 780 m N24°47'36.0" E093°53'25.5"	Colonies assemble to form amorphous	Dark green, straight	Thin	Basal	Attenuated
49	*Anabaena circinalis* Rabenhorst ex Born. et Flah. BTA246	Tangkham, Imphal East, Manipur	Alt: 783 m N24°52'54.7" E093°55'01.4"	Clumps colonies appeared	Light green, circinate	Absent	Subspherical	Rounded
50	*Anabaena circinalis* Rabenhorst ex Born. et Flah. BTA561	Tangkham, Imphal East, Manipur	Alt: 780 m N24°53'54.9" E093°59'03.8"	Colonies grow in filamentous clumps	Deep green, straight	Absent	Terminal and intercalary	Conical
51	*Anabaena* sp. BTA564	Sapermeina, Senapati, Manipur	Alt: 933 m N25°02'20.2" E093°55'36.0"	Colonies appeared clumps	Light green, straight	Absent	Terminal	Rounded
52	*Anabaena variabilis* Kutzing ex Born. et Flah. BTA600	Tangkham, Imphal East, Manipur	Alt: 780 m N24°53'54.9" E093°59'03.8"	Forming a dark green colony	Dark green, slightly curved	Absent	Barrel shaped	Conical
53	*Westiellopsis prolifica* Janet BTA645	Tangkham, Imphal East, Manipur	Alt: 780 m N24°53'54.9" E093°59'03.8"	Colonies float on water surface	Dark green, torulose multiseriate	Absent	Oblong	Rounded
54	*Anabaena orientalis* Dixit BTA653	Saparmeina, Senapati, Manipur	Alt: 933 m N24°02'19.1" E094°18'00.1"	Colonies in fascicle	Dull green, straight	Absent	Single	Conical

SN	Cyanobacterial strains with accession no.	Location of strains	GPS location of strains	Taxonomical enumeration of strains				
				Colony characteristic	Cell colour/ Filaments	Sheath	Heterocyst/ Akinetes	Trichome ends
55	*Anabaena variabilis* Kutzing ex Born. et Flah. BTA880	Mantripukhri, Imphal East, Manipur	Alt: 765 m N24°50'49.7" E093°56'22.7"	Forming a dark green colony	Dark green, curved	Absent	Barrel shaped	Conical
56	*Anabaena oryzae* Fritsch BTA881	Mantripukhri, Imphal East, Manipur	Alt: 765 m N24°50'49.7" E093°56'22.7"	Loose patches distinctly mucilage	Dull green, straight	Absent	Terminal and intercalary	Conical
57	*Anabaena fertilissima* Prasad BTA883	Mantripukhri, Imphal East, Manipur	Alt: 765 m N24°50'49.7" E093°56'22.7"	Colony is firm and leathery	Shining blue green, entangled	Diffluent	Barrel	Flattened
58	*Nostoc ellipsosporum* (Desm.) Rabenh. ex Born.et Flah. BTA902	Mantripukhri, Imphal East, Manipur	Alt: 765 m N24°50'49.7" E093°56'22.7"	Fasciculated colonies	Reddish brown, flexuous	Absent	Subspherical	Cylindrical
59	*Anabaena constricta* Skuja BTA903	Canchipur, Imphal West, Manipur	Alt: 769 m N24°46'06.7" E093°54'14.5"	Colony form in slimy matrix	Light green, curved	Absent	Intercalary	Broad
60	*Cylindrospermum muscicola* Kutzing ex Born. et. Flah. BTA904	Porompat, Imphal East, Manipur	Alt: 775 m N24°49'26.4" E093°57'52.0"	Colony mucilaginous dark green	Dark blue green, cylindrical	Absent	Oblong, akinete present	Quadrate
61	*Cylindrospermum doryphorum* Bruhl et Biswas BTA905	Porompat, Imphal East, Manipur	Alt: 775 m N24°49'26.4" E093°57'52.0"	Colony spread out	Green, straight	Absent	Both present	Flattened
62	*Cylindrospermum indentatum* West, G. S. BTA906	Singda, Imphal West, Manipur	Alt: 780 m N24°47'36.0" E093°53'25.5"	Highly mucilaginous colony form	Light green, curved	Absent	Hairy, akinete present	Flattened
63	*Anabaena oryzae* Fritsch BTA919	Moirang, Bishnupur, Manipur	Alt: 761 m N24°30'12.3" E093°46'46.4"	Colonies appeared dark green	Light green, straight	Absent	Terminal and intercalary	Conical
64	*Nostoc ellipsosporum* (Desm.) Rabenh. ex Born. et Flah. BTA923	Kakching, Thoubal, Manipur	Alt: 805 m N24°29'28.7" E094°00'24.1"	Colony gelatinous irregularly expanded	Brownish, flexuous	Absent	Subspherical	Cylindrical
65	*Microchaete grisea* Thuret ex Born. et Flah. BTA926	Lilong, Thoubal, Manipur	Alt: 782 m N24°39'18.5" E093°59'18.6"	Colony of many filament irregularly form	Greenish brown, aggregated	Firm	Basal	Cylindrical
66	*Anabaena anomala* Fritsch BTA927	Okram, Thoubal, Manipur	Alt: 782 m N24°39'18.5" E093°59'18.6"	Ball like colonies	Deep green, irregular torn	Absent	Intercalary	Rounded
67	*Nostoc verrucosum* Vaucher ex Born. et Flah. BTA939	Okram, Thoubal, Manipur	Alt: 782 m N24°39'18.5" E093°59'18.6"	Colony spherical	Light green, irregularly torn	Indistinct	Intercalary and terminal	Rounded
68	*Nostoc calcicola* Brebisson ex Born. et Flah. BTA942	Sora, Thoubal, Manipur	Alt: 782 m N24°39'18.5" E093°59'18.6"	Colony mucilaginous slightly diffluent	Yellowish green, entangled	Indistinct	Intercalary and terminal	Rounded
69	*Nostoc piscinale* Fremy BTA947	Sora, Thoubal Manipur	Alt: 805 m N24°29'28.7" E094°00'24.1"	Slimy dark green colony	Greenish, flexuous	Absent	Intercalary sub spherical	Cylindrical
70	*Cylindrospermum indicum* Rao, C. B, orth.mut. De Toni BTA960	Lilong, Thoubal, Manipur	Alt: 782 m N24°39'18.5" E093°59'18.6"	Colony mucilaginous dark green	Light green, cylindrical	Absent	Oblong, akinete present	Quadrate
71	*Anabaena variabilis* Kutzing ex Born. et Flah. BTA990	Kakching, Thoubal, Manipur	Alt: 805 m N24°29'28.7" E094°00'24.1"	Forming a dark green colonies	Dark green, slightly, curved	Absent	Intercalary	Rounded
72	*Dichothrix baueriana* Grun. Born. et Flah. BTA1059	Nambol, Bishnupur, Manipur	Alt: 773 m N24°42'09.6" E093°48'22.3"	Colony bushy cushion	Olive green, ultimate branches	Thick	Basal	Rounded

seasonally, temperature ranges between 0 to 36ºC and the hours of 10.00-11.30 AM and between 1.30-3.30 PM by using sterilized spatula and transferred to transparent polythene bags and recorded all the required data.

Preparation of the medium and processing of the collected samples: BG-11 (Stanier *et al*. 1971) culture medium with or without sodium nitrate was used for isolation of non heterocystous and heterocystous cyanobacteria respectively with addition of 15 g bacteriological agar in 1000 ml liquid medium for solid petriplates and slants. The cultures were incubated at 28±2ºC for 10 to 15 days or till the appearance of algal patches in growth media. *Spirulina platensis* was transferred and maintained in CFTRI medium (Venkataraman *et al*. 1995) after picked up from BG-11 medium. The cultures were observed under the phase contrast microscope (Nikon Eclipse 80i) and morphological characteristics of the species were carefully studied using the keys of Desikachary (1959) and Komarek and Anagnostidis (1998, 2005).

Purification of cyanobacteria: Depending on the consistency of the crude material, the samples were examined and placed on the slide with the platinum loop. Once the sample was thoroughly examined and its composition recorded, aliquot amount was transferred to liquid/solid BG-11 medium and CFTRI medium accordingly. The streaked algal patches on solid medium were examined under binocular research microscope (Unilab RH-87UXL) in order to isolate unialgal forms (Rippka *et al*. 1979).

Identification of cyanobacteria and microscopic observation: A portion of unialgal cyanobacteria was taken from periphery and mount on a cleaned slide with glycerol covered by a cleaned cover slip and observed under phase contrast microscope (NIKON-80i) at different interval of their growth phase. Identification of cyanobacterial isolates were carried out using morphological and reproductive structures, compared with Desikachary (1959) and Komarek and Anagnostidis (2005). Photomicrograph documentation was performed under different objective magnifications by using Carl Zeiss Microscope (Carl Zeiss-A1).

RESULTS

One hundred twelve (112) cyanobacterial strains belong to 16 genera including non heterocystous (07 genera 40 strains) and heterocystous (09 genera 72 strains) namely; *Myxosarcina* (01), *Spirulina* (01), *Oscillatoria* (01), *Phormidium* (15), *Lyngbya* (08), *Limnothrix* (04), *Cylindrospermum* (04), *Nostoc* (13), *Anabaena* (32), *Aulosira* (02), *Plectonema* (10), *Scytonema* (03), *Westiellopsis* (01), *Microchaete* (06), *Calothrix* (09) and *Dichothrix* (02) were isolated from rice fields of Manipur and incorporated in present study. These unialgal cyanobacterial strains were morphologically characterized (list -1 and list- 2).

DISCUSSION

Rice fields are temporary wetland ecosystems with variable biodiversity and cyanobacteria are known to be an integral component of waterlogged rice fields. The rice fields ecosystems with its optimum level of light, water, temperature, humidity and nutrient availability provide a favourable environment for the luxuriant growth of cyanobacteria (Venkataraman 1972, Nayak *et al*. 2001, 2004, Song *et al*. 2005). The remarkable adaptability of cyanobacteria to rice field habitats is well known (Hof and Fremy 1933, Desikachary 1959, Van Baalen 1962, Carr and Whitton 1982). It is also a well known fact that besides contributing to soil nitrogen and improvement in the physical, chemical and biological properties of soil and soil water interface of rice fields (Mandal *et al*. 1998, Nayak *et al*. 2004).

The abundance of cyanobacteria in various locations and habitats of rice fields in Manipur were recorded during almost all seasons. The density of heterocystous forms was most abundant followed by non heterocystous and unicellular forms. Similar reports on

cyanobacteria distribution are available from different parts of India. Laloraya and Mitra (1973) studied the cyanobacteria in the rice fields of India and identified 122 forms belong to different families. In the present study the distributional pattern showed that the heterocystous filamentous forms were dominated in all the sampling sites. In general, rice field habitats were harboured more heterocystous filamentous forms than non heterocystous and unicellular forms. The cultural studies make it possible to assess the identification and characterization of the cyanobacteria at the generic and species level. While in nature, especially in rice fields, they showed polymorphic behaviour because of the environmental factors. Study on biodiversity and seasonal variation of cyanobacterial strains in rice fields of Manipur showed that cyanobacterial diversity in moist soil fractions was higher than the dried soil fractions and in addition the highest diversity was found in the middle of growth season and the lowest after harvest of the rice plants.

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