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Cyanobacterial Diversity in Western Ghats Region of Maharashtra, India

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ABSTRACT

Cyanobacterial diversity in Ahmednagar, Pune and Satara district of Maharashtra State, Western Ghats – one of the biodiversity hotspots of India – was assessed. Screening of 627 soil samples from different locations in the above regions revealed that 94 cyanobacterial spp. belonged to 38 genera, 14 families and 5 orders. Diversity analysis revealed that *Westiellopsis prolifica* Janet. was relatively abundant (47.21%) followed by *Nostoc calcicola* Brebsson ex Born. et Flah. (44.82%). The frequency distribution of *Myxosarcina spectabilis* Geitler was less. *Nostoc* (Nostocaceae), *Chroococcus* (Chroococcaceae) and *Anabaena* (Nostocaceae) were the most densely populated genera. The information obtained will be useful in exploitation of cyanobacteria for biotechnological, pharmaceutical and other applications.

Keywords: biofertilizer, blue green algae, *Nostoc*, prokaryotes, Western Ghats, *Westiellopsis prolifica*

INTRODUCTION

Cyanobacteria (blue–green algae, BGA) are morphologically diverse group of pioneer oxygenic phototrophic prokaryotes with characteristics in common to both bacteria and algae. Their distribution is cosmopolitan and surpassed only by bacteria (Adams 2000; Govindjee and Shevela 2011). They are found to be useful in enhancing crop productivity in variety of environments due to their ability to fix dinitrogen. In recent decades, cyanobacteria were of academic interest and now they have been proved as organisms with a potential source of various biotechnological applications such as food, feed, fuel, fertilizer, medicine, industry, in diagnostics or pigments as fluorescent probes and in combating pollution (De 1939; Mitsui *et al*. 1981; Venkataraman 1981, 1983; Kannaiyan 1985; Borowitzka 1988; Gustafson *et al*. 1989; Prabaharan and Subramanian 1995; Subramanian and Uma 1996; Sundararaman and Sekar 2001; Thajuddin and Subramanian 2005).

The cyanobacteria are a good source of metabolites with biological activity such as antimalarial, antibacterial, antiviral, antifungal and cytotoxic properties similar to plant and animal products (Falch *et al*. 1995; Subramanian 1996). They are also a source for industrially important metabolites with properties like emulsifying agents, surfactants and flocculants (Bender *et al*. 1994; De Philippis and Vincenzini 1998).

To identify the best source of metabolite(s) and/or to explore metabolites having novel biological activity, one has to have information on cyanobacterial diversity from diverse habitats such as different types of soil, freshwater bodies, oceans, saline backwaters, estuaries and hyper saline saltpans (Subbaramaiah 1972; Srivastava and Odhwani 1992; Thajuddin and Subramanian 1992; Thajuddin *et al*. 2002; Chellappa *et al*. 2004; Rajkumar 2004).

Here we present the cyanobacterial diversity that exists in the soil from diverse habitats of Ahmednagar, Pune and Satara districts of Western Ghat region in Maharashtra, India.

MATERIALS AND METHODS

Area of collection

Soil samples were collected randomly from different locations belonging to three districts namely Ahmednagar, Pune and Satara of Maharashtra state, India (**Table 1; Fig. 1**). The three districts are situated at 19° 8′ N 74° 48′ E, 18° 31′ N, 73° 51′ E, 17° 42′ N 74° 02′ E, respectively (**Fig. 1**) on a plateau which is about 43187.89 km^2 in area. A total of 627 samples of dry soil, moist soil, rocky substratum and fresh water samples were collected during 2008, 2009 and 2010.

Methods of collection

Soil samples from 5-10 cm deep layers were collected using a sterile scalpel from well irrigated, occasionally irrigated and dry areas. The scalpel was inserted into the soil to create a circle and then raised. The sample were temporarily stored in a sterile polythene zip pouch (15 × 10) labeled with location, habitat, date of collection, temperature and soil type. The temperature was measured using soil thermometer. The soil types were assessed on the basis of particle size. The samples from rocky substrates were maintained in air-tight plastic bottles. Samples were brought to the laboratory; the samples from surface of the soil and water bodies were preserved in 4% formalin, while the samples from the deep layer of soils were shade dried and stored in air tight containers.

Identification and enumeration of cyanobacterial samples

One g of soil sample was ground using a sterile mortar in a pestle and suspended in sterile liquid BG11 media ($NaNO_3$ – 1.5; $K_2HPO_4{\cdot}3H_2O$ – 0.04; $MgSO_4{\cdot}7H_2O$ – 0.075; $CaCl_2{\cdot}2H_2O$ – 0.036; citric acid – 0.006; ferric ammonium citrate – 0.006; Na_2EDTA – 0.001; Na_2CO_3 – 0.02 g/l and H_3BO_3 – 286;

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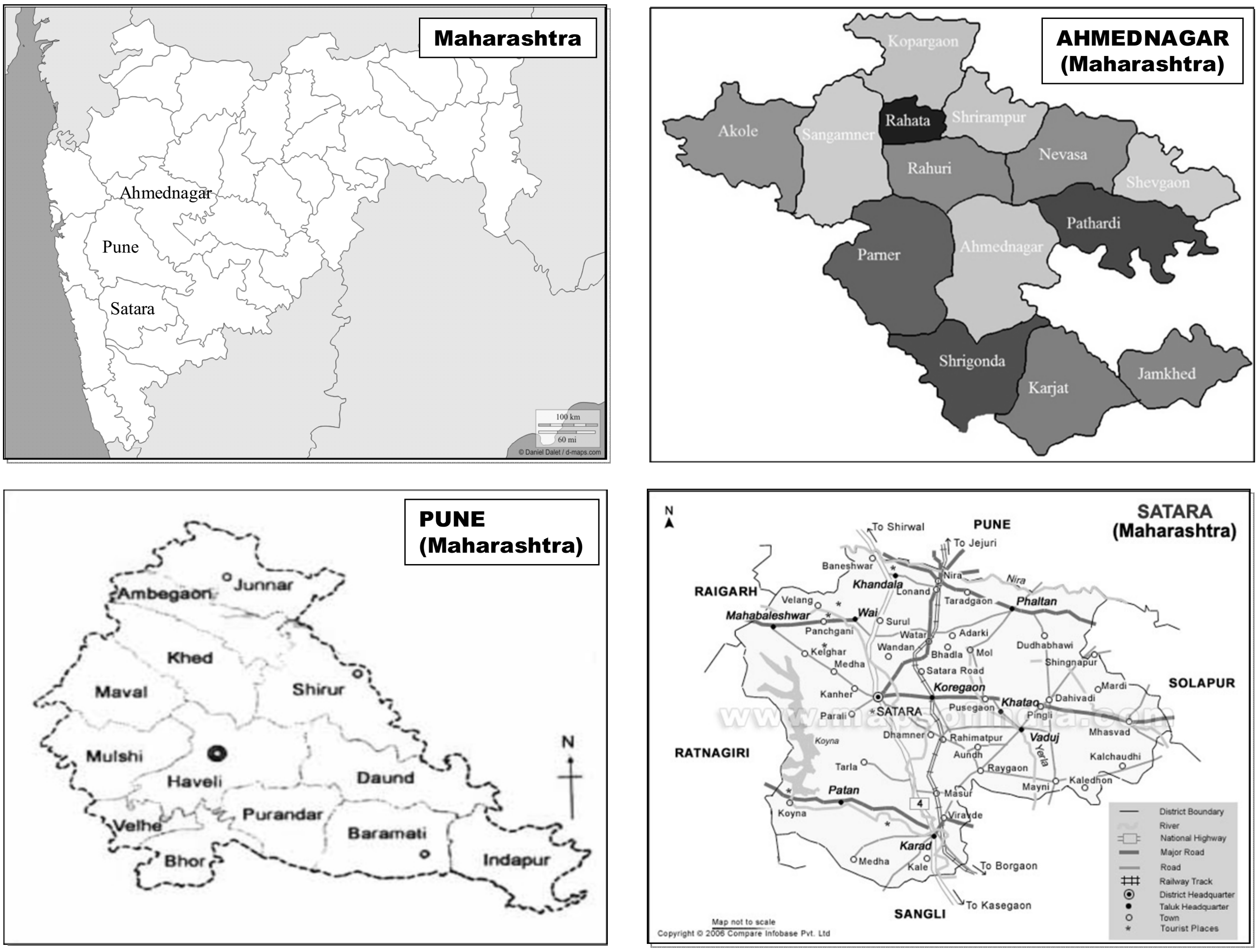

Fig. 1 District location of study area under Maharashtra (India).

$MnCl_2 \cdot 4H_2O$ – 181; $ZnSO_4.7H_2O$ – 220; $Na_2MO_4.2H_2O$ – 390; $CuSO_4 \cdot 5H_2O$ – 80, $CoCl_2 \cdot 6H_2O$ – 40 µg/l; pH – 7.5) (Rippka *et al.* 1979). The suspensions were serially diluted (10^{-1}-10^{-6}) and all the dilutions were streaked on a BG-11 agar plate. The plates were incubated at 25 ± 2°C and 50-60% relative humidity with a 8-h photoperiod (30-40 µmolm^{-2} s^{-1} light intensity). For morpohometric studies, the cultures were observed at 40X and 100X magnifications under a Nikon (Eclipse TE 2000-5) make trinocular research microscope. The cyanobacterial strains were identified following the monographs and keys of Prescott (1951), Desikachary (1959) and Anand (1990). The identified strains were arranged as per the classification system following Desikachary (1959).

The relative abundance and percent of cyanobacterial species were determined following the method of Devi *et al* (1999). The relative abundance was calculated using the formula:

Relative abundance = (Y/X) × 100

where X is the total number of samples collected and Y is number of samples from which a cyanobacterial strain was isolated. The percentage of cyanobaterial strains in the soil samples was calculated.

RESULTS AND DISCUSSION

The Western Ghats better known as Sahyadri range is a hilly range running parallel to the coast, at an average elevation of 1,200 m, is one of the hot spots of biodiversity in India. The area chosen for this study comes under the Sahyadri range in the state of Maharashtra and is represented by prominent peaks like Kalsubai (1646 m), old Mahabaleshwar (1326 m), Bhor ghat (1285 m), Purandar fort (1313 m), Rajgad (1103 m). Kalsubai is the highest peak of the Sahaydri ranges. The specific localities are described in **Table 1**.

By screening a total of 627 samples from 45 localities of Ahmednagar, Pune and Satara district we identified 94 cyanobacterial species belonging to 38 genera, 14 families and 5 orders (**Table 2**). Analyses of the data obtained for the percent frequency (depicted in **Fig. 2A**) revealed that the taxa belonging to order Nostocales (67.9%) was dominant followed by Chroococcales (16.7%) and Stigonematales (14.1%) and the members from order Chamaesiphonales and Pleurocapsales were rare (1.3%). At the family level (**Fig. 2B**), Nostocaceae and Oscillatoriaceae showed a higher percent frequency of distribution followed by Chroococcaceae, Scytonemataceae, Rivulariaceae and Stigonemataceae. The species were rarely recorded from the Entophysalidaceae, Chamesiphonaceae, Cyanidiaceae, Pleurocapsaceae, Microchaetaceae, Nostochopsidaceae, Mastigocladaceae and Mastigocladopsidaceae families (**Fig. 2B**).

The results on relative abundance of genera depicted in **Table 2** shows that *Westiellopsis prolifica* Janet (47.21%) was dominant. Other prominent and common cyanobacteria are *Nostoc calcicola* Brebsson ex Born. et Flah. (44.82%) and *Anabaena spiroides* Klebahn (44.02%). *Myxosarcina spectabilis* Geitler, *Chroococcus minor* (Kütz.) Nag., *Gloeocapsa kuetzingiana* Nag. and *Homoeothrix hansgirgi* (Schmidle) Lemmermann were observed only in 7 soil samples with 1.12% relative abundance. However, *Chamaesiphon fuscus* (Rostaf.) Hansgirg and *Chroococcus schizodermaticus* West were present occasionally and showed least relative abundance (**Table 2**).

Previous studies on the cyanobacteral diversity from regions from other Indian states revealed that *Nostoc* sp.

Table 1 Collection sites of the cyanobacterial samples from the state of Maharashtra (India).

District	Location	Latitude N	Longitude E	Altitude (meters)
Pune	Pune University campus	18° 32' 59.21"	73° 49' 31.75"	583
	Pashan Lake	18° 31' 56.64"	73° 74' 23.96"	592
	NCL ground	18° 32' 22.13"	73° 84' 28.14"	589
	Bhimashankar	19° 04' 15.16"	73° 32' 09.15"	933
	Chas	18° 55' 18.08"	73° 50' 14.08"	623
	Wada	18° 56' 49.68"	73° 48' 19.02"	623
	Bham	18° 56' 03.54"	73° 49' 11.93"	626
	Pirangut Ghat	18° 30' 03.25"	73° 42' 33.08"	699
	Paud	18° 31' 34.92"	73° 36' 58.29"	584
	Paud-Sus Road	18° 33' 42.19"	73° 40' 22.38"	606
	Mulshi	18° 31' 47.98"	73° 31' 28.71"	577
	Hinjewadi	18° 34' 53.97"	73° 43' 28.57"	572
	Katraj Ghat	18° 23' 42.62"	73° 51' 13.60"	915
	Nasarapur	18° 15' 21.29"	73° 53' 23.79"	663
	Shirwal	18° 08' 03.47"	73° 58' 53.23"	595
	Bhor Ghat, Bhor	18° 01' 44.50"	73° 51' 06.75"	1285
	Dive Ghat	18° 24' 55.63"	74° 00' 22.07"	846
	Purandar-Saswad Road	18° 18' 28.50"	73° 58' 48.70"	861
	Purandar Fort, Purandar	18° 16' 36.40"	73° 58' 18.56"	1312
	Bhugaon	18° 30' 02.68"	73° 45' 20.42"	648
	Paud Mulshi Road	18° 31' 41.46"	73° 36' 40.47"	568
	Mulshi Road	18° 34' 26.61"	73° 32' 36.75"	590
	Mulshi area	18° 31' 52.97"	73° 33' 03.89"	574
	Mulshi Dam	18° 28' 53.70"	73° 29' 53.00"	633
	Lenyadri	19° 14' 09.39"	73° 53' 10.89"	715
	Shivneri	19° 11' 39.66"	73° 51' 29.76"	918
	Varsai, Junnar	19° 10' 10.83"	73° 40' 32.21"	804
	Rajgad	18° 14' 58.34"	73° 41' 04.74"	1103
Ahmednagar	Arangaon	19° 01' 15.96"	74° 43' 19.23"	655
	Meherabad	19° 00' 41.99"	74° 42' 43.28"	666
	Bhandardara	19° 32' 45.25"	73° 47' 05.14"	702
	Akole	19° 32' 12.82"	73° 59' 01.38"	601
	Sangamner	19° 35' 10.52"	74° 19' 06.61"	576
	Rahata	19° 42' 03.91"	74° 29' 06.05"	523
	Shrirampur	19° 33' 37.25"	74° 38' 33.02"	503
	Rahuri	19° 22' 55.70"	74° 38' 54.82"	509
	Newase	19° 26' 29.84"	75° 04' 16.40"	497
	Shevgaon	19° 20' 39.20"	75° 12' 54.59"	491
	Pathardi	19° 07' 42.36"	74° 58' 30.60"	647
Satara	Khandala	18° 02' 57.72"	74° 00' 54.01"	665
	Khambataki Ghat	18° 00' 48.87"	74° 49' 46.95"	920
	Pasarani Ghat	17° 56' 25.70"	73° 51' 38.53"	763
	Pachgani	17° 55' 55.56"	73° 51' 04.33"	952
	Old Mahabaleshwar	17° 57' 43.42"	73° 39' 45.19"	1326
	Lingmala	17° 55' 21.00"	73° 42' 17.36"	1272

was dominant in Asam, Hariyana, Kerala, Tamilnadu, West Bengal (Venkatramn 1975), Orisa (Sahu *et al*. 1996) and Manipur (Devi *et al*. 1999). A limited study from the arable domain of the Pravara area of Ahmednagar district Maharashtra revealed that, in addition to Nostoc, other species such as *Oscillatoria*, *Westiellopsis*, *Scytonema*, *Microchaete*, *Anabaena* and *Tolypothrix* were the most common genera (Auti and Pingle 2010). The genus *Westiellopsis* showed restricted distribution in the rice field soils of Manipur (Devi *et al*. 1999). However, here we recorded *Westellopsis* as most dominant along with *Nostoc* and *Anabaena*. The genera *Scytonema* and *Oscillatoriia* were represented by maximum number of species in paddy fields of Western Maharashtra (Patil and Chaugule 2009). *Scytonema* was most abundant in salt-affected soils of Kolhapur district (Madane and Shinde 1993). In the area of the present investigation the relative abundance of *Scytonema* was only 2-17%, which is very low compared to Madane and Shinde's (1993) study which reported that *Scytonema* was most abundant in saline soils of Kolhapur district, Maharashtra state. This difference could be because our study was not specific to saline soils.

Our study revealed a rich diversity of cyanobacteria in the Western Ghats region of Maharashtra. The species identified from this region included those that have been reported to be a source for metabolites having a variety of biological activities.

Microcystis, *Oscillatoria*, *Anabeana*, *Nostoc*, *Hapalosiphon* and *Schizothrix* are reported to be a source of hepatotoxic, neurotoxic, inflammatory and tumor-promoting metabolites (Yadav *et al*. 2011). Besides, *Scytonema*, *Tolypothrix* and *Lyngbya* are reported to be good alternative sources for antibacterial, antifungal and antineoplastic agents (Moore *et al*. 1993; Harrigan *et al*. 1998). The scytophycin from *Scytonema* was 50 times more effective than existing anticancer drugs (Moore *et al*. 1993).

Oscillatoria salina, *Plectonema terebrans*, *Aphanocapsa* sp. and *Synechococcus* have been reported to be useful in the bioremediation of oil spills (Radwan and Al-Hasan 2001; Raghukumar *et al*. 2001; Cohen 2002). Several cyanobacterial species can also benefit plants by molecular nitrogen fixation and availing major nutrients such as nitrogen as well as producing plant growth-promoting substances which help in improving productivity (Rodger *et al*. 1979). UV-protective mycosporine-like amino acids and scytonemin produced by many species of cyanobacteria

Table 2 Cyanobacterial diversity from Ahmednagar, Pune and Satara districts.

Order, Family, Genus and Species	No. of species recorded/ family	No. of samples in which particular cyanobacteria observed	Relative abundance (%)	% distribution of Cyanobacterial species
I- Chroococcales				
Chroococcaceae	15			
Microcystis aeruginosa Kütz		21	3.35	0.28
Microcystis pulverea (Wood) Forti		9	1.44	0.12
Chroococcus micrococcus (Kütz.) Rabehn.		13	2.07	0.18
Chroococcus turgidus (Kütz.) Nag.		9	1.44	0.12
Chroococcus schizodermaticus West		5	0.80	0.07
Chroococcus minutus (Kütz.) Nag.		12	1.91	0.16
Chroococcus minor (Kütz.) Nag.		7	1.12	0.09
Chroococcus varius A. Br.		12	1.91	0.16
Chroococcus montanus Hansgirg		8	1.28	0.11
Chroococcus indicus Zeller		9	1.44	0.12
Gloeocapsa decorticans (A. Br.) Richter		7	1.12	0.09
Gloeocapsa kuetzingiana Nag.		16	2.55	0.22
Aphanocapsa biformis A. Br.		19	3.03	0.26
Aphanothece pallid (Kütz.) Rabenh.		11	1.75	0.15
Gomphosphaeria aponina Kütz.		23	3.67	0.31
Entophysalidaceae	1			
Chlorogloea microcystoides Geitler		17	2.71	0.23
II- Chamaesiphonales				
Cyanidiaceae	1			
Chroococcidiopsis indica sp. nov.		13	2.07	0.18
Chamaesiphonaceae	1			
Chamaesiphon fuscus (Rostaf.) Hansgirg		6	0.96	0.08
III - Pleurocapsales				
Pleurocapsaceae	1			
Myxosarcina spectabilis Geitler		7	1.12	0.09
IV- Nostocales				
Oscillatoriaceae	23			
Spirullina platensis (Nordst.) Geitler		19	3.03	0.26
Oscillatoria obscura Bruhl et. Biswas		56	8.93	0.76
Oscillatoria amoena (Kütz.) Gomont		39	6.22	0.53
Oscillatoria animalis Ag. ex. Gomont		43	6.86	0.58
Oscillatoria okeni Ag. ex. Gomont		34	5.42	0.46
Oscillatoria sp.		74	11.80	1.00
Dasygloea amorpha Thwaites. ex. Gomont		16	2.55	0.22
Phormidium fragile(Meneghini) Gomont		106	16.91	1.43
Phormidium tenue (Meneghini) Gomont		89	14.19	1.20
Phormidium rubroterricola Gardener		97	15.47	1.31
Phormidium sp. (1)		104	16.59	1.41
Phormidium sp. (2)		93	14.83	1.26
Lyngbya baculum Gomont		112	17.86	1.51
Lyngbya polysiphoniae Fremy		85	13.56	1.15
Lyngbya bipunctata Lemm.		74	11.80	1.00
Lyngbya majuscula Harvey. ex. Gomont		125	19.94	1.69
Lyngbya confervoides C. Ag. ex Gomont		68	10.85	0.92
Lyngbya sp.		81	12.92	1.10
Schizothrix lateritia (Kütz.) Gomont		14	2.23	0.19
Schizothrix delicatissima West et West		11	1.75	0.15
Schizothrix lamyi Gomont		18	2.87	0.24
Microcoleus lacustris (Rabenh.) Farlow		96	15.31	1.30
Microcoleus sociatus West et West		24	3.83	0.32
Nostocaceae	24			
Cylindrospermum majus Kützing ex Born. et Flah.		20	3.19	0.27
Cylindrospermum musicola Kützing ex Born.		21	3.35	0.28
Nostoc punctiforme Born. Et Flah.		269	42.90	3.64
Nostoc entophytum Born. Et Flah.		184	29.35	2.49
Nostoc paludosum Kützing ex Born. et Flah.		128	20.41	1.73
Nostoc linckia (Roth) Bornet ex Born. et Flah.		214	34.13	2.89
Nostoc rivulare Kützing ex Born. et Flah.		176	28.07	2.38
Nostoc sporangiaeforme Agardh ex Born. Flah.		197	31.42	2.66
Nostoc ellipsosporum (Desm.) Rabenh. Ex Born. et Flah.		248	39.55	3.35
Nostoc humifusum Carmichael ex Born. et Flah.		146	23.29	1.97
Nostoc calcicola Brebsson ex Born. et Flah.		281	44.82	3.80
Nostoc muscorum Ag. ex. Born. at Flah.		202	32.22	2.73
Nostoc microscopicum Carm. ex. Born. at Flah.		169	26.95	2.29
Nostoc hatei Dixit.		105	16.75	1.42
Anabaena spiroides Klebahn		276	44.02	3.73
Anabaena oryzae Fritsch		157	25.04	2.12
Anabaena gelatinicola Ghose		141	22.49	1.91

Table 2 (Cont.)

Order, Family, Genus and Species	No. of species recorded/ family	No. of samples in which particular cyanobacteria observed	Relative abundance (%)	% distribution of Cyanobacterial species
Nostocaceae (Cont.)	24			
Anabaena orientalis Dixit		168	26.79	2.27
Anabaena variabilis Kützing ex Born. et Flah.		237	37.80	3.221
Anabaena circinalis Rabenhorst ex Born. et Flah.		208	33.17	2.81
Anabaena sp.		168	26.79	2.27
Nodularia spumigena Mertens ex Born. et Flah.		13	2.07	0.18
Aulosira fertilissima Ghose		10	1.59	0.14
Aulosira aenigmatica Fremy		23	3.67	0.31
Scytonemataceae	9			
Scytonematopsis kashyapi (Bharadwaja) Geitler		69	11.00	0.93
Scytonema schmidtii Gom		83	13.24	1.12
Scytonema pascheri Bharadwaja		15	2.39	0.20
Scytonema subtile Möbius		103	16.43	1.39
Scytonema tolypothrichoides Kützing ex Born. et Flah		76	12.12	1.03
Scytonema mirabile (Dillw.) Born.		110	17.54	1.49
Tolypothrix tenuis (Kütz.) Johs. Schmidt em.		127	20.26	1.72
Tolypothrix distorta Kützing ex Born. et Flah		142	22.65	1.92
Tolypothrix fragilis (Gardner) Geitler		94	14.99	1.27
Microchaetaceae	2			
Microchaete uberrima Carter, N.		56	8.93	0.76
Microchaete tenera Thuret. Ex Born. et Flah		43	6.86	0.58
Rivulariaceae	7			
Homoeothrix hansgirgi (Schmidle) Lemmermann		7	1.12	0.09
Calothrix javanica de Wilde		168	26.79	2.27
Calothrix brevissima West, G. S.		145	23.13	1.96
Calothrix epiphytica W.et G. S. West		12	1.91	0.16
Calothrix marchica Lemmermann		138	22.01	1.87
Rivularia manginii Fremy		14	2.23	0.19
Gloeotrichia natans Rabenhorst ex Born. et Flah		49	7.81	0.66
V- Stigonematales				
Nostochopsidaceae	1			
Nostochopsis lobatus Wood em. Geitler		21	3.35	0.28
Mastigocladaceae	1			
Mastigocladopsis jogensis Iyengar et Desikachary		30	4.78	0.41
Mastigocladopsidaceae				
Mastigocladus laminosus Cohn	1	19	3.03	0.26
Stigonemataceae				
Hapalosiphon welwitschii W. et G. S. West	7	24	3.83	0.32
Hapalosiphon hibernicus W. et G. S. West		18	2.87	0.24
Westiella intricata Borzi		23	3.67	0.31
Westiellopsis prolifica Janet		296	47.21	4.00
Camptylonema indicum Schmidle		15	2.39	0.20
Stigonema mesentericum Geitler		20	3.19	0.27
Stigonema dendroideum Fremy		14	2.23	0.19

Total no. of samples 627; Total no. of cyanobacterial forms 7394; Total no. of cyanobacterial species 94

(Sinha and Hader 2008) were also found in the present study area.

In the recent past several pharmaceutical, nutraceutical, biofertilizer and other industries have successfully utilized cyanobacterial populations.

The strains of *Spirulina*, *Nostoc*, *Oscillatoria* and *Aphanizomenon* are being used in food and medicines since ages (Pandey and Pandey 2009). *Nostochopsis lobatus* is utilized by local tribes as dietary supplement (Pandey and Pandey 2008). *Arthrospira platensis* and *Arthrospira maxima* consumed by humans and animals as a nutritional supplement and is now becoming a health food worldwide (Layam *et al.* 2006). They are grown on large scale using either outdoor ponds or in bioreactors and marketed globally as a protein, vitamin and mineral rich source in the form of powder, flakes, tablets and capsules (Vonshak 1997; Narawade *et al.* 2011). *S. platensis* and *Arthrospira* sp. are also rich source of medically important Gamma linolenic acid (GLA). The GLA is converted in the human body into arachidionic acid and then into prostaglandin E2 (Abed *et al.* 2009).

Phormidium, *Lyngbya* and a few other cyanobacteria produce bioactive compounds that show a broad spectrum of biological activities which inhibit growth of different Gram positive and Gram-negative bacterial strains, yeasts, and fungi (Bloor and England 1989; Abed *et al.* 2009). Photosynthetic pigment C-PC of Cyanobacteria is reported to have various pharmacological characteristics including anti-inflammatory and anticancer activities because of its β-subunit (Wang *et al.* 2007). Phycobiliproteins possess several unique characteristics that make them attractive for use as fluorescence labels in the diagnostics, biomedical research and therapuetics (Ray *et al.* 2008; Singh *et al.* 2009). Cryptophycins from *Nostoc* sp. (Magarvey *et al.* 2006), scytophycin A-E from *Scytonema* sp. (Ishibashi *et al.* 1986; Beatriz and Marcela 2011), tolytoxin from *Tolypothrix* sp., Curacin A-C from *Lyngbya* sp. (Rajeev and Xu 2004; Jones *et al.* 2009), have been reported as anticancer agents. Several potent bioactive compounds are recorded from different strains of Cyanobacteria which may have prospects to establish as a commercial drug in future (Boopathy and Kathiresan 2010).

Heterocystous cyanobacteria and several non heterocystous cynobacteria have ability to fix atmospheric nitrogen (Abed *et al.* 2009). The strains of *Anabena*, *Nostoc*, *Calothrix* and *Stigonema* are proved to be biofertilizers especially in paddy fields (Saadatnia and Riahi 2009; Begum *et al.*

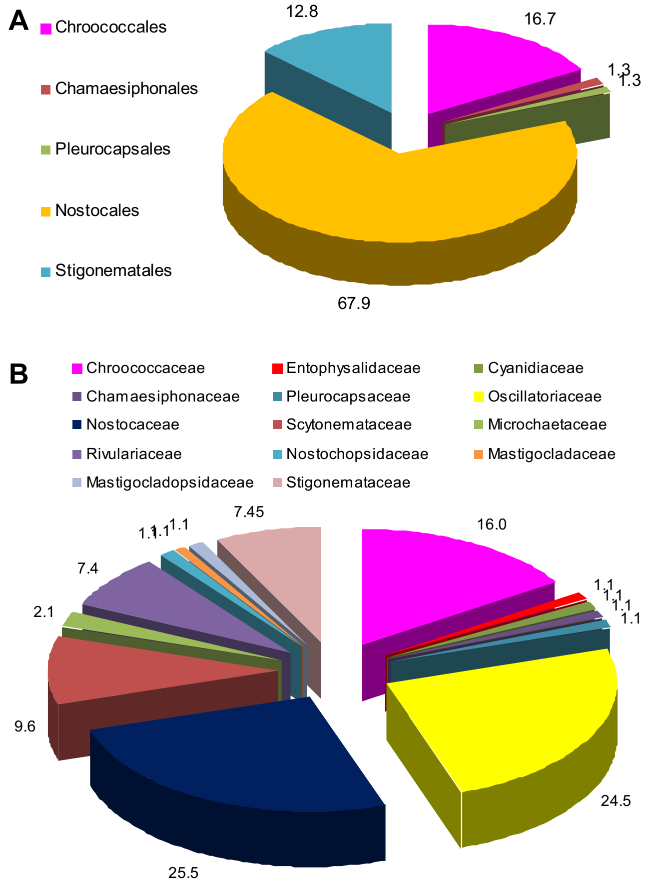

Fig. 2 Cyanobacterial diversity in relation to (A) orders and (B) families.

2011). The cyanobacteria produce polyhydroxyalkanoates, which can be used as a substitute for non biodegradable petrochemical-based plastics (Singh *et al*. 2011). Cyanobacteria within oil polluted sites facilitated the degradation processes by providing the associated oil-degrading bacteria with the necessary oxygen, organics and fixed nitrogen (Abed *et al*. 2006). The strains of *Anabaena*, *Calothrix*, *Oscillatoria*, *Cyanothece*, *Nostoc*, *Synechococcus*, *Microcystis*, *Gloeobacter*, *Aphanocapsa*, *Chroococcidiopsis* and *Microcoleus* are known for their ability to produce hydrogen gas under various culture conditions (Lambert and Smith 1977; Sveshnikov *et al*. 1997; Masukawa *et al*. 2002; Abed *et al*. 2009). Cyanobacterial hydrogen has now been made commercially available as source of alternative energy (Tiwari and Pandey 2012).

In this context, identifying and cataloguing the diversity of cyanobacterial species from different regions including the Sahyadri ranges, a biodiversity hot spot of India in Western Ghats, will be very beneficial in exploiting them for source for producing metabolites with novel biological activity.

Taxonomic enumeration of the species isolated

1. *Microcystis aeruginosa* Kütz (Desikachary 1959: 93) (**Fig. 3;1**). Colonial, found in fresh water, colonies spherical with distinct sheath; cells spherical with gas vacuole, ~6 µm in diameter.
2. *Microcystis pulverea* (Wood) Forti (Desikachary 1959: 96). Thallus free floating or attached to the substratum, colonies gelatinous, spherical with numerous cells irregularly distributed within the common slime; Cells 3-5 µm in diameter without gas vacuole.
3. *Chroococcus macrococcus* (Kütz.) Rabehn. (Desikachary 1959: 101) (**Fig. 3;2**). Thallus mucilaginous, yellowish brown; cells spherical, 2-4 cells, ~23 µm in diameter; sheath prominent, thick colorless.
4. *Chroococcus turgidus* (Kütz.) Nag. (Desikachary 1959: 101). Colonies 12-20 µm long, 4-2 µm broad; cells spherical, in groups of 2-4, blue green, with colourless sheath not distinctly lamellated, 14-30 µm broad.
5. *Chroococcus minutes* (Kütz.) Nag. (Desikachary 1959: 103). Cells oblong, in a group of 2-4, light blue green, with sheath 3-12 µm in diameter, colonies 7-20 µm long 10–31 µm broad; sheath colorless.
6. *Chroococcus schizodermaticus* West (Desikachary 1959: 103). Cells in groups of 2-4, blue-green, with sheath 23-35 µm in diameter; sheath yellowish, lamellated.
7. *Chroococcus minor* (Kütz.) Nag. (Desikachary 1959: 105). Thallus olive green, slimy-gelatinous; cells subspherical, 2-5 µm in diameter, in a group of 2-4; sheath thin, colorless, unlamellated.
8. *Chroococcus varius* A. Br. (Desikachary 1959: 107). Thallus gelatinous, olive green; cells globular, in a group of 2-4, irregularly arranged, without sheath 3-4 µm in diameter; sheath purple, thick.
9. *Chroococcus montanus* Hansgirg (Desikachary 1959: 108). Colony blackish brown, gelatinous; sheath lamellose, cells 4-7 µm in diameter, irregularly arranged in groups.
10. *Chroococcus indicus* Zeller (Desikachary 1959: 109). Colony pale brownish, gelatinous; cell single, subshperical, 3-7 µm in diameter; sheath hyaline.
11. *Gloeocapsa decorticans* (A. Br.) Richter (Desikachary 1959: 115). Cells spherical, 2–4 together; single cells 12 µm in diameter; sheath colorless thick.
12. *Gloeocapsa kuetzingiana* Nag. (Desikachary 1959: 118). Colonies soft, thin and brown; cells with sheath 4-5 µm in diameter; sheath yellow to brown.
13. *Aphanocapsa biformis* A. Br. (Desikachary 1959: 134) (**Fig. 3;3**). Thallus olive green, gelatinous; cell spherical some ellipsoidal, 5 µm in diameter, 1-2 cells loosely arranged in a common mucilaginous envelope.
14. *Aphanothece pallida* (Kütz.) Rabenh. (Desikachary 1959: 140). Thallus gelatinous, soft, blue-green, 2-5 mm in diameter; cells 3-8 µm broad and 9-20 µm long; sheath distinct in peripheral part of the thallus, yellow to brown.
15. *Gomphosphaeria aponina* Kütz. (Desikachary 1959:150) (**Fig. 3;4**). Colonies large 85 µm in diameter; cells 12 µm broad and 16 µm long with distinct mucilaginous envelope.
16. *Chlorogloea microcystoides* Geitler (Desikachary 1959: 163) (**Fig. 3;5**). Thallus thin, gelatinous, forming dull green crust; cells spherical 2-4 µm in diameter, cells closely arranged in erect rows.
17. *Chroococcidiopsis indica* sp. nov. (Desikachary 1959: 167). Cells solitary, rarely many, subshperical, 5-6 µm broad, cell with a firm wall.
18. *Chamaesiphon fuscus* (Rostaf.) Hansgirg (Desikachary 1959: 168). Thallus brown to blackish, forming crust with many sporangia, sporangia nearly cylindrical, up to 8 µm broad and up to 30 µm long, yellowish outside, inside very pale colored.
19. *Myxosarcina spectabilis* Geitler (Desikachary 1959: 178). Cells in three dimensional colonies, cells 5-10 µm broad; colonial sheath thin, distinct, hyaline
20. *Spirullina platensis* (Nordst.) Geitler (Desikachary 1959: 190). Multicellular, filamentous, unbranched, filaments composed of cylindrical cells; helicoidal trichomes, 6-8 µm broad not attenuated at the ends, spirally coiled, spirals 20-30 µm broad, 3-8 µm long; end cells broadly rounded.
21. *Oscillatoria obscura* Bruhl et. Biswas (Desikachary 1959: 207). Trichome straight, blue-green, free floating with distinct septa, cross walls granulated; cells 3-4 µm broad, 1.5-2 µm long, gas vacuoles present; apical cells rounded.
22. *Oscillatoria amoena* (Kütz.) Gomont (Desikachary 1959: 230). Trichomes straight, dull blue-green, constricted at the septa, septa granulated, end gradually attenuated; cells 5-13 µm wide, 2-4 µm long, end cell capitate, broadly conical with calyptra.
23. *Oscillatoria okeni* Ag. ex. Gomont (Desikachary 1959:

231). Trichomes straight, slightly constricted at cross walls, at the end gradually attenuated; cells 6-8 µm broad, 3-4 µm long, slightly bent; end cells 8-9 µm long and triangular without calyptra.

24. *Oscillatoria animalis* Ag. ex. Gomont (Desikachary 1959: 239). Trichomes straight, exhibit typical gliding movement over the substrate, not constricted at cross walls, 3-4 µm broad, 2.5-4 µm long; end cells acute without calyptra

25. *Oscillatoria* sp. Vaucher (Desikachary 1959: 198) (**Fig. 3; 6**). Trichomes unbranched with separating discs, sheath absent, motile, end cells thickened.

26. *Dasygloea amorpha* Thwaites. ex. Gomont (Desikachary 1959: 250) (**Fig. 3;7**). Thallus gelatinous, filaments much bent laciniated at the ends, sheath colorless, gelatinous or slimy; trichome constricted at the cross walls, 4-6 µm broad, 4-13 µm long.

27. *Phormidium fragile* (Meneghini) Gomont (Desikachary 1959: 253). Thallus yellowish blue-green, mucilaginous, lamellated; sheath diffluent; trichomes more or less flexuous, entangled, constricted at the cross walls, 1-3 µm broad; cells nearly quadrate, attenuated at the ends; end cell conical, calyptras absent.

28. *Phormidium tenue* (Meneghini) Gomont (Desikachary 1959: 259). Colony bright blue green, forming leathery mat; trichome straight, entangled, attenuated at the ends; cells 1-2 µm broad, 5 µm long; end cells long conical, calyptras absent; sheath thin, diffluent, gelatinous.

29. *Phormidium rubroterricola* Gardener (Desikachary 1959: 261). Trichome 2-3 µm broad, sheath distinct, not diffluent, with straight ends; cells quadrate, longer; end-cells conical.

30. *Phormidium* sp. (1) Kütz. (Desikachary 1959: 250) (**Fig. 3; 8**). Thallus attached by the lower side; filament blue green, gelatinous; sheath prominent; trichome constricted at the joints, bent; cells quadrangular.

31. *Phormidium* sp. Kütz. (2) (Desikachary 1959: 250). Thallus attached by lower side; filaments single long, thin; sheaths firm.

32. *Lyngbya baculum* Gomont (Desikachary 1959: 285). Filaments pale blue-green; sheath firm, thin, colorless opened at the apex; cells isodiametric; end cells rounded, without calyptra.

33. *Lyngbya polysiphoniae* Fremy (Desikachary 1959: 287). Trichome pale blue green, constricted at the cross-walls, about 2 µm broad, apices not attenuated; filaments curved, single, up to 150 µm long; sheath very thin, delicate, colorless; end cell convex.

34. *Lyngbya bipunctata* Lemm. (Desikachary 1959: 290). Trichomes solitary, free floating; cells 1-2 µm broad, 4-5 µm long, not constricted at the cross walls; sheath narrow, colorless; end cell rounded not attenuated.

35. *Lyngbya majuscula* Harvey. ex. Gomont (Desikachary 1959: 313) (**Fig. 3;9**); Trichome blue-green, not attenuated at the ends, 16-20 µm broad; filaments very long up to 3 cm; sheath colorless, lamellated up to 11 µm thick; cells very short, 2-4 µm long, cross-walls not granulated; end cells rotund, calyptra absent.

36. *Lyngbya confervoides* C. Ag. ex Gomont (Desikachary 1959: 314). Thallus dull green, fasciculate, up to 5 cm in height; trichome not constricted at cross-walls, granulated; filament entangled, straight; sheath colorless, when old lamellated; end cell rotund, calyptra absent.

37. *Lyngbya* sp. Ag. (Desikachary 1959: 278). Filaments long with rigid mucilage sheath; sheaths form tangles, colorless.

38. *Schizothrix lateritia* (Kütz.) Gomont (Desikachary 1959: 326). Filaments more or less branched, thick; sheath thin, colorless, pointed at the ends, with many trichomes; cells 1-2 µm broad, 3-5 µm long; end cells rounded.

39. *Schizothrix delicatissima* West et West (Desikachary 1959: 327). Filament thick, 5-6 µm broad, 250-400 µm long; sheaths fine, colorless, gelatinous, ends of sheaths closed containing more or less parallel trichomes; trichome not attenuated to the ends; end cells mainly conical without calyptra.

40. *Schizothrix lamyi* Gomont (Desikachary 1959: 330). Thallus greenish brown; filaments bent with spreading branches; sheath golden yellow, pointed at the ends, with few trichomes in each sheath; trichomes 3-4 µm broad; cells mostly longer than broad; end cells conical.

41. *Microcoleus lacustris* (Rabenh.) Farlow (Desikachary 1959: 345). Thallus blackish blue-green; sheath colorless, slimy, many trichomes in each; trichomes distinctly constricted at the cross-walls, 4-6 µm broad, 6-12 µm long; end cell more or less rounded, conical not capitate.

42. *Microcoleus sociatus* West et West (Desikachary 1959: 346). Colony bright blue-green; filaments with multiple trichomes (9-13), 50-60 µm broad; sheath firm, thin; trichomes 2-3 µm broad, non-motile, slightly constricted at the cross walls; end cells conical, not capitate, lacking calyptra.

43. *Cylindrospermum majus* Kützing ex Born. et Flah. (Desikachary 1959: 360). Colony bright blue green, mucilaginous; trichomes 3-4 µm broad, 6-8 µm long; end cells conical; heterocyst elongated, 4 µm wide, 6-8 µm long; akinete single, 7-9 µm wide, 12-15 µm long, wall smooth, colorless.

44. *Cylindrospermum musicola* Kützing ex Born. (Desikachary 1959: 366) (**Fig. 3; 10**). Thallus mucilaginous, dark green; cells 3-4 µm broad, 5-6 µm long; heterocyst 6-9 µm wide, 5-7 µm long; akinete single, ovoid rounded at the end, wall smooth golden-brown.

45. *Nostoc punctiforme* Born. Et Flah. (Desikachary 1959: 374). Thallus sub-globose, blue green, 2 mm in diameter, scattered, attached; filament densely entangled; sheath delicate, hyaline, mucilaginous; trichome 1-3 µm broad; cells barrel-shaped; heterocyst 2-5 µm broad.

46. *Nostoc entophytum* Born. et Flah. (Desikachary 1959: 375). Thallus blue-green, small, inconspicuous; filaments densely entangled with distinct sheath; sheath hyaline; trichome 2-3 µm broad; cells short, barrel shaped; heterocyst broader than vegetative cells.

47. *Nostoc paludosum* Kützing ex Born. et Flah. (Desikachary 1959: 375). Colony very small, mucilaginous; filaments flexuous loosely entangled with a broad, colorless sheath; trichomes 3-4 µm broad; cells barrel shaped, 1-3 µm wide, 2-4 µm long; heterocysts slightly larger than vegetative cells; akinete ellipsoidal, walls smooth, colorless.

48. *Nostoc linckia* (Roth) Bornet ex Born. et Flah. (Desikachary 1959: 377). Thallus blue-green, gelatinous, variable in size; filaments densely entangled, highly coiled; sheath diffluent, colorless; trichomes 2-3 µm broad, pale blue-green; cells short, barrel shaped; heterocyst subspherical.

49. *Nostoc rivulare* Kützing ex Born. et Flah. (Desikachary 1959: 379). Thallus light pale green, globose, up to 2-3 mm diameter, hollow, lobed, fragile; filaments loosely entangled, flexuous; sheath distinct; trichomes 4-5 µm broad; cells spherical to oblong, longer than broader; heterocyst oblong, 5-6 µm broad.

50. *Nostoc spongiaeforme* Agardh ex Born. Flah. (Desikachary 1959: 380). Thallus light blue green, gelatinous; filaments flexuous, loosely entangled; sheath diffluent, yellowish brown; trichome 2 µm broad; cells cylindrical, 4 µm long, barrel shaped; heterocyst 7-8 µm broad.

51. *Nostoc ellipsosporum* (Desm.) Rabenh. Ex Born. et Flah. (Desikachary 1959: 383). Thallus irregularly expanded, gelatinous; filaments flexuous, loosely entangled; cells 3-4 µm wide, 5-8 µm long; heterocysts subspherical, 4-7 µm wide, 4-10 µm long; akinetes ellipsoidal, wall smooth, colorless.

52. *Nostoc humifusum* Carmichael ex Born. et Flah. (Desikachary 1959: 384). Colony mucilaginous, blue green to dark brown, slightly diffluent, spread out to form mass up to 2-3 cm across; filaments flexuous, entangled; sheath distinct, yellow-brown; cells barrel shaped; heterocysts subspherical, 1-3 µm in diameter; akinete subspherical, wall smooth, brown.

53. *Nostoc calcicola* Brebsson ex Born. et Flah. (Desikachary 1959: 384) (**Fig. 3; 11**). Thallus olive grey, up to 2-3

cm in diameter, mucilaginous, slightly diffluent; filament loosely entangled; sheath indistinct, only at the periphery of the thallus, colorless; trichome blue-green, 2 µm broad; cells subspherical, longer than broad; heterocysts subspherical, 2-4 µm broad.
54. *Nostoc muscorum* Ag. ex. Born. et Flah. (Desikachary 1959: 385). Colony expanded, 3 cm in diameter, olive green; filaments thickly entangled; sheath distinct only at the periphery of the colony, yellow brown; trichome 4 µm broad; cells short barrel shaped; heterocysts subspherical, 6 µm wide; akinete oblong, 3-6 µm broad, 7-10 µm long, wall smooth, yellow.
55. *Nostoc microscopicum* Carm. ex. Born. at Flah. (Desikachary 1959: 387). Colony blue green, soft, spherical, mostly 7-8 mm in diameter; filaments flexuous; sheath distinct; trichome 4-7 µm broad; cells subspherical, 5-9 µm wide; heterocyst subspherical, 7 µm in diameter; akinetes ellipsoidal, wall smooth.
56. *Nostoc hatei* Dixit. (Desikachary 1959: 389). Thallus spherical, 10-15 mm in diameter; trichome 2-5 µm broad, highly entangled and curved; cells spherical; heterocyst single, flattened, 4-6 µm broad, 3 µm long.
57. *Anabaena spiroides* Klebahn (Desikachary 1959: 395). Trichome single, spirally coiled; sheath thick, mucilaginous; cells spherical, shorter than broad, with gas-vacuoles; heterocyst subspherical, 10-12 µm broad.
58. *Anabaena oryzae* Fritsch (Desikachary 1959: 396). Thallus blue green, soft, gelatinous, membranous; trichome many, shorter, straight, compact, parallel; cells 1-3 µm broad, barrel shaped; heterocyst terminal and intercalary, broader than vegetative cells, 2-4 µm broad, terminal heterocyst conical and intercalary barrel shaped; spores next to the terminal heterocyst.
59. *Anabaena gelatinicola* Ghose (Desikachary 1959: 398). Thallus olive green, thick, mucilaginous; trichome single, spirally arranged; cells subspherical, 4-6 µm broad; apex acute; heterocyst 5-6 µm broad, spherical.
60. *Anabaena orientalis* Dixit (Desikachary 1959: 405). Trichome solitary, straight, 3.5 µm broad; cells quadrate, 6 µm long; end cell conical; heterocyst intercalary, single, cylindrical, 5 µm broad and 7.3 µm long; spores one on each side of heterocyst.
61. *Anabaena variabilis* Kützing ex Born. et Flah. (Desikachary 1959: 410). Thallus dark green, mucilaginous; trichome single, straight, without sheath; cells barrel shaped, 3-5 µm broad, 4-7 µm long; end cells conical; heterocyst spherical, 5-8 µm broad, 8-10 µm long; akinetes longer, wall smooth, colorless.
62. *Anabaena circinalis* Rabenhorst ex Born. et Flah. (Desikachary 1959: 414). Thallus leathery; trichome coiled; cells barrel shaped, 7-12 µm broad, 6-8 µm long; heterocyst spherical, 8-10 µm broad, as long as broad; akinetes cylindrical, 10-12 µm wide, 16-24 µm long, wall smooth, colorless.
63. *Anabaena* sp. Bory (Desikachary 1959: 391) (**Fig. 3; 12**). Thallus blue green; trichome curved, uniseriate, constricted at the cell walls; cells spherical, blue-green to yellow-green; heterocyst intercalary, broader than vegetative cells, solitary; akinetes intercalary, solitary, ellipsoidal.
64. *Nodularia spumigena* Mertens ex Born. et Flah. (Desikachary 1959: 423). Thallus mucilaginous; filament single, bent, 7-10 µm broad; sheath thin; cells discoid; heterocyst 6-8 µm in diameter; akinetes present.
65. *Aulosira fertilissima* Ghose (Desikachary 1959: 431). Thallus expanded, blue-green, gelatinous, membranous; trichome straight; cells 5-10 µm broad, 6-12 µm long; sheath thick; heterocyst intercalary, elliptical, 6-8 µm broad and 8-10 µm long.
66. *Aulosira aenigmatica* Fremy (Desikachary 1959: 428) (**Fig. 3; 13**). Thallus expanded, hazy, blue green, filaments long, 4-6 µm broad, sheath colorless, thin, trichome 3-4 µm broad, constricted at cross walls, cells cylindrical, shorter than broad, heterocyst as broad as trichome, spherical.
67. *Scytonematopsis kashyapi* (Bharadwaja) Geitler (Desikachary 1959: 448). Thallus blue green, gelatinous; filaments straight, 5-6 mm in length; trichome 5-6 µm in diameter; sheath conspicuous, thick and firm; cells longer than wide; false branching, tapering towards the apices; heterocyst few, 10-18 µm long and 6-8 µm broad.
68. *Scytonema schmidtii* Gom (Desikachary 1959: 459). Thallus flat, olive green; filaments rolled, intricate; single trichome per filament, 8-13 µm broad., wide up to 17 mm in areas of twisted trichome; repeatedly false branched; sheath yellow-brown; cells granular; heterocyst intercalary, shorter than broad to quadratic.
69. *Scytonema pascheri* Bharadwaja (Desikachary 1959: 463). Thallus green; filament curved, densely entangled; sheath firm; cells flattened, as long as broad; heterocyst intercalary, single, quadratic.
70. *Scytonema subtile* Möbius (Desikachary 1959: 475). Thallus dark blue green; filaments single, 10-14 µm broad; false branches present, narrower than main filament; sheath colorless; trichome 1-3 µm in diameter; cells 2-3 times as long as broad, cylindrical; heterocyst oblong, 5 µm in diameter.
71. *Scytonema tolypothrichoides* Kützing ex Born. et Flah (Desikachary 1959: 479). Thallus dense, brownish green; filaments 8-10 µm broad, 2-3 mm long, repeatedly false branched, false branches very similar to main filaments; sheath lamellated; trichome 6-8 µm broad; cells longer, densely granulated; heterocyst varied.
72. *Scytonema mirabile* (Dillw.) Born. (Desikachary 1959: 483) (**Fig. 3; 14**). Colony bushy, blackish brown; filaments entangled, 2-12 mm long, mostly false branched; cells 8-12 µm wide, cylindrical, at the end of trichome disc-shaped; sheath blue green; heterocyst rounded.
73. *Tolypothrix tenuis* (Kütz.) Johs. Schmidt em. (Desikachary 1959: 494). Thallus dense; filaments 8–12 µm broad, up to 15 mm long, repeatedly branched; sheath thin, colorless, close to trichome; cells cylindrical, 4-8 µm broad, longer than broad; heterocyst cylindrical, solitary.
74. *Tolypothrix distorta* Kützing ex Born. et Flah (Desikachary 1959: 495). Thallus blue green, dense; filaments highly false branched, mostly erect, up to 20 mm long, 10-15 µm broad; sheath thin, close to trichome; trichome 7-10 µm broad; cells as long as broad; heterocyst 2-3, nearly spherical.
75. *Tolypothrix fragilis* (Gardner) Geitler (Desikachary 1959: 500) (**Fig. 3; 15**). Colonies dense, blue-green; filament heteropolar, united, free apical ends, falsely branched, solitary lateral branches; sheath distinct, colorless; trichome with basal cylindrical heterocyst; cells cylindrical.
76. *Microchaete uberrima* Carter, N. (Desikachary 1959: 511) (**Fig. 3;16**). Filaments blue green, solitary, heteropolar, with basal hemispherical heterocyst and free apical ends; sheath distinct, firm, and colorless; trichome cylindrical; cells shorter than wide, cylindrical; apical cells always rounded.
77. *Microchaete tenera* Thuret. Ex Born. et Flah (Desikachary 1959: 514). Filaments solitary, up to 1 mm long; sheath thin, close to trichome; trichome broad, blue-green; heterocyst basal, cylindrical, 4-6 µm long.
78. *Homoeothrix hansgirgi* (Schmidle) Lemmermann (Desikachary 1959: 521). Filaments many, unbranched, erect, 3-5 µm broad, 12-18 µm long; sheath thin, firm, colorless; trichome narrower towards end; cells short.
79. *Calothrix javanica* de Wilde (Desikachary 1959: 525) (**Fig. 3;17**). Filaments heteropolar, simple, lateral false branches, 30-40 µm broad; trichome with widened basal, constricted at the cross walls; sheath present, thick, yellow-brownish colored; heterocyst basal; cells cylindrical.
80. *Calothrix brevissima* West, G. S. (Desikachary 1959: 533). Filaments in clusters, 40-60 µm long, 3-4 µm broad; sheath firm, close to the trichome, thin, cylindrical; trichome olive green, short, 30-62 µm long; end cells rounded; cells as long as broad; heterocyst basal, single, hemispherical.
81. *Calothrix epiphytica* W.et G. S. West (Desikachary 1959: 543). Filaments in groups, 250 µm long with broad

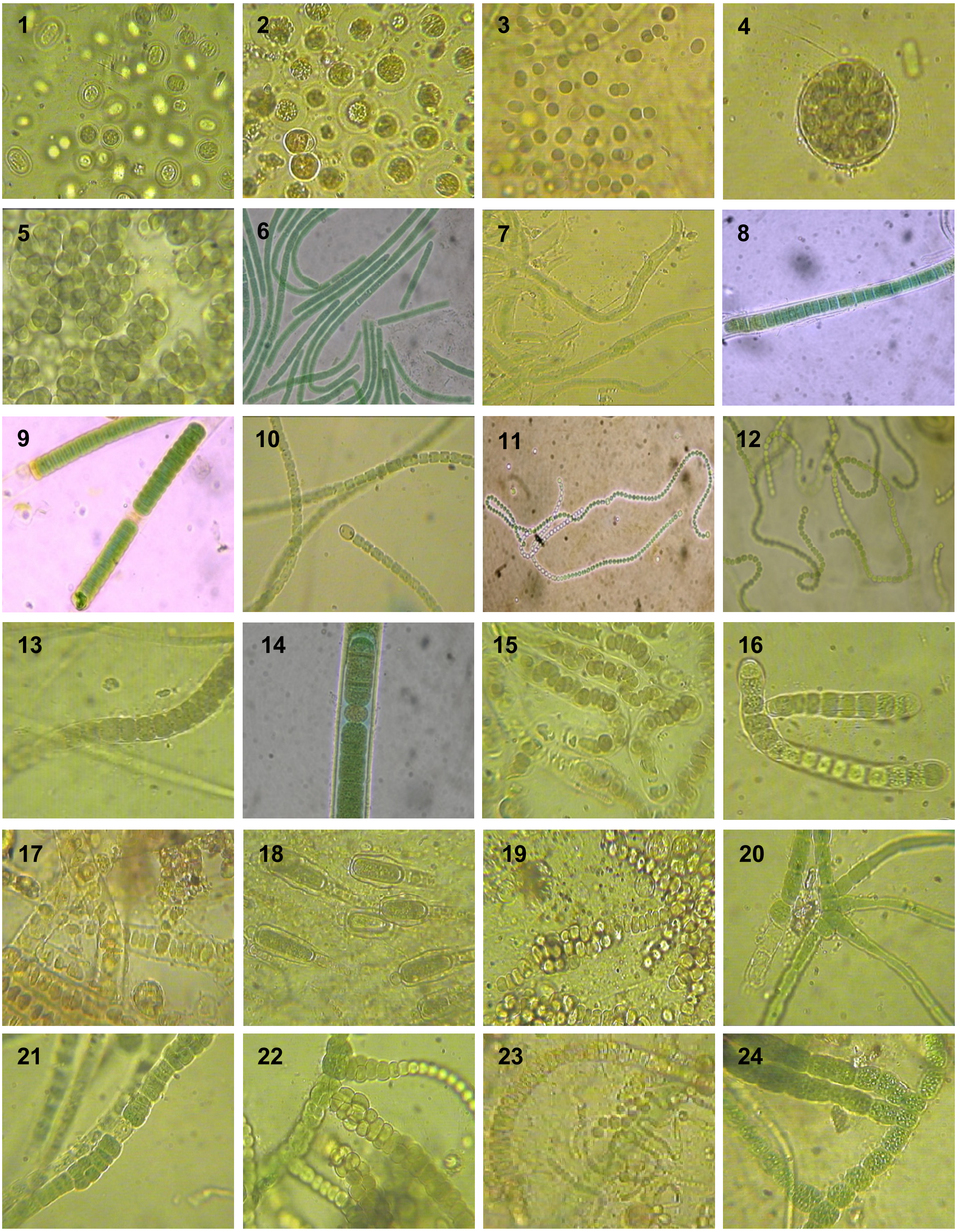

Fig. 3 Photomicrographs of selected species of cyanobacteria. 1. *Microcystis aeruginosa* Kütz. 2. *Chroococcus micrococcus* (Kütz.) Rabehn. 3. *Aphanocapsa biformis* A. Br. 4. *Gomphosphaeria aponina* Kütz. 5. *Chlorogloea microcystoides* Geitler. 6.*Oscillatoria* sp. Vaucher. 7. *Dasygloea amorpha* Thwaites. ex. Gomont. 8. *Phormidium* sp. (1) Kütz. 9. *Lyngbya majuscula* Harvey. ex. Gomont. 10. *Cylindrospermum musicola* Kützing ex Born. 11. *Nostoc calcicola* Brebsson ex Born. et Flah. 12. *Anabaena* sp. Bory. 13. *Aulosira aenigmatica* Fremy. 14. *Scytonema mirabile* (Dillw.) Born. 15. *Tolypothrix fragilis* (Gardner) Geitler. 16. *Microchaete uberrima* Carter, N. 17. *Calothrix javanica* de Wilde. 18. *Gloeotrichia natans* Ra benhorst ex Born. et Flah. 19. *Nostochopsis lobatus* Wood em. Geitler. 20. *Hapalosiphon welwitschii* W. et G. S. West. 21. *Westiella intricata* Borzi. 22. *Westiellopsis prolifica* Janet. 23. *Camptylonema indicum* Schmidle. 24. *Stigonema dendroideum* Fremy.

base, apex gradually attenuated; sheath thick, colorless; trichome 3-4 µm broad at the base; cells shorter than broader; heterocyst basal, single and small.

82. *Calothrix marchica* Lemmermann (Desikachary 1959: 543). Filaments with close thin colorless sheath; filament slightly bent; trichome blue green, constricted at the cross walls, base 4-5 µm broad; cells as long as broad; end cell conical; heterocyst single, 4-5 µm broad, basal and spherical.

83. *Rivularia manginii* Fremy (Desikachary 1959: 552). Thallus spherical, olive green, soft; filaments heteropolar, flat and thick; sheaths firm, colorless, densely agglomerated; trichome cylindrical, 3-5 µm broad, constricted at the cross walls with basal heterocyst, ending in long thin hair; hairs composed from the narrow, long, hyaline cells.

84. *Gloeotrichia natans* Rabenhorst ex Born. et Flah (Desikachary 1959: 561) (**Fig. 3;18**). Distinct spherical colony, yellow to brown; sheath firm, mucilaginous; filaments loosely arranged, ending in a distinct long hairs with own sheath; trichome slightly bent; cell barrel-shaped; heterocyst basal, cylindrical, 6-12 µm wide; spore cylindrical with sheath up to 40-45 µm broad, 150-250 µm long, saccate, transversely constricted, hyaline.

85. *Nostochopsis lobatus* Wood em. Geitler (Desikachary 1959: 570) (**Fig. 3; 19**). Thallus spherical, gelatinous, olive-green, smooth, solid in the centre, up to 3.5 cm in diameter; filaments with true lateral branching, long multi-celled; trichome radially arranged, composed of barrel-shaped cells; cells 4-5 µm broad, lateral branching, branches long, many-celled; heterocyst lateral, spherical.

86. *Mastigocladopsis jogensis* Iyengar et Desikachary (Desikachary 1959: 575). Filaments true branched, flexuous, branching reverse V-shaped; sheaths thin, colorless; trichomes 3-5 µm broad and 4-6 µm long, constricted at cross-walls, branches thinner than main trichome; terminal cells elongated; cells barrel-shaped in main trichome, cylindrical in branches; heterocyst intercalary lateral, spherical, wider than vegetative cells, 4-7 µm broad, 6-9 µm long.

87. *Mastigocladus laminosus* Cohn (Desikachary 1959: 581). Thallus olive green, membranous, firm; filaments densely entangle, 4-8 µm broad, curved, with distinct sheath, side branches about 3 µm broad, erect; cells in main filaments barrel shaped; heterocyst intercalary, ellipsoidal, 6.5 µm broad, single.

88. *Hapalosiphon welwitschii* W. et G. S. West (Desikachary 1959: 588) (**Fig. 3; 20**). Thallus dark green; filaments densely entangled with true branches, prostrate and erect, erect branches short, narrower, attenuated at the end; sheath thin, colorless, firm and hyaline; cells quadrate, longer than broad, 4-7 µm in diameter; end cells are more elongate and pointed; heterocyst rare, intercalary, elongated, 6-8 µm long.

89. *Hapalosiphon hibernicus* W. et G. S. West (Desikachary 1959: 593). Filaments single, somewhat flexuous, 7-10 µm broad, highly branched, lateral branches erect, false branches seen; sheath close to filaments, thin; cells rounded; heterocyst cylindrical, 5 µm broad.

90. *Westiella intricata* Borzi (Desikachary 1959: 594) (**Fig. 3; 21**). Filament free, creeping, with laterally true branches; trichome uniseriate, cylindrical, not constricted at cross walls; terminal cells rounded; sheath thin, firm, colorless; heterocyst intercalary, solitary, cylindrical, hormocyst with 2-4 cells.

91. *Westiellopsis prolifica* Janet (Desikachary 1959: 596) (**Fig. 3; 22**). Thallus filamentous, true-branched; filament of two types, primary thicker, creeping, torulous, two seriate, intensely constricted at cross walls, secondary branches thinner, composed of rounded cells, two seriate, pseudohormocyst; heterocyst cylindrical, intercalary, solitary.

92. *Camptylonema indicum* Schmidle (Desikachary 1959: 598) (**Fig. 3; 23**). Filaments crescent, yellowish brown, 10-15 µm broad; sheath lamellate, false branches present; cells cylindrical, 8-10 µm broad and 4-9 µm long; heterocyst intercalary, as broad as trichome.

93. *Stigonema mesentericum* Geitler (Desikachary 1959: 607). Filaments dense prostrate 20-30 µm broad; sheath thick, firm, yellow brown; trichome with 2-4 rows of cells; heterocyst lateral.

94. *Stigonema dendroideum* Fremy (Desikachary 1959: 609) (**Fig. 3; 24**). Thallus green, expanded; filaments creeping, 16-20 µm broad, highly branched, branches erect; sheath colorless, primary branches with 1-2 rows of cells, 14-20 µm broad, secondary branches in single row, 9-13 µm broad; heterocyst rare, intercalary.

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REFERENCES

Abed RMM, Dobretsov S, Sudesh K (2009) Applications of cyanobacteria in biotechnology. *Journal of Applied Microbiology* **106**, 1-121

Abed RMM, Thukair A, Beer DD (2006) Bacterial diversity of a cyanobacterial mat degrading petroleum compounds at elevated salinities and temperatures. *FEMS Microbiology Ecology* **57**, 290-301

Adams DG (2000) Symbiotic interactions In: Whitton BA, Potts M (Ed) *The Ecology of Cyanobacteria*, Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 523-561

Anand N (1990) *Handbook of Blue-green Algae*, Bishen Singh Mahendra Pal Singh, Dehradun, India, pp 1-79

Auti BK, Pingle SD (2010) Soil blue-green algal diversity from arable domain of Pravara area, district Ahmenagar. *Advances in Plant Sciences* **23**, 41-44

Beatriz HC, Marcela GA (2011) Metabolites from freshwater aquatic microalgae and fungi as potential natural pesticides. *Phytochemistry Review* **10**, 261-286

Begum ZNT, Mandal R, Islam S (2011) Effect of cyanobacterial biofertilizer on the growth and yield components of two HYV of rice. *Journal of Algal Bio-mass Utilization* **2 (1)**, 1-9

Bender J, Rodriguez-Eaton S, Ekanemesang UM, Phillips P (1994) Characterization of metal-binding bioflocculants produced by the cyanobacterial component of mixed microbial mats. *Applied Environmental Microbiology* **60**, 2311-2315

Bloor S, England RR (1989) Elucidation and optimization of the medium constituents controlling antibiotic production by the cyanobacterium *Nostoc muscorum*. *Enzyme and Microbial Technology* **13**, 76-81

Boopathy NS, Kathiresan K (2010) Anticancer drugs from marine flora: An overview. *Journal of Oncology*, Article ID 214186, 1-18

Borowitzka MA (1988) Vitamins and fine chemicals from microalgae. In: Borowitzka MA, Borowitzka LJ (Eds) *Microalgal Biotechnology*, Cambridge University Press, pp 153-196

Chellappa SL, Marinho IR, Chellappa NT (2004) Freshwater phytoplankton assemblages and the bloom of toxic cyanophyceae of Campo Grande reservoir of Rio Grande do Norte State of Brazil. *Indian Hydrobiology* **7**, 151-171

Cohen Y (2002) Bioremediation of oil by marine microbial mats. *International Microbiology* **5**, 189-193

De Philippis R, Vincenzini M (1998) Exocellular polysaccharides from cyanobacteria and their possible applications. *FEMS Microbiology Reviews* **22**, 151-175

De PK (1939) The role of blue green algae in nitrogen fixation in rice fields. *Proceedings of Royal Society B* **127**, 121

Desikachary TV (1959) *A Monograph on Cyanophyta*, Indian Council of Agricultural Research Publication, New Delhi

Devi AG, Dorycanta H, Singh NI (1999) Cyanobacterial flora of rice field soils of Manipur. *Phykos* **38**, 13-18

Falch PS, Konig GM, Wright AD (1995) Biological activities of cyanobacteria: Evaluation of bacteria and pure compounds. *Planta Medica* **61**, 321-328

Govindjee, Shevela D (2011) Adventures with cyanobacteria: A personal perspective. *Frontiers in Plant Science* **2**, 1-17

Gustafson KR, Cardellina JH, Furler RW, Weislon OS, Kiser RF, Sander KM (1989) Antiviral sulfolipids from cyanobacteria (blue-green algae). *Journal of the National Cancer Institute* **81**, 1254

Harrigan G, Yoshida W, Moore R, Nagle D, Park P, Biggs J, Paul V, Mooberry, Corbett T, Valeriote F (1998) Isolation, structure determination, and biological activity of Dolastatin 12 and Lyngbyastatin 1 from *Lyngbya majuscula/Schizothrix calcicola* cyanobacterial assemblages. *Journal of Natural Products* **61 (10)**, 1221-1225

Ishibashi M, Moore RE, Patterson GML (1986) Scytophycins, cytotoxic and antimycotic agents from the cyanophyte *Scytonema pseudohofmanni*. *Journal of Organic Chemistry* **51**, 5300-5306

Jones AC, Gerwick L, Gonzalez D, Dorrestein PC, Gerwick WH (2009) Transcriptional analysis of the jamaicamide gene cluster from the marine cyanobacterium *Lyngbya majuscula* and identification of possible regulatory proteins. *BMC Microbiology* **9**, 247-262

Kannaiyan S (1985) *Algal Biofertilizers for Low Land Rice*, Tamil Nadu Agricultural University, Coimbatore, 14 pp

Lambert GR, Smith GD (1977) Hydrogen formation by marine blue-green algae. *FEBS Letter* **83**, 159-162

Layam A, Reddy CLK (2006) Antidiabetic property of *Spirulina*. *Diabetoloiga Croatica* **35 (2)**, 29-33

Madane NP, Shinde PA (1993) Blue-green algae in salt affected soils of Kolhapur district (M. S.). *Journal of Maharashtra Agricultural Universities* **18**, 289-290

Magarvey NA, Beck ZQ, Golakoti T, Ding Y, Huber U, Hemscheidt TK, Abelson D, Moore RE, Sherman DH (2006) Biosynthetic characterization and chemoenzymatic assembly of the cryptophycins: Potent anticancer agents from cyanobionts. *ACS Chemical Biology* **15**, 766-779

Masukawa H, Mochimaru M, Sakurai H (2002) Hydrogenases and photobiological hydrogen production utilizing nitrogenase system in cyanobacteria. *International Journal of Hydrogen Energy* **27**, 1471-1474

Mitsui A, Murray R, Entenmann B, Miyazawa K, Polk E (1981) Utilization of marine blue-green algae and macroalgae in warm water mariculture. In: San Pietro A (Ed) *Biosaliine Research. A Look to the Future*, Plenum Press, New York, pp 215-225

Moore RE, Ohtani I, Moore BS, De K, CB, Yoshida WY, Runnegar MTC, Carmichael WW (1993) Cyanobacterial toxins. *Gazzetta Chimica Italiana* **123**, 329-336

Moore RE, Patterson GML, Mynderse JS, Barchi J (1986) Toxins from Cyanophytes belonging to the Scytonemataceae. *Pure and Applied Chemistry* **58**, 263-271

Narwade SS, Rajmalwar SA, Shrivastava P (2011) Photo bioreactor prototype for micro algae production. *Asiatic Journal of Biotechnology Resources* **2**, 471-477

Pandey U, Pandey J (2008) Enhanced production of high-quality biomass, δ-aminolevulinic acid, bilipigments, and antioxidant capacity of food alga *Nostochopsis lobatus*. *Applied Biochemistry and Biotechnology* **150**, 221-231

Pandey U, Pandey J (2009) Enhanced production of δ-aminolevulinic acid, bilipigments, and antioxidants from tropical algae of India. *Biotechnology and Bioprocess Engineering* **14**, 316-321

Patil SR, Chaugule BB (2009) Diversity of blue green algae in paddy fields of the Western Maharashtra. *Indian hydrobiology* **12**, 89-94

Prabaharan D, Subramanian G (1995) Hydrogen photoproduction by marine cyanobacterium *Dichothrix bauriana* BDU 40481. *Physiology and Molecular Biology of Plants* **1**, 45-57

Prescott GW (1951) *Algae of the Western Great Lakes Area*, Otto Koeltz Science Publishers, Koeningstein, pp 1-935

Radwan SS, Al-Hasan RH (2001) Potential application of coastal biofilm-coated gravel particles for treating oily waste. *Aquatic Microbial Ecology* **23**, 113-117

Raghukumar C, Vipparty V, David JJ, Chandramohan D (2001) Degradation of crude oil by marine cyanobacteria. *Applied Microbiology and Biotechnology* **57**, 433-436

Rajeev KJ, Xu Z (2004) Biomedical compounds from marine organisms. *Marine Drugs* **2**, 123-146

Ray K, Chowdhury MH, Lakowicz JR (2008) Single-molecule spectroscopic study of enhanced intrinsic phycoerythrin fluorescence on silver nanostructured surfaces. *Analytical Chemistry* **80**, 6942-6948

Rippka R, Deruelles J, Waterbury JB, Herdman M, Stainer RY (1979) Generic assignments. Strain histories and properties of pure cultures of cyanobacteria. *Journal of General Microbiology* **111**, 1-61

Rodgers GA, Bergman B, Henriksson U, Udris M (1979) Utilisation of blue green algae as biofertilisers. *Plant and Soil* **52**, 99-107

Saadatnia H, Riahi H (2009) Cyanobacteria from paddy fields in Iran as biofertilizer in rice plants. *Plant Soil Environment* **55 (5)**, 207-212

Sahu JK, Nayak H, Adhikari SP (1996) Blue-green algae of rice fields of Orissa state I. Distribution pattern in different agroclimatic zones. *Phykos* **35**, 93-110

Shweta Y, Sinha RP, M. B. Tyagi MB, Kumar A (2011) Cyanobacterial secondary metabolites. *International Journal of Pharma Bioscience* **2 (2)**, 144-167

Singh NK, Parmar A, Madamwar D (2009) Optimization of medium components for increased production of C-phycocyanin from *Phormidium ceylanicum* and its purification by single step process. *Bioresource Technology* **100**, 1663-1669

Singh SP, Rastogi RP, Häder D, Sinha RP (2011) An improved method for genomic DNA extraction from cyanobacteria. *World Journal of Microbiology and Biotechnology* **27**, 1225-1230

Sinha RP, Häder DP (2008) UV-protectants in cyanobacteria. *Plant Science* **174**, 278-289

Srivastava PN, Odhwani BR (1992) Algae from the inland salt pans. *Journal of the Indian Botanical Society* **71**, 23-27

Subbaramaiah K (1972) The biology of blue-green algae of Sambhar lake salt works. In: Desikachary TV (Ed) *Symposium of the Taxonomy and Biology of Blue-Green Algae*, Madras, pp 439-441

Subramanian G, Uma L (1996) Cyanobacteria in pollution control. *Journal of Science and Industrial Research* **55**, 685-692

Sundararaman M, Sekar S (2001) Biotechnological potential of cyanobacteria. In: Trivedi PC (Ed) *Algal Biotechnology*, Pointer Publishers, Jaipur, India, pp 31-52

Sundararaman M, Subramanian G, Averal HI, Akbarsha MA (1996) Evaluation of the bio-activity of marine cyanobacteria on some biochemical parameters of rat serum. *Phytotherapy Research* **10**, 9-12

Sveshnikov DA, Sveshnikova NV, Rao KK, Hall DO (1997) Hydrogen metabolism of mutant forms of *Anabaena variabilis* in continuous cultures and under nutritional stress. *FEBS Microbiology Letter* **147**, 297-301

Thajuddin N, Nagasathya A, Chelladevi R, Saravanan P (2002) Biodiversity of cyanobacteria in different saltpans of Pudukkottai district, Tamil Nadu. *Seaweed Research and Utilization* **24**, 1-11

Thajuddin N, Subramanian G (1992) Survey of cyanobacterial flora of the southern east coast of India. *Botanica Marina* **35**, 305-311

Thajuddin N, Subramanian G (2005) Cyanobacterial biodiversity and potential applications in biotechnology. *Current Science* **89**, 47-57

Tiwari A, Pandey A (2012) Cyanobacterial hydrogen production – A step towards clean environment. *International Journal of Hydrogen Energy* **37**, 139-150

Venkataraman GS (1975) The role of blue–green algae in tropical rice cultivation. In: Stewart WDP (Ed) *Nitrogen Fixation by Free-Living Micro-organisms*, Cambridge University Press, Cambridge, pp 207-218

Venkataraman GS (1981) Blue-green algae for rice production. *FAO Soil Bulletins* **16**, 33-42

Venkataraman LV (1983) *A monograph on Spirullina platensis – Biotechnology and Application*, DST, New Delhi

Vonshak A (1997) *Spirulina platensis (Arthospira): Physiology, Cell-biology and Biotechnology* (1st Edn), Taylor & Francis, UK, 233 pp

Wang H, Liu Y, Gao X, Carter CL, Liu ZR (2007) The recombinant b subunit of c-phycocyanin inhibits cell proliferation and induces apoptosis. *Cancer Letters* **247**, 150-158

Yadav S, Sinha RP, Tyagi MB, Kumar A (2011) Cyanobacterial secondary metabolites. *International Journal of Pharmaceutical Bioscience* **2**, 144-167