Journal of Threatened Taxa

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ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

COMMUNICATION

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26 October 2020 | Vol. 12 | No. 14 | Pages: 16979–16992
DOI: 10.11609/jott.5683.12.14.16979-16992

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Journal of Threatened Taxa | www.threatenedtaxa.org | 26 October 2020 | 12(14): 16979–16992
ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)
DOI: https://doi.org/10.11609/jott.5683.12.14.16979-16992
#5683 | Received 06 January 2020 | Final received 06 September 2020 | Finally accepted 20 September 2020
PLATINUM OPEN ACCESS

COMMUNICATION

Chroococcalean blue green algae from the paddy fields of Satara District, Maharashtra, India

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Abstract: Blue green algae are the photosynthetic prokaryotes representing a wide distribution in habitat, i.e., temperate, tropical, and polar region. Paddy fields are the best studied aquatic ecosystems on earth which fulfill all the necessary demands required for blue green algal growth. Blue green algal role in enhancement of paddy yield has been studied worldwide. Sustainable utilization of an organism for community use depends on how successfully the ecology of that organism is understood. Twenty-eight chroococcalean blue green algal taxa were recorded from the study area. They were taxonomically investigated and found to belong to two families and 11 genera. The first family Chroococcaceae was the largest family with 10 genera and 26 species while the second family Entophysalidaceae had only one genus and two species. The genus *Gloeocapsa* from the family Chroococcaceae exhibited largest species diversity (21.42%), as well as taxa *Chlorogloea fritschii* of family Entophysalidaceae showed species abundance from the study area. All heterocystous blue green algal forms are capable of fixation of atmospheric N_2. Many of the non-heterocystous or unicellular blue green algae also have the capacity of N_2 fixation. The taxonomical documentation of chroococcalean blue green algae provide information about such indigenous unicellular blue green algae which will help in the development of niche specific inoculants as biofertilizers for rice fields of the study region.

Keywords: *Gloeocapsa,* unicellular, biofertilizer, nitrogen fixation, taxonomy.

Editor: Asheesh Shivam Mishra, Nehru Gram Bharati (Deemed to be University), Prayagraj, India. **Date of publication:** 26 October 2020 (online & print)

Citation: Ghadage, S.J. & V.C. Karande (2020). Chroococcalean blue green algae from the paddy fields of Satara District, Maharashtra, India. *Journal of Threatened Taxa* 12(14): 16979–16992. https://doi.org/10.11609/jott.5683.12.14.16979-16992

Funding: None.

Competing interests: The authors declare no competing interests.

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Author contribution: SJG—Conceptualized study, collected and analyzed data, wrote final version of menuscript translated in the field. VCK—Supervised study, helped in the revision of menuscript.

Acknowledgements: We are thankful to Dr. K. G. Kanade, Principal, Yashwantrao Chavan Institute of Science, Satara for the encouragement during the work. Thanks are also due to the Head Department of Botany Y. C. Institute of Science, Satara for the facilities. We are thankful to staff members and colleagues and friends for the keen interest and suggestions during this work.

INTRODUCTION

Blue green algae are important components of soil microflora in paddy fields. They play an important role in maintaining and improving soil fertility, as they have the ability to fix atmospheric nitrogen and transform it to nitrate/nitrite (Anand 1990). The rice fields provide ideal environment for luxuriant growth of blue-green algae. They are found in paddy field soil throughout the year at various growth stages of the rice crop (Nayak et al. 2001). There is huge structural diversity found in class Cyanophyta (blue green algae) which is the main reason for attracting algologists to develop a keen interest in their taxonomic study.

Extensive work on blue green algae of paddy fields got in various parts of India (West Bengal, Kerala, Chattisgarh, Manipur, Mizoram, Uttar Pradesh, Madhya Pradesh, Odisha, Tamil Nadu, and Maharashtra) and in Bangladesh (Banarjee 1935; Goyal et al. 1984; Anand & Revati 1987; Anand et al. 1987, 1995; Santra 1993; Sahu et al. 1997; Ahmed 2001; Nayak et al. 2001). There are some reports on growth and nitrogen fixation potentials of blue green algae (Gupta 1964; Parasad & Mehrotra 1980; Santra 1991). Some workers recorded marked variations among the species of blue green algae from rice field soils of different regions of India (Tiwari 1972; Sinha & Mukherjee 1975a,b, 1984; Anand et al. 1987). Several studies have been conducted on the blue green algal flora from the paddy fields of Maharashtra (Gonzalves et al. 1949; Sardeshpande & Goyal 1981; Kolte & Goyal 1985; Patil & Satav 1986; Madane & Shinde 1993; Auti & Pingle 2006; Patil & Chougule 2009). Ghadage & Karande (2008) and Kamble & Karande (2018) studied the unicellular blue green algae from various habitats of Satara District. Ghadage (2009), Karande (2009), Kamble (2010), and Ghadage & Karande (2019), however, studied the biodiversity of blue green algae from paddy fields of Satara District. Though substantial studies were available in Satara District, it seems that much attention was not paid to the study of chroococcalean blue green algae. Thus, the present study was designed to view the systematic enumeration of chroococcalean blue green algae of paddy fields from the study region.

MATERIALS AND METHODS

Two-hundred-and-eighty-eight paddy fields were selected from Patan and Karad tehsils of Satara, Maharashtra. Patan is 65km away to the south-west of Satara and is located at 17.370N & 73.900E. Most of Patan Tehsil is hilly with deep valleys while some parts are plains and receives heavy rainfall. The common soil is red lateritic soil, in the plains it is black cottony soil while at elevations it is the basaltic and lateritic type. This tehsil is famous for the cultivation of local varieties of paddy, viz.: Dombya, Dodkya, Kolambya, Bhados, Panwel, Indrayani, Champakali, Ghansal, Jiresal, Teliansh, Kaveri, Krishnakusal, Basmati, and Ambemohar.

Karad is 52km to the south-east of Satara and is located at 17.289N & 74.181E. Karad city situated at southern part of Satara District near Agashiva, at the confluence of Koyna and Krishna rivers called 'Preeti sangam'. The tehsil receives moderate rainfall and the common soil type is black cottony soil. It is famous for the cultivation of local varieties of rice, viz.: Indrayani, Rethare Basmati, Pusa Basmati, Hansa, Khadkil Kolhapuri, Kolhapuri R-24, and Kaveri.

Frequent and timely collection of soil and algal samples were undertaken during the rainy season (2012–2017). Soil samples were collected from paddy fields of the study area (Fig. 1). Soil from rice fields were collected randomly from both the tehsils as per Somawanshi et al. (1999). The collected soil samples were brought into the laboratory using polythene bags, dried at room

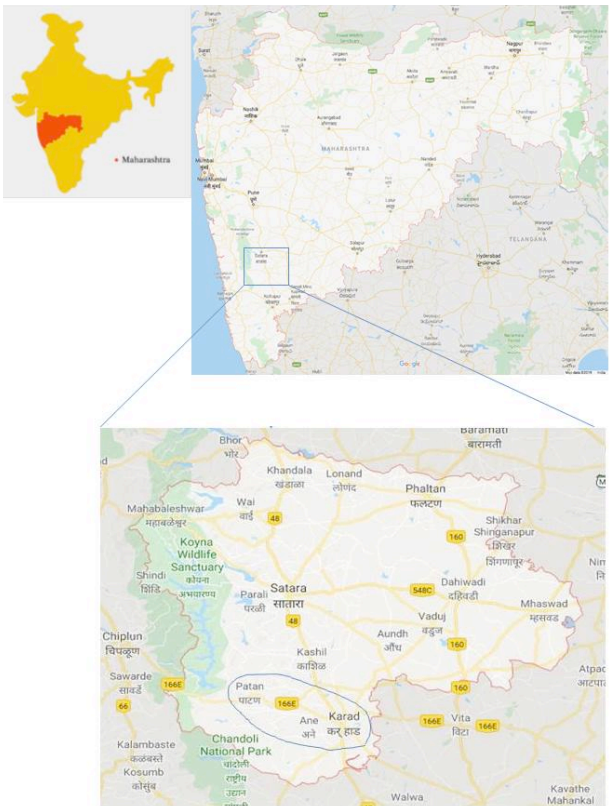

Figure 1. Study area—location of Karad and Patan Tahasils of Satara District. Source: Google maps.

temperature in diffused sunlight, and crushed with the help of a mortar and pestle. About 10g of sieved soil was inoculated in culture bottles containing 100ml culture media like BG – 11±, Foggs and Chu 10. We found good results in BG 11 medium, so for further culturing and sub culturing we prefer BG 11 ± medium. These cultures were incubated at 22±2˚c with 16/8 light dark cycle under 5 Klux intensity of light, after incubation algal growth appeared in the enriched cultures in laboratory. Cyanobacterial growth from enriched cultures were examined microscopically and identified with the help of standard literature (Dasikachary 1959; Anagnostidis & Komarek 1985; Anand 1990; Santra 1993). Photographs were taken by using photomicrography unit of Olympus CH20i (Photoplates I, II, III).

The species diversity % was calculated by using the following formula.

$$\text{Species diversity \%} = \frac{\text{Total no. of particular species recorded in that area}}{\text{Total no. of species recorded from that area}} \times 100$$

RESULT AND DISCUSSION

Systematic enumeration of Chroococcalean blue green algae

Order: Chroococcales Wettstein

Forms of this order are unicellular or colonial, not differentiated into base and apex; as well as trichome organization totally absent. Endospores or exospores not present.

Key to the families

A. Thallus forming small colonies .... Chroococcaceae

B. Forming pseudo filamentous thallus .... Entophysalidaceae

1. Family: Chroococcaceae Nageli

Cells single or forming shapeless, ellipsoidal or spherical colonies and cell shape may be spherical or cylindrical, ellipsoidal with thick mucilaginous membrane.

Key to the genera

A. Cells few in shapeless colony..... (1)
1) Spherical cells .....(2)
1) Elongated cells with transverse cell division..(4)

B. Cells many in a colony.....(6)
2) Absence of Individual envelope ....*Synechosystis*
2) Presence of Individual envelope.....(3)
3) Vesicular sheath.....*Gloeocapsa*
3) Non vesicular sheath.....*Chroococcus*
4) With firm vesicular sheath.....*Gloeothece*
4) Without such sheath.....(5)
5) Few cells in common mucilage...*Synechococcus*
5) Cells with tapering ends in spindle shaped colonies.....*Dacylococcopsis*
6) Cells without definite arrangement.....(7)
6) Cells with definite arrangement.....(9)
7) Cells in small well packed colonies .... *Microsystis*
7) Cells loosely arranged in colonies.....(8)
8) Cells spherical.....*Aphanocapsa*
8) Cells Ellipsoidal to Cylindrical .....*Aphanothece*
9) Cells in transverse longitudinal rows ....*Merismopedia*

A] Genus: *Aphanocapsa* Nag.

Loosely arranged spherical cells in a formless gelatinous mass. Cells having individual sheath which is more or less gelatinous.

Key to the species

1) In freshwater, planktonic.....(2)
2) Cells diameter 6.5–7.5µm.....*A. roseana*
2) Cells diameter 1.42–2 µm.....*A. elachista*

1) *Aphanocapsa roseana* de Bary

Cyanophyta: Desikachary, T. V. 1959, p – 132, photoplate II, Fig-h

Thallus irregularly spherical, bluish green in color. Cells 6.5–7.5 µm diameter, somewhat oval, sheath mucilaginous.

Locality: Patan: Nawsari, Mhawshi.

2) *Aphanocapsa elachista* var *irregularis* W. et. G.S.West

Cyanophyta: Desikachary, T.V. 1959, p – 132, pl. 21, Fig. 5, photoplate II, Fig-i

Irregular thallus. Cells loosely and closely arranged. Single or in pairs, 1.42–2 µm in diam., blue-green in color.

Locality: Patan: Sangwad, Marul Haweli, Maldan, Tondoshi.

Karad: Undale.

B] Genus : *Aphanothece* Nag.

Cells embedded in a shapeless expanded thallus; ellipsoidal to cylindrical with lamellated individual envelope.

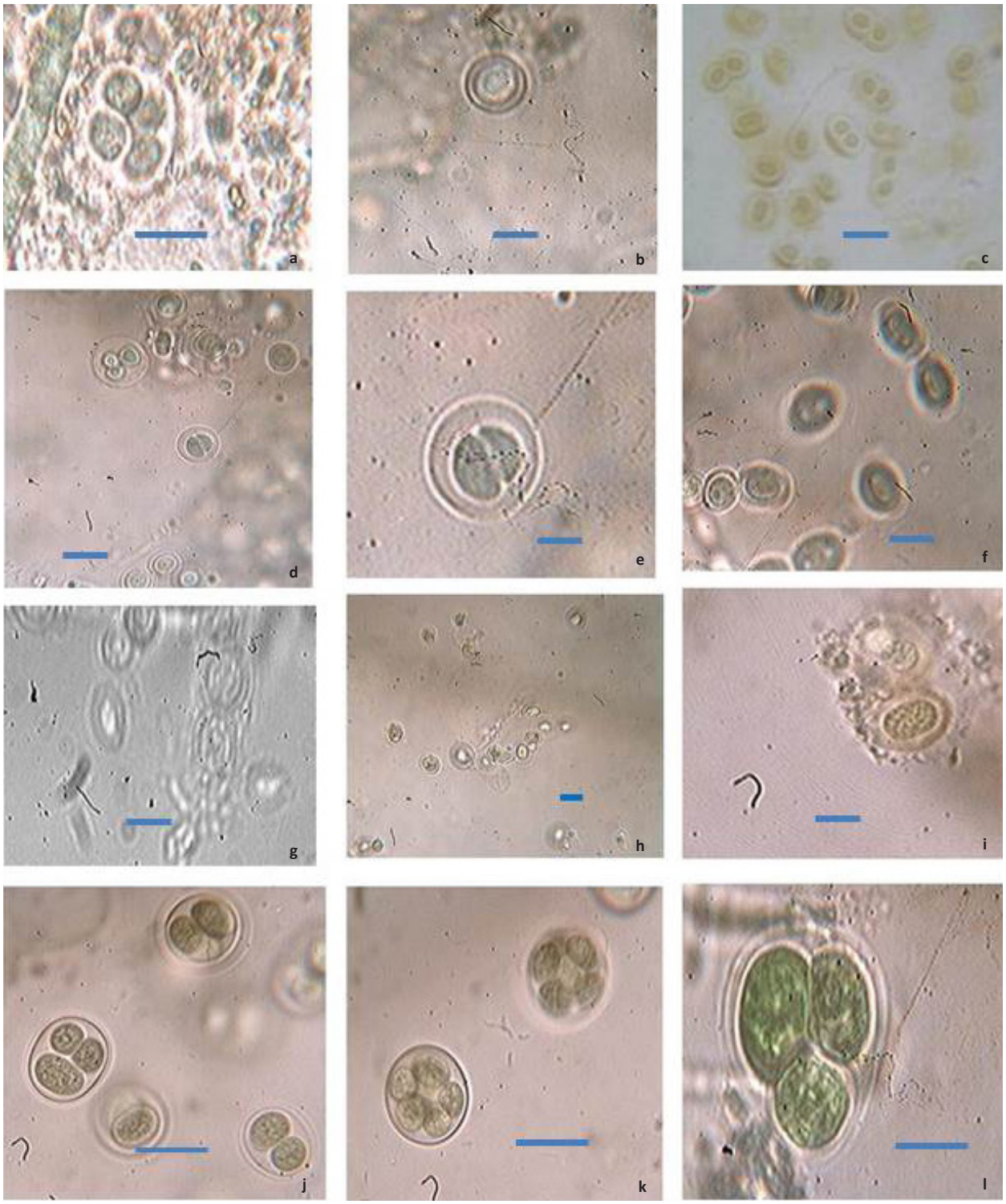

Image 1 Family 1 Chroococcaceae—Chroococcalean BGA: MS no. 5683: a—*Gloeocapsa livida* (Carm.) Kutz | b—*Gloeocapsa decorticans* (A. Br..) Richter | c—*Gloeocapsa nigrescens* Nag. | d–e—*Gloeocapsa polydermatica,* Kutz. | f—*Gloeocapsa areuginosa (Carm.)* Kutz. | g—*Gloeocapsaeothece atrata* (Turp) Kutz | h—*Gloeothece palea* (Kutz) Rabenh | i—*Gloeothece samoensis* Wille | j–k—*Gloeothece rupestris* (Lyngb) Bornet | l—*Chroococcus turgidus* (Kutz) Nag. Scale = 10µm. © Sharada Ghadage.

Key to the species

1) Mucilagenous expanded thallus.....(2)
2) 3.3–5.2 µm broad cells.....*A. pallida*
2) 3.8–4.3 µm broad cells.....(3)
3) Subaerial .....*A. naegelli*
3) Submerged, non-thermal.....*A. microscopia*

1) *Aphanothece naegeli* Wartm

Cyanophyta: Desikachary, T. V. 1959, p -141, pl. 22, Fig. 7, photoplate II, Fig-e

Thallus gelatinous, olive green. After division cells appear spherical, latter on becomes oval, cell breadth 3.8–4.3 µm and length up to 6.6–7.8 µm; sheath diffluent.

Locality: Patan – Chavanwadi, Gokul tarf Patan, Kokisare, Palashi, Telewadi.

Karad – Pali.

2) *Aphanothece microscopia* Nag.

Cyanophyta: Desikachary, T.V. 1959, p - 142, pl. 22, Figs. 4,5,9. Photoplate II, Fig-f

Thallus small, gelatinous, at first rounded, but latter amorphous; cells cylindrical, 3.9–5 µm broad, 7.5–9 µm long with distinct individual sheath, bluish-green. The thallus in culture grows attached at the sides of culture bottles.

Locality: Patan – Kuthare, Nanegaon, Gokul tarf Marali, Vitthalwadi.

Karad – Atke, Sabalwadi, Riswad, Chinchni, Abaichiwadi, Supane, Sajur, Kole.

3) *Aphanothece pallida* (kutz.) Rabenh.

Cyanophyta: Desikachary, T.V. 1959, p -140, pl. 22, Fig. 3. Photoplate II, Fig-g

Thallus appear gelatinous and soft,cells oblong, 3.3–5.2µm broad, up to 7µm long, olive green in color, sheath lamellated, yellowish in color.

Locality: Patan - Yeradwadi, Shitapwadi, Pachgani.

Karad – Talgaon, Shiwade, Charegaon, Pal.

C] Genus: *Gloeocapsa* Kutzing.

Cells mostly 2–8 in a colony and spherical in shape. Colonies many together. Cells having lamellated individual sheaths.

Key to the species

1) Colorless sheath.....(2)
2) Unlamellated sheath.....(3)
2) Lamellated sheath..... (8)
3) Without calcium impregnation.....(4)
4) Cells 3µm without sheath.....(5)
4) 5µm broad cells without sheath..... *Gl. livida*
5)Thallus blue green.....*Gl. aeruginosa*
6) Lamellated sheath.....*Gl. atrata*
6) Unlamellated sheath.....(7)
7) 4.2–5.32 µm broad cells without sheath.....
..... *Gl. nigrescens*
8) Cell diameter 8µm without sheath.....
..... *Gl. decorticans*
8) Cells 3.9µm diameter without sheath.....
.....*Gl. polydermatica*

1) *Goeocapsa nigrescens* Nag.

Cyanophyta: Desikachary, T. V. 1959, p -117, pl. 24, Figs. 15, 17. Photoplate I, Fig-g

Thallus thin, blackish, cells spherical, without sheath 4.2–5.32 µm; and with sheath 9.31–11.6 µm diam., sheath broad, not lamellate.

Locality: Patan – Nade, Telewadi.

Karad – Karve, Dhanakwadi.

2) *Goeocapsa atrata* (Turp.) Kutz.

Cyanophyta: Desikachary, T.V. 1959, p - 116, pl. 24, Fig. 8. Photoplate I, Fig-c

Thallus blackish in color. Cells without sheath up to 5.68µm broad and with sheath 9.5–12.5µm in diam. Many cells in a single colony, sheath colorless, unlamellated.

Locality: Patan – Korivale, Bambavade, Govare, Jyotibachiwadi, Zakade.

Karad – Kaletake.

3) *Goeocapsa polydermatica* Kutz.

Cyanophyta: Desikachary, T.V. 1959, p - 114, pl. 25, Fig. 1, photoplate I, Fig-d-e

Thallus mostly compact and mucilaginous; cells spherical, without sheath 3.9µm and with sheath 6.65µm in diam., bluish-green to colorless sheath and thick, and lamellated.

Locality: Patan – Divashi, Kadhne, Marloshi, Vitthalwadi.

4) *Goeocapsa decorticans* (A. Br.) Richter

Cyanophyta: Desikachary, T.V. 1959, p -114, pl. 24, Fig. 9. Photoplate I, Fig-b

Cells spherical to oval, bluish in color, 2–4 together, with sheath up to 19µm in diam., and without sheath 8µm broad, sheath colorless, thick.

Locality: Patan – Jamdarwadi, Sangwad.

Karad - Pachwad, Yenke.

5) *Goeocapsa aeruginosa* (Carm.) Kutz.

Cyanophyta: Desikachary, T.V. 1959, p -115.

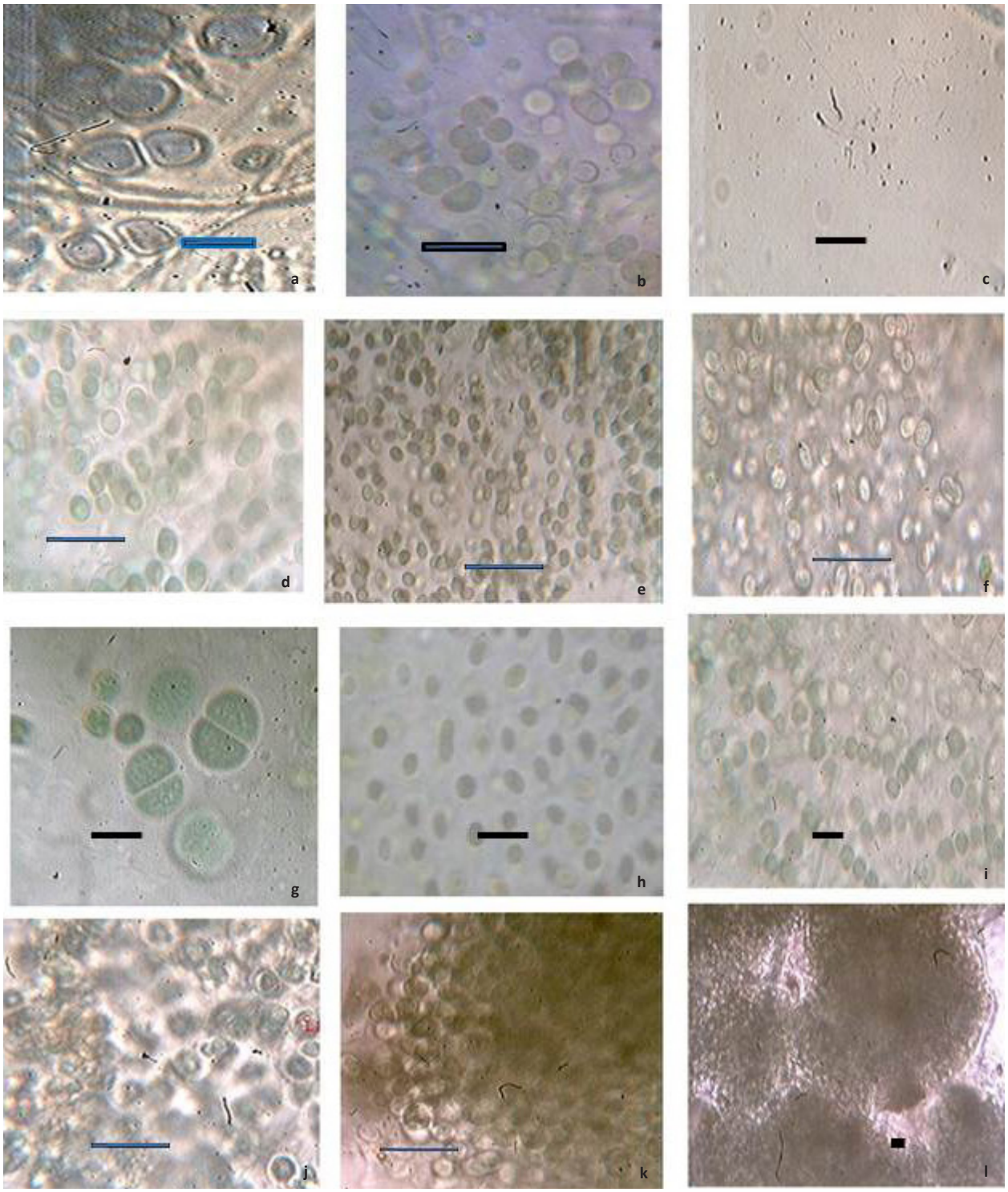

Image 2. Family 1 Chroococcaceae: *a—Chroococus Pallidus* Nag. | b—*Chroococcus minor* (Kutz) Nag. | c—*Chroococcus multicoloratus* Wood | d—*Chroococcus minutus* (Kutz) Nag. | e—*Aphanothece naegelli* Wartm. | f—*Aphanothece microscopia* Nag. | g—*Ahanothece pallida* (Kutz) Rabenh | h—*Aphanocapsa roseana* de Bary | i—*Ahanocapsa elachista* var *irregularis* W.et.G.S.West | *j—Microsystis robusta* (Clark) Nygaard | k–i—*Microsystis elabens* (Barb.) Kutz. Scale = 10µm. © Sharada Ghadage.

Photoplate I, Fig-f

Thallus mucilaginous, crustaceous. Cells with sheath 5.68µm broad and without sheath 2.84–3 µm broad. Cells in spherical colonies, sheath lamellated.

Locality: Patan – Urul, Surul, Gokul tarf Patan, Shiral, Telewadi.

6) *Goeocapsa livida* (Carm.) Kutz.

Cyanophyta: Desikachary, T. V. 1959, p - 116, pl. 27, Fig. 8.Photoplate I, Fig-a

Thallus mucilaginous greenish in color. Cells small, cells up to 5µm broad and colony diam. 11.8µm. Sheath hyaline, bluish-green.

Locality: Patan – Navadi, Gavanwadi, Kuthare, Ambavane, Jambhekarwadi, Govare, Jyotibachiwadi.

D] Genus**:** *Gloeothece* Nag.

Cells ellipsoidal, straight in small colonies. Sheath and colony structure same as that of *Gloeocapsa*.

Key to the species

1) Mucilage envelope colorless.....(2)
2) Cells 2.5–4.5 µm without envelope.....(3)
2) Cells 4–6 µm broad.....(4)
3) Cells cylindrical.....*Gl. palea*
3) Cells ellipsoidal .....*Gl. samoensis*
4) Cells ellipsoidal to cylindrical up to 15µm long .....*Gl. rupestris*

1) *Gloeothece palea* (Kutz.) Rabenh.

Cyanophyta: Desikachary, T. V. 1959, p -127. Photoplate I, Fig-h

Cells cylindrical and long, without envelope 2.5–4.5 µm in diameter. Cells with envelope 8.52µm broad and 9.94µm long, unlamellated, envelope lightly yellowish in color.

Locality: Patan – Ambeghar tarf Marali, Kusavade Khu.

Karad – Karve, Wadgaon haweli, Vadoli bhikeshwar, Korti, Bholewadi.

2) *Gloeothece rupestris*t (Lyngb.) Bornet

Cyanophyta: Desikachary, T.V. 1959, p - 127, pl. 25, Fig. 4. Photoplate I, Fig-j-k

Cells ellipsoidal, without envelope 4.2–5.5 µm broad, 7.5–8µm long, cells with envelope 9–12 µm broad, cells 2–4 together, envelope colorless, unlamellated.

Locality: Patan – Telewadi, Sawantwadi, Majgaon, Surul, Karate.

Karad – Rethre Bu., Charegaon.

3) *Gloeothece samoensis* Wille

Cyanophyta: Desikachary, T.V. 1959, p -128, pl. 23, Fig. 3. Photoplate I, Fig-i

Cells ellipsoidal, without sheath 4–4.2 µm broad and about 8µm long, cells yellowish in color, in ellipsoidal colonies, cells with unlamellated envelope.

Locality: Patan – Yeradwadi, Umarkanchan, Yerphale, Donichawada.

E] Genus : *Chroococcus* Nag.

Cells in small groups 2–4 together or sometimes 8–16 together. Cells spherical to hemispherical in shape with distinct and firm individual sheaths.

Key to the species

1) Cells single /8 (-16) later divided.....(2)
1) Large thallus formed.....(6)
2) Sheath lamellated .....(3)
2) Not lamellated .....(5)
3) Colorless envelope.....(4)
4) Sheath distinct, cells with sheath less than 32µm broad .....*Chr. turgidus*
5) Cells 4–10 µm without sheath.....*Chr. minutus*
5) Cells 3–4 µm without sheath .....*Chr. minor*
6) Subaerial colonies.....(7)
7) Unlamellated sheath.....(8)
8) Cells 4 –8 µm broad without sheath..... .....*Chr. Pallidus*
8) Cells less than 2µm broad without sheath ....*Chr. multicoloratus*

1) *Chroococcus minutus* (Kutz.) Nag.

Cyanophyta: Desikachary, T.V. 1959, p -103, pl. 24, Fig. 4 and pl. 26, Figs. 4, 15. Photoplate II, Fig-d

Cells spherical, single or in groups of 2, bluish-green, with sheath 7.8µm broad and without sheath 6.5µm in diameter. Colonies 12.78µm broad sheath not lamellated, colorless.

Locality: Patan – Awarde, Salave.

Karad – Kaletake, Shiwade, Koparde haweli, Charegaon, Bholewadi, Shelkewadi.

2) *Chroococcus minor* (Kutz.) Nag.

Cyanophyta: Desikachary, T.V. 1959, p - 105, pl. 24, Fig. 1. Photoplate II, Fig-b

Thallus olive green in color, gelatinous, cells spherical, 3.3–3.5 µm in diameter. Mostly single, sheath colorless, very thin.

Locality: Patan – Matekarwadi.

Karad – Kale, Hanbarwadi.

3) *Chroococcus multicoloratus* Wood.

Cyanophyta: Desikachary, T.V. 1959, p - 109. Photoplate II, Fig-c

Thallus mucilaginous mostly found among other algae; cells spherical, single or 2–4 together in a colony. Cells about 1µm in diameter. Sheath thick, unlamellated, hyaline, yellowish green.

Locality: Patan – Varekarwadi, Vajegaon.

Karad – Kaletake.

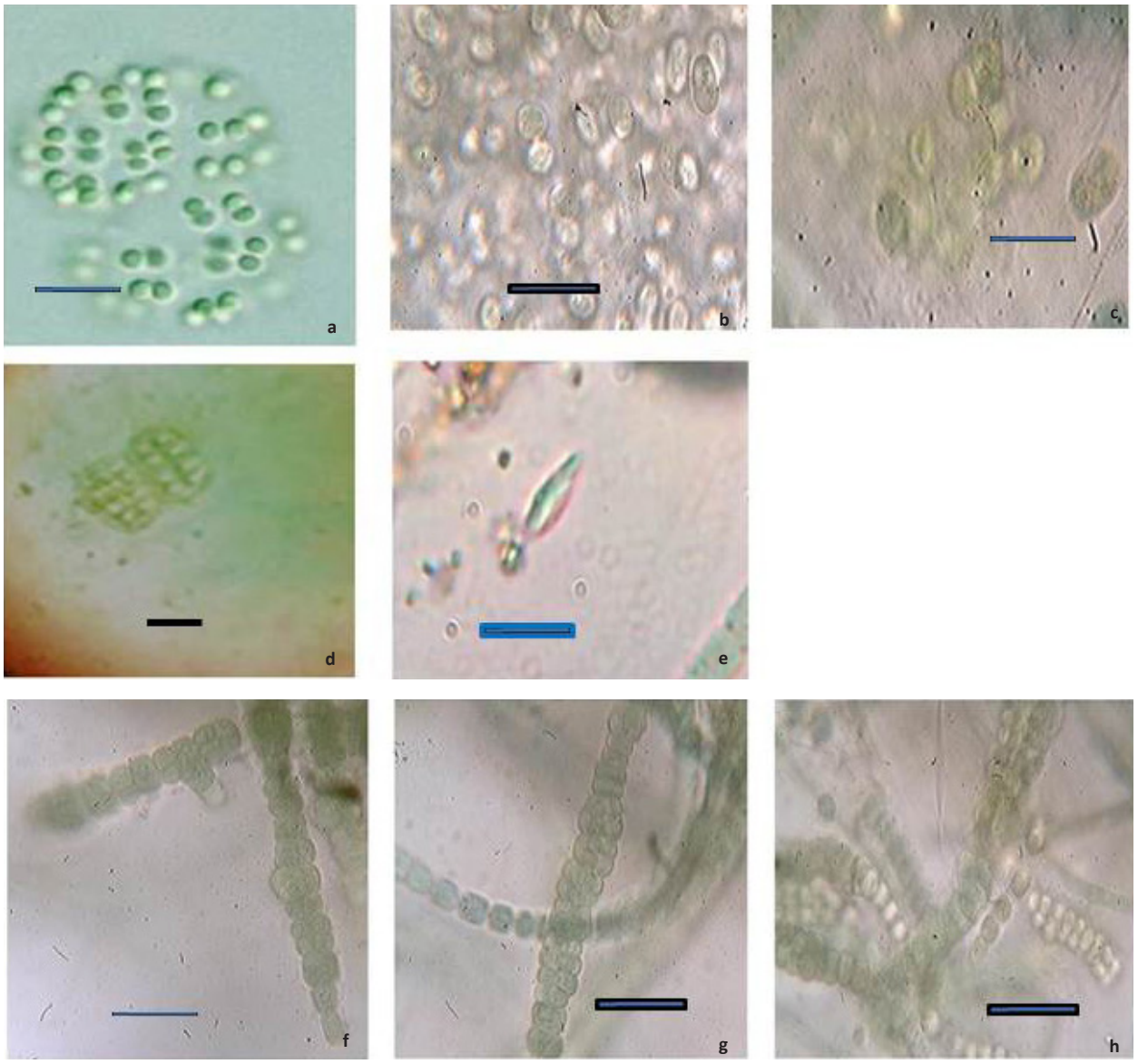

Image 3. Family 1 Chroococcaceae (a–e): a—*Synechosystis pevalekii* Ereegovic | b—*Synechococcus cedrorum* Sauvageau | c—*Synechococcus aeruginosus* Nag. | d—*Merismopedia tenuissima* Lemm. | e—*Dactylococcopsis raphidioides* Hansg. Family 2 Entophysalidaceae (f–h): f—*Chlorogloea microcystoides* Geitler | g–h—*Chlorogloea fritschii* Mitra. Scale bars = 10µm. © Sharada Ghadage.

4) *Chroococcus turgidus* (Kutz.) Nag.

Cyanophyta: Desikachary, T.V. 1959, p - 101, pl. 26, Fig. 6. Photoplate I, Fig-l

Cells spherical, mostly in groups of three, olive green in color, without sheath 8–15 µm broad, with sheath 16–25 µm broad; sheath colorless, not lamellated.

Locality: Patan – Kumbhargaon, Awarde, Kusavade.

5) *Chroococcus pallidus* Nag.

Cyanophyta: Desikachary, T.V. 1959, p - 108, pl. 26, Fig. 5. Photoplate II, Fig-a

Thallus gelatinous yellowish, cells in group of two, without sheath 5–6 µm broad and with sheath 7–8 µm broad bluish green in color.

Locality: Patan – Shidrukwadi, Budakewadi, Gaymukhwadi, Donichawada.

Karad – Charegaon.

F] Genus: *Synechosystis* Sauvageau

Cells spherical, single, after division found in colonies without mucilage envelope.

Key to the species

1) Cells diameter 2.8–3.5 µm.....*S. pevalekii*

1) *Synechosystis pevalekii* Ercegovic

Cyanophyta: Desikachary, T.V. 1959, p - 145, pl. 25, Fig. 11, photoplate III, Fig-a

Thallus associated among other algae; cells spherical or hemispherical, 2.84–3.5 µm broad, and colony breadth 3–5.68 µm. content bluish-green in color and homogenous.

Locality: Patan - Adul, Sangwad, Gaymukhwadi.

Karad – Yevati.

G] Genus: *Synechococcus* Nag.

Cells ellipsoidal with rounded ends, mostly cells are single. Mucilage envelope very thin.

Key to the species

1) Cells broader than 5µm .....
.....*Syn. aeruginosus*

1) Cells 3–4.3 µm broad ellipsoidal .....
.....*Syn. cedrorum*

1) *Synechococcus aeruginosus* Nag.

Cyanophyta: Desikachary, T. V. 1959, p - 143, pl. 25, Figs. 6, 12. Photoplate III, Fig-c

Cells cylindrical, 5.32–6.2 µm broad, up to 27µm long, single, pale bluish-green in color.

Locality: Patan – Nade, Jalu, Atoli.

Karad – Pachwad.

2) *Synechococcus cedrorum* Sauvageau

Cyanophyta: Desikachary, T. V. 1959, p - 144. Photoplate III, Fig-b

Cells single, elongate to rounded, up to 3.9µm broad; and 5.4–6 µm long, bluish-green in color.

Locality: Patan – Divashi, Dhadamwadi.

H] Genus: *Microsystis* Kutzing.

Cells spherical in shape and embedded in net-like colonies. Cells densely arranged and not having individual envelope.

Key to the species:

1) In fresh water.....(2)
2) Spherical cells.....(3)
2) Elongated cells.....(4)
3) 6–9 µm broad cells.....*M. robusta*
4) 2–4.5 µm broad cells.....*M. elabens*

1) *Microsystis elabens* (Breb.) Kutz.

Cyanophyta: Desikachary, T.V. 1959, p - 97, pl. 18, Fig. 12 and pl. 20, Figs. 6, 7. Photoplate II, Fig-k-i

Colony flat, bluish-green in color, daughter colonies come close together when become old; cells 2.2–3.6µm broad and up to 6.6µm long.

Locality: Karad – Potale.

2) *Microsystis robusta* (Clark) Nygaard

Cyanophyta: Desikachary, T.V. 1959, p - 85, pl. 17, Figs. 7–10. Photoplate II, Fig-j

Colonies first globose latter on irregularly expanded; cells spherical, with distinct gelatinous sheath. Cells spherical and 6.65µm in diameter.

Locality: Patan – Navadi, Girewadi, Marul haweli, Padloshi, Konjavade, Varpewadi, Atoli.

Karad – Karve, Dhanakwadi, Belavde haweli, Bamanwadi.

I] Genus: *Dactylococcopsis* Hansgirg.

Cells are elongated, spindle-shaped with pointed ends. Ends somewhat bent.

Key to the species

1) Cells breadth 1.85µm and length 6.6µm .....
..... *Dactylococcopsis raphidioides*

1) *Dactylococcopsis raphidioides* Hansg.

Cyanophyta: Desikachary, T.V. 1959, p - 158, pl. 29, Figs. 1, 2. Photoplate III, Fig-e

Cells spindle shaped, 1.85µm broad and 6.63µm long, light blue-green in color, mostly single in the mucilage of other algae.

Locality: Patan – Navsari, Nanegaon, Gokul tarf Patan, Telewadi.

J] Genus : *Merismopedia* Meyen

Cells in a homogenous mucilage and are 4–16 together in a tabular colonies. Arrangement of cells in a single plane.

Key to the specie

1) Cells about 5µm broad .....
..... *Merismopedia tenuissima*

1) *Merismopedia tenuissima* Lemm.

Cyanophyta: Desikachary, T.V. 1959, p - 154, pl. 29, Fig. 7 and pl. 30, Figs. 8, 9. Photoplate III, Fig-d

Cells pale bluish-green in color, closely packed in colonies of sixteen cells, sub spherical, about 2µm broad, without distinct individual mucilage.

Locality: Patan – Keloli.

2. Family: Entophysalidaceae Geitler

Thallus mostly attached to the substratum, cell arrangement in regular or irregular group of rows. Cells spherical or ellipsoidal in shape without individual

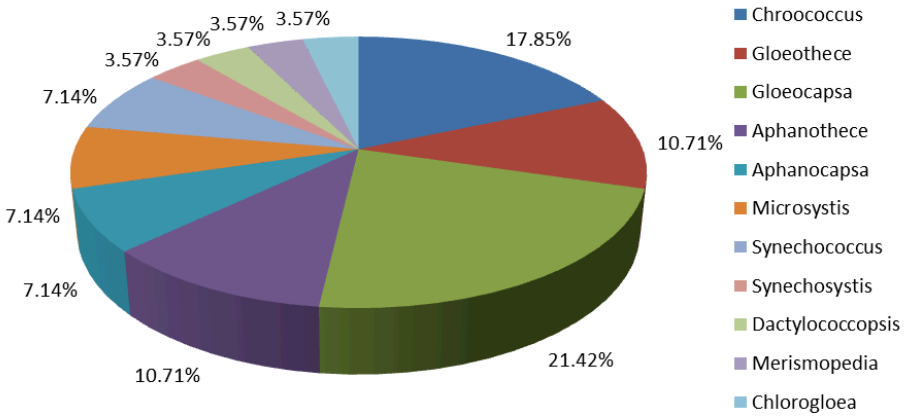

Figure 2. Species abundance of Chroococcalean taxa from study area.

sheath and not forming typical filament forms.

A] Genus: *Chlorogloea* Wille.

Cells mostly in straight erect rows, they are ellipsoidal to spherical in shape without individual envelopes. Cell divides in a single direction.

Key to the species

1) Cells diameter 2–3.8 µm.....*Chl. microcystoides*

1) Cells diameter 6–8 µm.....*Chl. fritschii*

1) *Chlorogloea fritschii* Mitra

Cyanophyta: Desikachary, T.V. 1959, p - 163, pl. 31, Figs. 1–16. Photoplate III, Fig-g

Thallus deep bluish-green in color, cell arrangement vertical as well as horizontal rows like, cells usually about 8µm in diameter, cells single or in groups of two, or four or more cells.

Locality: Patan – Adul, Sangwad, Divshi, Tupewadi, Chavanwadi, Kadave b., Donglewadi, Natoshi,

Palashi, Gokul tarf Patan, Telewadi.

Karad – Karve, Pachwad, Dhondewadi, Kale, Botrewadi, Yenpe, Akaichiwadi, Saidapur, Wadoli nileshwar, Shahapur, Shiwade, Hanumanwadi, Varade, Umbraj, Andharwadi, Hingnole, Chore, Chorajwadi, Pal, Hanumannagar (Karad city), Tembu, Hajarmachi, Riswad, Gaikwadwadi, Potale, Kole.

2) *Chlorogloea microcystoides* Geitler

Cyanophyta: Desikachary, T. V. 1959, p - 163, pl. 19, Fig. 8. Photoplate III, Fig-f

Thallus gelatinous, thin, dull green in color; cells spherical, closely arranged in erect or radial rows of more or less indistinct rows without individual envelope. Cells 2.5–3.6 µm in diameter.

Locality: Patan – Jamdarwadi, Varekarwadi, Nanegaon.

Karad – Malkapur, Savade, Hanumanwadi, Antavadi, Mundhe, Vijaynagar.

Patan and Karad tehsils of Satara districts are famous for paddy cultivation. An extensive study was made in search of diversity, distribution and occurrence of chroococcalean cyanobacteria. Order chroococcales contains two families—Chroococcaceae and Entophysalidaceae. Eleven genera and 28 eight species were recorded by screening 288 paddy field localities of study area. From family chroococcaceae 10 genera and 26 species were recorded. Genus *Gloeocapsa* with six species; followed by genera *Chroococcus* with five species, *Gloeothece* and *Aphanothece* with three species were dominant. While from family Entophysalidaceae only one genus *Chlorogloea* with two species, i.e., *Chlorogloea fritschii* and *C. microcystoides* were reported. But these two forms were frequently recorded from the study area. Genus *Gloeocapsa* showed species diversity i.e., six species of single genera recorded in study area while genus *Chlorogloea* with two species reported to be dominant taxa i.e., reported in most of the paddy fields repeatedly.

Some interesting observations were made while isolating and culturing of unicellular forms from paddy field soils of Patan and Karad tehsils. Generally at the beginning filamentous forms appear in the culture bottles while unicellular forms appeared in old cultures. The members from family Chroococcaceae showed coccoid appearance, they form smooth gelatinous loose colonies while members of family Entophysalidaceae are also coccoid but show colonial growth habit. The cells grow to give dense parenchymatous mass. The growth habitat in culture condition of these taxa become helpful to differentiate them visually.

Wyatt & Silcey (1969) also studied nitrogen fixation of chroococcalean blue green alga *Gloeocapsa* species while Zhou & Chen (1991) recorded their efficiency for nitrogen fixation. Our study area also showed

Table 1. Species diversity percentage of Chroococcalean taxa from study area.

	Genera	Species	No. of particular species	Species diversity %
1	*Chroococcus*	*Chroococcus minutus*	05	17.85 %
2		*Chroococcus multicoloratus*		
3		*Chroococcus minor*		
4		*Chroococcus turgidus*		
5		*Chroococcus pallidus*		
6	*Gloeothece*	*Gloeothece palea*	03	10.71 %
7		*Gloeothece rupestris*		
8		*Gloeothece samoensis*		
9	*Gloeocapsa*	*Gloeocapsa atrata*	06	21.42 %
10		*Gloeocapsa nigrescence*		
11		*Gloeocapsa decorticans*		
12		*Gloeocapsa aeruginosa*		
13		*Gloeocapsa livida*		
14		*Gloeocapsa polydermatica*		
15	*Aphanothece*	*Aphanothece microscopia*	03	10.71 %
16		*Aphanothece naegelii*		
17		*Aphanothece pallida*		
18	*Aphanocapsa*	*Aphanocapsa roseana*	02	7.14 %
19		*Aphanocapsa elachista* var *irregularis*		
20	*Microsystis*	*Microsystis robusta*	02	7.14 %
21		*Microsystis elabens*		
22	*Synechococcus*	*Synechococcus cedrorum*	02	7.14 %
23		*Synechococcus aeruginosus*		
24	*Synechosystis*	*Synechosystis pevalekii*	01	3.57 %
25	*Dactylococcopsis*	*Dactylococcopsis raphidioides*	01	3.57 %
26	*Merismopedia*	*Merismopedia tenuissima*	01	3.57 %
27	*Chlorogloea*	*Chlorogloea fritschii*	02	7.14
28		*Chlorogloea microcystoides*		
		Total No. of species	**28**	**100 %**

predominance of *Gloeocapsa* species with high species diversity percentage (21.42%) denote species diversity from the study area; followed by *Chroococcus* with 17.85%, *Gloeothece* and *Aphanothece* with 10.71% and *Aphanocapsa*, *Microsystis,* and *Synechococcus* with 7.14%. This showed their moderate occurrence in the paddy fields of study region. Least species diversity percentage was recorded in *Chlorogloea, Merismopedia*, *Dactylococcopsis,* and *Synechosystis* (3.57%) (Table 1) (Figure 2). Nitrogen fixation by *Gloeothece* species was noted by Maryan et al. (1986). The least diverse species did not show their adaptability for changing pH condition of the cultures and they vanish very soon. But *Gloeocapsa*, *Chroococcus*, *Gloeothece*, and *Aphanothece* proved their adaptability to changing pH. *Chlorogloea fritschii* showed high dominance (reported from 11 localities of Patan Tehsil and 26 localities of Karad Tehsil) followed by *Microsytis*, *Chroococcus* & *Gloeothece*. This data would provide the knowledge about such indigenous chroococcalean species which showed species diversity and occur frequently in paddy soil cultures. This will help in development of niche specific inoculants as biofertilizers for rice fields of the study region.

The abundant growth of chroococcophyceae members in aquatic environment especially planktonic state than in terrestrial environment was recorded by Naz et al. (2003). They surveyed fresh water cyanophyta from certain areas of northern region of Pakistan and Azad Kashmir. Naz et al. (2004) reported 46 planktonic, edaphic, epipsammic, epioikotic, epilithic & epiphytic blue green algae belonging to class Chroococcophyceae (cyanophyta) from various fresh water habitats of Pakistan. They reported these chroococcalean forms from various habitalts; but we recorded 28 chroococcalean taxa from paddy field

Table 2. Distribution of Chroococcalean blue green algal species in study area.

Order	Family	Genera	Species	Taxa from Patan Tehsil	Taxa from Karad Tehsil	Common taxa (from both the Tehsils)
Chroococcales	1) Chroococcaceae	1) *Chroococcus*	*Chroococcus minutus*	-	-	+
			Chr. multicolor Ataus	-	-	+
			Chr. minor	-	-	+
			Chr. turgidus	+	-	-
			Chr. pallidus	-	-	+
		2) *Gloeothece*	*Gloeothece palea*	-	-	+
			Gl. rupestris	-	-	+
			Gl. samoensis	+	-	-
		3) *Gloeocapsa*	*Gloeocapsa atrata*	-	-	+
			Gl. nigrescence	-	-	+
			Gl. decorticans	-	-	+
			Gl. aeruginosa	+	-	-
			Gl. livida	+	-	-
			Gl. polydermatica	+	-	-
		4) *Aphanothece*	*Aphanothece microscopia*	-	-	+
			A. naegelii	-	-	+
			A.pallida	-	-	+
		5) *Aphanocapsa*	*Aphanocapsa roseana*	-	-	+
			A. *elachista* var *irregularis*	-	-	+
		6) *Microsystis*	*Microsystis robusta*	-	-	+
			M. elabens	-	+	-
		7) *Synechococcus*	*Synechococcus cedrorum*	+	-	-
			S. aeruginosus	-	-	+
		8) *Synechosystis*	*Synechosystis pevalekii*	+	-	-
		9) *Dactylococcopsis*	*Dactylococcopsis raphidioides*	+	-	-
		10) *Merismopedia*	*Merismopedia tenuissima*	+	-	-
	2) Entophysaledaceae	1) *Chlorogloea*	*Chlorogloea fritschii*	-	-	+
			Chl. microcystoides	-	-	+

Taxa Present = sign **+**
Taxa absent = sign **-**

soil cultures only. Nitrogen fixation by unicellular blue green algae *Aphanothece* was reported by Singh (1973). Majority taxa found in paddy in fresh form as well as in soil cultures was of filamentous heterocystous and filamentous non-heterocystous type. Non-heterocystous chroococcalean cyanobacteria, however, also fixes atmospheric nitroge (Wyatt & Silvery 1969). Huang & Chow (1988) showed comparative account of nitrogen fixing unicellular cyanobacteria from rice fields. Capacity of nitrogen fixation by chroococcalean blue green algae *Aphanothece pallida* was recorded by Van et al. (1988) by isolating it from paddy fields. Unicellular forms were not recorded from paddy fields in the study region (Not as field collected specimens). They showed their occurrence in paddy soil cultures only and especially when cultures become 3–4 weeks old. The reason behind less number of chroococcalean taxa is, majority of the chroococcalean forms occur in soil cultures; not in field conditions and especially when soil cultures becomes 3–4 weeks old.

At first filamentous heterosystous and filamentous non-heterosystous forms occur in cultures and when cultures became old (3–4 weeks) and when the nitrogen content of the medium slow down, chroococcalean forms grow upward direction in the culture bottles. Out

of 28 chroococcalean blue green algal forms, 18 forms show common occurrence, nine restricted to paddy field soils of Patan Tehsil and only one taxa restricted to paddy field soils of Karad Tehsil. Detailed distribution of chroococcalean blue green algae in study area is given in tabular form (Table 2).

Taxonomic as well as ecological study of chroococcalean blue green algae was done from paddy fields of many regions of the world. Roger (1985) made a report on mucilaginous bloom of unicellular blue green algae and its application as a biofertilizer. Majority forms recorded at field and cultures are filamentous heterosystous and filamentous non-heterosystous type. Ahmed & Kalita (2002) recorded abundance of unicellular chroococcalean forms in paddy fields. They isolated 53 chroococcalean forms from paddy fields of Nagaon. Our observations differ from them, we did not find abundance of chroococcalean forms in the field, only paddy field soil cultures showed their presence and especially when cultures become old. Cyanobacterial distribution pattern from paddy field soils of Konkan region, Maharashtra has been studied by Sardeshpande & Goyal (1981). Roger & Reynaud (1979) reported luxuriant growth of blue green algae from rice fields of Japan. Mukhopadhyay & Chatterjee (1980) published a checklist of paddy field blue green algae from West Bengal. Nitrogen fixing potential in rice fields of Sri Lanka studied by Kulasooriya & De Silva (1978). Cyanobacterial taxa from Tripura was studied by Singh et al. (1997). Aerobic growth and nitrogenase activity of marine unicellular blue green alga *Synechococcus* was reported by Duerr & Mitsui (1980). Dhanya & Ray (2015) studied cyanobacterial diversity and ecology from Kuttanadu paddy wetlands of Kerala. Prasad & Prasad (2003) showed increase in rice yield up to 5–24 % by applying cyano-biofertilizers in paddy fields of Nepal. A large variety of cyanobacterial species fix nitrogen and their importance to improve soil fertility for sustainable agriculture in submerged and irrigated rice cultivation is well recognized by Saikia & Bordoloi (1994). The great majority of cyanobacteria that fixed atmospheric nitrogen were probably heterocystous (Rodrigo & Eberto 2007), however non-heterocystous unicellular cyanobacteria also fixed atmospheric nitrogen (Wyatt & Silvery 1969). Aerobic nitrogen fixation without heterocyst was studied by Carpenter & Price (1976) in Marine *Oscillatoria* (*Trichodesmium* species). In our study area we found high diversity of *Gloeocapsa* species and dominance of *Chlorogloea* species which could serve as the best nitrogen fertilizer for paddy. Our observations differed with those proposed by Chudhary (2009) that members of Chroococcaceae are dominant in paddy fields. We found least abundance of chroococcaceae members in field condition as well as in culture condition. Majority taxa recorded was filamentous type. Algae stabilize the surface layer of soil, prevent soil erosion, improve infiltration of water, produce organic matter in the soil by death and decay of algae & hence increase soil fertility (Dawes 1998). Thus the role of unicellular blue green algae in nitrogen economy of paddy fields is recorded by many studies all over the world. Culture study of these unicellular taxa showed that the rate of survival and N_2 fixing capacity of chroococcaceae members, viz., *Gloeocapsa, Oscillatoria* (*Trichodesmium* species & *Synechococcus* is more (Wyatt & Silvery 1969; Carpenter & Price 1976; Duerr & Mitsui 1980). Therefore taxonomic documentation of unicellular blue green algae will provide the knowledge about such sturdy and durable indigenous species of chroococcalean blue green algae which will help in development of niche specific inoculants as biofertilizers for rice fields in the study region

CONCLUSION

The present study showed diversity and dominance of chroococcalean blue green algae. Overall the data obtained by thorough screening of paddy field soils indicates the dominance of heterocystous filamentous taxa followed by non-heterocystous taxa; besides these unicellular taxa also showed diversity and abundance of taxa from paddy soil cultures of study region. Study reports also showed beneficial role of many unicellular blue green algae in nitrogen economy of paddy soil. Our study area showed genus *Gloeocapsa* with high species diversity (21.42%) followed by *Chroococcus*, *Aphanothece* & *Gloeothece* from family Chroococcaceae & species dominance with *Chlorogloea* followed by *Microsystis*, *Chroococcus* & *Gloeothece* from family Entophysalidaceae. This survey on chroococcalean blue green algae will help in developing niche specific inoculum of indigenous species of the study area. These local strains should be cultured on a large scale for their mass production which would serve the best and low cost biofertilizer especially for paddy fields.

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Journal of Threatened Taxa

www.threatenedtaxa.org

PLATINUM OPEN ACCESS

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

October 2020 | Vol. 12 | No. 14 | Pages: 16927–17062
Date of Publication: 26 October 2020 (Online & Print)
DOI: 10.11609/jott.2020.12.14.16927-17062

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