

FILAMENTOUS CYANOBACTERIA FROM WESTERN GHATS OF NORTH KERALA, INDIA

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Abstract

Cyanobacteria are Gram negative, photosynthetic and nitrogen fixing microorganisms which contribute much to our present-day life as medicines, foods, biofuels and biofertilizers. Western Ghats are the hotspots of biodiversity with rich combination of microbial flora including cyanobacteria. Though cosmopolitan in distribution, their abundance in tropical forests are not fully exploited. To fill up this knowledge gap, the present research was carried out on the cyanobacterial flora of Peruvannamuzhi forest and Janaki forests of Western Ghats in Kozhikode District, North Kerala State, India. Extensive specimen collections were conducted during South-West monsoon (June to September) and North-East monsoon (October to December) in the year 2019. The highest diversity of cyanobacteria was found on rock surfaces. A total of 18 cyanobacterial taxa were identified. Among them filamentous heterocystous forms showed maximum diversity with 10 species followed by non- heterocystous forms with 8 species. The highest number of cyanobacteria were identified from Peruvannamuzhi forest with 15 taxa followed by Janaki forest with 3 taxa. The non- heterocystous cyanobacterial genus *Oscillatoria* Voucher *ex* Gomont showed maximum abundance with 4 species. In this study we reported *Planktothrix planktonica* (Elenkin) Agagnostidis & Komárek 1988, *Oscillatoria euboica* Agagnostidis 2001 and *Nostoc interbryum* Sant' Anna *et al.* 2007 as three new records from India.

Introduction

Cyanobacteria are morphologically distinct group of Gram negative, photosynthetic and nitrogen fixing microorganisms. They are believed to evolve during Proterozoic Era between 2.5 and 3.5 billion years ago commonly known as the Age of Cyanobacteria (Hoek *et al.*, 1993) and these prokaryotes made our planet earth oxygenic (Gupta *et al.*, 2006). They have constituted the most diverse group of organisms in Plant Kingdom. They are ubiquitous and highly versatile to grow in various climatic conditions such as freshwater, marine, hot springs, polar deserts, epilithic, epipelagic, epiphytic, endophytic, halophytic and thermophilic conditions (Halder, 2015, 2016). Cyanobacteria are economically important because of their ability to fix atmospheric nitrogen and are used as biofertilizers (Mishra and Pabby 2004). Besides, it excretes various secondary metabolites and bioactive compounds which are useful in various industries such as pharmaceuticals, biofuels, cosmetics, etc. Being rich in phycobiliproteins they are used as natural colorants (Pandey *et al.*, 2013).

Tropical India provides favourable environments for the luxuriant growth of cyanobacteria in her natural ecosystems (Thajuddin *et al.*, 2002; Chellappa *et al.*, 2004). So far, the cyanobacteria of India have been studied by various workers such as Chakraborty *et al.* (2010), Naskar *et al.* (2008), Keshri and Chatterjee (2010), Ansari *et al.* (2012), Bhosale and Dhupal (2012), Tiwari

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and Chauhan (2006, 2008), Dhingra and Ahluwalia (2007a,b), Gupta (2012), Halder and Sinha (2013), Dey (2012), Roy *et al.* (2014a,b) and Datta and Keshri (2014).

The Western Ghats of India are one of the richest biodiversity hotspot in the world. Western Ghats supports a vast vegetation including 7400 species of flowering plants, 493 species of bryophytes, 320 species of ferns and 750 species of fungi. But for cyanobacterial flora, it is believed that the area is least explored and as a result many cyanobacterial taxa remains undiscovered. To fulfil this knowledge gaps, the present research was undertaken to explore the diversity of filamentous cyanobacteria in Peruvannamuzhi forest range of Western Ghats region.

Materials and Methods

The study was conducted in Peruvannamuzhi forest and Janaki forest of Western Ghats located in Kozhikode District, Kerala state, India. This area is a part of Malabar Wild life Sanctuary and this region stretches between 11.5966° N and 75.8232° E covering an area of 74.215015 km².

Extensive specimen collection trips were conducted during South-West monsoon (June to September) and North-East monsoon (October to December) in 2019. All specimens were collected using forceps, knife, scalpels, needles, for the habitats like the surfaces of rock, soil, tree bark, etc. For the water bodies or moistened parts plastic bottles were used. All the field observations on habit, habitat and soil pH were noted in the field book at the time of collection. Sub-samples from the collected specimens were carefully examined under compound microscope (Model-Leica DM 1000 Compound Microscope, Germany). All studied specimens were cultured in BG-11 medium (Rippka *et al.* 1979). A part of the cultured specimen was preserved in 4% commercial formaldehyde and deposited in the culture collection at Cyanobacterial Diversity Division, University of Calicut, India.

Classification of cyanobacteria by Komarek *et al.*, (2014) was followed in the present study. Based on cellular morphology, the cyanobacterial individuals were identified up to the species or genus level consulting monographs and floras of Desikachary (1959), Anand (1989), John and Francis (2013) and Komárek and Anagnostidis (2005).

Results and Discussion

In the present investigation, a total of 18 taxa of filamentous cyanobacteria belonging to the orders Oscillatoriales and Nostocales were recorded. The detailed taxonomic description of those have been given below.

Division: Cyanophyta; Class: Cyanophyceae; Order: Oscillatoriales
Family: Microcoleaceae; Genus: Microcoleus Desmazières *ex* Gomont

1. *Planktothrix planctonica* (Elenkin) Anagnostidis *et* Komárek (Fig. 1A)
 (Anagnostidis & Komarek in Archiv für Hydrobiologie, 80, 416, 1988; Dey *et al.* in Flora of Australia Supplementary Series 4: i-vii, 1-276, 1995)

Filaments blue green, slightly waved; cells 7.4 – 8.2 µm wide, 2.2 – 3.8 µm long, shorter than broad, slightly or not constricted at cross walls; apical cells widely rounded, 3.0 – 5.2 µm long, 7 µm broad; granules present; sheath absent.

Ecology: Attached scum on stone in stream.

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India: 13 Sep 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut, CU No: 158535

Distribution: Kerala, Peruvannamuzhi forest, India; The Netherlands, Romania, Czech Republic; Russia, Tajikistan; South Australia; Pacific Islands; Hawaiian Islands.

Comment: The species has been reported as a first record in India

Family: Oscillatoriaceae; Genus: Oscillatoria Vaucher *ex* Gomont

2. Oscillatoria princeps Vaucher *ex* Gomont (Fig. 1B)

(Vaucher, *Historie des conferves d' eau douce*, 190, pl. 15, fig. 2, 1803; Gomont, *Monogr. Oscillatores*, 206, pl. fig. 9, 1892; Forti in De Toni, *Sylloge Algarum*, 5 : 150, 1907; Frey, *Myxo. d' Afr. Equat. Franc.*, 208, fig. 175, 1929; Geitler, *Kryptogamenflora*, 947, figs. 598a, 601-cg 1932)

Trichome blue green to dark green, straight, not constricted at cross walls, 12.2 - 14.5 μm broad, 2.9–3.5 μm long; end cell flatly rounded or hemispherical, pale yellow, 3.3 μm long; granules present; necridia present.

Ecology: Attached to stone.

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India: 21 Nov 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut, CU No: 158535 .

Distribution: Kerala, Peruvannamuzhi forest, India; The Baltic Sea, Black Sea, Britain, Czech Republic, France, Georgia, Germany, Greece, Ireland, Lithuania, Netherlands, Romania, Scandinavia, Slovakia, Spain; Atlantic Islands: Canary Islands;: Arkansas, Florida, Great Lakes, Mexico, Northwest Territories, Québec; Caribbean Islands: Cuba; Argentina, Brazil; Africa: Ghana, Mozambique, Sierra Leone, Sudan, Mauritius, Bangladesh, India, Iraq, Israel, Kuwait, Pakistan, Punjab, Saudi Arabia, Sri Lanka, China, Japan, Korea, Nepal, Russia, South China Sea, Taiwan, Tajikistan, Thailand, Vietnam, Australia, New Zealand

3. Oscillatoria subbrevis Schmidle (Fig. 1C)

(Engler's *Bot. Jahrb.*, 30, pl. IV [4], fig. 7, 243, 1901; Forti in De Toni, *Sylloge Algarum*, 5, fig. 174, 208, 1907; Frey in *Myxo. d' Afr. Equat. Franc.*, fig. 174, 208, 1929; Geitler in *Kryptogamenflora*, fig. 601b, 949, 1932; Desikachary in *Cyanophyta*, pl. 37, fig. 2, pl. 40, fig 1, 207, 1959)

Filaments greenish brown, without sheath 10.3 – 11.9 μm broad, with sheath 11.9 μm broad; trichome 1.3 – 1.9 μm long, 7.9 μm broad, greenish brown; end cell rounded, pale yellow, 2.7 – 4 μm long, 7.9 μm broad; sheath colourless, 0.89 μm thick.

Ecology: Attached scum on stone.

Specimen examined: Kozhikode District, Janaki forest, Kerala, India: 21 Jan 2019, V. Geethu, Cyanobacterial Diversity Division, University of Calicut, CU No: 167110.

Distribution: Kerala, Janaki forest, India, Britain, Greece, The Netherlands, Romania, Spain, Argentina, Brazil; Africa: Sierra Leone, Sudan, Bangladesh, India, Iran, China, Japan, Korea, Nepal, Singapore, Australia, The New Zealand.

4. Oscillatoria euboeica Anagnostidis (Fig. 1D)

(Anagnostidis in *Preslia*, Praha 73: 359 – 375, 2001; Temraleeva in *Microbiology*, 87: 2, tab, 251, 2018)

Filaments light green, 8.2 – 9.2 μm broad; cells short, 3.5 – 4.1 μm long, apex curved, constrictions absent; apical cell rounded, pale yellow 3.2 μm long, 6.4 μm broad; sheath absent ; granules present.

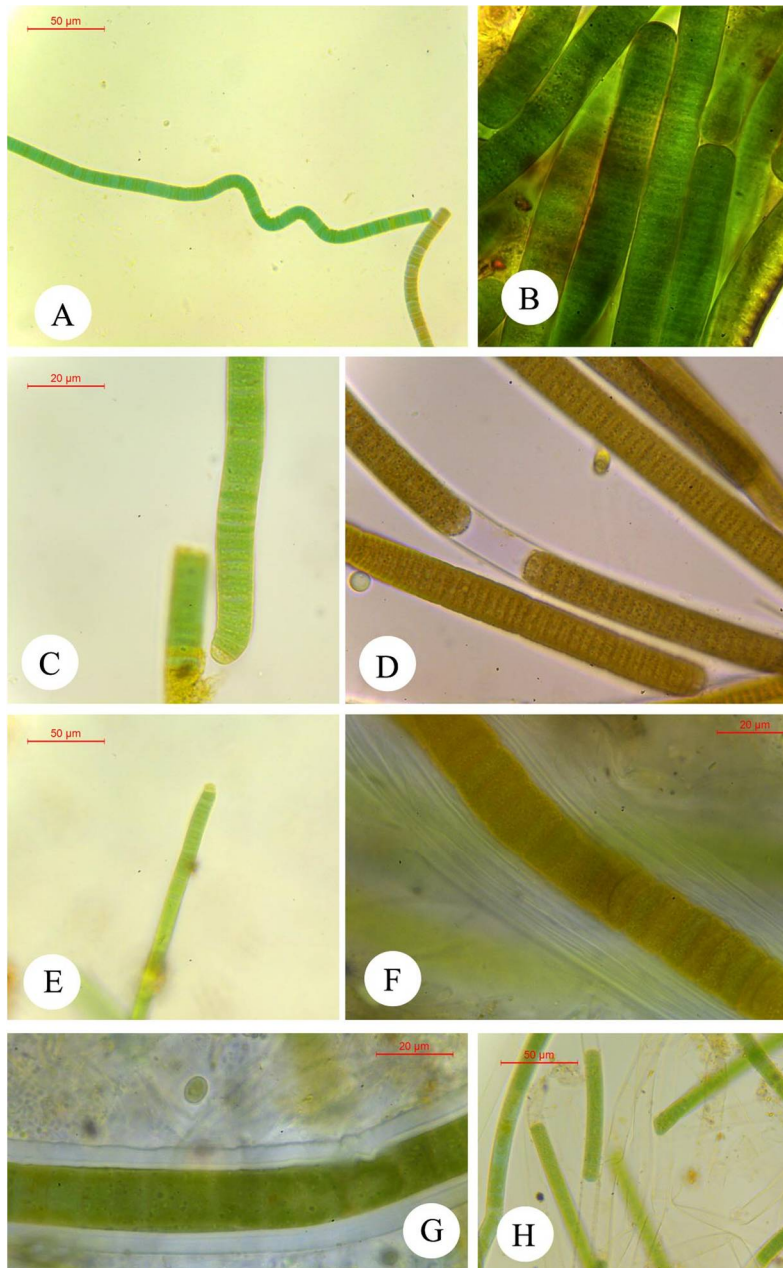


Fig. 1. A. *Planktothrix planctonica*, B. *Oscillatoria princeps*, C. *O. subbrevis*, D. *O. euboica*, E. *O. limosa*, F. *Lyngbya majuscula*, G. *L. subconfervoides*, H. *Phormidium retzi* var. major.

Ecology: Attached to soil.

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India: 13 Sep 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut, CU No: 158537.

Distribution: Kerala, Peruvannamuzhi forest, India.

Comment: The species has been reported as a first record in India.

5. *Oscillatoria limosa* Agardh. ex Gomont (Fig. 1E)

(Agardh, *Dispositio Algarum Sueciae*, 35, 1812; Gomont, *Mongr. Oscillatores*, 210, pl. 6, fig. 13, 1892; Forti in De Toni, *Sylloge Algarum*, 5 : 154, 1907)

Filaments straight, light green; trichome not constricted at cross wall, 9.6 μm broad, 2 – 2.5 μm long; granules present; end cell flatly rounded, pale yellow in colour.

Ecology: Attached to stone.

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India: 21 Nov 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut, CU No: 158537.

Distribution: Kerala, Peruvannamuzhi forest, India, Svalbard, Baltic Sea, Britain, Channel Islands, Czech Republic, France, Georgia, Germany, Greece, Italy, Lithuania, Norway, Poland, Romania, Russia, Scandinavia, Slovakia, Spain, Sweden, Ukraine, Arkansas Great Lakes, Mexico, Northwest Territories, Québec, Tennessee, Caribbean Islands, Cuba, Argentina, Brazil, Africa, Egypt, South Africa, Sudan, Bangladesh, India, Iraq, Israel, Saudi Arabia, Caspian Sea, China, Japan, Korea, Nepal, Tajikistan, Vietnam; Australia, The New Zealand, Australia, Pacific Islands, , Singapore.

6. *Lyngbya majuscula* Harvey ex Gomont (Fig. 1F)

(Harvey in Hooker, *English Flora*, 5, Part 1: 370, 1833; Gomont, *Monogr. Oscillatores*, 151, pl. 3, fig. 3, 4, 1892; Forti in De Toni, *Sylloge Algarum*, 5: 268, 1907)

Filaments yellowish green, 46 μm broad; cells 16 μm broad, 4 – 6 μm long; sheath thick, colourless, lamellated, 11.5 – 12.9 μm in thick; granules present.

Ecology: Attached to stone on the stream

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India: 21 Nov 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut CU No 167101.

Distribution: Peruvannamuzhi forest, Kerala, India; Baltic Sea, Britain, Channel Islands, France, France (Breizh), Greece, Ireland, Romania, Russia, Scandinavia, Spain, Canary Islands, Florida, Isla Guadalupe, Mexico, Brazil, Colombia, Venezuela, Djibouti, Egypt, Eritrea, Ethiopia, Kenya, Madagascar, Mauritius, Mediterranean Sea, Mozambique, South Africa, Sudan, Tanzania, Indian Ocean Islands, Aldabra Islands, Chagos Archipelago, Comoros and Mayotte, Laccadive Islands, Maldives, Réunion, Rodrigues; South-west Asia: Bangladesh, India, Iran, Iraq, Kuwait, Pakistan, Saudi Arabia, Sri Lanka, Turkey, Yemen, China, Japan, Korea, Nepal, South China Sea, Taiwan, Indonesia, Malaysia, Philippines, Singapore, Vietnam, Australia, The New Zealand, Central Polynesia, Federated States of Micronesia, French Polynesia, Guam, Hawaiian Islands (HI), Line Islands, Mariana Islands, Marshall Islands, Northwestern Hawaiian Islands, Republic of Palau.

7. *Lyngbya subconfervoides* Borge (Fig. 1G)

(Die von Dr. Loefgren in Sao Paulo gessammelte Susswasseralgen, *Ark. F. Bot.* 15(13) : 91, pl. 7, fig. 6, 1918; Geitler, *Kryptogamenflora*, 1067, fig. 681, 1932; Desikachary in *Cyanophyta*, 321, 1959)

Filaments long, straight, 26.6 – 35.0 μm broad, bluish green, not constricted at cross wall, cross walls not granulated, 16.5 μm broad, 6.1 – 7.3 μm long; end cell rounded; sheath thick, colourless, unlamellated, 5.6 μm thick; calyptra absent.

Ecology: Attached to stones on stream

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India: 21 Nov 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut CU No: 167101.

Distribution: Kerala, Peruvannamuzhi forest, India; China, Japan.

8. Phormidium retzi var. major Kützing ex Gomont **(Fig. 1H)**

(Myxophyceae of Travancore State, Proc. Indian Acad. Sci. B, 11 : 122, 1940; Desikachary in Cyanophyta, 268, 1959; Yadhav *et al.* in Asian J. Environ. Sci., 7: 2, tab. 1, 256, 2012)

Filaments dull blue green, more or less straight, unconstructed at the cross walls, 9.9 – 10.3 µm broad; trichome shorter than broad, 9.7 – 10 µm broad, 6.4 – 7.2 µm long; septa not granulated; end cell rounded; sheath extension present, sheath, colourless, unlamellated

Ecology: Seen on soil

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India: 21 Nov 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut CU No: 158537.

Distribution: Kerala, Peruvannamuzhi forest, India.

Division : Cyanophyta; Class: Cyanophyceae; Order: Nostocales

Family: Scytonemataceae; Genus :Scytonema C.Agardh *ex* É.Bornet *et* C.Flahault

9. Scytonema pascheri Bharadwaja **(Fig. 2A)**

(Desikachary in *Cyanophyta*. pp. i-x, 1-686, pls 1-139. New Delhi: Indian Council of Agricultural Research, 1959)

Filaments brown, 19–22.8 µm broad; cells quadrate, 17 – 21.5 µm long, 12 – 14 µm broad; heterocyst intercalary, rounded, 11.8 µm long, 12.7µm broad; sheath yellowish brown, lamellated, 2.25–4.3 µm in thickness; granules present.

Ecology: Attached scum on stone

Specimen examined: Kozhikode District, Chembanoda, Kerala, India: 17 Mar 2019, V. Geethu, Cyanobacterial Diversity Division, University of Calicut CU No: 167126.

Distribution: Kerala, Peruvannamuzhi forest, India; China, Bangladesh

Family: Rivulariaceae; Genus: Rivularia C.Agardh *ex* Bornet *et* Flahault

10. Microchaete investiens Frey **(Fig. 2B)**

(Frey in Archives de Botanique, Memoires, 3: 2, fig. 249, 283, 1930; Hirose *et al.* in Illustrations of Japanese fresh water algae, 1-933, 1977)

Filaments long, brown, 6.1–8.1 µm broad; cells elongated, cylindrical or barrel shaped, 5.7–8.1 µm broad, 6.5 – 11 µm long; heterocyst basal or intercalary, 4–6.3 µm long, 5.6–11 µm broad; granules present; sheath colourless to yellowish, 0.94 µm in thickness.

Ecology: Attached scum on stone

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India: 13 Sep 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut, CU No: 158537.

Distribution: Kerala, Peruvannamuzhi forest, India; Japan

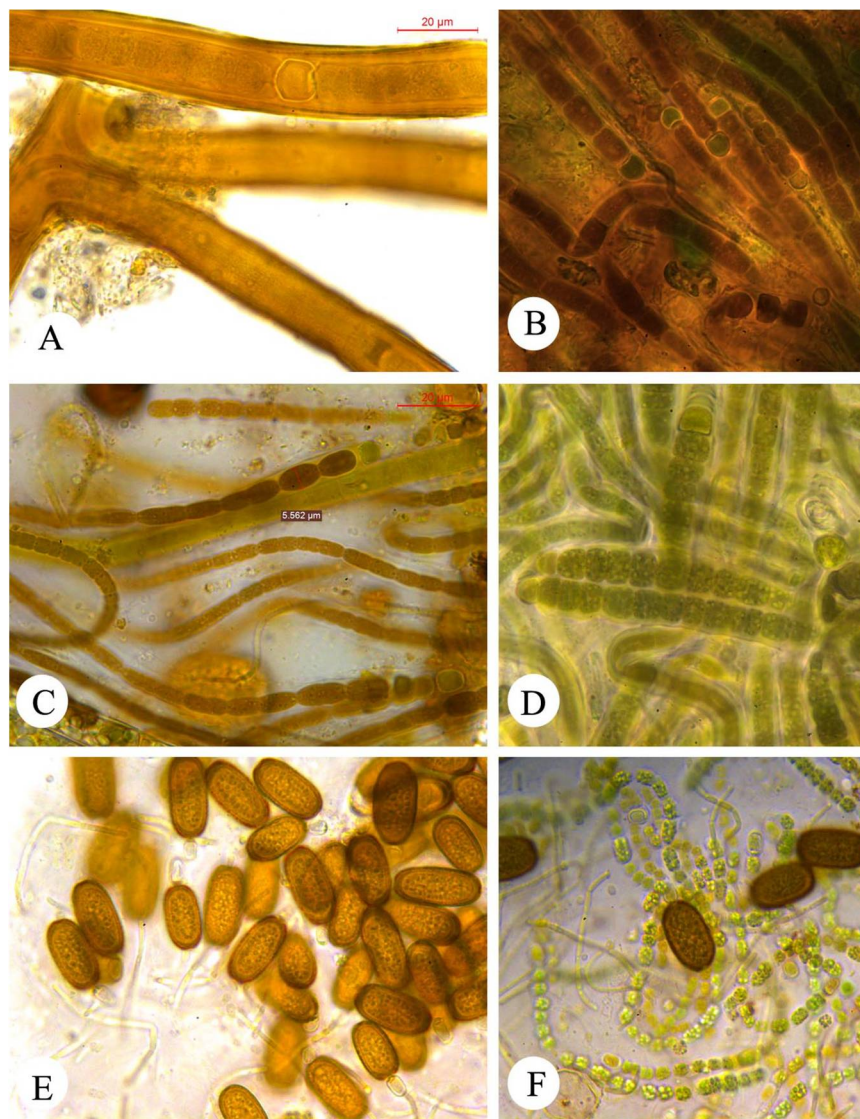


Fig. 2. A. *Scytonema pascheri*, B. *Microchaete investiens*, C. *Microchaete* species 1, D. *Microchaete* species 2, E,F. *Cylandrospermum muscicola*.

11. *Microchaete* species 1

(Fig. 2C)

Filaments long, 9.8 µm broad; trichome olive green, barrel shape, 3.5 – 7 µm long, 5.8 – 7.8 µm broad, broader than long towards the base; heterocyst basal, 4.8 – 6.5 µm long, 5.5 – 6.7 µm broad; sheath colourless, 1.72 µm thick, slightly lamellated; granules prominent.

Ecology: Attached scum on stone

Specimen examined: Kozhikode District, Chembanoda, Kerala, India: 11 Mar 2019, V. Geethu, Cyanobacterial Diversity Division, University of Calicut, CU No: 167121.

12. Microchaete species 2 (Fig. 2D)

Filaments straight or coiled, brown coloured, tip of the filament is rounded; trichome 6.1–6.8 μm broad; cells elongated and cylindrical, 3.6–16 μm long, 4–3 μm broad; heterocysts spherical to hemispherical, basal or intercalary, sometimes 2–3 heterocysts comes together, 5.3–6.0 μm long, 6.0–7.2 μm broad; sheath firm, thin, hyaline, unlamellated, close to the trichome; granules present.

Ecology: Attached scum on stone

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India: 13 Sep 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut, CU No: 158537.

Family: Nostocaceae; Genus: Cyindrospermum Kützing *ex* É. Bornet *et* C. Flahault

13. Cyindrospermum muscicola Kützing *ex* Bornet *et* Flahault (Fig. 2E,F)

(Kützing in Phyc. germ., 173, 1845, Tab. Phycologie, 1, 53, pl. 98, fig. 1, 1849; Bornet *et* Flahault in Revision des Nostocacees heterocystees, 254, 1888; Forti in De Toni, Sylloge Algarum, 5, 477, 1907)

Trichome green, cylindrical or quadrate, 3–5 μm long, 3 μm broad; heterocyst terminal, yellow, 3.2–5 μm long, 4–4 μm broad; granules present; akinete dark brown, 15–21 μm long, 8–10 μm broad; sheath absent.

Ecology: Seen on soil

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India : 21 Jan 2019, V. Geethu, Cyanobacterial Diversity Division, University of Calicut, CU No: 167109.

Distribution: Kerala, Peruvannamuzhi forest, India; Britain, Czech Republic, Germany, Greece, Romania, Russia, Slovakia, Spain; North America, Arkansas, Cuba; South America: Argentina, Brazil, Sudan, Bangladesh, India, Iraq, Israel, Pakistan, China, Tajikistan, Japan, Russia, Pacific

14. Desmonostoc muscorum (Agardh *ex* Bornet *et* Flahault) Hrouzek *et* Ventura (Fig. 3A)

(Hrouzek *et al.* in Fottea, Olomouc, 13:(2), 211, 2013; Whitton *et al.* in A coded list of freshwater algae of the British Isles, 2nd edn, 2003)

Trichome irregularly flexous, green; cells barrel shaped, granulated, 4.7 μm broad, 4.6 – 6.3 μm long; heterocyst rounded or hemispherical, pale green, terminal or intercalary, 4.3 – 5 μm long, 3.5 – 4.3 μm broad; akinetes oval, 8 – 12 $\mu\text{m} \times 4 – 8 \mu\text{m}$.

Ecology: Seen on soil

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India: 21 Nov 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut CU No: 167103.

Distribution: Kerala, Peruvannamuzhi forest, India; Romania, Russia, Britain, Czech Republic, France, Ireland, Scandinavia, Slovakia, Spain, Israel, America, Argentina, Brazil, Bangladesh, India, Iraq, Pakistan, Japan, Nepal, Taiwan, Australia, The New Zealand, Ghana, Sudan.

15. Desmonostoc sp. (Fig. 3B)

Trichome yellowish green, rounded, enclosed in a sheath, 5 – 8.3 μm long, 5 – 7 μm broad; heterocyst intercalary, elongated or oval, yellow, 7 – 11.5 μm long, 6 – 7 μm broad; sheath hyaline, colourless, 2 – 2.5 μm thick.

Ecology: Attached to stone.

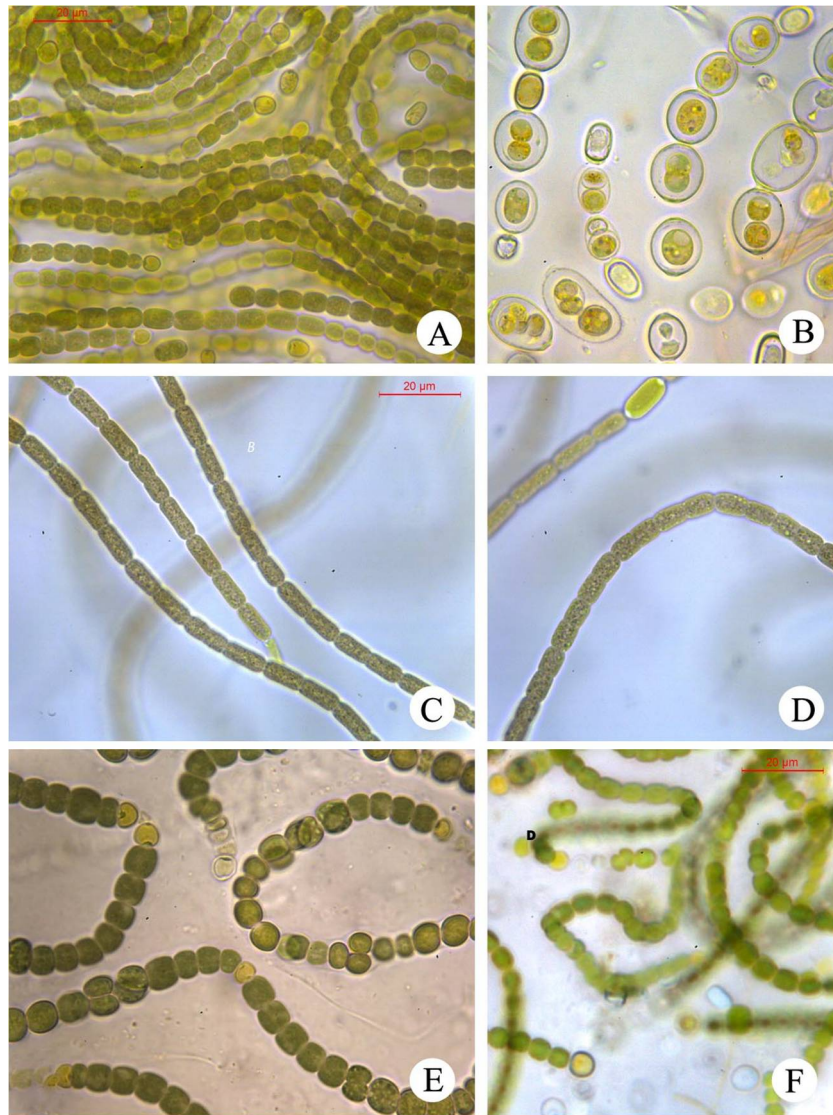


Fig. 3 A. *Desmonostoc muscorum*, B. *Desmonostoc* sp., C-D. *Nostoc nylstromicum*, E. *N. commune*, F. *N. interbryum*.

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, india: 21 Nove 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut, CU No: 167106.

16. *Nostoc commune* Vaucher ex Bornet et Flahault

(Fig. 3E)

Vaucher in *Historie des Conferves d' eau douce*, pl. 16, fig. 1, 222, 1803; Bornet et flahault in *Revision des Nostocacees heterocystees*, 203, 1888; Forti in De Toni, *Sylloge Algarum*, 5, 404, 1907

Colonies macroscopic, gelatinous; trichome olive green; cells spherical or barrel shaped, 6.2 – 7.8 μm long, 6 – 8 μm broad; heterocyst yellow, intercalary or terminal, intercalary ones spherical shaped, terminal one hemispherical, 5 – 7.2 μm broad, 3.8 – 6.5 μm long; granules absent.

Ecology: Attached to stone

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India: 13 Sep 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut, CU No: 158539.

Distribution: Kerala, Peruvannamuzhi forest, India, Arctic, Ellesmere Island, Russia, Britain, Czech Republic, France, Georgia, Germany, Greece, Ireland, Italy, Lithuania, Romania,, Scandinavia, Slovakia, Spain, , Turkey , Alaska , Arkansas, Argentina, Ghana, Indian Ocean Islands, Rodrigues Island, Bangladesh, India, Iraq, Israel, Pakistan, Sri Lanka, Japan, Korea, Nepal, Russia Singapore, Vietnam, Australia and The New Zealand, Australia

17. *Nostoc nylstromicum* Classenn (Fig. 3C,D)

(Claassen in Bothalia, 7: 3, pl. 2, fig. 2, 563, 1961; Komárek in Susswasserflora von Mitteleuropa, Vol. 19 pp. i-xviii, 1-1130, 2013)

Filaments yellowish brown; cells barrel or cylindrical, 2.3 μm broad, 2.8 – 3.6 μm long; heterocyst terminal, pale yellow in colour, 3.7 μm long, 2.6 μm broad.

Ecology: Attached to stone.

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India: 21 Nov 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut, CU No : 167103.

Distribution: Kerala, Peruvannamuzhi forest, India.

Comment: The species has been reported as a first record in India.

18. *Nostoc interbryum* Sant'Anna *et al.* (Fig. 3F)

(Anna *et al.* in Hoehnea, 34:1, fig. 1, 96, 2007; Werner in Catálogo de plantas e fungos do Brasil, 1, pp. 356-366, 2010; Komarek in Susswasserflora von Mitteleuropa. Cyanoprokaryota: 3rd part: heterocystous genera, 19, pp. i-xviii, 1-1130, 2013)

Filaments flexous, dark green; cells 4.6 – 5.2 μm broad, 5 μm long, rounded or spherical; heterocyst terminal, spherical, pale yellow, 5 – 5.5 μm long , 4.5 – 5.6 μm broad.

Ecology: Attached to soil.

Specimen examined: Kozhikode District, Peruvannamuzhi forest, Kerala, India: 21 Nov 2018, V. Geethu, Cyanobacterial Diversity Division, University of Calicut, CU No: 167103.

Distribution: Kerala, Peruvannamuzhi forest, India.

Comment: The species has been reported as a first record in India.

During the present study of filamentous cyanobacteria in Peruvannamuzhi forest and Janaki forest of Western Ghats, a total of 18 species belonging to 9 genera distributed in 4 families such as Oscillatoriaceae, Scytonemataceae, Microchaetaceae, Nostocaceae under 2 orders such as Oscillatoriales and Nostocales were identified. The diversity of filamentous cyanobacteria in this area is very high. Both heterocystous and non- heterocystous forms were equally dominating in this region were noticed in this study. About 10 heterocystous species under 5 genera were identified followed by 8 non-heterocystous species under 4 genera. They were found in aquatic, terrestrial and lithophytic habitats. But most of the sampling were done from rocky habitats. They are luxuriantly flourishing in these tropical forest because the litter as well as the alkaline pH of the soil greatly influences its abundance and diversity. In place like Kerala, the rainfall is always there around nine months in a year. This also greatly influence in the existence of these microorganisms under undisturbed evergreen forest of Western Ghats. Several studies were

conducted about the tropical cyanobacteria and contributed much from Amazon forest of Brazil by Sant'Anna *et al.* (1991, 2007) and Branco *et al.* (2009)

Among heterocystous forms, the cyanobacterial genera *Nostoc* and *Microchaete* showed maximum abundance with 3 species each, followed by *Desmonostoc* with 2 species. The heterocystous genera, *Cylindrospermum* and *Scytonema* were represented by single species each and showed least abundance in the study area. Among non- heterocystous forms, the genus *Oscillatoria* showed maximum species richness with 4 species followed by *Lyngbya* with 2 species. The genera *Planktothrix* and *Phormidium* showed least abundance represented by single species each (*Planktothrix planktonica* and *Phormidium retzi*).

According to the present study diversity of filamentous forms were more in Peruvannamuzhi forest as compared to Janaki forest. About 15 taxa of cyanobacteria under 8 genera were identified from Peruvannamuzhi forest and 3 cyanobacterial taxa were identified from Janaki forest. Among 18 taxa 14 cyanobacterial taxa were identified up to species level the remaining 4 taxa were identified up to genus level. The species richness is very high in tropical forests such as Western Ghats. There are reports on cyanobacteria of Western Ghats of Maharashtra by Nikam *et al.* (2013), Many species found in this study were also distributed in other parts of the world. The cyanobacteria are highly adapted to these regions because they occur as thick leathery sheaths or mucilaginous masses which protects it from desiccation is also considered as an adaptation to this prokaryotic organisms.

Conclusion

The cyanobacterial taxonomy has been changing from time to time. Due to its microscopic and plasticity in its morphology it is very difficult in its identification, but owing to its varied application in many industries it is important to find out the undiscovered taxa especially from tropical forest because they are the biodiversity hotspots. In the present study we recorded eighteen cyanobacterial taxa out of which three taxa (*Planktothrix planktonica*, *Oscillatoria euboica* and *Nostoc interbryum* are new to India). This study also helps to understand the geographical distribution as well as the type of habitat which will be beneficial for the further exploration of these organisms.

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Author contribution

M. S. designed the research. G.V. contributed to data acquisition and collection. G.V. and M.S. analyzed and interpreted the results. G.V. and M.S. led the writing. Both authors revised and approved the manuscript.

Additional information

The authors declare no competing financial interests.

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