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Diversity and Phylogenetic Relationships of *Cylindrospermum* Species from the Aquatic and Semi-Aquatic Habitats of Meerut, Western Uttar Pradesh, Bharat

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ABSTRACT

The present paper dealt with diversity of the genus *Cylindrospermum* from different aquatic and semi aquatic habitats of Meerut and adjoining areas of Western Uttar Pradesh, Bharat. *Cylindrospermum* is a genus of heterocystous cyanobacterium. The species of the *Cylindrospermum* occur periodically in aquatic and semi-aquatic habitats including flooded paddy fields. In the present investigation, a total of 23 taxa belonging twenty species, two varieties and one forma of the genus *Cylindrospermum* from three different aquatic and semi aquatic regimes along with their distribution pattern and species diversity in three different sites, are reported. Additionally, in the present communication, the phylogenetic relationship, arrangement of the hierarchical clusters, dendrogram using Ward Linkage Euclidean Distance Proximity matrix, Pearson correlation linear relationship and cross-correlation coefficient of 23 taxa of *Cylindrospermum* including *C. ecballisporum*, *C. dobrudjense*, *C. licheniforme*, *C. bourrellyi*, *C. muscicola* var. *kashmiriense*, *C. muscicola* var. *variabilis*, *C. desikacharyi*, *C. identatum*, *C. pellucidum*, *C. minutissimum*, *C. majus*, *C. stagnale* f. *variablis*, *C. kazachstanicum*, *C. gregarium*, *C. breve*, *C. stagnale*, *C. michailovskoense*, *C. skujae*, *C. longisporum*, *C. voukii*, *C. alatosporum*, *C. marichicum* and *C. rectangularis* from Meerut and adjoining area, were reported. Phylogenetic relationship on the basis of morphological characters indicated the formation of two major and seven minor groups. Hierarchical clusters analyses illustrated the arrangement of the clusters while dendrogram using Ward Linkage formed two clusters I and II. Based on Pearson's correlation linear relationship, morphological characters showed both positive and negative relationship while Euclidean Distance Proximity Matrix reveals how close the characters are to each other.

INTRODUCTION

Cyanobacteria (Blue-green algae/ Cyanoprokaryotes) are impressive ecosystem engineers with an evolutionary history stretching back at least 2.15 billion years **(Hayes *et al*., 2007; Rasmussen *et al*., 2008)**. They are often referred to as 'miniature factories' of the biological world and represent an alternative source of a variety of bioactive compounds, lipids, fatty acids, proteins, enzymes, pigments, polysaccharides, compounds of pharmaceutical and nutraceutical value **(Schaeffer & Krylov, 2000; Rastogi & Sinha, 2009; Gauri *et al*., 2024; Deepti *et al*., 2025)**.

According to **Castenholz (1989)** and **Komárek and Anagnostidis (1989)**, the order Nostocales includes filamentous cyanobacteria that are capable of cell differentiation in heterocysts, akinetes or reproductive trichomes (hormogonia). The genera *Anabaena, Aphanizomenon, Cylindrospermum* and *Nostoc* belong to the family Nostocaceae by traditional classification and subsection IV according to bacteriological classification **(Rippka *et al*., 1979; Castenholz, 1989; Komárek & Anagnostidis, 1989; Komárek, 2010)**. This family is characterized morphologically by (i) isopolar filaments, (ii) absence of any branching (with the exception of certain anomalies), (iii) presence of heterocysts (with the exception of secondary derived genotypes) and (iv) facultative presence of typical para-heterocytic or apo-heterocytic akinetes **(Komárek, 2010)**.

The genus *Cylindrospermum* Kutzing ex Bornet et Flahault is a filamentous, unbranched and heterocystous cyanoprokaryote (cyanobacterium), and well known for its biological applications for different purposes. They have tremendous potential in environmental management as soil conditioner, biofertilizer, biomonitors of soil fertility, water quality, feed for animals and protein supplements **(Whitton & Pots, 2000)**. The genus *Cylindrospermum* has nitrogenase enzyme and capable of fixing atmospheric nitrogen and make it available to the plants thus playing a significant role in ecosystem. The members of the genus *Cylindrospermum* are well known for their application as biofertilizer to maintain and improve soil health status **(Ahmed, 2001)**. This genus is often found associated with damp soils, but also occurs in periodically flooded soils (such as rice paddies) and some species have even been reported to be present in permanent aquatic habitats **(Singh *et al*., 1980, Cronberg 2003)**.

The present study focused on the biodiversity of the genus *Cylindrospermum* across various aquatic and semi-aquatic habitats in Meerut and its adjoining areas. A total of 23 species of *Cylindrospermum* were recorded from three different habitat types, along with their distribution patterns and species diversity across different sites. Additionally, this study reported the phylogenetic relationships among the species, the arrangement of hierarchical clusters, and the construction of a dendrogram using Ward's linkage method with a Euclidean distance proximity matrix. Pearson correlation, linear relationships, and cross-correlation coefficients among the 23 species were also analyzed.

MATERIALS AND METHODS

Study sites and collection areas

The three different biotopes of the present investigation include roadside wetlands of Hastinapur (S-1); Rice fields of Sisauli, Meerut (S-2) and Botanical Garden of the CCS University (S-3), Meerut, U.P., Bharat. Details of study area and sampling sites are given in Table (1) and Figs. (1A, 2A-R).

Enrichment culturing, isolation and purification

A total of 46 algal growth-containing samples were collected on three separate dates—23rd April 2023, 10th August 2023, and 12th September 2023—from an area within a 50-meter radius of GPS coordinates listed in Table (1), representing three different biotopes. Each sample was assigned a unique sample number along with the date of collection. From each sample, 5mL was preserved in 4% (v/v) formaldehyde and deposited at the Department of Botany, Chaudhary Charan Singh University, Meerut, Uttar Pradesh. An additional 5mL from each sample was inoculated into solid or liquid nitrogenous BG-11 medium **(Stainer *et al.,* 1971)** for enrichment culturing under controlled conditions (temperature: 28 ± 2 °C; light intensity: 140 µmol photons $m^{-2}s^{-1}$; photoperiod: 14:10 h light:dark) for seven days. Unialgal cultures were established through repeated culturing and sub-culturing techniques as described by **Kant *et al.* (2005)**.

Microscopic analysis and identification of *Cylindrospermum*

The growth and morphological details of the members of the genus *Cylindrospermum* were observed with the help of Trinocular Research Microscope (Olympus, CH20i) fitted with digital camera (Magnus, Magcam DC-10) with software (Magnus) MagVision, and the morphological observation were recorded. Taxonomic identification of *Cylindrospermum* is based on different morphological characteristics like habitat, colony, size and shape of vegetative cells, heterocysts, akinetes, etc. All the isolated strains of *Cylindrospermum* were identified upto the species level with the help of available literatures **(Geitler, 1932; Desikachary, 1959; Komárek, 2013)**.

Morphological characters taken into consideration

For the development of the phylogenetic relationships, hierarchical cluster analyses, and dendrogram construction using Ward's linkage method, Euclidean distance proximity matrix, and Pearson’s correlation for linear relationships, the following morphological characters were considered: trichome length, trichome shape, trichome constriction, cell structure, length and width of cells, terminal cells, cell length-to-width ratio, heterocyst shape, length and width of heterocysts, heterocyst length-to-width ratio, akinete structure, akinete surface, length and width of akinetes, akinete length-to-width ratio, and presence of an exosporic layer.

RESULTS

Species diversity of *Cylindrospermum* from three different sites:

From the total of 46 mixotrophic algal growth-containing samples collected, 98 strains belonging to 12 genera of Cyanophyceae were identified. All samples, collected from three different sites, were analyzed for species diversity of the genus *Cylindrospermum*, which included 16 species from Site 1 (S1), 14 species from Site 2 (S2), and 11 species from Site 3 (S3). The highest number of species was observed in samples collected from the roadside wetlands of Hastinapur, while the lowest number was recorded from the grounds of the Department of Botany at Chaudhary Charan Singh University. A detailed representation of species diversity percentages across the three biotopes is provided in Fig. (1B). The list of observed taxa and their distribution across the different sites is presented in Table (2).

Diversity of *Cylindrospermum* from cultivated and uncultivated land

Out of the 23 species collected from the three different sites, 18 species were found in cultivated land, 5 species were found exclusively in uncultivated land, and 4 species were present in both cultivated and uncultivated land. Detailed results on the occurrence of species across these land types are presented in Fig. (1C).

Morphological details of *Cylindrospermum*

A total of 23 taxa belonging to twenty species, two varieties and one form of the genus *Cylindrospermum* have been identified, including *C. ecballisporum*, *C. dobrudjense*, *C. licheniforme*, *C. bourrellyi*, *C. muscicola* var. *kashmiriense*, *C. muscicola* var. *variabilis*, *C. desikacharyi*, *C. identatum*, *C. pellucidum*, *C. minutissimum*, *C. majus*, *C. stagnale* f. *variablis*, *C. kazachstanicum*, *C. gregarium*, *C. breve*, *C. stagnale*, *C. michailovskoense*, *C. skujae*, *C. longisporum*, *C. voukii*, *C. alatosporum*, *C. marichicum* and *C. rectangularis*. Identification and morphological details of all the 23 strains of *Cylindrospermum* species are described in the present paper.

1. ***C. alatosporum* Fritsch (Fig. 4G)**

Colony: Bright blue-green, forming thin mucilaginous mats.

Trichome: Long, flexuous, densely aggregated, constricted at cross walls.

Cells: Cylindrical or slightly barrel-shaped, almost iso-diametric or elongated, 7-8µm long and 3.5-4 µm wide, blue-green and slightly granular, apical cells barrel-shaped or slightly narrowed and rounded.

Heterocysts: Oval or sub-conical, 7.5-10 µm long and 4-5 µm wide.

Akinetes: Mostly solitary, ellipsoidal-oval, hyaline, widened and with yellowish endospore, 20-30µm long and 16-21µm wide.

2. ***C. bourrellyi* Komàrek (Fig. 3D)**

Colony: Blue-green, forming mats with mucilaginous thallus.

Trichomes: Relatively short, straight or flexuous, intricate, constricted at the cross walls,

Cells: Cylindrical to barrel shaped isodiametric, 3.2-5.2µm long and 2.3-4.9 µm wide.

Heterocysts: Spherical, widely oval or less frequently, sub-spherical or ovoid; 4-5 µm in diameter.

Akinetes: Solitary or ovoid, with brownish, varicose exospores, 20-28.5µm long and 15-19.1 µm wide.

3. ***C. breve*** **Welsh (Fig. 4A)**

Colony: Blue-green, forming thin mucilaginous mats.

Trichomes: Solitary or in clusters, straight or slightly curved, not attenuated towards ends, generally short, up to 100 µm long, distinctly and deeply constricted at the cross-walls.

Cells: Short, barrel shaped to almost spherical, 3-5.2µm long and 2.3-3 µm wide.

Heterocysts: Typically spherical, rarely widely oval, 2.5-7.5µm long and 2.2-3.5 µm wide.

Akinetes: Cylindrical-oval to oval, with smooth colorless exospores, 6-10µm long and 3.5-9.3 µm wide.

4. ***C. desikacharyi*** **Komàrek (Fig. 3G)**

Colony: Dark blue-green, forming expanded mats with entangled filaments.

Trichomes: Flexuous, constricted at the cross walls.

Cells: Cylindrical, iso-diametric, 7.2-9.1µm long and 3-3.5 µm wide.

Heterocysts: Cylindrical to ovoid, rounded at the ends, 6-11.5 µm long and 3.6-5 µm wide.

Akinetes: Solitary, widely ellipsoidal with widened, hyaline or brownish, with widened exospores, 17-23µm long and 11.3 -21.5 µm wide.

5. ***C. dobrudjense*** **Draganov (Fig. 3B)**

Colony: Blue green mat forming mucilaginous thallus.

Trichomes: Trichomes coiled, slightly constricted at the cross walls.

Cells: Cylindrical, always longer that wide, 6.6-9.2long and 3.5-4 µm wide, pale blue-green with several granules.

Heterocysts: On both ends of trichomes, elongate-ellipsoidal, colonial or sub-spherical, 9.4- 13.4µm long and 6.7-7 µm wide.

Akinetes: Solitary, elongated, ellipsoidal with rounded ends, exospore greenish-yellow, 22.8-28.8 µm long and 9.2-10.5 µm wide, covered with very fine and short spines, 1.9 µm long.

6. ***C. ecballisporum*** **Komàrek (Fig. 3A)**

Colony: Greenish to yellow brown, mucilaginous, flattened, macroscopic mat.

Trichomes: Densely entangled, flexuous to coiled together, constricted at the cross-walls.

Cell: Cylindrical, isodiametric or longer than wide, pale blue-green, slightly granular, 2.5-7.5µm long and 2-3.4 µm wide, end cells (without heterocysts) cylindrical and rounded.

Heterocyst: Heterocysts almost spherical, ellipsoidal, cylindrical or ovoid, 5-10µm long and 3.5-6 µm wide.

Akinetes: Solitary, rarely in pairs, cylindrical-oval, rarely ellipsoidal, with thick cell-wall with spines, 14–33 µm long and 9–14.5 µm wide.

7. *C. gregarium* (Zakrzewski) Elenkin (Fig. 3O)

Colony: Bright blue-green, forming thin mats.

Trichomes: Solitary or in clusters, slightly constricted at cross walls, filaments straight, up to more than 40 µm long.

Cells: Cylindrical, rarely quadratic, 3-6.5 µm long and 3-4 µm wide.

Heterocysts: Ellipsoidal, 5.5-8µm long and 3-5 µm wide.

Akinetes: Not observed in culture.

8. *C. identatum* G.S. West (Fig. 3H-I)

Colony: Dark blue-green, forming small and irregular mucilaginous mats, upto 3.5 mm in size.

Trichomes: Slightly flexuous, constricted at the cross- walls.

Cells: Barrel to almost cylindrical, isodiametric or longer than wide, 6.2- 8µm long and 5- 6µm wide.

Heterocysts: Elongate-ellipsoidal, rounded at the ends, 9- 15.4µm long and 5.8- 7.2µm wide.

Akinetes: Solitary, ellipsoidal-ovoid, rounded at the ends oriented towards trichomes, concave toward the heterocysts, with smooth exospores, 34- 38µm long and 16- 18.5µm wide.

9. *C. kazachstanicum* Obuchova (Fig. 3N)

Colony: Blue-green or yellowish, free-floating, flocculent (flaky), forming fine mats.

Trichomes: Coiled, cylindrical, slightly constricted at the cross walls.

Cells: Cylindrical or very slightly barrel shaped, pale blue-green, 4.3- 6.5µm long and 2.8- 4.5µm wide.

Heterocysts: Elongated, sometimes slightly conical or cylindrical, 7.2- 10.8µm long and 3.6- 4.8µm wide.

Akinetes: Solitary, spherical or widely oval, with smooth, dark brownish exospores, 15.6-20.8µm long and 15.6-19.5 µm wide.

10. *C. licheniforme* (Bory) Kützing (Fig. 3C)

Colony: Pale olive green to bright blue-green, forming macroscopic mucilaginous mats.

Trichomes: Flexuous, constricted at the cross walls.

Cells: Iso-diametric,usually bright blue-green, cylindrical to barrel-shaped,4- 7µm long and 2.5- 4.2µm wide.

Heterocysts: Elongated, conical, conical or ovoid upto cylindrical with rounded ends, slightly wider than trichomes, 7- 12µm long and 3- 6µm wide.

Akinetes: Elongated ellipsoid and often upto rhomboid with belly like widened side and narrowed or little flattened at the ends, rarely almost cylindrical, with smooth, brownish exospores, 20-40 µm longand 10-18.2 µm wide.

11. *C. longisporum* Komàrek (Fig. 4E)

Colony: Bright blue-green, consisting of solitary filaments or fine microscopic clusters.

Trichomes: Straight or slightly flexuous, cylindrical, constricted at the cross-walls.

Cells: Cylindrical, longer than wide, pale blue-green or yellowish, with vacuoles, 4-11µm long and 3.2-4.1 µm wide; terminal cells cylindrical and widely rounded.

Heterocysts: Cylindrical or long-ovoid, usually develop only at one end of a trichome, 11- 17µm length and 4.5- 6µm wide.

Akinetes: Cylindrical, solitary, with smooth, colorless exospores, 28- 43µm long and 7-11.6µm wide.

12. *C. majus* Kützing ex Bornet et Flahault (Fig. 3L)

Colony: Dark green or brownish, forming mucilaginous flat macroscopic mats.

Trichomes: Flexuous,cylindrical, constricted at the cross walls.

Cells: Cylindrical to slightly barrel shaped, isodiametric or slightly longer than wide, bright blue-green, 3- 6µm long and 3- 5µm wide.

Heterocysts: Oval, slightly elongated, slightly wider than vegetative cells, 8- 10µm long and 3.8- 5.3µm wide.

Akinetes: Solitary, ellipsoid to oval or widely oval, with yellow brownish or brown, granular to warty exospores, 20- 30µm long and 10- 15µm wide.

13. *C. marichicum* (Lemmermann) Lemmermann (Fig. 4H)

Colony: Bright blue-green, forming mucilaginous mats.

Trichomes: Flexuous, constricted at the cross-walls.

Cells: Pale blue-green, cylindrical,iso-diametric, elongate-cylindrical, 2.7- 6.2µm long and 2.7- 3µm wide.

Heterocysts: Elongated, oval or ovoid, 5.1- 7.3µm long and 2.5- 3.2µm wide.

Akinetes: Elongate cylindrical up to cylindrical oval, sometimes slightly arcuate, with smooth, colorless exospores, sometimes in rows, 12-21µm long and 4.5-6 µm wide.

14. *C. michailovskoense* Elenkin (Fig. 4C)

Colony: Blue-green, often expanded, with densely aggregated mucilaginous filaments.

Trichomes: Mostly flexuous or coiled, rarely straight, constricted at the cross-walls.

Cells: Pale blue-green, slightly barrel shaped up to cylindrical, iso-diametric, 3.7-7.2 µm long and 3-5 µm wide, with rounded end cells.

Heterocysts: Rarely almost spherical, mostly a little elongated, 5.7- 12µm long and 3.1-5.9µm wide.

Akinetes: Solitary, rarely in pairs, ellipsoid or oval with colorless smooth exospores, 12-32 µm long and 8- 13µm wide.

15. *C. minutissimum* Collins (Fig. 3K)

Colony: Pale blue-green or olive-green with loosely entangled filamentous mats.

Trichomes: Slightly flexuous, cylindrical not constricted at cross walls.

Cells: Cylindrical, 4- 7µm long and 2- 2.7µm wide, with conical terminal cells.

Heterocysts: Elongated, oval or cylindrical-oval, 6- 8µm long and 3.5- 4µm wide.

Akinetes: Solitary or in pairs, long oval with smooth colorless exospores, 16- 25µm long and7- 9µm wide.

16. *C. muscicola* var.*kashmiriensis* Bharadwaja (Fig. 3E)

Colony: Bluish-green, thin velvety, shining, irregular layer, very soft and mucilaginous mats.

Trichomes: More or less straight and parallel, irregularly bent, and more or less entangled, slightly constricted at the cross walls.

Cells: Barrel shaped with indistinct septa, 2.6-8.4 µm long and 2.6-3.9 µm wide.

Heterocysts: One at either end of mature filament or only one in the younger ones, oval or ellipsoidal 5.2-10.5 µm long and 3.9-5.2 µm wide.

Akinites: Barrel shaped or ellipsoidal, with smooth and brownish thick exospores, 9.4-13.6µm long and 5.2- 7.8µm wide.

17. *C. muscicola* var. *variabilis* Hedwigia (Fig. 3F)

Colony: Dark green, slimy, forming mucilaginous mats.

Trichomes: Flexuous, slightly constricted at cross walls.

Cells: Bright blue-green, cylindrical, 4- 5µm long and 2.8- 4.7µm wide, with rounded end cells.

Heterocysts: Elongated, 4-7µm long and 4-5 µm wide.

Akinetes: Single, oval, with smooth brown exospores, 10-20 µm long and 8- 11µm wide.

18. *C. pellucidum* Johansen et Bohunicka (Fig. 3M)

Colony: Blue-green becoming green to yellowish with age, forming slimy to leathery mats, with star-like spreading filaments in bundles.

Trichomes: Flexuous, short or long, dispersed in wide mucilage, constricted at the cross walls, isopolar or heteropolar.

Cells: Cylindrical or slightly concave, iso-diametric, pale blue-green with parietal thylakoids, 3.0-7.8µm long and 2.2- 4.6µm wide. End cells rounded or conical.

Heterocysts: Solitary, unipored, spherical to elongated or conical, formed terminally after trichomes fragmentation with smooth content, 3.2- 9.7µm long and 3.1- 5.5µm wide.

Akinetes: Solitary or in pairs, elongated oval, with smooth, thin, colorless exospores, 10-25µm long, 5.2- 9.0µm wide.

19. *C. rectangular* Playfair (Fig. 4I)

Colony: Dirty-brown on stony substrates forming leathery flat mat.

Trichomes: Very pale blue-green, straight, constricted at the cross-walls, with very thin sheaths.

Cells: Cylindrical, pale blue-green, 4- 10µm long and 3- 4µm wide with apical cells slightly conical and rounded.

Heterocysts: Cylindrical-rounded, rarely ovoid or conical, 6- 10µm long and 3.5- 6µm wide.

Akinetes: Solitary, cylindrical up to slightly ellipsoidal with smooth or widened akinetes, 29- 38µm long and 9.5- 12µm wide.

20. *C. skujae* Komàrek (Fig. 4D)

Colony: Blue-green or olive green, forming fine mats.

Trichomes: Slightly flexuous and constricted at the cross walls.

Cells: Cylindrical, blue-green or grey-blue, rarely iso-diametric, terminal cells are conical or cylindrical and rounded, 2.2- 5µm long and 1.5-3.4 µmwide.

Heterocysts: At one end of trichomes, oval, ovoid to cylindrical, with rounded ends, 6-8µm long and 2.8- 4.5µm.

Akinetes: Oval-cylindrical, solitary in pairs or up to in row, with smooth, brownish exospores or brownish endospore, 12- 36µm long and 7-11.5 µm wide.

21. *C. stagnale* (Kützing) ex Bornetet flahault (Fig. 4B)

Colony: Blue-green, grayish or brownish green, forming submerged, amorphous, mucilaginous, macroscopic mats attached to submerged substrates, mostly water-plants, later free-floating.

Trichomes: Flexuous, distinctly constricted at the cross- walls.

Cells: Cylindrical, iso-diametric, pale to bright blue-green, 6.8- 9.5µm long and 3.8-5.7 µm wide.

Heterocysts: Oval, ovoid, or cylindrical with rounded ends, 7-16µm longand 5.3-7 µm wide.

Akinetes: Solitary, cylindrical, rounded at the ends, with smooth, yellow-brown exospores which is sometimes only slightly widened, but usually indistinctly radially striated, 32- 40µm long and 10- 16µm wide,

22. *C. stagnale* f. *variablis* Prasad (Fig. 3J)

Colony: Light blue-green, forming a soft dense mucilaginous mat.

Trichomes: Single, blue-green, often entangled with each other, slightly constricted at cross walls.

Cells: Cylindrical or quadrate, 6.5- 8µm long and 4- 4.8µm wide.

Heterocysts: Narrowly cylindrical, sub-elliptical or almost ellipsoidal at both the ends of filaments varying in shape, 9.6- 16µm long and 5.6- 6.4µm wide.

Akinetes: Elongate, sub-cylindrically, flattened slightly at the sides formed singularly, sub-terminally, with a thick hyaline exospores and a thin colorless endospore, 29- 32µm long and 16.4- 17.6µm wide.

23. *C. voukii* Pevalek (Fig. 4F)

Colony: Blackish green, expanded, forming mucilaginous mats.

Trichomes: Slightly curved, distinctly constricted at the cross- walls.

Cells: Barrel shaped, (3) 4-4.5 × 2-3µm, pale blue-green.

Heterocysts: Slightly elongated, shortly to long oval or slightly ovoid, 5-9 × 3.5-4µm.

Akinetes: Solitary, cylindrical to long cylindrical, rounded at the ends,with smooth, colorless or yellowish exospores,14- 28µm long and 4- 5µm wide.

Phylogenetic relationship of *Cylindrospermum* species

Phylogenetic tree puts crucial insights into phylogenetic relatedness of the heterocystous cyanobacterial genus *Cylindrospermum*, collected both from cultivated and uncultivated fields. Phylogenetic tree of 23 different *Cylindrospermum* species based on morphological characteristics was made using PAUP and UPGMA which showed the presence of two major clusters A and B consists of seven minor clusters A1, A2, A3, B1, B2, B3 and B4. The cluster A has three minor clusters while the cluster B has four minor clusters. The clusters B1, B3 and B4 are the largest and have four members each, while clusters A1, A2 and B2 have three members each. Cluster A3 is the smallest consisting of only two members. A phylogenetic relationship of similarity among 23 different *Cylindrospermum* species is given in Fig. (5).

Hierarchical cluster analysis

The illustration of cluster arrangement based on morphological characters, produced through hierarchical cluster analysis using SPSS software, is presented in Fig. (6A). The phenogram, constructed using Ward's linkage method, revealed two main clusters—Cluster I and Cluster II (Fig. 6B).

Cluster I was further divided into two subclusters: IA and IB.

- **Cluster IA** comprised six species: *C. stagnale*, *C. stagnale* f. *variablis*, *C. alatosporum*, *C. dobrudjense*, *C. majus*, and *C. desikacharyi*.
- **Cluster IB** also included six species: *C. marichicum*, *C. michailovskoense*, *C. breve*, *C. identatum*, *C. longisporum*, and *C. ecballisporum*.

Cluster II was further subdivided into IIA and IIB:

- **Cluster IIA** was again divided into IIA1 and IIA2:
    - **IIA1** included two species: *C. minutissimum* and *C. pellucidum*.
    - **IIA2** comprised *C. rectangularis* and *C. skujae*.
- **Cluster IIB** was also subdivided into IIB1 and IIB2:
    - **IIB1** included five species: *C. muscicola* var. *kashmiriense*, *C. muscicola* var. *variablis*, *C. bourrellyi*, *C. kazachstanicum*, and *C. licheniforme*.
    - **IIB2** consisted of two species: *C. gregarium* and *C. voukii*.

Pearson's correlation linear relationship

The Pearson's correlation linear relationship on the basis of morphological characteristics among 23 different *Cylindrospermum* species has been characterized. The *C. gregarium*have negative relationship with *C. alatosporum*, *C. desikacharyi*, *C. dobrudjense*, *C. licheniforme*, *C. longisporum*, *C. muscicola* var. *kashmiriensis*, *C. pellucidum* and *C. stagnale*; *C. identatum* have negative relationship with *C. marichicum*; *C. michailovskoense* and *C. rectangularis* have negative relationship with *C. kazachstanicum*; *C. bourrellyi* have negative *C. breve*, *C. gregarium*, *C. majus and C. stagnale* f. *variablis*; *C. identatum* have negative linear relationship with *C. majus*, *C.*

marichicum, while *C. ecballisporum C. minutissimum and C. voukii* have no negative linear relationship. Detailed results on Pearson's correlation linear relationship is given in Table (3).

Euclidean distance proximity matrix

Morphometric analysis of biological forms is an important subject. Many different kinds of data are utilized to analyze biological forms. Traditionally, scientists have used various linear distances across the form. Morphological characters of 23 different *Cylindrospermum* species were used to determine Euclidean Distance Proximity Matrix and to observe how close the characters are to each other, and determine the proximity. Detailed results using Euclidean Distance Proximity matrix is given in Table (4).

Fig. 1. Map of three different sites of collection of samples from Meerut

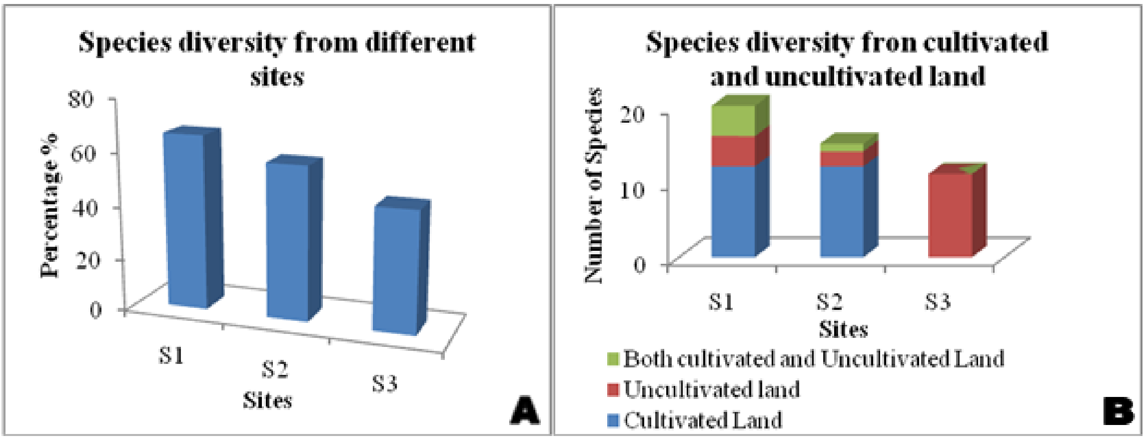

Fig. 2A, B. (A) Showing species diversity of *Cylindrospermum* from different sites; **(B)** Showing species diversity of *Cylindrospermum* from cultivated and uncultivated land

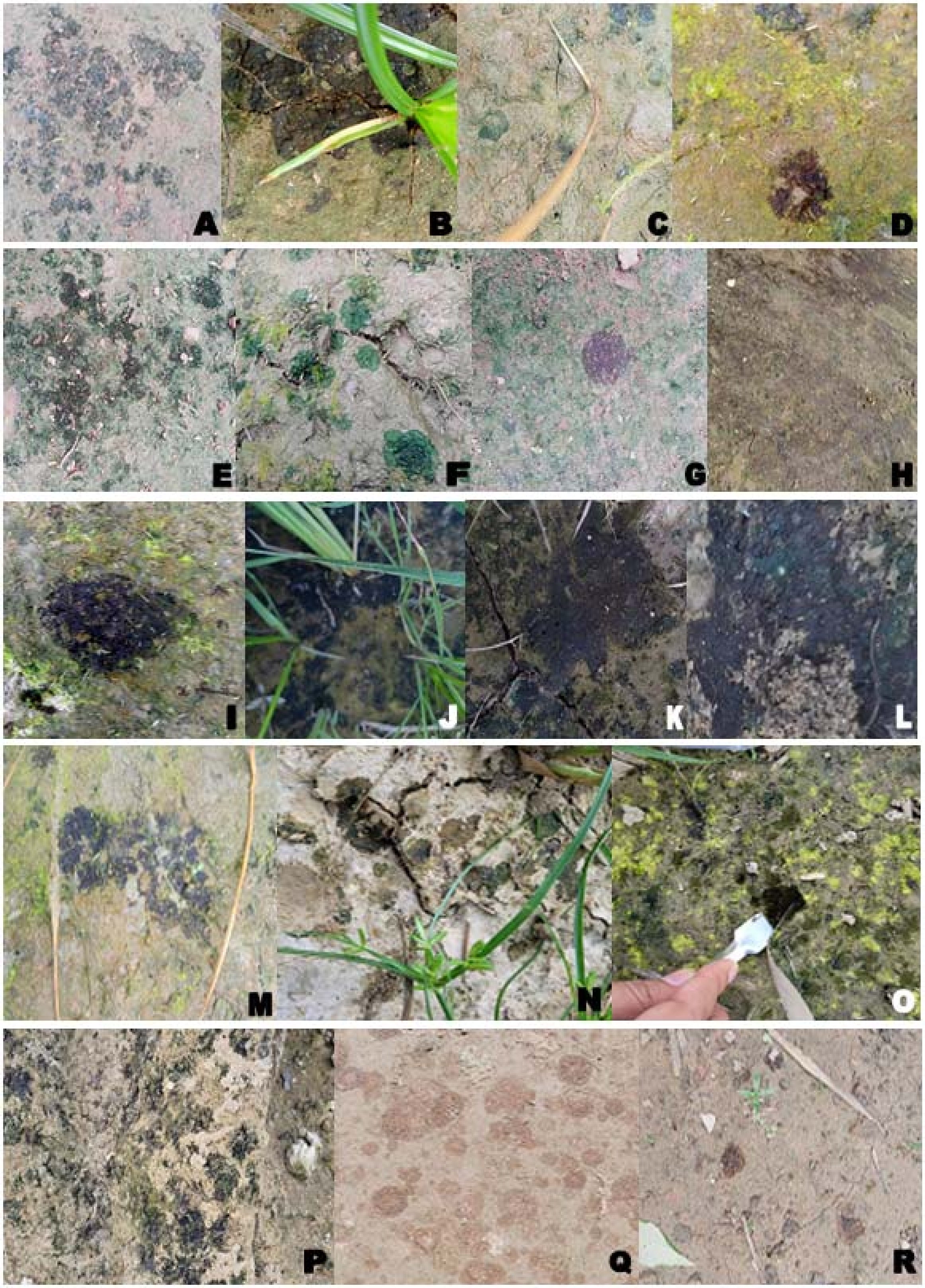

Fig. 3A-R. Growth of different species of *Cylindrospermum* in natural habitats of Meerut and its adjoining areas

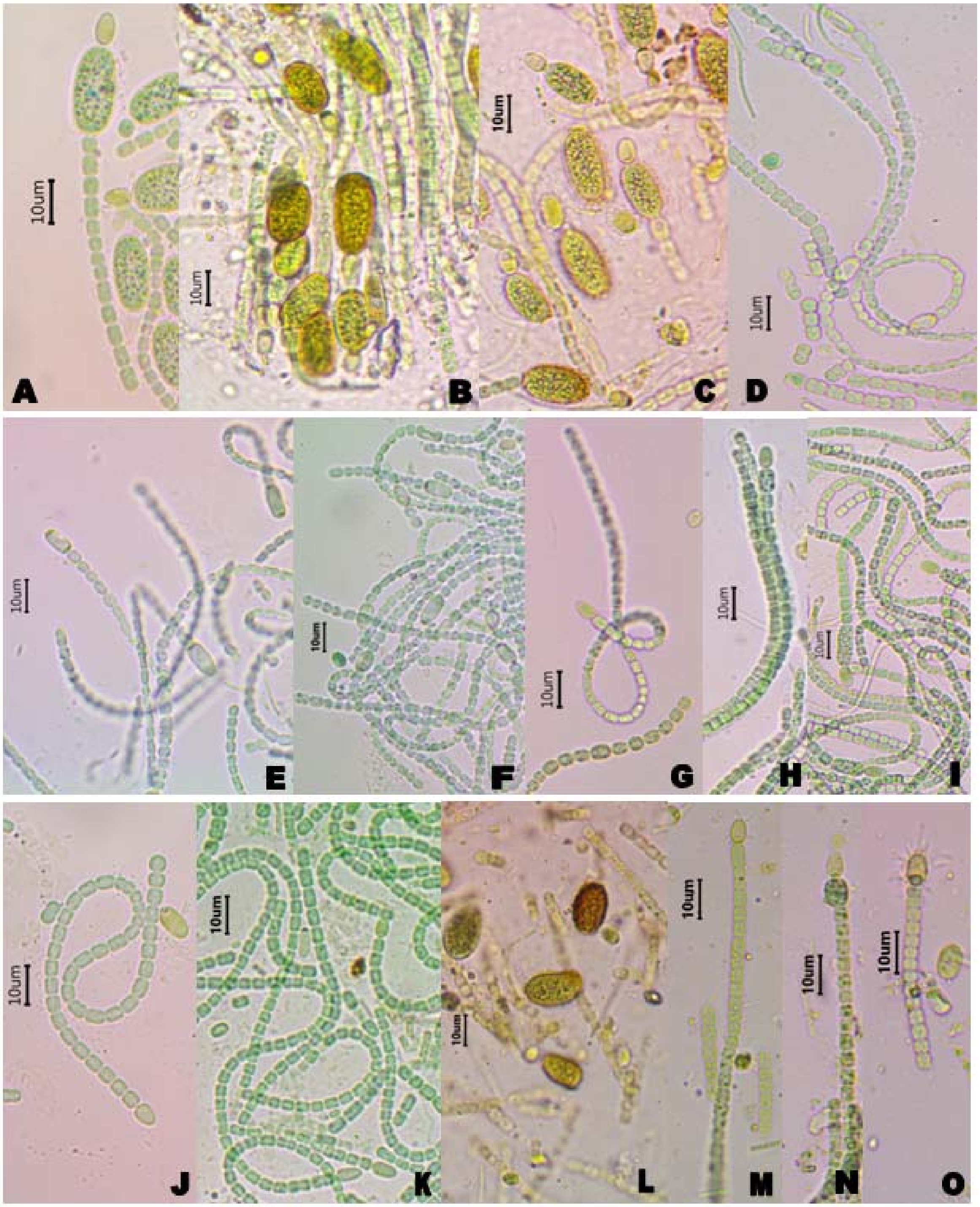

Fig. 4A-O. Morphological description of *Cylindrospermum* (A) *C. ecballisporum*, (B) *C. dobrudjense*, (C) *C. licheniforme*, (D) *C. bourrellyi*, (E) *C. muscicola* var. *kashmiriensis*, (F) *C. muscicola* var. *variabilis*, (G) *C. desikacharyi*; (H-I) *C. identatum*, (J) *C. stagnale* f. *variablis*, (K) *C. minutissimum*, (L) *C. majus*, (M) *C. pellucidum*, (N) *C. kazachstanicum*, (O) *C. gregarium*

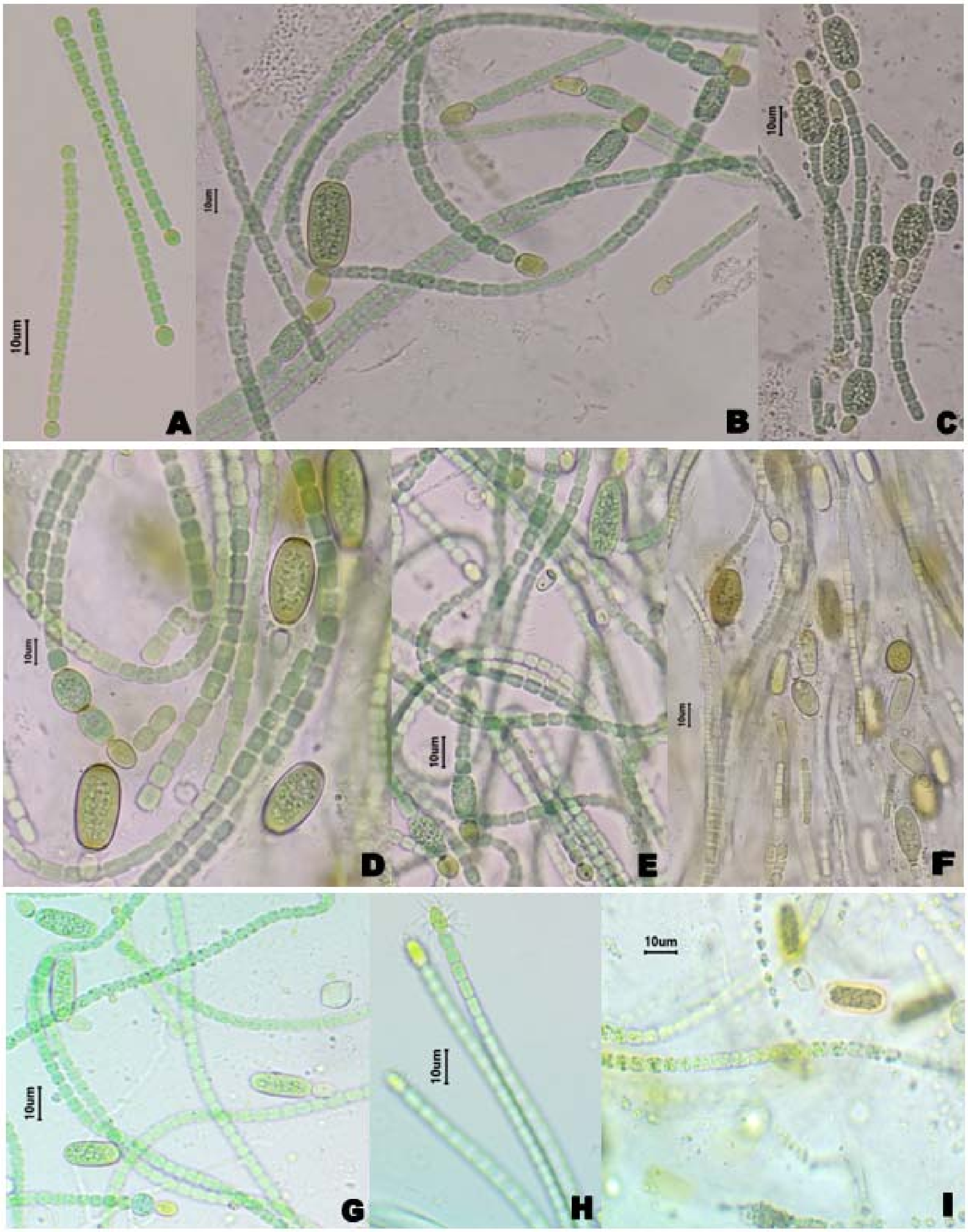

Fig. 5A-I. Morphological description of *Cylindrospermum* (A) *C. breve*, (B) *C. stagnale*, (C) *C. michailovskoense*, (D) *C. skujae*, (E) *C. longisporum*, (F) *C. voukii*, (G) *C. alatosporum*, (H) *C. marichicum*, (I) *C. rectangularis*

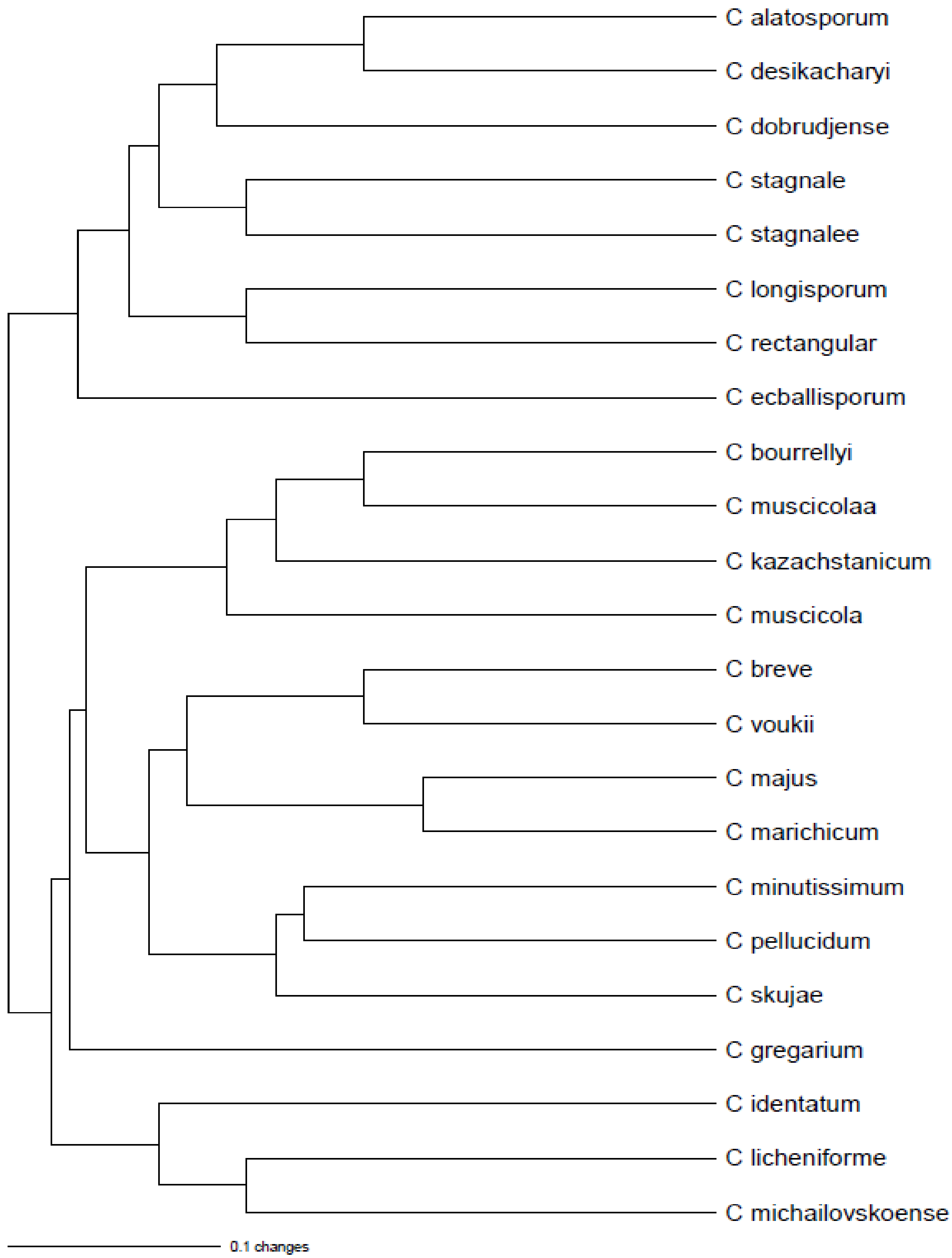

Fig. 6. Dendogram representing the phylogenetic relationships of similarity among twenty three different species *of Cylindrospermum*

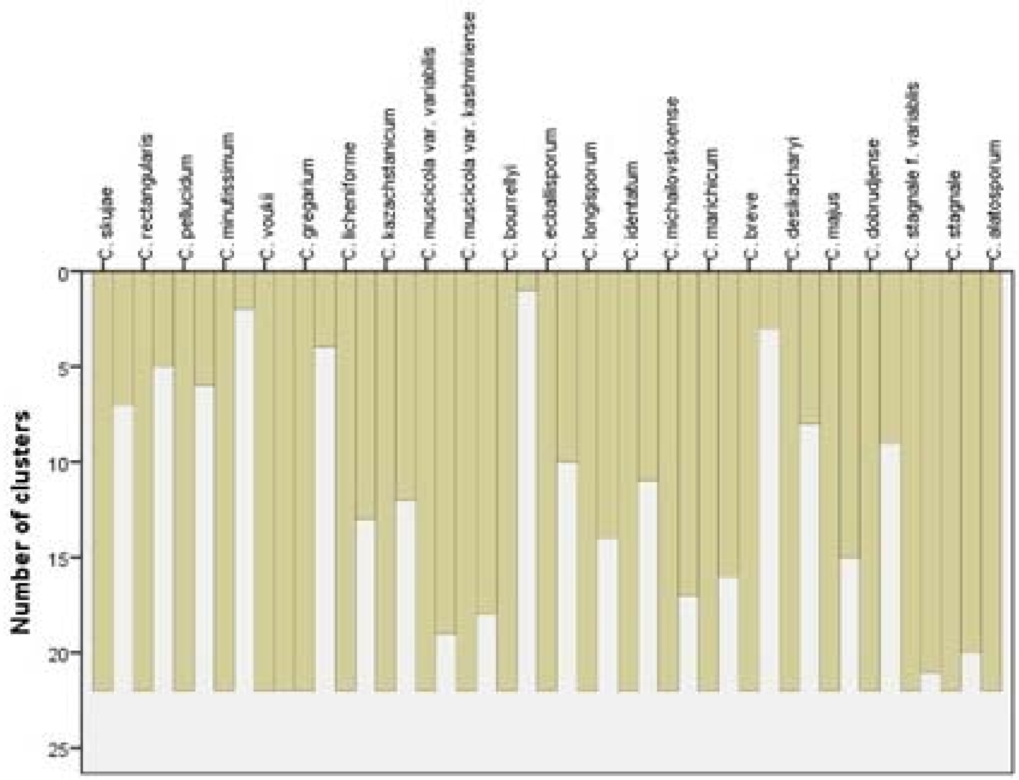

Fig. 7. Illustration of the arrangement of the clusters produced by the corresponding Hierarchical clusters analyses

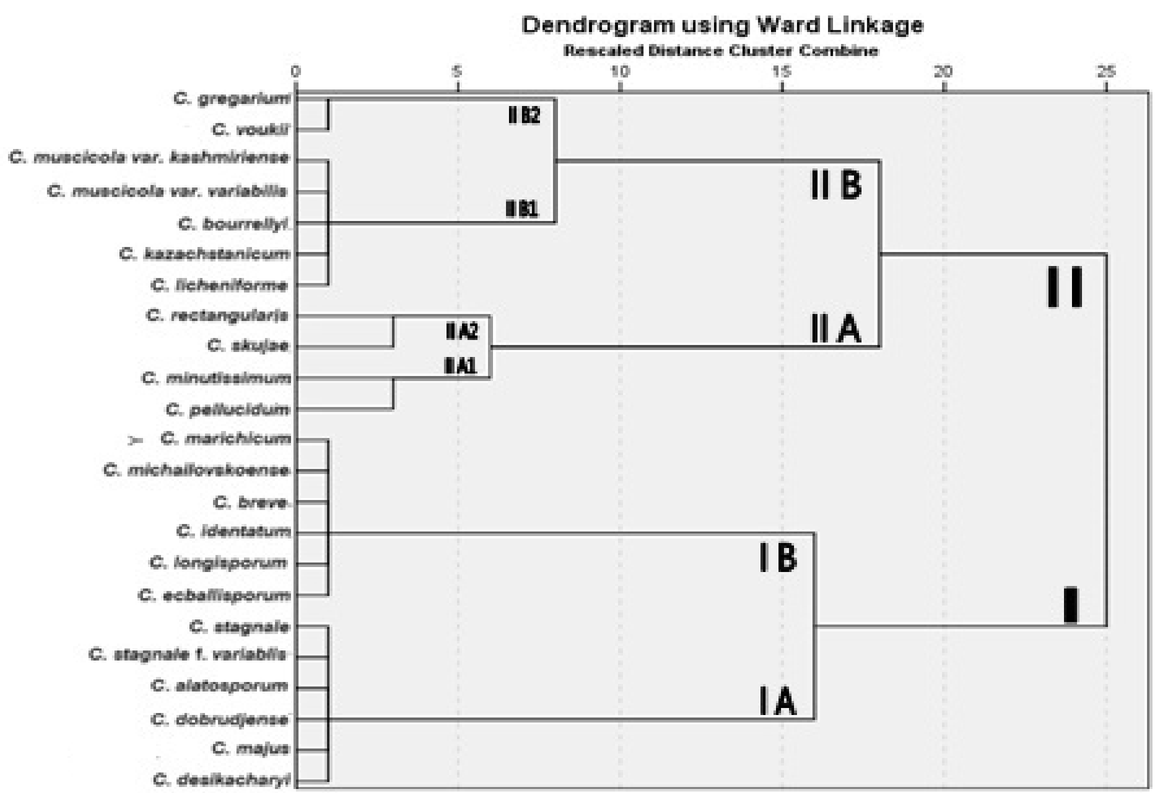

Fig. 8. Dendrogram for twenty three species of *Cylindrospermum* using Ward Linkage

Table 1. Characteristics of different biotopes

Site Details	Characteristics of Biotopes		
Sampling Site Codes	S1	S2	S3
Location	Roadside wetlands of Hastinapur	Rice fields of Sisauli, Meerut	Botany Department ground, CCS University
GPS Location	29.14°N, 78.03°E	29.41°N, 77.47°E	28.96°N, 77.74°E
Habitat	Cultivated/ Uncultivated land	Cultivated Land	Uncultivated land
Water source	Flood and ground water	Ground water irrigation system	Pipeline water from rain water harvesting
Number of Samples collected	19	16	11
Sample Number	MT-1-19	MT-20-35	MT-36-46
Number of Species	16	14	11
Date of collection	23rd April 2023	10th August 2023	12th September 2023

Table 2. Occurrence of *Cylindrospermum* species in different biotopes

Sl. No	Species	Sites		
		S1	**S2**	**S3**
1.	*C. alatosporum*	+	+	-
2.	*C. bourrellyi*	+	+	-
3.	*C. breve*	+	-	+
4.	*C. desikacharyi*	-	-	+
5.	*C. dobrudjense*	+	+	-
6.	*C. ecballisporum*	-	-	+
7.	*C. gregarium*	+	+	-
8.	*C. identatum*	-	-	+
9.	*C. kazachstanicum*	+	+	-
10.	*C. licheniforme*	-	-	+
11.	*C. longisporum*	+	+	-
12.	*C. majus*	+	-	+
13.	*C. marichicum*	+	+	-
14.	*C. michailovskoense*	-	-	+
15.	*C. minutissimum*	+	+	-
16.	*C. muscicola* var. *kashmiriense*	+	+	-

17.	*C. muscicola* var. *variabilis*	+	+	-
18.	*C. pellucidum*	+	+	-
19.	*C. rectangular*	-	-	+
20.	*C. skujae*	+	-	+
21.	*C. stagnale*	+	+	+
22.	*C. stagnale* f. *variablis*	+	+	-
23.	*C. voukii*	-	+	-

Table 3. Pearson's correlation linear relationship between 23 different *Cylindrospermum* species

		C. alatosporum	*C. bourrellyi*	*C. breve*	*C. desikacharyi*	*C. dobrudjense*	*C. ecballisporum*	*C. gregarium*	*C. identatum*	*C. kazachstanicum*	*C. licheniforme*	*C. longisporum*	*C. majus*	*C. marichicum*	*C. michailovskoense*	*C. minutissimum*	*C. muscicola* var. *kashmiriense*	*C. muscicola* var. *variabilis*	*C. pellucidum*	*C. rectangularis*	*C. skujae*	*C. stagnale*	*C. stagnale* f. *variablis*	*C. voukii*
C. alatosporum	Pearson Correlation	1	.540*	.278	.668**	.232	.173	-.200	.257	.321	.000	.612**	.021	.252	.151	.260	.182	.000	.409	.670**	.421	.630**	.132	.248
	Sig. (2-tailed)		.021	.264	.002	.353	.492	.427	.303	.194	1.000	.007	.934	.313	.549	.297	.471	1.000	.092	.002	.082	.005	.603	.322
C. bourrellyi	Pearson Correlation	.540*	1	-.090	.217	.000	.000	-.029	.128	.000	.000	.290	-.137	.000	.408	.130	.084	.297	.464	.638**	.531*	.408	-.213	.160
	Sig. (2-tailed)	.021		.722	.388	1.000	1.000	.908	.612	1.000	1.000	.243	.588	1.000	.093	.608	.740	.231	.052	.004	.023	.093	.396	.525
C. desikacharyi	Pearson Correlation	.668**	.217	.442	1	.553*	.385	-.272	.370	.343	.289	.684**	.277	.471*	.495*	.375	.486*	.086	.536*	.645**	.328	.707**	.185	.324
	Sig. (2-tailed)	.002	.388	.066		.017	.115	.275	.131	.163	.245	.002	.266	.048	.037	.125	.041	.735	.022	.004	.184	.001	.463	.189
C. dobrudjense	Pearson Correlation	.232	.000	.460	.553*	1	.698**	-.005	.486*	.271	.662**	.574*	.350	.447	.425	.492*	.430	.217	.387	.414	.291	.522*	.525*	.388
	Sig. (2-tailed)	.353	1.000	.055	.017		.001	.983	.041	.276	.003	.013	.154	.063	.079	.038	.075	.387	.112	.088	.242	.026	.025	.111
C. ecballisporum	Pearson Correlation	.173	.000	.711**	.385	.698**	1	.139	.291	.424	.608**	.418	.397	.630**	.263	.649**	.629**	.347	.332	.298	.330	.248	.568*	.544*
	Sig. (2-tailed)	.492	1.000	.001	.115	.001		.582	.242	.080	.007	.084	.103	.005	.291	.004	.005	.158	.179	.229	.182	.321	.014	.020
C. gregarium	Pearson Correlation	-.200	-.029	-.009	-.272	-.005	.139	1	-.119	-.460	-.069	-.206	.271	.000	.139	.051	-.231	-.309	-.220	.110	-.103	-.184	-.088	.124
	Sig. (2-tailed)	.427	.908	.972	.275	.983	.582		.637	.055	.787	.412	.276	1.000	.581	.841	.356	.212	.381	.663	.685	.464	.729	.623
C. identatum	Pearson Correlation	.257	.128	.227	.370	.486*	.291	-.119	1	.374	.662**	.486*	-.275	-.052	.325	.039	.115	-.165	.020	.153	-.126	.611**	.629**	.099
	Sig. (2-tailed)	.303	.612	.365	.131	.041	.242	.637		.126	.003	.041	.269	.837	.189	.878	.649	.513	.938	.545	.617	.007	.005	.695
C. kazachstanicum	Pearson Correlation	.321	.000	.526*	.343	.271	.424	-.460	.374	1	.421	.091	.095	.303	-.049	.148	.267	.324	.223	-.158	.113	.323	.760**	.159
	Sig. (2-tailed)	.194	1.000	.025	.163	.276	.080	.055	.126		.082	.719	.708	.221	.848	.558	.285	.190	.373	.531	.656	.191	.000	.529
C. licheniforme	Pearson Correlation	.000	.000	.570*	.289	.662**	.608**	-.069	.662**	.421	1	.468	.160	.272	.327	.151	.365	.099	.111	.085	.227	.476*	.640**	.508*
	Sig. (2-tailed)	1.000	1.000	.013	.245	.003	.007	.787	.003	.082		.050	.527	.275	.186	.549	.137	.696	.662	.737	.364	.046	.004	.031
C. longisporum	Pearson Correlation	.612**	.290	.369	.684**	.574*	.418	-.206	.486*	.091	.468	1	.102	.434	.466	.511*	.320	.010	.473*	.712**	.535*	.685**	.144	.546*
	Sig. (2-tailed)	.007	.243	.132	.002	.013	.084	.412	.041	.719	.050		.688	.072	.051	.030	.195	.970	.048	.001	.022	.002	.568	.019
C. majus	Pearson Correlation	.021	-.137	.649**	.277	.350	.397	.271	-.275	.095	.160	.102	1	.783**	.380	.415	.330	.434	.430	.216	.519*	.149	.175	.601**
	Sig. (2-tailed)	.934	.588	.004	.266	.154	.103	.276	.269	.708	.527	.688		.000	.120	.087	.181	.072	.075	.390	.027	.555	.487	.008
C. marichicum	Pearson Correlation	.252	.000	.735**	.471*	.447	.630**	.000	-.052	.303	.272	.434	.783**	1	.533*	.742**	.481*	.566*	.704**	.365	.619**	.278	.232	.786**
	Sig. (2-tailed)	.313	1.000	.001	.048	.063	.005	1.000	.837	.221	.275	.072	.000		.023	.000	.043	.014	.001	.137	.006	.264	.354	.000
C. michailovskoense	Pearson Correlation	.151	.408	.191	.495*	.425	.263	.139	.325	-.049	.327	.466	.380	.533*	1	.424	.137	.340	.639**	.542*	.409	.533*	-.035	.485*

	Sig. (2-tailed)	.549	.093	.447	.037	.079	.291	.581	.189	.848	.186	.051	.120	.023		.080	.587	.168	.004	.020	.092	.023	.891	.041
C. minutissimum	Pearson Correlation	.260	.130	.405	.375	.492*	.649**	.051	.039	.148	.151	.511*	.415	.742**	.424	1	.379	.488*	.666**	.553*	.551*	.247	.166	.569*
	Sig. (2-tailed)	.297	.608	.095	.125	.038	.004	.841	.878	.558	.549	.030	.087	.000	.080		.121	.040	.003	.017	.018	.322	.510	.014
C. muscicola* var. *kashmiriense	Pearson Correlation	.182	.084	.616**	.486*	.430	.629**	-.231	.115	.267	.365	.320	.330	.481*	.137	.379	1	.433	.394	.329	.408	.114	.215	.333
	Sig. (2-tailed)	.471	.740	.006	.041	.075	.005	.356	.649	.285	.137	.195	.181	.043	.587	.121		.073	.105	.182	.093	.651	.391	.177
C. muscicola* var. *variabilis	Pearson Correlation	.000	.297	.303	.086	.217	.347	-.309	-.165	.324	.099	.010	.434	.566*	.340	.488*	.433	1	.722**	.177	.585*	.162	.127	.365
	Sig. (2-tailed)	1.000	.231	.221	.735	.387	.158	.212	.513	.190	.696	.970	.072	.014	.168	.040	.073		.001	.482	.011	.522	.616	.136
C. pellucidum	Pearson Correlation	.409	.464	.315	.536*	.387	.332	-.220	.020	.223	.111	.473*	.430	.704**	.639**	.666**	.394	.722**	1	.638**	.734**	.505*	-.028	.578*
	Sig. (2-tailed)	.092	.052	.204	.022	.112	.179	.381	.938	.373	.662	.048	.075	.001	.004	.003	.105	.001		.004	.001	.032	.911	.012
C. rectangularis	Pearson Correlation	.670**	.638**	.146	.645**	.414	.298	.110	.153	-.158	.085	.712**	.216	.365	.542*	.553*	.329	.177	.638**	1	.658**	.608**	-.163	.396
	Sig. (2-tailed)	.002	.004	.564	.004	.088	.229	.663	.545	.531	.737	.001	.390	.137	.020	.017	.182	.482	.004		.003	.007	.517	.104
C. skujae	Pearson Correlation	.421	.531*	.396	.328	.291	.330	-.103	-.126	.113	.227	.535*	.519*	.619**	.409	.551*	.408	.585*	.734**	.658**	1	.371	-.032	.645**
	Sig. (2-tailed)	.082	.023	.104	.184	.242	.182	.685	.617	.656	.364	.022	.027	.006	.092	.018	.093	.011	.001	.003		.129	.899	.004
C. stagnale	Pearson Correlation	.630**	.408	.343	.707**	.522*	.248	-.184	.611**	.323	.476*	.685**	.149	.278	.533*	.247	.114	.162	.505*	.608**	.371	1	.348	.437
	Sig. (2-tailed)	.005	.093	.163	.001	.026	.321	.464	.007	.191	.046	.002	.555	.264	.023	.322	.651	.522	.032	.007	.129		.157	.070
C. stagnale* f. *variablis	Pearson Correlation	.132	-.213	.576*	.185	.525*	.568*	-.088	.629**	.760**	.640**	.144	.175	.232	-.035	.166	.215	.127	-.028	-.163	-.032	.348	1	.171
	Sig. (2-tailed)	.603	.396	.012	.463	.025	.014	.729	.005	.000	.004	.568	.487	.354	.891	.510	.391	.616	.911	.517	.899	.157		.497
C. voukii	Pearson Correlation	.248	.160	.747**	.324	.388	.544*	.124	.099	.159	.508*	.546*	.601**	.786**	.485*	.569*	.333	.365	.578*	.396	.645**	.437	.171	1
	Sig. (2-tailed)	.322	.525	.000	.189	.111	.020	.623	.695	.529	.031	.019	.008	.000	.041	.014	.177	.136	.012	.104	.004	.070	.497	

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4. Euclidean distance proximity matrix

	Euclidean Distance Proximity Matrix																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	.000	7.746	4.000	7.681	3.162	6.782	10.149	7.280	3.742	6.245	5.000	8.602	8.367	9.220	10.296	7.483	7.071	10.817
2	7.746	.000	6.164	7.550	6.928	8.832	9.434	5.000	5.657	6.557	6.083	6.782	5.831	6.557	6.633	8.602	8.246	9.000
3	4.000	6.164	.000	7.000	3.464	6.481	8.185	5.000	3.464	4.583	4.123	6.164	6.782	7.681	8.367	6.481	6.633	9.110
4	7.681	7.550	7.000	.000	7.681	4.796	10.392	7.071	6.083	7.746	6.782	7.550	7.280	8.367	8.775	4.796	5.385	7.746
5	3.162	6.928	3.464	7.681	.000	6.633	8.888	6.245	3.162	5.196	4.123	7.746	7.211	7.937	9.274	7.616	7.071	10.817
6	6.782	8.832	6.481	4.796	6.633	.000	11.269	7.937	6.325	7.937	7.000	8.944	9.055	10.050	10.488	4.899	4.690	9.434
7	10.149	9.434	8.185	10.392	8.888	11.269	.000	6.782	8.660	6.633	7.874	7.000	8.185	7.211	7.810	9.539	10.536	9.165
8	7.280	5.000	5.000	7.071	6.245	7.937	6.782	.000	5.385	5.831	6.000	3.606	5.568	5.831	4.359	7.141	7.550	6.481
9	3.742	5.657	3.464	6.083	3.162	6.325	8.660	5.385	.000	4.359	3.606	6.782	5.831	7.000	7.874	6.481	6.164	9.539
10	6.245	6.557	4.583	7.746	5.196	7.937	6.633	5.831	4.359	.000	4.000	6.403	4.796	6.000	7.681	6.856	7.681	9.899
11	5.000	6.083	4.123	6.782	4.123	7.000	7.874	6.000	3.606	4.000	.000	7.416	5.745	5.831	8.544	6.245	5.916	10.198
12	8.602	6.782	6.164	7.550	7.746	8.944	7.000	3.606	6.782	6.403	7.416	.000	6.164	6.245	5.831	7.483	8.718	7.000
13	8.367	5.831	6.782	7.280	7.211	9.055	8.185	5.568	5.831	4.796	5.745	6.164	.000	3.873	6.164	7.483	8.124	9.220
14	9.220	6.557	7.681	8.367	7.937	10.050	7.211	5.831	7.000	6.000	5.831	6.245	3.873	.000	6.557	8.062	8.307	9.381
15	10.296	6.633	8.367	8.775	9.274	10.488	7.810	4.359	7.874	7.681	8.544	5.831	6.164	6.557	.000	9.274	9.695	7.416
16	7.483	8.602	6.481	4.796	7.616	4.899	9.539	7.141	6.481	6.856	6.245	7.483	7.483	8.062	9.274	.000	4.243	7.810
17	7.071	8.246	6.633	5.385	7.071	4.690	10.536	7.550	6.164	7.681	5.916	8.718	8.124	8.307	9.695	4.243	.000	9.539
18	10.817	9.000	9.110	7.746	10.817	9.434	9.165	6.481	9.539	9.899	10.198	7.000	9.220	9.381	7.416	7.810	9.539	.000

DISCUSSION

The Nostocalean members of cyanoprokaryotes have become the most fascinating group of microbes due to their importance in fertilization of the agricultural soil and bio-molecules in the field of biotechnology **(Kant *et al.*, 2006; Sarma *et al.*, 2024, 2025)**. Among the Nostocalean group, the members of the family Nostocales including

Cylindrospermum gained much attention because of their nitrogen fixing ability and conditioning soil health **(Singh, 1961; Tiwari *et al*., 1972)**. The genus *Cylindrospermum* is a heteropolar, filamentous and heterocystous cyanobacterium and its trichomes are differentiated into vegetative cells, heterocysts and akinetes **(Castenholz 1989; Komárek, 2013)**. Taxonomically, there are seventy six taxa including fifty three species, twelve varieties and eleven forma which are taxonomically accepted **(Guiry & Guiry, 2023)**. **Geitler (1932)** described seventeen species and one variety of the genus *Cylindrospermum*. **Desikachary (1959)** described fourteen species, three varieties and three forma of the genus *Cylindrospermum* but recognized only twelve species, while **Komárek (2013)** revised thoroughly known species of *Cylindrospermum* reported from different parts of the world and described 45 species of *Cylindrospermum* but recognized only eighteen species.

In India after independence, the diversity of the blue-green algae has been studied by many algologists **(Mitra, 1951; Desikachary, 1959; Bharadwaja, 1963; Tiwari, 1972; Sinha & Mukharjee, 1975; Tiwari & Pandey, 1976; Prasad & Mehrotra, 1980; Anand, 1989; Santra, 1993; Tiwari *et al*., 2007; Kant, 2011; 2012; Srivastava *et al*., 2014; Rishi & Awasti, 2015; Roy *et al*., 2015; Singh *et al*., 2018; Maurya & Paliwal, 2019; Kant *et al*., 2003, 2004, 2005, 2020a, b, 2021a, b, 2022; Sarma *et al*., 2020a, b, 2022a, b, 2023; Yadav *et al*., 2021; Kumar *et al*., 2023)**.

Desikachary (1959) reported 677 taxa including 541 species 102 varieties and 34 forma of cyanobacteria from India. Similarly in **Srinivasan** (**1965)** listed 326 taxa, which were first described from India. **Sarma and Khan (1980)** listed 91 genera and 817 taxa of blue-green algae from India. **Anand (1989)** surveyed the diversity of blue-green algae of rice fields of Tamil Nadu and Kerala and described 182 species of 31 genera. Similarly **Sahu *et al*. (1996)** surveyed different rice-fields of Orissa and reported 143 species. **Santra (1993)** reported 682 species of 67 genera from West Bengal. Both **Tiwari (1972)** and **Tiwari and Pandey (1976)** studied the cyanobacteria from different habitats of Uttar Pradesh. **Tiwari *et al.* (2007)** made an exhaustive survey and reported total 97 genera and 1528 taxa including 1083 species and 445 varieties and forma. In their study, they covered more than one and half dozen states of India, out of which they reported 45 taxa including 26 species, 19 variety and forma from all types of habitats from India. In their survey, they reported about 40% of species from paddy-fields and *C. muscicola* was considered as common to the semi aquatic habitats of paddy-fields. **Kant (2011, 2012)**, **Kant *et al.* (2020a, b, 2021a, b, 2022)** explored different habitats and reported 78+ species belonging to 17+ genera, while **Sarma *et al*. (2020a, b, 2022a, b, 2023a, b)** reported 47 species belonging to 4 genera from Tripura.

Meerut and its adjoining area belong to doab region and located between Ganga and Yamuna. This doab region is endowed with a rich diversity of cyanobacterium. **Pal and Yadav (1974)** studied many channels, permanent and temporary ponds, ditches and rice fields of Saharanpur district of western Uttar Pradesh and reported 108 species belonging to 29 genera. **Pal (1975)** reported 195 species belonging to 31 genera from Ghaziabad district of Western Uttar Pradesh of India. **Kumar (1970)** surveyed the Sardhana and adjoin area and reported four species including *Cylindrospermum licheniforme, C. majus, C. muscicola* var. *longispora, C. stagnale*. **Bendre and Kumar (1975)** explored many habitats of Meerut and reported a total of 131 species belonging to 27 genera, with a single species of *Cylindrospermum* (*C. majus*). Later after 46 years, **Singh *et al*. (2021; 2022a, b, 2023)** made exclusive survey of blue green algae belonging to Oscillatoriales from different polluted habitats of Meerut and its adjoining areas and reported 69 species belonging to 14 genera, but no such data on the diversity of nostocalean cyanobacteria from cultivated and uncultivated land is available. **Doli *et al.* (2023)**, after a gap of 49 years since the report by Bendre and Kumar, recorded the presence of *Cylindrospermum muscicola* from moist soil along the banks of the Ganga River in Hastinapur, Meerut.

In the present study, we assessed the diversity of the genus *Cylindrospermum* across three different cultivated and uncultivated aquatic and semi-aquatic habitats in Meerut and its adjoining areas. A total of 23 taxa were recorded, including two varieties and one forma of *Cylindrospermum*.

Species diversity across the different sites revealed that the highest number of species was found at Site S1 (roadside wetlands of Hastinapur), while the lowest was recorded at Site S3 (Botanical Garden, CCS University, Meerut). In terms of land type, 18 species were found exclusively in cultivated land, 5 species occurred only in uncultivated land, and 4 species were observed in both.

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CONCLUSION

The primary goal of this study was to determine the diversity of the genus *Cylindrospermum* in various cultivated and uncultivated lands of Meerut and its adjoining areas. From the present investigation, we have report 23 species of *Cylindrospermum*, including *C. ecballisporum*, *C. dobrudjense*, *C. licheniforme*, *C. bourrellyi*, *C. muscicola* var. *kashmiriense*, *C. muscicola* var. *variabilis*, *C. desikacharyi*, *C. identatum*, *C. pellucidum*, *C. minutissimum*, *C. majus*, *C. stagnale* f. *variablis*, *C. kazachstanicum*, *C. gregarium*, *C. breve*, *C. stagnale*, *C. michailovskoense*, *C. skujae*, *C. longisporum*, *C. voukii*, *C. alatosporum*, *C. marichicum*, and *C. rectangularis*.

Species diversity across different sites indicates that the highest number of species was found in the roadside wetlands of Hastinapur, while the lowest number was recorded in the garden of the Department of Botany, Chaudhary Charan Singh University, Meerut. A total of 18 species were observed exclusively in cultivated land, 5 species in uncultivated land, and 4 species were common to both land types. Phylogenetic analysis based on morphological characters revealed the formation of two major groups and seven minor clusters. Hierarchical cluster analysis illustrated the arrangement of these groups, and the dendrogram constructed using Ward's linkage method showed two primary clusters, labeled I and II. Pearson's correlation analysis of morphological characters indicated both positive and negative linear relationships, while the Euclidean distance proximity matrix revealed the closeness among the characters. This study is the first to report 23 species of *Cylindrospermum* from Meerut and its adjoining areas.

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