# Taxonomic Study of Some Cyanobacteria Species in Natural Habitats of *Tanacetum parthenium* Emphasising on *Wollea* and *Cylindrospermum* Morphological Characters

**Maedeh Davari[1], Zakieh Modaressi[1], Zeinab Shariatmadari[1*]**

Received: 2018- 07- 12 Revised and accepted: 2018-08-26


## Abstract

Floristic study of cyanobacteria in the terrestrial habitats of Iran, revealed several taxa belonging to seven genera. Soil samples were collected from natural habitats of medicinal plant, *Tanacetum parthenium*, located in four provinces of Iran (Qom, Isfahan, Lorestan, Razavi Khorasan Provinces). All studied provinces are located in semi-arid regions of the country. The results of this study indicated the presence of 13 species belong to three families of cyanobacteria. Among these families, Nostocaceae with four genera and eight species showed the highest diversity, whereas Rivulariaceae with one genera and one species exhibited the lowest diversity. Among several heterocystous and non heterocystous taxa, *Nostoc* and *Oscillatoria* were found to be the most dominant genera in almost all the studied sites. *Wollea* and *Cylindrospermum* with limited distribution in terrestrial habitats of Iran were found. Therefore, part of the current systematic study has been done with emphasis on these two specific taxa. A distribution of local area and camera lucida pictures of identified taxa is subjected in this study.


**Keywords**: Blue-green algae, Diversity, Iran, Nostocaceae, Terrestrial habitat, *Tanacetum parthenium*

## Introduction

Algae are an important part of the surface soil and play a special role in soil health and dynamics (Metting, 1981). Blue-green algae (cyanobacteria) are one of the most important and most efficient groups of algae, because they can affect properties of the soil and play a special role in the growth and productivity of plants through their ability to stabilize nitrogen and the production of growth-promoting metabolites. Cyanobacteria are also capable to release complex organic carbon compounds in the rhizosphere (Chamizo et al., 2018), which can improve soil density, texture, permeability, and water holding capacity through the binding to soil particles (Kaushik, 2007). So that, the positive effects of cyanobacteria as a biofertilizer for some crops and medicinal plants such as saffron (*Crocus sativus* L.), mint (*Mentha aquatica* L.), peppermint (*Mentha piperita* L.) and savoury (*Satureja hortensis* L.) were emphasized in previous studies (Riahi et al.,

1- Faculty of Life Sciences and Biotechnology, Shahid Beheshti University, Tehran, Iran
*email: (z_shariat@sbu.ac.ir)

2013; Zand et al., 2015; Shariatmadari et al., 2015).

Due to the practical value of these photosynthetic microorganisms as bio-fertilizers and regarding the importance of medicinal plants in human societies, in recent decade, the study of the cyanobacteria present in bed soil of medicinal plants has been emphasized by several researchers (Riahi et al., 2013, Riahi et al., 2017). *Tanacetum parthenium* (L.) Sch. Bip. or fever few known as a perennial herbaceous medicinal plant with a right stem and pinnatifid leaves and belongs to *Asteraceae* family. This species is expanded throughout the northern, western, central and eastern parts of Iran and is used to treat diseases such as fevers, migraine headaches, rheumatoid arthritis, stomach aches, toothaches and insect bites (Pareek et al., 2011). In addition, this plant has antibiotic and anticancer agent (Pareek et al., 2011; Mathema et al., 2012). Like any other plant, the growth and productivity of feverfew can be improved by applying the biofertilizers, including algae based fertilizers, because of the ability of these organisms to produce growth stimulants such as auxins, amino acids, sugars and vitamins (Sergeeva, 2002; Singh et al., 2016). There are also reports implying the ability of these photosynthetic organisms to produce antifungal and antibacterial compounds (El-Mougy and Abdel-Kader, 2013).

The study of algal flora, especially cyanobacterial flora of terrestrial ecosystems of Iran has no long history and returns to last decade. Due to limited information present about the algal flora of terrestrial ecosystems, especially the microflora of several plants rhizosphere, this study can be considered as a step towards the completion of algal flora of Iran. In addition, according to the results of previous studies regarding the positive effect of cyanobacteria on the growth and productivity of some crops and medicinal plants (Saadatnia et al., 2009; Riahi et al., 2012), also considering the medicinal value of the *Tanacetum parthenium*, the present study provides an opportunity to introduce effective cyanobacterial taxa for improving growth of this medicinal plant.

## Materials and Methods

*Study sites*

Soil samples were collected from natural habitats of *Tanacetum parthenium* located in four provinces of Iran (Table 1), according to Rangaswamy method (1966). Soil sampling was done in the summer of two consecutive years 2012 to 2013. All investigated provinces are located in semi-arid regions of the country, and altitude of 1400 to 2500 meters.

*Cyanobacterial species Identification*

The sieved soils from different sites were transferred to sterile petri dishes containing sterile liquid nitrate free BG-11 medium (Stanier et al., 1971). The petri dishes were incubated in a culture chamber at 25±2°C for two weeks of artificial light illumination (74 µmol photons $m^{-2}s^{-1}$) with a 12/12 hours light-dark cycle. After colonization, isolates were transferred to agar plates for purification. For taxonomic determinations, the semipermanent slides of colonies were

**Table 1.** Geographic details of the sampling locations.

| Sites | Origin | Altitude (m) | Latitude/Longitude |
|---|---|---|---|
| 1 | Iran, Isfahan, Abyaneh | 1820 | 33° 15′ N 51° 49′ E |
| 2 | Iran, Qom, Avel | 2501 | 34° 16′ N 50° 59′ E |
| 3 | Iran, Razavi Khorasan, Neyshabur | 1680 | 36° 64′ N 59° 28′ E |
| 4 | Iran, Qom, Veshnavah | 2472 | 34° 15′ N 50° 59′ E |
| 5 | Iran, Lorestan, DareDurak | 1400 | 33° 11′ N 49° 56′ E |

prepared and morphometric study was performed by light microscopy (Olympus, Model BH-2) and based on Desikachary (1959), Prescott (1970) and Komárek (2013). The microscopic images were provided by the digital camera (Canon, Model G10) and were drawn by means of camera lucida (Olympus, Japan).

## Results

In this study, 13 specimens belonging to seven genera were identified (Figs 1, 2). The comparison of cyanobacterial diversity of *Tanacetum parthenium* bed soil in studied sites showed that higher cyanobacterial diversity occurred at the Veshnaveh village of Qom with five taxa compared to other stations. The stations, Avel village of Qom and Abyaneh in Isfahan provinces with four taxa was in the second level of diversity. All species and their distribution are located in Table 2.

1. ***Nostoc verrucosum*** Vaucher ex Bornet & Flahault 1886. (Fig. 1a)
Syn.: *Nostocella verrucosa* (Vaucher) Gaillon., *Nostoc rothii* C. Agardh 1824.
General Distribution: Europe (Whitton, 2011), Asia (Desikachary, 1959; Hirose et al., 1977; Shariatmadari et al., 2013).
Distribution in studied sites: Isfahan: Abyaneh (33°15′ N 51°49′ E).

2. ***Nostoc calcicola*** Brébisson ex Bornet & Flahault 1888. Brébisson in Meneghini, Monographia *Nostochinearum italicarum*, 121, 1843. (Fig. 1b).
General distribution: Europe (Alvarez-Cobelas and Gallardo, 1988), Asia (Desikachary 1959; Hu and Wei 2006; Shariatmadari et al., 2011), Australia and New Zealand (Day et al., 1995).
Distribution in studied sites: Isfahan: Abyaneh (33°15′ N 51°49′ E), Razavi Khorasan: Neyshabur (36°64′ N 59°28′ E).

3. ***Nostoc linckia*** Bornet ex Bornet & Flahault 1886: 193 (as ‘Linckia’ ).
Syn.: *Nostoc confusum* C. Agardh, *Monormia intricata* Berkeley, *Nostoc* intricatum (Berkeley) Meneghini, *Anabaena* intricata (Berkeley) Kützing, *Nostoc* piscinale Kützing ex Bornet & Flahault, *Nostoc* rivulare Kützing ex Bornet & Flahault
General distribution: Europe (Whitton, 2011), Asia (Desikachary, 1959; Hirose et

**Table 2.** List of soil cyanobacterial species recorded from natural habitats of *Tanacetum parthenium* and their distributions.

| Species | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 |
|---|---|---|---|---|---|
| **Nostocales** | | | | | |
| **I. Nostocaceae** | | | | | |
| *Cylindrospermum voukii* Pevalek | | | | | • |
| *Nostoc verrucosum* Vaucher ex Bornet & Flahault | • | | | | |
| *Nostoc calcicola* Brébisson ex Bornet & Flahault | • | | • | | |
| *Nostoc linckia* Bornet ex Bornet & Flahault | | • | | | |
| *Nostoc punctiforme* Hariot | | | • | • | |
| *Nostoc carneum* C.Agardh ex Bornet & Flahault | | | | • | |
| *Trichormus fertilissimus* (C.B.Rao) Komárek & Anagnostidis | | | | • | |
| *Wollea saccata* Bornet & Flahault | | | | | • |
| **II. Rivulariaceae** | | | | | |
| *Calothrix stagnalis* Gomont | | • | | | |
| **III. Oscillatoriaceae** | | | | | |
| *Oscillatoria perornata* Skuja | • | | | • | |
| *Oscillatoria chilkensis* Biswas | • | • | | • | |
| *Oscillatoria subbrevis* Schmidle | | | | | • |
| *Phormidium articulatum* (N.L.Gardner) Anagnostidis & Komárek | | • | | | |

Site 1. Abyaneh; Site 2. Avel; Site 3. Neyshabur; Site 4. Veshnavah; Site 5. DareDurak

al., 1977).

Distribution in studied sites: Qom: Avel (34 °16′ N 50 °59′ E).

4. ***Nostoc punctiforme*** Hariot 1891. (Fig. 1c).

Syn.: *Nostoc hederulae* Meneghini ex Bornet & Flahault, *Polycoccus punctiformis* Kützing.

General distribution: Europe (Alvarez-Cobelas and Gallardo 1988; Whitton et al., 1998; Caraus, 2002; O′Brien et al., 2006), Asia (Desikachary, 1959; Shariatmadari et al., 2013), Pacific Islands (Sherwood, 2004), Australia and New Zealand (O′Brien et al., 2006).

Distribution in studied sites: Razavi Khorasan: Neyshabur (36 ° 64′ N 59 °28′ E), Qom: Veshnavah (34 °15′ N 50 °59′ E).

5. ***Nostoc carneum*** C. Agardh ex Bornet & Flahault 1886. (Fig. 1d)

Syn.: *Nostoc rufescens* C. Agardh, *Anabaena rufescens* (C. Agardh) Kirchner, *Nostoc spongiaeforme* C. Agardh ex Bornet & Flahault.

General distribution: Europe (Whitton, 2011; Loza et al., 2013), Asia (Desikachary,

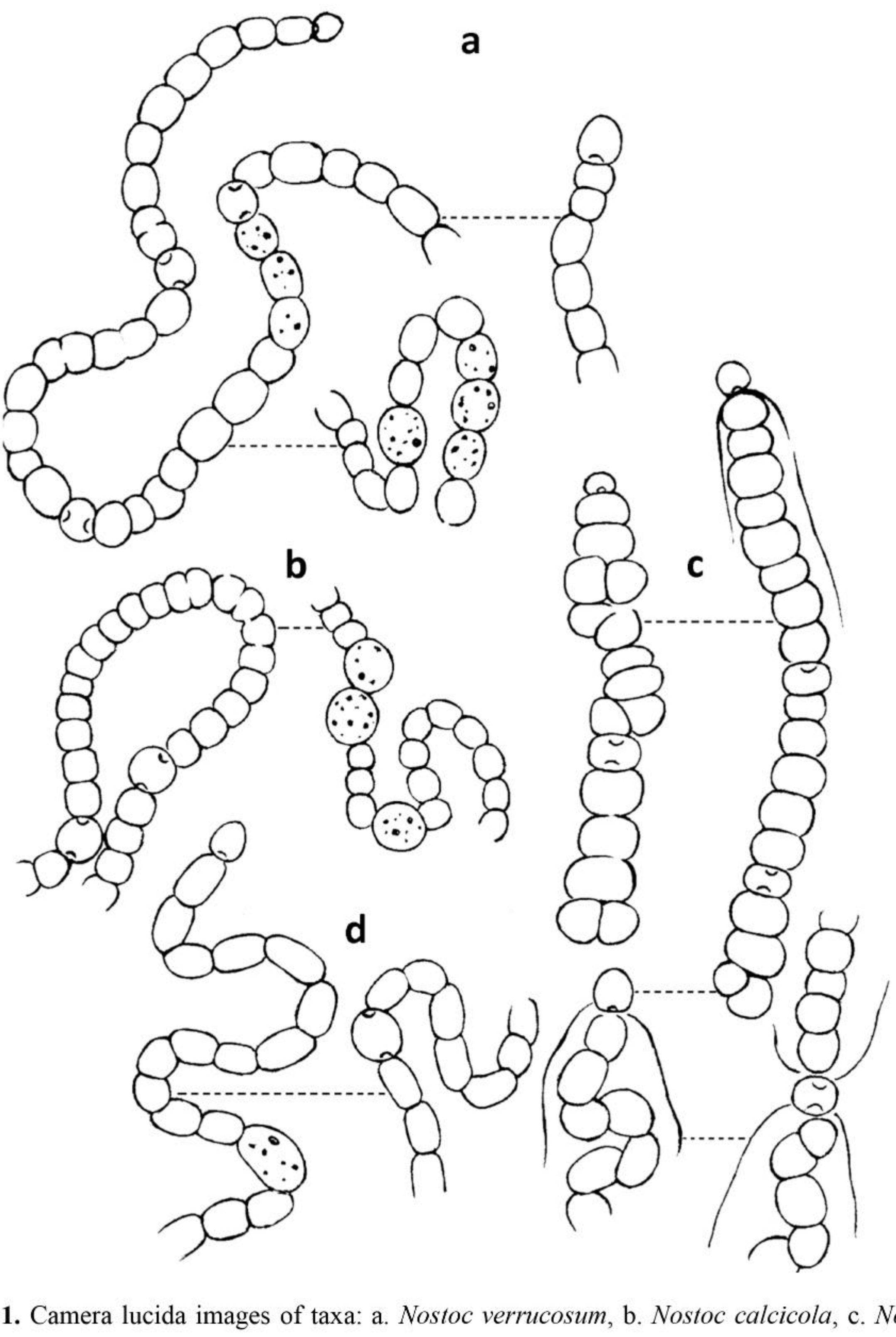


**Fig. 1.** Camera lucida images of taxa: a. *Nostoc verrucosum*, b. *Nostoc calcicola*, c. *Nostoc punctiforme*, d. *Nostoc carneum* (Scale: 10 μm).

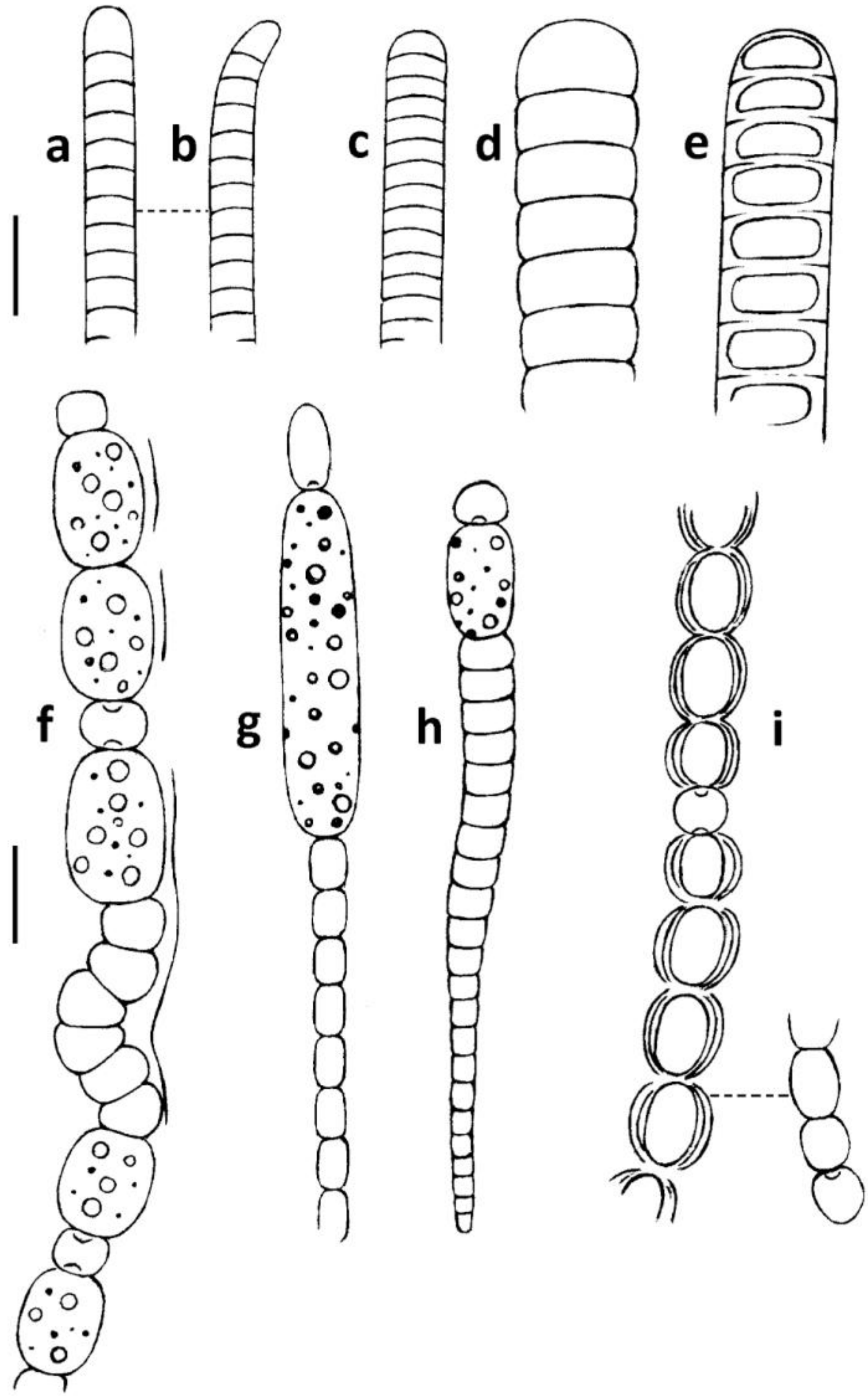


**Fig. 2.** Camera lucida images of taxa: a, b. *Oscillatoria chilkensis*, c. *Oscillatoria subbrevis*, d. *Oscillatoria peronata*, e. *Phormidium articulatum*, f. *Wollea saccata*, g. *Cylindrospermum voukii*, h. *Calothrix stagnalis*, i. *Trichormus fertilissimus* (Scale: 10µm).

1959; Hirose et al., 1977).
Distribution in studied sites: Qom: Veshnavah (34°15′ N 50°59′ E).

6. ***Wollea saccata*** Bornet & Flahault 1886. (Fig. 2f)
Syn.: *Sphaerozyga saccata* Wolle
General distribution: Northern of eastern Siberia, North America (Kozhevnikov and Kozhevnikova, 2011), Asia (Shariatmadari et al., 2018)
Distribution in studied sites: DareDurak (33 °11′ N 49°56′ E).

7. ***Trichormus fertilissimus*** (CB Rao) Komárek & Anagnostidis, 1989. (Fig. 2i)
Syn.: *Anabaena fertilissima* CB Rao.
General distribution: America (Dawes, 1974), Asia (Desikachary, 1959; Shariatmadari et al., 2011).
Distribution in studied sites: Qom: Veshnavah (34°15′ N 50°59′ E).

8. ***Cylindrospermum voukii*** Pevalek 1916. (Fig. 2g).
Syn.: No synonyms are currently included in AlgaeBase.
Distribution in studied sites: Lorestan: DareDurak (33 ° 11′ N 49 ° 56′ E).

9. ***Calothrix stagnalis*** Gomont 1895. (Fig. 2h)
Syn.: No synonyms are currently included in AlgaeBase.
General distribution: Europe (Whitton 2011), Asia (Leghari et al., 2005; Shariatmadari et al., 2013).
Distribution in studied sites: Qom: Avel (34° 16′ N 50°59′ E).

10. ***Oscillatoria perornata*** Skuja 1949. (Fig. 2d).
Syn.: *Planktothrix perornata* (Skuja) Anagnostidis & Komárek
General distribution: North-Eastern Australia (McGregor, 2007), Asia (Desikachary, 1959).
Distribution in studied sites: Isfahan: Abyaneh (33°15′ N 51°49′ E), Qom: Veshnavah (34°15′ N 50°59′ E).

11. ***Oscillatoria chilkensis*** Biswas 1932. (Figs 2a, b).
Syn.: No synonyms are currently included in AlgaeBase.
General distribution: South-west Asia (Siddiqui et al., 2009, Silva et al., 1996, Gupta, 2012, Kesarwani et al., 2015, Rao and Gupta, 2015)
Distribution in studied sites: Isfahan: Abyaneh (33°15′ N 51°49′ E). Qom: Avel (34° 16′ N 50°59′ E), Qom: Veshnavah (34°15′ N 50°59′ E).

12. ***Oscillatoria subbrevis*** Schmidle 1901. (Fig. 2c).
Syn.: No synonyms are currently included in AlgaeBase.
General distribution: Asia (Vynogradova, 2014; Park, 2012; Gul et al., 2007; Hirose et al., 1977), North-Eastern Australia (McGregor 2007), Europe (Whitton 2011).
Distribution in studied sites: Lorestan: DareDurak (33 °11′ N 49 °56′ E).

13. ***Phormidium articulatum*** (NL.Gardner) Anagnostidis & Komárek 1988. (Fig. 2e).
Syn.: *Oscillatoria articulata* NL.Gardner, *Oscillatoria grunowiana* var. *articulata* (Gardner) Drouet.
General distribution: Asia (Park, 2012; Desikachary, 1959).
Distribution in studied sites: Qom: Avel (34 °16′ N 50°59′ E).

## Discussion

Algal flora in terrestrial habitats of Iran indicate the importance of floristic study of these special ecosystems. Considering to complete the data bank of algal flora, cyanobacteria presented in bed soil of medicinal plant, *Tanacetum parthenium*, was studied. A total of 13 taxa of cyanobacteria belonging to the Nostocales and Oscillatoriales were identified, from which the family Nostocaceae with 61.5% of total taxa include the largest number and the families Oscillatoriaceae and Rivulariaceae with 30.5 % and 8% of total taxa, respectively, were in the next places. *Nostoc* and *Oscillatoria*, with 38.5% and 23% of total specimens, counted as highest biodiversity among identified taxa. *Wollea, Trichormus, Cylindrospermum, Calothrix* and *Phormidium,* each with one species, constituted only 7.8% of the total taxa, thus accounted for the least species diversity in the studied microflora. The results of this study are consistent with another study on cyanobacteria in agricultural lands, such as rice fields of Iran, which reported that the Nostocacea family was more diverse than other identified families (Shariatmadari et al., 2013). Similar results also were reported by Prasanna and Nayak (2007) in agricultural soils of India.

In another part of present study, the selection of efficient characteristics for identification of studied taxa were considered. Separating characteristics such as thallus structure, existence or absence of heterocysts, akinete position, size and shape of akinetes and presence or absence of gelatinous sheath around the trichomes have shown the importance of morphometric studies. It should be noted that in relation to some taxa, such as Wollea Bornet et Flahault, the morphological characteristics is even more effective than genetic traits. Wollea is a poorly known genus which is most morphologically similar to genera *Anabaena* and *Nostoc* (Komárek 2010; Kozhevnikov and Kozhevnikova, 2011). Several species of this genus was reported from aquatic and terrestrial habitats of Iran (Table 3). From these taxa can be pointed out to species, *Wollea ambigua* (Rao) Singh and *Wollea vaginicola* (Fritsch & Rich) Singh, which are reported from rice fields of Iran (Shariatmadari et al., 2014). *Wollea saccata* is another species of this genus which is reported from *Tanacetum parthenium* habitats in present study. The difference in the shape and size of akinetes as well as akinete color in maturity stage are the most important differences of this taxon with the other species (Shariatmadari et al., 2018).

*Cylindrospermum voukii* is another species that have limited distribution in terrestrial habitats of Iran and reported from *Tanace-*

*tum parthenium* habitats (Shariatmadari et al., 2018). One of the distinguishing characteristic of this taxon is its long and narrow akinete. *Cylindrospermum zonatum Komárek* and *Cylindrospermum minutissimum* Collins are other taxa with cylindrical akinetes (Komárek, 1989). But length/width ratio of akinetes (3.7-4.0 respectively) is far more than these taxa and is consistent with the *Cylindrospermum voukii* (Tables 4, 5, 6). Among the identified taxa, genera such as *Nostoc, Wollea, Trichormus, Cylindrospermum* and *Calothrix* are classified as heterocystous cyanobacteria. The heterocystous cyanobacteria can fix molecular nitrogen due to the presence of specific cells called heterocyst. It should be noted that some of the heterocystous taxa, such as *Nostoc linckia* Bornet ex Bornet & Flahault, are known as poisonous specimens (Hallegraeff et al., 2003). Therefore, it can be said that any specimens is not suitable for the production of bio-fertilizers, despite its nitrogen fixation capabilities. On the other hand, among the identified taxa, another species *Nostoc calcicola* Brébisson ex Bornet & Flahault, can be considered as a biofertilizer (Shariatmadari et al., 2013). The ability to add total nitrogen, nitrite, nitrate, ammonium and cations such as $Na^+$, $K^+$ and $Ca^{2+}$ into the rhizosphere of plants, as well as the relatively high compatibility of this taxon against environmental stresses such as salinity and pH stresses make this cyanobacteria an appropriate choice for fertilizer production (Obana et al., 2007). In addition, the ability to biosynthesize secondary metabolites effective in plant growth, such as hormonal compounds, indole butyric acid and indole acetic acid (Seyed Hashtroudi et al., 2012) and other undeniable capabilities such as improving soil texture, facilitating soil moisture retention, increasing the amount of organic matter in the soil have made this species with high practical value in the production of bio fertilizers. Therefore, using this taxon as bio fertilizer for feverfew can be a starting point for further research in this regard.

**Acknowledgment**

The authors wish to thank University of Shahid Beheshti for funding this project. Thanks are also due to Dr. Hossein Riahi and Dr. Ali Sonboli for their kind assistance during the research.

**Table 3.** Comparision of main morphological characteristics of the *Wollea* species has been reported from Iran.

| Characters | ***Wollea saccata*** **Bornet & Flahault** | ***Wollea ambigua*** **(Rao) RY.Singh** | ***Wollea vaginicola*** **(Fritsch & Rich) Singh** |
|---|---|---|---|
| **Vegetative cells** | | | |
| **Form** | barrel shaped or discoid | discoid | sub-quadrate |
| **Length (µm)** | 3.0-5.0 | 5.0-7.0 | 4.5-5.0 |
| **Width (µm)** | 4.0-6.0 | 8.5-9.0 | 4.5-5.0 |
| **Terminal cells** | | | |
| **Form** | conical-rounded | widely rounded | conical with rounded apex or spherical |
| **Heterocyst** | | | |
| **Form** | barrel shaped or slightly longer than wide | spherical or sub-spherical | spherical or elongated spherical |
| **Length (µm)** | 4.0-6.0 | 9.0-10.0 | 5.5-7.0 |
| **Width (µm)** | 4.0-5.0 | 9.0-10.0 | 5.0-6.0 |
| **Akinete** | | | |
| **Form** | ellipsoidal or ovate | ellipsoidal or widely oval | oblong |
| **Color** | yellowish brown in maturity stage | yellowish green in maturity stage | yellowish green in maturity stage |
| **Position** | solitary or several in both sides of heterocysts | solitary aside of both sides of heterocystes | 2-4 in rows aside of both sides of heterocystes |
| **Length (µm)** | 12.0-17.0 | 14.0-27.0 | 8.0-11.0 |
| **Width (µm)** | 6.0-8.0 | 14.0-16.0 | 6.0-8.0 |
| **Ecology** | bed soil of *Tanacetum parthenium* | submerged soils and aquatic ecosystems (Shariatmadari et al., 2011) | submerged soils and aquatic ecosystems (Shariatmadari et al., 2011) |

Table 4. Comparision of main morphological characteristics of the some *Cylindrospermum* species has been reported from Iran

| Characters | *Cylindrospermum voukii* Pevalek | *Cylindrospermum catenatum* Ralfs ex Bornet & Flahault | *Cylindrospermum minutissimum* Collins |
|---|---|---|---|
| **Vegetative cells** | | | |
| **Form** | barrel-shaped or slightly longer | sub-quadrate or sub-cylindrical | sub-quadrate or cylindrical |
| **Length (µm)** | 4.0-5.0 | 5.0-7.0 | 5.0-6.0 |
| **Width (µm)** | 3.0-4.0 | 4.0-4.5 | 3.0-3.5 |
| **Heterocyst** | | | |
| **Form** | obovoid | obvoid or oblong-ovate | oblong-ovate |
| **Length (µm)** | 7.0-8.0 | 8.0-11.0 | 6.0-11.0 |
| **Width (µm)** | 4.0-4.5 | 4.5-5.0 | 5.0-8.0 |
| **Akinete** | | | |
| **Form** | oblong | ovate | cylindrical |
| **Color** | epispore colorless | epispore yellowish brown | epispore colorless |
| **Position** | solitary adjacent to the heterocystes | several adjacent to the heterocystes | solitary adjacent to the heterocystes |
| **Length (µm)** | 20.0-27.0 | 13.0-25.0 | 11.0-22.0 |
| **Width (µm)** | 5.0-8.0 | 8.0-9.0 | 6.0-8.0 |
| **Ecology** | bed soil of *Tanacetum parthenium* | submerged soils and aquatic ecosystems (Shariatmadari and Riahi, 2012) | submerged soils and aquatic ecosystems (Shariatmadari and Riahi, 2012) |

**Table 5.** Comparision of main morphological characteristics of the *Cylindrospermum* species has been reported from Iran.

| **Characters** | ***Cylindrospermum marchicum* (Lemmermann) Lemmermann** | ***Cylindrospermum michailovskoense* Elenkin** | ***Cylindrospermum muscicola* Kützing ex Bornet & Flahault** |
|---|---|---|---|
| **Vegetative cells** | | | |
| **Form** | barrel-shaped or sub-cylindrical | quadrate or slightly longer than broad | sub-quadrate or slightly longer than broad |
| **Length (µm)** | 6.0-6.5 | 4.0-5.0 | 5.0-6.0 |
| **Width (µm)** | 4.0-4.5 | 4.0-4.5 | 4.0-6.0 |
| **Heterocyst** | | | |
| **Form** | ovoid with rounded apex | sub-sherical or ovoid | oblong or ovoid |
| **Length (µm)** | 10.0-10.5 | 8.0-9.0 | 6.0-9.0 |
| **Width (µm)** | 5.0-5.5 | 7.0-7.5 | 4.0-6.0 |
| **Akinete** | | | |
| **Form** | ovate to barrel-shaped | ovate | oval or broadly oval |
| **Color** | epispore colorless | epispore colorless | epispore brownish or yellowish brown |
| **Position** | catenate series adjoining the heterocyst | solitary adjacent to the heterocyste | solitary adjacent to the heterocyste |
| **Length (µm)** | 6.0-9.0 | 21.0-27.0 | 17.0-23.0 |
| **Width (µm)** | 4.0-6.0 | 10.0-15.0 | 7.0-10.0 |
| **Ecology** | submerged soils and aquatic ecosystems (Shariatmadari and Riahi, 2012) | submerged soils and aquatic ecosystems (Shariatmadari and Riahi, 2012) | submerged soils and aquatic ecosystems (Shariatmadari and Riahi, 2012) |

**Table 6.** Comparision of main morphological characteristics of the *Cylindrospermum* species has been reported from Iran.

| **Characters** | ***Cylindrospermum majus*** **Kützing ex Bornet & Flahault** | ***Cylindrospermum sphaericum*** **B.N.Prasad** | ***Cylindrospermum stagnale*** **Bornet & Flahault** |
|---|---|---|---|
| **Vegetative cells** | | | |
| **Form** | sub-quadrate | sub-quadrate or cylindrical | sub- cylindrical |
| **Length (µm)** | 5.0-6.0 | 5.0-8.0 | 6.0-6.5 |
| **Width (µm)** | 5.0-5.5 | 4.0-4.5 | 3.5-4.5 |
| **Heterocyst** | | | |
| **Form** | sub-spherical or ovoid | ovoid, sub-spherical or ellipsoidal | elongate or ovoid |
| **Length (µm)** | 5.0-6.5 | 6.0-7.0 | 8.0-10.0 |
| **Width (µm)** | 6.0-6.5 | 4.0-5.0 | 5.0-6.0 |
| **Akinete** | | | |
| **Form** | ovate | spherical | oblong or sub-cylindrical |
| **Color** | epispore brownish with distinct papillae | epispore brownish | epispore brownish |
| **Position** | solitary adjacent to the heterocyste | singly or in pair adjacent to the heterocyste, rarely with intermediate akinet | solitary adjacent to the heterocyste |
| **Length (µm)** | 20.0-33.0 | 7.0-17.0 | 20.0-29.0 |
| **Width (µm)** | 10.0-14.0 | 7.0-17.0 | 13.0-18.0 |
| **Ecology** | submerged soils and aquatic ecosystems (Shariatmadari and Riahi, 2012) | submerged soils and aquatic ecosystems (Shariatmadari and Riahi, 2012) | submerged soils and aquatic ecosystems (Shariatmadari and Riahi, 2012) |

## References


Alvarez-Cobelas M and Gallardo T. (1988). Catálogo de las algas continentales españolas V. Cyanophyceae Schaffner 1909. Acta Botanica Malacitana. 13: 53-76.

Anagnostidis K and Komárek J. (1988). Modern approach to the classification system of cyanophytes. 3. Oscillatoriales. Archiv für Hydrobiologie, Supplement. 80: 327-472.

Biswas K. (1932). Algal flora of the Chilka Lake. Memoirs of the Asiatic Society of Bengal. 11: 165-198.

Bornet É and Flahault C. (1886 '1888'). Revision des Nostocacées hétérocystées contenues dans les principaux herbiers de France (quatrième et dernier fragment). Annales des Sciences Naturelles, Botanique, Septième Série. 7: 177-262.

Caraus I. (2002). The algae of Romania. Studii si Cercetari, Universitatea Bacau. Biologie. 7: 1-694.

Chamizo S, Mugnai G, Rossi F, Certini G, Philippis R. (2018). Cyanobacteria inoculation improves foil stability and fertility on different textured soils: Gaining Insights for Applicability in Soil Restoration. Frontiers in Environmental Science. 6: 1-14.

Dawes CJ. (1974). Marine algae of the west coast of Florida. Coral Gables, Florida, University of Miami Press. 201 pp.

Day SA, Wickham RP, Entwisle TJ, Tyler PA. (1995). Bibliographic check-list of non-marine algae in Australia. Flora of Australia Supplementary Series. 4: 1-276.

Desikachary TV. (1959). Cyanophyta. Indian council of agricultural research, New Delhi. 684 pp.

El-Mougy NS and Abdel-Kader MM. (2013). Effect of commercial cyanobacteria products on the growth and antagonistic ability of some bioagents under laboratory conditions. Journal of Pathogens. 7: 1-11.

Gomont MA. (1895). Note sur un *Calothrix* sporifère *(Calothrix stagnalis* sp. nov.). Journal de Botanique. 9: 197-202.

Gul R, Zarina A, Ul-Hasan M, Shameel M. (2007). Taxonomic study of cyanophyta from Sialkot, Pakistan. International Journal of Phycology and Phycochemistry. 3 (1): 37-48.

Gupta P. (2012). Algae of India: Vol. 1. A checklist of cyanoprokaryota (Cyanophyceae). Botanical Survey of India. 174 pp.

Hallegraeff GM, Anderson DM, Cembella AD. (2003). Manual on harmful marine microalgae. Paris: UNESCO. 793 pp.

Hariot P. (1891). Le genre *Polycoccus* Kützing. Journal de Botanique [Morot]. 5: 29-32.

Hirose H, Yamagishi T, Akiyama M. (1977). Illustrations of the Japanese freshwater algae. Uchida Rokakuho Publishing Company, Tokyo. 933 pp.

Hu H and Wei Y. (2006). The freshwater algae of China. Systematics, taxonomy and ecology. 1023 pp.

Kaushik BD. (2007). Cyanobacterial biofertilizer technology. In: Kannaiyan, SK and Venkataraman GS. (1972). Algal biofertilizer and rice cultivation. Today and Tomorrows Printer and Publishers. New Delhi. 71 pp.

Kesarwani S, Tandon R, Tiwari GL. (2015). The genus *Oscillatoria* Vaucher (Cyanoprokaryota) from India. Phykos. 45 (1): 18-29.

Komárek J and Anagnostidis K. (1989). Modern approach to the classification system of Cyanophytes 4 - Nostocales. Algological Studies. 56: 247-345.

Komárek J. (1989). Studies on the cyanophytes of Cuba. Folia Geobot. Phytotax. 24: 171-206.

Komárek J. (2010). Modern taxonomic revision of planktic Nostocaceae cyanobacteria: a short review of genera. Hydrobiology. 639: 231-243.

Komárek J. (2013). Süßwasserflora von Mitteleuropa, Bd. 19/3: Cyanoprokaryota: 3rd part: Heterocytous genera. Springer Spektrum. 1131 pp.

Kozhevnikov I and Kozhevnikova N. (2011). Phylogenetic and morphological evaluation of *Wollea saccata* (Nostocales, Cyanobacteria) isolated from the Yenissei river basin (Eastern Siberia, Russia). Fottea. 11 (1): 99-106.

Leghari MK, Qureshi RM, Mashiatullah A, Yaqoob N, Javed T. (2005). Harmful algal species from various freshwater localities of Pakistan. International Journal of Phycology and Phycochemistry. 1 (2): 199-206.

Loza V, Berrendero E, Perona E, Mateo P. (2013). Polyphasic characterization of benthic cyanobacterial diversity from biofilms of the Guadarrama river (Spain): morphological, molecular, and ecological approaches. Journal of Phycology. 49 (2): 282-297.

Mathema VB, Koh YS, Thakuri BC, Sillanpää M. (2012). Parthenolide, a sesquiterpene lactone, expresses multiple anti-cancer and anti-inflammatory activities. Inflammation. 35 (2): 560-565.

McGregor GB. (2007). Freshwater cyanoprokaryota of north-eastern Australia 1: Oscillatoriales. Flora of Australia supplementary series number 24. Canberra. Australia Biological Resources Study. 123 pp.

Metting B. (1981). The systematics and ecology of soil algae. The Botanical Review. 47: 195- 312.

Obana S, Miyamoto K, Morita S, Ohmori M, Inubushi K. (2007). Effect of *Nostoc* sp. on soil characteristics, plant growth and nutrient uptake. Journal of Applied Phycology. 19: 641-646.

O'brien HE, Miadlikowska J, Lutzoni F. (2006). Assessing host specialization in symbiotic cyanobacteria associated with four closely related species of the lichen fungus Peltigera. European Journal of Phycology. 40: 363-378.

Pareek A, Suthar M, Rathore GS, Bansal V. (2011). Feverfew (*Tanacetum parthenium* L.): A systematic review. Pharmacognosy Reviews. 5 (9): 103-110.

Park JG. (2012). Algal flora of Korea. Cyanophyta: Cyanophyceae; Chlrococcales, Oscillatoriales freshwater cyanoprokaryota I. Vol. 5, No. 1. Incheon: National institute of biological resources. 71 pp.

Prasanna R and Nayak S. (2007). Influence of diverse rice soil ecologies on cyanobacterial diversity and abundance. Wetlands Ecology and Management. 15: 127-134.

Prescott GW. (1970). Algae of the western great lakes area. WMC. Brown Company Publishers, Dubuque, Iowa. 977 pp.

Rangaswamy G. (1966). Agricultural microbiology. Asia publishing house, Bombay.

Rao PSN. and Gupta RK. (2015). Algae of India

Volume 3. A checklist of Indian marine algae (excluding diatoms & dinoflagellates). Salt Lake, Kolkata: Botanical Survey of India Ministry of Environment, Forests and Climate Change Government of India. 104 pp.

Riahi H, Chookalaii H, Shariatmadari Z, Ghassempour AR. (2017). Enhancement of phenolic acid and flavonoid in *Plantago major* by extract of cyanobacteria. In 11th International Phycological Congress (IPC 11).

Riahi H, Shariatmadari Z, Khangir M, Azizi A. (2013). Effect of *Anabaena* vaginicola inoculum on growth of pot plants. Proceeding of International Symposium on Growing Media, Composting and Substrate Analysis. Acta Horticulturae. 1013, 507-513.

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

Schmidle W. (1901). Schizophyceae, Conjugatae, Chlorophyceae. In: Die von W. Goetze am Rukwa-See und Nyassa-See sowie in den zwischen beiden Seen gelegenen Gebirgsländern, insbesondere dem Kinga-Gebirge gesammelten Pflanzen, nebst einigen Nachträgen (durch*bezeichnet) zu Bericht III. 30: 240-253.

Sergeeva E, Liaimer A, Bergman B. (2002). Evidence for production of the phytohormone indole-3-acetic acid by cyanobacteria. Planta. 215: 229–238.

Seyed Hashtroudi M, Ghassempour, AR, Riahi H, Z, Khanjir M. (2012). Endogenous auxins in plant growth promoting cyanobacteria *Anabaena vaginicola* and *Nostoc calcicola*. Journal of Applied Phycology. 25 (2): 379-386.

Shariatmadari Z, Davari M, Riahi H, Modaressi Z. (2018). *Cylindrospermum voukii* and *Wollea saccata*, new records for algal flora of Iran. Rostaniha. 19 (2): 184-188.

Shariatmadari Z, Riahi H, Abdi M, Seyed Hashtroudi M, Ghassempour AR. (2015). Impact of cyanobacterial extracts on the growth and oil content of the medicinal plant *Mentha piperita* L.. Journal of Applied Phycology. 27 (6): 2279-2287.

Shariatmadari Z, Riahi H, Seyed Hashtroudi M, Ghassempour AR, Aghashariatmadary Z. (2013). Plant growth promoting cyanobacteria and their distribution in terrestrial habitats of Iran. Soil Science and Plant Nutrition. 59: 535-547.

Shariatmadari Z, Riahi H, Sonboli A. (2014). Morphometric and phylogenetic analyses of *Anabaena* strains (Cyanoprokaryota) from terrestrial habitats of Iran. The Iranian Journal of Botany. 20 (1): 119-129.

Sherwood AR. (2004). Bibliographic checklist of the nonmarine algae of the Hawaiian Islands. Records of the Hawaii Biological Survey for 2003. Bishop Museum Occasional Papers. 80: 1-26.

Siddiqui KU, Islam MA, Ahmed ZU, Begum ZNT, Hassan MA, Khondker M, Rahman MM, Kabir SMH, Ahmad ATA, Rahman AKA, Haque EU. (2009). Cyanobacteria, Bacteria and Fungi Vol. 2. In: Encyclopedia of flora and fauna of Bangladesh. Dhaka (Eds). Asiatic Society of Bangladesh. pp. 1-415.

Silva PC, Basson PW, Moe RL. (1996). Catalogue of the benthic marine algae of the Indian Ocean. University of California Publications in Botany. 79: 1-1259.

Singh JS, Kumar A, Rai AN, Singh DP. (2016). Cyanobacteria: A precious bioresource in agriculture, ecosystem, and environmental sustainability. Frontiers in Microbiology. 7: 1-19.

Skuja H. (1949). Zur Süsswasser algen flora Burmas. Nova Acta Regiae Societatis Scientiarum Upsaliensis, Series 4. 14 (5): 1-188.

Stanier RY, Kunisawa R, Mandal M, Cohen-Bazire G. (1971). Purification and properties of unicellular blue-green algae (Order. Chroococcales). Bacteriological Reviews. 35: 171-305.

Vynogradova OM. (2015 '2014'). Cyanoprokaryota. In: Algae of Ukraine: diversity, nomenclature, taxonomy, ecology and geography. Volume 4: Charophyta. (Tsarenko PM, Wasser SP, Nevo E. Eds). Ruggell: Koeltz Scientific Books. pp. 470-475.

Whitton BA, John DM, Johnso LR, Boulton PNG, Kelly MG, Haworth EY. (1998). A coded list of freshwater algae of the British Isles. LOIS Publication number 222. Wallingford: Institute of Hydrology and NERC. pp. 1-274.

Whitton BA. (2011). Cyanobacteria (Cyanophyta). In: The freshwater algal flora of the British Isles. An identification guide to freshwater and terrestrial algae. Second edition. (John DM, Whitton, BA, Broo, AJ. Eds). Cambridge: Cambridge University Press. pp. 31-158

Zand A, Riahi H, Shariatmadari Z, Zangeneh S. (2015). Effect of *Funneliformis mosseae* mycorrihza symbiosis on growth and yield of *Crocus sativus* L.. Journal of Saffron Research. 2: 141-151.