A TAXONOMIC STUDY ON SOIL TAXA OF APOHETEROCYTIC CYANOPROKARYOTA FROM NOSTOCACEAE FAMILY IN IRAN

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In a revision of the family Nostocaceae Kützing in terrestrial habitats of Iran, several taxa belonging to six genera were identified. Isolates were collected from 20 paddy field soils located in seven provinces of Iran. Among the identified taxa, 18 species and one variety belong to four genera, Nostoc Vaucher ex Bornet & Flahault, Trichormus (Ralfs ex Bornet & Flahault) Komárek & Anagnostidis, Nodularia Mertens ex Bornet & Flahault and Aulosira Kirchner ex Bornet & Flahault, known as apoheterocytic cyanoprokaryota and 20 taxa from two genera, Anabaena Bory ex Bornet & Flahault and Cylindrospermum Kützing ex Bornet & Flahault, known as paraheterocytic cyanoprokaryota. Among these taxa, Nostoc linckia var. arvense C. B. Rao, Nostoc alatosporum Sant Anna & al., Nostoc spongiaeforme Agardh ex Born. & Flah. and Nostoc verrucosum Vaucher ex Born. & Flah. are reported as four new records from this family in Iran. An identification key, distribution area and camera lucida pictures of apoheterocytic species as well as description of new taxa are presented in this study.

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Key words. Apoheterocytic form, akinete, cyanoprokaryota, Nostocaceae, morphospecies, new record, Iran.

INTRODUCTION

The family Nostocaceae (Order Nostocales) consists of diazotrophic cyanoprokaryota, which are broadly characterized by unbranched filaments and the production of up to three kinds of differentiated cells (Rezanka & Dembitsky 2006). In all genera of this family, trichomes comprised three kinds of cells or the vegetative cells, heterocysts and akinetes. Among these different forms of cells, the akinetes which are enlarged reproductive cells with thick walls have great taxonomic value (Prescott 1970). The shape and location of akinetes in the trichome as well as apoheterocytic or paraheterocytic form of trichome are the most important characters for separation of several genera in this family. In apoheterocytic forms, akinetes start to develop from vegetative cells in the middle...
between two heterocysts and later all or almost all vegetative cells change into akinetes, towards heterocysts. Contrary to apoheterocytic forms, in paraheterocytic cyanoprokaryota, akinetes form near the heterocysts or separated from them by one to several vegetative cells (Komárek & Hauer 2011; Pliński 2005). Apoheterocytic form of trichomes can be seen in several nostocacean cyanoprokaryota such as Nostoc Vaucher ex Bornet & Flahault, Trichormus (Ralfs ex Bornet & Flahault) Komárek & Anagnostidis, Nodulalia Mertens ex Bornet & Flahault and Aulosira Kirchner ex Bornet & Flahault and paraheterocytic form of them can be seen in genera such as Anabaena Bory ex Bornet & Flahault, Anabaenopsis (Wolosz,) Miller, Aphaniizomenon Morren and Cylindrospermum Kützing ex Bornet & Flahault.

Up to now, several species from different genera of nostocacean cyanoprokaryota were reported from terrestrial habitats of Iran but most of records related to paraheterocytic forms such as Anabaena and Cylindrospermum (Shariatmadari & al. 2011a, Shariatmadari & Riahi 2012). Report of 11 species of Nostoc, 5 species of Trichormus and 1 species of Nodularia from paddy field soils of Gilan and Golestan provinces was the previous records of this group from paddy soils of Iran (Novruz & Ahmadimoghadam 2006; Shariatmadari & Riahi 2010). This study is focused on seven main rice cultivation provinces situated in north, centre, south, west and east of Iran. In present study, an attempt was made to contribute a new knowledge about apoheterocytic genera comprised to Nostoc, Nodularia, Trichormus and Aulosira.

MATERIALS AND METHODS
The soil samples were collected from 20 paddy fields from April 2008 to May 2010 (Table 1) according to Rangaswamy’s method (1996). The collected soil samples were transferred to sterile Petri dishes and sterilized nitrate free BG-11 medium was added (Table 2). The Petri dishes were placed in a culture chamber (Noorsanat Tissue Culture Shelf, Model SB5520) at 25±5°C and a 12/12h light-dark cycle under fluorescent illumination of 2,000 to 2,500 Lux for two weeks. After colonization, blue-green algae were transferred to the agar plates for purification. Taxonomic determination was carried out by light microscopy (Olympus, Model BM-2) and based on Desikachary (1959), Prescott (1970), Wehr & al. (2002), Whitford & Schumacher (1973) and John & al. (2002) by prepared semipermanent slides. The morphological studies were focused on 41 populations from nineteen morphospecies of apoheterocytic genera, Nostoc, Nodularia, Aulosira and Trichormus, which were isolated from paddy soils of diverse geographical locations in Iran. The physico-chemical properties of the paddy soils, such as electrical conductivity (EC) and pH, were analyzed for all the soil samples following the methodology outlined by Hayes (1981).

RESULTS
In this study, 41 isolates belonging to nineteen morphospecies of apoheterocytic nostocacean cyanoprokaryota were identified. The vegetative and reproductive characters such as shape, colour and size of the thallus; wide and length of trichomes; entangled or not entangled form of trichomes; shape, colour and thickness of mucilaginous envelope; shape, size and colour of vegetative cells, heterocysts and akinetes as well as colour and ornamentation of cell walls of the akinetes were used in the taxonomic determination. All species and their distribution are listed in table 3.

key to apoheterocytic form genera distributed in some paddy field soils of Iran
1. Filaments usually with distinct mucilaginous envelope 2. Filaments sometimes without distinct mucilaginous envelope
2. Filaments entangled, generally in a definite colony
3. Vegetative cells free, generally single
4. Vegetative cells short and discoid, Heterocysts sometimes flattened
5. Vegetative cells not discoid, Heterocysts semi spherical or barrel shape

Type species. Nostoc commune Vaucher ex Bornet & Flahault

A key to Nostoc species distributed in some paddy field soils of Iran
1. Colonies spherical; Trichomes very densely coiled
2. Colonies not spherical; Trichomes densely or not densely coiled
3. Mucilaginous envelope very broad, slightly yellowish or yellowish-brown
4. Mucilaginous envelope narrow, colourless or slightly yellowish-brown
5. Mucilaginous sheath lamellated

Nostoc linckia var. arvense (4)
- Mucilaginous sheath not lamellated Nostoc sp.1 (11)
4. Filaments densely entangled Nostoc punctiforme (8)
- Filaments slightly entangled
5. Mucilaginous envelope yellowish-brown

Nostoc spongiaeform (9)
Table 1. Geographical and some ecological details of the sampling locations.

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude/Longitude</th>
<th>pH</th>
<th>EC (dS/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mazandaran: Tonkabon, Tazehabad village</td>
<td>36°39’ N 51°25’ E</td>
<td>8.1</td>
<td>1.16</td>
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<tr>
<td>Mazandaran: Tonkabon</td>
<td>36°48’ N 50°52’ E</td>
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<tr>
<td>Mazandaran: Gharakheil</td>
<td>36°27’ N 52°46’ E</td>
<td>7.9</td>
<td>0.73</td>
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<tr>
<td>Mazandaran: Savadkoh</td>
<td>36°08’ N 53°02’ E</td>
<td>7.8</td>
<td>1.87</td>
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<tr>
<td>Gilan: Rostamabad</td>
<td>36°53’ N 49°20’ E</td>
<td>8.1</td>
<td>3.18</td>
</tr>
<tr>
<td>Gilan: Sangar, Omsheh village</td>
<td>37°16’ N 49°35’ E</td>
<td>8.2</td>
<td>2.39</td>
</tr>
<tr>
<td>Gilan: Rodsar, Rahimabad village</td>
<td>36°51’ N 50°13’ E</td>
<td>8.0</td>
<td>1.47</td>
</tr>
<tr>
<td>Gilan: Rasht, Saravan village</td>
<td>37°05’ N 49°24’ E</td>
<td>8.1</td>
<td>2.79</td>
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<tr>
<td>Qazvin: Alamut village</td>
<td>36°23’ N 50°33’ E</td>
<td>8.1</td>
<td>2.47</td>
</tr>
<tr>
<td>Lorestan: Visan village</td>
<td>33°49’ N 48°07’ E</td>
<td>8.4</td>
<td>1.03</td>
</tr>
<tr>
<td>Fars: Firuzabad, Ebrahimabad village</td>
<td>29°00’ N 52°56’ E</td>
<td>8.1</td>
<td>9.55</td>
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<tr>
<td>Fars: Marvdasht, Esmaeilabad village</td>
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<td>8.3</td>
<td>2.38</td>
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<td>Fars: Marvdasht, Kamfiroz village</td>
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<td>8.0</td>
<td>2.50</td>
</tr>
<tr>
<td>Fars: Fathabad</td>
<td>29°19’ N 52°37’ E</td>
<td>8.0</td>
<td>18.92</td>
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<tr>
<td>Khorasan razavi: Kalat village</td>
<td>36°59’ N 59°47’ E</td>
<td>8.1</td>
<td>2.93</td>
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<tr>
<td>Esfahan: Flavarjan village</td>
<td>32°32’ N 51°30’ E</td>
<td>8.4</td>
<td>2.48</td>
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<tr>
<td>Esfahan: Lenjan, Zarirshahr village</td>
<td>32°22’ N 51°22’ E</td>
<td>8.3</td>
<td>3.31</td>
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<tr>
<td>Esfahan: Varnamkhast</td>
<td>32°21’ N 51°22’ E</td>
<td>8.1</td>
<td>3.53</td>
</tr>
<tr>
<td>Esfahan: Ghahadarijan</td>
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<td>8.3</td>
<td>1.26</td>
</tr>
<tr>
<td>Esfahan: Falavarjan, Jujil village</td>
<td>32°34’ N 51°28’ E</td>
<td>8.1</td>
<td>3.53</td>
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</table>

Table 2. Chemical composition of Nitrate free BG-11 medium (Stanier & al. 1971).

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Quantity (g L⁻¹)</th>
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<tbody>
<tr>
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</tr>
<tr>
<td>K₂HPO₄</td>
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</tr>
<tr>
<td>MgSO₄.7H₂O</td>
<td>0.075</td>
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<tr>
<td>CaCl₂.2H₂O</td>
<td>0.036</td>
</tr>
<tr>
<td>Citric acid</td>
<td>0.006</td>
</tr>
<tr>
<td>Ferric ammonium citrate</td>
<td>0.006</td>
</tr>
<tr>
<td>EDTA</td>
<td>0.001</td>
</tr>
<tr>
<td>Na₂CO₃</td>
<td>0.02</td>
</tr>
<tr>
<td>Trace metal mix</td>
<td>1 ml L⁻¹</td>
</tr>
<tr>
<td>H₃BO₄</td>
<td>2.86</td>
</tr>
<tr>
<td>MnCl₂.4H₂O</td>
<td>1.81</td>
</tr>
<tr>
<td>ZnSO₄.7H₂O</td>
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</tr>
<tr>
<td>Na₂MoO₄.2H₂O</td>
<td>0.390</td>
</tr>
<tr>
<td>CuSO₄.5H₂O</td>
<td>0.079</td>
</tr>
<tr>
<td>Co(NO₃)₂.6H₂O</td>
<td>0.0494</td>
</tr>
</tbody>
</table>

- Mucilaginous envelope colourless 6
6. Vegetative cells barrel-shaped 7
- Vegetative cells cylindrical to barrel-shape 10
7. Spores spherical; epispore yellowish-brown 9
- Spores semi-sphaerical to ellipsoidal; epispore colourless or yellowish-brown 8
8. Heterocysts sub-spherical; akinetes sub-spherical 11
- Heterocysts ellipsoidal or barrel-shape, rarely sub-spherical Nostoc paludosum (7)
9. Epispore brown; spores ellipsoidal Nostoc alatosporum (1)
- Epispore colourless; spores semi round Nostoc sp.2(12)
10. Trichomes entangled 11
- Trichomes not entangled or slightly entangled 12
11. Terminal heterocysts broader than vegetative cells; akinetes ellipsoidal Nostoc paludosum (7)
- Terminal heterocysts broad lower than vegetative cells; akinetes semispherical Nostoc verrucosum (14)
12. Spores sub-spherical or slightly longer than broad

<table>
<thead>
<tr>
<th>Species</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Nostoc oryzae</em> (Fritsch) Komárek &amp; Anagnostidis</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
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<tr>
<td><em>Anabaena oryzae</em> Fritsch</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>Anabaena gelatinosa</em> Fritsch ex De</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Nostoc linckia</em> var. arvense C. B. Rao</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>Trichormus arvensis</em> (C. B. Rao) Komárek &amp; Anagnostidis</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Nostoc paludosum</em> Kützing ex Bornet &amp; Flahault</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Nostoc punctiforme</em> (Kützing) Hariot.</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
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<tr>
<td><em>Nostoc muscorum</em> C. Agardh.</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>=<em>Desmonostoc muscorum</em> (C.Agardh ex Bornet &amp; Flahault)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Trichormus ellipsosporum</em> var. violaceum C. B. Rao.</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Nodularia harveyana</em> (Thwaites) Thuret</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

**Species (3)**

- Spores ellipsoidal
- Thallus dull olive or brown
- Thallus pale blue-green

1. *Nostoc alatosporum* Sant’Anna & al. 2007. Hoehnea 34 (1): 95-101. (Fig. 1A). 
**Description.** Colonies macroscopic, mucilaginous, dark blue-green. Vegetative cells ellipsoidal to cylindrical, with 4 µm broad and 7-11 µm long; apical cells sub-cylindrical. Heterocysts terminal and intermediate with hyaline yellowish content; intermediate heterocyst solitary, ellipsoidal or long ellipsoidal, with 6 µm broad and 9-11 µm long; terminal heterocyst sub-spherical, with 5 µm broad and 5-5.5 µm long. Akinetes in rows, ellipsoidal, with 9 µm broad and 8-11 µm long, includes widened epispore with distinct widened, radially striated epispore.

2. *Nostoc calcicola* Brébisson ex Born. & Flah. 1888. Brébisson in Meneghini, Monographia Nostochinearum italicarum, 121, 1843; Bornet and Flahault, Revision des Nostocacées hétérocystées, 202, 1888. (Fig. 2A). 

**General distribution.** Brazil (Sant’Anna & al. 2007; Werner 2010).
1937. The Myxophyceae of the United Provinces-III, Proc. Indian Acad. Sci., B, 6: 359. (Fig. 2B).

**General distribution.** Asia (Desikachary 1959; Shariatmadari & Riahi 2010).

**Distribution in studied sites.** Gilan: Omsheh (37°16’ N 49°35’ E). -Lorestan: Visan (33°49’ N 48°07’ E).

4. *Nostoc linckia var. arvensis* C. B. Rao 1937. The Myxophyceae of United Provinces, III, Proc. Indian Acad. Sci., B, 6: 358, Fig. 4A, 1937. (Fig. 1B).

This name is currently regarded as a taxonomic synonym of *Trichormus arvensis* (C. B. Rao) Komárek & Anagnostidis.

**Description.** Colonies gelatinous, yellowish brown. Trichomes broad, enveloped by a lamellated and yellowish brown mucilaginous envelope. Vegetative cells barrel-shaped, with 4-6 µm broad and 5 µm long. Heterocysts intermediate, almost spherical, 6-7 µm broad, usually not enveloped by any mucilage. Akinetes in long chains, spherical or short ellipsoidal, with 6 µm broad and 6-8 µm long.

**General distribution.** Europe (Caraus 2002). -Asia (Desikachary 1959).

**Distribution in studied sites.** Fars: Kamfiroz (30°15’ N 52°17’ E).

5. *Nostoc muscorum* Agardh ex Born. & Flah. 1888. Agardh, Dispositio Algar. Sueciae, 44, 1812; Bornet & Flahault, Revision des Nostocacées hétérocystées, 200, 1888. (Fig. 3A).

This name is currently regarded as a taxonomic synonym of *Desmonostoc muscorum* (C. Agardh ex Bornet & Flahault) Hrouzek & Ventura.


6. *Nostoc oryzae* (Fritsch) Komárek & Anagnostidis (Fig. 6A).


7. *Nostoc paludosum* Kützing ex Bornet & Flahault 1888. Kützing, Tab. Phycologicae, 2: 1, pl. 1, fig. 2, 1850; Bornet & Flahault, Revision des Nostocacées hétérocystées, 191, 1888. (Fig. 6B).


**Distribution in studied sites.** Gilan: Omsheh (37°16’ N 49°35’ E). -Qazvin: Alamut (36°23’ N 50°33’ E).

8. *Nostoc punctiforme* Hariot 1891. J. de Bot., 5: 31. (Fig. 6C).


**Distribution in studied sites.** Gilan: Saravan (37°05’ N 49°24’ E).

9. *Nostoc spongiforme* Agardh ex Born. & Flah. 1888. C. Ag., Syst. Alg. 22, 1824; Bornet and Flahault, Revision des Nostocacées hétérocystées, 197, 1888. (Fig. 4A).

**Syn.:** Nostoc spongiforme C. Agardh 1824. C. Ag., Syst. Alg. 22, 1824.

**Description.** Colonies sphaerical, gelatinous, light blue-green; Filaments flexuous, loosely entangled; gelatinous sheath more or less distinct along the periphery, yellowish-brown. Vegetative cells short barrel-shaped, 5-5.5 µm broad and 4.5-5 µm long. Heterocysts terminal and intermediate; intermediate heterocysts sub-spherical, with 8 µm broad; terminal heterocysts obovoid, with 4.5 µm broad and 6 µm long. Akinetes oblong, with 5-6 µm broad and 7-9 µm long.


**Distribution in studied sites.** Fars: Esmaeilabad (28°60’ N 53°60’ E).

10. *Nostoc sphaericum* Vaucher ex Born. & Flah. 1888. Vaucher, Histoire des Conflèves deau douce, 225, pl. 16, Fig 3, 1803; Bornet and Flahault, Revision des Nostocacées hétérocystées, 216, 1888. (Fig. 5B).

**General distribution.** Asia (Desikachary 1959).

**Distribution in studied sites.** Gilan: Omsheh (37°16’ N 49°35’ E).

11. *Nostoc sp.;* (Fig. 3B).

**Description.** Colonies not sphaerical, gelatinous, pale blue-green; filaments flexuous, loosely entangled; gelatinous sheath very broad, about 36 µm wide, not lamellated, slightly yellowish brown. Vegetative cells barrel-shape, 4.5-5 µm broad and 5-8 µm long. Heterocysts short barrel-shape, with 5.5-6 µm broad and 7 µm long. Akinetes ellipsoidal, with 6-7 µm broad...
and 8-11 µm long.

**Distribution in studied sites.** Qazvin: Alamut (36°23' N 50°33' E).

12. **Nostoc sp.** (Fig.5A).

**Description.** Colonies not sphaerical, gelatinous, blue-green; filaments flexuous, loosely entangled; gelatinous sheath very narrow, not lamellated, colourless. Vegetative cells short barrel shape, 6.5 µm broad and 5.5-6 µm long. Heterocysts short barrel shape or semi sphaerical, with 7 µm broad and 6.5 µm long. Akinetes semi sphaerical or ellipsoidal, with 7-8 µm broad and 8-10 µm long.

**Distribution in studied sites.** Qazvin: Alamut (36°23' N 50°33' E).

13. **Nostoc sp.** (Fig.5B).

**Description.** Colonies completely sphaerical, gelatinous, light blue-green; filaments very densely coiled, gelatinous sheath sphaerical, colourless. Vegetative cells short barrel shape, 2.5 µm broad and 2.5-5 µm long. Heterocysts semi sphaerical, with 4.5-5 µm broad and 4.4-5 µm long. Akinetes semi sphaerical, with 3.5-4 µm broad and 5.5-5.5 µm long.

**Distribution in studied sites.** Esfahan: Lenjan (32°22' N 51°22' E).

14. **Nostoc verrucosum** Vaucher ex Born. & Flah. 1888. Vaucher, Histoire des Conferves deau douce, 225, pl. 16, Fig 3, 1803; Bornet and Flahault, Revision des Nostocacées hétérocystées, 216, 1888. (Fig. 4B).

**Syn.:** Nostoccella verrucosa (Vaucher) Gaillon., Nostoc verrucosum Vaucher 1803.

**Description.** Colonies sub-spherical, gelatinous, verrucose on the surface, blackish-green. Filaments flexuous and densely entangled; inner sheath hyaline and diffuent. Vegetative cells short barrel-shaped, shorter than broad, 4-5 µm broad and 5 µm long. Heterocysts intermediate and terminal; intermediate heterocyst sub-spherical 5 µm broad; terminal heterocysts obovoid. Akinetes ovate or semi around, 6-9 µm long, 5-7 broad, epispore smooth, colourless.


**Distribution in studied sites.** Gilan: Omsheh (37°16' N 49°35' E).


**key to Trichormus species distributed in some paddy field soils of Iran**

1. Spores sphaerical, in even size, adjoining the heterocysts; epispore yellowish-brown

**Trichormus fertilissimus**

- Spores in uneven size, barrel-shaped; not contiguous with the heterocysts **Trichormus ellipsosporus**

1. **Trichormus ellipsosporus** (Fritsch) Komárek & Anagnostidis 1989. Algolog. Stud. 56: 303. (Fig. 7A).


2. **Trichormus fertilissimus** (C. B. Rao) Komárek & Anagnostidis 1989, (Fig. 7B).


**General distribution.** America (Dawes 1974). - Asia (Desikachary 1959; Shariatmadari & al. 2011a). **Distribution in studied sites.** Lorestan: Visan (33°49' N 48°07' E).

**Nodularia** Mertens ex Bornet & Flahault 1888. In Jurgens, Algae aquaticae, Dec., 15, nr. 4, 1822; Bornet and Flahault, Revision des Nostocacées hétérocystées, 243, 1888.


**key to Nodularia species distributed in some paddy field soils of Iran**

1. Spores ellipsoidal; vegetative cells with more than 10 µm broad **Nodularia spumigena**

- Spores semi-around; Vegetative cells with lower than 10 µm broad **Nodularia harveyana**


2. **Nodularia spumigena** Mertens ex Bornet & Flahault 1888. Revision des Nostocacées hétérocystées continues dans les principaux herbiers de France. Annales des Sciences Naturelles, Botanique, Septieme Serie 7: 177-262. (Fig. 8B).
Fig. 1. A. *Nostoc alatosporum*: a- part of trichomes with heterocyst and akinetes, b- akinetes, c- apical heterocyst. B. *Nostoc linckia* var. *arvense*: a- part of trichomes with heterocyst and akinetes, b- akinetes, c- immature trichome, d- gelatinous sheath (Scale: 10 µm).

Fig. 2. A. *Nostoc calcicola*: a- part of trichomes with heterocyst, b- akinetes, c- apical heterocyst. B. *Nostoc ellipsosporum* var. *violaceum*: a- immature trichome, b- part of trichomes with heterocyst and akinetes, c- akinete, d- apical heterocyst (Scale: 10 µm).

Fig. 3. A. *Nostoc muscorum*: a- part of immature trichome, b- gelatinous sheath, c- apical heterocyst, d- akinetes. B. *Nostoc sp.*: a- part of immature trichome, b- gelatinous sheath (Scale: 10 µm).

Fig. 4. A. *Nostoc spongiaeforme*: a- part of immature trichome, b- gelatinous sheath, c- apical heterocyst, d- akinetes. B. *Nostoc verrucosum*: a- part of immature trichome, b- akinetes (Scale: 10 µm).
Fig. 5. A. Nostoc sp2.: a- part of trichomes with heterocyst., b- akinetes., c- apical cell. B. Nostoc sphaericum: a- immature trichome, b- part of trichomes with heterocyst and akinetes., c- akinete (Scale: 10 µm).

Fig. 6. A. Nostoc oryzae : a- part of immature trichome, b- apical heterocyst., c- part of mature trichome., d- akinetes., B. Nostoc paludosom: a- part of immature trichome., b- Apical heterocyst., c- gelatinous sheath., C. Nostoc punctiforme (Scale: 10 µm).

Fig. 7. A. Trichormus ellipsosporus: a- immature trichome., b-part of trichomes with heterocysts and akinetes., c- apical part of trichome, d- akinetes. B. Trichormus fertilissimus: a- immature trichome., b- part of trichomes with heterocysts and akinetes, c- apical part of trichome, d- akinetes (Scale: 10 µm).

Fig. 8. A. Nodularia harveyana: a- part of immature trichome, b- akinetes., c- part of trichomes with heterocyst and akinetes., B. Nodularia spumigena: a-part of immature trichomes., b- akinetes (Scale: 10 µm).
Syn.: *Nodularia* *spumigena* Mertens 1822., *Nostoc* *spumigena* (Mertens) Drouet 1978.


*Distribution in studied sites.* Gilan: Rostamabad (36°53’ N 49°20’ E). - Fars: Ebrahimabad (29°00’ N 52°56’ E).


Type species. *Aulosira laxa* Kirchner ex Bornet & Flahault 1888.


**General distribution.** Asia (Desikachary 1959).

*Distribution in studied sites.* Gilan: Saravan (37°05’ N 49°24’ E).

**DISCUSSION**

The family *Nostocaceae* comprised of uniseriate and unbranched filamentous cyanoprokaryota which do not taper toward their apices (Prescott 1970). All members of this family are characterized by a three kinds of cells in their mature trichomes: vegetative cells, heterocysts (nitrogen-fixing cells) and akinetes (resting spores). The shape and location of akinetes are characters which have a great taxonomic value in this family. Apoheterocytic or paraheterocytic form of trichomes also is another important character which can be determined according to position of akinetes in filaments (Komárek 2010). This character not only is used for separation of genera such as *Anabaena* and *Nostoc*, but can divide similar taxa from genera such as *Anabaena* and *Trichormus*. However, the apoheterocytic formation of akinetes in genera such as *Nostoc*, *Trichormus*, *Nodularia* and *Aulosira* separate them from other taxa in this family, several morphometric and phylogenetic studies show close relationship of apoheterocytic genera to paraheterocytic taxa such as *Anabaena* and *Aphanizomenon* (Rajaniemi & al. 2005; Svanning & al. 2005; Henson & al. 2004).

In present study, 19 taxa from apoheterocytic cyanoprokaryota were identified, which are belonging to four genera, *Nostoc*, *Trichormus*, *Nodularia* and *Aulosira*. Morphological characters such as presence or absence of mucilaginous envelope, free or entangled form of filaments, as well as the heterocyst and vegetative cells shape were used for separation of apoheterocytic genera in this study. Among identified taxa, *Nostoc* species easily are separated from the others according to entangled form of trichomes. Definite shape of colony in some of *Nostoc* species is another character that supports identification of these taxa. These genera with 14 species showed predominance among the other genera and *Aulosira* with 1 species showed the lowest diversity. Previously predominance of *Nostoc* in paddy soils of India was reported by Prassana and Nayak (2007). The maximum number and variation of species was recorded in paddy fields of Gilan province with 12 identified taxa from apoheterocytic nostocacean cyanoprokaryota. Gilan province is one of the largest producers of rice in Iran which is located near the Caspian Sea with favorable climate condition. Until now, several taxa of these genera were reported by several authors from paddy soils of Northern provinces of Iran (Nowruzi & Ahmadimoghdam 2006, Shariatmadari & Riahi 2010) but there is a little information from terrestrial blue-green algae in other provinces of the country. Our results showed distribution of these algae in terrestrial habitats of seven main rice cultivation provinces of Iran. Among identified taxa, *Nostoc linckia* var. arvense C. B. Rao, *Nostoc alatosporum* Sant Anna & al., *Nostoc spongiaeforme* Agardh ex Born. & Flah. and *Nostoc verrucosum* Vaucher ex Born. & Flah. are reported as four new records from this family in Iran. In conclusion, our report emphasis the predominance of *Nostoc* spp. from apoheterocytic nostocacean cyanoprokaryota in paddy soils of Iran and introduce four taxa as new record for Iran.

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