

# A TAXONOMIC STUDY ON SOIL TAXA OF APOHETEROCYTTIC 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. *arvensis* 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.

مطالعه سیانوپروکاریوت‌های خاکری با ساختار آپوهتروسیستیک از خانواده *Nostocaceae* در ایران

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جهت بررسی نمونه‌های خاکری خانواده *Nostocaceae* Kützing، تاکسون‌های موجود در خاک 20 ایستگاه از 7 استان دارای کشت برنج کشور مورد مطالعه قرار گرفت. طی این تحقیق در مجموع تاکسون‌هایی متعلق به 6 جنس از این خانواده شناسایی شد که از میان تاکسون‌های شناسایی شده، 18 گونه و 1 واریته از 4 جنس *Nostoc* Vaucher ex Bornet & Flahault، *Trichormus* (Ralfs ex Bornet & Flahault) Komárek & Anagnostidis، *Nodularia* Mertens ex Bornet & Flahault، *Aulosira* Kirchner ex Bornet & Flahault و 20 تاکسون از 2 جنس *Anabaena* Bory ex Bornet & Flahault و *Cylindrospermum* Kützing ex Bornet & Flahault دارای ساختار ترایکمی آپوهتروسیستیک و 20 تاکسون از 2 جنس *Anabaena* Bory ex Bornet & Flahault و *Cylindrospermum* Kützing ex Bornet & Flahault دارای ساختار پراهرتروسیستیک می‌باشند. از میان گونه‌های شناسایی شده از این خانواده، چهار گونه زیر برای نخستین بار از ایران گزارش می‌شوند و کلید شناسایی، محدوده پراکنش و تصاویر کامرا لوسیدای گونه‌های شناسایی شده، به همراه شرح گونه‌های جدید با تاکید بر تاکسون‌های دارای ساختار آپوهتروسیستیک ارائه می‌گردد.

*Nostoc linckia* var. *arvensis* C. B. Rao, *Nostoc alatosporum* Sant Anna & al., *Nostoc spongiaeforme* Agardh ex Born. & Flah. and *Nostoc verrucosum* Vaucher ex Born. & Flah.

## 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 (Řezanka & 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, *Nodularia* 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, *Aphanizomenon* 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 (Nowruzi & 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 *Trichormus*
2. Filaments entangled, generally in a definite colony *Nostoc*  
- Filaments free, generally single 3
3. Vegetative cells short and discoid, Heterocysts sometimes flattened *Nodularia*  
- Vegetative cells not discoid, Heterocysts semi spherical or barrel shape *Aulosira*

*Nostoc* Vaucher ex Bornet & Flahault, 1888. Ann. Sci. Nat. Bot., Ser. VII, 7: 181.

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 *Nostoc* sp.3 (13)  
- Colonies not spherical; Trichomes densely or not densely coiled 2
2. Mucilaginous envelope very broad, slightly yellowish or yellowish-brown 3  
- Mucilaginous envelope narrow, colourless or slightly yellowish-brown 4
3. 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
5. Mucilaginous envelope yellowish-brown *Nostoc spongiaeforme* (9)

Table 1. Geographical and some ecological details of the sampling locations.

Location	Latitude/Longitude	pH	EC (dS/m)
Mazandaran: Tonkabon, Tazehabad village	36° 39' N 51° 25' E	8.1	1.16
Mazandaran: Tonkabon	36° 48' N 50° 52' E	8.1	1.52
Mazandaran: Gharakheil	36° 27' N 52° 46' E	7.9	0.73
Mazandaran: Savadkoh	36° 08' N 53° 02' E	7.8	1.87
Gilan: Rostamabad	36° 53' N 49° 20' E	8.1	3.18
Gilan: Sangar, Omsheh village	37° 16' N 49° 35' E	8.2	2.39
Gilan: Rodsar, Rahimabad village	36° 51' N 50° 13' E	8.0	1.47
Gilan: Rasht, Saravan village	37° 05' N 49° 24' E	8.1	2.79
Qazvin: Alamut village	36° 23' N 50° 33' E	8.1	2.47
Lorestan: Visan village	33° 49' N 48° 07' E	8.4	1.03
Fars: Firuzabad, Ebrahimabad village	29° 00' N 52° 56' E	8.1	9.55
Fars: Marvdasht, Esmailabad village	28° 60' N 53° 60' E	8.3	2.38
Fars: Marv dasht, Kamfiroz village	30° 15' N 52° 17' E	8.0	2.50
Fars: Fathabad	29° 19' N 52° 37' E	8.0	18.92
Khorasan razavi: Kalat village	36° 59' N 59° 47' E	8.1	2.93
Esfahan: Flavarjan village	32° 32' N 51° 30' E	8.4	2.48
Esfahan: Lenjan, Zarrinshahr village	32° 22' N 51° 22' E	8.3	3.31
Esfahan: Varnamkhast	32° 21' N 51° 22' E	8.1	3.53
Esfahan: Ghahdarijan	32° 30' N 51° 30' E	8.3	1.26
Esfahan: Falavarjan, Jujil village	32° 34' N 51° 28' E	8.1	3.53

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

Ingredients	Quantity (g L <sup>-1</sup> )
NaCl	1.5
K <sub>2</sub> HPO <sub>4</sub>	0.04
MgSO <sub>4</sub> .7H <sub>2</sub> O	0.075
CaCl <sub>2</sub> .2H <sub>2</sub> O	0.036
Citric acid	0.006
Ferric ammonium citrate	0.006
EDTA	0.001
Na <sub>2</sub> CO <sub>3</sub>	0.02
Trace metal mix	1 ml L <sup>-1</sup>
H <sub>3</sub> BO <sub>4</sub>	2.86
MnCl <sub>2</sub> .4H <sub>2</sub> O	1.81
ZnSO <sub>4</sub> .7H <sub>2</sub> O	0.222
Na <sub>2</sub> MoO <sub>4</sub> .2H <sub>2</sub> O	0.390
CuSO <sub>4</sub> . 5 H <sub>2</sub> O	0.079
Co(NO <sub>3</sub> ) <sub>2</sub> . 6H <sub>2</sub> O	0.0494

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

Table 3. List of apoheterocytic cyanoprokaryota recorded from several paddy soils of Iran and their distributions (1. Gilan province, 2. Mazandaran province, 3. Qazvin province, 4. Lorestan province, 5. Fars province, 6. Esfahan province, 7. Khorasane Razavi province).

Species	1	2	3	4	5	6	7
<i>Nostoc oryzae</i> (Fritsch) Komárek & Anagnostidis							
= <i>Anabaena oryzae</i> Fritsch							
= <i>Anabaena gelatinosa</i> Fritsch ex De	+	-	-	+	+	-	+
<i>Nostoc linckia</i> var. <i>arvense</i> C. B. Rao	-	-	-	-	+	-	-
= <i>Trichormus arvensis</i> (C. B. Rao) Komárek & Anagnostidis							
<i>Nostoc paludosum</i> Kützing ex Bornet & Flahault	+	-	+	-	-	-	-
<i>Nostoc punctiforme</i> (Kützing) Hariot.							
= <i>Nostoc hederula</i> Meneghini	+	-	-	-	-	-	-
= <i>Polycoccus punctiformis</i> Kützing							
<i>Nostoc ellipsoforum</i> var. <i>violaceum</i> C. B. Rao.	+	-	-	+	-	-	-
<i>Nostoc muscorum</i> C. Agardh.							
= <i>Desmonostoc muscorum</i> (C. Agardh ex Bornet & Flahault)	+	+	+	+	+	+	-
Hrouzek & Ventura							
<i>Nostoc calcicola</i> Brébisson ex Born. & Flah.	+	+	+	+	+	+	-
<i>Nostoc alatosporum</i> Sant' Anna & al.	-	-	+	-	+	-	-
<i>Nostoc spongiaeforme</i> Agardh ex Born. & Flah.							
= <i>Nostoc spongiaeforme</i> C. Agardh	-	-	-	-	+	-	-
<i>Nostoc sphaericum</i> Vaucher ex Born. & Flah.	+	-	-	-	-	-	-
<i>Nostoc verrucosum</i> Vaucher ex Born. & Flah.							
= <i>Nostocella verrucosa</i> (Vaucher) Gaillon	+	-	-	-	-	-	-
= <i>Nostoc verrucosum</i> Vaucher							
<i>Nostoc</i> sp. <sub>1</sub>	-	-	+	-	-	-	-
<i>Nostoc</i> sp. <sub>2</sub>	-	-	-	-	-	+	-
<i>Nostoc</i> sp. <sub>3</sub>	-	-	-	-	-	+	-
<i>Nodularia harveyana</i> (Thwaites) Thuret	+	-	-	-	+	+	-
<i>Nodularia spumigena</i> Mertens ex Bornet & Flahault	+	-	-	-	+	-	-
<i>Aulosira fertilissima</i> Ghose	+	-	-	-	-	-	-
<i>Trichormus ellipsoforum</i> (Fritsch) Komárek & Anagnostidis	+	+	-	-	-	+	+
= <i>A. variabilis</i> var. <i>ellipsoforma</i> F. E. Fritsch							
<i>Trichormus fertilissimus</i> (C. B. Rao) Komárek & Anagnostidis	-	-	-	+	-	-	-
= <i>A. fertilissima</i> C. B. Rao							

*Nostoc ellipsoforum* var. *violaceum* (3)  
 - Spores ellipsoidal 13  
 13. Thallus dull olive or brown *Nostoc muscorum* (5)  
 - Thallus pale blue-green *Nostoc oryzae* (6)

**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 episore with distinct widened, radially striated episore.

**General distribution.** Brazil (Sant'Anna & al. 2007; Werner 2010).

**Distribution in studied sites.** Qazvin: Alamut (36° 23' N 50° 33' E). -Fars: Kamfiroz (30° 15' N 52° 17' E).

**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.** Europe (Alvarez-Cobelas & Gallardo 1988). -Asia (Desikachary 1959; Hu & Wei 2006; Shariatmadari & al. 2011b). -Australia and New Zealand (Day & al. 1995).

**Distribution in studied sites.** Gilan: Rahimabad (36° 51' N 50° 13' E). -Mazandaran: Tonkabon (36° 48' N 50° 52' E). -Qazvin: Alamut (36° 23' N 50° 33' E). -Lorestan: Visan (33° 49' N 48° 07' E). -Esfahan: Falavarjan (32° 32' N 51° 30' E). -Fars: Easmaeilabad

(28° 60' N 53° 60' E).

**3. *Nostoc ellipsosporum* var. *violaceum*** C. B. Rao. 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. *arvense*** 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 (Carau 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.

*General distribution.* Europe (Whitton & al. 1998; Carau 2002; Alvarez-Cobelas & Gallardo 1988; O'Brien & al. 2006). -Asia (Leghari & al. 2005; Desikachary 1959; Shariatmadari & Riahi 2010; Nowruzi & Ahmadimoghadam 2006). -Australia and New Zealand (Day & al. 1995).

*Distribution in studied sites.* Gilan: Omsheh (37° 16' N 49° 35' E). -Mazandaran: Tazehabad (36° 39' N 51° 25' E). -Qazvin: Alamut (36° 23' N 50° 33' E). -Lorestan: Visan (33° 49' N 48° 07' E). -Esfahan: Lenjan (32° 22' N 51° 22' E). -Fars: Ebrahimabad (29° 00' N 52° 56' E), Esmaeilabad (28° 60' N 53° 60' E).

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

Syn.: *Anabaena oryzae* Fritsch. 1949, J. Indian bot. Soc., 28: 135, figs. 1-16; *Anabaena gelatinosa* Fritsch ex De 1939 (nomen nudum) non Reinsch non Wood.

*General distribution.* Asia (Shariatmadari & Riahi 2010; Naz & al. 2004; Desikachary 1959).

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

-Fars: Esmaeilabad (28° 60' N 53° 60' E). -Khorasan Razavi: Kalat (36° 59' N 59° 47' E).

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

*General distribution.* Europe (Alvarez-Cobelas & Gallardo 1988; Carau 2002). -Asia (Hu & Wei 2006; Desikachary 1959).

*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).

Syn.: *Nostoc hederulae* Meneghini in Kützing, Sp. Alg., 287, 1849; Born. and Flah., Revision des Nostocacées hétérocystées, 189, 1888.

*General distribution.* Europe (Alvarez-Cobelas & Gallardo 1988; Whitton & al. 1998; Carau 2002; O'Brien & al. 2006). -Asia (Desikachary 1959). -Pacific Islands (Sherwood 2004). -Australia and New Zealand (O'Brien & al. 2006).

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

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

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

*Description.* Colonies globose, gelatinous, light blue-green; Filaments flexuous, loosely entangled; gelatinous sheath more or less distinct along the periphery, yellowish-brown. Vegetative cells short barrel shape, 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.

*General distribution.* Europe (Whitton & al. 1998; Carau 2002). -Asia (Hu & Wei 2006). -Pacific Islands (Sherwood 2004).

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

**10. *Nostoc sphaericum*** 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. 5B).

*General distribution.* Asia (Desikachary 1959).

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

**11. *Nostoc* sp.<sub>1</sub>** (Fig. 3B).

*Description.* Colonies not spherical, 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.<sub>2</sub>** (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.* Esfahan: Lenjan (32° 22' N 51° 22' E).

**13. *Nostoc* sp.<sub>3</sub>**

*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 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.: *Nostocella 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 diffluent. 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, episporangium smooth, colourless.

*General distribution.* Europe (Alvarez-Cobelas & Gallardo 1988; Whitton & al. 1998; Caraus 2002). - Asia (Desikachary 1959; Hu & Wei 2006). -Australia and New Zealand (Day & al. 1995).

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

***Trichormus*** (Ralfs ex Bornet & Flahault) Komárek & Anagnostidis 1989, Algolog. Stud. 56: 303.

Type species. *Trichormus variabilis* (Kützing ex Born. & Flahault) Komárek & Anagnostidis 1989.

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

1. Spores sphaerical, in even size, adjoining the heterocysts; episporangium 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).  
Syn.: *A. variabilis* var. *ellipsospora* Fritsch, J. Indian Bot. Soc., 28: 142, 1949.

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

*Distribution in studied sites.* Gilan: Rahimabad (36° 51' N 50° 13' E). -Mazandaran: Tazehabad (36° 39' N 51° 25' E). -Esfahan: Falavarjan (32° 32' N 51° 30' E). -Khorasan Razavi: Kalat (36° 59' N 59° 47' E).

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

Syn.: *A. fertilissima* C. B. Rao, Proc. Indian Acad. Sci., B, 6: 363, 1937.

*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.

Syn.: *Spermosira* Kützing, 1843. Phycol. Gener., p. 213.

Type species. *Nodularia spumigena* Mertens ex Bornet & Flahault 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*

**1. *Nodularia harveyana*** (Thwaites) Thuret ex Bornet & Flahault 1888. Ann. Sci. Nat. Bot., ser. VII, 7: 243. (Fig. 8A).

*General distribution.* Europe (Alvarez-Cobelas & Gallardo 1988; Whitton & al. 1998; O'Brien & al. 2006). -Asia (Desikachary 1959; Shariatmadari & Riahi 2010). -Indian Ocean Islands (Silva & al. 1996). -Australia and New Zealand (Chapman 1956).

*Distribution in studied sites.* Gilan: Rostamabad (36° 53' N 49° 20' E). -Esfahan: Falavarjan (32° 32' N 51° 30' E). -Fars: Fathabad (29° 19' N 52° 37' E).

**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).

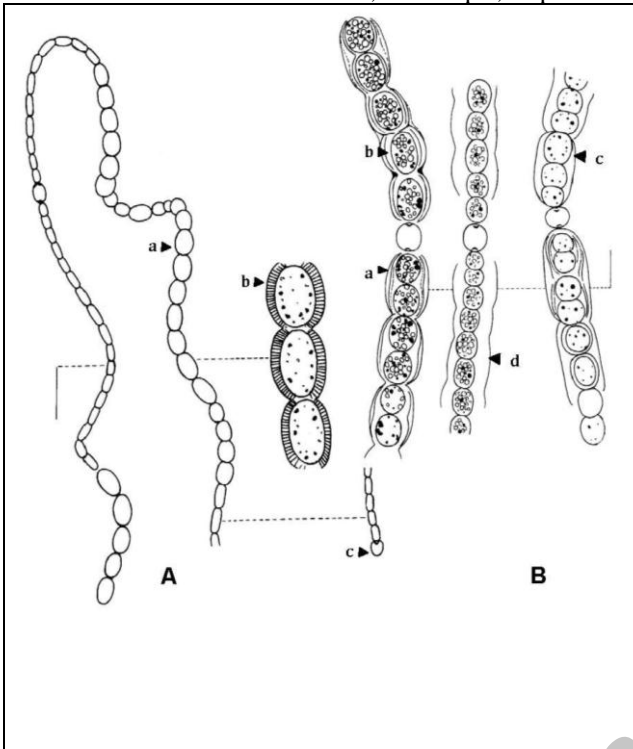


Fig. 1. A. *Nostoc alatosporum*: a- part of trichomes with heterocyst and akinetes, b- akinetes., c- apical heterocyst., B. *Nostoc linckia* var. *arvense*: a- part of trichomes with heterocyst and akinetes., b- akinetes., c- immature trichome., d- gelatinous sheath (Scale: 10  $\mu$ m).

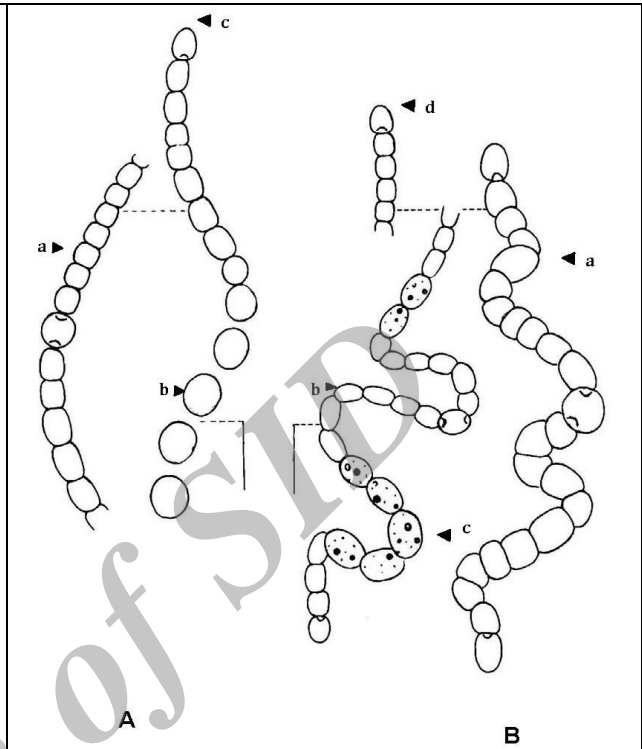


Fig. 2. A. *Nostoc calcicola*: a- part of trichomes with heterocyst., b- akinetes., c- apical heterocyst., B. *Nostoc ellipsosporum* var. *violaceum*: a- immature trichome, b- part of trichomes with heterocyst and akinetes., c- akinete., d- apical heterocyst (Scale: 10  $\mu$ m).

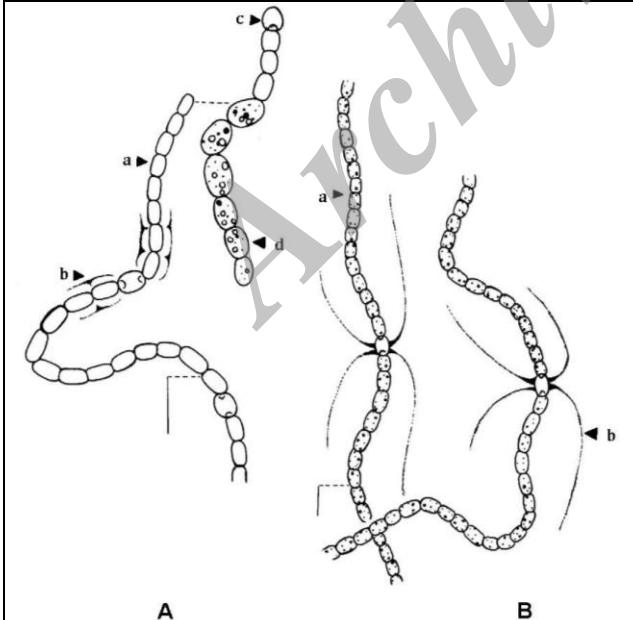


Fig. 3. A. *Nostoc muscorum*: a- part of immature trichome, b- gelatinous sheath., c- apical heterocyst., d- akinetes., B. *Nostoc* sp<sub>1</sub>: a- part of immature trichome., b-

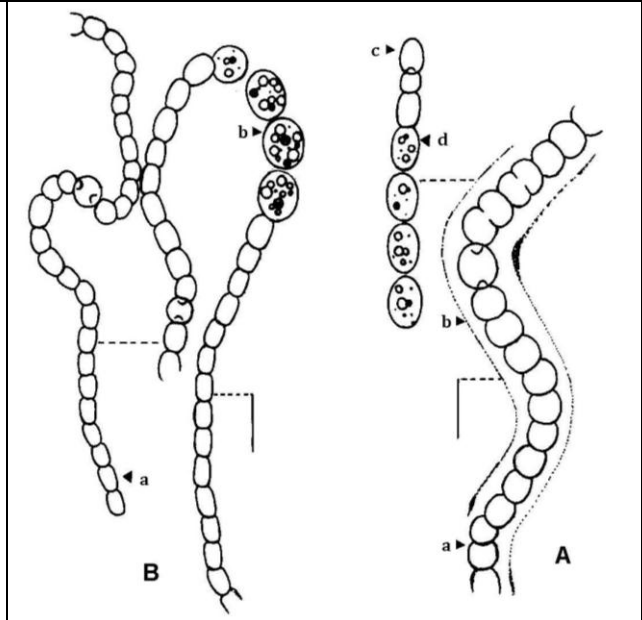


Fig. 4. A. *Nostoc spongiaeforme* : a- part of immature trichome, b- gelatinous sheath., c- apical heterocyst., d- akinetes., B. *Nostoc verrucosum*: a- part of immature

gelatinous sheath (Scale: 10 µm).

trichome., b- akinetes (Scale: 10 µm).

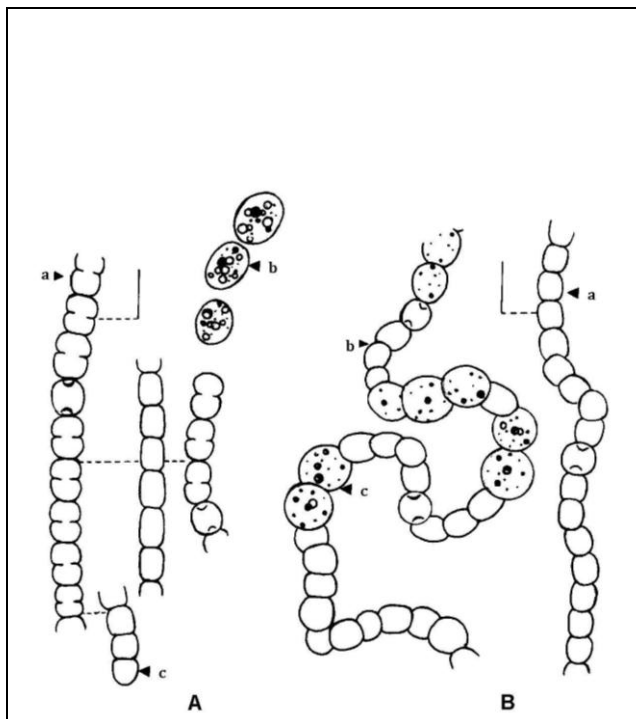


Fig. 5. A. *Nostoc* sp.: a- part of trichomes with heterocyst., b- akinetes., c- apical cell., B. *Nostoc sphaericum*: a- immature trichome, b- part of trichomes with heterocyst and akinetes., c- akinete (Scale: 10 µm).

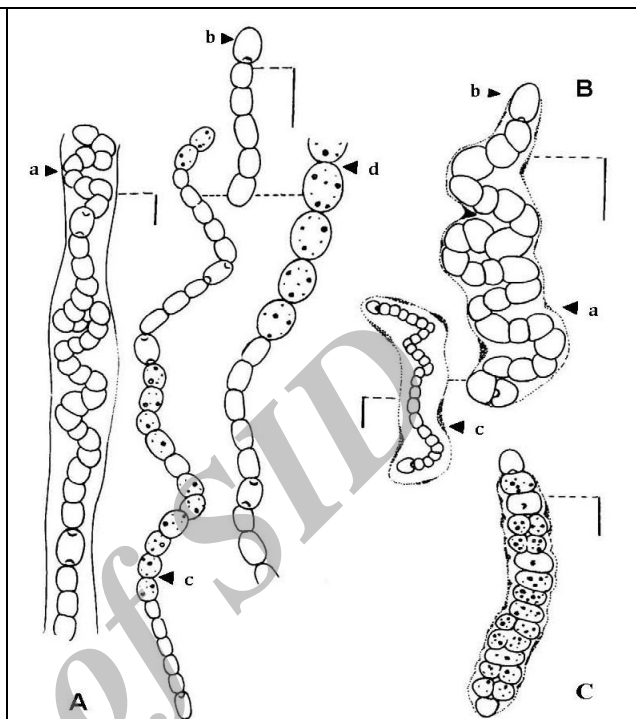


Fig. 6. A. *Nostoc oryzae* : a- part of immature trichome, b- apical heterocyst., c- part of mature trichome., d- akinetes., B. *Nostoc paludosom*: a- part of immature trichome., b- Apical heterocyst., c- gelatinous sheath., C. *Nostoc punctiforme* (Scale: 10 µm).

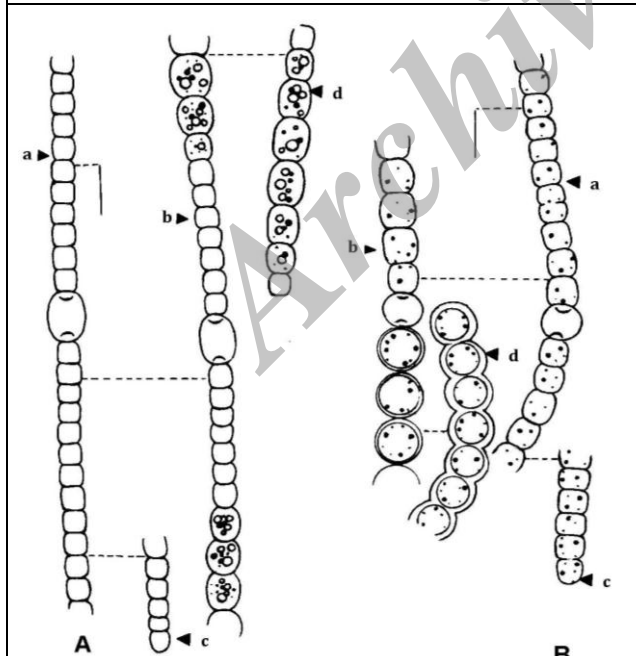


Fig. 7. A. *Trichormus ellipsosporus*: a- immature trichome., b-part of trichomes with heterocysts and akinetes., c- apical part of trichome, d- Akinetes., B.

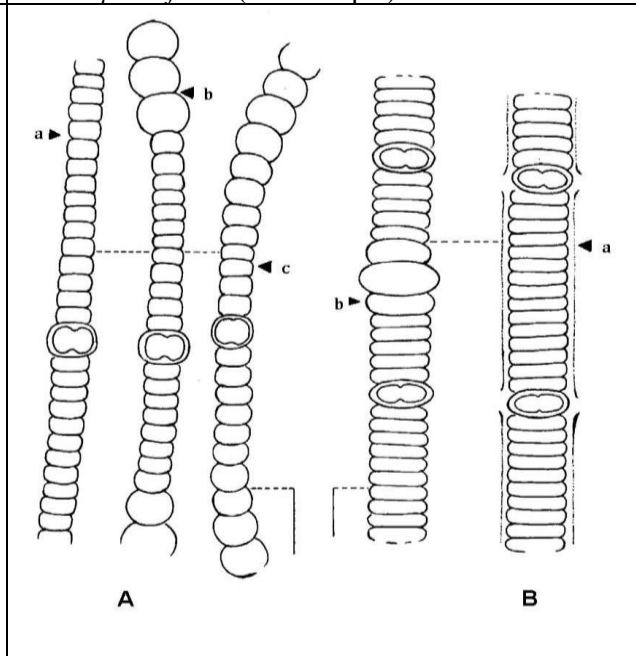


Fig. 8. A. *Nodularia harveyana*: a- part of immature trichome, b- akinetes., c- part of trichomes with heterocyst and akinetes., B. *Nodularia spumigena*: a-



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

part of immature trichomes., b- akinetes (Scale: 10 µm).

Syn.: *Nodularia spumigena* Mertens 1822., *Nostoc spumigena* (Mertens) Drouet 1978.

*General distribution.* Europe (Alvarez-Cobelas & Gallardo 1988; Whitton & al. 1998; Caraus 2002). - Canada (O'Brien & al. 2006). -Brazil (Werner 2010). - Asia (Silva & al. 1996; Afsharzadeh & al. 2003; Hu & Wei 2006; Shariatmadari & Riahi 2010). -Australia and New Zealand (Silva & al. 1996).

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

*Aulosira* Kirchner ex Bornet & Flahault 1888. Ann. Sci. Nat. Bot., Ser. 7, 7: 256.

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

**1. *Aulosira fertilissima*** Ghose 1924. J. Linn. Soc. Bot., 46: 342, pl. 31.

*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; Svenning & 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 & Ahmadimoghadam 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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