SOIL TAXONOMIC STUDY ON TAXA OF APOHETEROCYTIC A 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 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 خاکزی با ساختار آپوهتروسیتیک از خانواده Nostocaceae در ایران رینب شریعتمداری، استادیاردانشکده زیستشناسی دانشگاه شهید بهشتی. حسین ریاحی، استاد دانشکده زیستشناسی دانشگاه شهید بهشتی.

جهت بررسی نمونههای خاکزی 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 حانواده شناسایی شد که از میان تاکسونهای شناسایی شده، 18 گونه و 1 واریته از 4 جنس Ralfs ex Bornet & Nostoc Vaucher ex Bornet & Flahault شناسایی شده، 18 Aulosira Kirchner ex Bornet & J. Nodularia Mertens ex Bornet & Flahault, Flahault) Komárek & Anagnostidis Flahault دارای ساختار ترایکمی آپوهتروسیتیک و 20 تاکسون از 2 جنس Anabaena Bory ex Bornet & Flahault و Cylindrospermum Kützing ex Bornet & Flahault دارای ساختار پاراهتروسیتیک میباشند. از میان گونه های شناسایی شده از این خانواده، چهار گونه زیر برای نخستین بار از ایران گزارش می شوند و کلید شناسایی، محدوده پراکنش و تصاویر کامرا لوسیدای گونه های شناسایی شده، به همراه شرح گونههای جدید با تاکید بر تاکسونهای دارای ساختار آپوهتروسیتیک ارائه می گردد.

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.

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 heterocystes and later all or almost all vegetative cells change into akinetes, towards heterocysts. Contrary to apoheterocytic forms, in paraheterocytic cyanoprokaryota, akinetes form near the heterocystes 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, Nodualria 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 (Shariatmadari & al. 2011a, Cylindrospermum 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 nineteen focused on 41 populations from 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
 Vegetative cells short and discoid, Heterocysts sometimes flattened *Nodularia* Vegetative cells not discoid, Heterosysts 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)

5. Mucilaginous envelope yellowish-brown Nostoc spongiaeforme (9)

5

⁻ Filaments slightly entangled

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

Location	Latitude/Longitude	pН	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	37ໍ 16´ N 49ໍ 35´ E	8.2	2.39
Gilan: Rodsar, Rahimabad village	36° 51´ N 50° 13´ E	8.0	1.47
Gilan: Rasht, Saravan village	37ໍ 05´ N 49ໍ 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, Esmaeilabad 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	36ໍ 59´ N 59ໍ 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 & al. 1971).

NaCl 1.5 K_2HPO_4 0.04 MgSO_4.7H_2O 0.075 CaCl_2.2H_2O 0.036 Citric acid 0.006 Ferric ammonium citrate 0.006 EDTA 0.001 Na_2CO_3 0.02 Trace metal mix 1 ml L ⁻¹ H_3BO_4 2.86 MnCl_2.4H_2O 0.222 Na_2MoO_4.2H_2O 0.390 CuSO_4. 5 H_2O 0.079 Co(NO_3)_2. 6H_2O 0.0494	Ingredients	Quantity (g L ⁻¹)
K_2HPO_4 0.04 MgSO_4.7H_2O 0.075 CaCl_2.2H_2O 0.036 Citric acid 0.006 Ferric ammonium citrate 0.001 Na_2CO_3 0.02 Trace metal mix 1 ml L ⁻¹ H_3BO_4 2.86 MnCl_2.4H_2O 0.222 Na_2MoO_4.2H_2O 0.390 CuSO_4. 5 H_2O 0.079 Co(NO_3)_2. 6H_2O 0.04	NaCl	1.5
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$	MgSO ₄ .7H ₂ O	0.075
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EDTA 0.001 Na ₂ CO ₃ 0.02 Trace metal mix $1 ml L^{-1}$ H ₃ BO ₄ 2.86 MnCl ₂ .4H ₂ 0 1.81 ZnSO ₄ .7H ₂ O 0.222 Na ₂ MoO ₄ .2H ₂ O 0.390 CuSO ₄ . 5 H ₂ O 0.079 Co(NO ₃) ₂ . 6H ₂ O 0.0494	Ferric ammonium citrate	0.006
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Trace metal mix 1 ml L^{-1} H_3BO_4 2.86 MnCl_2.4H_20 1.81 ZnSO_4.7H_2O 0.222 Na_2MoO_4.2H_2O 0.390 CuSO_4. 5 H_2O 0.079 Co(NO_3)_2. 6H_2O 0.0494	Na ₂ CO ₃	0.02
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$\begin{array}{llllllllllllllllllllllllllllllllllll$	MnCl ₂ .4H ₂ 0	1.81
$\begin{array}{llllllllllllllllllllllllllllllllllll$	ZnSO ₄ .7H ₂ O	0.222
CuSO ₄ . 5 H ₂ O Co(NO ₃) ₂ . 6H ₂ O 0.0494	Na ₂ MoO ₄ .2H ₂ O	0.390
Co(NO ₃) ₂ . 6H ₂ 0	CuSO ₄ . 5 H ₂ O	0.079
	$Co(NO_3)_2$. $6H_20$	0.0494

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6. Vegetative cells barrel-shaped

- Vegetative cells cylindrical to barrel-shape 10

7. Spores spherical; epispore yellowish-brown

Nostoc sphaericum (10) -Spores semi-sphaerical to ellipsoidal; epispore colourless or yellowish-brown 8 8. Heterocysts sub-spherical; akinetes sub-spherical Nostoc calcicola (2)

- Heterocysts ellipsoidal or barrel-shape, rarely subspherical 9 9. Epispore brown; spores ellipsoidal

Nostoc alatosporum (1)

- Epispore colourless; spores semi round

Nostoc sp.2(12)

10. Trichomes entangled11- Trichomes not entangled or slightly entangled1211.Terminal heterocystes broader than vegetative cells;12akinetes ellipsoidalNostoc paludosum (7)- Terminal heterocysts broad lower than vegetativecells; akinetes semispherical..Nostoc verrucosum (14)12. Spores sub-spherical or slightly longer than broad

Table 3. List of apoheterocytic	cyanoprokary	ota recor	ded from	several p	addy s	soils of	Iran an	d their dist	ribu	tions (1.
Gilan province, 2. Mazandarar	province, 3.	Qazvin	province,	4. Lores	stan pr	ovince,	5. Far	s province,	6.	Esfahan
province, 7. Khorasane Razavi	province).									

Nostoc oryzae (Fritsch) Koma Trikch ex Anagonstidis= Anabaena oryzae Fritsch+-+++= Anabaena gelatinosa Fritsch ex De+-+++Nostoc linckia var. arvense (C. B. Rao) Komárek & AnagnostidisNostoc paludosum Kützing ex Bornet & Flahault+-+ <t< th=""><th>Species</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></t<>	Species	1	2	3	4	5	6	7
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Nostoc sp.1 $ +$ $ -$ </td <td>=Nostoc verrucosum Vaucher</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	=Nostoc verrucosum Vaucher							
Nostoc sp.2+-Nostoc sp.3+-+-Nodularia harveyana (Thwaites) Thuret+++-++Nodularia spumigena Mertens ex Bornet & Flahault+++++Aulosira fertilissima Ghose+++++Trichormus ellipsosporus (Fritsch) Komárek & Anagnostidis++ <td< td=""><td>Nostoc sp.₁</td><td>-</td><td>-</td><td>+</td><td>-</td><td>-</td><td>-</td><td>-</td></td<>	Nostoc sp. ₁	-	-	+	-	-	-	-
Nostoc sp.3 - - - - + - + - + - + - + + - + + - + + - + + - + + - + + - + + - + + - - + + - - + + - - + + - - + + - - + + - <td< td=""><td>Nostoc sp.₂</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>+</td><td>-</td></td<>	Nostoc sp. ₂	-	-	-	-	-	+	-
Nodularia harveyana (Thwaites) Thuret + - - + + - + + - + + - + + - + + - - + + - - + + - - + + - - + - - - + - + - - - + + - - - + + - - + + - - + + + -	Nostoc sp. ₃	-	-	-	-	-	+	-
Nodularia spumigena Mertens ex Bornet & Flahault + - - + - - + - + + - - - + + - - + + - - + + + + + + + - - + + + - - + +	Nodularia harveyana (Thwaites) Thuret	+	-	-	-	+	+	-
Aulosira fertilissima Ghose + - - - - - - - - - - - - - - - - - + + - - + + - - + + - - + + + - - +	Nodularia spumigena Mertens ex Bornet & Flahault	+	-	-	-	+	-	-
Trichormus ellipsosporus (Fritsch) Komárek & Anagnostidis + + - + <td>Aulosira fertilissima Ghose</td> <td>+</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td>	Aulosira fertilissima Ghose	+	-	-	-	-	-	-
= A. variabilis var.ellipsospora F. E. Fritsch Trichormus fertilissimus (C. B. Rao) Komárek & Anagnostidis - A. fortilissimus C. P. Pro-	Trichormus ellipsosporus (Fritsch) Komárek & Anagnostidis	+	+	-	-	-	+	+
Trichormus fertilissimus (C. B. Rao) Komárek & Anagnostidis	= A. variabilis var.ellipsospora F. E. Fritsch							
- A fortilizing C P Pro	Trichormus fertilissimus (C. B. Rao) Komárek & Anagnostidis							
– A. jeruussinu C. D. Kao	= A. fertilissima C. B. Rao	-	-	-	+	-	-	-

13

Nostoc ellipsosporum var. violaceum (3)

- Spores ellipsoidal

13. Thallus dull olive or brownNostoc muscorum (5)- Thallus pale blue-greenNostoc 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 μ m broad and 7-11 μ m long; apical cells sub-cylindrical. Heterocysts terminal and intermediate with hyaline yellowish content; intermediate heterocyst solitary, ellipsoidal or long ellipsoidal, with 6 μ m broad and 9-11 μ m long; terminal heterocyst sub-spherical, with 5 μ m broad and 5-5.5 μ m long. Akinetes in rows, ellipsoidal, with 9 μ m broad and 8-11 μ m long; includes widened epispore with distinct widened, radially striated epispore.

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 μ m broad and 5 μ m long. Heterocysts intermediate, almost spherical, 6-7 μ m broad, usually not enveloped by any mucilage. Akinetes in long chains, spherical or short ellipsoidal, with 6 μ broad and 6-8 μ m 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.

General distribution. Europe (Whitton & al. 1998; Caraus 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 $(37^{\circ} 16' N 49^{\circ} 35' E)$. -Mazandaran: Tazehabad $(36^{\circ} 39' N 51^{\circ} 25' E)$. -Qazvin: Alamut $(36^{\circ} 23' N 50^{\circ} 33' E)$. -Lorestan: Visan $(33^{\circ} 49' N 48^{\circ} 07' E)$. -Esfahan: Lenjan $(32^{\circ} 22' N 51^{\circ} 22' E)$. -Fars: Ebrahimabad $(29^{\circ} 00' N 52^{\circ} 56' E)$, Esmaeilabad $(28^{\circ} 60' N 53^{\circ} 60' E)$.

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 $(37^{\circ} \ 16' \text{ N} \ 49^{\circ} \ 35' \text{ E})$. -Lorestan: Visan $(33^{\circ} \ 49' \text{ N} \ 48^{\circ} \ 07' \text{ E})$.

-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; Caraus 2002). -Asia (Hu & Wei 2006; Desikachary 1959).

Distribution in studied sites. Gilan: Omsheh $(37^{\circ} 16' N 49^{\circ} 35' E)$. -Qazvin: Alamut $(36^{\circ} 23' N 50^{\circ} 33' E)$.

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; Caraus 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 bluegreen; Filaments flexuous, loosely entangled; gelatinous sheath more or less distinct along the periphery, yellowish-brown. Vegetative cells short barrel shape, 5-5.5 μ m broad and 4.5-5 μ m long. Heterocysts terminal and intermediate; intermediate heterocysts sub-spherical, with 8 μ m broad; terminal heterocysts obovoid, with 4.5 μ m broad and 6 μ m long. Akinetes oblong, with 5-6 μ m broad and 7-9 μ m long.

General distribution. Europe (Whitton & al. 1998; Caraus 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.₁ (Fig.3B).

Description. Colonies not sphaerical, gelatinous, pale blue-green; filaments flexuous, loosely entangled; gelatinous sheath very broad, about 36 μ m wide, not lamellated, slightly yellowish brown. Vegetative cells

barrel-shape, $4.5-5 \ \mu m$ broad and $5-8 \ \mu m$ long. Heterocysts short barrel-shape, with $5.5-6 \ \mu m$ broad and $7 \ \mu m$ long. Akinetes ellipsoidal, with $6-7 \ \mu m$ broad and $8-11 \ \mu m$ long.

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

12. *Nostoc* sp.₂ (Fig.5A).

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

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

13. Nostoc sp.₃

Description. Colonies completely sphaerical, gelatinous, light blue-green; filaments very densely coiled, gelatinous sheath sphaerical, colourless. Vegetative cells short barrel shape, 2.5 μ m broad and 2.5-5 μ m long. Heterocysts semi sphaerical, with 4.5-5 μ m broad and 4-4.5 μ m long. Akinetes semi sphaerical, with 3.5-4 μ m broad and 5-5.5 μ m 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, vertucose 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 μ m broad and 5 μ m long. Heterocysts intermediate and terminal; intermediate heterocyst sub-spherical 5 μ m broad; terminal heterocysts obovoid. Akinetes ovate or semi around, 6-9 μ m long, 5-7 broad, epispore 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

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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). Syn.: *A. variabilis* var. *ellipsospora* Fritsch, J. Indian

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 $(36^{\circ} 51^{\circ} N 50^{\circ} 13^{\circ} E)$. -Mazandaran: Tazehabad $(36^{\circ} 39^{\circ} N 51^{\circ} 25^{\circ} E)$. -Esfahan: Falavarjan $(32^{\circ} 32^{\circ} N 51^{\circ} 30^{\circ} E)$. -Khorasan Razavi: Kalat $(36^{\circ} 59^{\circ} N 59^{\circ} 47^{\circ} E)$.

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

 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







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Trichormus fertilissimus: a- immature trichome., b- part	part of immature trichomes., b- akinetes (Scale: 10 µm).
of trichomes with heterocysts and akinetes, c- apical part	
of trichome, d- akinetes (Scale: 10 µm).	
Syn.: Nodularia spumigena Mertens 1822., Nostoc	taxa, Nostoc species easily are separated from the
spumigena (Mertens) Drouet 1978.	others according to entangled form of trichomes.
General distribution. Europe (Alvarez-Cobelas &	Definite shape of colony in some of <i>Nostoc</i> species is
Gallardo 1988: Whitton & al 1998: Caraus 2002)	

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 (36⁵53′ 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 akinets 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 and Trichormus. Anabaena 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

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 appoheterocytic nostocacean cyanoprokaryota in paddy soils of Iran and introduce four taxa as new record for Iran.

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