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BIODIVERSITY OF CYANOBACTERIA IN INDUSTRIAL EFFLUENTS

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ABSTRACT. *Biodiversity of cyanobacteria in industrial effluents*. In order to study the biodiversity of cyanobacteria in industrial effluents, four different effluents such as dye, paper mill, pharmaceutical and sugar were selected. The physicochemical characteristics of all the effluents studied were more or less similar. Totally 59 species of cyanobacteria distributed in four different effluents were recorded. Among the effluents, sugar mill recorded the maximum number of species (55) followed by dye (54), paper mill (45) and pharmaceutical (30). Except pharmaceutical effluent, others recorded heterocystous cyanobacteria. In total 26 species of cyanobacteria were recorded in common to all the effluents analysed. Of them, *Oscillatoria* with 13 species was the dominant genus which was followed by *Phormidium* (8), *Lyngbya* (2), *Microcystis* (2) and *Synechococcus* with single species. The abundance of cyanobacteria in these effluents was due to favourable contents of oxidizable organic matter, rich calcium and abundant nutrients such as nitrates and phosphates with less dissolved oxygen. Indicator species from each effluent and their immense value for the future pollution abatement programmes have also been discussed.

Key words. Cyanobacteria, Industrial effluents.

RESUMEN. *Biodiversidad de cianobacterias en vertidos industriales*. Se ha estudiado la biodiversidad de cianobacterias presente en vertidos industriales de diferente naturaleza (colorantes, fabricación de papel, sector farmacéutico y azúcar). Las características físico-químicas de los vertidos fueron más o menos similares. Se han identificado un total de 59 especies de cianobacterias en los cuatro tipos de vertidos. La mayor riqueza específica se encontró en el vertido de la industria azucarera (55 especies), seguida luego por la industria de colorantes, papel y productos farmacéuticos (54, 45 y 30 especies, respectivamente). Con la excepción del vertido de la industria farmacéutica, en los restantes vertidos se detectaron cianobacterias heterocistadas. El número de especies comunes a los cuatro vertidos ascendió a 26. Entre éstas, *Oscillatoria*, con 13 especies, fue el género dominante, seguido por *Phormidium* (8), *Lyngbya* y *Microcystis* (ambas con 2) y *Synechococcus* (1). La abundancia de cianobacterias en estos vertidos se debió al contenido en materia orgánica oxidable, altos niveles de calcio y nutrientes inorgánicos (nitratos y fosfatos) y bajos niveles de oxígeno disuelto. Se discuten el valor del indicador de especies de cada vertido y su importancia para los programas de reducción de la contaminación.

Palabras clave. Cianobacterias, vertidos industriales.

INTRODUCTION

During the recent past, studies on cyanobacteria have emphasized their important role in ecosystem. They grow at any place and in any environment where moisture and sunlight are available. However, specific algae grow in specific environment and therefore their distribution pattern, ecology, periodicity, qualitative and quantitative occurrence differ widely. The abundance and composition of blue-green algal population in surface waters of ponds and lakes have been discussed in many works and a conflicting general impression exists. It is said that they fluorish well either in nutrient rich and warm water or at times in water with apparently low nutrient concentrations, subjected to higher temperature and bright light conditions (Ganapati, 1940; Philipose, 1960; Munawar, 1970; Fogg, 1975). In addition, pH, carbon-di-oxide, organic matter, alkalinity, nitrates and phosphates are factors important in determining the distribution of cyanobacteria.

Several reports are now available on the occurrence of algae in polluted waters (Palmer, 1969; Somashekar and Ramaswamy, 1983; Tarar *et al.*, 1990). However, the diversity in physical, chemical and biological characteristics of industrial effluents is so great that each waste water habitat requires a separate study. A thorough knowledge of the physical, chemical and biological characteristics of an industrial waste is a preliminary and essential requirement for any attempt at chemical and / or biological treatment of the waste. Hence, the present study was aimed to assess the physico-chemical characteristics and cyanobacterial diversity of four different industrial effluents such as dye, paper mill, pharmaceutical and sugar mill.

MATERIALS AND METHODS

Samples (both effluent and cyanobacteria) were collected from four different industrial effluents such as dye – Modern Dye Industry, Tirupur, Tamil Nadu, India; Paper mill – Tamil Nadu Newsprint and Papers Limited, Puhalur, Tamil Nadu, India; Pharmaceutical – Pharm Product, Thanjavur, Tamil Nadu, India and SugarMill – Arignar Anna Sugar Factory, Kurungulam, Tamil Nadu, India. Effluent samples and cyanobacteria were collected in large sterilized containers and polythene bags respectively. Physico-chemical characteristics of waste waters were carried out according to standard methods (APHA, 1995). Standard microbiological methods were followed for the isolation of cyanobacteria. Algal samples were microscopically examined and plated on solid agar medium. The inoculated plates were incubated in culture room maintained at 25 ± 2°C fitted with cool white fluorescent tube emitting 2500 lux for 18 hrs a day. The isolated cyanobacteria were identified with the help of classical manuals (Geitler, 1932 and Desikachary, 1959) and subcultured in BG_{11} medium (Rippka *et al.*, 1979) under the above said culture conditions.

RESULTS AND DISCUSSION

In the present study, 59 species of cyanobacteria distributed in four different effluents were recorded (tab. 2). Of the effluents studied, sugar mill recorded the maximum number of species (55) followed by dye (54), paper mill (45) and pharmaceutical (30). Among the effluents, heterocystous forms were identified in sugar, dye and paper mill and not in pharmaceutical effluent. Heterocystous cyanobacteria such

Parameters	**Various industrial effluents**			
	Dye	**Paper mill**	**Pharmaceutical**	**Sugar mill**
Colour	Dark brown	Pale brown	Colourless	Dark brown
pH	8.5	6.8	7.0	5.3
Temperature	40	35	28	31
Free CO_2	Nil	65	Nil	90
Carbonate	60	Nil	68	Nil
Bicarbonate	180	150	115	270
BOD	280	250	290	333
COD	501	700	662	826
DO	1.52	2.1	2.2	1.4
Nitrate	150	160	160	168
Nitrite	78	65	67	72
Ammonia	82	230	55	298
Total phosphorus	57	43	40	46
Inorganic phosphate	20	20	23	24
Organic phosphate	30	22	20	23
Calcium	65	55	78	133
Magnesium	60	38	70	99
Chloride	5011	1599	1599	1639

Except pH and temperature, all values are expressed in mgl^{-1}.

Table 1. Characteristics of industrial effluents. *Características de los vertidos industriales.*

as *Anabaena beckii, A. fertilissima, Nostoc calcicola* and *Westiellopsis prolifica* were recorded in dye effluent, on the other hand paper mill effluent recorded only *N. calcicola* and *A. fertilissima*. Similarly, sugar mill effluent was represented only with *N. calcicola* and *A. beckii*. *Westiellopsis prolifica* was not identified from paper and sugar mill effluents (tab. 2). In total 26 species of cyanobacteria were recorded in common to all the effluents analysed. Of them, *Oscillatoria* with 13 species was the dominant genus, which was followed by *Phormidium* (8), *Lyngbya* (2), *Microcystis* (2) and *Synechococcus* with single species.

The abundance of cyanobacteria is attributed to favourable contents of oxidizable organic matter and less dissolved oxygen (tab. 1) an observation which supports Rao (1955), Venkateswarlu (1969b), Boominathan (2005) and Vijayakumar *et al.* (2005). Observations of

S.No.	Name of the organism	Various industrial effluents							
		Dye	%	Paper	%	Pharmaceutical	%	Sugar	%
CHROOCOCCACEAE									
1.	***Microcystis aeruginosa*** Khtz.	+	75	+	75	+	58	+	50
2.	***M. flos-aquae*** (Wittr.) Kirchker	+	58	+	33	-	0	+	25
3.	***M. robusta*** (Clark) Nygaard	+	75	+	75	+	50	+	33
4.	***Gloeocapsa calcarea*** Tilden	+	66	-	0	-	0	+	8
5.	***G. livida*** (Carm.) Khtz.	+	58	-	0	-	0	-	0
6.	***Aphanocapsa banaresensis*** Bharadwaja	+	50	-	0	-	0	+	8
7.	***Synechococcus elongatus*** Nag.	+	66	+	33	+	25	+	25
8.	***Synechocystis pevalekii*** Ercegovic	+	58	-	0	-	0	+	25
OSCILLATORIACEAE									
9.	***Oscillatoria acuminata*** Gomont	+	33	+	33	+	16	+	50
10.	***O. animalis*** Ag. ex Gomont	+	75	+	75	-	0	+	41
11.	***O. brevis*** (Khtz) Gomont	+	100	+	100	+	91	+	75
12.	***O. chalybea*** (Mertens) Gomont	+	41	+	75	-	0	+	41
13.	***O. chlorine*** Khtz ex Gomont	+	25	+	41	+	25	+	41
14.	***O. clarisentrosa*** Gardner	+	16	+	33	-	0	+	16
15.	***O. corallinae*** (Khtz) Gomont	+	25	+	33	-	0	+	18
16.	***O. cortiana*** Meneghini ex Gomont	+	16	-	0	-	0	+	58
17.	***O. curviceps*** Ag. ex Gomont	+	33	+	58	+	41	+	25
18.	***O. earlei*** Gardner	+	91	+	66	+	50	+	16
19.	***O. laete-virens*** (Crouan) Gomont	+	66	+	100	+	50	+	41
20.	***O. martini*** Fremy	+	16	+	58	+	25	+	58
21.	***O. perornata*** Skuja	+	16	+	33	-	0	+	50
22.	***O. princeps*** Vaucher ex Gomont	+	66	+	33	+	25	+	83
23.	***O. proboscidea*** Gomont	+	33	-	0	-	0	+	41
24.	***O. pseudogeminata*** G. Schmid	+	66	+	66	+	50	+	75
25.	***O. rubescens*** Dc ex Gomont	+	50	+	50	+	66	+	33
26.	***O. salina*** Biswas	+	58	+	50	-	0	+	16
27.	***O. splendida*** Grev. ex Gomont	+	16	-	0	-	0	+	25
28.	***O. subbrevis*** Schmidle	+	58	+	91	+	58	+	41
29.	***O. terebriformis*** Ag. ex Gomont	+	66	+	66	+	50	+	25
30.	***O. trichoides*** Szafer	+	16	+	58	-	0	+	25
31.	***O. willei*** Gardner em. Drouet	+	91	+	75	+	75	+	50
32.	***Phormidium ambiguum*** Gomont	+	16	+	50	+	66	+	25

Table 2

S.No.	Name of the organism	Various industrial effluents							
		Dye	**%**	**Paper**	**%**	**Pharmaceutical**	**%**	**Sugar**	**%**
33.	***P. anomala*** Rao, C.B.	+	16	+	66	+	83	+	33
34.	***P. corium*** (Ag.) Gomont	+	50	+	58	+	50	+	25
35.	***P. fragile*** (Meneghini) Gomont	+	83	+	75	+	66	+	75
36.	***P. incrustatum*** (Nag.) Gomont	+	33	-	0	-	0	+	33
37.	***P. laminosum*** Gomont	+	33	+	50	+	50	+	41
38.	***P. pachydermaticum*** Fremy	+	25	-	0	+	50	+	33
39.	***P. purpurascens*** (Khtz) Gomont	+	33	+	50	+	33	+	41
40.	***P. tenue*** (Menegh) Gomont	+	91	+	100	+	91	+	75
41.	***P. uncinatum*** (Ag.) Gomont	+	8	+	33	+	91	+	33
42.	***Phormidium*** sp.	+	25	+	33	-	0	+	33
43.	***Lyngbya borgerti*** Lemmermann	+	33	+	41	+	8	+	8
44.	***L. confervoides*** C. Ag. ex Gomont	-	0	+	33	+	16	+	41
45.	***L. digueti*** Gomont	+	25	+	66	+	33	+	41
46.	***L. infixa*** Fremy	+	25	+	41	+	33	-	0
47.	***L. limnetica*** Lemmermann	+	8	+	41	-	0	+	25
48.	***L. majusculla*** Harvey ex Gomont	+	16	+	58	-	0	+	16
49.	***L. mesotricha*** Skuja	+	33	+	66	-	0	+	16
50.	***L. shackletoni*** W.et G.S. West	-	0	-	0	-	0	+	41
51.	***L. spiralis*** Geitler	-	0	+	33	+	33	+	25
52.	***L. spirulinoides*** Gomont	-	0	-	0	-	0	+	8
53.	***L. martensiana*** Menegh. ex. Gomont	-	0	+	41	-	0	+	41
NOSTOCACEAE									
54.	***Nostoc calcicola*** Brebission ex. Born et. Flash	+	58	+	25	-	0	+	16
55.	***Anabaena fertilissima*** Rao, C.B.	+	25	+	16	-	0	-	0
56.	***A. beckii*** De Toni G.B.	+	58	-	0	-	0	+	8
SCYTONEMATACEAE									
57.	***Plectonema radiosum*** (Schiederm) Gomont	+	33	+	25	-	0	+	8
58.	***P. gracillimum*** (Zopf) Hansgirg	+	25	-	0	-	0	+	16
STIGONEMATACEAE									
59.	***Westiellopsis prolifica*** Janet.	+	66	-	0	-	0	-	0
	Total number of species	54		45		30		55	

Table 2 (cont.). Cyanobacterial flora of various industrial effluents. + = Observed; - = Not observed.
Flora de cianobacterias de diferentes vertidos industriales.

Munawar (1970a and b) and Kannan (2006) suggest that cyanophyceae grow luxuriantly with great variety and abundance in ponds rich in calcium. The present data in all the four effluents also showed that calcium is possibly one of the factors (tab. 1). Whether it plays its role individually or in combination with other factor complexes can only be understood by culture studies. Besides calcium, high amounts of oxidizable organic matter, traces of dissolved oxygen, considerable amounts of nitrate and phosphates in all the effluents investigated were probably the factors favouring the growth of cyanobacteria as suggested by Venkateswarlu (1969a), Rai and Kumar (1977), Nazneen (1980), Venu *et al.* (1984), Anand (1998), Boominathan (2005), Murugesan (2005) and Vijayakumar *et al.* (2005). Singh (1969) and Venkateswarlu (1976) reported that high values of BOD, COD, phosphates and nitrates with very low DO favoured the growth of cyanobacteria than any other algae. Their findings were supported by the observations of Boominathan (2005), Vijayakumar *et al.* (2005) and Jeganathan (2006) in dairy, dye and oil refinery industry effluents respectively. In the present study also, all the effluents showed a considerable amount of nitrates and phosphates, with increased level of BOD and COD along with very low DO level. This could be the reason for the fluorishing growth of cyanobacteria in the effluents investigated. Moreover, Stewart and Parson (1970) observed rapid growth of cyanobacteria in the microaerophilic conditions. Fogg *et al.* (1973) inferred that the correlation between abundance of planktonic cyanobacteria and high concentration of dissolved organic matter may be due to the depletion of oxygen.

Heterocystous cyanobacteria have not been recorded in polluted waters rich in nitrogen (Rai and Kumar, 1976b; Boominathan, 2005). However, in the present study heterocystous forms such as *A. beckii, A. fertilissima, N. calcicola* and *W. prolifica* in dye, *A. beckii* and *A. fertilissima* in paper mill, and *A. beckii* and *N. calcicola* in sugar mill effluent were also observed (tab. 2).

Rai and Kumar (1976b) reported that the genus *Oscillatoria* has been found to be very tolerant to pollution which frequently inhabits the polluted water. Similarly, Singh *et al.* (1969) found *Oscillatoria* and *Phormidium* were the most dominant genera in sewage. Present study also confirmed their observation as *Oscillatoria* and *Phormidium* along with *Lyngbya* were found dominating all the effluents studied (tab. 2). Palmer (1969, 1980) emphasized the use of algae as reliable indicators of pollution. There are certain members of Cyanophyceae which are tolerant to organic pollution and resist environmental stress caused by the pollutants. Such species can be used as 'Marker Species' or indicators of particular habitat (Prasad and Saxena, 1980). Indicator species are of immense value for the future pollution abatement programmes. In the present study, dye effluent with 8 species, paper mill with 11, pharmaceutical and sugar mill effluents with 5 species each (tabs. 2), the percentage values of which were 75 and above, should be considered as indicators of the respective effluents as reported by Somashekar and Ramaswamy (1983). Of the indicator species observed in different effluents, *O. brevis* and *P. tenue* were found with more than 75 per cent representation in all the effluents and thus considered as the indicators of the effluents analysed. Compared to other species they were seen growing and multiplying profusely. Their higher representation indicate their capacity to thrive in this type of man made habitat.

From the foregoing discussion, it is concluded that physico-chemical characters together with biological monitoring provided converging lines of evidences for evaluation of polluted habitats in this case as in some other studies (Cairns and Dickson, 1971; James and Evison, 1979).

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