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RESEARCH ARTICLE

Chlorophytes of biological soil crusts in Gurbantunggut Desert, Xinjiang Autonomous Region, China

Jiancheng ZHAO (✉)[1], Bingchang ZHANG[2,3], Yuanming ZHANG[2]

1 College of Life Science, Hebei Normal University, Shijiazhuang 050016, China
2 Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumuqi 830011, China
3 Graduate University of Chinese Academy of Sciences, Beijing 100049, China

Abstract In this paper, chlorophytes collected from 253 biological soil crust samples in Gurbantunggut Desert in Xinjiang Autonomous Region, China were studied by field investigation and microscopical observation in lab. The flora composition, ecological distribution of chlorophytes in the desert and dynamic changes of species composition of chlorophytes in different developing stages of biological soil crusts are preliminarily analyzed. Results showed that there were 26 species belonging to 14 genera and 10 families, in which unicellular chlorophytes were dominant. There existed some differences in distribution of varied sand dune positions. The taxa of chlorophytes in leeward of sand dunes are most abundant, but the taxa in windward, interdune and the top of sand dunes reduced gradually. Chlorophytes were mainly distributed within the crust and the taxa of chlorophytes decrease obviously under the crust. In the developing stages of the biological soil crust, species diversity of chlorophytes changed a little, but species composition presented some differences. *Chlorococcum humicola*, *Chlorella vulgaris*, *Chlamydomonas ovalis* and *Chlamydomonas* sp. nearly existed in all developing stages of biological crusts. In several former stages of the biological soil crust there were spherical chlorophytes and filamentous ones. When moss crust formed, filamentous chlorophytes disappeared, such as *Microspora* and *Ulothrix*.

Keywords Gurbantunggut Desert, Xinjiang, biological soil crust, chlorophytes

1 Introduction

Biological soil crust is a complex organic integrity of cyanobacteria, chlorophytes, lichens, mosses, fungi and other bacteria. It is a common and widespread phenomenon in desert areas all over the world. In arid and semiarid areas, there is up to 70% of landscapes covered by biological soil crust (Hu et al., 2003b). Biologically, this kind of crust differs a lot from physical soil crusts in physical and chemical properties. Its formation, growth and development, especially its stabilization of nitrogen, promotes congregation of organic matter and creates conditions for reproduction of ephemeral herbaceous plant and soil microbe. Therefore, it becomes a significant biological factor in vegetation succession (Nash et al., 1979; Belnap et al., 1994; Wei, 2005). Chlorophytes are an important component of biological soil crust. Not only can it provide carbon sources and organic matter to desert soil, but also algae crust can develop to lichen crust with an increase in the amount of unicellular chlorophytes (Shields and Durrel, 1964). In this paper, this study is to investigate flora composition, ecological distribution of chlorophytes in the desert and dynamic changes of species composition of chlorophytes in different developing stages of biological crusts preliminarily. The objective of this study is to enrich knowledge on species diversity of biological soil crust in desert. And this can provide a theoretical basis for understanding ecological distribution of chlorophytes and its influence on biological soil crust.

2 Study area

The Gurbantunggut Desert is situated in the center of the Jungger Basin (44°11′–46°20′N, 84°31′–90°00′E), North Xinjiang Uygur Autonomous Region of China, and also the largest fixed and semi-fixed desert in China with an area of 4.88×10^4 km^2. The formation of desert center is mainly sand dunes, which accountered for 80% of the total area in fixed and semi-fixed deserts. The mean annual precipitation in Gurbantunggut Desert is no more than 150 mm and that in the center of the desert is only 70–100 mm, falling

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E-mail: zhaojiancheng@mail.hebtu.edu.cn

predominantly during spring. Mean annual evaporation is more than 2000 mm. Average temperature is 6°C–10°C and extreme temperature is higher than 40°C. Annual cumulative temperature reaches 3000°C–5000°C. Average air relative humidity is 50%–60%. It is usually lower than 45% from May to August. Small half-shrubs, small half-arbors composed of *Halaxylon persicum*, *H. ammodendron* and other desert plants are developed widely. Due to a longer steady firn period in autumn and more precipitation in spring, ephemeral and ephemeroidpla plants in spring develop to a certain extent. The sand surface of this desert is covered with well-developed biological soil crust (Intergrated Study Team to Xinjiang Weger Autonomous Region, Academic Sinica, 1978; Zhang et al., 2004; Zhang, 2005; Zhang et al., 2006).

3 Materials and methods

The materials were sampled from Gurbantunggut Desert in the first and last ten days of August 2004 respectively. Nine samples were settled in the first ten days of August. They are Beishawo (four samples), North side of the desert along watering engineering (11 samples), Third site (eight samples), Cainan (15 samples), the site between Third site and Cainan (six samples), the place between Cainan and Middle station (nine samples), the site from North site of the desert along watering engineering of 15 km southwards (11 samples), the site from Cainan of 20 km eastwards (six samples), the site from watering engineering of 50 km westwards along Shixi Road (three samples). The samples sum up to 73. The dominating area of sample sites approximately accounts for 70% of the total area of Gurbantunggut Desert. When being sampled, typical sand dunes with biological soil crust were chosen. Each sample was sampled according to the sequence of interdune, windward, top, leeward of sand dunes. In the last ten days of August, 30 sampling sites and 90 plots were settled along Caike Road (from Cainan oil field to Kelamayi city) in Gurbantunggut Desert. The plot area is 1 m × 1 m. The total of samples is 180 (150–200 g per sample). When sampling, samples were collected in crust layers and beneath crust layers respectively with aseptic ring-knife (its height is 12 cm and the diameter is 8 cm). Beneath crust layers is from next to crust to 10 cm depth. The samples were collected with enclosed plastic bag and carried to laboratory as soon as possible. The sampling tool was cleaned with 70% alcohol for fear that they were contaminated crossways (Hu et al., 2000a; Hu and Liu, 2003).

Observations included direct observation and liquid culture observation. Direct observation: biological soil crust sample is put into test tube and diluted with distilled water. They were made into symmetrical soil suspension. A drop of suspension was got out and make to temporary slice. Then, it was observed and its photograph was taken. Culture observation: 50 ml liquid culture was put into a 100 ml triangular flask, and sterilized. Then, 5 g biological soil crust sample was put into liquid culture and cultured still after surging adequately. Two or three weeks later, they were observed and identified when algae was in logarithmic phase (Soil Microbiology Seminar, 1983).

4 Results

4.1 Flora composition of chlorophytes in Gurbantunggut Desert

There are 26 species chlorophytes in Gurbantunggut Desert, which belong to 14 genera, ten families and four orders (Volvocales, Chlorococcales, Ulotrichales and Desmidiales). The details can be seen in species list. The composition of species, genera and families is shown in Table 1.

4.1.1 Genera composition and families composition

As shown in Table 1, there are ten families of chlorophytes in the study areas. The characteristic is that there is no dominant family distinctly in its composition. The main families are those with a single genus. They are Chlamydomonadaceae, Chlorococaceae, Characiaceae, Oocystaceae, Sorastraceae, Scenedsmaceae and Microsporaceae (seven families). The

Table 1 Statistics of family, genus, species of chlorophytes in Gurbantugut Desert

Order	Family	Genus	Rate of the total genera (%)	Species	Rate of the total species (%)
Volvocales	Chlamydomonadaceae	1	7.14	7	26.92
	Chlorococaceae	1	7.14	1	3.85
	Characiaceae	1	7.14	1	3.85
Chlorococcales	Chlorellaceae	3	21.43	3	11.54
	Oocystaceae	1	7.14	4	15.38
	Sorastraceae	1	7.14	1	3.85
	Scenedesmaceae	1	7.14	2	7.69
Ulotrichales	Ulotrichaceae	2	14.29	3	11.54
	Microsporaceae	1	7.14	2	7.69
Desmidiales	Desmidiaceae	2	14.29	2	7.69
4	**10**	**14**	**100**	**26**	**100**

other three families only contain two or three genera. Chlamydomonadaceae consist of the most species (seven species), while the species in the other families is fewer (2–3 species).

In the study areas, there are 14 genera of chlorophytes. The distribution characteristic is that a genus with a single species is main and a dominant genus is not distinct, similar to families. A genus with the most species is *Chlamydomonas* (seven species). The genera with single species are *Chlorella*, *Palmellococcus*, *Selenastrum*, *Chlorococcum*, *Schroederia*, *Actinastrum*, *Hormidium*, *Xanthidium* and *Cosmarium* (nine genera). The number of species contained in other four genera is 2–4. They are *Microspore*, *Ulothrix*, *Scenedemus* and *Ankistrodesmus*.

Single families and genera, scant families and genera are many. Dominant families and genera are not obvious. These show that algae flora in the areas is not only abundant, complicated but also archaic.

4.1.2 Species composition

There are 26 species chlorophytes. Unicellular algae are 17 species which account for 65.38% of the total chlorophytes. Multicellular taxa are nine occupied 34.62% of the total. In morphologic, there are 12 spherical species (46.15%), five filaceous species (19.23%), and nine other morphologic (34.62%). *Chlorococcum humicola* is the most familiar species and exists in all different locations and layers of sand dunes. Meanwhile, it is also a wide-spread species of desert algae. Second, the common species also consist of *Chlorella vulgaris*, *Chlamydomonas ovalis*, *C. microsphaera*, *C. mutabilis*, *Palmellococcus* sp. However, *Selematrum* sp., *Schroederia nitzschioides*, *Actinastrum hantzschii*, *Scenedesmus* sp., *Xanthidium* sp., *Cosmurium* sp., *Ankistrodesmus acicularis*, *A. falcatus*, *A. angustus* and *A.* sp. are uncommon. They only occur in single biological soil crust.

4.2 Characteristics of ecological distribution

4.2.1 Distribution of chlorophytes in different locations of sand dunes

There exist differences in species diversity and species composition in different locations of sand dunes in Gurbantungut Desert. In species diversity, the taxa of chlorophytes in leeward of sand dunes are most abundant, but the taxa in windward, interdune and top of sand dunes reduced gradually. *Chlorococcum humicola*, *Chlamydomonas ovalis* and *Chlorella vulgaris* are not selective upon locations. They exist in different locations. However, the other species have some choices in locations. For example, *Palmellococcus miniatus*, *Chlamydomonas reinhardi* and *Ulothrix tenerrima* are only in leeward, *Chlamydomonas stellata* only in windward. They do not exist in other location. *Chlamydomonas mutabilis* is in leeward, interdune and the top of sand dunes but not in windward (Table 2).

Table 2 Distribution of chlorophytes in different locations of sand dunes

Locations	different species	common species
Windward	*Chlamydomonas stellata*, *Ulothrix* sp., *Chlamydomonas* sp.	*Chlamydomonas Ovalis*, *Chlorococcum humicola*, *Chlorella vulgaris*
Leeward	*Chlamydomonas mutabilis*, *Chlamydomonas stellata*, *Chlamydomonas* sp., *Palmellococcus miniatus*, *Chlamydomonas reinhardi, Ulothrix tenerrima*	
Interdune	*Chlamydomonas debaryana*, *Chlamydomonas mutabilis*, *Ulothrix* sp.	
Top	*Chlamydomonas mutabilis*	

4.2.2 Distribution of chlorophytes in different layers

Chlorophytes were mainly distributed within crust and the taxa of chlorophytes decrease obviously under the crust. The taxa under the crust all exist in the crust. The species both in the crust and under the crust are *Chlamydomonas* sp., *C. mutabilis* and *Chlorococcum humicola*. Otherwise, there are some species existing in the crust. They are *Microspora quadrata*, *M. pachyderma*, *Palmellococcus miniatus*, *Ulothrix tenerrina*, *U.* sp., *Chlorella vulgaris*, *Chlamydomonas microsphaera*, *C. stellata*, *Ankistrodesmus* sp., *A. acicularis*, *A. falcatus*, *A. angustus*, *Xanthidium* sp. and *Cosmarium* sp.

4.3 Varieties of chlorophytes in different developing stages of biological crust

According to different developing levels of biological crust in desert, biological crust can be classified into sand (without any crust), algae crust (crust is characterized by algae and 1–2 mm thick), algae-lichen crust (lichen begin to occur in algae crust about 2 mm thick), lichen crust (the crust is dominated mainly by lichen and 2–5 mm thick), lichen-moss crust (moss begin to occur in lichen crust about 5–10 mm thick) and moss crust (the crust is covered mainly by moss mats). In these different developing stages, species diversity of chlorophytes has few differences. Six to seven species often occur in different stages and their species composition is shown in Table 3.

As shown in Table 3, *Chlorococcum humicola*, *Chlorella vulgaris*, *Chlamydomonas* sp. and *Chlamydomonas ovalis* almost exist in all the different developing stages. In several former developing stages, there are spherical chlorophytes and filamentous ones. However, when crust is dominated by moss or developed into moss mats, filamentous chlorophytes decreased distinctly or even disappeared, such as *Ulothrix* sp., *U. tenerrima* and *Microspora quadrata*.

Table 3 Comparison among specific composition of chlorophytes in different developmental stages of biological crust

Developmental stages	Species composition	Common species
Sand	*Ulothrix tenerrima*, *Chlamydomonas mutabilis*, *Scenedesmus* sp.	*Chlorococcum humicola*, *Chlorella vulgaris*, *Chlamydomonas* sp., *Chlamydomonas ovalis*
Algae crust	*Chlamydomonas microsphaera*, *Chlamydomonas mutabilis*	
Algae-lichen crust	*Palmellococcus miniatus*, *Microspora quadrata*, *Ulothrix* sp.	
Lichen crust	*Chlamydomonas mutabilis*, *Chlamydomonas braunii*	
Liche-moss crust	*Chlamydomonas mutabilis*, *Chlamydomonas braunii*, *Microspora quadrata*,	
Moss crust	*Palmellococcus miniatus*, *Scenedesmup* sp.	

5 Discussion

Based on our investigations, 26 species of chlorophytes are found in Gurbantunggut Desert (details is shown by species list). Studies by Hu et al. suggested that ten species of chlorophytes appeared in Shapotou area, Ningxia Hui Autonomous Region. The common species are mainly six species, i.e. *Chlamydomonas* sp. (2 species), *Chlorococcum humicola*, *Chlorella vulgaris*, *Palmellococcus miniatus* and *Desmococcus olivaceu* (Hu et al., 1999; 2000a). There are seven species of chlorophytes in North Mountain, Lanzhou, i.e. *Chlorococcum humicola*, *Chlorella vulgaris*, *Chlamydomonas* sp., *Pandorina* sp., *Gloeotilopsis planctonica*, *Klebsormidium flaccidum* and *K. pseudostichococcus* (Hu et al., 2003a). In these three areas, there exist some differences in species diversity and composition. And this reflects the characteristics of the species composition of chlorophytes in biological soil crusts of different areal ecosystem. In the Gurbantunggut Desert, the species diversity is more abundant than that in Shapotou area and North Mountain in Lanzhou. This indicates that the environment in the Gurbantungut Desert is very special, especially various microenvironment and complexity in origin of algae flora. In addition, by contrasting the species composition of chlorophytes in the three areas, it can be concluded that *Chlorococcum humicola*, *Chlorella vulgaris* and *Chlamydomonas* sp. are common species in biological soil crusts in deserts. In a word, there exist some relationships among the species compositions of chlorophytes in these three different areas. Additionally, there are some differences.

Compared with cyanobacteria in the Gurbantunggut Desert, there are no dominant families or genera distinctly in the composition of chlorophytes. For example, for chlorophytes, the family containing most species is Chlamydomonadaceae. Studies on cyanobacteria in the Gurbantunggut Desert from Zhang et al. indicate: for cyanobacteria, there are 44 species in Oscillatoriaceae, which contains most species; Chroococcaceae the second, which contains 21 species; there are 21 species in *Oscillatoria* (Zhang et al., 2005). Moreover, the biomass of chlorophytes is far lower than that of cyanobacteria. The algae in the eyeshot is mainly cyanobacteria by observing in microscope directly, especially filamentous cyanobacteria. And the amount of chlorophytes is fewer in the whole. However, in culturing conditions, chlorophytes can grow rapidly and their biomass is increased in a great degree due to improvement of conditions especially plenteous water. Therefore, in Gurbantungut Desert, cyanobacteria dominate in the algae of biological soil crust. And chlorophytes exist only as company species.

In different locations of sand dunes in Gurbantunggut Desert, the taxa of chlorophytes are most abundant in leeward, the windward and interdune the second, the top the least. The lowest water content in the top may be the cause that makes taxa of chlorophytes least. In interdune, water environment is better than that of the top. While with increasing of lichen and moss, they compete with chlorophytes each other. This leads to decreasing of taxa of chlorophytes (Hu et al., 2000a). In different layers, most chlorophytes distribute within crust, the taxa under the crust are few, only *Chlamydomonas* sp., *Chlamydomonas mutabilis* and *Chlorococcum humicola*, etc. This shows that enough illuminations make benefits for the survival of chlorophytes. *Chlorococcum humicola*, *Chlorella vulgaris* and *Chlamydomonas ovalis* have a strong adaptability to environment. Thus, they distribute in all different locations and layers of sand dunes.

There are few differences in the species composition of chlorophytes in the different developing stages of biological soil crust. There are six to seven familiar species. *Chlorococcum humicola*, *Chlorella vulgaris*, *Chlamydomonas* sp. and *Chlamydomo-nas ovalis* are common species in the several developing stages. This indicates that these species have better adaptability and competitive ability. They are not only pioneer species in biological soil crust but also companion species in these stages of biological soil crust. However, when algae crust develops into moss crust, filamentous species such as *Ulothrix* sp. and *Microspora* sp. can not be seen. The main reason may be that *Ulothrix* sp. and *Microspora* sp. are eliminated through selection during competing with moss when moss becomes a dominant group in biological soil crust.

How does algae crust develop into moss crust in Gurbantunggut Desert? Its process is another significant problem in the studies of biological soil crust and needs further study.

Appendix: list of Chlorophyta plant in Gurbantunggut Desert, Xinjiang

1 Chlamydomonadaceae
  1.1 *Chlamydomonas* Ehr.
    (1) *Chlamydomonas microsphaera* Pasch. et Jah. 04-1-4, 04-4-5, 04-4-9, 04-5-6, 04-7-9, 04-8-2, 04-8-3

(2) *Chlamydomonas stellata* Dill. 04-2-8, 04-2-9, 04-4-4, 04-4-5, 04-6-3, 04-8-3, 04-8-6
(3) *Chlamydomonas ovalis* Pasch. 04-2-7, 04-2-9, 04-4-1, 04-4-14, 04-5-6, 04-6-3, 04-6-4, 04-7-1, 04-7-3, 04-8-2, 04-8-5
(4) *Chlamydomonas mutabilis* Gerl. 04-2-7, 04-2-9, 04-4-1, 04-4-9, 04-6-8, 04-7-8, 04-7-12, 04-8-2
(5) *Chlamydomonas reinhardi* Dang. 04-2-9
(6) *Chlamydomonas braunii* Gor. 04-4-2, 04-6-5
(7) *Chlamydomonas debaryana* Gor. 04-2-4, 04-2-7, 04-4-13

2 Chlorellaceae
2.1 *Chlorella* Beij
(8) *Chlorella vulgaris* Beij. 04-1-1, 04-1-2, 04-2-5, 04-2-11, 04-3-1, 04-3-7, 04-4-4, 04-4-14, 04-5-3, 04-6-4, 04-6-9, 04-7-8, 04-7-11, 04-8-2
2.2 *Palmellococcus* chod
(9) *Palmellococcus miniatus* (Kütz) Chod. 04-2-8, 04-2-9, 04-3-8, 04-4-14, 04-6-1, 04-6-2, 04-8-2
2.3 *Selenastrum* reinsch
(10) *Selenastrum* sp. 04-gl-8-2-up, 04-gl-19-3-up

3 Chlorococaceae
3.1 *Chlorococcum* Fries
(11) *Chlorococcum humicola* (Näg.) Rab. 04-1-1, 04-1-2, 04-2-3, 04-2-6, 04-2-7, 04-3-2, 04-3-4, 04-4-3, 04-4-7, 04-5-3, 04-5-5, 04-6-1, 04-6-2, 04-7-3, 04-7-12, 04-8-1, 04-8-6, 04-9-1, 04-9-3

4 Characiaceae
4.1 *Schroederia* lemm
(12) *Schroederia nitzschioides* (West) Korsch. 04-4-11

5 Sorastraceae
5.1 *Actinastrum* Lag.
(13) *Actinastrum hantzschii* Lag. 04-1-4

6 Microsporaceae
6.1 *Microspora* Thuret
(14) *Microspora pachyderma* (Wille) Lag. 04-1-2, 04-4-3
(15) *Microspora quadrata* Haz. 04-4-2, 04-4-15, 04-8-3

7 Ulotrichaceae
7.1 *Ulothrix* Kütz.
(16) *Ulothrix tenerrima* (Kütz.) Kütz. 04-2-7, 04-7-3, 04-7-10, 04-7-11, 04-7-12, 04-8-2
(17) *Ulothrix* sp. 04-1-3, 04-2-8, 04-4-8, 04-4-10, 04-4-11
7.2 *Hormidium* (Kütz.) Klebs
(18) *Hormidium* sp. 04-4-1, 04-8-2, 04-8-5

8 Scenedesmaceae
8.1 *Scenedesmus* Mey.
(19) *Scenedesmus* sp. 04-4-14
(20) *Scenedesmus* sp. 04-gl-5-1-up

9 Desmidiaceae
9.1 *Xanthidium* Ehr.
(21) *Xanthidium* sp. 04-gl-24-1-up
9.2 *Cosmarium* Cord
(22) *Cosmarium* sp. 04-gl-24-1-up

10 Oocystaceae
10.1 *Ankistrodesmus* Cord
(23) *Ankistrodesmus acicularis* (A.Br.) Korsch. 04-gl-19-1-up
(24) *Ankistrodesmus falcatus* (Cord.) Ralts. 04-gl-19-1-up
(25) *Ankistrodesmus angustus* Bern. 04-gl-19-1-up
(26) *Ankistrodesmus* sp. 04-gl-19-1-up

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