Yuzuncu Yil University
Journal of Agricultural Sciences
(Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi)
https://dergipark.org.tr/en/pub/yyutbd

ISSN: 1308-7576 e-ISSN: 1308-7584

Research Article

Diversity and Distribution of Cyanobacteria in Camel Barn Soil in Libya

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Article Info

Received: 19.03.2025
Accepted: 07.11.2025
Online published: 15.12.2025
DOI: 10.29133/yyutbd.1660642

Keywords

Camel barn,
Cyanobacteria,
Desert soil,
Diversity,
Libya

Abstract: Libya features semi-arid lands that are predominantly pastoral, and its microbiological diversity remains largely unexplored. The objectives of the present study were to evaluate the distribution and diversity of cyanobacteria in the soil of camel barns and to determine how physical and chemical variables affect cyanobacteria species and the communities in three semi-arid areas east of Al-Qubbah city during May (summer) of 2024. In this work, 23 cyanobacterial species belonging to 14 genera, representing five common orders (Chroococcales, Oscillatoriales, Nostocales, Scytonematales, and Spirulinales), were identified using morphological features and the culture-dependent technique. Biodiversity indicators showed that camel barn sites are richer in cyanobacteria species than sites outside the barns; the first site had the highest species richness with (5.882±0.2 species/stand), Shannon index (2.89±0.42), and overall abundance (0.78±0.08). Four groups of cyanobacteria were identified using Pearson correlation, principal component analysis, and multivariate analysis; their presence was positively correlated with the quantity of organic matter, soil moisture, potassium, and nitrate content. Cyanobacteria and the amount of sand in the soil were shown to be strongly negatively correlated. Most sites were dominated by the orders Oscillatoriales and Nostocales. *Woella saccata* was documented (100/100) at every site under study. This work highlights the potential applications of animal waste as a new source for cultivating microorganisms in semi-arid regions.

To Cite: Abdulrraziq, A, Salih, S, Abdulrraziq, A, 2025. Diversity and Distribution of Cyanobacteria in Camel Barn Soil in Libya. *Yuzuncu Yil University Journal of Agricultural Sciences*, 35(4): 679-692. DOI: https://doi.org/10.29133/yyutbd.1660942

1. Introduction

Cyanobacteria (blue-green algae) are prokaryotic organisms and a major phylum of Gram-negative bacteria (Bishoyi et al., 2022). Dating back to the Archean, they are among the oldest photoautotrophic organisms that release oxygen during photosynthesis (Büdel, 2024). Cyanobacteria contain three pigments: green (chlorophyll), blue, and red (beta-carotene) (Jassim et al., 2023). Cyanobacteria produce a range of bioactive compounds, including flavonoids, phenolic acids, alkaloids, terpenoids, tannins, polysaccharides, cyclic peptides, phenols, and vitamins, which exhibit effects against various human cancer types, as well as antibacterial and antifungal properties, and antioxidant activity (Bouyahya et al., 2024; Khan et al., 2024). Furthermore, these bacteria offer new insights into their agronomic importance by reducing reliance on synthetic nitrogen fertilizers through natural

nitrogen fixation; it boosts soil fertility by adding organic matter (Whitton and Potts 2007; Saud et al., 2024), which mitigates soil erosion and thus improves the stability of vascular plants (Ramakrishnan et al. 2023). Moreover, it is characterized by its ability to decompose organic waste and remove heavy metals and other pollutants (Akmukhanova et al., 2025; Narayanan, 2025). The desert environment is among the most challenging for the growth and development of microorganisms, due to high temperatures, radiation, water scarcity, and high salinity (Perera et al., 2018).

However, cyanobacteria have been able to survive in arid and semi-arid habitats (Garcia et al., 2025). Libya is one of the desert countries of North Africa, and its arid lands cover approximately 90% of the total Libyan land area. Its indigenous population is famous for herding camels (El-Zarroug et al., 2020). Livestock waste byproducts are a good source for increasing cyanobacterial growth and activity (Abdulrraziq et al., 2025). The proliferation of cyanobacteria enhances the stability of soil particles, hence creating a conducive environment for the colonization of more microorganisms (Gufwan et al., 2025). Especially since recent reports have provided new insights into the link between microbial biodiversity and arid land restoration (Li et al., 2025). Since camel barns are widely distributed across the Libyan semi-arid lands, they may provide a fertile environment for cyanobacterial diversity. This was the main starting point for our study, which we had not encountered in any published scientific literature. This study aimed to assess the diversity and prevalence of cyanobacteria in camel barn soil and to compare them with those in soil outside pens in a semi-arid environment. Additionally, assess the effects of soil physical and chemical treatments on cyanobacterial community distribution, and identify factors influencing their distribution and diversity in response to land-use practices. This work provides the first comprehensive report on the survey and inventory of cyanobacterial communities inside and outside camel barns in a semi-arid environment.

2. Materials and Methods

2.1. Study area

Al Qubbah city is located east of Al-Jabal Al-Akhdar municipality, between 32.7675"N and 22.2324"E. It has an area of approximately 14,722 square kilometers and an elevation of approximately 532 meters above sea level. Like other regions of Al-Jabal Al-Akhdar, it is characterized by abundant pastures. It has hot, dry summers and damp winters due to its Mediterranean climate. The profusion of semi-arid terrain, winds, and dust is characteristic of the southern regions. The Soil samples were collected during May (summer season) from three camel barns in three semi-desert areas south of Al-Qubbah City (Martoubah, Al-Aziyat, and Al-Makhili). Three soil samples were also collected from outside the barns in these three areas for comparison (6 sites × 3 replicates per site). The three areas represent the semi-desert southern region of Al Qubbah city, known for camel breeding. The latitude and longitude of the listed locations were determined from Google Maps (Table 1 and Figure 1). Moreover, the use of three sites as a comparative area is justified by the homogeneous geochemical composition of the soil study area, allowing the separation of camel barn soil impacts from natural variability in the soil and its effect on the distribution of cyanobacteria. Samples were taken with a sterile spoon from the surface layer, 10 cm in diameter, at a depth of 5 cm after removing camel dung and straw, and kept in polyethylene bags.

Table 1. Description of sampling sites

Sampling sites	Coordinates	Internal /external	The area	Site description
S1	32.5832"N 22.6809"E	Inside	Martoubah	Hajj Hafiz Sharaf al-Din's camel barn
S2	32.3363"N 22.7158"E	Outside	Martoubah	1 km away from the first site
S3	32.2108"N 22.7025"E	Inside	Al-Aziyat	Obaid Al-Ghaithi's camel barn
S4	32.2567"N 22.6611"E	Outside	Al-Aziyat	2 km away from the third site
S5	32.1401"N 22.2752"E	Inside	Al-Makhili	Hajj Muhammad Al-Adli's camel barn
S6	32.1562"N 22.2885"E	Outside	Al-Makhili	1 km away from the fifth site

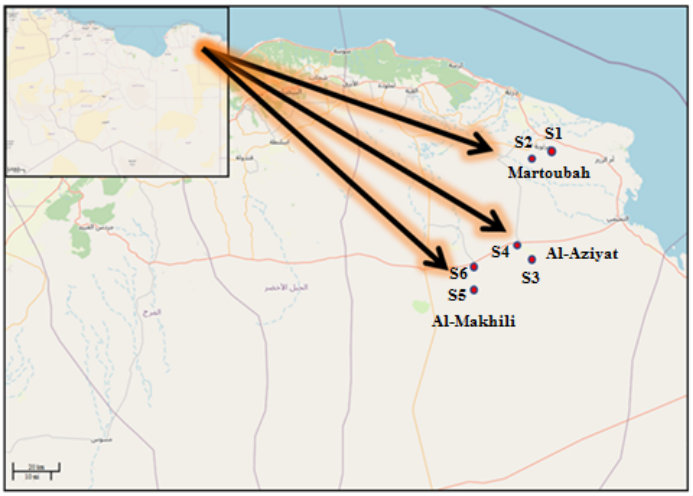

Figure 1. Illustrative map of sampling sites at the three sites.

2.2. Soil property

Soil sample preparation and analysis were conducted in the Biology Laboratory of the Department of Biology at Omar Al-Mukhtar University. The soil samples were sieved (less than 2 mm) for physicochemical analysis and allowed to air-dry at room temperature in the laboratory. After being oven-dried at 105°C, the soil samples were coarsely crushed and passed through a 2 mm sieve.

2.2.1. Soil sampling

The hydrometer technique (ASTM type 151H) was used to do the mechanical study of soil texture. To determine the effect of sample size on the results, two hydrometer tests were conducted with two samples: the first with a 60 g sample and the second with a 100 g sample. Samples were treated with a 0.5% sodium hexametaphosphate solution and stirred for 30 minutes. The soil suspension was mixed using a multimixer for 15 minutes. According to Beretta et al. (2014) description of the textural triangle of soil, the hydrometer reading after 40 seconds and two hours, respectively, corresponds to the proportion of (silt + clay) and clay.

2.2.2. Physigical analysis

Electrical conductivity was measured using a YSI Model 35 conductivity meter (Yellow Springs, Ohio, USA). A pH meter (pH Pen, Jenco Electronics, USA) was used to measure pH, and a soil thermometer was used to monitor temperature at the locations. Soil moisture was determined after 50 g of newly harvested soil were weighed, dried for about 24 hours at 105 °C in an oven, and then re-weighed; the drying process was repeated until a steady weight was achieved according to (Möller et al. 2022).

2.2.3. Algal biomass

According to Wetzel and Likens (2000), the following method was employed to estimate chlorophyll a. Following the air-dried algal crusts of a small region (obtained with a sharp scalpel using a 1.25 cm × 1.25 cm cover glass), the algal crusts were extracted in the dark for 24 hours at 5 ºC after homogenization in 10 mL of 90% acetone. The centrifuge was rotated at 3000 rpm for 5 min to clarify the samples. To estimate chlorophyll a and determine algal biomass, the mixture was decanted into a spectrophotometric tube and measured at 665 nm and 750 nm, both before and after acidification with one drop of concentrated hydrochloric acid.

$$Chlorophyll - a\ (mg/m^2)\ = 26.37(665b - 750b) \times (665a - 750a) \times V/A \quad (1)$$

Where 665b and 750b are absorbance at 665 and 750 nm before and after acidification, V is the volume of sample filtered in liters, and Ais the path length of the cuvette.

2.3. Chemical analysis

2.3.1. Determination of nitrate-N

The Nitrate was measured using the sodium salicylate method (Monteiro, 2003). The optical density of the resulting color was estimated by measuring it with a spectrophotometer at 420nm.

2.3.2. Determination of orthophosphate

According to Dewis and Freitas (1970), 1 mL of soil extract, 1 mL of ammonium molybdate reagent, 2 mL of distilled water, and 1 mL of SnCl2 reagent were mixed, allowed to stand for about 10 minutes, and then the resulting color was measured spectrophotometrically at 660 nm.

2.3.3. Determination of sodium and potassium

Sodium (Na+) and Potassium (K+) were determined by the flame photometric technique using Dr. Lange Flame Photometer M 71 D type Nr/LPG 075.

2.4. Cultivation and taxonomic identification of cyanobacteria

The moist plate method, as suggested by Jurgensen and Davey (1968), was used to cultivate and isolate the cyanobacteria. One gram of each soil sample was placed in 99 mL of distilled water and shaken for 2 hr in a reciprocating shaker. Three replicate Petri dishes (9 cm diameter) were inoculated each with 1 ml of the soil extract (1g soil: 100 ml H_2O), and 20 ml of the molten medium Z8 (45 °C) was added. Petri dishes were incubated at 30 ± 1 °C for blue-green algae. These were incubated for 16/8 hours. Light-dark cycle with a light intensity of 3000-4000 Lux. The colonies were counted after about 25 days of incubation; the number of colonies was proportioned to the dry-weight soil. Cyanobacterial species were examined using a binocular microscope (Zeiss, with camera M35 W) and identified according to the following references: Ettl and Gärtner (2014), Komárek and Anagnostidis (1999 and 2005), and Komárek (2013), which were used to identify species based on morphological characteristics. The internet database AlgaeBase provided clarification on the taxonomic relationship and species names.

2.5. Indices and Statistical Analysis

2.5.1. Diversity indices

Relative evenness: This was done by calculating Shannon-Weaver index according to the equation:

$$\hat{H} = -\sum_{i=1}^{s} \mathcal{P}i(\mathrm{Log}\mathcal{P}i) \quad (2)$$

Where,
p = Percentage (n/N) of individuals of one specific species discovered.
(n) = Divided by the total number of individuals identified.
Σ = Sum of the computations, and's' is the number of species

Relative dominance: This was done by calculating Simpson index according to the equation:

$$D = 1 - \sum_{i=1}^{s} (\mathcal{P}i)^2 \quad (3)$$

Species richness: expressed by comparing the closeness between the accumulation of species in the sites

Pearson correlation: The strength of the association between the relative density of cyanobacterial groups and physicochemical variables at P-value was measured using the equation:

$$r = \frac{\Sigma(Xi - X)(yi - y)}{\sqrt{\Sigma(Xi - X)^2 \Sigma(yi - y)^2}} \quad (4)$$

Where, N is the number of samples, x and xi, are the series being analyzed.

Principal Component Analysis (PCA): The environmental variable distance matrix was used to create a principal component analysis for two basic variables: 23 cyanobacterial species and 12 physicochemical variables.Hierarchical clustering analysis: Based on soil physicochemical similarity, clusters of cyanobacteria species group, and six sites were created using (Ward's method); a hierarchical tree diagram was created to represent the similarity of (cyanobacteria and Sites) homogeneous groups.

2.5.2. Statistical Analysis

All statistical analyses were performed using SPSS version 24 (Statistical Package for the Social Sciences). The results are reported as mean ± standard error (SE). Analysis of Variance (ANOVA) was performed to assess the physicochemical characteristics of the soil and Algal biomass, and Tukey's test was used to determine differences. Statistical significance was set at $p < 0.05$ for all analyses. Principal component analysis (PCA) was used in a multivariate analysis to identify correlations between various cyanobacterial groupings and soil characteristics. The cyanobacteria taxa (23) and the physicochemical characteristics (11) are the variables in the data matrix, whereas the sampling locations (6) are the individuals. A distance matrix of environmental factors was used to create the PCA ordinations. After that, a cluster analysis was performed to determine a soil typology and assess how similar the sample locations were. XLSTAT 2015 version 1 was used for the analysis.

3. Results

3.1. Physiological characters of soil samples

All study locations had rather low clay levels (>26%) regarding soil texture. The soils of the Al-Aziyat and Al-Makhili sites were described as having a light texture, thick sand, and low moisture content. In contrast, the soils of the Martouba sites were distinguished by their thick, high bulk density. Most micronutrients in soils of the three groups are positively and significantly correlated with silt, clay, and sand contents. Regarding soil temperature, Table 1 shows no significant differences among the six soil sites. It ranged between 24-33 °C in this month (May. Regarding pH, the soil samples collected were neutral to slightly alkaline, ranging from 7.09 (site 5) in the Al-Makhili area to 8.34 (site 1) in the Martouba area. The soils collected from the camel barns in three areas had high moisture content. They contained on higher average (33.1%) in comparison to the other collected soil samples outside the barn, where the averages (22.5, 23.0, and 24.6%) were for the second, fourth, and sixth sites, respectively. Electrical conductivity (E.C.) (μS cm^{-1}) was generally high in all soils collected from camel barns compared to other samples. However, the lowest value of E.C. (109 μS cm^{-1}) was recorded at the fourth site in the Al-Aziyat area.

3.2. Chemical characters of soil samples

In general, Soil samples from camel pens in the three areas contained higher contents of nitrate and orthophosphate. The highest nitrogen content was in the soil of the fifth site (0.39 mg g^{-1}), and the high orthophosphate content was in the soil of the fifth site (0.75 mg g^{-1}). The percentage of sodium and potassium in the soil of the barns was higher than at the other sites; the highest levels were in the first and fifth sites, at 5.6 and 12.3 mg g^{-1}, respectively. On the contrary, the soils of the other three sites (outside barns) were very poor in nitrate, orthophosphate, sodium, and potassium.

3.2.1. Algal biomass

The ANOVA showed a significant effect of the sampling Sites on soil chl-a ($p < 0.05$). The total algal biomass ranged from 0.90 μg g^{-1} at the fourth site to 20.6 μg g^{-1} at the fifth site. The three camel barn sites had the highest chlorophyll content among the sites.

Table 2. Physio-chemical parameters of soils inside and outside camel barns

Sites Parameters		S1	S2	S3	S4	S5	S6
Soil texture	Sand (%)	41.09±0.28^{c}	48.34±0.45^{b}	47.23±0.77^{b}	51.31 ±0.13^{ab}	47.93±0.52^{b}	53.12 ±0.78^{a}
	Silt (%)	33.71±0.24^{a}	29.59±0.68^{b}	31.36±0.15^{ab}	29.54±0.21^{b}	27.48±0.67^{c}	26.32±0.19^{c}
	Clay (%)	25.24±0.66^{a}	22.07±0.31^{b}	21.44±0.37^{bc}	19.16±0.75^{c}	24.62±0.82^{ab}	20.58±0.23^{c}
Temp (°C)		24.0±0.2^{c}	25.0±0.3^{c}	33.0±0.5^{a}	33.0±0.1^{a}	29.0±0.2^{b}	30.0±0.3^{b}
pH		8.34±0.01^{a}	8.27±0.00^{a}	7.45±0.01^{b}	7.23±0.00^{b}	7.09±0.01^{c}	7.14±0.02^{bc}
OM (%)		33.1±0.4^{a}	22.5±0.1^{c}	29.9±0.5^{bc}	23.0±0.3^{c}	30.5±0.2^{b}	24.6±0.2^{c}
EC (µS/cm)		162.84±0.20^{b}	120.06±0.08^{de}	180.44±0.31^{a}	109.23±0.11^{e}	153.38±0.17^{c}	132.86±0.35^{d}
Organic (%)		4.56±0.38^{a}	2.97±0.26^{c}	3.48±0.33^{bc}	2.82±0.24^{c}	3.29±0.17^{b}	2.35±0.23^{c}
NO_3-N (mg g^{-1})		0.36±0.17^{a}	0.17±0.07^{c}	0.28±0.11^{b}	0.20±0.10^{bc}	0.39±0.14^{a}	0.22±0.09^{bc}
PO_3-P (mg g^{-1})		0.59±0.20^{c}	0.26±0.14^{c}	0.70±0.17^{b}	0.29±0.09^{d}	0.75±0.23^{a}	0.31±0.08^{d}
Na (mg g^{-1})		5.2±0.2^{ab}	1.7±0.1^{d}	5.6±0.2^{a}	2.3±0.3^{c}	4.9±0.2^{b}	1.0±0.1^{e}
K (mg g^{-1})		12.3±0.2^{a}	7.9±0.1^{b}	11.6±0.2^{a}	7.7±0.3^{b}	11.8±0.2^{a}	5.6±0.1^{c}
Chl-a (µg g^{-1})		16.5±0.98^{b}	2.5±0.16^{d}	12.3±0.22^{c}	0.90±0.00^{c}	20.6±0.50^{a}	1.4±0.00^{d}

* Different letters in each row represent significant differences at $p < 0.05$.
*Note: Temp= temperature; OM= Mituree; EC= Electrical conductivity; Organic= organic matter; NO_3-N = Nitrates; PO_3-P = Orthophosphates; Na= sodium; K= potassium; Chl-a=chlorophyll-a.

3.2.2. Cyanobacterial diversity: morphological identification and strain isolation

In this work, 23 cyanobacterial species belonging to 14 genera, representing five common cyanobacterial orders (Chroococcales, Oscillatoriales, Nostocales, Scytonematales, and Spirulinales), were isolated from soil. This list was derived using morphological features and the culture-dependent technique (Table 3). The order Oscillatoriales dominated the majority of sites with an occurrence rate of (37.03%), followed by the order Nostocales (27.77%), while Chroococcales and Spirulinales were closely related (16.66 and 14.81%), respectively. In comparison, the order Synechococcales was the least diverse (3.70%). At the genus and species level, Oscillatoria (13 taxa) dominated with an occurrence rate of (24.07%), followed by Spirulina (8 taxa) with an occurrence rate of (14.81%), and the least abundant Aphanizomenon, Merismopedia, and Leptolyngbya (1 taxa) with an occurrence rate of (1.85%) were recorded exclusively in camel barns. The species richness of *Woella saccata* was recorded at all studied sites. The presence of cyanobacteria varied across the six sites, with the first site recording the highest total abundance of orders (5/5 orders), genera (11/17 genera), and species (18/23 species), with an overall mean of (0.78±0.08), Shannon index (Ĥ) (2.89±0.42), species richness (5.882±0.2 species/stand), with a low Simpson index (0.05±0.001). Followed by the fifth and third sites in the abundance of orders (4/5 order) and genera (6,7/17) and species (11, 10/23) with a mean total (0.47±0.1, 0.43±0.05), Shannon index (Ĥ) (2.398±0.33, 2.303±0.38), species richness (4.170±0.2, 3.909±0.5) and Simpson's index (0.090±0.01, 0.100±0.008) respectively (Table 4). In contrast, sites outside camel barns showed a significant decrease in the abundance and numbers of cyanobacterial species, which was noted by a reduction of biodiversity indicators. The greatest decrease was recorded at site 6, with total mean (0.13±0.07), species richness (1.820±0.3), Shannon index (1.099±0.37), and Simpson index (0.333±0.084) all decreasing.

Table 3. Cyanobacteria species distribution of soils inside and outside camel barns

Cyanobacteria		Site						To.
Order/Family	Species	S1	S2	S3	S4	S5	S6	
1-Order/Nostocales								
Nostocaceae	*Anabaena sircinalis*. Rabh	+	-	+	-	-	-	2
	Anabaena spiroides. Lemm	+	-	-	-	-	-	1
	Nostoc commune. Vaucher	-	+	+	-	-	-	2
	Nostoc linckia. Bornet	-	-	+	-	-	-	1
	Woella saccata. Wolle	+	+	+	+	+	+	6
Aphanizomenonaceae	*Aphanizomenon flos-aquae*. Ralfs	-	-	-	-	+	-	1
Scytonemataceae	*Scytonema archangelii.* Born	+	-	-	+	-	-	2
2-Order/Oscillatoriales								
Oscillatoriaceae	*Lyngbya contort*. Lemm	+	-	-	-	+	-	2
	Lyngbya borgertii. Lemm	+	-	+	-	+	-	3
	Oscillatoria Formosa. Bory	-	+	+	+	+	+	5
	Oscillatoria Limosa. Bory	+	-	+	+	+	+	5
	Oscillatoria nigra. Vaucher	+	-	-	+	+	-	3
	Phormidium molle. Vaucher	+	-	-	-	+	-	2
3-Order/Chroococcales								
Chroococcaceae	*Chroococcus majore*. Lemm	+	+	-	-	-	-	2
	Chroococcus minor. Lemm	+	-	-	-	-	-	1
	Gloeocapsa magma (Brébisson)	+	-	+	-	-	-	2
Microcystaceae	*Microcystis flos-aquae*. Smith	-	-	-	-	+	-	1
	Microcystis areuginosa. Smith	+	+	-	-	+	-	3
4-Order/Synechococcales								
Merismopediaceae	*Merismopedia glauca*. Ehrenb	+	-	-	-	-	-	1
Leptolyngbyaceae	*Leptolyngbya benthonica (Sku.) An.*	+	-	-	-	-	-	1
5- Order/ Spirulinales								
Spirulinaceae	*Spirulina laxa*. Smith	+	-	-	-	-	-	1
	Spirulina platensis. Kutz	+	+	+	+	+	-	5
	Spirulna major. Kutz	+	-	+	-	-	-	2
No. Species		18	6	10	6	11	3	54
No. Genus		11	6	7	4	6	2	36
No. Order		5	4	4	3	4	2	22

Table 4. Diversity indices of cyanobacteria species of soils inside and outside camel barns

Diversity indices	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Total speices	18	6	10	6	11	3
Mean	0.78±0.08	0.26±0.09	0.43±0.05	0.26±0.09	0.47±0.1	0.13±0.07
Species richness	5.882±0.2	2.791±0.3	3.909±0.5	2.790±0.1	4.170±0.2	1.820±0.3
Shannon index ($\hat{H}$)	2.890±0.42	1.792±0.35	2.303±0.38	1.791±0.41	2.398±0.33	1.099±0.37
Simpson (dominance D)	0.055±0.001	0.167±0.011	0.100±0.008	0.166±0.015	0.090±0.01	0.333±0.084

3.2.3. Correlation between cyanobacteria and physicochemical characteristics

Pearson's correlation coefficients indicated from (Table 5) to that variables such as K (r=0.963; $p \leq 0.01$), Na (r=0.950; $p \leq 0.05$), total organic matter (r=0.954; $p \leq 0.01$) and Mituree (r=0.699; $p \leq 0.05$) had a significant impact on the distribution of algal biomass and the number of colonies of cyanobacteria (a positive correlation). The distribution of orders was also correlated to the previous factors and the percentage of clay and silt. Additionally, the quantity of potassium and the percentage of silt in the soil had an impact on the distribution of genera, whereas the amount of potassium (r=0.908; $p \leq 0.05$) and the amount of organic matter (r=0.955; $p \leq 0.05$) in the soil had an impact on the distribution and number of species. On the other hand, the correlation results showed an inverse relationship between the percentage of sand in the soil (strong negative correlations) and the distribution of species, genera, orders, number of colonies, and biomass (r = -0.960, -0.980, -0.942, -0.889, -0.817; $p \leq 0.01$).

Table 5. Pearson's correlation coefficients between cyanobacteria species and soil parameters inside and outside camel barns

Cyanobacteria parameters	Algal biomass	No. Colonies	No. Order	No. Genera	NO. Species
Sand (%)	-0.817**	-0.889**	-0.942**	-0.980**	-0.960**
Silt (%)	0.550	0.625	0.792*	0.898**	0.824
Clay (%)	0.822	0.863*	0.766*	0.715	0.763
Temp (°C)	-0.238	-0.392	-0.553	-0.482	-0.398
pH	0.345	0.372	0.800	0.732	0.623
OM (%)	0.699*	0.874	0.899	0.913	0.864
EC (µS cm^{-1})	0.816	0.700	0.529	0.666	0.707
Organic (%)	0.984*	0.954**	0.812**	0.861	0.955*
NO_3-N (mg g^{-1})	0.965	0.841	0.846	0.865	0.904
PO_3-P (mg g^{-1})	0.900	0.821	0.503	0.555	0.659
Na (mg g^{-1})	0.950*	0.904	0.721	0.784	0.859
K (mg g^{-1})	0.963**	0.974*	0.862**	0.862**	0.908*

** significant at $p \leq .01$, * significant at $p \leq .05$.

3.2.4. The relationships between the distribution of cyanobacterial groups and environmental conditions

Table 4 displays the results of the two principal component analyses (PCA). At the camel barns, soil conditions accounted for 94.13% of PC1 and PC2. The variables were mostly correlated with two axes (F1 and F2), which accounted for 58.22% of the data's overall variance (Figure 2). According to the PCA analysis, some cyanobacteria species and camel barns showed positive correlations based on physicochemical characteristics. For instance, there was a strong correlation between clay, total organic matter, Orthophosphate, sodium and potassium, soil moisture, and conductivity of *Nostoc linckia*, *Lyngbya borgertii*, *Microcystis areuginosa*, and *Gloeocapsa magma*. The taxa *Oscillatoria nigra*, *Anabaena sircinalis*, *Anabaenaspiroides*, *Scytonema archangelii*, *Leptolyngbya benthonica*, *Chroococcus majore*, and *Chroococcus minor*, on the other hand, demonstrated the strongest correlation with nitrogen content, nitrate nitrogen. Other taxa, including *Oscillatoria limosa*, *Merismopedaglauca*, *Woella saccata*, *Oscillatoria Formosa*, and *Spirulina laxa*, were correlated with temperature to sand. Other species associated with silt and pH include *Spirulina platensis*, *Aphanizomenon flos-aquae*, *Spirulina major*, *Nostoc commune*, and *Lyngbya contorta*. Finally, a strong negative correlation was

observed between nitrate nitrogen and soil moisture, and among some species such as *Nostoc commune*, *Spirulina major*, *Lyngbya* contorta, and *Microcystis flos-aquae*.

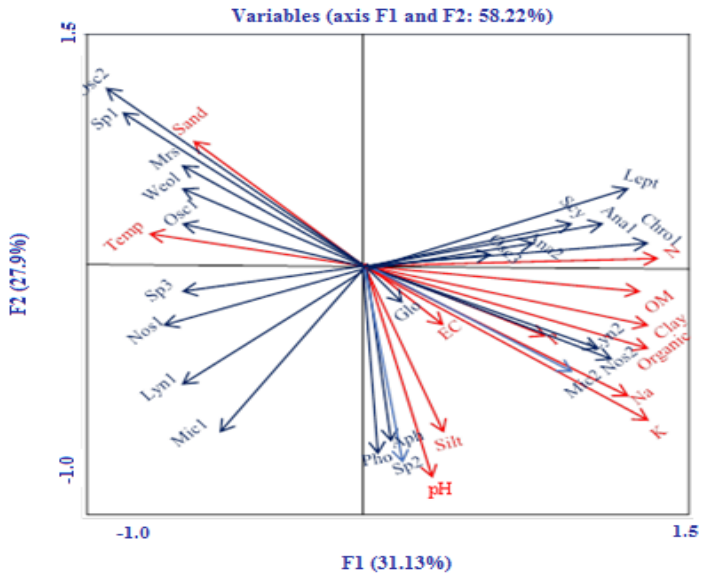

Figure 2. Diagram of PCA ordination of *Cyanobacteria genera* and environmental variables of soil.

Note: Temp= temperature; OM= Mituree; EC= Electrical conductivity; Organic= organic matter; N= Nitrates; P= Orthophosphates; Na= sodium; K= potassium; Lept=*Leptolyngbya benthonica*; Scy= *Scytonema archangelii*; Ana1= *Anabaena sircinalis*; Ana2= *Anabaena spiroides*; Chro1= *Chroococcus majore*; Chro2= *Chroococcus minor*; Lyn1= *Lyngbya contort*; Lyn2= *Lyngbya borgertii*; Mic1= *Microcystis flos-aquae*; Mic2= *Microcystis areuginosa*; Osc1= *Oscillatoria Formosa*; Osc2= *Oscillatoria Limosa*; Osc3= *Oscillatoria nigra*; Nos1= *Nostoc commune*; Nos2= *Nostoc linckia*; Sp1= *Spirulina laxa*; Sp2= *Spirulina platensis*; Sp3= *Spirulna major*; Mrs= *Merismopedia glauca*; Pho= *Phormidium molle*; Aph= *Aphanizomenon flos-aquae*; Glo= *Gloeocapsa magma*; Weol=*Woella saccata*.

3.2.5. The relationships between the distribution of cyanobacterial groups and environmental conditions

The correlation between cyanobacterial group distributions and environmental conditions was examined using multivariate analysis. Based on the hierarchical cluster analysis, four homogeneous groups may be identified from the dendrogram using Ward's method based on soil physicochemical similarity (Figure 3 and Figure 4):

- The first group: distributed in most of the studied sites and included four species (*Woellasaccata*, *Spirulina platensis*, *Oscillatoria Formosa*, and *Oscillatoria* Limosa) belonging to three genera and three orders.
- The second group: distribution in general across the first and third sites (camel barns), and included six species (*Anabaena sircinalis*, *Nostoc commune*, *Gloeocapsa magma*, Spirulna *major*, *Lyngbya borgertii*, and *Nostoc linckia*) belonging to six genera and three orders.
- The third group included seven species (*Scytonema archangelii*, *Oscillatoria nigra*, *Spirulina laxa*, *Anabaena spiroides*, *Leptolyngbya benthonica*, *Chroococcus minor*, and *Merismopedia glauca*) belonging to seven genera and four orders; the order Synechococcales was observed only in this group. Generally, the species were distributed in the first and fourth sites.
- The fourth group, distributed across the fifth and second sites, included six species (*Chroococcus major*, *Microcystis flos-aquae*, *Microcystis aeruginosa*, *Aphanizomenon flos-aquae*, *Phormidium molle*, and *Lyngbya contorta*) belonging to five genera and three orders.

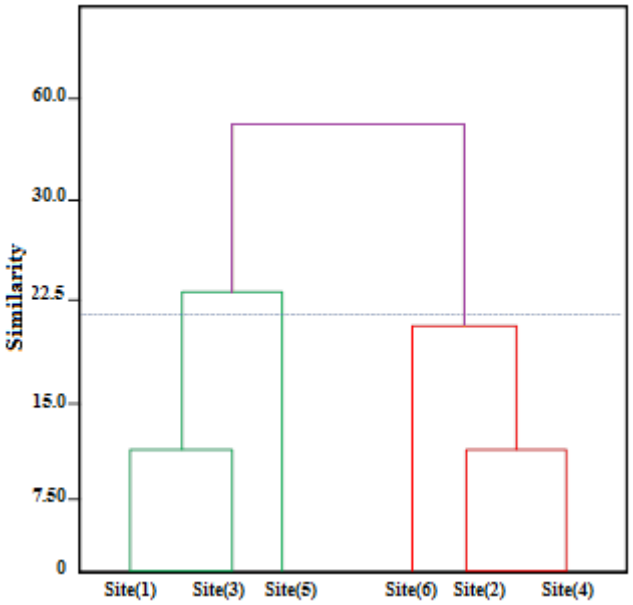

Figure 3. Ward's approach of hierarchical clustering analysis is used to sample Sites according to the physicochemical similarity of the soil.

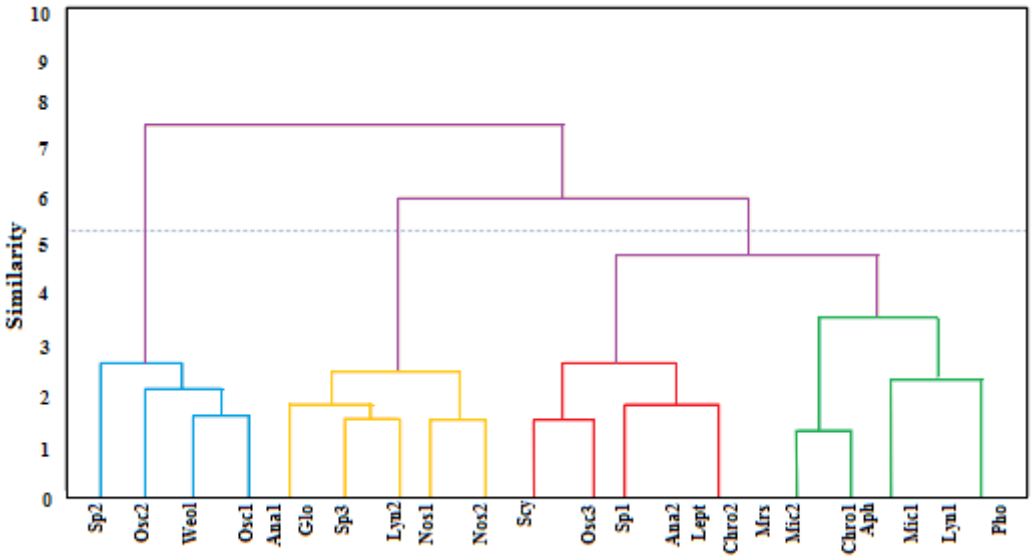

Figure 4. Dendrogram of similarity showing the closest accessions in homogenous groupings using standardized Euclidean distances.

4. Discussion

This work is the first attempt to study the diversity of cyanobacteria in camel barn soil, an environment that contradicts many studies' reports on cyanobacteria distribution. In this study, 23 cyanobacterial species from 18 genera and five orders were identified, and the results revealed that camel barn sites showed the highest diversity and occurrence indices. On the other hand, the least varied areas were those outside the camel barn. This may be due to the abundance of organic matter resulting from camel waste, as cyanobacteria are directly linked to the availability of organic matter and soil moisture (Strong et al., 2013). Our results demonstrated that only certain species of cyanobacteria could adapt to arid environments, both inside and outside the camel barn (*Oscillatoria formosa*, *Oscillatoria* limosa, and *Spirulina platensis*). This may not entirely align with Chilton et al. (2022), who reported that cyanobacteria colonize arid lands in Australia. Analysis of the overall richness of cyanobacteria species

revealed significant differences between the inside and outside of camel barns within the same study areas, despite their proximity within each area. This variation demonstrates a direct correlation between cyanobacteria and organic matter concentrations; Zhang et al. (2011) confirmed that phosphorus and magnesium ion content, soil texture, and moisture content are the main factors responsible for the distribution of cyanobacteria and microalgae in desert lands in China.

Additionally, Al-Sudani et al. (2018) found that in dry areas, plant chemical secretions affect the dispersal of cyanobacteria. On the other hand, Hageman et al. (2015) noted that cyanobacterial diversity in drylands appears to depend on available rainfall, whereas differences in soil chemistry are of lesser importance. At the order level, Oscillatoriales dominated most sites under study, particularly the camel barn sites. Our findings are corroborated by those of Řeháková et al. (2011), who found that *Oscillatoria* species tend to occur in soils high in organic matter. The second most varied order was Nostococcales. Rancel-Rodríguez et al. (2024) state that cyanobacteria are composed of heterogeneous cells that live in various environments, particularly nitrogen-poor environments. Synechococcales individuals have only been discovered at the first camel barn site. This is explained by the fact that they are affected by the lack of fundamental components and are directly related to organic matter (Te et al., 2023). In most sites, *Oscillatoria* and *Spirulina* species predominated, with camel barn sites having the highest richness of these two taxa. Our findings aligned with several studies showing that these two cyanobacteria species could thrive in wastewater and animal manure settings (Sopandi et al., 2020; Abdulrraziq and Salih, 2023; Elmousel et al., 2023; Liang et al., 2023). *Woella saccata* had the highest presence index (100%). The fact that this cyanobacteria can flourish in many arid soil conditions may help to explain this. The richness of cyanobacterial diversity at the first site demonstrates that cyanobacterial distribution is closely correlated with soil chemical and physical characteristics. This variety may be explained by the correlation among high nutrient levels, organic carbon, and moisture (Strong et al., 2013). Since our study was conducted in May, during the height of the summer season, seasonal factors may have a significant effect on cyanobacteria dispersion. For instance, it has been noted that February in the winter is the best time of year for cyanobacteria richness in desert environments (Hakkoum et al., 2021).

Generally, our results indicate that soil physical and chemical properties were the primary factors influencing the distribution and spread of cyanobacteria at the study sites. Outside the camel enclosures, the distribution of species, genera, orders, colonies, and biomass was strongly inversely correlated with the sand content and soil moisture. Conversely, within the camel enclosures, the distribution of biomass and the number of cyanobacterial colonies were generally correlated with potassium, sodium, moisture, and total organic matter. According to reports, camel waste and urine contain significant amounts of calcium, magnesium, and potassium (Abdalla et al., 2018), as well as phenol, p-cresol, salicylic acid, cinnamic acid, azelaic acid, and benzoic acid (Khedr and Khorshid, 2016). According to the aforementioned, camel barns may be considered an appropriate habitat for the development of cyanobacteria in desert soils, as camel waste is rich in nutrients necessary for the growth of this type of microbe. Finally, Changes in physical and chemical properties and environmental factors are key drivers of soil microalgae abundance and diversity (Joseph and Ray, 2024; Chang et al., 2025). However, generalizing about the relationship between cyanobacteria and soil properties poses significant challenges, especially given cyanobacteria's inherent properties.

Conclusion

In conclusion, this work represents the first survey of cyanobacterial species in camel pens in arid Libyan lands, recording 23 taxa of spherical and filamentous cyanobacteria. The results revealed correlations between the distribution and diversity of cyanobacterial groups and the chemical and physical properties of the soil in these pens, compared with those at outdoor sites. This study provides a simplified overview of how to exploit animal waste and wastewater as new sources for cultivating microorganisms.

Ethical Statement

Ethical approval is not required for this study.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Funding Statement

This research did not receive specific grants from funding agencies in public, commercial or not-for-profit sectors.

Author Contributions

The research idea was formulated by Author 1. The statistical analysis was performed by Authors 1 and 2. The physicochemical analyses were performed by Authors 1 and 3. All authors wrote the text. Reviewed the work by authors 1 and 2.

Acknowledgements

The authors would like to thank the owners of the camel pens south of Al Qubbah city.

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