Antioxidant activities of some edaphic algae in Egypt

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Abstract

Background: Algae in general characterized by their rich content of biological compounds. However, few studies were conducted on the soil-inhabiting algae and their antioxidant characteristics.

Results: The present study was designed to evaluate the antioxidant activity of four edaphic algae including one on-soil alga (Vaucheria geminata) and three axenic isolated in-soil algae (Pleurochloris pyrenoidosa, Botrydiopsis eriensis, and Scenedesmus obliquus). Total antioxidant activity by Phosphomolybdenum assay ranged from 6.66 to 36.33 mg of Asc/g dwt; meanwhile, the percentage inhibition of DPPH radical was up to 97.37%. Antioxidant activity of each alga was assessed also by measuring their contents of total phenols, flavonoids, and pigments (chlorophyll a and carotenoids). B. eriensis and S. obliquus recorded the highest levels of phenols, flavonoids, and chlorophyll a followed by P. pyrenoidosa and V. geminata, while B. eriensis showed the highest carotenoids content. Moreover, about seven types of each phenol and flavonoid compound were identified by HPLC chromatography in the four algae under investigation. The most common detected phenols were gallic, chlorogenic, caffeic, and ferulic, while rutin, quercetin, apigenin, and quercitrin were the most abundant flavonoids among all algae under investigation.

Conclusion: All the tested algae were characterized with high antioxidant activities besides the rich contents of compounds with antioxidant properties which recommend their further potential using in nutritional, pharmaceutical, and medicinal implications.

Keywords: Algae, Edaphic, Antioxidant, Phenols, Flavonoids, Chlorophyll, Carotenoids

1 Background

Algae are a diverse group of photosynthetic organisms representing the most abundant primary producers among all living organisms. They are usually inhabitants of aquatic biotopes either freshwater or marine, although they are widespread also in a wide range of ecological habitats including air, soil, or even extreme habitats [1]. Algae that occur in terrestrial habitats including either in or on soil surfaces are called edaphic algae. To cope with different environmental conditions, algae synthesize and accumulate a wide range of bioactive compounds [2–4].

Microalgae have an interesting antioxidant system, which considered more effective due to the interactions among different compounds with antioxidant properties. The most powerful antioxidants found in algae being pigments, phenols, flavonoids, and vitamins [5]. The term antioxidant can be considered to describe any compound capable of quenching various forms of activated oxygen without itself undergoing conversion to a destructive form. In addition, when present at low concentrations significantly delays or prevents oxidation of different molecules by reactive oxygen species [6]. Accumulation of these destructive radicals can be extremely harmful to the cell components causing severe damage to crucial biomolecules such as nucleic acids, lipids, proteins, and carbohydrates [7].
Among antioxidants, phenolics comprise a wide range of compounds characterized with diverse physiological functions [8]. Various studies have reported the high phenolic content and antioxidant activity of many algal species [9–11]. In addition to its antioxidant characteristics, phenols documented in various researches for their antimicrobial, anti-inflammatory, and anti-proliferative activities on various types of cancer [12–14]. Also, the consumption of dietary supplements rich in polyphenols, associated with a lower risk of chronic diseases such as cardiovascular diseases [15]. Also, flavonoids, a group of phenolic compounds, found in many algae have a significant antioxidant activity. Many researches explored different types of flavonoids in many algae [16, 17]. Flavonoids have a wide range of biological functions including anticarcinogenic, antimicrobial, anti-inflammatory, antidiabetic, and anti-obesity effects [18–21].

Moreover, algae have a wide range of pigments other than chlorophylls; most commonly carotenoids, phycobiliproteins, xanthophylls, etc. Pigments not only have an important role for algae in photosynthesis but also having antioxidative properties and other biological functions [22–24]. The advantage of using microalgae for pigment production is their high rate of growth as well as its ability to grow under adverse cultivation conditions. Different studies were conducted to increase the pigment yield from algae by manipulating their growth conditions such as light, temperature, and nutrients [25–27]. Chlorophyll from algae usually used in pharmaceutical applications as well as a natural additive in the food industry [28, 29]. Carotenoids also display very high antioxidative properties due to their ability for quenching reactive oxygen species [30]. Under specific growth conditions, some algae can increase their carotenoid content to high values [31, 32].

Finally, certain studies reported the antioxidative activities of algae especially seaweeds; however, few studies concerned with the antioxidative properties of microalgae especially algae growing on and in soil. So, the objective of the present study is to investigate different compounds such as phenols, flavonoids, chlorophylls, and carotenoids as well as their antioxidative properties in some soil-inhabiting algae.

2 Methods

2.1 Sample collection and preparation

Unialgal masses of Vaucheria geminata (Vaucher) De Candolle were collected from the soil surface of the humid canal near agricultural field at El Sharqia government (30° 35′–51° 04′ N/31° 44′–67° 27′ E). Samples were transported immediately into the lab, and siphons were collected gently from the surface of algal mats, shade-dried, and preserved in a dry place until phytochemical analysis. On the other hand, three algal taxa were isolated from different soil samples at MitHelfa, Qalyoub, El Obour, and El Khankah (30° 14′–98° 92′ N/31° 23′–52° 29′ E, 30° 24′–92° 69′ N/31° 48′–02° 98′ E, and 30° 23′–35° 23′ N/31° 37′–96° 77′ E, respectively). Soil samples were enriched synthetic nutritive media (Chu10) for algal propagation, then algal samples were isolated and purified from any other microorganisms. The axenic algal samples include two yellow green algae (Pleurorchloris pyrenoidosa Pasch and Botrydiopsis eriensis Snow) and one green alga (Scedesmus obliquus Turpin Kütz). Identification of the four algal taxa was carried out [33, 34], while isolation of uni-algal samples was carried out using the plating and serial dilution method [35]. Under aseptic conditions, each isolate was cultivated in a sterilized BG 11 media for further mass culture according to the modified method [36]. Then, all flasks were kept in an incubator (with continuous light) at about 24 °C with continuous shaking until harvesting. After about 2 weeks, algal cultures were collected at the stationary phase and finally preserved dry at room temperature until phytochemical analysis also. Photomicrographs were taken using the binocular BEL photons biological microscope fitted with a Canon Powershot G12 digital camera (Fig. 1a–d).

2.2 Phytochemical analysis

2.2.1 Determination of total antioxidant capacity (TAC)

Total antioxidant activities of crude methanolic extracts were determined [37]. Briefly, 0.3 ml of sample solution (0.1 mg/ml) was mixed with 3.0 ml reagent solution (0.6 M sulfuric acid, 28 mM sodium phosphate, and 4 mM ammonium molybdate). Reaction mixture was incubated at 95 °C for 90 min in a water bath. The absorbance of all the sample mixture was measured at 695 nm with Unico 1201 spectrophotometer. Total antioxidant capacity is expressed as the number of equivalence of ascorbic acid.

2.2.2 Assay of 1,1-diphenyl-2-picrylhydrazyl radical (DPPH)

The DPPH radical scavenging assay was performed according to the method described by [38]. Mix the 0.5 ml of algal methanolic extract with 0.5 ml of 0.2 mM DPPH solution (prepared with methanol) and incubate for 30 min in the dark at room temperature. The absorbance of each sample was recorded at 515 nm using Unico 1201 spectrophotometer. The percentage of scavenged DPPH radical was calculated according to the following equation:

$$\text{DPPH scavenging activity (\%)} = \left[1 - \frac{(A_s - A_c)}{A_c}\right] \times 100$$

where $A_s$ is the absorbance of the sample (sample with DPPH), $A_c$ is the absorbance of the sample control.
Fig. 1 Photomicrographs of algal samples (a) Vaucheria geminata, (b) Pleurochloris pyrenoidosa, (c) Botrydiopsis eriensis, and (d) Scenedesmus obliquus. Scale bar = 10 μ

Fig. 2 Total antioxidant activity (Phosphomolybdenum assay) of methanol extract of V. geminata, P. pyrenoidosa, B. eriensis, and S. obliquus expressed as mg/g of ascorbic acid
(sample in methanol), and \( Ac \) is the absorbance of the control (DPPH solution).

### 2.2.3 Total phenols

A known weight of algal samples was extracted with 80% cold methanol, and phenolic contents were determined by the method of [39]. Briefly, 0.1 ml of each sample was mixed with 0.4 ml of Folin–Ciocalteu reagent (10%) and allowed to stand at room temperature for about 5 min. Then, 0.5 ml of 7.5% \( \text{Na}_2\text{CO}_3 \) solution was added and the mixture incubated for 1.5 h in the dark at room temperature. Finally, the absorbance of each sample was measured at 760 nm with Unico 1201 spectrophotometer, and total phenols were calculated from a standard curve of gallic acid as milligram per gram dry weight.

### 2.2.4 Total flavonoids

The modified method was used for the determination of flavonoid contents [40]. About 0.5 ml of methanolic extract was mixed with 1.5 ml of 95% ethanol, 0.1 ml of 10% aluminum chloride, 0.1 ml of 1 M potassium acetate, and 2.8 ml of distilled water. After incubation at room temperature for 30 min, the absorbance of the reaction mixture was measured at 415 nm with Unico 1201 spectrophotometer and Quercetin was used to make the calibration curve.

### 2.2.5 Pigments

Photosynthetic pigments (chlorophyll \( a \) and carotenoids) were measured in the acetone algal extracts at wavelengths of 663 and 452.5 nm using Unico 1201 spectrophotometer [41]. Finally, the concentrations of the pigment fractions of chlorophyll \( a \) and carotenoids were determined as microgram per milligram, according to the following equations:

\[
\text{Chlorophyll a} = 10.3 \cdot E_{663} - 0.918 \cdot E_{644}
\]

\[
\text{Chlorophyll b} = 19.7 \cdot E_{644} - 3.870 \cdot E_{663}
\]

\[
\text{Carotenoids} = 4.2 \cdot E_{452.5} - (0.0264 \cdot \text{chlorophyll a} + 0.426 \cdot \text{chlorophyll b})
\]

### 2.2.6 Determination of phenols and flavonoids by HPLC

Chromatographic separation of phenols and flavonoids of algal methanolic extracts was accomplished on a KROMASIL column (150 mm × 4.6 mm) using HPLC device (GBC, Australia) with a UV/Vis detector and LC 1110 Pump at Al-Azhar university fungi research. The HPLC analysis was performed using methanol to water to tetrahydrofuran to acetic acid (23:75:1:1 v/v/v/v) as a mobile phase with a flow rate of 1 ml/min, and chromatograms were registered at UV 280 nm in case of

|                  | V. geminata | P. pyrenoidosa | B. eriensis | S. obliquus |
|------------------|-------------|----------------|-------------|-------------|
| Total phenols (mg/g dwt) | 13.68 ± 1.11 | 27.07 ± 0.76 | 30.89 ± 1.61 | 29.25 ± 0.24 |
| Total flavonoids (mg/g dwt) | 9.59 ± 0.14  | 16.84 ± 1.87 | 24.73 ± 0.29 | 22.34 ± 0.32 |
| Total antioxidant activity (mg of ascorbic acid/g dwt) | 6.66 ± 0.06 | 21.47 ± 0.04 | 30.05 ± 0.69 | 36.33 ± 0.45 |
| Percentage inhibition of DPPH | 36.89 ± 3.83 | 89.47 ± 1.53 | 77.66 ± 1.27 | 97.37 ± 1.33 |

Results are means ± SE of three replicates. Different letters mean statistically significant differences (\( p < 0.05 \))
phenols. While for flavonoids, acetonitrile to water to formic acid (85:14:1 v/v/v) was used as a mobile phase with a flow rate was 0.8 ml/min, and chromatograms were registered at UV 356 nm. Finally, qualitative and quantitative evaluation of both phenolic and flavonoid compounds were done by comparison of their retention times with those of pure standards using Win Chromatography Ver. 1.3 software.

2.3 Statistical analysis
Data are reported as mean ± standard error from triplicate determination. The phytochemical analysis of samples was compared using one-way ANOVA (SPSS for Windows, version 20) to identify the significant difference ($p < 0.05$) between samples [42].

3 Results
3.1 Total antioxidant activity
The total antioxidant activity expressed by Phosphomolybdenum assay was illustrated in Fig. 2. Higher activity occupied by *S. obliquus* and *B. eriensis* followed by *P. pyrenoidosa* (36.33, 30.05, and 21.47 mg of ascorbic acid/g dwt, respectively) while lower activity was for *V. geminata* (6.66 mg of ascorbic acid/g dwt, respectively). Also, the percentage inhibition of DPPH radical was determined for all algal taxa under investigation. A maximum percentage of activity was for *S. obliquus*, *P. pyrenoidosa*, and *B. eriensis* (97.37, 89.47, and 77.66%, respectively) and moderate activity for *V. geminata* (36.89%) were detected (Fig. 3).

3.2 Total phenols and flavonoids
The total phenols and total flavonoids of *V. geminata*, *P. pyrenoidosa*, *B. eriensis*, and *S. obliquus* are illustrated in Fig. 4. The values are expressed as mg/g dwt.

3.3 Chlorophyll a and total carotenoids
The chlorophyll a and total carotenoids of *V. geminata*, *P. pyrenoidosa*, *B. eriensis*, and *S. obliquus* are illustrated in Fig. 5. The values are expressed in μg/m.
3.2 Total phenol and flavonoid content
To determine the antioxidant activity of the algae under study, total phenols and total flavonoids were estimated (Table 1). Data revealed that both total phenol and flavonoid content showed a similar pattern in each alga. The maximum content of total phenols was detected in \( \text{B. eriensis} \) and \( \text{S. obliquus} \) (30.89 and 29.25 mg/g dwt, respectively) and for total flavonoids (22.05 and 22.34 mg/g dwt, respectively), while \( \text{P. pyrenoidosa} \) showed moderate content of both phenol and flavonoid content (27.07 and 16.84 mg/g dwt, respectively). On the other hand, lower content of phenols and flavonoids (13.68 and 9.59 mg/g dwt, respectively) were recorded in \( \text{V. geminata} \) (Fig. 4).

3.3 Chlorophyll \( \alpha \) and carotenoid content
Additionally, the pigment composition (chlorophyll \( \alpha \) and carotenoid) of the four algae was estimated (Fig. 5). It was noticeable that \( \text{B. eriensis} \) recorded the highest content of both chlorophyll \( \alpha \) and carotenoid (0.70 and 0.68 mg/g dwt, respectively). Although \( \text{S. obliquus} \) recorded higher content of chlorophyll \( \alpha \), lower carotenoid content was noticed (0.63 and 0.14 mg/g dwt, respectively). On the other hand, a moderate concentration of chlorophyll \( \alpha \) and carotenoid was detected in \( \text{P. pyrenoidosa} \) (0.36 and 0.29 mg/g dwt, respectively). In \( \text{V. geminata} \), a lower value of both chlorophyll \( \alpha \) and carotenoid (0.29 and 0.10 mg/g dwt, respectively) was recorded (Table 2).

3.4 Phenol and flavonoid identification by HPLC
Moreover, phenol and flavonoid fractions were identified by HPLC (Tables 3 and 4). Seven different types of phenolic compounds were identified in \( \text{V. geminata} \) and \( \text{P. pyrenoidosa} \) while only five in \( \text{B. eriensis} \) and six in \( \text{S. obliquus} \). From Fig. 6a, \( \text{V. geminata} \) revealed nearable data from 2.11 (syringic) to 4.52 (coumaric) \( \mu \)g/g fwt. On the other hand, resorcinol and coumaric recorded maximum values (4.73 and 4.45 \( \mu \)g/g fwt) in \( \text{P. pyrenoidosa} \) (Fig. 6b). With regard to \( \text{B. eriensis} \) (Fig. 6c), a maximum value of caffeic followed by resorcinol, gallic and ferulic, and low ratio of chlorogenic (4.22, 3.95, 3.62, 3.11, and 1.90 \( \mu \)g/g fwt, respectively). A maximum value for the green alga \( \text{S. obliquus} \) (Fig. 6d) was recorded for gallic and caffeic (3.44 and 3.42 \( \mu \)g/g fwt, respectively). Similarly, flavonoids exhibited a narrow range among all algae under investigation from 1.45 to 4.52 \( \mu \)g/g fwt. Seven types of flavonoids were detected in both \( \text{V. geminata} \) and \( \text{P. pyrenoidosa} \) while only five flavonoids for each \( \text{B. eriensis} \) and \( \text{S. obliquus} \) were recorded (Table 4). A maximum flavonoid value in \( \text{V. geminata} \) was for quercetin, and lowest value for hesperetin (3.34 and 1.45 \( \mu \)g/g fwt) as well as the nearable values of quercitrin, kaempferol, rutin, catechin, and apigenin (3.22, 3.15, 2.70, 2.13, and 1.96 \( \mu \)g/g fwt, respectively) were detected (Fig. 7a). In \( \text{P. pyrenoidosa} \) (Fig. 7b), quercitrin and rutin reached its maximum value (4.52 and 4.13 \( \mu \)g/g fwt, respectively). On the other side, \( \text{B. eriensis} \) (Fig. 7c) recorded the highest content for quercitrin and apigenin (4.25 and 3.70 \( \mu \)g/g fwt, respectively). Finally, \( \text{S. obliquus} \) (Fig. 7d) showed a maximum value for quercetin, quercitrin and rutin, apigenin, and catechin (3.99, 3.97, and 3.54 \( \mu \)g/g fwt, respectively).

4 Discussion
Several studies were conducted on the antioxidant activity of aquatic microalgae or seaweeds through the determination of their contents of phenols, flavonoids, or carotenoids [43–45]. In the current study, total phenols and flavonoids were estimated in order to evaluate the

### Table 2 Chlorophyll \( \alpha \) and carotenoid contents of \( \text{V. geminata} \), \( \text{P. pyrenoidosa} \), \( \text{B. eriensis} \), and \( \text{S. obliquus} \)

|                  | \( \text{V. geminata} \) | \( \text{P. pyrenoidosa} \) | \( \text{B. eriensis} \) | \( \text{S. obliquus} \) |
|------------------|--------------------------|-----------------------------|--------------------------|--------------------------|
| Chlorophyll \( \alpha \) (mg/g dwt) | 0.29\( ^{\text{a}} \) ± 0.003 | 0.36\( ^{\text{b}} \) ± 0.005 | 0.70\( ^{\text{c}} \) ± 0.025 | 0.63\( ^{\text{d}} \) ± 0.003 |
| Carotenoids (mg/g dwt) | 0.10\( ^{\text{d}} \) ± 0.000 | 0.29\( ^{\text{b}} \) ± 0.006 | 0.69\( ^{\text{d}} \) ± 0.016 | 0.14\( ^{\text{d}} \) ± 0.003 |

Results are mean ± SE of three replicates
Different letters mean statistically significant differences (\( p < 0.05 \))
antioxidant capacity of four soil-inhabiting algae. From results, methanol extracts of *Botrydiopsis eriensis*, *Scenedesmus obliquus*, and *Pleurochloris pyrenoidosa* exhibited the highest contents of both total phenols and total flavonoids. Recent studies revealed similar total phenolic contents of *Scenedesmus* sp. to our work [46, 47]. Several studies have been concluded that phenolic compounds (along with flavonoids) of algae contribute significantly to their antioxidant capacity [48–50]. In addition to their antioxidant activity, these compounds display a wide range of biological activities which explains their commercial potential uses in nutritional, medicinal, and pharmaceutical applications [51–53].

Moreover, the phosphomolybdenum assay was performed to evaluate the total antioxidant activity of the algal taxa under investigation. Results revealed higher activity occupied by the methanol extracts of *S. obliquus* and *B. eriensis* followed by *P. pyrenoidosa* and lower

Table 4 HPLC fractions of flavonoid content of *V. geminata, P. pyrenoidosa, B. eriensis, and S. obliquus*

| Flavonoids    | Chemical structure | *V. geminata* | *P. pyrenoidosa* | *B. eriensis* | *S. obliquus* | Retention time |
|---------------|--------------------|---------------|------------------|---------------|---------------|----------------|
| Catechin      | Proanthocyanidins  | 2.13          | 2.32             | ND            | 2.55          | 1.5            |
| Kaempferol    | Flavonols          | 3.15          | 3.77             | ND            | ND            | 2.9            |
| Rutin         | Flavonols          | 2.70          | 4.13             | 2.92          | 3.54          | 3.7            |
| Quercitrin    | Flavonols          | 3.22          | 4.52             | 4.25          | 3.97          | 4.1            |
| Hesperetin    | Flavanones         | 1.45          | 2.46             | 2.46          | ND            | 4.9            |
| Apigenin      | Flavones           | 1.96          | 3.71             | 3.70          | 2.58          | 5.8            |
| Quercetin     | Flavonols          | 3.34          | 3.50             | 2.26          | 3.99          | 6.5            |

![Fig. 6](https://example.com/image6.png)  
**Fig. 6** HPLC phenol chromatograms of (a) *V. geminata*, (b) *P. pyrenoidosa*, (c) *B. eriensis*, and (d) *S. obliquus*
activity for *Vaucheria geminata*. In addition, the antioxidant activity expressed by measuring the percentage inhibition of DPPH radical recorded the very high antioxidant activity of most algae (up to 97% in *S. obliquus*). In agreement, other studies recorded the effective scavenging activity of DPPH radicals (up to 68.18%) in some green algae in which also the highest content of total phenolic compounds was detected [54]. Particularly, *Scenedesmus* sp. reported by many authors contributing high antioxidant activity [55–57]. Recent studies explained the antioxidant potential of some green and yellow-green microalgae is comparable to the antioxidant activity displayed by raspberry fruit [58]. High antioxidant activity was observed in some algal members of Xanthophyta [59]. In exception, the lower antioxidant capacity of *Vaucheria sessilis* was observed in comparative studies of different algae [60]. On the other hand, relatively little known about the antioxidant capacity of Xanthophyta especially the currently isolated algae *Botrydiopsis* and *Pleurochloris* [61].

Although, it was reported before the high correlation between scavenging activity and total phenolic content of algae [10, 43, 62]. In another studies, carotenoid and chlorophyll contents of algae contribute to their antioxidant potentiality [44, 63, 64]. So, the pigment composition represented by chlorophyll *a* and carotenoid of the four studied algal taxa was estimated. Among all, *B. eriensis* reached the maximum contents of both chlorophyll *a* and carotenoid followed by *P. pyrenoidosa*. However, a higher ratio of chlorophyll *a* along with a lower carotenoid content was noticed in *S. obliquus*. The present finding agrees well with earlier reports on *S. obliquus* [65]. Chlorophyll and carotenoids are the major pigments in algae, and their concentrations can vary among algal species and according to the environmental conditions [66–68] as well as the extraction and purification techniques [69, 70]. Microalgae containing large quantities and different types of carotenoids with high nutritional values [71–73]. So, they represent natural alternatives for synthetic colorants exhibiting a strong
antioxidant activity which have multiple applications in the food industry [74–76].

As the antioxidant activity of phenolic compounds depends largely on the chemical structure of these substances, the qualitative identification of phenols and flavonoids of the four studied algae was assessed also by HPLC chromatography. Seven types of phenolic compounds were identified nearly in all algae under study (gallic, resorcinol, chlorogenic, caffeic, coumaric, ferulic, and syringic). From results, the higher antioxidant capacity of S. obliquus in the present study may be due to their relative higher ratio of phenols of cinnamic nature (see Table 3). According to earlier studies [77], the capacity of quenching activity of phenols with cinnamic acid derivatives is more efficient than their benzoic counterparts exhibiting strong antioxidant activity [78–80]. Moreover, the biological functions of ferulic, caffeic, chlorogenic, and other phenolic cinnamic acids had been identified by various studies [81–83]. On the other hand, flavonoids are natural antioxidant phenolics found in many algae involved in various processes such as protection, signaling, and pigmentation [16]. The difference in flavonoids among the studied algae may be species-specific [84]. Results of flavonoids HPLC showed also that quercetin and quercitrin are the most abundant flavonoid compounds among all algae under investigation. Quercetin and its derivative rutin contents of some microalgae are comparable to the levels in some highly flavonoid-containing vegetables and fruits [16, 17]. In human health, algal flavonoids have many health-promoting benefits and protecting against different diseases [85]. In the current study, flavonoids of S. obliquus showed maximum value for quercetin followed by quercitrin, rutin, apigenin, and catechin. On the other hand, a maximum value for phenols was recorded for gallic followed by caffeic and chlorogenic. In agreement with our study, investigation of Scenedesmus sp. revealed similar results [46].

Finally, the higher antioxidant capacity of B. eriensis, P. pyrenoidosa, and S. obliquus in the present study could be explained by the rich amounts and synergic effects of phenolics, flavonoids, chlorophyll a, and/or carotenoids.

5 Conclusion

Previous studies were concerned with antioxidant activities of seaweeds, aquatic microalgae, and macroalgae. However, this study concerned with the edaphic algae including on and in-soil habitats. The investigated edaphic algae showed high antioxidant contents and activities, and so, they prospectively considered as promising natural antioxidant resources.

Abbreviations
DPPH: 2,2-Diphenyl-1-picrylhydrazyl, HPLC: High-performance liquid chromatography

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Authors’ contributions
AMS designed the experimental approach, analyzed the data, and help in writing the manuscript. NHE carried out isolation of algae and all the phytochemical studies. NHE generated all the tables and figures in the manuscript. HAM helped to draft the manuscript. The authors read and approved the final manuscript.

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