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Adding to Our Knowledge on the Diatom and Green Algae Biodiversity of Egypt: Some New-to-Science, Poorly Known, and Newly Recorded Species

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Abstract: During our research on the diversity of diatoms and green microalgae from Egypt, four new-to-science, newly recorded, and poorly known species were retrieved from different Egyptian habitats. The new benthic diatom species *Halamphora shaabanii* A.A. Saber, El-Sheekh, Levkov, H. Saber et Cantonati sp. nov., which could not be identified using the currently available literature, was described from the high-conductivity, oasis lake Abu Nuss in the El-Farafra Oasis, located in the Western Desert of Egypt, employing both light (LM) and scanning electron (SEM) microscopy observations. A detailed comparison of the biometrically distinctive traits, and ecological preferences, of this new diatom species revealed sufficient differentiations from its morphologically most closely related species: *H. atacamana*, *H. caribaea*, *H. ectorii*, *H. gasseae*, *H. halophila*, *H. mosensis*, *H. poianensis*, and *H. vantushpaensis*. Ecologically, *Halamphora shaabanii* can tolerate relatively high nutrients (N and P) and prefers saline inland environments with NaCl water types. The araphid diatom *Pseudostaurosiropsis geocollegarum* was observed in the epilithic diatom assemblages of the River Nile Damietta Branch and identified on the basis of LM and SEM. From an ecological standpoint, *P. geocollegarum* seems to prefer elevated nutrient concentrations (meso-eutraphentic species), reflecting different human influences on the freshwater River Nile Damietta Branch. Based on the available literature, this is the first documentation of this freshwater diatom species for Egypt, and the second record for the African continent. Two green motile microalgae, *Chlamydomonas proboscigera* and *Gonium pectorale*, were isolated and identified from the terrestrial biomes of the arid habitat "Wadi El-Atshan" in the Eastern Desert of Egypt. *C. proboscigera* is reported herein for the first time in the Egyptian algal flora, while *G. pectorale* is poorly documented in the available literature. In light of our findings, the Egyptian habitats, particularly the isolated desert ecosystems, are interesting biodiversity hotspots and have a richer algal microflora than earlier anticipated. Furthermore, more in-depth taxonomic studies, using a combined

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polyphasic approach, are needed not only to foster our knowledge of the Egyptian and African algal and cyanobacterial diversity and biogeography, but also to be further used in applied environmental sciences.

Keywords: algae; diatoms; species diversity; Egypt; the Nile River; the Sahara Desert

1. Introduction

In Egypt, numerous floristic and taxonomic investigations on non-marine diatoms and green microalgae have been conducted on different aquatic and terrestrial environments across the country (e.g., [1–9]). However, species identification has been dependent only on classical light microscopical observations, overlooking detailed cell ultrastructures, which are primarily crucial for accurate species delimitation, particularly for diatoms. In the last few years, the modern diatom standards have been applied, and this has led to the discovery of some new-to-science and novel species in Egypt. The new amphoroid diatom *Seminavis aegyptiaca*, for instance, was described from the epilithic substrata of the Damietta Branch estuary of the Nile River based on modern diatom taxonomy standards [7]. *Pinnunavis edkuensis* has also been reported as a new species for the Egyptian diatom flora from both the brackish and marine habitats [10]. Considering that most of the previous Egyptian phycological investigations focused on the River Nile basin, the less-studied desert ecosystems in the Eastern and Western Deserts are still biodiversity hotspots and, consequently, they are in need of more intensive phycological studies [8,11]. Supporting this opinion, Levanets and Resburg [12] emphasized in their bibliography on the diversity and distribution of non-marine "freshwater" algae in Africa that the north-eastern region has been poorly investigated. The Egyptian oases and desert valleys in general are considered to be isolated islands with unique and interesting algal and cyanobacterial diversity that are still enigmatic taxonomically [11].

The genus *Halamphora* (Cleve) Levkov [13] was introduced for the first time as a subgenus of *Amphora* Ehrenberg ex Kützing [14], and later it was raised to the genus level by Levkov [13], who provided a synopsis of *Amphora* and *Halamphora* to include more than 300 species and infraspecies. Taxonomically, the species belonging to the genus *Halamphora* are very close to those assigned to *Amphora* as they are characterized by valves moderately to strongly asymmetric to the apical axis, a symmetrical transapical axis, a valve mantle with a deep dorsal margin, and a shallow ventral margin. Moreover, based on Levkov's classification system [13], the main taxonomic features that can be used to distinguish *Halamphora* from *Amphora* are: (1) plastids centrally constricted and H-shaped; (2) dorsiventrally linear, semi-lanceolate to semi-elliptical valves with variable, but often protracted, valve ends; (3) striae composed of round, elliptical to transversely elongated areolae; (4) raphe lying on a raphe ledge near the ventral margin with dorsally curved distal ends; and (5) numerous girdle bands with one to two rows of pores. This taxonomic separation from *Amphora* sensu stricto was confirmed by applying phylogenetic analyses [15–18]. Ecologically, species of the genus *Halamphora* usually occur in diverse brackish, inland saline (mineral rich) or marine habitats, although they also inhabit fresh waters [13].

The biodiversity of terrestrial green microalgae in the Egyptian Desert, the part of the Sahara Desert that is located east of the Nile River, is also still grossly underestimated [19–21]. The Eastern Desert green microalgae gained only a little research interest in this respect (e.g., [22,23]), and, therefore, our knowledge about the diversity and distribution of green microalgae, particularly the motile species, in this arid ecosystem remains poor.

Through this study, which is part of an extensive survey of the Egyptian diatom and terrestrial microalgae in the isolated deserts and valleys, we attempted to expand our knowledge of the diatom and green microalgal assemblages inhabiting the different aquatic and terrestrial Egyptian habitats. Four microalgal taxa, new-to-science, poorly known, and newly recorded for Egypt, were described using modern taxonomy standards. Importantly, the novel diatom species *Halamphora shaabanii* sp. nov. (Naviculales, Bacillariophyceae) was described and established based on its diagnosable taxonomic features using LM and SEM, as well as ecological preferences. A detailed comparison with other morphologically similar taxa was also provided. The results obtained not only improved our limited understanding of the cryptic biodiversity of diatoms and microalgae in Egypt, but they also addressed the ecological values of the ecosystems they inhabit, which should be properly managed and conserved by policymakers for the sake of all stakeholders.

2. Materials and Methods

2.1. Sampling Sites

In our recent surveys of the Egyptian freshwater and terrestrial algae and cyanobacteria from different habitats, as part of the project "The phycological biodiversity in Egyptian oases and other comparable habitats with special attention to the challenges of its use in bioassessment of water resources—*PhyBiO*", diatom and green algal specimens, on which this study was based, were collected from three different ecosystems.

Benthic specimens of *Halamphora shaabanii* were sampled on August 10th 2018 from the high-conductivity (26.7 mS.cm^{-1}), saline oasis lake Abu Nuss (27°04′29″ N, 27°55′40″ E, 50 m a.s.l.) in the El-Farafra Oasis, the Western Desert of Egypt (Figure 1A). Abu Nuss Lake is one of the main attractions of the El-Farafra Oasis, and is home to abundant birdlife. It is located in the El-Nahda village, with a total area of ~15 km^2, and ranges in depth between 2 and 3 m. It is ca. 11 km north of Qasr El-Farafra, the capital and administrative center of the El-Farafra Oasis. Abu Nuss Lake receives huge amounts of nutrient-rich agricultural discharge water, and is also exploited by the local people for fish farming activities. The water evaporation rate in the lake during the summer season is very high, influencing the salinity gradients and ecological functioning of this desert ecosystem with remarkable changes in diatom and microalgal diversity. The El-Farafra Oasis constitutes the smallest oasis dug out of the limestone plateau that forms the central region of Western Egypt. This natural geological depression is located about 650 km SW of Cairo and covers an area of ~10,000 km^2. The hyper-arid desert climate of the El-Farafra Oasis is characterized by an average air temperature of about 22 °C and by less than 10 mm of annual precipitation [24].

Specimens of *Pseudostaurosiropsis geocollegarum* were gathered on 25th August 2016 from the epilithon of the northern part of the River Nile Damietta Branch (31°20′23.3″ N, 31°42′44.5″ E) (Figure 1B). The Damietta Branch (240 km long) is one of the two branches of the River Nile reaching the Mediterranean Sea. Its width is about 280 m, and it has a maximum depth ranging between 12 and 20 m. The Damietta Branch is a pivotal water source for a wide range of domestic, agricultural, and industrial activities in Egypt [7].

The last sampling site (25°49.558′ N, 34°3.880′ E), where *Chlamydomonas proboscigera* and *Gonium pectorale* were isolated, was Wadi El-Atshan, located in the Eastern Desert of Egypt (Figure 1C). These taxa were isolated on 1st November 2017 from the rocky surfaces of this arid valley. Wadi El-Atshan is located to the south of the Quseir-Qift road, about 10 km west of Quseir city, Red Sea Governorate, the Eastern Desert of Egypt. This valley is in general characterized by a hot arid desert climate and limited rainfall during winter. However, it is occasionally subjected to sporadic torrential rainfalls of short duration that cause flash flooding, encouraging the growth and propagation of the terrestrial droughtresistant microalgae on its rocks. The algal biodiversity in this isolated desert valley is completely unknown.

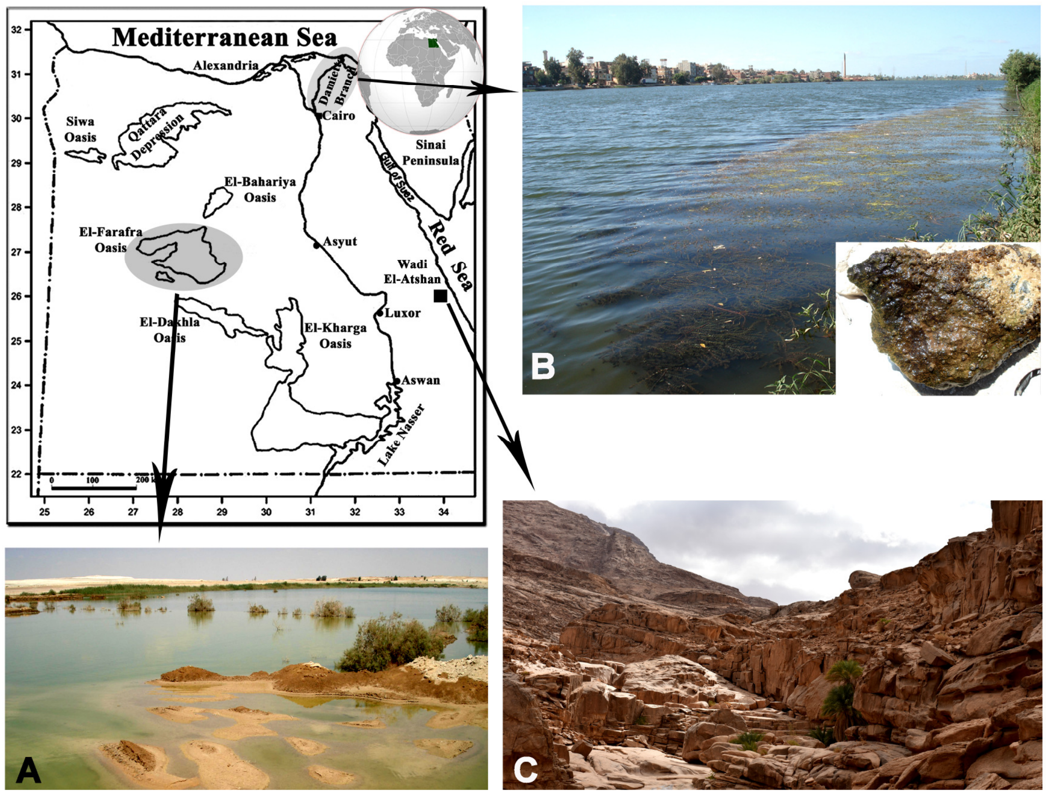

Figure 1. Sampling sites in the present studies. (**A**) the desert oasis lake Abu Nuss in the El-Farafra Oasis, the Western Desert of Egypt; (**B**) the Damietta Branch of the River Nile, note the epilithon where the diatom samples were collected; and (**C**) the arid valley "Wadi El-Atshan", located in the Eastern Desert of Egypt.

2.2. Samples Processing and Taxa Identification

The diatom specimens were collected following the European standard methods for sampling phytobenthos in running waters and preserved with formalin (4% final concentration) [25]. For the epilithon, five cobbles were sampled from shallow depths and the diatom film was removed using a clean toothbrush. For the epipelic diatoms, five areas, each approximately 10 cm^2, were sampled using a spoon. In the laboratory, the diatoms were cleaned by adding hot 37% hydrogen peroxide (H_2O_2) and hydrochloric acid (HCl) to remove organic matter and carbonate particles. Next, they were rinsed and centrifuged three times for 5 min at 3000 rpm using deionized water. Permanent diatom slides, where the cleaned diatom frustules were air-dried onto coverslips, were made with Naphrax®, a synthetic mounting medium with a high refractive index of 1.74. Light microscopy (LM) investigations were conducted at ×1000 magnification using a Zeiss Axioskop 2 microscope (Zeiss, Jena, Germany) fitted with phase contrast, and an Axiocam digital camera at the MUSE—Museo delle Scienze, Limnology and Phycology Section, Trento, Italy, and also a BEL® photonics biological light microscope (BEL® Engineering, Monza, Italy), equipped with a Canon Powershot G12 digital camera, at the Botany Department, Faculty of Science, Ain Shams University, Cairo, Egypt. Scanning electron microscopy (SEM) examinations were performed using a LEO XVP scanning electron microscope (Carl Zeiss SMT Ltd., Cambridge, UK) at high vacuum on gold-coated prepared material at the MUSE—Museo delle Scienze, Trento, Italy. Additional SEM observations were made at the University of Frankfurt using a Hitachi S-4500 (Hitachi Ltd., Tokyo, Japan). Measurements of different specimens representative of the size diminution series were made to obtain ranges and averages of the morphological and ultrastructural traits. Diatom micrographs were prepared in plates with Adobe Photoshop version CS6. Permanent slides and aliquots of the original specimens, along with the holotype and isotype of the new species, were deposited at the Phycology Unit (No. 341), Botany Department, Faculty of Science, Ain Shams University [26], Cairo, Egypt, and the Diatom Collection of the MUSE—Museo delle Scienze Herbarium (TR) in Trento, Northern Italy. The morphological terminology primarily followed Levkov [13].

The green microalgae *Chlamydomonas proboscigera* and *Gonium pectorale* were isolated from the surfaces of rocks of Wadi El-Atshan. The dark algal batches were collected from the rocky surfaces using forceps and placed in clean polyethylene bottles for transport. The specimens were cultivated on Bold's Basal Medium (BBM; [27,28]) in a growth chamber at 24 °C ± 1 °C and 16:8 h L:D photoperiod using 20 W cool white fluorescent lamps at an irradiance of 55 μmol photons m^{-2} s^{-1}. Identification was conducted using Ettl [29]. The main diagnostic features for *C. proboscigera*, including the shape and size of the vegetative cells, papilla, stigma, chloroplast, pyrenoid, contractile vacuoles, and reproductive cells were investigated. A total of 15 cells, ranging in size, were measured to obtain an average size of the species in our samples.

2.3. Hydrochemical Characterization

Hydrochemical characteristics of the oasis lake Abu Nuss and the Damietta Branch of the River Nile, including major ions, nutrients, trace elements, and metals, were analyzed following standard procedures adopted by Chapman and Pratt [30] and Clesceri et al. [31]. Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, HCO_3^{-}, CO_3^{2-}, SO_4^{2-}, and trace elements and metals were measured using ionic chromatography (ICS 1500 Dionex Corp., Sunnyvale, CA, USA). NO_3^{-}, NO_2^{-}, NH_4^{+}, and SRP were measured by molecular absorption spectrometry. Silicates (SiO_2) were determined by the molybdosilicate method. Water temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) were measured in situ with a portable calibrated HANNA HI 991301 meter. Due to the rocky nature of Wadi El-Atshan, we could not collect soil samples to be analyzed, and, unfortunately, there was no rainwater during the sampling time. However, hydrochemical data of rainwater in another close valley, "Wadi Al-Naqœat", which shares the same geological nature, were assessed and can be briefly described as alkaline freshwater with lower concentrations of nutrients [8].

3. Results

3.1. Halamphora shaabanii A.A. Saber, El-Sheekh, Levkov, H. Saber et Cantonati sp. nov.

Description: LM (Figure 2): Frustules elliptical with rounded truncate apices. Valves are narrow, semi-elliptical with strongly arched dorsal margin and almost straight ventral margin. In medium-sized specimens, the ventral margin might be slightly tumid midvalve. Valve ends narrowly rounded, weakly protracted, and ventrally deflected. Valve length 23–29 μm, valve breadth 4.0–4.5 μm (n = 30). Axial area is narrow, expanding into a small irregularly rounded central area. Raphe positioned near the dorsal margin and proximal raphe ends slightly dorsally deflected. Both ventral and dorsal striae hardly visible in LM, 30–36 in 10 μm (dorsally) and 30–34 in 10 μm (ventrally).

SEM (Figure 3): Externally, marginal ridge absent and transition valve face/mantle gradual. Ventral valve side very broad, occupying most of the valve width. Raphe ledge narrow, continuous along whole valve length, slightly dorsally expanded in the central area. Axial area from ventral side narrow, expanded in an irregularly rounded central area. Raphe branches curved, with proximal raphe ends slightly expanded and dorsally deflected. Distal raphe ends strongly dorsally deflected. Striae entirely uniseriate composed of transapically oriented and slit-like areolae. Internally, areolae slit-like to mostly ovoid near the central area. Proximal raphe ends terminate in small fused central helictoglossae. Distal raphe end deflected ventrally and terminating with poorly developed helictoglossae. Both dorsal and ventral striae uniseriate, separated by thin virgae. Central dorsal virgae not thickened and slightly wider than the others. Internal occlusions of areolae not observed due to corrosion of specimens.

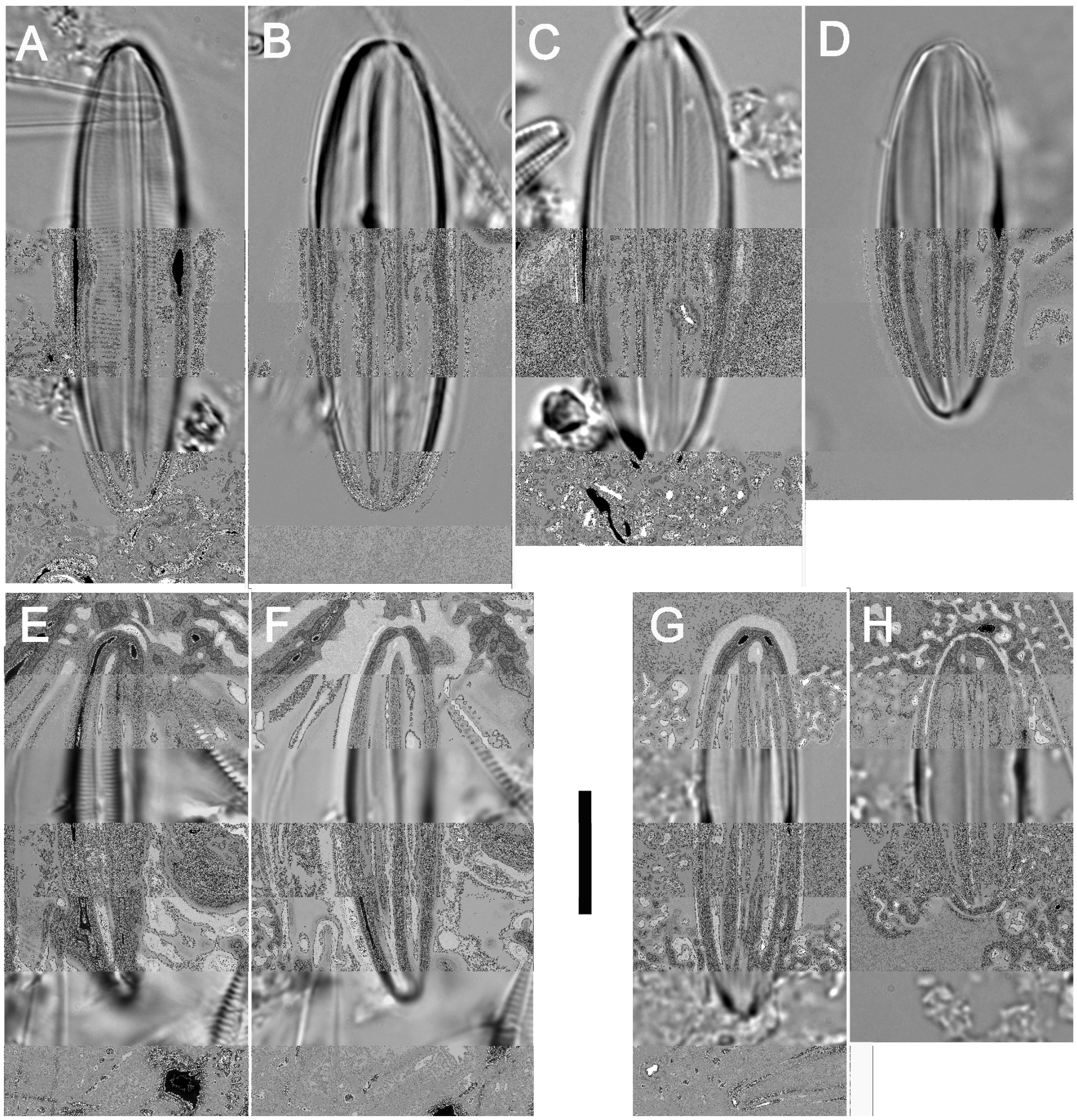

Figure 2. (**A–H**) Type material of *Halamphora shaabanii* sp. nov. from the high-conductivity, oasis lake Abu Nuss in the El-Farafra Oasis, the Western Desert of Egypt. LM micrographs showing the size range of the species. Scale bar 10 μm.

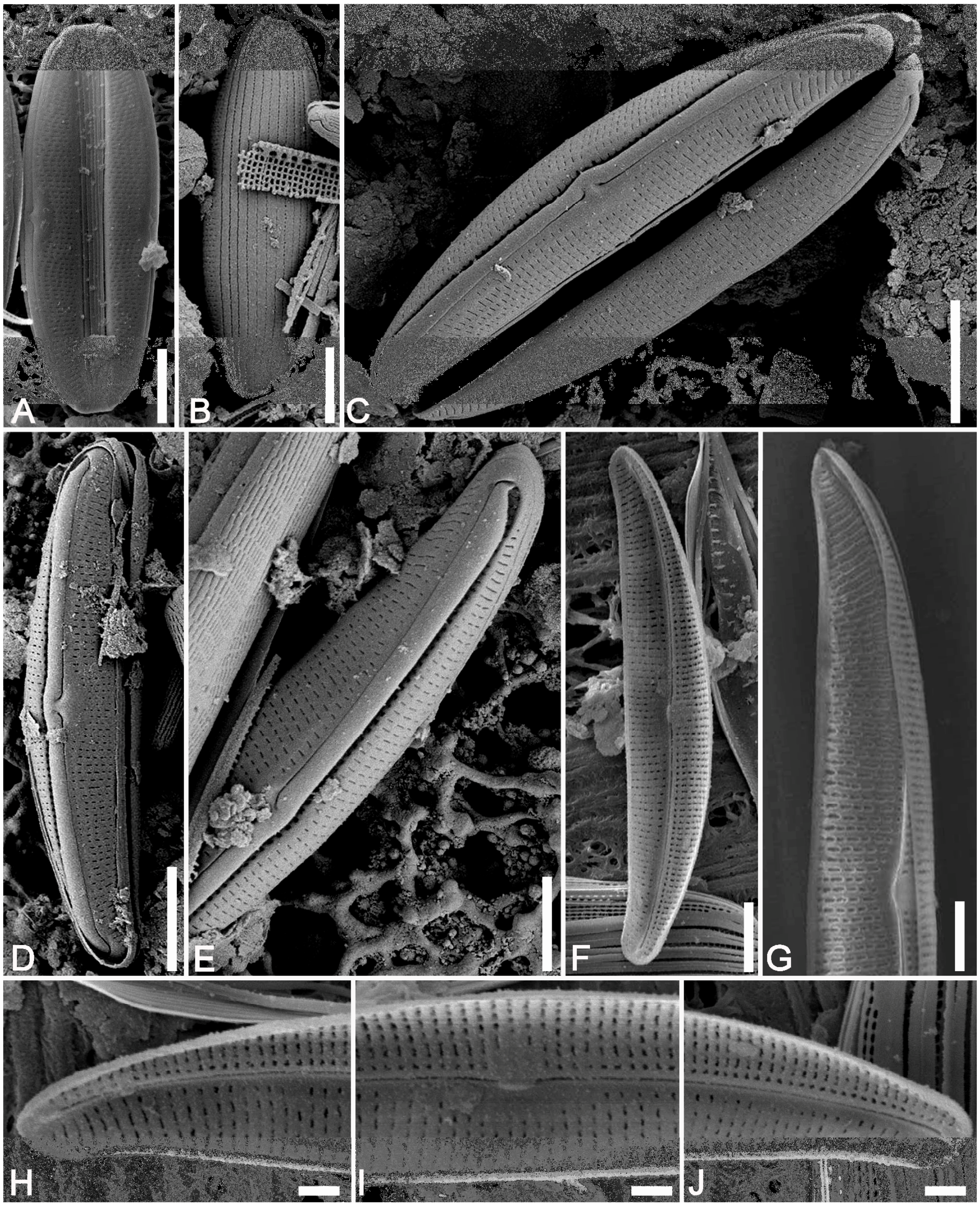

Figure 3. (**A**–**H**) SEM micrographs of the type population of *Halamphora shaabanii* sp. nov.; (**A**–**C**) girdle views of whole frustules. Notice the numerous girdle bands; (**D**) external view of whole valve; (**E**) external detailed view of mid-valve showing the raphe ledge and proximal raphe ends; (**F**,**G**) internal views of whole valves; (**H**,**J**) internal detailed views of distal raphe ends and helictoglossae; and (**I**) internal detailed view of mid-valve showing fused central helictoglossa and detail of areolae. Scale bars = 5 µm (**A**–**D**), 3 µm (**E**–**G**), and 1 µm (**H**–**J**).

Holotype: The original material of *Halamphora shaabanii* sp. nov. (slide and suspension of prepared material) was deposited in the collections of the Phycology Unit (No. 341), Botany Department, Faculty of Science, Ain Shams University in Cairo (Egypt) (CAIA), accession code: CAIA PBA–1802. This material, partially shown here in Figures 2 and 3, was collected by Abdullah A. Saber on 10th August 2018. Figure 2A illustrates the holotype.

Isotype: Diatom collection of the MUSE—Museo delle Scienze, Trento, Italy: MUSE-LIM-DIAT 4106 (including a diatom mount, and an aliquot of cleaned material).

Registration: http://phycobank.org/105193 (accessed on 23 January 2025)

Type locality: The high-conductivity, desert oasis lake Abu Nuss in the El-Farafra Oasis, the Western Desert of Egypt (27° 04′ 29″ N, 27° 55′ 40″ E, 50 m a.s.l.).

Etymology: The specific epithet "*shaabanii*" is a dedication to the renowned Egyptian phycologist Prof. Abd El-Salam M. Shaaban in recognition of his truly outstanding contribution to the study of the Egyptian diatom and algal flora.

Ecology and co-occurring diatom species: *Halamphora shaabanii* sp. nov. was dominant in the benthic epipelic diatom assemblage sampled from the high-conductivity, desert oasis lake Abu Nuss with an abundance of almost 50%. This desert lake was characterized by warm, alkaline water with very high conductivity (water temperature: 38 °C; pH: 8.75; conductivity: 26.7 mS.cm^{-1}; average total dissolved salts: 22.16 g.L^{-1}). In general, *H. shaabanii* seems to prefer saline (mineral-rich) habitats rich in sodium chloride (Table 1). Concentrations of major cations and anions were 5930, 1244, 865, 310, 11780, 153, and 73 mg.L^{-1} for Na^+, Ca^{2+}, K^+, Mg^{2+}, Cl^-, HCO_3^-, and SO_4^{2-}, respectively. Regarding the trophic status, Abu Nuss lake can be classified as a eutrophic ecosystem based on N (average values of NO_2^- and NO_3^- were 219 and 2850 µg.L^{-1}, respectively) and P (SRP: 350 µg.L^{-1}) concentrations. Cu, Fe, Zn, and Mn were the heavy metals with the highest concentrations (Table 1) due to the desert bedrock characteristics of this habitat, the hydrochemical characteristics of the Nubian Sandstone Aquifer (the world's largest non-renewable water resource) feeding the Western Desert, and different human impacts (including agriculture) significantly affecting the lake. Other diatom species in the sample included *Navicymbula pusilla*, *Proschkinia* spp., *Halamphora aponina*, *Brachysira aponina*, and *Cyclotella striata*. So far, *Halamphora shaabanii* was observed only from the type locality.

Table 1. Hydrochemical data of the oasis lake Abu Nuss and the Damietta Branch of the River Nile.

Parameters	Unit	The Oasis Lake Abu Nuss (El-Farafra Oasis)	The River-Nile Damietta Branch
Water temperature	°C	38.0	33.8
pH		8.75	7.96
Electrical conductivity (EC)	µS.cm^{-1}	26700	449
Total dissolved solids (TDS)	mg.L^{-1}	22160	227
Calcium (Ca^{2+})	mg.L^{-1}	1244	37.2
Potassium (K^+)	mg.L^{-1}	865	8.0
Magnesium (Mg^{2+})	mg.L^{-1}	310	10.6
Sodium (Na^+)	mg.L^{-1}	5930	34.1
Chloride (Cl^-)	mg.L^{-1}	11780	22.0
Sulphate (SO_4^{2-})	mg.L^{-1}	73.0	27.7
Bicarbonate (HCO_3^-)	mg.L^{-1}	153	201
Carbonate (CO_3^{2-})	mg.L^{-1}	0.0	0.0
Nitrite (NO_2^-)	µg.L^{-1}	219	43.0
Nitrate (NO_3^-)	µg.L^{-1}	2850	1567
Ammonium (NH_4^+)	µg.L^{-1}	ND	87.0
Soluble reactive phosphorus (SRP)	µg.L^{-1}	350	488
Silica (as SiO_2)	mg.L^{-1}	6.50	9.2
Copper (Cu)	µg.L^{-1}	15.0	5.0
Iron (Fe)	µg.L^{-1}	1120	14.0
Manganese (Mn)	µg.L^{-1}	135	9.0
Zinc (Zn)	µg.L^{-1}	280	1.5

3.2. *Pseudostaurosiropsis geocollegarum* (Witkowski et Lange-Bertalot) E.A. Morales

Description (Figure 4): Valves small, elliptical to linear, with a slightly inflated central portion. Length 11.5–16 µm, breadth 3.0–4.0 µm, and striae density 13–16 in 10 µm (n = 10). The striae are commonly composed of two areolae (rarely three), one located on the valve face and the other on the valve mantle. A disc-like closing vola occludes each areola.

The striae are interrupted at the valve edge by simple or bifurcated spines. Apical porefields absent externally, but internally a few isolated pores can be present. Rimoportulae absent.

Distribution in Egypt and ecology: This is the first record of this species in Egypt, and it was found in the epilithon of the River Nile Damietta Branch. This freshwater branch (TDS: 227 mg.L^{-1}) is nutrient-enriched, i.e., SRP: 488 μg.L^{-1}, NO_2^-: 43 μg.L^{-1}, NH_4^+: 87 μg.L^{-1}, and NO_3^-: 1567 μg.L^{-1} (Table 1).

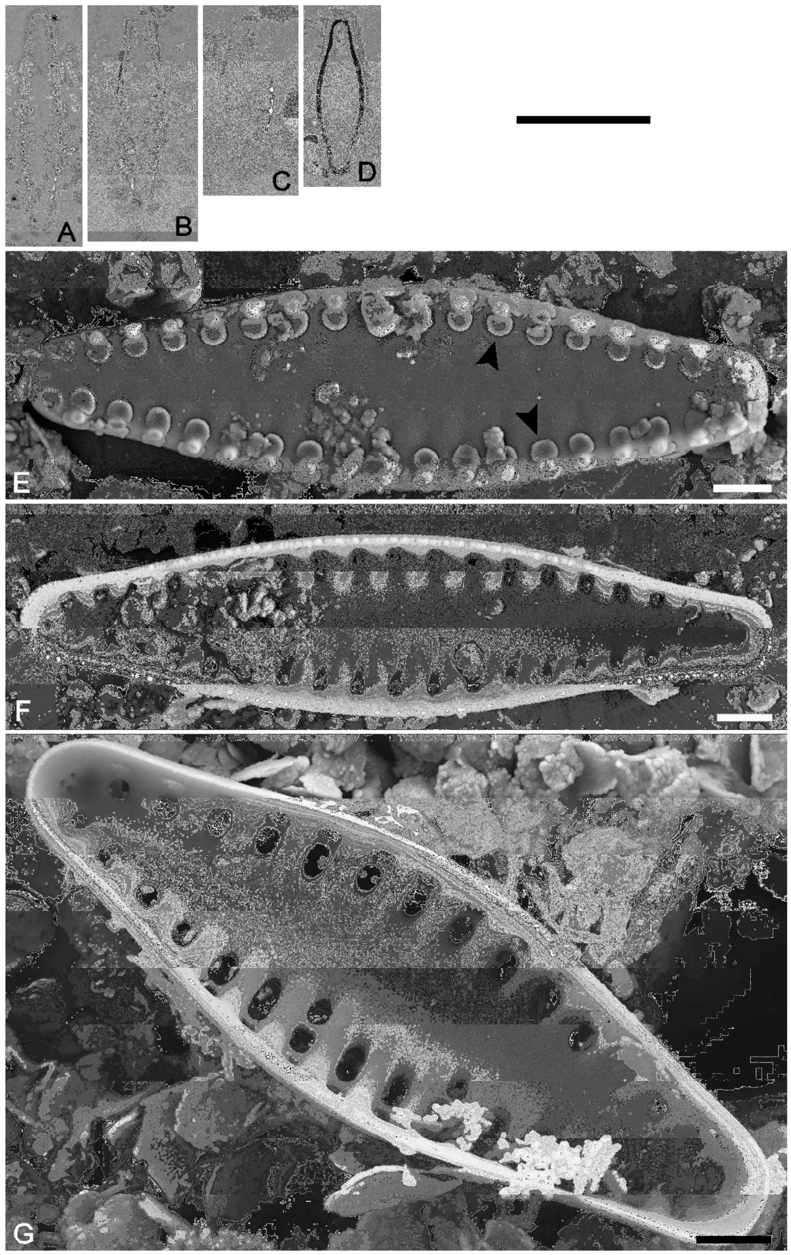

Figure 4. *Pseudostaurosiropsis geocollegarum* sampled from the River Nile-Damietta Branch. (**A**–**D**) LM micrographs presenting external details of the valves, and (**E**–**G**) SEM micrographs showing external and internal details of the valve, sternum, and striae. Notice striae are commonly composed of two rows of areolae and occluded with disc-like volae (arrowheads). Spines simple, bifurcate. Internally, notice the absence of rimoportulae and details of apical pore fields. Scale bars = 10 μm (**A**–**D**), and 1 μm (**E**–**G**).

3.3. Chlamydomonas proboscigera Korshikov

Description (Figure 5): Cells subspherical to ellipsoid, becoming more rounded to spherical with age, 8.0–13 µm long × 7.5–10 µm wide, with flattened papilla, flagella as long as the cell or longer. Chloroplast cup shaped and with a large, basal, almost spherical pyrenoid. Stigma located anteriorly in the chloroplast. Palmelloid stages present and zoosporangia containing numerous spores were seen. No sexual stages were observed.

Distribution in Egypt and ecology: This is the first record of this species in Egypt, where it was isolated from the rocky surfaces of "Wadi El-Atshan" in the Eastern Desert of Egypt. Rainwater is the only water source in this arid desert valley.

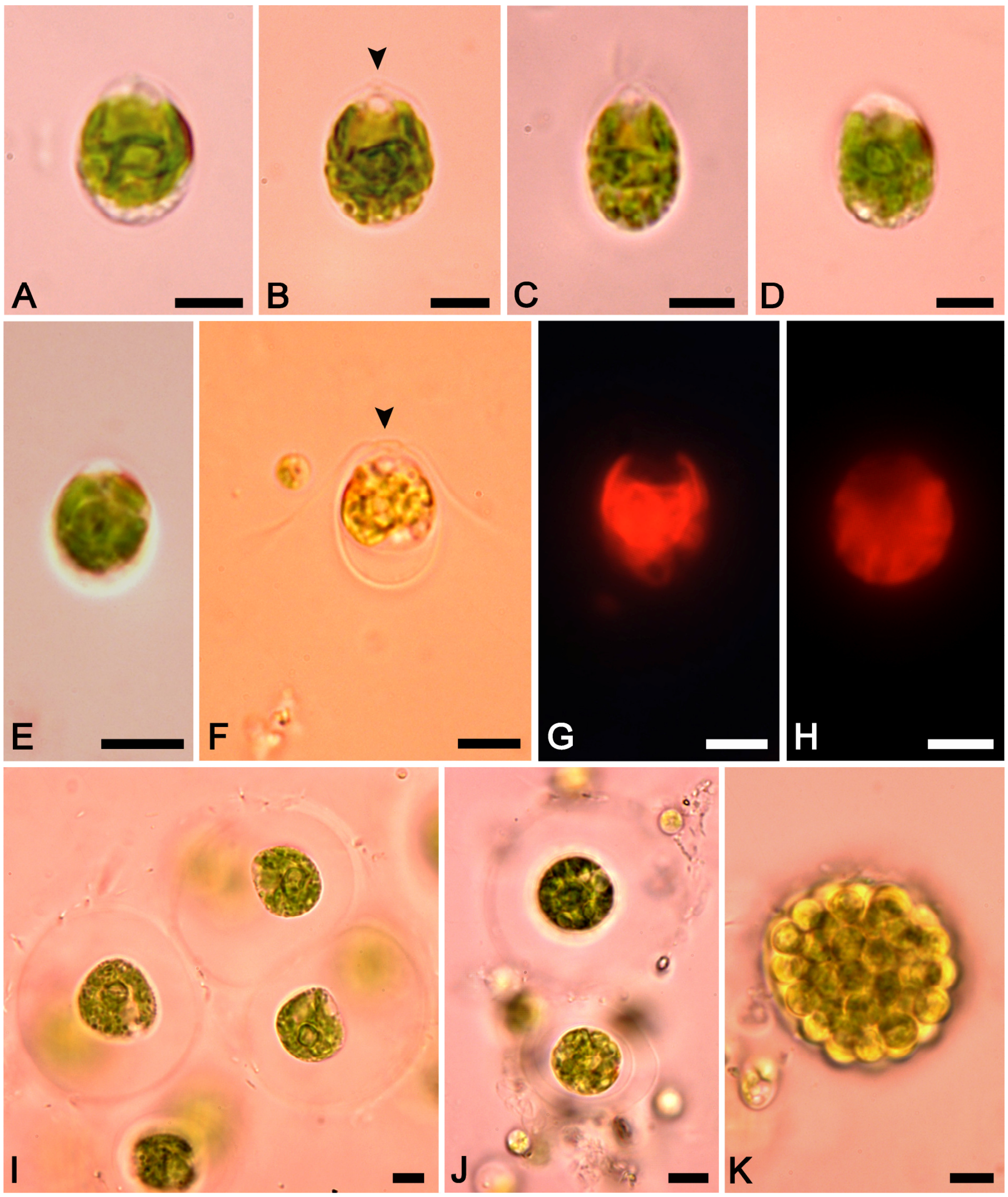

Figure 5. Light micrographs of *Chlamydomonas proboscigera* showing its detailed morphotaxonomic features and lifecycle stages. (**A**–**F**) Subspherical to ellipsoidal vegetative cells. Notice flattened papilla (arrowheads) and stigma located anteriorly in the chloroplast; (**G**,**H**) autofluorescent cup-shaped chloroplasts; (**I**,**J**) palmelloid stages; and (**K**) asexual zoosporangium. Scale bars = 5 µm.

3.4. Gonium pectorale O.F. Müller

Description (Figure 6): Coenobium a flattened to slightly curved plate, 45–60 mm wide, usually of 16 cells, 12 at periphery, with radially directed flagella and the remainder in the center. Cells usually weakly pear-shaped to spherical, 5.0–12.5 µm long × 5.0–8.5 µm wide, chloroplast cup-shaped, with a prominent basal pyrenoid.

Distribution in Egypt and ecology: So far, little information is available on the diversity and ecological distribution of *G. pectorale* in Egypt. In the present study, *G. pectorale* was found on the rocky ravine "Wadi El-Atshan" in the Eastern Desert of Egypt.

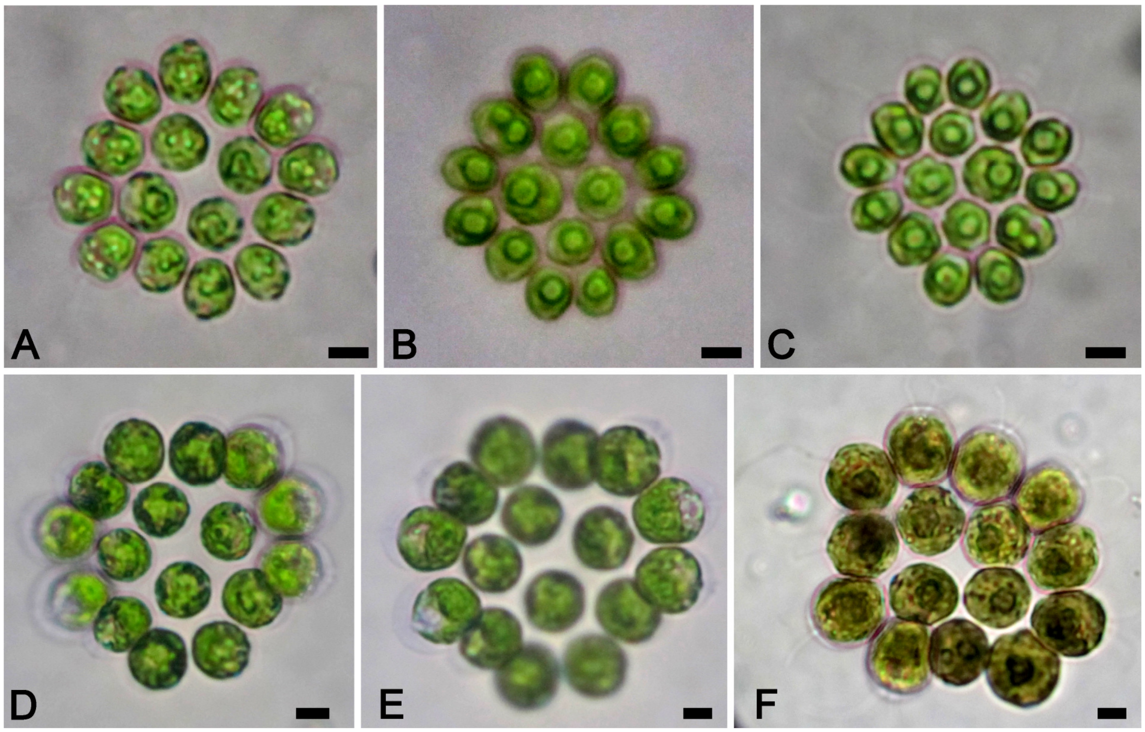

Figure 6. Light micrographs of *Gonium pectorale* showing the general diagnostic features. (**A**–**E**) Details of coenobia and the vegetative cells; (**F**) cells stained with Lugol's iodine showing the pyrenoids and flagella. Scale bar = 5 µm.

4. Discussion

In most of *Halamphora* species, the raphe is located near the ventral margin and usually raphe branches are straight or weakly curved (Table 2). Only a few known species have the raphe located in the median part of the valve or closer to the dorsal margin, and thus a wide ventral valve side [13,32,33]. Through LM, it was seen that *Halamphora shaabanii* has morphological features similar to *H. ectorii* Levkov and Zaova, particularly concerning the hyaline appearance of the valve [34]. The differences between these two species can be clearly observed with SEM. *Halamphora shaabanii* is characterized by a narrower and linear raphe ledge (opposed to broad and constricted in the middle raphe ledge in *H. ectorii*), the absence of a central area on both sides (opposed to the very broad transapically elongated central area in *H. ectorii*), and striae composed of slit-like areolae (opposed to the small, rounded areolae in *H. ectorii*). The valves of *H. shaabanii* have a similar outline to *H. mosensis* Stepanek and Kociolek [33], Figures 60: 9–12; 63: 1–3), but differences can be noticed in the position of the raphe (close to the valve margin in *H. shaabanii* as opposed to a central position in *H. mosensis*) and stria density (striae clearly visible on both ventral and dorsal side, 26–28 in 10 µm in *H. mosensis*). Additional differences can be seen via SEM; whereas in *H. mosensis,* striae are partly biseriate, especially noticeable internally (entirely uniseriate in *H. shaabanii*), central striae are strongly thickened in *H. mosensis* (central striae with the same thickness as other striae in *H. shaabanii*). Moreover, the raphe ledge in *H. mosensis* is much broader compared to the raphe ledge in *H. shaabanii*. Another species with a similar valve outline is *Halamphora halophila* Stepanek and Kociolek ([33], Figures 49: 1–4; 50: Figures 3–6). It has a similar valve size and shape as *H. shaabanii*, but both species can be easily distinguished by the stria morphology (coarsely punctate in *H. halophila*), stria structure (internally partly biseriate in *H. halophila*), and stria density (21–22 in 10 μm in *H. halophila*). In *H. caribaea* (Wachnicka and Gaiser) Rimet and Jahn (= *Amphora caribaea* [32], Figures 35–37), the raphe is more dorsally displaced, but it can be easily differentiated from *H. shaabanii* by the stria density (11–17 in 10 μm) and valve breadth (6–8 μm). *Halamphora atacamana* (Patrick) Levkov has a comparable valve size (length 29–45 μm) and ultrastructure as *H. shaabanii* (narrow raphe ledge, uniseriate striae, and central area semi-elliptically present on dorsal valve side), but clear differences can be seen in the position of the raphe (located in the mid-valve with more or less equal dorsal and ventral valve side), valve breadth (4.5–8.0 μm) and stria density (25–28 in 10 μm in *H. atacamana*), and shape of areola foramina (small, round in *H. atacamana*).

Table 2. Comparison of morphometric data of *Halamphora shaabanii* sp. nov. with other similar species.

Features /Species	*Halamphora shaabanii* sp. nov.	*H. atacamana*	*H. caribaea*	*H. ectorii*	*H. gasseae*	*H. halophila*	*H. mosensis*	*H. poianensis*	*H. vantushpaensis*
Valve outline	Semi-elliptical with strongly arched dorsal margin and almost straight ventral margin	Semi-lanceolate, arched dorsal margin, concave or straight to weakly tumid ventral margin	Semi-lanceolate with convex dorsal and straight ventral margins	Narrow semi-lanceolate with dorsally a strongly arched, convex margin and a concave ventral margin, slightly tumid in mid-valve	Semi-lanceolate, smoothly arched dorsal margin, straight to weakly concave ventral margin	Semi-elliptical, moderately dorsiventral, dorsal margin arched and ventral margin relatively straight	Narrowly semi-elliptical, weakly dorsiventral, with dorsal margin smoothly arched and ventral margin straight	Semi-lanceolate with a smoothly arched dorsal margin and a straight to very slightly convex ventral margin	Semi-lanceolate with arched dorsal margin, slightly tumid ventral margin
Valve length (μm)	(23–) 25–29.0	29.0–45.0	34–39	16.0–41.0	19.0–35.0	29.0–33.0	21.0–37.0	18–25	24.0–42.0
Valve width (μm)	(3.5–) 4.0–4.5	4.5–8.0	6.0–8.0	3.0–3.5	3.5–4.5	4.5–5.0	4.0–4.5	3.2–4.1	4.0–5.0
Valve endings	Narrowly rounded, weakly protracted, both ventrally deflected	Slightly subprotracted, both ventrally bent	Rostrate and slightly ventrally deflected	Narrowly rounded, weakly to moderately protracted, ventrally deflected	Shortly protracted and capitate	Weakly protracted, rounded and ventrally deflected	Narrowly rounded, ventrally deflected	Protracted, rostrate to sub-capitate, bent ventrally	Subprotracted in smaller specimens, protracted capitate in larger specimens and ventrally bent
Raphe ledge	Narrow, continuous along the whole valve, slightly dorsally expanded in the central area	Narrow, equal width throughout, dorsally elevated from the valve face	–	Distinct on dorsal valve side, moderately wide, continuous along whole valve length, slightly dorsally expanded and constricted in middle	–	Broad and continuous along the valve	Broad and continuous along the valve	Very broad across the dorsal striae	Narrow, arched with equal width throughout
Axial area	Narrow, expanding into small irregularly rounded central area.	Narrow, widening ventrally	Narrow, centrally expanded ventrally	Very narrow, ventrally moderately wide	Narrow, widening ventrally	Narrow on the dorsal side, difficult to differentiate along the ventral side	Narrow dorsally and centrally expanded ventrally	Very narrow with a semi-elliptic central area	Narrow, widening ventrally
Raphe	Near the dorsal margin, externally proximal ends slightly expanded and dorsally deflected, distal ends strongly dorsally deflected.	Near ventral margin of the valve	With straight branches, proximal and distal ends deflected dorsally	Near median line margin, almost straight with expanded and dorsally deflected central raphe ends	Arched with dorsally deflected ends	Slightly arched with dorsally deflected ends	Arched, centrally positioned on the valve face	Slightly arched, proximal and distal ends deflected dorsally	Almost straight, slightly arched, near the median line of the valve or slightly dorsal in valve view
Striae	Hardly visible in LM, uniseriate, composed of transapically oriented, slit-like	Uniseriate with elongated areolae of variable length	Delicate, parallel, shorter at the center	Uniseriate with small, round areolae	Dorsal striae with fine punctuation and radiate throughout,	Uniseriate with small round to ovoid areolae, but dorsal striae finely	Dorsal striae biseriate near the raphe ledge, becoming irregularly uni- to biseriate towards the	Dorsally slightly radiate throughout, very finely areolate with round to ovoid areolae which	Uniseriate with small round or slightly elongate poroids

	(and ovoid near the center internally) areolae				ventral striae indistinct and hard to be resolved with LM	biseriate near the axial area	margin, ventral striae finely uniseriate	internally biseriate near the center, ventrally very dense	
Stria (density in 10 μm	Dorsally 30–36 (–38), ventrally (30–) 32–34 (–36)	25–28	Dorsally 11–17 at the center, 13–20 near the ends. Ventrally, 19–24 at the center, 20–29 near the ends	Dorsally 30–35, ventrally 40–50	20–24	Dorsally 21–22, ventrally 35–36	Dorsally 26–28, ventrally 28	Dorsally 24–32, ventrally 32–40, areola density 66–86 in 10 μm	27–32
References	This study	[13]	[35]	[34]	[13]	[33]	[33]	[36]	[37]

Diatom analyses have been extensively used to reconstruct our backgrounds for public environmental concerns such as eutrophication [11], and they should therefore be precisely identified. In Egypt, small araphid diatom studies, using the state-of-the-art diatom taxonomy standards, are still in their infancy. Therefore, several araphid diatom species, particularly those belonging to the genus *Fragilaria* and other morphologically close taxa, should be re-investigated [38]. In this context, the present study reported for the first time the diatom species *Pseudostaurosiropsis geocollegarum* as a new record for the Egyptian diatoms based on a thorough morphological analysis using LM and SEM observations. It is also the second documentation for this freshwater diatom in the African continent; Marquardt et al. [39] reported it in Lake Edward, the smallest of the African Great Lakes, on the border between the Democratic Republic of Congo and Uganda. At first glance, and using LM only, this taxon was incorrectly identified as the most widely occurring species in the Nile River *Fragilaria brevistriata* Grunow [currently taxonomically known as *Pseudostaurosira brevistriata* (Grunow) D.M. Williams et Round]. Detailed SEM analysis revealed that this diatom species shares the main diagnostic features of *P. geocollegarum*, including valves that are small and elliptic, uniseriate striae commonly composed of two (rarely three) round areolae, externally occluded with discoid volae, flattened and bifurcate spines within striae at the valve–mantle junction, and, internally, apical porefields, composed of a few isolated pores, might be present [40]. Ecologically, *P. geocollegarum* seems to prefer nutrient-enriched freshwater environments. This is in agreement with the ecological preferences suggested by Morales [40], who reported that *P. geocollegarum* prefers more alkaline waters (pH 7.1–8.3), higher conductivity (458–1120 $\mu S.cm^{-1}$), and more eutrophic conditions.

Taxonomic features and dimensions of our *Chlamydomonas proboscigera* corresponded well to the descriptions and dimensions documented by Ettl [29] and Ettl and Gärtner [41]: ellipsoidal-to-spherical cells, 8–20 μm long and 6–18 μm wide, with a flattened papilla, a prominent spherical pyrenoid, and stigma located anteriorly in a cup-shaped chloroplast. The new record of *C. proboscigera* from Egypt is an important finding as it is the first documentation of this species in Egypt, and the third record for the African continent, where it has only been found in Algeria (Sahara) and South Africa [42]. This study extended its known geographical distribution. From an ecological point of view, in line with our results, where we found it in a terrestrial habitat, *C. proboscigera* has been recorded in both freshwater [42] and terrestrial habitats, such as soils [29,41]. The Egyptian *Gonium pectorale* specimens coincide with the key taxonomic features described by Ettl [29]. Despite its wide distribution worldwide, and also based on information available on its biogeographical distribution in Egypt, this chlorophyte in general has been scarcely reported in the previous Egyptian literature. Shaaban [2], for instance, recorded it in the Nile but without any description or illustrations. In a similar study, El-Awamri et al. [43] documented it, but in a small population, within the algal and cyanobacterial communities inhabiting the rocky ravines of the Saint Catherine Protected Area, south Sinai. From an ecological standpoint, our *G. pectorale* specimens were isolated from a terrestrial desert ecosystem, expanding our little knowledge about its distribution and ecological preferences in Egypt. However, it is widely distributed across the globe, and sometimes common, in nutrient-rich lakes, ponds, ditches, and slow-flowing rivers with pH 4.6–8.4 [44].

This study expands our knowledge on the diversity of microalgae in general, and diatoms in particular, and their biogeography in Egypt, especially in the understudied desert habitats. It is very likely that new records of microalgae, and even taxa new to science, will be discovered in Egypt in the next few decades. Lastly, the biomes in the Egyptian Western and Eastern Deserts we studied are the last refuges of interesting biodiversity, representing habitats mainly reliant on cycles of drought and floods. We could say that these harsh habitats induce specialization and speciation in diatoms and other microalgal groups. Intense human activities have worsened the environmental conditions in these naturally harsh ecosystems, but many taxa seem to have survived. These taxa deserve to be considered in conservation proposals and in different biotechnological studies due to their notable ecophysiological adaptations to tolerate environmental stressors.

5. Conclusions

The new diatom species *Halamphora shaabanii* A.A. Saber, El-Sheekh, Levkov, H. Saber et Cantonati sp. nov. was described in the present study using both LM and SEM approaches, and was also compared with the morphologically most similar taxa. Biogeographically, this species was found in the high-conductivity, saline oasis lake Abu Nuss in the El-Farafra Oasis (the Western Desert of Egypt, Africa). In light of our findings, additional research on the different populations of the genus *Halamphora* from different Egyptian habitats will clarify our understanding of the actual taxonomic position and ecological distribution of this genus, with a high possibility of discovering more taxa new to science. Both the araphid diatom *Pseudostaurosiropsis geocollegarum*, found in the Nile River, and the unicellular green motile microalga *Chlamydomonas proboscigera*, isolated from the terrestrial habitat of the arid valley "Wadi El-Atshan" located in the Eastern Desert of Egypt, are new algal species records for the Egyptian microflora. Also, the green motile colonial microalga *Gonium pectorale* was isolated and illustrated from the terrestrial biome of Wadi El-Atshan, and it is, in general, poorly documented in the Egyptian algal flora, most likely due to the lack of floristic studies with an in-depth taxonomic component. Overall, more detailed and high-resolution taxonomic investigations, combining modern diatom and algal taxonomy criteria, are necessary to uncover the cryptic species complexes of microalgae and diatoms in Egypt.

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