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EUGLENOIDS FROM THE EL FARAFRA OASIS (WESTERN DESERT, EGYPT)

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Abstract. The paper reports the first detailed study of the diversity of euglenoids recorded from the El Farafra Oasis in the Western Desert of Egypt. Four of the 20 identified species are new records for the Egyptian algal flora: the colorless *Peranema inflexum* Skuja, and the three pigmented species *Euglena adhaerens* Matv., *Phacus crassus* Zakryś & M. Łukomska and *Ph. cristatus* Zakryś & M. Łukomska. A brief description and original documentation are given for each reported morphospecies.

Key words: Africa, biodiversity, El-Farafra Oasis, Egypt, Euglenophyta, new records

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Introduction

About a third of the world's land surface has arid or semi-arid climate. Africa is one of the continents with the most dry land. In the northern part of the continent is the largest desert in the world, the Sahara. Oases are a characteristic element of it. Oases are groundwater-sustained islands of verdant fertility in a barren and relatively isolated landscape (Powell *et al.* 2015; Powell & Fensham 2016).

On the basis of the *ca* 2100 records in Levanets and Resburg's (2010) bibliography on the freshwater algae of Africa, which includes most of the available literature, we may conclude that the African freshwater algal flora is not sufficiently investigated, particularly in the northeastern region. Wołowski (2012) pointed out that most of the information about the biodiversity of African euglenoids relates mainly to East and Central Africa and narrow strips of Northern and Southern Africa. Recent literature offers a relatively good background on the phycological structure of other algal and cyanobacterial groups in African countries (e.g., Touliabah *et al.* 2002; Shaaban *et al.* 2013, 2015; Amarouche-Yala *et al.* 2014; Bere & Mangadze 2014; Edger *et al.* 2015; Mansour *et al.* 2015; Cantonati *et al.* 2016; Saber & Cantonati 2016; Saber *et al.* 2016; Taylor *et al.* 2016; Janse van Vuuren & Taylor 2016). Previous studies of euglenoids reported a preponderance of common and cosmopolitan taxa that are considered good bioindicators for eutrophic and polluted inland waters, even those recorded from extreme, isolated or remote habitats. To complete our knowledge of the euglenoids of Africa, however, more in-depth studies are still needed, particularly in oases and other remote habitats. To date only a few papers have been devoted to the euglenoids of Africa (van Oye 1924, 1927; Conrad & Van Meel 1952; Gerrath & Denny 1979; Couté & Iltis 1981; Kadiri 1992, 2004; Kadiri & Opute 2000; Kemka *et al*. 2004; Zongo *et al.* 2006; Nguetsop *et al*. 2007; Da *et al.* 2009; Wołowski 2012). Compére's (1975) studies on Lake Chad and its

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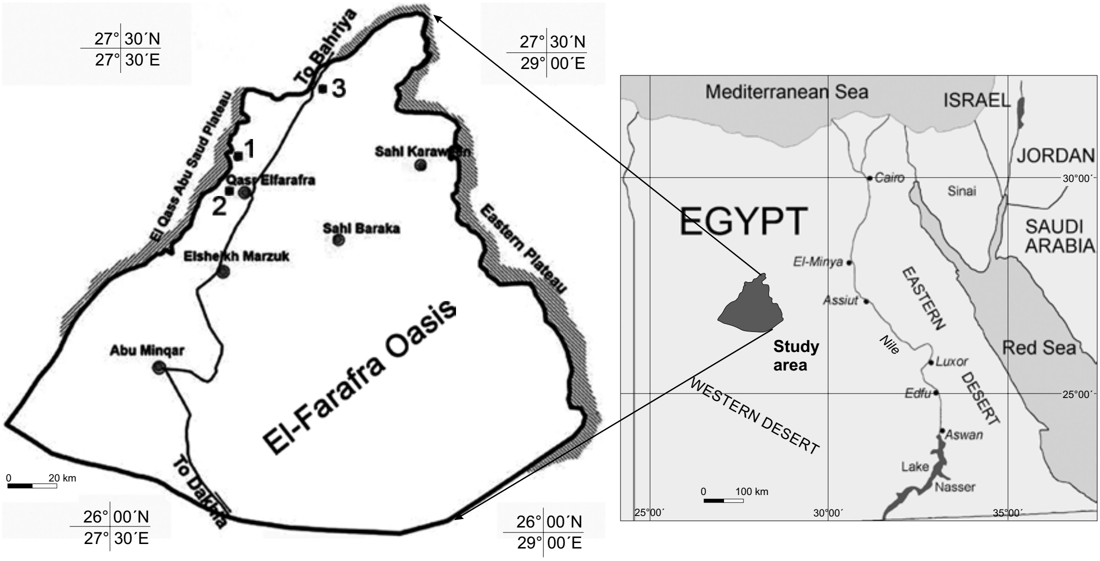

Fig. 1. Location of the studied habitats in El-Farafra Oasis (Western Desert, Egypt). 1 – Abu Nuss Lake, 2 – agricultural drainage at Lewa Soubah village, 3 – Ain Khadra rheocrenic ambient spring in White Desert National Park (WDNP).

surrounding areas included ecological data on 75 different euglenoid species.

There seems to be little information about the species composition and distribution of euglenoids in Egyptian inland waters, particularity in desert oasis habitats. During their phycological investigation of the El-Kharga Oasis, Shaaban and El Habibi (1978) recorded *Trachelomonas hispida* Skvortsov and *T. volvocina* Ehrenberg from the outlet channels of three drilled wells. A more recent contribution by El-Naghy *et al.* (2004) on some rice fields in the El-Kharga Oasis documented the presence of only five euglenoids belonging to three genera: *Euglena deses* var. *digrana* Zakryś, *E. deses* var. *intermedia* G. A. Klebs, *E. hemichromata* Skuja, *Lepocinclis colligera* Deflandre and *Phacus curvicauda* Svirenko. The available information on the algal flora of the Siwa, El-Bahariya and El-Dakhla Oases does not include any species of Euglenophyta (e.g., Shaaban 1985; Shaaban *et al.* 1997). From the El-Farafra Oasis, Shaaban *et al.* (2015) reported only *Euglena acus* (O. F. Müll.) B. Marin & Melkonian, *E. oxyuris* (Schmarda) B. Marin & Melkonian, *E. texta* Lemmerm. and *Lepocinclis fusiformis* (H. J. Carter) Lemmerm., from the lakes and drainages investigated during the summer and winter seasons. In general, documentation of euglenoids from the other Egyptian inland water habitats is limited, as confirmed by, for example, a reliable survey of Egyptian freshwaters (Shaaban 1994) which focused mainly on the River Nile and its two branches, pools, lakes and ditches, from which 42 species were reported, 9 of which are considered extinct. Further contributions by El Otify *et al.* (2003), Gaballa (2014) and El-Kassas and Gharib (2016) also supported this observation. Saber (2010) recorded 14 cosmopolitan species from the main branch of the River Nile and its Rosetta branch. El-Otify (2015) noted the co-occurrence of 5 euglenophytes in his recent study of the algal communities of irrigation and drainage canals in Aswan Province, southern Egypt. Khairy *et al.* (2015) found 19 euglenoid species in 5 Egyptian Mediterranean lakes.

Here we report our study on the biodiversity of euglenoids inhabiting the Egyptian oases and particularly the El-Farafra Oasis (Fig. 1). We provide detailed information on the morphology, taxonomy and ecology of euglenoids from the hyper-arid desert habitats of the El-Farafra Oasis, including brief descriptions and original documentation for each reported species.

Materials and methods

Study site

El-Farafra Oasis (26°00′–27°30′N, 26°30′–29°00′E), located *ca* 650 km southwest of Cairo, is one of the smallest oases (*ca* 10,000 km^2) on the limestone plateau occupying the central part of western Egypt (Fig. 1) (El Bastawesy & Ali 2013). This natural depression is in a hyper-arid region with a hot desert climate; it has 10 mm or less average annual precipitation and *ca* 22°C mean annual air temperature (MAAT) (Elsheikh 2015; Powell & Fensham 2016). Groundwater in the El-Farafra Oasis is drawn mainly from natural and artificial wells discharging from the world's largest non-renewable groundwater resource, the Nubian Sandstone Aquifer (Voss & Soliman 2014). The specimens in this study were collected mainly from three different habitats in the oasis (Figs 1 & 2): (1) agricultural-water-fed Abu Nuss Lake (27°09′49.4″N, 27°55′46.2″E, 60 m a.s.l.) in El-Nahda village, (2) an agricultural drainage (27°03′30.5″N, 27°54′03.3″E, 70 m a.s.l.) in Lewa Soubah village, and (3) a slow-flowing rheocrenic ambient spring, Ain Khadra, also called Ain El-Wadi (27°22′15″N, 28°13′08.8″E, 31 m a.s.l.) in White Desert National Park (WDNP).

Abu Nuss Lake is one of the main attractions of the El-Farafra Oasis, and is home to abundant birdlife (Fig. 2a). Located in El-Nahda village, it has a total area

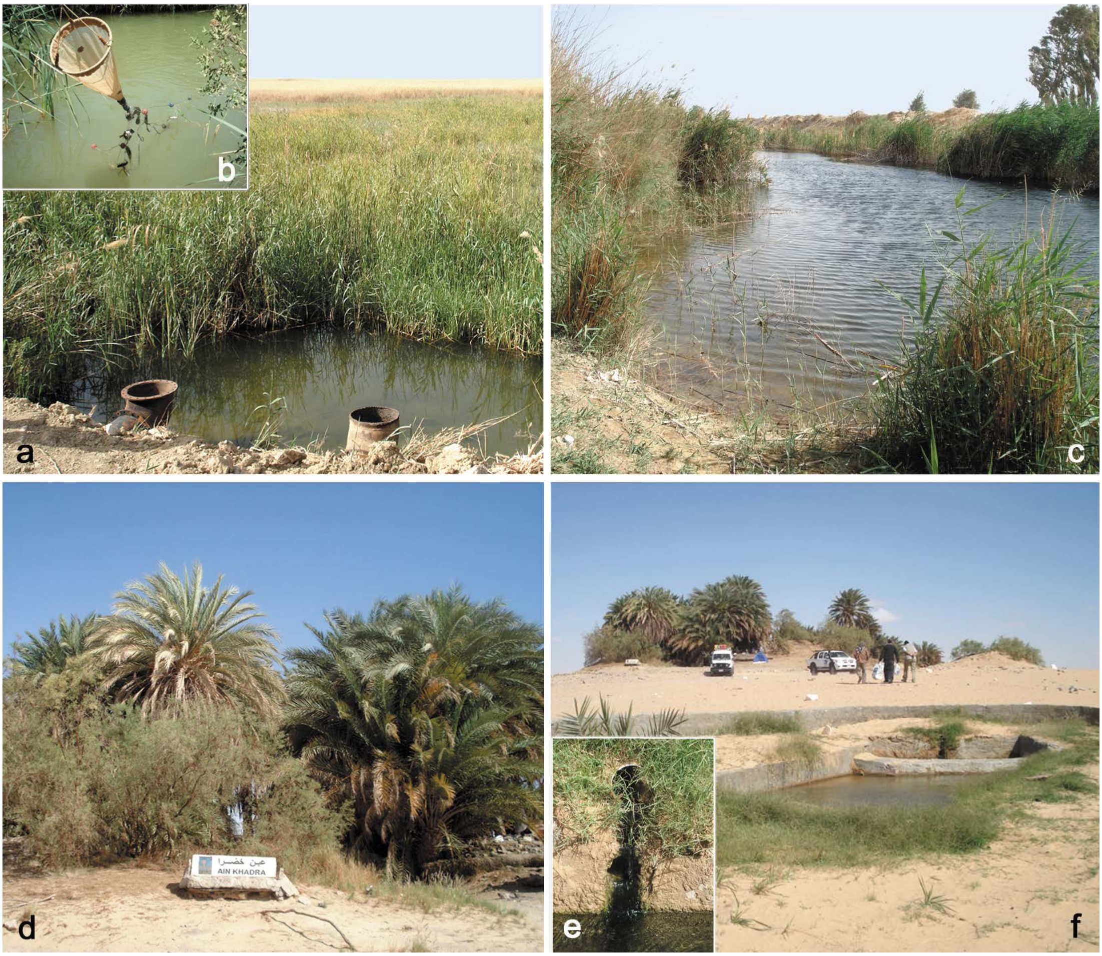

Fig. 2. Landscape views of the sampling sites: a – Abu Nuss Lake with massive growth of the common reed *Phragmites australis* (Cav.) Trin. *ex* Steud., b – plankton net hooked by its cone with a fishnet in Abu Nuss Lake, c – agricultural drainage at Lewa Soubah village, d – springhead of Ain Khadra (sustaining vegetated hillocks of palm trees), e – water flowing from Ain Khadra through an underground polypropylene tube, f – small concrete pool receiving water from Ain Khadra.

of *ca* 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 El-Farafra Oasis. This lake might be more properly classified as a wetland, and is mainly fed by the water discharged from neighboring agricultural land. It is widely used for fish farming (Fig. 2b). The lake is densely covered with massive growth of the common reed *Phragmites australis* (Cav.) Trin *ex* Steud.

The second studied habitat is an agricultural drainage in the vicinity of Lewa Soubah village. The water of this shallow drainage (mean depth *ca* 1.5 m) is supplied by runoff from agricultural land (Fig. 2c).

The third investigated station, a rheocrenic ambient spring called Ain Khadra, is one of the three main springs that remained active in the WDNP. It is located in the northern extremity of El-Farafra Oasis, *ca* 35 km from Qasr El-Farafra. This spring still yields freshwater, with average discharge of 7 L min^{-1} (Powell & Fensham 2016), and sustains vegetated hillocks rising several meters above the plain (Fig. 2d). The springhead is completely shaded and discharges its water through a large polypropylene tube (Fig. 2e) in a small concrete pool used for recreation and for animals to drink in this isolated desert habitat (Fig. 2f).

HYDROCHEMICAL CHARACTERIZATION

Water was sampled using polyethylene bottles previously cleaned with ultrapure water and Suprapure nitric acid (1%). Water temperature (°C), pH, specific conductivity (µS cm^{-1}) and total dissolved solids (mg l^{-1}) were measured *in situ* using a HANNA HI 991301 calibrated portable Temp/pH/EC/Total Dissolved Solids (TDS) meter. Dissolved oxygen (DO) was determined with a Lutron® YK-22DO in-field calibrated dissolved oxygen meter. Detailed hydrochemical characteristics of the studied habitats, including major ions, nutrients, trace elements and metals were determined by standard procedures and methods (Clescerl *et al.* 2001). Metals were analyzed with a PerkinElmer Optima 5300 inductively coupled plasma optical emission spectrometer (ICP–OES). Na^+, K^+, Ca^{2+} and Mg^{2+} were measured by ionic chromatography (ICS 1500, Dionex Corp.).

Table 1. Main hydrochemical characteristics of the studied habitats in El-Farafra Oasis (Western Desert, Egypt).

Parameter	Abu Nuss Lake in El-Nahda village	Agricultural drainage in Lewa Soubah village	Ain Khadra
Temp. (ºC)	24.5	22.4	24.0
pH	7.3	6.6	7.25
Conductivity (µS cm^{-1})	4040	5930	330
T.D.S. (mg l^{-1})	2090	2990	170
Dissolved oxygen (mg l^{-1})	6.2	4.4	1.5
Na^+ (mg l^{-1})	502	820	14.5
K^+ (mg l^{-1})	49.3	62.2	20.2
Ca^{2+} (mg l^{-1})	145	243	10.8
Mg^{2+} (mg l^{-1})	128	172	14.2
Cl^- (mg l^{-1})	944.5	2119.32	102.03
SO_4^{2-} (mg l^{-1})	532.7	343.63	1.11
HCO_3^- (mg l^{-1})	163.71	100	24.37
CO_3^{2-} (mg l^{-1})	0.0	0.0	0.0
NO_2^- (µg l^{-1})	112	452	0.0
NO_3^- (µg l^{-1})	3760	157000	400
NH_4^+ (µg l^{-1})	60	80	15
TP (µg l^{-1})	325	0.0	0.0
SiO_2 (mg l^{-1})	6.8	9.2	5.5
Sr (µg l^{-1})	3497	5860	233
B (µg l^{-1})	68.6	64.6	137
Li (µg l^{-1})	49.1	79.6	4.0
Fe (µg l^{-1})	32.3	24.0	29.4
Mn (µg l^{-1})	5.1	2.9	4.6
Zn (µg l^{-1})	3.2	3.0	7.6
Cu (µg l^{-1})	0.5	0.84	0.12

HCO_3^-, CO_3^{2-}, Cl^- and SO_4^{2-} were determined according to Chapman and Pratt (1978). Nutrients (NO_2^-, NO_3^-, NH_4^+, TP) were measured by molecular absorption spectrometry, and silicates as SiO_2 by the molybdosilicate method (Clescerl *et al.* 2001). The main hydrochemical characteristics of the studied habitats in El-Farafra Oasis are given in Table 1.

COLLECTED MATERIALS

Euglenoid specimens were sampled April 9–11 2015. The specimens were filtered using a plankton net (15 µm mesh) and transferred in 100 ml sterile clean polyethylene bottles following the method adopted by Bellinger and Sigee (2010). Fresh specimens were transported chilled in a cooler to the laboratory. The materials were studied and identified using a BEL® Photonics biological light microscope, and later preserved with 4% (v/v) formaldehyde solution. All descriptions are based on morphotaxonomic observations of living specimens. Voucher specimens were deposited in Phycology Unit No. 341, Botany Department, Faculty of Science, Ain Shams University, Cairo, Egypt. Diagnostic morphometric characters were measured and photographed using Canon Powershot G12 digital camera; 15 measurements of each morphometric character were made. The specimens were identified using the relevant literature: Starmach (1983), Wołowski (1998), Wołowski and Hindák (2005) and Wołowski (2011).

RESULTS AND DISCUSSION

In the studied habitats of the El-Farafra Oasis we recorded 20 different species and intraspecific taxa of euglenoids belonging to 8 genera: *Peranema* Dujard. (1), *Euglena* Ehrenb. (4), *Euglenaformis* M. S. Bennett & Triemer (1), *Euglenaria* Karnkowska-Ishikawa, E. W. Linton & Kwiat. (2), *Discoplastis* Triemer (1), *Lepocinclis* Perty (4), *Phacus* Dujard. (6) and *Trachelomonas* Ehrenb. (1) (Table 2). All these taxa have a cosmopolitan distribution and are known to thrive in moderately to highly polluted waters rich in organic matter (Wołowski 2011; Duangjan *et al.* 2014; Triemer & Zakryś 2015). Our results confirm that these euglenoids usually prefer, and proliferate in, warm and stagnant waterbodies (e.g., Wołowski 1998, Ciugulea & Triemer 2010; Wołowski *et al.* 2013; Shaaban *et al.* 2015; Varol & Şen 2016). These habitat conditions are observed mainly in two of the three studied habitats: Abu Nuss Lake and the agricultural drainage, which showed high concentrations of N and P compounds (see Table 1 for more details). Only *Trachelomonas volvocina* Ehrenb. var. *volvocina* was found in the rheocrenic ambient spring known as Ain Khadra. Shaaban and El Habibi (1978) documented similar findings in his study of some drilled wells in the El-Kharga Oasis, where only *T. hispida* (Perty) F. Stein and *T. volvocina* were recorded. Wołowski (1998, 2011) and Poniewozik (2009) reported that the genus *Trachelomonas* Ehrenb. mostly prefers colder and clean waters, although it can also be found in warmer and polluted waters.

Phacus crassus Zakryś & M. Łukomska and *Ph. cristatus* Zakryś & M. Łukomska were previously included in the species complex *Ph. longicauda* in assessments of Egyptian euglenoids

Table 2. Euglenoid taxa reported from various sites of El-Farafra Oasis (I – Abu Nuss Lake, II – agricultural drainage, III – Ain Khadra ambient spring).

Figs	Taxon	Taxonomical descriptions	Sites and occurrence		
			I	II	III
3a, b	*Peranema inflexum* Skuja	Cell 32–25 µm long × 8–9 µm wide, colorless, various in shape; common	+	–	–
3c, d	*Euglena adhaerens* Matvienko	Cell 80–85 µm long × 7.5 µm wide, cylindrical; chloroplasts discoid; not common	+	+	–
3e, f	*E. granulata* (G. A. Klebs) F. Schmitz	Cell 90–105 µm long × 25–30 µm wideW, spindle-shaped; flexible; chloroplasts disc-shaped with diplopyrenoids; common	+	–	–
3g	*E.* cf. *geniculata* Dujard.	Cell 75–80 µm long × 17.5 µm wide, cylindrical; two stellate chloroplasts but slightly damaged; common	+	–	–
3h	*Euglena* sp.	Cell 40–45 µm long × 25–30 µm wide	+	+	–

Table 2. *Continued*.

Figs	Taxon	Taxonomical descriptions	Sites and occurrence		
			I	II	III
3i, j	*Euglenamorfis proxima* (P. A. Dang.) M. S. Bennett & Triemer	Cell 52–55 µm long × 17.5–22.5 µm wide, spindle-shaped; chloroplasts discoid, lacking pyrenoids, several paramylon grains; common	+	+	–
3k, l	*Euglenaria caudata* (E. F. W. Hübner) Karnkowska-Ishikawa, E. W. Linton & Kwiat.	Cell 100–110 µm long × 27.5–30.0 µm wide, spindle-shaped, chloroplasts discoid with diplopyrenoids; very common	+	–	–
3m	*E.* cf. *clavata* (Skuja) Karnkowska-Ishikawa & E. W. Linton	Cell 35–40 µm long × 20.0–22.5 µm wide, club-shaped, chloroplasts discoid and irregularly lobed; common	+	+	–
3n	*Discoplastis spathirhyncha* (Skuja) Triemer	Cell 65–70 µm long × 17.5–20.0 µm wide, variable in shape, usually from spindle to spinning top; chloroplasts numerous, discoid; not common	+	–	–
3o, p	*Lepocinclis acus* (O. F. Müller) B. Marin & Melkonian	Cell 75–150 µm long × 7.5–10.0 µm wide, spindle-shaped, narrow, elongated, rigid; chloroplasts numerous, discoid without pyrenoids; paramylon bodies numerous, long, rod-shaped; common	+	+	–
4a	*L. fusiformis* (H. J. Carter) Lemmerm.	Cell 27.5–30 µm long × 18–20 µm wide, citroform, rigid; chloroplasts disc-shaped without pyrenoid, one large ring-like paramylon; common	+	–	–
4b–d	*L. oxyuris* (Schmarda) B. Marin & Melkonian	Cell 132.5–140.0 µm long × 12.5–17.5 µm wide, cylindrical with hyaline caudus; chloroplasts small, numerous, discoid, two large paramylon body; common	+	+	–
4e, f	*L. texta* (Dujard.) Lemmerm.	Cell 37.5–40.0 µm long × 27.5–30.0 µm wide, ovoid, with small depression at apex; chloroplasts discoid without pyrenoid; paramylon bodies small, numerous, oval; common	+	+	–
4g	*Phacus anomalus* F. E. Fritsch & M. F. Rich	Cell 25.0–27.5 µm long × 15–20 µm wide, irregular in shape, usually pear-shaped, with bent caudus; chloroplasts discoid, two paramylon bodies; not common	+	–	–
4h	*Ph. crassus* Zakryś & M. Łukomska (delimited from the *Ph. longicauda* complex)	Cell *ca* 60 µm long × 27.5–35.0 µm wide, widely oval, flattened with long straight cauda, with a short S-shaped fold; probably common	+	–	–
4i, j	*Ph. cristatus* Zakryś & M. Łukomska (delimited from the *Ph. longicauda* complex)	Cell 50–60 µm long × 27.5–35.0 µm wide, widely oval, semi-flattened, with long fold, spirally twisted with long sharp caudus, chloroplasts discoid, small; paramylon body ring-like; common	+	–	–
4k, l	*Ph. curvicauda* Svirenko	Cell 38.8–40.0 µm long × 25–30 µm wide, broadly ovoid, with longitudinal groove, short bent cauda; chloroplasts small, discoid, two large disc-like paramylon bodies; common	+	+	–
4m	*Ph. orbicularis* K. Hübner	Cell 52.5–75.0 µm long × 30–50 wide, broadly ovoid, with sharp slightly bent cauda; chloroplasts small, discoid; one or two disc-like paramylon bodies; common	+	+	–
4n	*Ph. pleuronectes* (O. F. Müller) Nitzsch *ex* Dujard.	Cell 75–80 µm long × 45–50 µm wide, broadly oval with short slightly bent caudus, slightly twisted; chloroplasts numerous, discoid, usually two disc-like paramylon bodies; common	+	+	–
4o	*Trachelomonas* cf. *volvocina* (Ehrenb.) Ehrenb.	Lorica 17.5–20.0 µm in diam., smooth, cell with two parietal chloroplasts, each with pyrenoids; common	–	–	+

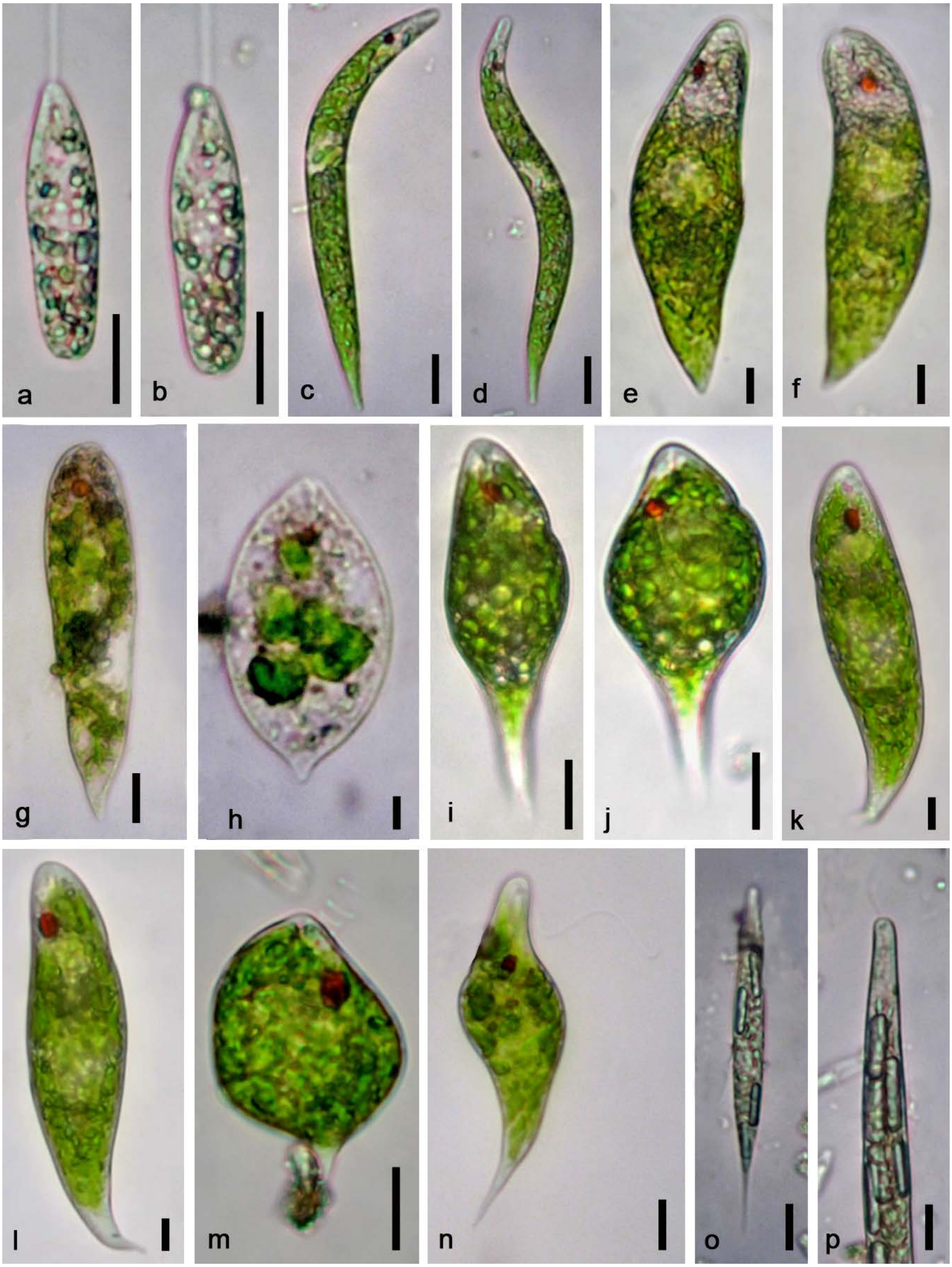

Fig. 3. a & b – *Peranema inflexum* Skuja, c & d – *Euglena adhaerens* Matvienko, e & f – *E. granulata* (G. A. Klebs) F. Schmitz, g – *E.* cf. *geniculata* Dujard., h – *Euglena* sp., i & j – *Euglenaformis proxima* (P. A. Dang.) M. S. Bennett & Triemer, k & l – *Euglenaria caudata* (E. F. W. Hübner) Karnkowska-Ishikawa, E. W. Linton & Kwiat., m – *E.* cf. *clavata* Karnkowska Ishikawa & E. W. Linton, n – *Discoplastis spathirhyncha* (Skuja) Triemer, o & p – *Lepocinclis acus* (O. F. Müller) B. Marin & Melkonian. Scale bars = 10 µm.

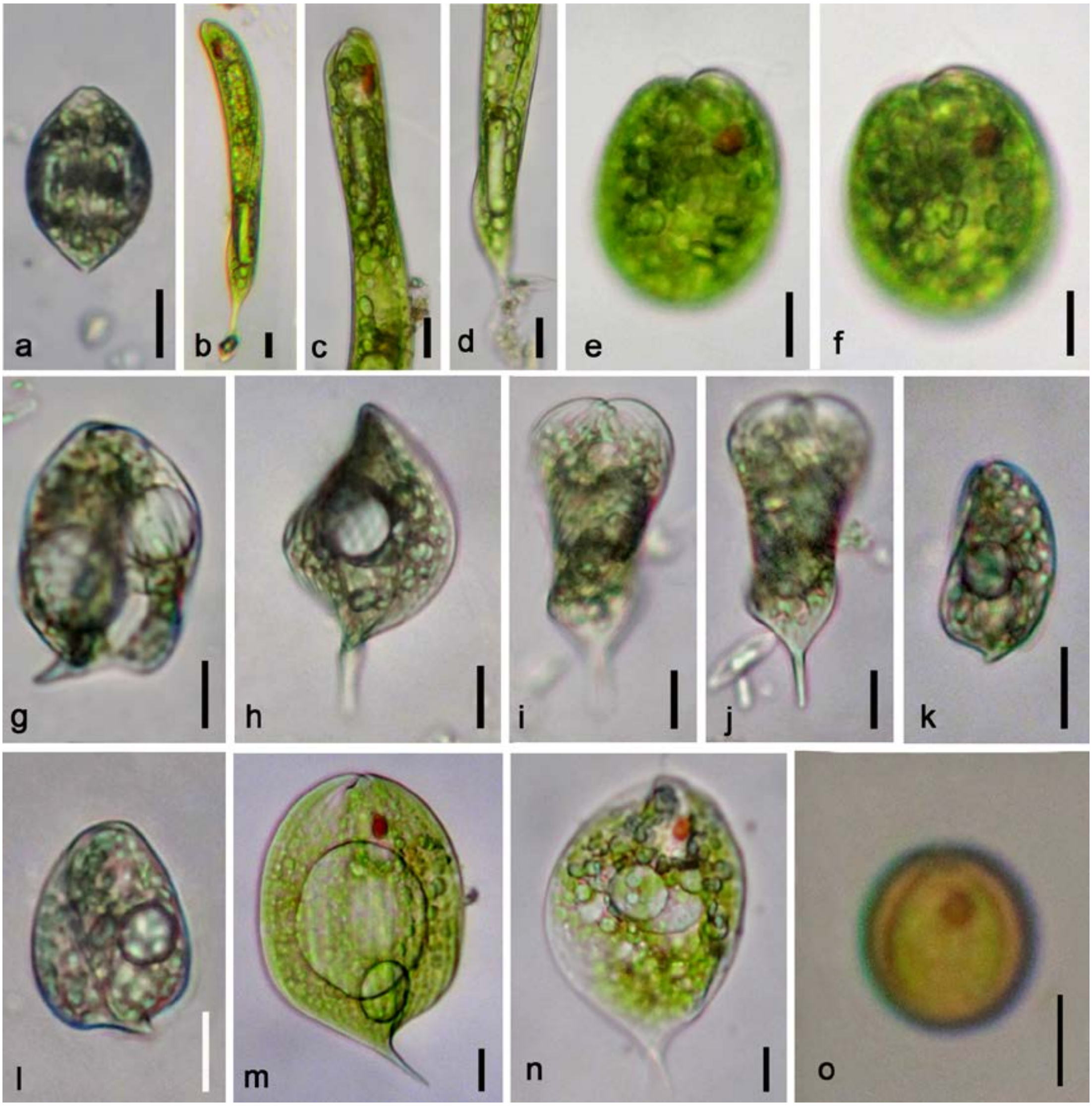

Fig. 4. a – *Lepocinclis fusiformis* (H. J. Carter) Lemmerm., b–d – *L. oxyuris* (Schmarda) B. Marin & Melkonian, e & f – *L. texta* (Dujard.) Lemmerm., g – *Phacus anomalus* F. E. Fritsch & M. F. Rich, h – *Ph. crassus* Zakryś & M. Łukomska, i & j – *Ph. cristatus* Zakryś & M. Łukomska, k & l – *Ph. curvicauda* Svirenko, m – *Ph. orbicularis* K. Hübner, n – *Ph. pleuronectes* (O. F. Müller) Nitzsch *ex* Dujard., o – *Trachelomonas* cf. *volvocina* (Ehrenb.) Ehrenb. Scale bars = 10 μm.

(Saber, unpublished data) but Łukomska-Kowalczyk *et al.* (2015) recently delimited them as new species based on molecular and morphological. Here we identify them as new records for Egypt.

Detailed observations of the investigated species indicated that their chloroplast shape and structure were somewhat different from those typically observed under laboratory conditions. The chemical properties of the habitats might be responsible for these changes, as suggested by results from Płachno *et al.* (2015), who found that the shape and arrangement of chloroplasts in some euglenophytes [particularly *Euglena viridis* (O. F. Müll.) Ehrenb. and *E. mutabilis* F. Schmitz] sampled from heavily polluted streams in Poland varied markedly and did not always fit the original descriptions. Our present work, the first in-depth study of euglenoid species composition in Egypt, points to the need for further investigation of these isolated desert habitats.

Conclusions

Twenty different euglenoids were identified from samples collected in the El-Farafra Oasis (The Western Desert). Four of these species (*Peranema inflexum*, *Euglena adhaerens*, *Phacus crassus*, *Ph. cristatus*) are new records for Egypt. All the species found occurred in agricultural and/or human-impacted habitats. More in-depth studies in Egypt will no doubt produce records of other interesting species, especially in isolated desert habitats.

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