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ORIGINAL ARTICLE

PALYNOLOGICAL AND FOLIAR EPIDERMAL STUDIES OF GENUS *OXALIS* LINNAEUS, 1753 (OXALIDALES, OXALIDACEAE) FROM EGYPT

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ABSTRACT

By using light microscopy (LM) and scanning electron microscopy (SEM), the pollen grains and foliar epidermal morphology of four species and two varieties of Egyptian *Oxalis* Linnaeus, 1753 belonging to three sections of the subgenus *Oxalis* Linnaeus, 1753 were studied. The objective was to determine the importance of pollen and foliar epidermal characters as taxonomic evidence. The current study revealed that the pollen grains of all taxa examined are monads, radially symmetric, isopolar, and of medium size; the shape varied from sub-spheroidal to subprolate. The pollen apertures were tricolpate with ornamented colpal membranes (rugulate, warty, congregated granules). Exine is semi-tectate, with micro-reticulate to reticulate ornamentation, perforate in *O. debilis* Kunth, 1822. The study also revealed the presence of four types of stomata: actinocytic, anisocytic, anomocytic, and an unusual 4-celled anisocytic. Both abaxial and adaxial epidermal cells were irregular or polygonal in shape, with undulate or straight anticlinal walls and semi-swollen to swollen periclinal walls with dispersed epicuticular wax. Two forms of non-glandular, unicellular trichomes were observed: short clavate and long with a tapering apex and papillate surface. The study further discussed numerical results based on combined morphological, palynological, and foliar epidermal characters. This study is the first report dealing with anatomical and palynological features of the genus *Oxalis* in Egypt.

Keywords: Egypt, Foliar epidermis, Numerical analysis, *Oxalis*, Pollen morphology.

INTRODUCTION

Oxalis Linnaeus, 1753 is a cosmopolitan genus and presents about 566 accepted species (POWO, 2023), distributed within four subgenera: *Monoxalis* (Small) Lourt., *Trifidus* Lourt., *Thamnoxys* (Endl.) Reiche and *Oxalis*. It is believed that South America and Southern Africa

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are the centers of distribution, and South America is probably the place of origin of this genus (Knuth, 1930; Denton, 1973; Lourteig, 1994, 2000; De Azkue, 2000). The genus presents many difficulties in identification, mainly because of the use of morphological characteristics that are not very clear (Abreu *et al.*, 2012).

Pollen morphology has a taxonomic importance and can support the morphological and the phylogenetic studies (Chen and Xia, 2011; Tripathi *et al.*, 2017). The taxonomic significance of pollen morphology for the genus *Oxalis* was a topic for many studies. These palynological studies were performed on *Oxalis* from various aspects such as morphology (Perveen and Kaiser, 2003; Rosenfeldt and Galati, 2007), type of pollen grains (Ghosh and Verma, 1985; Dreyer, 1996), formation of aberrant pollen (Dreyer and Van Wyk, 1998), and orbicule morphology (Rosenfeldt and Galati, 2005, 2008; Lòpez and Rosenfeldt, 2015, 2016). A comprehensive study on the pollen morphology of American and African members of the genus *Oxalis* has been performed by Huynh (1969 a, b), who identified four pollen types and 13 pollen subtypes based on the presence, or absence of a distinct supra-reticulum and the simple or complex constitution of apertures (colpate, porate, or colporate); in addition to the differences in grain size that were observed in anthers from the different stamen whorls of *Oxalis* flowers.

Dreyer (1996) examined the pollen micro-morphology of all the Southern African members of *Oxalis* (270 taxa) using LM, SEM, and TEM techniques. Four main pollen types and 19 subtypes were described based on tectum structure and the number and arrangements of apertures. The study also recorded the presence of variable percentages of aberrant pollen grains in some taxa of *Oxalis*. The occurrence of aberrant pollen in this genus has been reported previously by Dreyer and Van Wyk (1998). They studied the pollen from both stylar whorls to detect the relation between palynological variation and tristyly. They showed that the aberrations always affect the number and arrangement of the apertures, but never alter the exine structure of the grain and also revealed that reticulate pollen displays a low percentage of aberrations.

The macro- and micro-morphology of the epidermis and its appendages have been used by various authors to classify certain taxa of the angiosperms (Adedeji *et al.*, 2007; Chukwuma *et al.*, 2017; Bahadur *et al.*, 2022; Chukwuma *et al.*, 2022). The most important epidermal traits are trichome types, shape of epidermal cells, stomata types, stomata position, and subsidiary cells. These traits are useful for identification purposes and for the determination of phylogenetic relationships between taxa (Metcalf and Chalk, 1950, 1979; Jones, 1986; Judd *et al.*, 2008; Ogunidipe *et al.*, 2009; Araujo *et al.*, 2010; Zhang *et al.*, 2018; Bahadur *et al.*, 2023).

Oxalis is tremendously variable in the number and shape of leaflets, leaf and leaflet size, degree of leaflet conduplication, petiole length and shape, nature of the epidermis, and indumentum attributes (Salter, 1944). However, only a few studies have focused on the leaf anatomy of this genus. Metcalfe and Chalk (1950); dos Reis and Alvim (2013); Jooste (2015); and Richetti *et al.* (2022) are among the authors who have investigated and described the leaf

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anatomical features of the genus *Oxalis*. Singh (2010) showed that anatomical features have played an important role in the clarification of phylogenetic relationships among South American *Oxalis* species. Jooste *et al.* (2016) assessed the variation of fifty-nine leaflet anatomical traits of 109 Southern African species in a phylogenetic context and stated that a combination of six leaflet anatomical traits (stomatal position, adaxial epidermal cell types, abaxial epidermal cell types, mesophyll type, presence or absence of a sheath around vascular tissue, and degree of leaflet conduplication) is useful and supports various Southern African taxa clades previously defined by DNA-based phylogenetic work (Oberlander *et al.*, 2011).

In Egypt, this genus is represented by four species and two varieties belonging to three sections in the subgenus *Oxalis* (Draz *et al.*, 2021; Shamso *et al.*, 2021). The current study presents a description of the macro- and micromorphology of pollen grains and foliar epidermal cells using both LM and SEM for the evaluation of their taxonomic significance and uses numerical taxonomy to better understand the phenetic relationships among the studied taxa within the genus.

MATERIALS AND METHODS

Plant materials: The present study is based on field studies and herbarium specimens held at the following herbaria: Cairo University (CAI), National Research Centre (CAIRC); Tanta University (TANE), and the Agriculture Museum, Flora and Phytotaxonomy Researches (CAIM) [Herbaria acronyms according to Thiers (2023); continuously updated] (Tab. 1). The nomenclature of all taxa has been updated according to several websites: POWO (2023) and IPNI (2023). The morphological data were obtained from both fresh and herbarium specimens. For each taxon, at least 3-4 specimens were chosen (if available) to encompass the range of variations.

Light investigation: The following steps were carried to examine the pollen and lamina samples:

1. Pollen examination: Pollen samples were taken from mature anthers of flowering buds. For light microscopy (LM), the pollen grains were prepared using the technique of Erdtman (1960) and then mounted in glycerin jelly. Light microscopic observations were made using a Serico research microscope under (E 40, 0.65) with a 16-x eye piece. The measurements of pollen grains were based on at least 15-20 pollen grains for each specimen. Various pollen characters: shape, size, aperture type, and exine sculpture were determined (Tab. 2). Pollen terminology is followed Punt *et al.* (2007); Hesse *et al.* (2009) and Halbritter *et al.* (2018).
2. Epidermal examination: Three pieces of lamina were embedded in KOH 5% for 24-48 hrs. Transverse sections of all studied taxa were taken in lamina through hand cutting, and stained with a Safranin-fast green standard double stain to show the shape of epidermal cells (Sass, 1961). In an additional method, the epidermal peels were obtained from fresh leaves after being washed in water, painted with colorless nail polish on abaxial and adaxial surfaces; each epidermal peel was fixed and examined under a light microscope. The micromorphological characters of both surfaces were studied at different

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magnifications (10X, 40X objectives) and photographed using an Olympus - cx41 light microscope equipped with an Olympus digital camera. The qualitative characteristics include the shape of epidermal cells, stomata, and trichomes, their presence and absence, and their types (Tab. 3). Terminology was followed by Metcalfe and Chalk (1950) and Barthlott (1981). Voucher specimens and slides were kept in the Cairo University Herbarium (CAI).

SEM Microscopy investigation: For each taxon, non-acetolyzed pollen grains and small pieces of the median portion of dry lamina were mounted onto stubs with double sided adhesive tape, and then these stubs were sputter-coated with gold. After coating, they were examined using a field emission scanning electron microscope (FE-SEM) QUANTA FEG250Y at an accelerating voltage of 20 KV, at the Electron Microscopy Unit, National Research Centre, Dokki.

Data Analysis: Forty-eight morphological, palynological, and foliar epidermal traits, divided into 113 character states, were analyzed and scored. The data matrix was constructed of six OTUs (App. 1). In this study, the similarity will be measured at the species level (represented by specimens). An equal number of specimens of each species (three specimens, if available) were used. The resemblance between the fundamental taxonomic units was determined in two steps: first, measure the similarity values (or distance values) between all possible pairs of specimens under study of the studied characters and character states; and second, form the similarity matrix. This matrix was analyzed using the numerical taxonomy technique supplied in the Minitab program, version 20 (Minitab, 2020).

Table (1): The collection data of the taxa included in the present study:

Taxon	Locality and date of collection	Collector and Number	Herbarium and specimen code
Section: <i>Cernuae</i> Knuth, 1914			
<i>O. anthelmintica</i> A. Rich., 1847	-Mountain tributary, Wadi Akwametra, Gebel Elba, 27-2-1967. -Wadi Darawein, Gebel Elba, 3-2-1979.	Osborn & Helmy s.n. Boulos 12924	(CAI), cai.46.240.722.18 (CAIRC), A306
<i>O. pes-caprae</i> L., 1753	-Bramly's grotto, Burg El-Arab, 28-2-2019 -Behig, 4-5-1976 -Maruit, 23-3-2006	A. Draz s.n. Ahmed & Mokhtar 71 D.A.Ahmed 2937	(CAIRC), A304 (CAI), cai.46.240.721.33 (TANE), Not coded

<p>Section: <i>Corniculatae</i> DC., 1824</p> <p><i>O. corniculata</i> var. <i>corniculata</i></p> <p><i>O. corniculata</i> var. <i>repens</i> (Thunb.) Zucc., 1831</p>	<p>- El Bagor, Monufia, 12-4-2019 - Bir Romani, Budkhulu, Dakhla, 12-2-1952; - Wadi Feiran, 19-10-2012</p> <p>- National research center garden, Giza, 13-5-2019 - ibid, 18-4-2021</p>	<p>A. Draz s.n.</p> <p>Täckholm & Kassas 185 Keshta s.n.</p> <p>A. Draz s.n</p> <p>A. Draz s.n</p>	<p>(CAIRC), A301</p> <p>(CAI), cai.46.240.723.1.10</p> <p>(TANE), Not coded</p> <p>(CAI), cai.240.723.2.1</p> <p>(CAIRC), A302</p>
<p>Section: <i>Ionoxalis</i> Small, 1903 <i>O. debilis</i> Kunth, 1822 (= <i>O. corymbosa</i> DC)</p> <p><i>O. latifolia</i> Kunth, 1822</p>	<p>-Giza, 12-4-2020 -Dokki, 20-2-2021</p> <p>-Arab El-Ghadir, Qalubia, French bean, 20-5-2003 -Giza, Cairo University Garden, 15-4-2021</p>	<p>A. Draz s.n. H. Hosni s.n.</p> <p>El Khanagry s.n.</p> <p>E. Shamso s.n.</p>	<p>(CAIRC), A303 (CAI), cai.46.240.723.5.11</p> <p>(CAIM), Not coded</p> <p>(CAI), cai.46.240.723.8.4</p>

RESULTS AND DISCUSSION

The current study of pollen morphology and the epidermal features of leaflet lamina using LM & SEM have revealed some valid characters for identification and classification of the studied *Oxalis* taxa (Tab. 2, 3).

I-Pollen grains morphology: Palynological characters of six taxa belonging to the genus *Oxalis* were studied under LM and SEM for detecting various characteristics such as polarity, size, shape, aperture type, aperture arrangements, aperture membrane sculpture, and exine sculpture of pollen grains. Detailed pollen morphological features of the investigated taxa are summarized in Table (2), and representative pollen grains are illustrated in Plates (1-3).

The morphological characters showed that the pollen grains of all studied taxa were monads, isopolar, radially symmetrical, and circular in polar view. Pollen size medium (medium to large in *O. pes-caprae*) with mean polar axis ranges from $26.9\mu\text{m} \pm 1.1$ in *O. corniculata* var. *corniculata* to $38.6\mu\text{m} \pm 0.94$ in *O. anthelmintica*; mean equatorial diameter ranges from $22.6\mu\text{m} \pm 1.2$ in *O. debilis* to $33.8\mu\text{m} \pm 1.2$ in *O. corniculata* var. *repens*. The shape of pollen grains varied from sub-spheroidal to sub-prolate in an equatorial view. The sub-spheroidal grains ranged from prolate-spheroidal in *O. corniculata* var. *corniculata* (P/E= 1.08) to oblate-spheroidal in *O. corniculata* var. *repens* (P/E= 0.97). The results of this study agree with Dreyer (1996) that the shape of pollen is of minor importance among the southern

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African members of *Oxalis*, and most grains ranged from spherical to oblate (seldomly prolate) in an equatorial view.

The present study showed that the pollen grains are normally tricolpate, and tetracolpate grains are also observed within the same species, as in *O. debilis*, *O. corniculata* var. *repens*, and *O. latifolia* (Pls. 2, 3). These findings are in agreement with Ghosh and Verma (1985); Dreyer and Van Wyk (1998). Moore (1973) and Goldblatt (1987) suggested that the presence of two types of grains (tri- and tetracolpate) within the same species is the result of polyploidy. Colpi apocolpate, vary from elliptic to fusiform or oblong; the colpal membrane was densely granulated to rugulated in *O. corniculata* (Pl. 1 C), scabrous to warty in *O. corniculata* var. *repens*, with congregated granules distributed irregularly in *O. pes-caprae* (Pl. 1 G), and warty in *O. anthelmintica*, *O. latifolia*, and *O. debilis* (Pl. 1 J, M).

The exine of the studied taxa was semi-tectate, brochate, uniform, and generally micro-reticulate to reticulate ornamentation, and rarely perforate in *O. debilis* (Pl. 1 O). Brochi are circular to polygonal, diminishing in size towards the colpi. Lumina with free single columella in *O. pes-caprae* (Pl. 1 I). Huynh (1969 a, b) and Dreyer (1996) indicated that the reticulate pollen type is the most common type among the South African members of *Oxalis*. Our results coincide with those of previous studies, and the exine features have little taxonomic value for identification and species delimitation.

Key to the examined taxa of *Oxalis* based on pollen morphology:

1. Pollen prolate-spheroidal or oblate-spheroidal (Pl. 1 A, D)..... 2
 - Pollen sub-prolate (Pl. 1 G, J, M).....3
2. Pollen prolate-spheroidal, with P/E= 1.08 μm , tri-colpate, colpus 15-20 μm long, granulate to rugulate membrane (Pl. 1 A-C and Pl. 2 A) *O. corniculata* var. *corniculata*
 - Pollen oblate-spheroidal, with P/E=0.97 μm , tri- or tetra-colpate, colpus 20-25 μm long, scabrous to warty membrane (Pl. 1 D-F and Pl. 3 B) *O. corniculata* var. *repens*
3. Pollen with tricolpate (Pl. 2 B, C)..... 4
 - Pollen with tricolpate and tetracolpate (Pl. 2 A) 5
4. Exine sculpture micro-reticulate, colpal membrane warty (Pl. 1 K, L)*O. anthelmintica*
 - Exine sculpture reticulate with free single columella in lumina, colpal membrane with congregated granules (Pl. 1 G, I)*O. pes-caprae*
5. Pollen grains mean polar axis 29.1 μm , mean equatorial diameter 22.57 μm . Exine sculpture perforate (Pl. 1 O) *O. debilis*
 - Pollen grains mean polar axis 34.75 μm , mean equatorial diameter 28.75 μm . Exine sculpture reticulate (Pl. 3 B) *O. latifolia*

Table (2): Pollen morphological characters of investigated taxa.

Taxon	Polar axis (P)		Equatorial diameter (E)		P/E Ratio (μm)	Pollen shape	Pollen size	Aperture-type	Colpus shape	Colpus fusion	Colpus length	Colpus membrane	Exine sculpture
	Range (μm)	Mean	Range (μm)	Mean									
<i>O. anthelmintica</i>	45 - 35	38.6 (0.94 \pm)	45 - 25	31.4 (1.3 \pm)	1.2	Sub-pro- late	Medium sized	Tricolpate	Elliptic	Apocolpate	30-20	warty	Micro-reticulate
<i>O. pes-caprae</i>	60-25	37 (1.5 \pm)	60 - 15	30.8 (2.9 \pm)	1.2	Sub-pro- late	Medium to large sized	Tricolpate	Fusiform	Apocolpate	40-20	With congregated granules distributed irregularly	Reticulate lumina with free single columella
<i>O. corniculata</i> var. <i>corniculata</i>	35 - 25	26.9 (1.1 \pm)	35 - 20	24.7 (1.4 \pm)	1.1	Prolate - spheroidal	Medium sized	Tricolpate	Elliptic	Apocolpate	20-15	Densely granules to rugulate	Micro-Reticulate to reticulate
<i>O. corniculata</i> var. <i>repens</i>	35-30	33.1 (0.7 \pm)	40-25	33.8 (1.2 \pm)	1	Oblate- spheroidal	Medium sized	Tri- and tetracolpate	Oblong	Apocolpate	25-20	Scabrous to warty	Reticulate
<i>O. debilis</i>	35 - 20	29.1 (1.5 \pm)	35 - 15	22.6 (1.2 \pm)	1.3	Sub-pro- late	Medium sized	Tri- and Tetracolpate	Fusiform	Apocolpate	25-20	Warty	to Perforate microreticulate
<i>O. latifolia</i>	39-30	34.8 (1.2 \pm)	-26 45	28.8 (1.1 \pm)	1.2	Sub-pro- late	Medium sized	Tri- and Tetracolpate	Fusiform	Apocolpate	30-20	Warty	Reticulate

Size category: Small: 10-25 μm , Medium sized: 26-50 μm , large 51-100 μm , and shape classes were categorized based on the ratio of the mean polar axis (P) and mean equatorial diameter (E) (Erdtman, 1952).

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Table (3): Foliar epidermal characteristics of investigated taxa.

Taxon	Abaxial Epidermal cells				Adaxial Epidermal cells			Epicuticular wax	Stomatal position	Stomatal pattern	Stomatal shape	Trichome type
	Shape	Anticlinal wall pattern	Periclinal wall	Periclinal wall surface	Shape	Anticlinal wall pattern	Periclinal wall					
<i>O. anthelminitica</i>	Polygonal	straight	Semi-swollen	glebulate	Polygonal	straight	Semi-swollen	absent	Hyposomatic	Anisocytic and unusual 4-celled anisocytic	Oblong	Clavate unicellular
<i>O. pes-caprae</i>	± Polygonal	Straight to slightly curved	Swollen	glebulate	± Polygonal	Straight to slightly curved	Swollen	Present	Hyposomatic	Anisocytic and unusual 4-celled anisocytic	Ellipsoid	Long unicellular
<i>O. corniculata</i> var. <i>corniculata</i>	Irregular	Undulate	Semi-swollen	Smooth	Irregular	Undulate	Slightly Semi-swollen	Present	Amphistomatic	Anisocytic, unusual 4-celled anisocytic and sometimes anomocytic	Oblong	Long unicellular
<i>O. corniculata</i> var. <i>repens</i>	± Polygonal	Straight	Swollen	Smooth	± Polygonal	Straight	Swollen	Present	Amphistomatic	Anisocytic and sometimes actinocytic	Silt-like	Long unicellular
<i>O. debilis</i>	Irregular	Undulate	Semi-swollen	± Smooth	Irregular	Undulate	Semi-swollen	Present	Amphistomatic	Anisocytic, unusual 4-celled anisocytic and sometimes anomocytic	Ellipsoid	Clavate and long unicellular sometimes multicellular uniseriate
<i>O. latifolia</i>	Polygonal	Straight	Swollen	With central papillae	Polygonal	Straight	Swollen	Present	Hyposomatic	Anisocytic, unusual 4-celled anisocytic and sometimes anomocytic	Ellipsoid	Clavate and long unicellular

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II- Foliar epidermal characteristics: The current study primarily focuses on micro-morphological features of trichomes, epidermal cells, and stomata. The data on the foliar epidermal characters of the taxa examined are presented in Table (3).

Trichomes on plants are extremely variable in their presence, density, and form; therefore, their morphology and structure could be of taxonomical importance in certain plant groups (Che Amri *et al.*, 2018; Bahadur *et al.*, 2023). According to previous studies by Metcalf and Chalk (1950); dos Reis and Alvim (2013); and Jooste (2015), *Oxalis* is recognized for having two types of foliar trichomes: glandular and non-glandular trichomes. In the present study, the majority of the studied taxa were sparsely pubescent, restricted to the midrib, abaxial surface, and margin of the leaf blade. Unicellular trichomes were the main type, with two forms: short, clavate unicellular (Pl. 4 C) and long unicellular with a tapering apex and papillate surface (Pl. 4 A, B); while multicellular uniseriate trichomes were observed only in *O. debilis* (Pl. 4D). The presence of glandular trichomes is not reported in Egyptian taxa, and trichome characters were rather uniform and of little taxonomic importance.

Epidermal anticlinal walls have low interspecific variation in *Oxalis* and can be regarded as a taxonomically stable character (Jooste, 2015; Jooste *et al.*, 2016). In the present study, both abaxial and adaxial epidermal cells were polygonal or irregular in shape with a straight to undulate anticlinal wall pattern (Pl. 6). The variability in the anticlinal cell wall pattern may be related to the environmental conditions (Stace, 1965; Metcalf and Chalk, 1979). All studied taxa are listed as having semi-swollen to swollen periclinal walls (Pl. 5), and their surfaces were smooth in *O. corniculata* and *O. debilis* (Pl. 6C); glebulate in *O. anthelminthica* and *O. pes-caprae* (Pl. 6B), and with central papillae in *O. latifolia* (Pl. 6A). Jooste (2015) reported the occurrence of swollen and papillose epidermal cells in some African *Oxalis* species, which act as lenses to focus light through the epidermis into the chloroplast-rich palisade cells (Poulson and Vogelmann, 1990; Myers *et al.*, 1994; Vogelmann *et al.*, 1996). Moreover, Gkikas *et al.* (2015) reported the production of epicuticular wax by those papillose cells that functioned as a water repellent material, a character that was assigned in the present study for *O. corniculata*, *O. pes-caprae*, *O. debilis*, and *O. latifolia*.

The types and distribution of stomata provide taxonomically useful information in some taxa (Metcalf and Chalk, 1950). According to Jooste *et al.* (2016), stomata display great variations in their types and distribution, and recorded the presence of epistomatic, hypostomatic, and amphistomatic leaflets in southern African *Oxalis*. In this study, the majority of the studied taxa have hypostomatic leaves, in the case of *O. anthelminthica*, *O. pes-caprae*, and *O. latifolia*. However, in the case of *O. corniculata* and *O. debilis* leaves, were amphistomatic, similar to previous studies by dos Reis and Alvim (2013).

Anomocytic and paracytic stomatal complex types have been reported in the Oxalidaceae by Metcalf and Chalk (1950); dos Reis and Alvim (2013); while Jooste *et al.* (2016) reported four types of stomata: anomocytic, anisocytic, actinocytic, and an unusual 4-celled anisocytic stomatal type. These four types of stomata were observed in the studied taxa, where the anisocytic and an unusual 4-celled anisocytic types of stomata were present in all studied taxa

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(Pl. 7). However, the actinocytic type was encountered in *O. corniculata* var. *repens* and *O. latifolia*, while the anomocytic type was restricted to *O. corniculata* var. *corniculata* and *O. debilis*. Baranova (1992) suggested that the multiple stomatal types within a leaf are a common occurrence, which is taxonomically significant. Despite the general consensus that stomatal complex types can be taxonomically informative, we could not detect any clear pattern based on these traits among the studied taxa.

The subsequent key was based on the foliar epidermal cell characters, which might be used to distinguish between the studied taxa:

- 1- Both abaxial and adaxial epidermal cells irregular with undulated anticlinal walls (Pl. 6 B, C) 2
 - Both abaxial and adaxial epidermal cells polygonal with straight anticlinal walls (Pl. 6 A) 3
- 2- Stomata oblong; trichomes long unicellular (Pl. 4 A, B and Pl. 8 B) *O. corniculata* var. *corniculata*
 - Stomata ellipsoid; trichomes clavate and long unicellular sometimes multicellular uniseriate (Pl. 4 and Pl. 8 A) *O. debilis*
- 3- Epidermal cells with smooth periclinal wall, amphistomatic stomata (Pl. 6 C) *O. corniculata* var. *repens*
 - Epidermal cells with glabulate or with central papillae periclinal wall, hypostomatic stomata (Pl. 6 A, B) 4
- 4- Epidermal cells with central papillae periclinal wall (Pl. 6 A) *O. latifolia*
 - Epidermal cells with glabulate periclinal wall (Pl. 6 B) 5
- 5- Epidermal cells with semi-swollen periclinal wall and epicuticular wax absent. Trichomes clavate (Pl. 4 C, Pl. 5 A) *O. anthelmintica*
 - Epidermal cells with swollen periclinal wall and epicuticular wax present. Trichomes long unicellular (Pl. 4 A and Pl. 5 C) *O. pes-caprae*

III-Numerical analysis

The 113 morphological, palynological, and foliar epidermal character states and their binary codes (0, 1) are given in Appendix (1). The numerical analysis obtained is represented as a dendrogram (Diag. 1). The dendrogram shows that the studied taxa were classified into two main series (I, II), which included three clusters (I, II, and III) at a similarity level of 34.18%.

Series (I) included four taxa, namely *O. anthelmintica*, *O. pes-caprae*, *O. debilis*, and *O. latifolia*. The series is characterized by geophytes, stemless herbs with bulbous-rooted, basal rosette leaves, inflorescence on long, erect scape-like peduncle, and pollen subprolate with fusiform colpate. At a 50.36% similarity level, this series is subdivided into two distinct clusters based on the presence or absence of vertical rhizomes, bulb morphology, and the number of pollen apertures. The first cluster (I) represented *O. anthelmintica* and *O. pes-caprae* (Section: Cernuae), which are very close with a 72.91% similarity level. Morphologically, these two species are very similar, except for their leaf morphology, flower color, exine sculpture, and epidermal anticlinal wall. The second cluster (II) included *O.*

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debilis and *O. latifolia* (section: *Ionoxalis*) with a 53.38% similarity level, and are differentiated by the leaf shape, bulb, and foliar eidermal characteristics (Pl. 6 A, C).

Series (II) included a single cluster (III), represented by the two taxa; *O. corniculata* var. *corniculata* and *O. corniculata* var. *repens*, with a 74.02% similarity level. Morphologically, these two taxa are very close, except for their leaf color, fruit and seed characters, pollen apertures, and foliar epidermal walls (Pl.1A-C, 2A-C).

In general, the numerical analysis based on the combined pollen morphology and foliar epidermal characters, along with morphological traits, is consistent with Lourteig's (2000) taxonomic treatment concerning the sectional affinities of the studied taxa.

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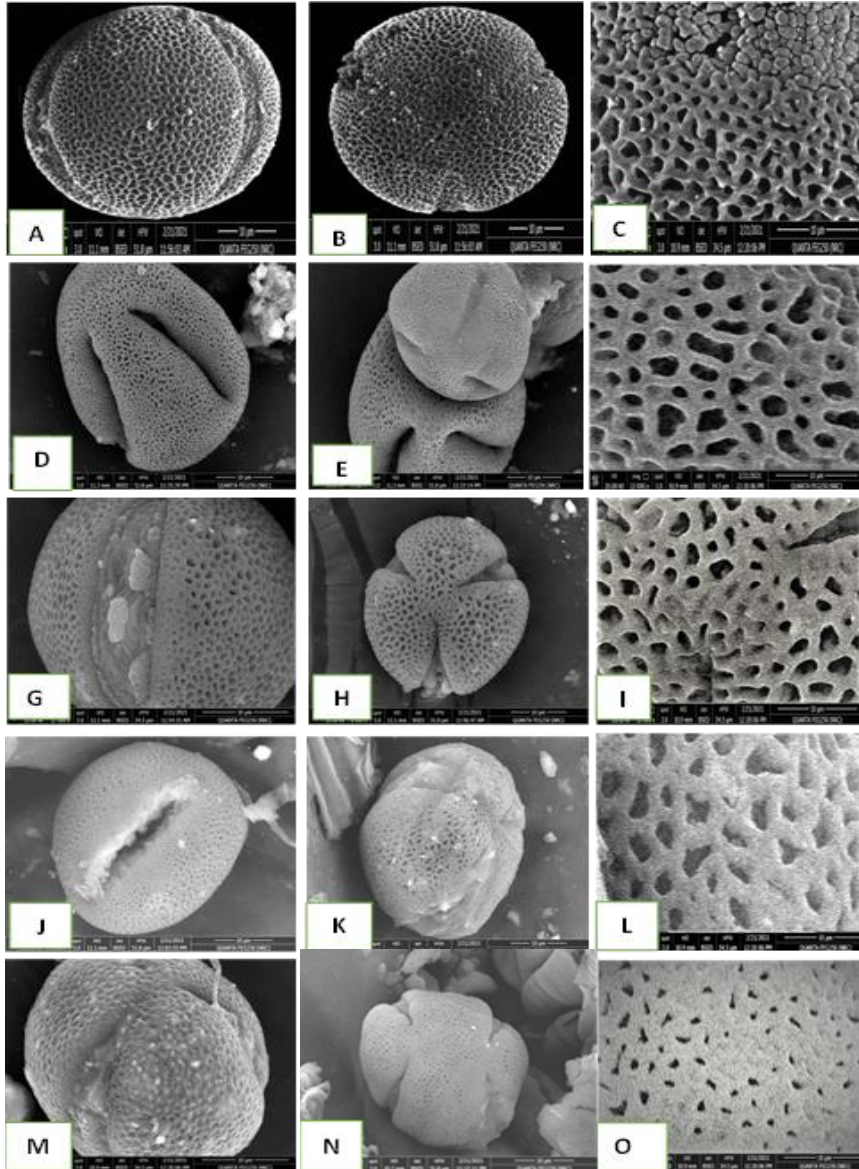


Plate (1): SEM micrographs of the *Oxalis* taxa pollen grains; (A-C) *O. corniculata* var. *corniculata*: A- Pollen in equatorial view, B- Pollen in polar view, C- Exine sculpture. (D-F) *O. corniculata* var. *repens*: D- Pollen in equatorial view, E- Pollen in polar view, F- Exine sculpture. (G-I) *O. pes-caprae*: G- Pollen in equatorial view, H- Pollen in polar view, I- Exine sculpture. (J-L) *O. anthelmintica*: J- Pollen in equatorial view, K- Pollen in polar view, L- Exine sculpture. (M-O) *O. debilis*: M- Pollen in equatorial view, N- Pollen in polar view, O- Exine sculpture.

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Plate (2): Pollen with tricolpate apertures; (A) *Oxalis corniculata* var. *corniculata*, (B) *O. pes-caprae* and (C) *O. anthelmintica*. (A. polar view; B & C. polar and equatorial view).

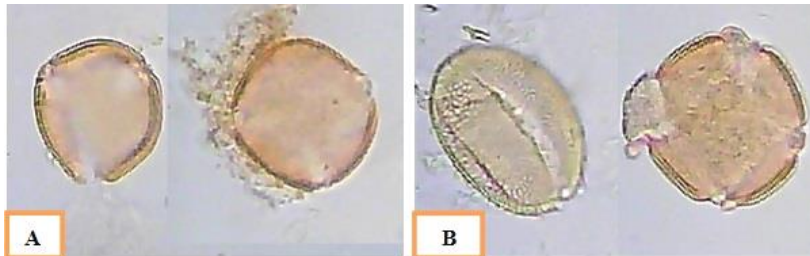


Plate (3): Pollen with tri- and tetra-colpate apertures; (A) *Oxalis corniculata* var. *repens*, (B) *O. latifolia*.

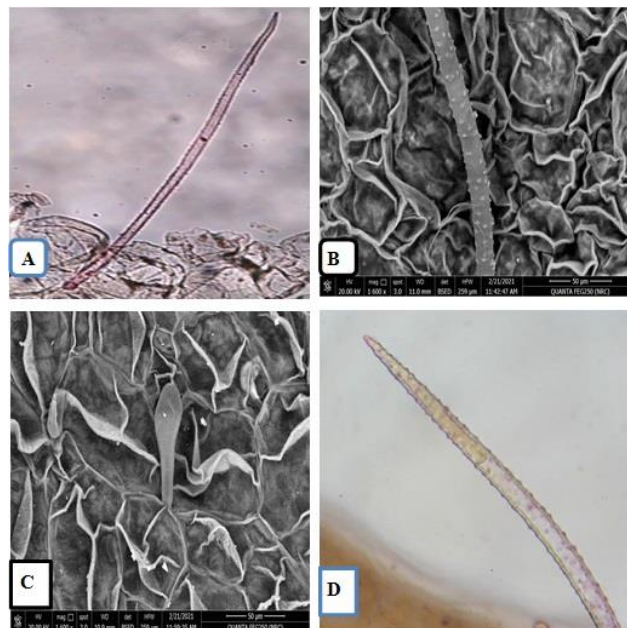


Plate (4): Types of foliar trichomes; (A) Long unicellular with tapering apex (LM, X40), (B) Long unicellular with papillate surface (SEM, X 1600), (C) Short, clavate unicellular (SEM, X 1600), (D) Multicellular uniseriate (LM, X40).

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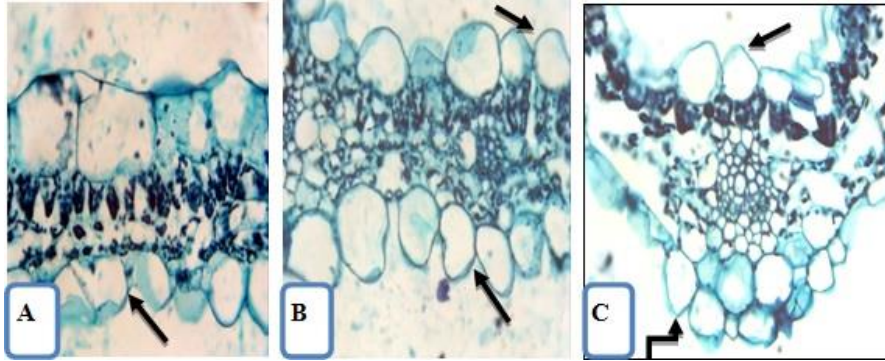


Plate (5): T.S. in lamina to show the periclinal wall of the epidermal cells; (A) Semi swollen on abaxial surface in *O. debilis*, (B & C) Swollen on both surfaces in *O. latifolia* and *O. corniculata* var. *repens* respectively (LM, X40).

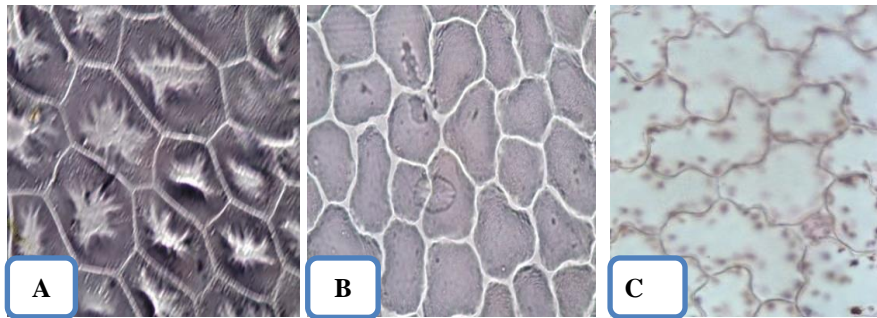


Plate (6): Lamina surface to show the anticlinal wall pattern and periclinal wall surface; (A) straight anticlinal wall with papillate surface in *O. latifolia*, (B) slightly curved anticlinal wall with glebulate surface in *O. pes-caprae*, (C) undulate anticlinal wall with smooth surface in *O. corniculata* var. *corniculata*. (LM, X 40).

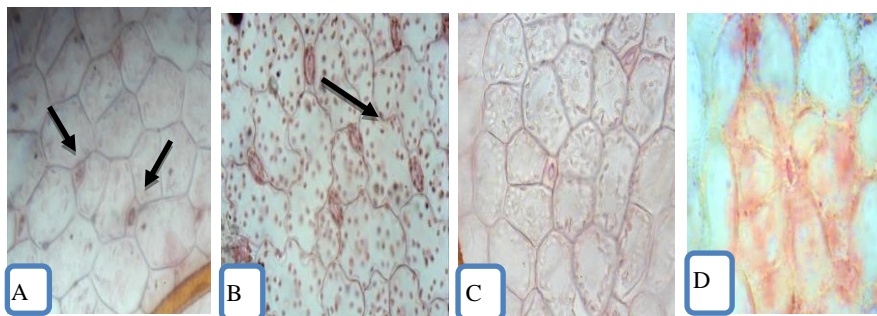


Plate (7): Lamina abaxial surface to show stomatal types; (A) Anisocytic and unusual 4-celled anisocytic stomata in *O. anthelmintica*, (B) anomocytic stomata in *O. debilis*, (C & D) actinocytic stomata in *O. corniculata* var. *repens* and *O. latifolia* respectively (LM, X40).

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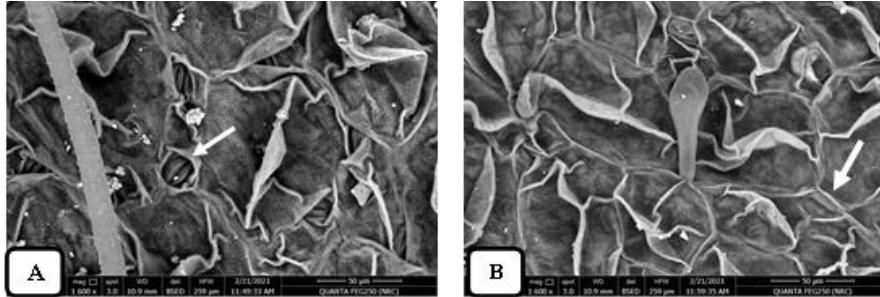


Plate (8): Lamina adaxial surface showing; (A) Ellipsoid and sunken stomata in *O. debilis*, (B) Oblong and slightly sunken stomata, unicellular clavate trichomes in *O. corniculata* var. *corniculata* (SEM, X1600).

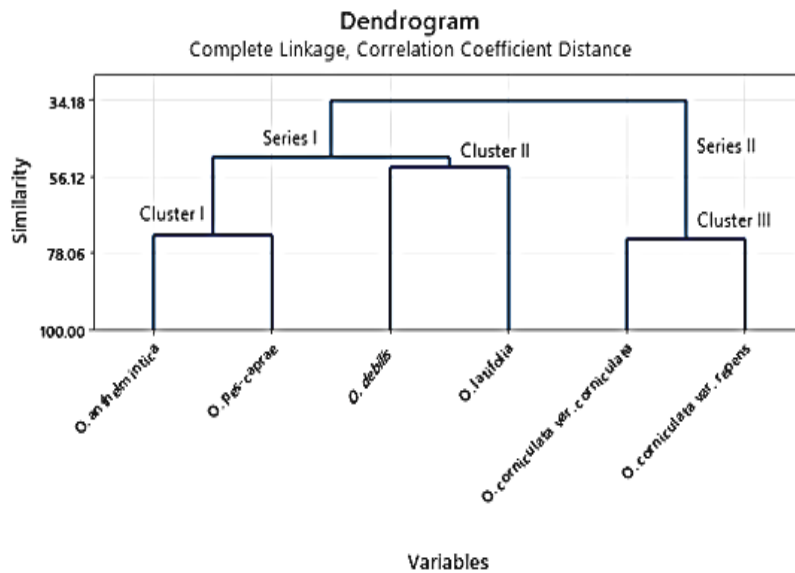


Diagram (1): Cluster dendrogram of the six taxonomic taxa based on a similarity matrix using a single linkage analysis software.

CONCLUSIONS

Despite that pollen morphology and foliar epidermal cell characters of the six taxa of Egyptian *Oxalis* described here show considerable agreement with previous characteristics found in other *Oxalis* taxa, their potential taxonomic significance may be limited. Nevertheless, when these data and morphological traits are combined, they become valuable for identifying and classifying the taxa at specific and sectional levels. Thus, this study can indeed serve as a reference for future studies of *Oxalis* taxa.

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CONFLICT OF INTEREST STATEMENT

"The authors declare no conflict of interest".

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Appendix (1): Data Matrix of the studied characters, character states and their taxonomic codes of studied taxa. [(1) *Oxalis anthelmintica*; (2) *O. pes-caprae*; (3) *O. corniculata* var. *corniculata*; (4) *O. corniculata* var. *repens*; (5) *O. debilis*; (6) *O. latifolia*]; (0 = absent; 1 = present)

Character	Sub-character	Character state	1	2	3	4	5	6
1- Life form		Epiphytes	0	0	1	1	0	0
		Geophytes	1	1	0	0	1	1
2- Duration		Perennial	1	1	0	0	1	1
		Annual or perennial	0	0	1	1	0	0
3- Bulb		Present	1	1	0	0	1	1
		Absent	0	0	1	1	0	0
4- Number of bulbs		Solitary	1	1	0	0	0	1
		Numerous	0	0	0	0	1	0
5- Bulb shape		Ovoid to pyriform	1	1	0	0	0	1
		Globose	0	0	0	0	1	1
6- Rhizome		Present	1	1	0	0	0	0
		Absent	0	0	1	1	1	1
7- Rhizome colour		Brownish	1	0	0	0	0	0
		Whitish	0	1	0	0	0	0
8- Root type		Fibrous	0	0	1	1	0	0
		Contractile	1	1	0	0	0	1
		Translucent tuberous	0	0	0	0	1	0
9- Stem presence		Present	0	0	1	1	0	0
		Absent	1	1	0	0	1	1
10- Stem surface		Hairy	0	0	1	1	0	0
		Glabrous	1	1	0	0	1	1
11- Leaves arrangement		Alternate	0	0	1	1	0	0
		Basal rosette	1	1	0	0	1	1
12- Petiole surface		Hairy	0	0	1	1	1	1
		Glabrous	1	1	0	0	0	0

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13- Petiole flexuous near the base	Present	0	0	0	0	1	0
	Absent	1	1	1	1	0	1
14- Stipule shape	Broadly oblong	0	0	1	1	0	0
	Ovate – oblong	1	1	1	0	0	0
	Elliptic	1	0	0	0	0	0
	Oblong-lanceolate	0	0	0	0	1	0
	Ovate or rectangular	0	0	0	0	0	1
15- Auriculate apex of stipules	Present	0	0	1	0	1	1
	Absent	1	1	0	1	0	0
16- Stipules with nerves	Present	0	0	0	0	1	1
	Absent	1	1	1	1	0	0
17- Leaflet shape	Obdeltoid	0	0	0	0	0	1
	Obcordate	0	1	1	1	1	0
	Subcircular to obovate	1	0	0	0	0	0
18- Leaflet's lobes symmetry	Symmetrical	1	0	1	1	1	1
	Asymmetrical	0	1	0	0	0	0
19- Leaflet dotting	Present	1	1	0	0	1	0
	Absent	0	0	1	1	0	1
20- Sinus width	Wide	0	1	0	1	0	1
	Narrow	1	0	1	0	1	0
21- Sinus depth	Deep	0	0	0	1	0	0
	Shallow	1	1	1	0	1	1
22- Peduncle surface	Hairy	1	0	1	1	1	1
	Glabrous	0	1	0	0	0	0
23- Bracts relative lengths	Equal bracts	1	1	0	0	1	1
	Unequal bracts	0	0	1	1	0	0
24- Bract apex with brownish calli	Present	0	1	0	0	1	0
	Absent	1	0	1	1	0	1
25- Bracteole presence	Present	0	0	1	0	1	0

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	Absent	1	1	0	1	0	1
26- Flower color	Yellow	0	1	1	1	0	0
	Pink to purple	1	0	0	0	1	1
	Oblong-lanceolate	0	1	1	1	0	0
27- Sepal shape	Lanceolate to ovate-lanceolate	1	0	0	0	1	1
	Present	1	1	0	0	1	1
28- Sepal's calli	Absent	0	0	1	1	0	0
	Spathulate	1	1	1	1	0	0
29- Petal shape	Obovate	0	0	0	0	1	1
	Present	0	1	0	0	0	0
30- Long stamens with appendage	Absent	1	0	1	1	1	1
	Hairy	1	0	0	0	1	1
31-Long stamens surface	Glabrous	0	1	1	1	0	0
	Capitate	1	1	1	1	0	1
32-Shape of stigma	Laciniate	0	0	0	0	1	0
	Prolate-spheroidal	0	0	1	0	0	0
	Subprolate	1	1	0	0	1	1
33- Pollen shape in equatorial view	Oblate-spheroidal	0	0	0	1	0	0
	Tri-zonocolpate	1	1	1	0	0	0
	Tri- or tetra-zonocolpate	0	0	0	1	1	1
34- Pollen aperture type	Elliptic	0	0	1	0	0	0
	Fusiform	0	1	0	0	1	1
	Oblong	0	0	0	1	0	0
	Fusiform or oblong	1	0	0	0	0	0
35- Colpus shape	Densely granulated to rugulate	0	0	1	0	0	0
	With congregated granules distributed irregularly	0	1	0	0	0	0
	Scabrous to warty	0	0	0	1	0	0
	Warty	1	0	0	0	1	1

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37- Exine sculpture	Microreticulate	1	0	1	1	0	1
	Reticulate, lumina with single baculum	0	1	0	0	0	0
	Perforate or microreticulate	0	0	0	0	1	0
38- P/E ratio	> 1	1	1	1	0	1	1
	< 1	0	0	0	1	0	0
39- Epidermal anticlinal wall	Undulate	0	1	1	0	1	0
	Straight	1	0	0	1	0	1
40- Epidermal anticlinal wall thickness	Thick	0	0	0	0	0	1
	Thin	1	1	1	1	1	0
41- Adaxial epidermal periclinal wall	Swollen	0	0	0	1	0	0
	Semiswollen	1	1	1	0	1	0
	Papillate	0	0	0	0	0	1
42- Abaxial epidermal periclinal wall	Swollen	0	1	0	1	0	1
	Semiswollen	1	0	1	0	1	0
43- Epidermal cell surface sculpture	Reticulate-foveolate	0	0	1	0	0	1
	Smooth	0	0	0	1	1	0
	Glebulate	1	1	0	0	0	0
44- Epicuticular wax on epidermis	Present	0	1	1	1	1	1
	Absent	1	0	0	0	0	0
45- Stomatal position	Hypostomatic	1	1	0	0	0	1
	Amphistomatic	0	0	1	1	1	0
46- Stomatal types	Anomocytic	0	0	1	1	1	0
	Actinocytic	0	0	0	1	0	1
	Anisocytic	1	1	1	1	1	1
	Unusual 4-celled anisocytic	1	1	1	1	1	1
47- Stomatal shape	Oblong	1	0	1	0	0	0
	Silt	0	0	0	1	0	0
	Elliptic	0	1	0	0	1	1
48- Trichome type	Unicellular with tapering apex	0	1	1	1	1	0
	Multicellular	0	0	0	0	1	0
	Clavate unicellular	1	0	0	0	1	1

دراسة حبوب اللقاح والتشريح السطحي لأوراق جنس *Oxalis* Linnaeus, 1753
عائلة Oxalidaceae ، رتبة Oxalidales) في مصر

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ص ب 12613، مصر.
** قسم الكيمياء وتصنيف النباتات/المركز القومي للبحوث، الدقي، الجيزة
ص ب 12622، مصر.

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الخلاصة

باستخدام الميكروسكوب الضوئي والميكروسكوب الإلكتروني الماسح (SEM)، دُرست حبوب اللقاح و مورفولوجيا البشرة الخارجية للأوراق لأربعة أنواع وصنيفين من الأوكساليس المصرية *Oxalis* Linnaeus, 1753 التابعة لثلاثة أقسام في لجنيس *Oxalis* Linnaeus, 1753، كان الهدف من الدراسة تحديد أهمية خصائص حبوب اللقاح و البشرة الخارجية للأوراق كأدلة تصنيفية. أظهرت الدراسة الحالية أن حبوب اللقاح في جميع الأنواع المدروسة هي أحادية ومتماثلة، و من الحجم المتوسط، و يتراوح الشكل من تحت الكروي إلى تحت البيضيوي. كما كانت فتحات حبوب اللقاح ثلاثية الثقوب مع أغشية مزخرفة (بنمط مموج، أو نتوءات متجمعة). كان الجدار الخارجي لحبوب اللقاح شبه مغطى، مع تزخرف ميكرو-شبيكي إلى شبكي، و مثقب في Kunth, 1822 *O. debilis*. كما كشفت الدراسة عن وجود أربعة أنواع من الثغور: actinocytic, anisocytic, anomocytic and an unusual 4-celled anisocytic.

كانت خلايا البشرة العليا والسفلية غير منتظمة أو مضلعة الشكل، مع جدران متموجة أو مستقيمة، و جدران داخلية شبه منتفخة إلى منتفخة مع وجود طبقة شمعية خارجية منتشرة. لوحظ نوعان من الشعيرات غير الغدية وأحادية الخلية: شعر

Palynological and foliar epidermal studies

قصير بشكل مدبب وشعر طويل ذو طرف مدبب مع سطح محبب. ناقشت الدراسة أيضا النتائج العددية استنادًا إلى الخصائص المظهرية المجمعة وخصائص حبوب اللقاح والبشرة الخارجية للأوراق. بالإضافة إلى ذلك، تم تصميم مفتاح اصطناعي لتصنيف الأنواع المدروسة. تعتبر هذه الدراسة أول تقرير يتعامل مع الخصائص التشريحية وحبوب اللقاح لأنواع هذا الجنس في مصر.