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RESEARCH ARTICLE

Taxonomic evaluation of Aizoaceae in western and southwestern Saudi Arabia: Insights into morphology, anatomy, and palynology with records of two new species

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Abstract

Aizoaceae is a leaf-succulent family represented by 132 genera and approximately 1,900 species, originating from South Africa and known as the ice family. This research investigates selected genera of Aizoaceae found in Saudi Arabia, focusing on their morphology, anatomy, and palynology. Specimens were collected from various regions in western and southwestern Saudi Arabia, representing different ecological conditions. The study involved field observations, laboratory analysis, and numerical evaluation using Principal Coordinates Analysis (PCoA) through the Multivariate Statistical Package (MVSP). Results revealed the identification of five genera from the western and southwestern regions, including the new record species *Malephora crocea* and *Mesembryanthemum cordifolium*. Both species were included under the subfamily Mesembryanthemoidea, while *Sesuvium verrucosum* and *Zaleya pentandra* were classified under Sesuvioideae. Morphological, anatomical, and palynological data were crucial in distinguishing these taxa, demonstrating the need for using diverse taxonomic approaches.

Keywords: Taxonomy, *Sesuvium*, Mesembryanthemum, Malephora, Zaleya, New Species, New record

Introduction

Flora of Saudi Arabia has about 2282 species in 855 genera containing 97 (4.25%) trees, 565 (24.73%) shrubs and about 1620 (71.02%) herbs (Chaudary and Al Jowaid, 1999). In Saudi Arabia, approximately 290 species belonging to 23 families are generally recognised as succulent (Al Farhan and Jackson, 2002). These succulents are found in semi-arid and arid areas of Saudi Arabia. They store water in stems, roots and leaves (Al Turki, et al. 2000). Succulents are found mostly in the eastern slopes of the Southern Hijaz Mountains. Al Fawaz, 2006 mentioned that families including Aizoaceae, Asclepiadaceae, Aloaceae, Chenopodiaceae, Cactaceae, Zygophyllaceae, Euphorbiaceae, Dracaenaceae, and Chenopodiaceae represent succulents in Saudi Arabia. Several succulents have high ornamental value, while others are economically important to the country's culture and local fibre industry in Saudi Arabia.

The family Aizoaceae, commonly known as ice plants, is characterised by leaf-succulent members distributed across tropical regions, particularly in Africa, the Arabian Peninsula, and the Americas (Balakrishnan, 2012). In Saudi Arabia, Aizoaceae can be found

in the eastern parts of the Southern Hijaz Mountains and along the Arabian Gulf. They are also spotted along the coast of the Red Sea. In the Hijaz Mountains, they generally grow on the slopes and are also found in the central regions of Saudi Arabia. Aizoaceae is represented in Saudi Arabia by 12 genera containing 20 species (Migahid, 1996, Collenette, 1999, Chaudhary, 2001). According to Newton, 2004, Aizoaceae is primarily known in Saudi Arabia by the genera *Aizoon, Delosperma, Sesuvium, Mesembryanthemum, Trianthema, Zelaya*, and others.

Although Aizoaceae holds ecological importance, there is a lack of thorough taxonomic studies on this family in Saudi Arabia. This research seeks to address this gap by analyzing the morphological, anatomical, and palynological traits of Aizoaceae taxa gathered from various ecological zones in western and southwestern Saudi Arabia. The main objective is to pinpoint the distinguishing characteristics of these genera and document new species to enhance knowledge of the family's diversity in the area.

Materials and Methods

Plant specimens were gathered from different locations in western and southwestern Saudi Arabia, such as Jeddah, Makkah Al Mukarramah, Al-Jamoum, Al-Taif, Allieth, and Bani Malik. These areas were chosen to encompass a diverse array of ecological zones. Both fresh and herbarium specimens were used for morphological, anatomical, and palynological studies. Herbarium specimens were obtained from King Abdulaziz University Herbarium (KAUH) and King Saud University Herbarium in Riyadh (KSUH). All specimens, whether they were collected from the field or borrowed from herbaria, were identified and described according to literature and by the authors (Tabs. 1,2 and Figs. 1-3).

Table 1. Locality of specimens.

Plant specimens	Fresh	Herbal specimen	Location
Malephora crocea (Jacq.) Schwantes	✓	-	Taif (Alhada)
Sesuvium verrucosum Raf	✓	✓	Makkah, Aljamoum, Allith Road, Buraida and Khafji
Mesembryanthum cordifolium L.	✓	-	Bni Malik
Aizoon canariense L.	✓	✓	Taif (Alshifa and Wdi gazal)and Bni Malik
Zaleya pentandra (L.) C. Jeffrey	✓	✓	Bader-Madina Road and Allith

Table 2. List of fresh and herbarium specimens.

Species	Date of collection	Voucher Specimens Collector (No)	Location	Herbarium
Aizoon canarensi	12/6/2017	Alotaibi and Altoukhy (8)	Taif-Alshifa	Fresh
Aizoon canarensi	12/6/2017	Alotaibi and Altoukhy (9)	Taif-Wadi Gzal	Fresh
Aizoon canarensi	7/4/2018	Alotaibi (7)	Bni Malik	Fresh
Sesuvium verrucosum	15/7/2017	Alotaibi and Altoukhy (3)	Makkah - Aljamoum	Fresh
Sesuvium verrucosum	25/7/2017	Alotaibi and Altoukhy (4)	Allith Road	Fresh
Malephora crocea	12/6/2017	Alotaibi and Altoukhy (1)	Taif - Alhada	Fresh
Malephora crocea	12/6/2017	Alotaibi & Altoukhy (2)	Taif - Alhada	Fresh
Mesembryanthum cordifolium	7/4/2018	Alotaibi (5)	Bni Malik	Fresh
Mesembryanthum cordifolium	7/4/2018	Alotaibi (6)	Bni Malik	Fresh
Zaleya pentandra	29/3/1978	Baeshin and Batanouny	Bader- Madina Road	King Abdulaziz University
Zaleya pentandra	8/9/1982	-	Allith	King Abdulaziz University
Aizoon canarensis	3/5/1995	-	Bni Malik	King Abdulaziz University
Sesuvium verrucosum	22/3/1978	Chaudhary and Howaisshell (11321)	Buraida	King Saud University
Sesuvium verrucosum	4/9/1981	Migahid and El-Sheiki (551)	Khafji	King Saud University

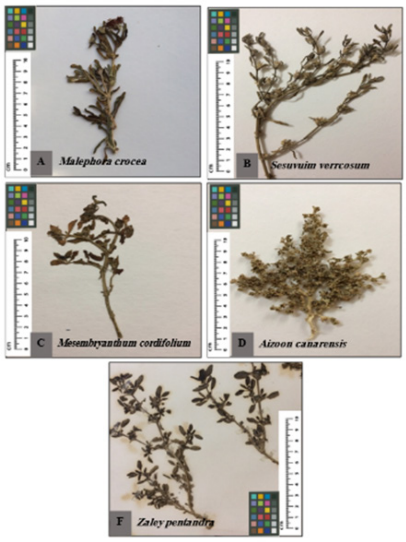


Figure 1. Specimens of Aizoaceae from filed (A) *Malephora crocea* (B) *Sesuvium verrucosum* (C) *Mesembryanthum cordifolium*, (D) *Aizoon canarensis* (f) *Zaleya pentandra*. (Pictures were taken by Alotaibi with a Samsung phone Galaxy s7 Edge camera).

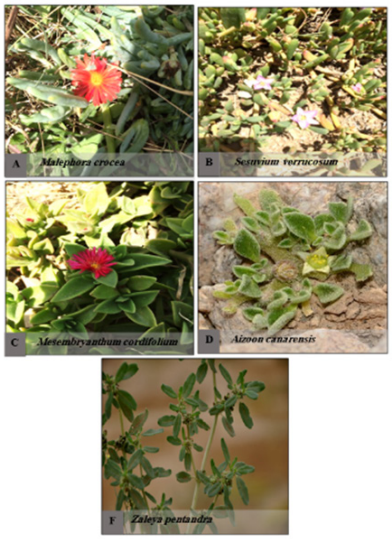


Figure 2. Samples studied collected by author Aizoaceae (A) *Malephora crocea* (B) Sesuvium errucosum (C) *Mesembryanthum cordifolium*, (D) *Aizoon canarensis* (F) *Zaleya pentandra*.

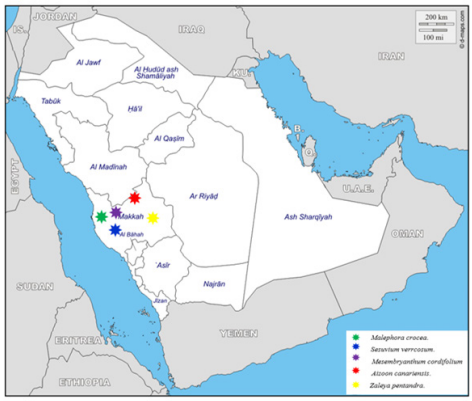


Figure 3. Distribution map of Aizoaceae samples studied and collected by the authors in Saudi Arabia.

For morphological analysis, both fresh and dried plant materials were used to examine the characteristics of stems, leaves, flowers, and fruits *via* a stereomicroscope (Am Scope 90-265 VAC). Anatomical studies were conducted on samples preserved in 70%

ethanol, and sections were analysed using a light microscope, NIKON ECLIPSE 50i. Palynological studies focused on flower buds, which were collected and preserved for further pollen analysis. Pollen grains were prepared for Light Microscopy (LM) according to the standard methods described by Erdtman, 1952 and 1969 using the acetolysis method. Additionally, for Scanning Electron Microscopy (SEM), crushed anthers were mounted on aluminium stubs and gold-coated with an EMITECH K550X before being examined in a FEI Quanta 250.

Morphological, anatomical, and palynological characteristics were recorded for each species. Measurements were taken using a stereomicroscope, and distinctive vegetative and reproductive traits were documented. Forty-seven characters, comprising 39 morphological, three anatomical, and five palynological features, were employed to conduct a phenetic analysis *via* Principal Coordinates Analysis (PCoA). Gower's general similarity coefficient was utilised to assess the similarities and differences among taxa using the MVSP software.

Results

Morphological observations

Morphological examination revealed significant differences among the five studied taxa: *Malephora crocea* (Jacq.) Schwantes, *Mesembryanthemum cordifolium* L., *Sesuvium verrucosum* Raf., *Aizoon canariense* L., and *Zaleya pentandra* (L.) C. Jeffrey. *Malephora crocea* (Jacq.) Schwantes and *Mesembryanthemum cordifolium* L. fil. were classified as annuals, while the others were perennial. The growth habit ranged from prostrate shrubs (*Malephora crocea*, *Mesembryanthemum cordifolium*, *Sesuvium verrucosum*, and *Aizoon canariensis*) to erect forms (*Zaleya pentandra*) (Tab. 3 and Fig. 4).

Table 3. Morphological characters and measurements of the stem in the studied taxa of Aizoacea.

Character/Taxa	Stem		Stem surface				Stem color	Size (cm) of Stem	
	Stem shape	Type of Stem	Hair		Shining of stem surface	Type of Stem Surface		Length	Width
			Existence Hair in stem surface	Size (CM)					
Malephora crocea	Prostrate	Succulent	-	-	Glossy	Smooth	Green	20.6	1.5
Sesuvium verrucosum	Prostrate	Sub succulent	-	-	matte	Smooth	Yellow	24	1.3
Mesembryanthum cordifolium	Prostrate	Succulent	-	-	Glossy	Bladder cell	Green	19.7	1.4
Aizoon canariensis	Prostrate	Sub succulent	+	0.1 cm	Matte	Hairy	Yellow	1.6	1.4
Zaleya pentandra	Erect	Sub succulent	-	-	Matte	Smooth	Yellow	24.3	1.5

Note: (-) absent; (+) present.



Figure 4. Stems shapes (A.B.C.D) *Malephora crocea*, *Sesuvium verrucosum*, *Mesembryanthum cordifolium* and *Aizoon canariensis* are prostrate; (F) *Zaleya pentandra* is erect. (Pictures were taken by Alotaibi with a Samsung phone Galaxy s7 Edge camera).

Leaf morphology varied significantly among the taxa (Tabs. 4,5 and Fig.5). *Malephora crocea* exhibited cylindrical leaves with a tapering apex, measuring an average length of 3.2 cm and a width of 0.5 cm. *Sesuvium verrucosum* had triquetrous leaves with an obtuse apex, averaging 4.1 cm in length and 0.7 cm in width. *Mesembryanthemum cordifolium* displayed bladder cells in the leaf epidermis, which were absent in the other taxa. *Aizoon canariense* presented hairy, sub-succulent leaves, whilst *Zaleya pentandra* displayed oblong leaves with a smooth surface. The leaf surface varied from glossy in *Malephora crocea* to matte in *Sesuvium verrucosum*.

Table 4. Morphological characters of leaf in studied taxa of Aizoaceae.

			Adaxial leaf			Abaxial leaf							
	Leaf Shape	Type of leaf	Surface of leaf Adaxial	Shining of leaf Adaxial	Hair in leaf Adaxial	Surface of leaf Abaxial	Shining of leaf Abaxial	hair in leaf Abaxial	Apex of leaf	Mid rib Adaxial (by eye)	Mid-rib Abax-ial (by eye)	Base of leaf	Petiole
Malephora crocea	Cylindrical (Terete)	Succulent	Smooth	Glossy	-	Smooth	Glossy	-	Tapering	-	-	Cylindrical	Sessile
Sesuvium verrucosum	Triquetrous	Succulent	Smooth	Matte	-	Smooth	Matte	-	Obtuse	-	-	Attenuate	Petiolate
Mesembryanthum cordifolium	Heart	Succulent	Bladder cell	Glossy	-	Bladder cell	Glossy	-	Acute	-	+	Attenuate	Petiolate
Aizoon canariensis	Obovate	Sub succulent	Hairy	Matte	+	Hairy	Matte	+	Obtuse	-	+	Decurent	Petiolate
Zaleya pentandra	oblanceolate	Sub succulent	Smooth	Glossy	-	Smooth	Glossy	-	Obtuse	+	+	Attenuate	Petiolate

Note: (-) absent; (+) present.

Table 5. Measurements of leaves for the studied taxa of Aizoaceae.

	Mature leaf (cm) Ave.		Small Leaf (cm) Ave.	
	Length	Width	Length	Width
Malephora crocea	5.73	0.71	1.42	0.4
Sesuvium verrucosum	1.27	0.36	1.23	0.31
Mesembryanthum cordifolium	2.5	1.23	1.27	1.1
Aizoon canariensis	0.93	0.32	0.25	0.16
Zaleya pentandra	1.21	0.31	1.2	0.3



Figure 5. Different shapes and surfaces of leaves in Aizoaceae (A) Cylindrical succulent leaf in *Malephora crocea*, (B) *Sesuvium verrucosum* triquetrous smooth, (C) *Mesembryanthum cordifolium* heart, surface bladder cell, (D) *Aizoon canariensis* Obovate, hairy and (F) *Zaleya pentandra* Oblanceolate, smooth. (Picture were taken by Alotaibi with Samsung phone Galaxy s7 Edge camera).

The flowers of *Malephora crocea* and *Mesembryanthemum cordifolium* were lirulate and pedicellate, with *Malephora crocea* featuring red flowers measuring 2.5 cm in diameter, whereas *Mesembryanthemum cordifolium* bore pink flowers measuring 3.0 cm. In contrast, *Sesuvium verrucosum*, *Zaleya pentandra*, and *Aizoon canariense* produced sessile flowers. The number and characteristics of sepals varied among the taxa, with *Malephora crocea* possessing five green sepaloid sepals ranging from 0.7 to 1 cm in length (Tabs. 6,7 and Fig. 6).

Table 6. Non-fundamental parts characteristic of the flower in the studied taxa of Aizoaceae.

	Flower							
	Corolla					Calyx		
	Colour of petals	Flower Pedicsel	Petals No	Corolla Shape	Sepals No.	Hair in Calyx	Calyx Surface	Type of Calyx
Malephora crocea	Red	Pedicellate	Numerous	Lirulate	5-polysepalous	-	Smooth-glossy	Succulent
Sesuvium verrucosum	Purple	Sessile	5	Salver	5-syncarpous	-	Smooth-matte	Sub succulent
Mesembryanthum cordifolium	Pink	Pedicellate	Numerous	Lirulate	5-polysepalous	-	Bladder cell-glossy	Succulent
Aizoon canariensis	Yellow	Sessile	5	Salver	5-syncarpous	+	Hairy-matte	Sub succulent
Zaleya pentandra	Purple	Sessile	5	Salver	5-syncarpous	-	Smooth-glossy	Sub succulent

Note: (-) absent; (+) present.

Table 7. Non-fundamental parts characteristic of the flower in the studied taxa of Aizoaceae.

	Carpeles		Stigma	Ovary	
	Type and number of carpels	Fusion of Carpels	Type of stigma	Ovary Type	placentation
Malephora crocea	5 (pentacarpellary)	Syncarpous	Dumb-bell	epigynous	Superfical
Sesuvium verrucosum	3 (Tricarpellary)	Syncarpous	Discod	perigynous	Axille
Mesembryanthum cordifolium	4 (Tetracarpellary)	Syncarpous	Discod	epigynous	Axille
Aizoon canariensis	3 (Tricarpellary)	Syncarpous	Discod	perigynous	Axille
Zaleya pentandra	3 (Tricarpellary)	Syncarpous	Discod	perigynous	Axille



Figure 6. Different shape, Colour and pedicellate of flowers in Aizoaceae (A) and (C) *Malephora crocea* and *Mesembryanthum cordifolium* shape lirulate; (B.D and F) *Sesuvium verrucosum*, *Aizoon canariensis*, *Zaleya pentandra* shape is salver. (Picture were taken by Alotaibi with Samsung phone Galaxy s7 Edge camera).

Anatomical features

Anatomical analysis revealed the presence of anomalous secondary growth in the stems of all studied species, characterised by successive cambia ranging from five to seven rings and a ring of vascular bundles (Fig. 7). The stem of *Malephora crocea* exhibited large bladder cells in the epidermis, measuring up to 90 µm in diameter, which were also observed in *Mesembryanthemum cordifolium* and *Aizoon canariense* (Fig. 8). In contrast, *Sesuvium verrucosum* and *Zaleya pentandra* lacked these specialised cells. A similar phenomenon is also observed in the leaves (Fig. 9). Calcium oxalate crystals, in the form of raphides, were found in the parenchymatous tissue of *Malephora crocea*, *Mesembryanthemum cordifolium*, and *Aizoon canariense*, contributing to their distinguishing features (Fig. 10).

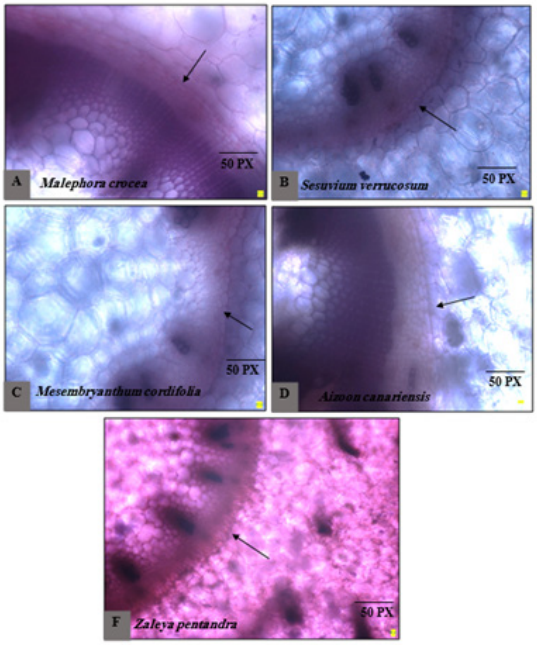


Figure 7. LM photograph cross section in stem at [mag 50×] shows (A.B.C.D.F) have successive cambia which gives rise to a ring of vascular bundles this start of normal secondary growth in *Malephora crocea*, *Sesuvium verrucosum*, *Mesembryanthum cordifolium*, *Aizoon canariensis* and *Zaleya pentandra*.

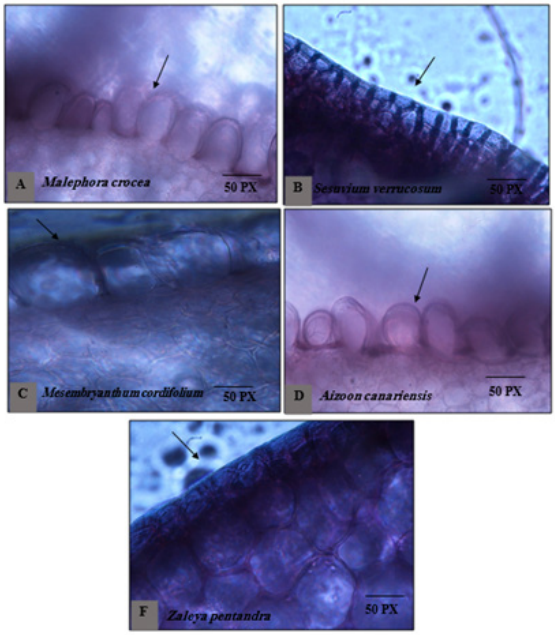


Figure 7. LM photograph cross section in stem at [mag 50×] shows (A.B.C.D.F) have successive cambia which gives rise to a ring of vascular bundles this start of normal secondary growth in *Malephora crocea*, *Sesuvium verrucosum*, *Mesembryanthum cordifolium*, *Aizoon canariensis* and *Zaleya pentandra*.

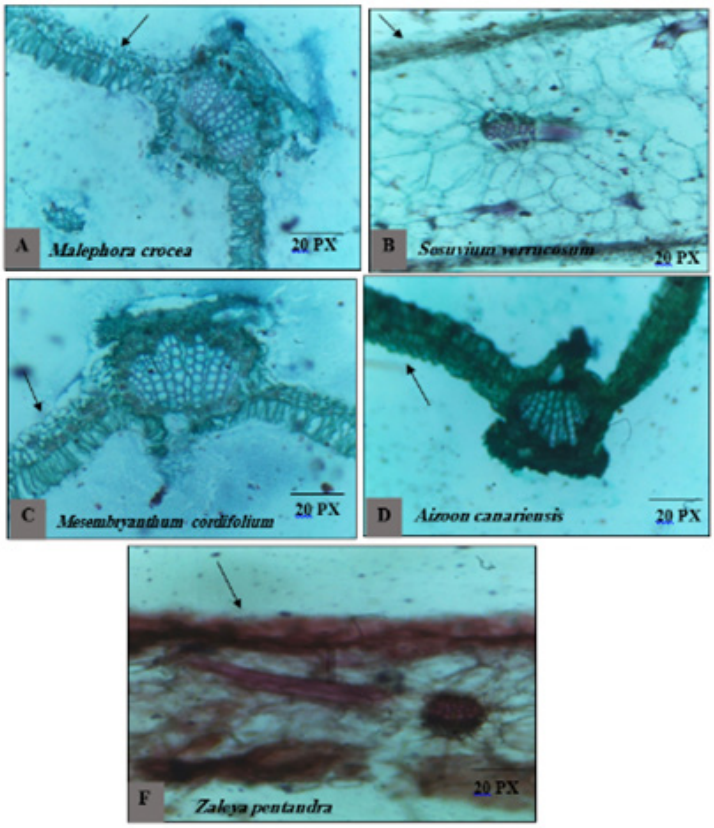


Figure 8. Light Microscopic (LM) photograph cross-section in the stem, the image at [mag50×] shows epidermal bladder cells in *Malephora crocea*, *Mesembryanthum cordifolium* and *Aizoon canariensis* (A.C.D). While *Sesuvium verrucosum* and *Zaleya pentandra* (B.F) do not have bladder cells.

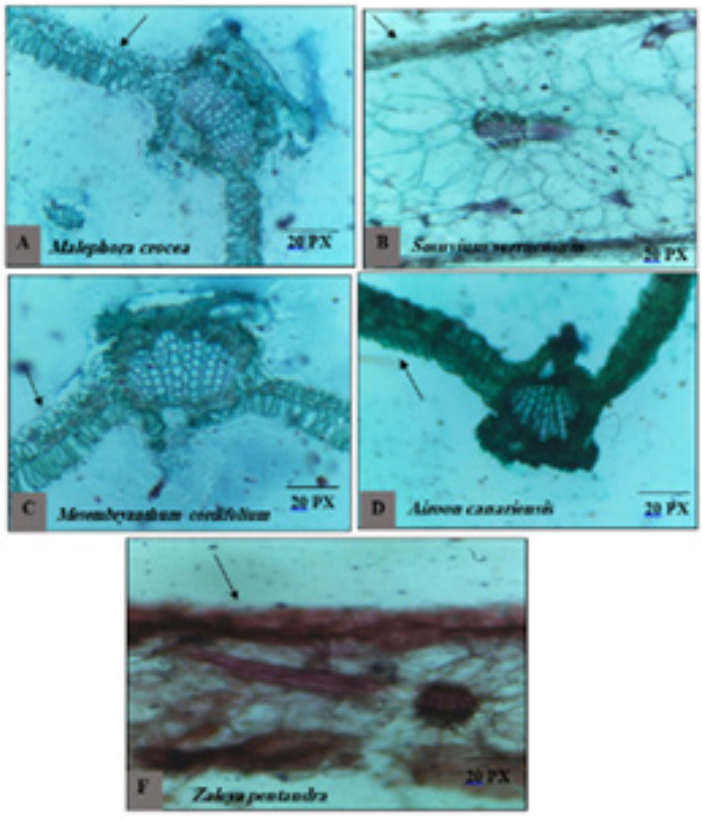


Figure 9. LM photograph cross-section in leaf image at [mag20×] shows bladder cells in *Malephora crocea*, *Mesembryanthum cordifolium* and *Aizoon canariensis* (A.C.D), *Sesuvium verrucosum* and *Zaleya pentandra* do not have it (B.F).

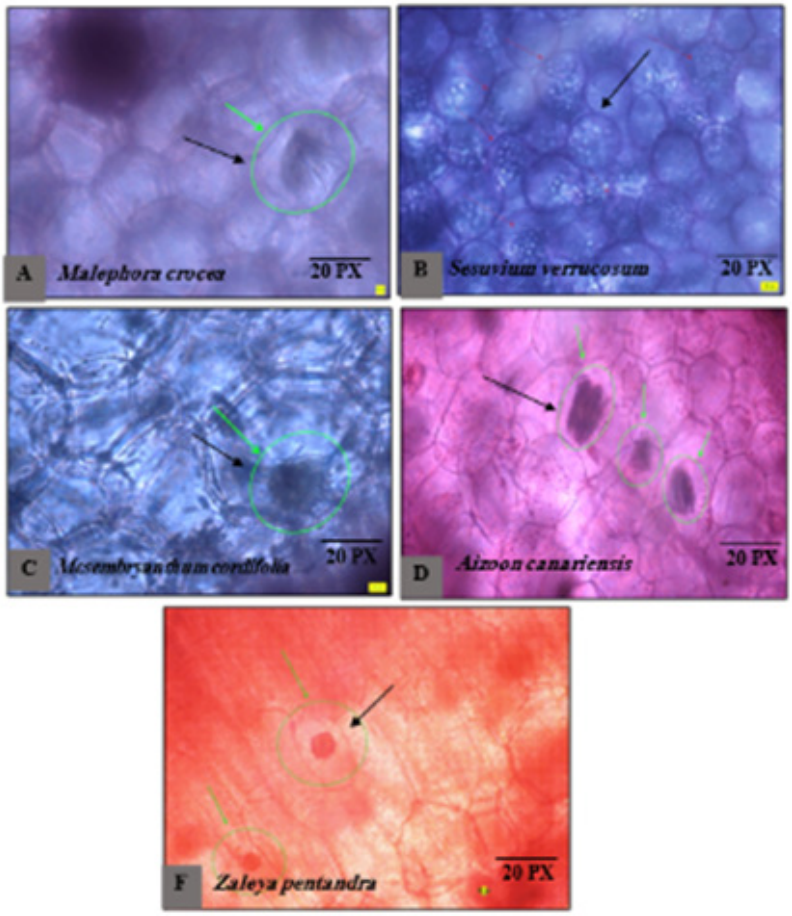


Figure 10. LM photograph cross-section in stem image at [mag20×] shows raphioles calcium oxalate crystals of needle type in *Malephora crocea*, *Mesembryanthum cordifolium* and *Aizoon canariensis* (A.C.D); sand crystal type in *Sesuvium verrucosum* (B); stellate druses type in *Zaleya pentandra* (F).

Palynological analysis

Palynological studies revealed notable variations in pollen grain size, colpus length, and exine ornamentation among the five taxa (Tabs. 8, Figs 11-15). *Malephora crocea* displayed dicolpate pollen with reticulate exine ornamentation, wherein the pollen grains measured 26.5 µm in polar axis length and 18.2 µm in equatorial diameter. *Sesuvium verrucosum* exhibited monocolpate pollen with granulate ornamentation, with an average polar axis length of 23.1 µm and an equatorial diameter of 22.5 µm. *Mesembryanthemum cordifolium* featured aperture pollen, characterised by echinate ornamentation, with a polar axis length of 28.0 µm. *Aizoon canariense* and *Zaleya pentandra* presented tricolpate pollen, with *Aizoon canariense* demonstrating the largest pollen size, measuring 30.0 µm in polar axis and 20.5 µm in equatorial diameter. The colpus length varied considerably, with *Malephora crocea* displaying the shortest colpus at 15.8 µm, whereas *Sesuvium verrucosum* exhibited the longest at 18.2 µm. The exine ornamentation patterns were diverse, with *Malephora crocea* showing reticulate ornamentation, while *Sesuvium verrucosum*, *Aizoon canariense*, and *Zaleya pentandra* featured granulate ornamentation. Unique among them, *Mesembryanthemum cordifolium* showcased its echinate ornamentation.

Table 8. Pollen morphology of the studied taxa of Aizoaceae in Saudi Arabia.

Taxa	Pollen shape	Polar axes (P) µm	Equatorial diameter (E) µm	P/E Ratio µm	Length of colpi µm	Pollen type	Exine ornamenation
Malephora crocea	prolate	20.1	14.6	1.4	15.8	dicolpate	reticulate
Sesuvium verrucosum	prolate	25.75	17.1	1.5	18.2	monocolpate	granulose
Mesembryanthum cordifolia	oblate	23.02	17.23	1.3	-	inperturate	echinate
Aizoon canariensis	prolate	22.15	13.2	1.6	17.51	tricolpate	granulose
Zaleya pentandra	Prolate	23.1	22.5	1.02	16.4	tricolpate	granulose

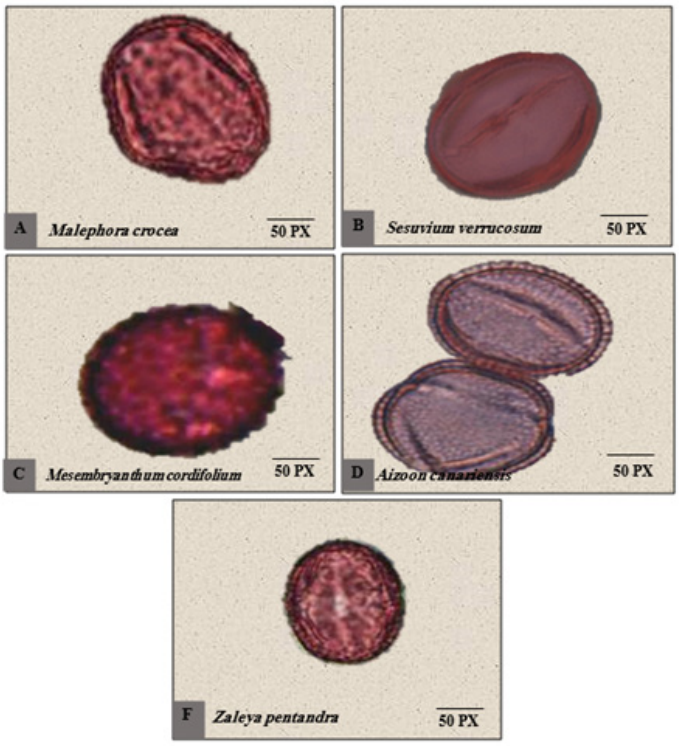


Figure 11. LM photograph polar view shows shape of pollen grains type "prolate" in *Malephora crocea*, *Sesuvium verrucosum*, *Aizoon canariensis* and *Zaleya pentandra* (A.B.D.F); type "oblate"in *Mesembryanthum cordifolium* (C).

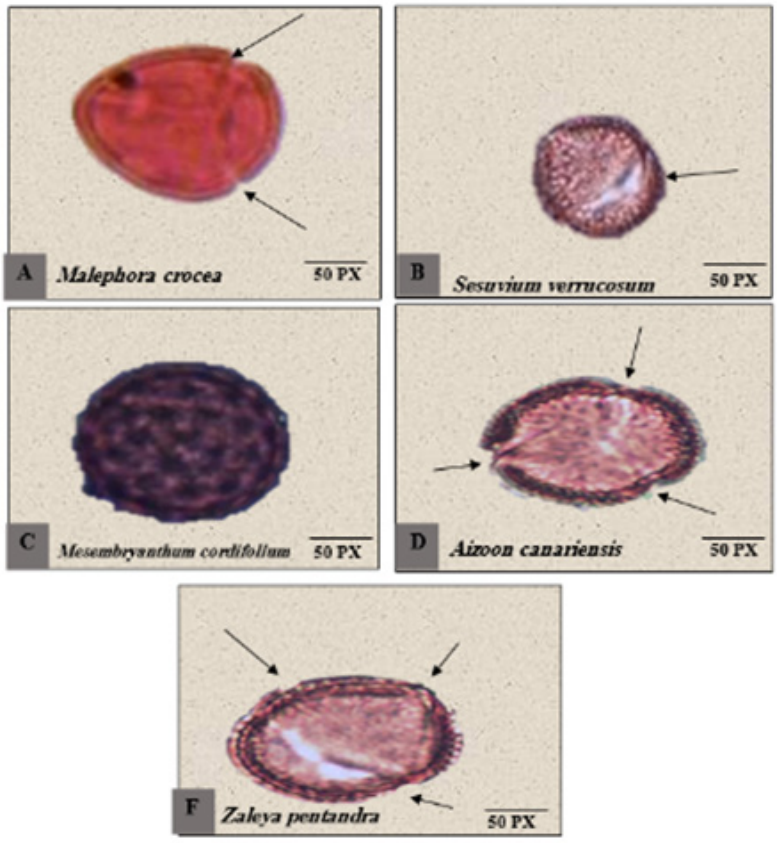


Figure 12. LM photograph equatorial and polar view at [mag 8000×] shows number and shape of aperture of pollen grain (A). Two aperture shape "Dicolpate" in *Malephora crocea* and *Zaleya pentandra*, (B). One aperture shape"monocolpate" in *Sesuvium verrucosum*, (C). Aperture shape "Inaperturate"in *Mesembryanthum cordifoliaum* (D.F). Three aperture shape "Tricolpate"in *Aizoon canarensis* and *Zaleya pentandra*.

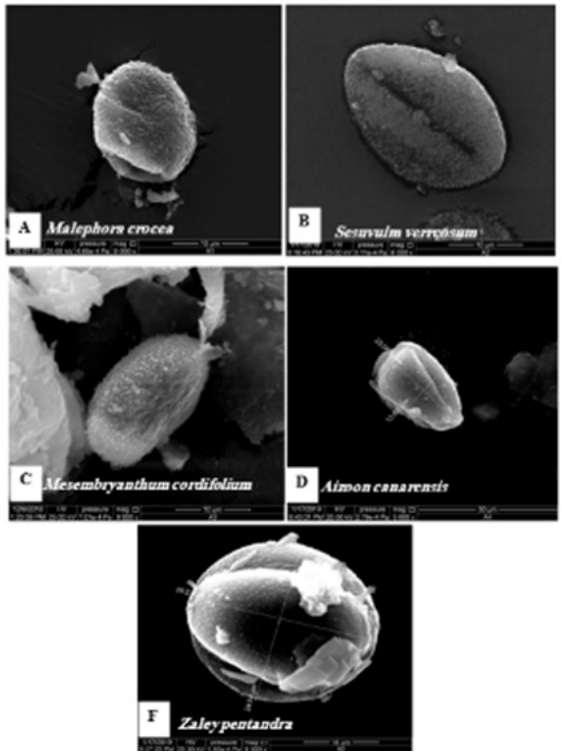


Figure 13. SEM micrograph polar view at [mag 8000×] shows shape of pollen grain Shape type "prolate" in *Malephora crocea*, *Sesuvium verrucosum*, *Aizoon canariensis* and *Zaleya pentandra* (A.B.D.F). Shape type "oblate" in *Mesembryanthum cordifolium* (C).

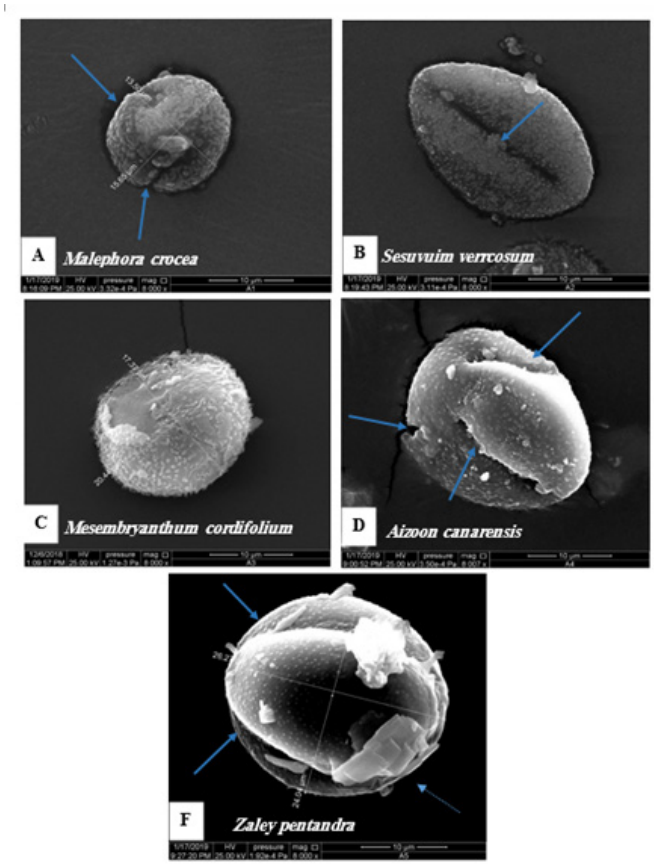


Figure 14. SEM micrograph equatorial and polar view at [mag 8000×] shows number and shape of aperture of the pollen grain (A). Two aperture shape "Dicolpate" in *Malephora crocea* (B). One aperture shape"monocopate" in *Sesuvium verrucosum*, (C). Aperture shape "Inaperturate"in *Mesembryanthum cordifolium* (D.F). Three-aperture shape "Tricolpate"in *Aizoon canarensis* and *Zaleya pentandra*.

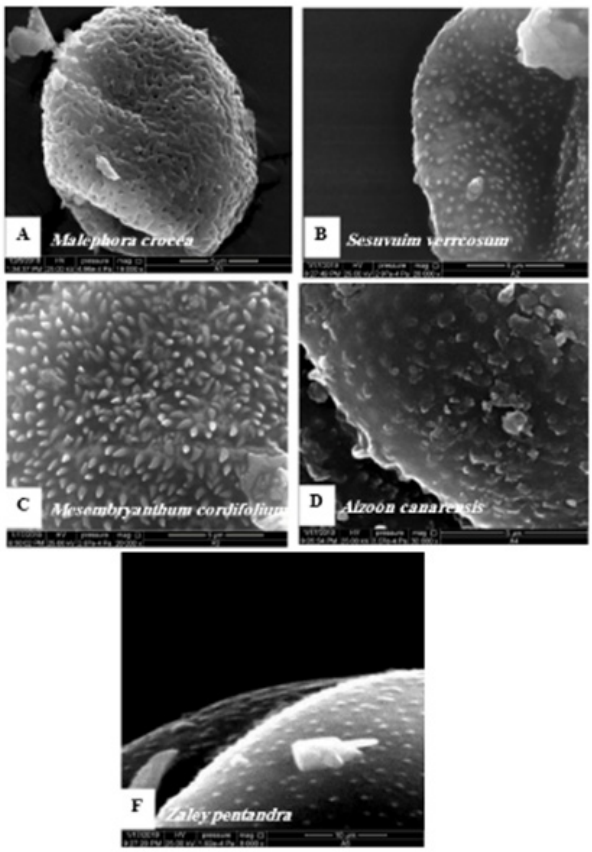


Figure 15. SEM micrograph close-up image at [mag 16000×] shows pollen grain wall ornamentation of exine (A). Reticulate type in *Malephora crocea* (B.D.F). Granulose in *Sesuvium verrucosum*, *Aizoon canariensis* and *Zaleya pentandra*. (C). Echinate in *Mesembryanthum cordifolium*.

Principal Coordinates Analysis (PCoA)

PCoA identified clear groupings of the studied taxa based on their morphological, anatomical, and palynological characteristics. *Malephora crocea* and *Mesembryanthemum cordifolium* were closely related, forming the green group, while *Sesuvium verrucosum* and *Zaleya pentandra* were more closely affiliated, together in the blue group. *Aizoon canariense* distinguished itself by forming a separate cluster, highlighting its unique traits compared to the other taxa (Fig. 16).

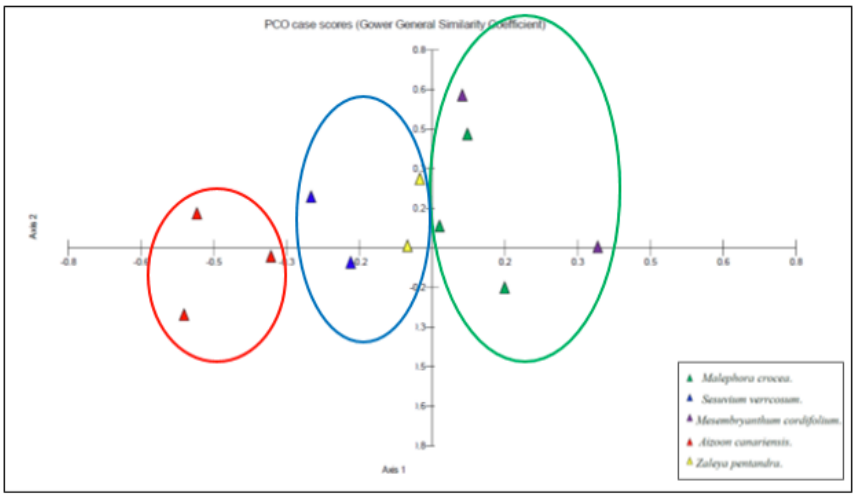


Figure 16. Principal Coordinate analysis (PCO) of morphological, anatomical and Palynological data of the studied taxa of Aizoaceae in Saudi Arabia using Gower similarity coefficient (Gower, 1966).

The two new records species to Saudi Arabia: Two new record species were identified for the first time in the flora of Saudi Arabia. *Malephora crocea* and *Mesembryanthum cordifolium* are the new records and they have similar characters. Therefore, they were included under sub family Mesembryanthemoidea.

Genus *Malephora*: (Jacq.) Schwant, Möller's Gärtn.-Zeitung 43:7 (1928)

Subshrubs Stems succulent prostrate 2 cm, becoming woody with age. Leaves crowded at end of short shoots, pale green, sometimes red-tinged; blade triangular in cross-section, 2.5-6(-12) × 0.6 cm, apex blunt, glaucous. Inflorescences terminal, flowers solitary; pedicel 1-6 cm. Flowers: calyx 0.8-1.5 cm; calyx lobes (4-)5(-6), 3 longer, with translucent margins, 2 shorter, apex acute; petals 40-65, purplish abaxially, orange adaxially, sometimes completely yellow, orange, or red, 4-12 mm; nectary present; stamens 2–5 mm; filaments connate basally, forming dense ring, white-hairy; ovary inferior. Capsules obcuneiform, 8(-12)-loculed; adaxial seed pockets with bifid placental tubercles. Seeds ca. 75, 3-15 per locule, 1 × 0.8 mm. 2n=36.

Malephora crocea (Jacq.) Schwant. New record to Saudi Arabia

Habit and vegetative morphology: Herbs are annual branched succulent, prostrate, stem succulent, glossy smooth green color length approximately up to 20.6 cm width 1.5-3 cm. Leaves shape cylindrical and slightly tapering in the top of leaf (terete), succulent, adaxial and abaxial of leaf is smooth and glossy, petiole type of sessile. Length of leaf in mature leaf approximately 5.73 cm width 0.71, while small leaf length 1.42 cm width 0.4 cm (Fig. 4:20 A) (Fig. 4:21 A).

Inflorescence and floral morphology: solitary, summetry actinomorphic, flower pedicel pedicellate, petals number type of numerous shape lirulate, color of corolla is red abaxially, orang adaxially sometime completely orang or red-petoloid and polypetaloud.

Calyx number 5-polysepalous color of calyx is sepaloid (green), succulent, smooth and glossy. Gynoecium, carples number 5-pentacarpellary, fusion syncarpous, placentation superficial, postion of ovary inferior-pigynnous, stigma type dumb bell. Androecium cohesion of stamen polyandrous, length of stamen heterostemnous.

Flowering period: February-March

Distribution: Taif, Alhada 21.5423800° N 39.1979700 E, Taif 21°.127736 N 40°.363111 E.

Sample examined: Alotaibi and Altoukhy (1) (2)

Genus: *Mesembryanthemum* Linnaeus, Sp. 2: 1461 (1759)

Perennial, prostrate, ground-covering herb with small heart-shaped, glossy green succulent leaves sparkling in the sun. It appears to crawl along the soil and hug the ground forming a tight, almost clipped appearance and stays green year-round. Plants grow no taller than about 7-10 cm but can climb on neighboring vegetation cloaking the base of trees and shrubs up to 2 meters tall, and forming a thick mat by growing over itself. It produces small bright pink flowers in spring and summer. Stems moderately thick, succulent, flexible, trailing to 60(-200) cm long and easily snapped. Internodes, 4-angled, widely spaced, base of stems woody. Nodes root when they touch the ground. Leaves 1-3 cm long, flat, heart-shaped, petiolate, free, dark-green, glossy, bladder cell. Flowers solitary, axillary, daisies like, bright pink or purplish, small, 20 mm in diameter. Peduncle 8-15 mm long. Hypanthium 6-7 mm long. Sepals, four of unequal size approx. 5 mm long, the largest flat, the others awl-shaped. Carpel lobes free, Petals numerous bright pink to purple, approx. 3 mm long, inner ones slightly narrower and shorter and of lighter colour, filamentous staminodes absent, ovary inferior.

Mesembryanthum cordifolium Schwantes (1958) new record to Saudi Arabia

Habit and vegetative morphology: shrubs are annual branched succulent, prostrate, stem succulent, glossy smooth, bladder cell in stems green color length approximately up to 19.7 cm width 1.4 cm, leaves shape heart apex acute, base of leaf attenuate, succulent, adaxial and abaxial of leaf is smooth and glossy, bladder cell, petiole type of petiolat. Length of leaf in mature leaf approximately 2.73 cm width 1.23 cm, while small leaf length 1.27 cm width 1.1 cm. (Fig. 4:20 C) (Fig. 4:21 C).

Inflorescence and floral morphology: solitary, summetry actinomorphic, flower pedicel pedicellate, petals number type of numerous shape lirulate, color of corolla is pink Calyx number 5-polysepalous color of calyx is sepaloid (green), succulent, bladder cell and glossy. Gynoecium, carples number 4-tetracarpellary, fusion syncarpous, placentation axille, postion of ovary inferior-epigynnous, stigma type discod. Androecium cohesion of stamen polyandrous, length of stamen heterostemnous.

Flowering period: January-April

Distribution: Bani Malik 21.05.568° N 38.17917 E, Taif 21°34.5079 N 40°21.83951 E

Sample examined: Alotaibi (5), Alotaibi (6).

Discussion

This study reveals new insights into the diversity of Aizoaceae in Saudi Arabia, featuring the identification of two new species within the country's flora: *Malephora crocea* and *Mesembryanthemum cordifolium*. Alongside these species, other taxa displayed notable morphological, anatomical, and palynological diversity, highlighting the necessity of combining various forms of evidence in taxonomic studies. The occurrence of unusual secondary growth and specialized bladder cells in some taxa shows how Aizoaceae adapt to

arid environments. The employment of numerical phenetic analysis enabled an objective assessment of the similarities and differences among the studied taxa, which resulted in a deeper understanding of their relationships. The placement of *Malephora crocea* and *Mesembryanthemum cordifolium* in the subfamily Mesembryanthemoidea, along with *Sesuvium verrucosum* and *Zaleya pentandra* in Sesuvioideae, is matched with previous taxonomic frameworks. On the other hand, it is offering new insights into the distribution of these taxa in Saudi Arabia.

From a morphological perspective, *Malephora crocea* and *Mesembryanthemum cordifolium* are categorized as annuals, in contrast to the other species, which are identified as perennials. This classification aligns with the ecological adaptations shown by the Aizoaceae family, where annuals typically demonstrate rapid growth cycles and a notable resilience to arid environments. The leaf morphology of these species revealed considerable variation, a significant characteristic of the family, as highlighted by Bittrich and Hartmann, 1988. For example, the cylindrical leaves of *Malephora crocea* noticeably differ from the triquetrous leaves observed in *Sesuvium verrucosum*. This diversity in leaf morphology not only constitutes a critical taxonomic attribute but also acts as a significant adaptation to arid conditions, where preserving water is essential for survival. Recent research, such as Wang, et al. 2021 and Mohanta, et al. 2024, has clarified the adaptive relevance of leaf morphology in succulents with extreme drought conditions.

The anatomical characteristics exhibited secondary growth in the stems across all taxa, distinguished by successive cambia. This result aligns with the records of Newton, 2004 and El-Raouf, 2020, who highlighted its significance in assisting water storage and providing structural support in arid conditions. The occurrence of specialized bladder cells within the epidermis of *Malephora crocea* and *Mesembryanthemum cordifolium* is a distinctive anatomical attribute of these species, which assists in water storage and protection against desiccation. Moreover, Aline, et al. 2018, noted that bladder cells and other specialized features are crucial for the survival of Aizoaceae species in dry environments.

From a palynological perspective, this study identifies significant variations in pollen morphology, particularly in relation to the number and shape of apertures, which are critical features for taxonomic classification, as expressed by Erdtman, 1952. The reticulate exine of *Malephora crocea* and *Mesembryanthemum cordifolium* is consistent with the findings of Gower, 1966, who suggested that the exine ornamentation represents a characteristic feature of the subfamily Mesembryanthemoidea. Furthermore, the prolate shape of the pollen grain in the majority of species and the oblate shape in *Mesembryanthemum cordifolium*, aligns with prior palynological studies conducted on Aizoaceae in Egypt and Pakistan (Abo El-Naga, et al. 2014, Perveen and Qaiser, 2000). These variations highlight the capability of palynology as a constructive tool in addressing taxonomic uncertainties within the Aizoaceae.

The Principal Coordinates Analysis (PCoA) further verified the morphological, anatomical, and palynological distinctions among the taxa examined. The close relationship between *Malephora crocea* and *Mesembryanthemum cordifolium*, along with their classification within the subfamily Mesembryanthemoidea, aligns with the previous findings of Hartmann and Niesler, 2001. Additionally, the grouping of *Sesuvium verrucosum* and *Zaleya pentandra* within Sesuvioideae supports prior taxonomic classifications (Chaudhary, 2001) and emphasizes the efficacy of PCoA in validating these relationships.

The identification of *Malephora crocea* and *Mesembryanthemum cordifolium* as new species records for Saudi Arabia underscores the significance and the need of continued botanical exploration in Saudi Arabia. As previously pointed out by , the flora of Saudi Arabia is both rich and inadequately explored, especially in isolated areas such as the southwestern regions, which are very rich in plant diversity. These new records enrich the known flora of Saudi Arabia, supporting conservation and ecological research.

Conclusion

This research revealed that the Aizoaceae family is represented in western and southwestern Saudi Arabia by five taxa, with two new species records to the country: *Malephora crocea* and *Mesembryanthemum cordifolium*. The results emphasize that using more than one taxonomic evidence is essential for reaching an appropriate taxonomic classification. Through morphological, anatomical, and palynological analyses, we added valuable insights into the distinguishing features of these taxa in Saudi Arabia. The addition of the new records enhances the known diversity of Aizoaceae in Saudi Arabia and draws attention to the importance of ongoing botanical exploration in the country.

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Data availability statement

All data is available in the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

Chaudary A, Aljowaid A. (1999). Vegetation of the Arabian Peninsula. Ministry of agriculture and water research center, Riyadh. **1**:141-155.

Al Farhan A, Jakson PW. (2002). Vegetation flora of Saudi Arabia. King Saud University Press, Riyadh. **1**:389.

Al-Turki TA, Filfilan SA, Mehmood SF. (2000). A cytological study of flowering plants from Saudi Arabia. *Willdenowia*. 339-358.

Al Fawaz MA. (2006). Chemical composition of hummayd (*Rumex vesicarius*) grown in Saudi Arabia. *J Food Compos Anal*. **19**:552-555.

Balakrishnan NP. (Ed.). (2012). Aizoaceae (Magnoliopsida: Caryophyllales) a new family record to the flora of Andaman Islands. *J Threat Taxa*. 4: 2653-2655.

Migahid A. (1996). Flora of Saudi Arabia. King Saud University press, Riyadh. **1**:126.

Collenette SA. (1999). Wild flowers of Saudi Arabia. National Commission for Wildlife Conservation. King Saud University Press, Riyadh. **1**:699.

Chaudhary SA. (2001). Flora of the kingdom of Saudi Arabia. Ministry of agriculture and water research center, Riyadh. **1**:689.

Newton LE. (2004). Aloes in habitat: History and role in modern biology. *Am J Bot.* **15**:143-175.

Erdtman G. (1952). Pollen morphology and plant taxonomy. *Bot Not*. **107**:65-81.

Erdtman G. (1952). Handbook of palynology: Morphology, taxonomy, ecology. An introduction to the study of pollen grains and spores. *Copenhagen: Munksgaard*.

Bittrich V, Struck M. (1989). What is primitive in Mesembryanthemaceae? An analysis of evolutionary polarity of character states. *S Afr J Bot*. **55**:321-331.

Wang H, Wang R, Harrison SP, Prentice IC. (2022). Leaf morphological traits as adaptations to multiple climate gradients. *J Ecol*. **110**:1344-55.

Mohanta TK, Mohanta YK, Kaushik P, Kumar J. (2024). Physiology, genomics, and evolutionary aspects of desert plants. *J Adv Res*. **58**:63-78.

Abd El-Raouf HS. (2021). Taxonomic significance of leaves in Aizoaceae. *Saudi J Biol Sci*. **28**:1016.

Gower JC. (1966). Some distance properties of latent root and vector method used in multivariate analysis. *Biometrika*. 53:325-338.

El-Naga AA, Rabei S, Khedr AA, Al-Shibany F. (2014). Pollen morphology of Aizoaceae in Egypt. *SJDFS*. **3**:133-9.

Perveen A, Qaiser M. (2000). Pollen Flora of Pakistan. "Pollen Flora of Pakistan -XIX. Aizoaceae,". *Turkish J Bot*. **24**:29-33.

Hartmann HEK, Niesler IM. (2001). Aizoaceae A-E. Illustrated Handbook of Succulent Plants. *Springer, Berlin-Heidelberg*. **2**:537.