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Short Title: Taxonomic evaluation of aizoaceae in western and southwestern Saudi Arabia: insights into morphology, anatomy, and palynology with records of two new species

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 855genera containing 97 (4.25%) trees, 565 (24.73%) shrubs and about 1620 (71.02%) herbs (Chaudhary and Al Jowaid, 1999). In Saudi Arabia, approximately 290 species belonging to 23 families are generally recognised as succulent (Al Farhan & 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 (Mohammadayn, 2001). 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 (Tab. 1 and 2) (Fig. 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 & 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	Loction	Herbarium
Aizoon canarensis	12/6/2017	Alotaibi & Altoukhy 8	Taif - Alshifa	Fresh
Aizoon canarensis	12/6/2017	Alotaibi & Altoukhy 9	Taif –Wadi Gzal	Fresh
Aizoon canarensis	7/4/2018	Alotaibi 7	Bni Malik	Fresh
Sesuvium verrucosum	15/7/2017	Alotaibi & Altoukhy 3	Makkah - Aljamoum	Fresh
Sesuvium verrucosum	25/7/2017	Alotaibi & Altoukhy 4	Allith Road	Fresh
Malephora crocea	12/6/2017	Alotaibi & Altoukhy1	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 & 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 & Howaisshell 11321	Buraida	King Saud University
Sesuvium verrucosum	4/9/1981	Migahid & 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).

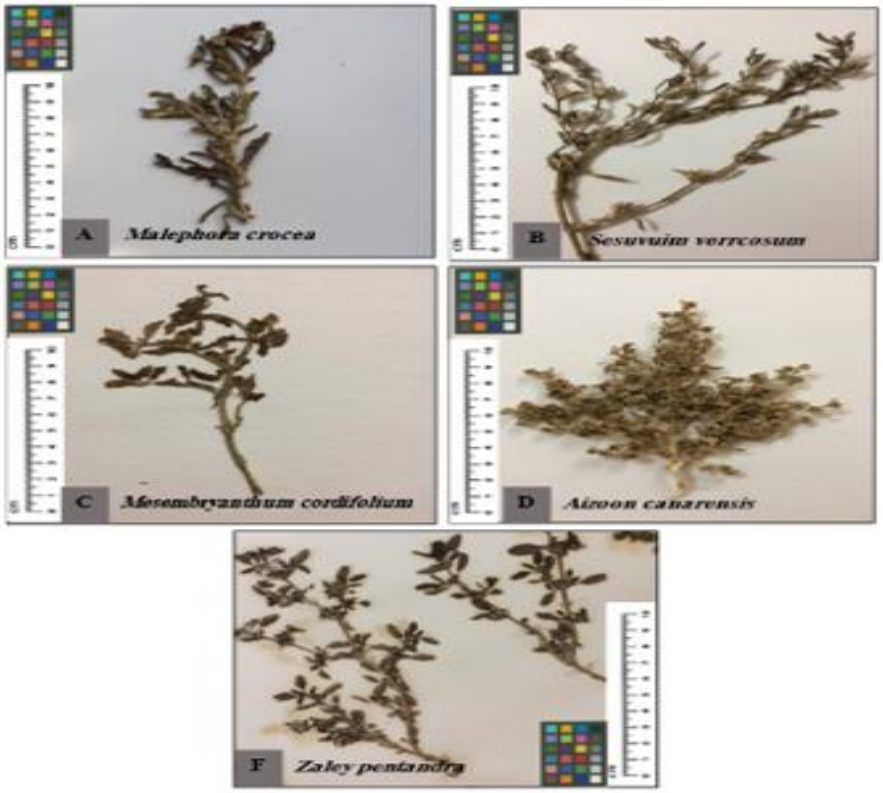

Figure 2. Samples studied collected by author Aizoaceae (A) *Malephora crocea* (B) *Sesuvium verrucosum* (C) *Mesembryanthum cordifolium*,(D) *Aizoon canarensis* (F) *Zaleya pentandra*.

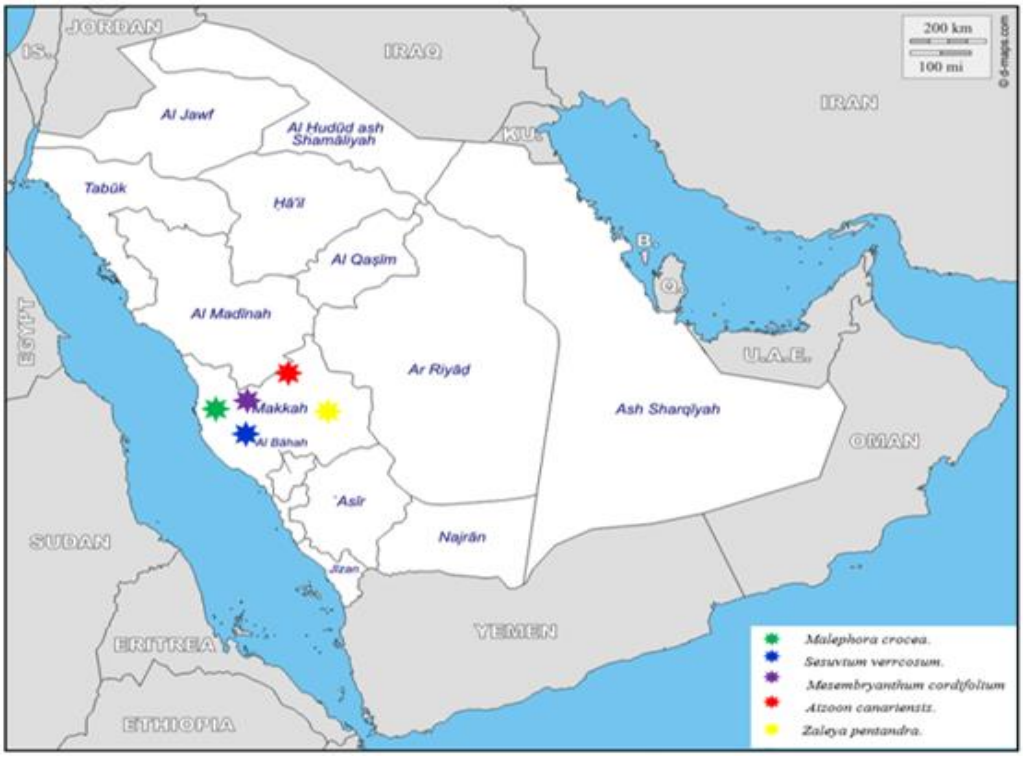

Figure 3. **Distribution map of Aizoaceae samples studied and collected by the authors in Saudi Arabia.**

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 90-265VAC). 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 & 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) (Fig. 4).

Leaf morphology varied significantly among the taxa (Tab. 4 and 5) (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*.

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 (Tab. 6 and 7) (Fig.6).

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

Taxa\ Character	Stem		Stem surface				Stem color	Size (cm) of Stem	
			Hair						
	Stem shape	Type of Stem	Existence Hair in stem surface	Size (CM)	Shining of stem surface	Type of Stem Surface		Length	Width
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	+	0.1cm.	Matte	Hairy	Yellow	1.6	1.4
Zaleya pentandra	Erect	Sub succulent	-	-	Matte	Smooth	Yellow	24.3	1.5

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

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

(-) absent, (+) present.

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

Taxa	Mature leaf (cm)	Small Leaf (cm)

	Ave. Length	Width	Ave. 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

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

Taxa	**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

Table 7. Gynoecium (Female parts) characteristic in the studied taxa of Aizoaceae in Saudi Arabia.

Taxa	**Carpeles**		**Stigma**	**Ovary**	
	Type & 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 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).

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).

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.8). 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.7). In contrast, *Sesuvium verrucosum* and *Zaleya pentandra* lacked these specialised cells. A similar phenomenon is also observed in the leaves (Fig. 10). 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.9).

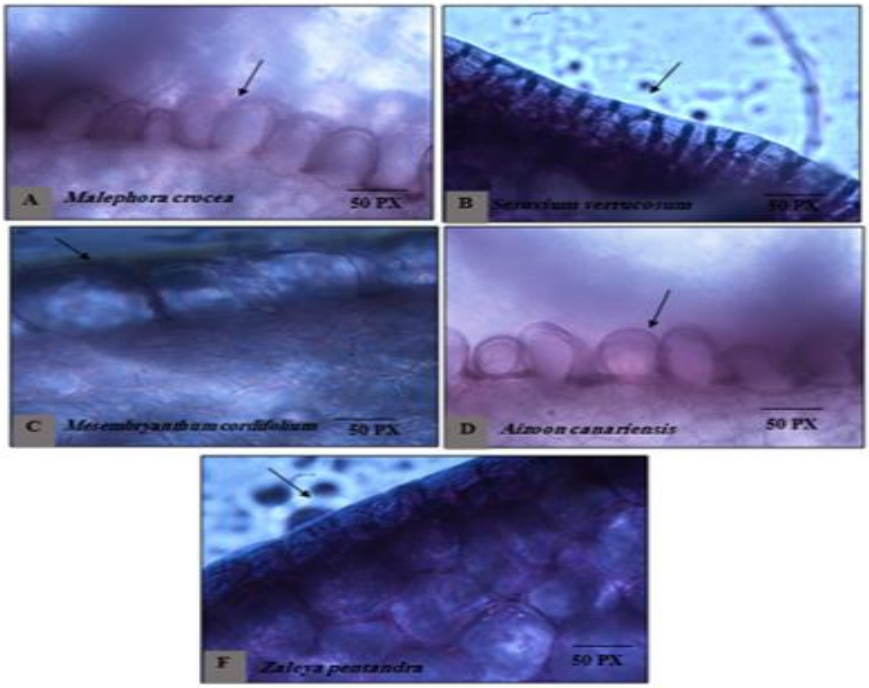

Figure 7. Light microscopic (LM) photograph cross-section in the stem, the image at [mag50×] shows epidermal bladder cells in *Malephora crocea*, *Mesembryanthum cordifolium* and *Aizoon canariensis* (A.C.D). While *Sesuvium verrucosum* and *Zaleya pentandra* (B.F) do not have bladder cells.

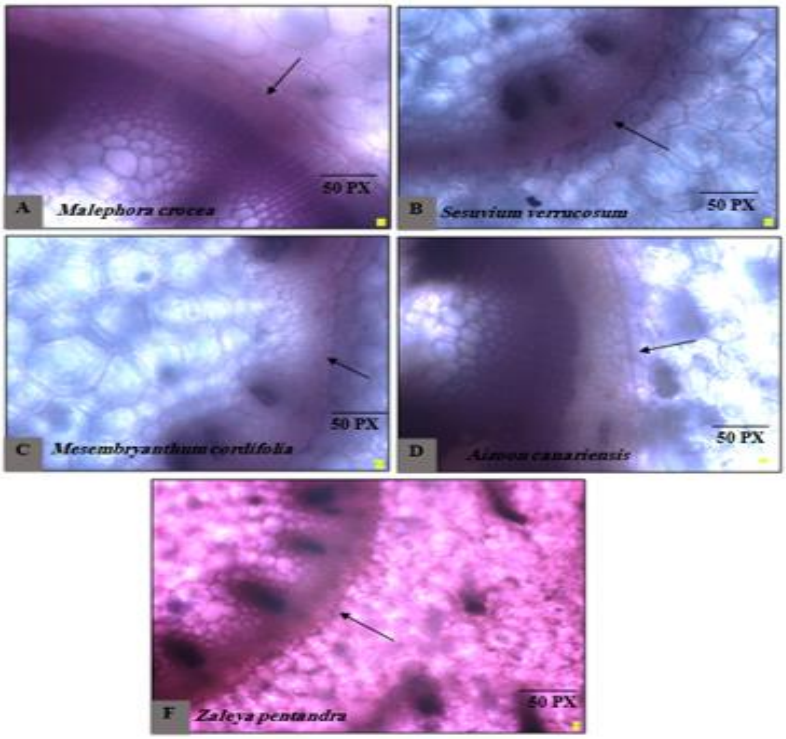

Figure 8. LM photograph cross section in stem at [mag 50×] shows (A.B.C.D.F) have successive cambia which gives rise to a ring of vascular bundles this start of normal secondary growth in *Malephora crocea, Sesuvium verrucosum, Mesembryanthum cordifolium, Aizoon canariensis* and *Zaleya pentandra*

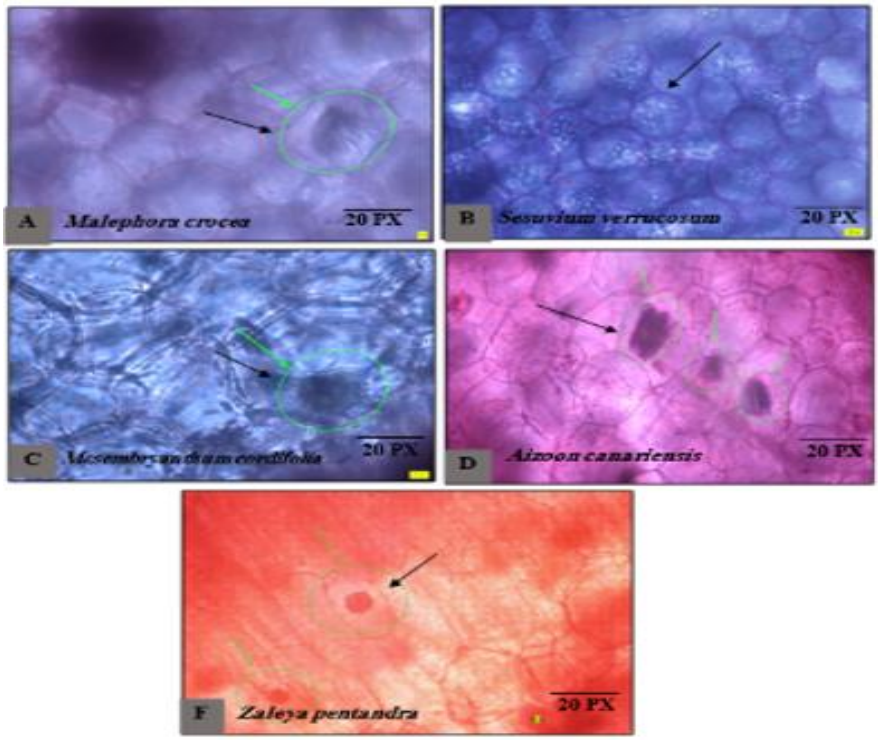

Figure 9. LM photograph cross-section in stem image at [mag20×] shows raphioles calcium oxalate crystals of needle type in *Malephora crocea, Mesembryanthum cordifolium* and *Aizoon canariensis* (A.C.D); sand crystal type in *Sesuvium verrucosum* (B); stellate druses type in *Zaleya pentandra* (F).

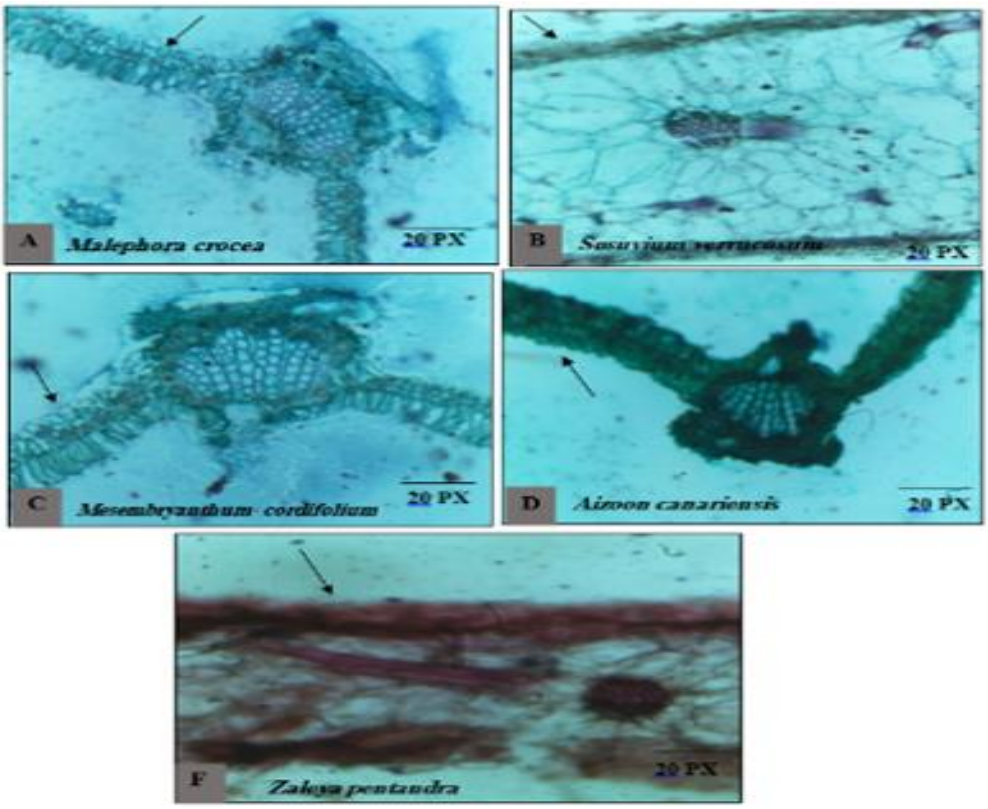

Figure 10. LM photograph cross-section in leaf image at [mag20 ×] shows bladder cells in *Malephora crocea, Mesembryanthum cordifolium and Aizoon canariensis*(A.C.D), *Sesuvium verrucosum* and *Zaleya pentandra* do not have it (B.F)

Palynological Analysis

Palynological studies revealed notable variations in pollen grain size, colpus length, and exine ornamentation among the five taxa (Tab. 8) (Fig 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

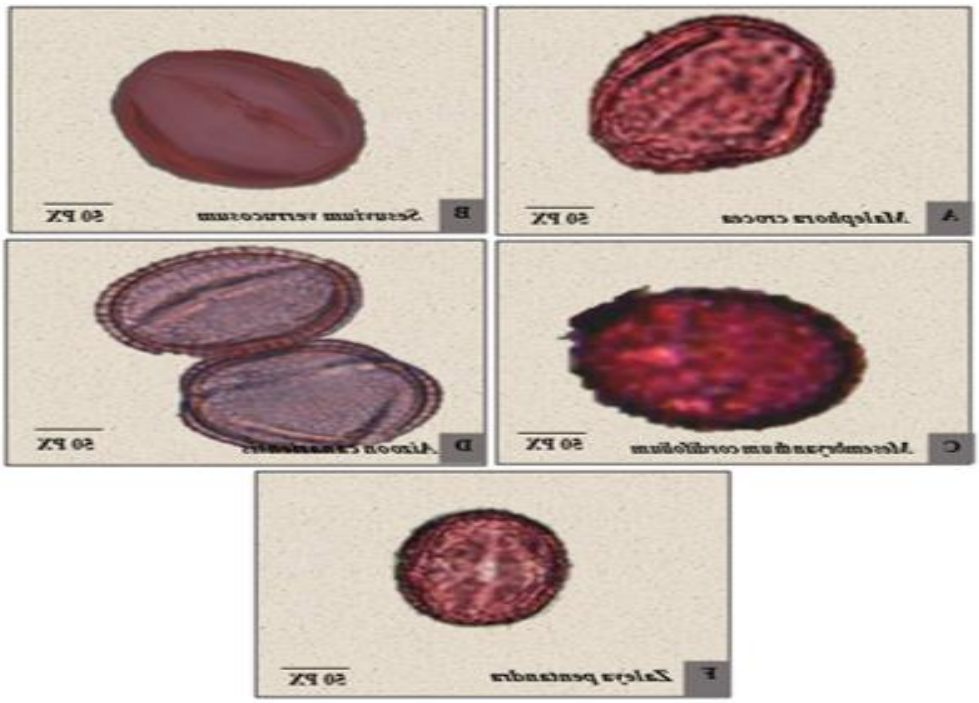

Figure 11. **LM photograph polar view shows shape of pollen grains type "prolate" in Malephora crocea, Sesuvium verrucosum, Aizoon canariensis and Zaleya pentandra (A.B.D.F); type "oblate"in Mesembryanthum cordifolium (C).**

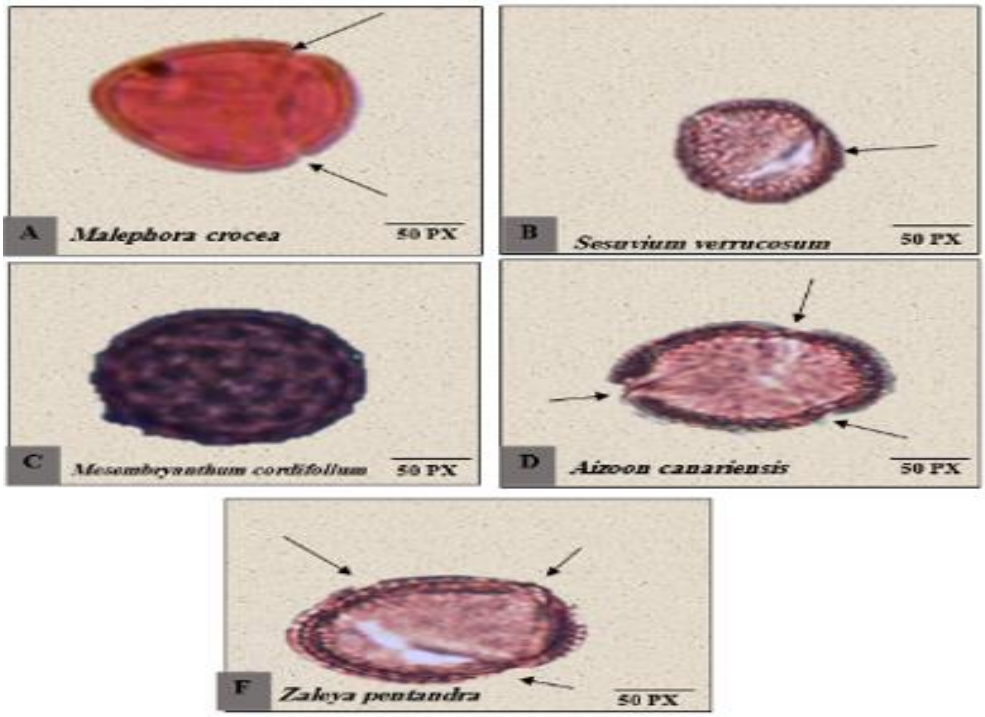

Figure 12. LM photograph equatorial and polar view at [mag 8000×] shows number and shape of aperture of pollen grain (A). two aperture shape "Dicolpate" in Malephora crocea and Zaleya pentandra, (B). one aperture shape"monocolpate" in Sesuvium verrucosum, (C). aperture shape "Inaperturate"in Mesembryanthum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

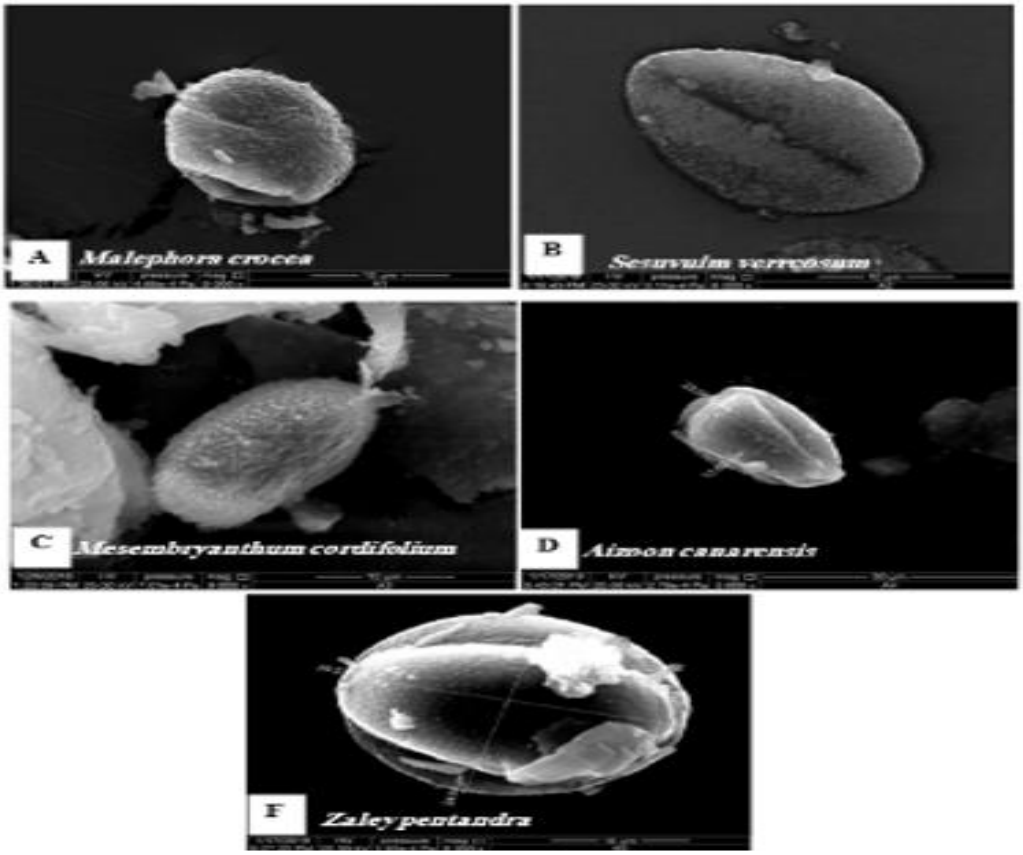

Figure 13. SEM micrograph polar view at [mag 8000×] shows shape of pollen grain Shape type "prolate" in Malephora crocea, Sesuvium verrucosum, Aizoon canariensis and Zaleya pentandra (A.B.D.F). Shape type "oblate" in Mesembryanthum cordifolium (C).

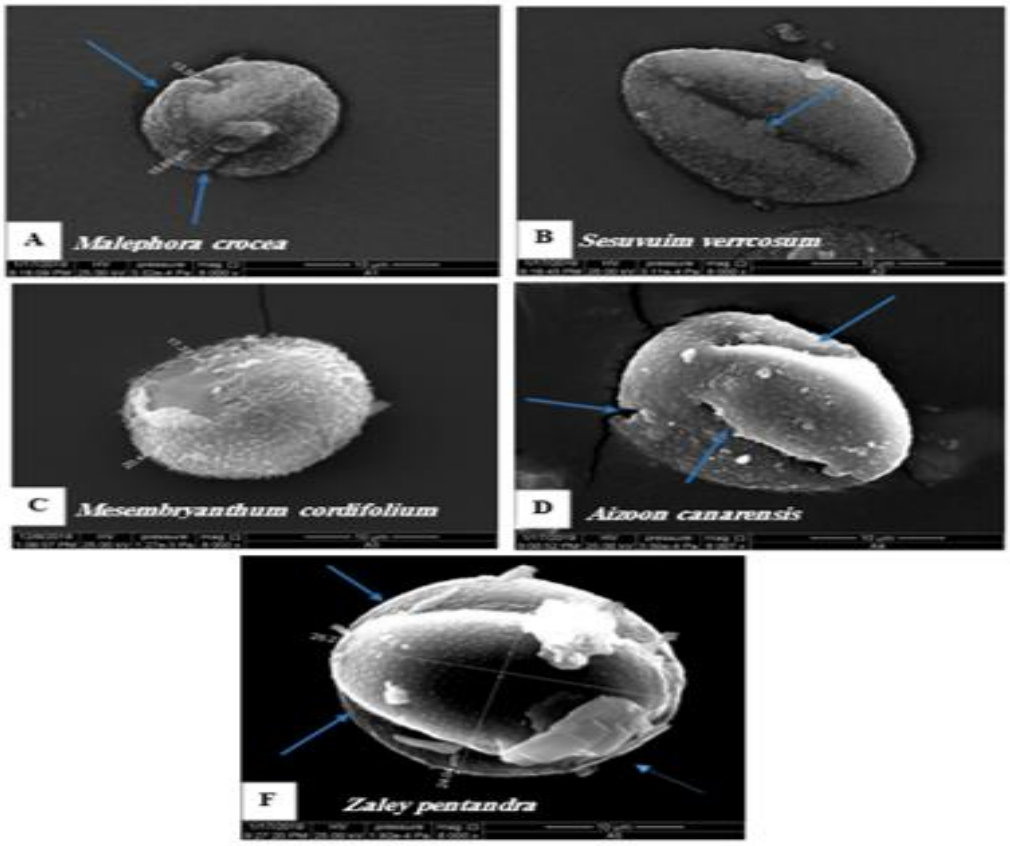

Figure 14. SEM micrograph equatorial and polar view at [mag 8000×] shows number and shape of aperture of the pollen grain (A). Two aperture shape "Dicolpate" in Malephora crocea (B). One aperture shape"monocopate" in Sesuvium verrucosum, (C). Aperture shape "Inaperturate"in Mesembryanthum cordifolium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

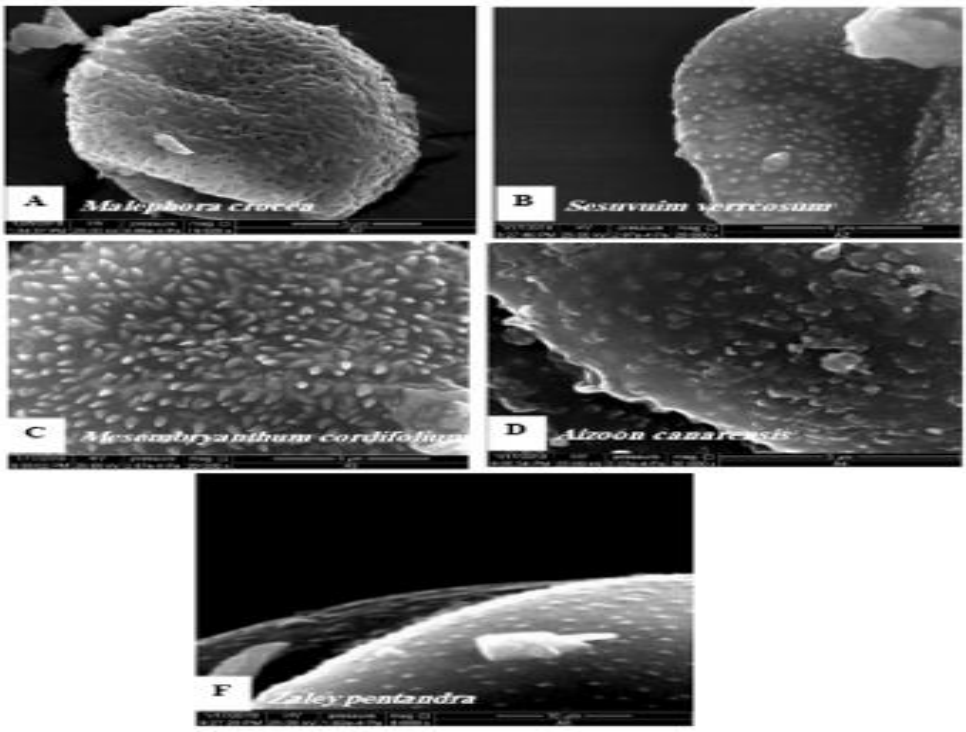

Figure 15. SEM micrograph close-up image at [mag 16000×] shows pollen grain wall ornamentation of exine (A). Reticulate type in Malephora crocea (B.D.F). Granulose in Sesuvium verrucosum, Aizoon canariensis and Zaleya pentandra. (C). Echinate in Mesembryanthum cordifolium.

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).

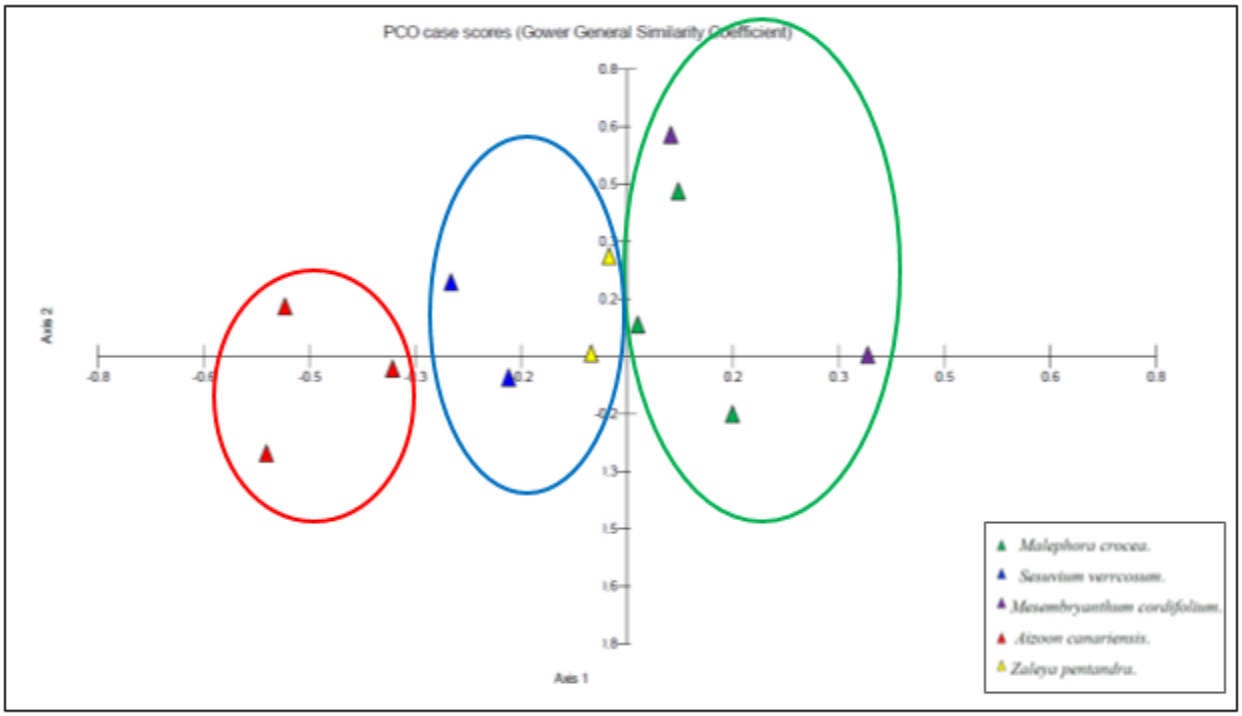

Figure 16. Principal Coordinate analysis (PCO) of Morphological, Anatomical and Palynological data of the studied taxa of Aizoaceae in Saudi Arabia using Gower similarity coefficient (Gower,1966).

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 cm–6 cm(–12 cm) × 0.6 cm, apex blunt, glaucous. Inflorescences terminal, flowers solitary; pedicel 1 cm–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 mm–12 mm; nectary present; stamens 2 mm–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 mm× 0.8 mm. 2n=36.

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

Habit & vegetative morphology: herbs are annual branched succulent, prostrate, stem succulent, glossy smooth green color length approximately up to 20.6 cm width 1.5 cm-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 ses. Length of leaf in mature leaf approximately 5.73 cm width 0.71, while small leaf length 1.42cm width 0.4cm (Fig. 4:20 A) (Fig. 4:21 A).

Inflorescence & 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 & 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 cm-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 cm-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 mm-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 & 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 attenuates, succulent, adaxial and abaxial of leaf is smooth and glossy, bladder cell, petiole type of petio. Length of leaf in mature leaf approximately 2.73 cm width 1.23 cm, while small leaf length 1.27cm width 1.1cm. (Fig. 4:20 C) (Fig. 4:21 C).

Inflorescence & 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 & 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 Collenette (1999), 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.

Conclusions

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.

Conflict of interest disclosure

The authors declare no conflict of interest.

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