

## Morphological Revision of the Desert Shrub *Fagonia* L. in Libya

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### Abstract

Ten *Fagonia* species grown in the Libyan Desert subjected in this study. The study focused on both micro- and macro-morphological characters by using Stereomicroscope, light Microscope and Scanning Electron Microscope (SEM). These species include *Fagonia arabica* L., *Fagonia bruguieri* DC, *Fagonia cretica* L., *Fagonia glutinosa* Delile, *Fagonia indica* Burm., *Fagonia microphylla* Pomel, *Fagonia sinaica* Boiss, *Fagonia schweinfurthii* Hadidi, *Fagonia tenuifolia* Steud. and *Fagonia thebaica* Boiss. This study has elucidated the importance of the vegetative macro characters in the taxonomy of the genus as first step in identification, especially the length of the spiny stipules and the type of leaf blade. Leaf or leaflet shape as well as margins and apices are of minor taxonomic importance. Microcharacters can be used to recess the identification and can be consider as the second step in identification. An identification key has been constructed and the previous trials of classification have been discussed according to the obtained results.

**Keywords:** Desert plants, *Fagonia*, Leaf Macromorphology, Leaf Micromorphology, Libya, Stomata, taxonomy.

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### Introduction

The genus *Fagonia* is a member of Zygophyllaceae, which is included in the eurosid I clad (APG III, 2009). In a phylogenetic analysis of Zygophylloideae, based on molecular and morphological data, *Fagonia* was shown to have a well-supported position as sister to the genus *Melocarpum*, endemic to the Horn of Africa region (Beier *et al.*, 2003). *Fagonia* consists of shrubs with free spinescent or pointed stipules, pink or purple petals, and an obconical, more or less pubescent, loculi-cidal capsule, often with

persisting sepals. Most species of *Fagonia* have three-foliolate leaves, but there are also several species that are one-foliolate. The free stipules and the pubescent, obconical capsules are particularly important in the circumscription of *Fagonia*. Porter 1963 states that *Fagonia* is a genus known from the warm arid regions of all continents except Australia. In Libya the family comprises eight genera and twenty five species (Feng *et al.*, 2013). One of the important genera belonging to this family is *Fagonia*. The genus comprises twelve species growing in different phytogeographical regions in Libya ([Abdul Ghafour & Khan, 1977](#)).

The taxonomy of *Fagonia* is very difficult mainly due to a high degree of plasticity and thereby adaptations to climatic conditions (Zohary 1972; Danin 1996). Ozenda & Quézel (1956) grouped the North African *Fagonia* species into four natural groups, according to vegetative morphological characters: (1) *F. kahirina-cretica-flamandii* group, (2) *F. arabica-bruguieri* group,

(3) *F. glutinosa-latifolia* group, and (4) *F. microphylla*- group. However, according to Batanouny and Batanouny (1970), El Hadidi (1966) described 18 species of *Fagonia* and constructed an artificial key for their identification. The latter author classified the *Fagonia* species in Egypt into three groups. These groups are summarized in table 1.

**Table 1** summarizes Quezel and El-Hadidi classification of *Fagonia* Sp.

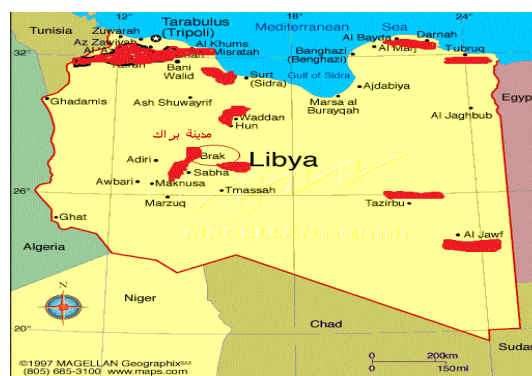
Ozenda & Quézel 1956	Group	<i>F. kahirina-cretica-flamandii</i>	<i>F. arabica-bruguieri</i>	<i>F. glutinosa-latifolia</i>	<i>F. microphylla</i>
El Hadidi 1966	Group	<i>F. arabica-bruguieri</i> group <i>F. arabica</i> , <i>F. bruguieri</i> , <i>F. myriacantha</i> , <i>F. hassasi</i> , <i>F. thebaica</i> , <i>F. boulosii</i> , <i>F. indica</i> , <i>F. taechholmiana</i> and <i>F. alba</i> ..	<i>F. glutinosa</i> group <i>F. glutinosa</i> , <i>F. tristis</i> , <i>F. mollis</i> , <i>F. microphylla</i> , <i>F. latifolia</i> and <i>F. isotricha</i> .	<i>F. sinica</i> group <i>F. sinica</i> , <i>F. cretica</i> and <i>F. bisharorum</i> .	

The delimitation of species in *Fagonia* is known for being notoriously difficult. This is caused by the great variation in most morphological characters in many of the species. Accordingly, this work has carried out to investigate how much the difference in macro- and micro-morphological characters of both the stem and leaf can aid in the taxonomy of the genus.

## Materials and Methods

### A-Location and General Description

Libya is a country in the Maghreb region of North Africa. It is bordered by the Mediterranean Sea, Egypt, Sudan, Chad, Niger, and Tunisia. In Libya about 94 to 96% of the land is desert and it is one of the driest countries in the world (Holdridge, 1974). The genus is represented by twelve species distributed in the arid Libyan Desert as illustrated in Map 2 and mentioned in Jafri and El-Gadi (1977-1984). Species of *Fagonia* grow in different phygeographical regions with different environmental conditions. Table 3 shows the studied *Fagonia* species which we can gather and collected from the field and allocate in Bengasi and Tripoli university herbaria. These species prefer sandy or gravelly habitats and tolerate with soil salinity.



Map 1 Distribution of *Fagonia* species in Libya

### B-Methods

Herbarium Sheets allocated in Benghazi and Tripoli universities herbaria as well as fresh materials collected from El-Gabel Al-Akhdar are subjected in this study. The herbarium sheets were photographed and the fourth internode in all the studied species was chosen for investigations and morphological description and measurements. The fourth leaves in each species from at least ten specimens were subjected in this study and photographed by stereomicroscope.

For light microscope study (LM), the fourth leaf, from three individuals in each species, was washed with water to remove the dust and photographed using Stereomicroscope. Parts of the leaves were put in test tubes with 5ml. dist. water, 2 drop tepol, and 2 drop 1N HCl and warmed gently to remove the epidermal layer.

For scanning electron microscope (SEM) studies, dried mature leaves were placed on stubs, coated with a thin layer of gold then scanned and photographed at 15 KV with JEOL JSM 5300

SEM at the Electron Microscope Unit, Alexandria University. The descriptive terms used for epidermal cells, stomata in this works follow Barthlott (1981).

**Table 2** The studied *Fagonia* species grown in Libya, their locations in Libya and throughout the world as well as their growing habitats.

	<b>Fagonia Species Libyan</b>	<b>Distribution in Libya</b>	<b>Global distribution</b>	<b>Habitat</b>
1	<i>Fagonia arabica</i> L. (two varieties; <i>thilhoana</i> & <i>viscidissima</i> )	Brak – Wadi Bughrara ( Tumb ) - Tijarbi – sabha - Hun - Gebel Uweinat	Algeria, Libya, Egypt, Palestine, Arabia.	Rocky and gravelly deserts
2	<i>Fagonia bruguieri</i> DC	Gara Al-Tifarni, (Weshka) -El- Washka-Fezzan,- Sebha, along Hun highway, - Wadi Soda.	N. and E. Tropical Africa. Saudi Arabia, Jordan, Syria, Iraq, Iran, Afghanistan and Pakistan.	Sandy and gravelly plains and desert wadis.
3	<i>Fagonia cretica</i> L.	Gharian ( Gebel Nafousa) - shik Shook (Jadoo) - El Homs, - Sharshara, near Tarhuna - El- Naggaza (Khoms)- WadiDerna - Wadi al-Ramlah - Derna - Tobruk – Wadi Malah (Nalut)	Mediterranean element; found in S. Europe, canary Islands & Noth Africa	Calcareous Coastal Ridges.
4	<i>Fagonia glutinosa</i> Delile	Wazen, Libyan-Tunisian Boundary - Gebel Nefousa, - Hun- wadi Soda. - Gara El-Tifarni, - Weshka	North African Sahara Eastwards to Kuwait, Bahrein and Pakistan	Sandy and Stony Wadis and Plains
5	<i>Fagonia indica</i> Burm.	Sebha on Sebha-hun -Al-Abiad - Brak, -wadiBughrara, - WadiAtiq. – Tuarbi	Pakistan Westward to N. Africa.	Sandy plains
6	<i>Fagonia microphylla</i> Pomel	Nalut.	Sinai, Tunisia, Algeria, Morocco.	Stony Wadis
7	<i>Fagonia sinaica</i> Boiss ( three varieties; <i>pseudocretica</i> , <i>longips</i> & <i>kahirina</i> )	Wadi Malah, (Nalut) - Gharian Hills., Roadside, - Shak Shook ( Jadoo) - Abu-Gheilana. Wadi Al- Aital-BetweenSokna and Wadi Weshka,	North Africa, Sinai and Palestine	Sandy plains
8	<i>Fagonia schweinfurthii</i> Hadidi	Gare al Tifarni (Weshka) - Hun - El – Soda Mountains Fezzan.	Oman, Emarates, Arabia, India , Pakistan, Libya, Egypt and Palestine	Wetland habitats
9	<i>Fagonia tenuifolia</i> Steud.	Wadi Malah (Nalut) - Besalt hillock, near Hun, wadi Sada - Weshka.	Arabia. S. Egypt, South Libya and Algeria, Central Sahara, Arabia.	Wadi sandy beds
10	<i>Fagonia thebaica</i> Boiss	upper heights of Karkur Ibrahim at Jebel Uweinat	Libya, Egypt and Palestine	Sandy and Stony Wadis and Plains

## Results

Chosen herbarium sheets of the studied *Fagonia* species were photographed and illustrated in Fig. 1. Stem stipule and petiole characters are summarized in table 3. From the table we found that all the studied *Fagonia* species were either pale or dark green, except the three varieties of *F. sinaica* which were pink. The stem is either quadrangular or striate except in *F. indica* it was cylindrical and terete in both *F. arabica* v. *thilhoana* and *F. glutinosa* (table 7). The stem was hairy with different densities within the different taxa. *F. bruguieri*, *F. indica*, *F. schweinfurthii* and

*F. tenuifolia* the stem was glabrous. The length and width of the fourth internodes varied within the studied taxa. The length of the spiny stipules is more important within the studied species and according to it three categories can be recognized: the first category has species possess short spiny stipules range from 1.5 to 5 mm includes *F. cretica*, *F. glutinosa*, *F. microphylla*, *F. sinaica* (the three varieties), *F. tenuifolia* and *F. thebaica*. The second category includes species possess medium spiny stipules range from 6 to 10 mm. and has two species; *F. arabica* v. *thilhoana* and *F. bruguieri*. The third group has species possess long spiny stipules range from 10-20 mm. and includes *F. Arabica* v. *viscidissima*, *F. indica*

and *F. schweinfurthii*. The spine tips may be straight or curved as shown in table 3.

The leaves of *Fagonia* are important in the circumscription of the genus. All the species have petiolate leaves with entire leaf margins and different lengths (table 3). The leaf blades are either unifoliate in both *F. arabica* (the two varieties) and *F. indica*, has two types of leaf blades; unifoliate and trifoliate; in *F. bruguieri*, *F. glutinosa*, *F. tenuifolia* and *F. thebaica*. Trifoliate leaf blades are found in *F. cretica*, *F. microphylla*, *F. sinaica* (three varieties) and *F. schweinfurthii* (Fig. 2). The mid leaf length are either small, not exceed 10 mm, *F. arabica* (the two varieties), *F. bruguieri*, *F. glutinosa*, *F. microphylla*, *F. sinaica* (three varieties) and *F. thebaica*. In *F. cretica*, *F. schweinfurthii* and *F. tenuifolia* the mid leaf exceeds the 10 mm length. The ratio between the mid leaf length and width express the leaf shape which varies between the linear to the ovate shapes. The leaf apices can be used in the identification of certain species, as all of them have mucronate apices, except *F. cretica* has piliferous apices and *F. arabica v. thilhoana* and *F. glutinosa* have acute apices.

The leaf micro-characters are studied by SEM to clarify the differences between the studied taxa. The results obtained are summarized in table (5 & 6), while the terminology used was according to Barthlott (1984). The studied species exhibit homogenous pattern of epidermal cells which was isodiametric straight. The leaves are either glabrous or hairy with different hair densities (table 5). The hairs are mostly bicellular and either tabular or glandular (Fig. 3). In *F. arabica* (two varieties), *F. bruguieri*, *F. cretica*, *F. glutinosa*, *F. sinaica v. kahirica*, *F. tenuifolia* and *F. thebaica*

the surface of the leaves are enriched with large or small flakes of wax (table 5 and Fig. 4). The stomata in all the studied species was of the anomocytic type with different indices. The guard cells showed great variation in lengths between the different taxa and they were extremely long in *F. microphylla* (exceed 12  $\mu\text{m}$ ) (Fig. 4).

The primary and secondary sculpture of the epidermal cells, other than those modified by their relationship to trichome, stomata, the venation system or other special structures, provide many characters of taxonomic value. For that, we investigated these characters by both light and Scanning Electron Microscopes. The result obtained are summarized in table 6 and illustrated in Fig. 5. The thickness of the epidermal cells wall, as seen by light microscope, was thin in all the studied species except in *F. cretica*, *F. glutinosa* and *F. indica* it was considerably thicker. The outline of the epidermal cells was tetra-, penta- or hexagonal; except *F. cretica* and *F. sinaica* (three varieties) it was flattened. They were either isodiametric or elongated in one direction with straight cell boundaries (anticlinal walls), except *F. cretica* which has wavy anticlinal walls and *F. sinaica v. longipes* and *v. kahirica* as well as *F. thebaica* have undulated anticlinal walls as seen by light microscope (Fig. 5). Under SEM the cell boundaries appeared either raised with straight periclinal walls or channeled with convex periclinal walls. The surface of the periclinal walls may be smooth as in *F. cretica*, *F. schweinfurthii* and *F. thebaica*, granulate in *F. indica* and *F. sinaica v. longipes* and *v. kahirica*, papillate in *F. bruguieri* or striate in the rest of the species (Fig. 4).

**Table 3** Stem stipule and petiole characters of the studied *Fagonia* sp.

**Key to table 3:** Color, D.G. = dark green, P.G. = Pale green; Outline, Quad. = quadrangular, Cylin.=cylindrical; inter L.= internode length; inter W.= internode width; D.H.= density of hairs ; Sp.H.= sparsely hairy.

	Characters → ↓Species	Stem					Spiny stipules		Petiole Length
		Color	Outline	3-4 <sup>th</sup> inter L. (mm)	3-4 <sup>th</sup> Inter W. (mm)	D.H.	Length	Spine tips	
1	<i>F. arabica v. thilhoana</i>	P.G.	Terete	7 - 9 7.4 ± 0.894	1.0	Woolly	6 - 10 7.8 ± 1.92	Straight	1.5 - 2 1.8 ± 0.273
2	<i>F. arabica v. viscidissima</i>	D.G.	Striate	4 - 18 10.9 ± 6.29	1 - 1.5 1.1 ± 0.210	Woolly	10 - 19 13.3 ± 3.43	Straight	2 - 4 3.3 ± 0.632
3	<i>F. bruguieri</i>	P.G.	Quad.	6 - 14 8.6 ± 1.95	1.0	Glabrous	6 - 10 8.45 ± 1.87	Curved	2 - 5.5 3.35 ± 1.40
4	<i>F. cretica</i>	D.G.	Quad	9 - 20 14.6 ± 3.13	1.0	Spar. Hairy	2 - 5 3.42 ± 0.862	Straight	3 - 6 4.68 ± 0.945
5	<i>F. glutinosa</i>	D.G.	Terete	8 - 28 16.6 ± 6.77	1.0	Hairy	2 - 4 2.6 ± 0.735	Straight	1.5 - 4 2.88 ± 0.545
6	<i>F. indica</i>	P.G.	Cylin.	7 - 22 13.56 ± 4.80	0.5 - 2 1.06 ± 0.3	Glabrous	10 - 20 12.08 ± 3.13	Straight	1 - 5 2.72 ± 1.06
7	<i>F. microphylla</i>	D.G.	Striate	11 - 20 14.6 ± 3.06	1 - 1.5 1.06 ± 0.176	Sp.H.	1.5 - 4 2.37 ± 0.790	Curved	6 - 14 8.75 ± 2.43

8	<i>F. sinaica</i> v. <i>pseudocretica</i>	Pink	Quad	14 - 20 18 ± 2.34	1.0	Sp.H.	3 - 4 3.2 ± 0.447	Straight	2.5 - 3.5 3 ± 0.353
9	<i>F. sinaica</i> v. <i>longipes</i>	Pink	Quad	16 - 31 20.9 ± 4.20	1.0	Hairy	2 - 4.5 3.4 ± 0.774	Straight	4 - 9 5.7 ± 1.41
10	<i>F. sinaica</i> v. <i>kahirina</i>	Pink	Quad	20 - 26 23 ± 2.82	1 - 1.5 1.2 ± 0.273	Hairy	3 - 3.5 3.1 ± 0.223	Straight	2.5 - 4 3.3 ± 0.670
11	<i>F. schweinfurthii</i>	D.G.	striate	15 - 23 18.8 ± 3.49	1 - 1.5 1.2 ± 0.273	Glabrous	10 - 16 12.8 ± 2.58	Straight	4 - 8 6 ± 1.58
12	<i>F. tenuifolia</i>	D.G.	Quad	17 - 27 21.8 ± 3.89	1.0	Glabrous	3 - 5 4.2 ± 0.836	Straight	6 - 9 7.4 ± 1.51
13	<i>F. thebaica</i>	P.G.	striate	6 - 7 6.6 ± 0.547	1.0	Woolly	2 - 3 2.2 ± 0.447	Straight	2 - 2.5 2.3 ± 0.273

**Table 4** Leaf macro-characters of the studied *Fagonia* sp.

**Key to table 4:** Color, D.G.= dark green, P.G.= Pale green; Type, Uni.= Unifoliate, Tri.= Trifoliate; M.L.L.=Mid leaf length; M.L.W.= Mid leaf width; Shape, Lin.-Lan.= Linear to lanceolate, Lan. =Lanceolate, Lin. = Linear.

	Characters → ↓Species	Color	Type	M.L.L. (mm)	M.L.W. (mm)	RL/W	Shape	Apex	Marg in
1	<i>F.arabica</i> v. <i>thilhoana</i>	P.G.	Uni.	4 - 5 4.8 ± 0.447	1.5 - 2.5 2.84 ± 0.273	2.5 - 3.3 2.84 ± 0.421	Ovate	Acute	Entire
2	<i>F.arabica</i> v. <i>viscidissima</i>	D.G.	Uni.	4 - 9 6.2 ± 1.87	1 - 1.5 1.45 ± 0.158	2.6 - 6 4.23 ± 1.15	Lan.	Piliferus	Entire
3	<i>F.bruguieri</i>	P.G.	Uni - Tri	4 - 9 5.45 ± 1.31	1 - 2 1.5 ± 0.362	2.5 - 5 3.69 ± 0.680	Lan	Piliferus	Entire
4	<i>F. cretica</i>	D.G.	Tri.	8 - 13 9.76 ± 1.422	1.5 - 3 1.88 ± 0.361	4 - 6.6 5.26 ± 0.631	Lin.- Lan.	Piliferus	Entire
5	<i>F. glutinosa</i>	D.G.	Uni - Tri	4 - 7 5.08 ± 0.759	2 - 4 2.72 ± 0.541	1.6 - 2.5 1.87 ± 0.266	Ovate	Acute	Entire
6	<i>F. indica</i>	P.G.	Uni.	5 - 11 8.24 ± 1.78	2.0 - 3 2.4 ± 0.559	2.3 - 7.3 4.14 ± 1.38	Lan.	Mucronate	Entire
7	<i>F. microphylla</i>	D.G.	Tri	2.5 - 7 4.31 ± 1.48	1.5 - 3 1.93 ± 0.728	2 - 2.6 2.25 ± 0.282	Ovate	Mucronate	Entire
8	<i>F. sinaica</i> v. <i>pseudocretica</i>	D.G.	Tri	7 - 10 8.6 ± 1.34	1.5 - 2 1.9 ± 0.223	3.5 - 5.3 4.56 ± 0.770.	Lan.	Mucronate	Entire
9	<i>F. sinaicav. Longipes</i>	D.G.	Tri	7 - 9 8.1 ± 0.875	2 - 3 2.75 ± 0.353	2.3 - 4 2.99 ± 0.613	Ovate.	Mucronate	Entire
10	<i>F. sinaicav. Kahirina</i>	D.G.	Tri	8 - 9 8.8 ± 0.447	2 - 3 2.6 ± 0.418	3 - 4.5 3.46 ± 0.630	Lan.	Mucronate.	Entire
11	<i>F. schweinfurthii</i>	D.G.	Tri	10 - 17 12.8 ± 3.42	2 - 3 2.3 ± 0.447	4.4 - 8 5.6 ± 1.407	Lin.- Lan.	Mucronate	Entire
12	<i>F. tenuifolia</i>	D.G.	Uni- Tri.	7 - 12 10.4 ± 2.07	1.5 - 2 1.7 ± 0.273	4.6 - 7.3 6.1 ± 0.994	Lin.	Mucronate	Entire
13	<i>F. thebaica</i>	P.G.	Uni- Tri	4 - 5 4.4 ± 0.547	1 - 1.5 1.2 ± 0.273	2.6 - 5 3.78 ± 0.895	Lan.	Mucronate	Entire

**Table 5** Leaf micro-characters of the studied *Fagonia* species

**Key to table 5:** Tab. = Tabular, Glan. = Glandular; B.Gr. = Big granules; S.Gr. = Small granules;

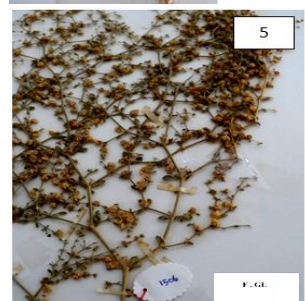
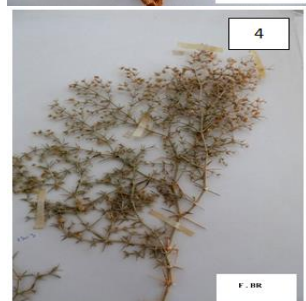
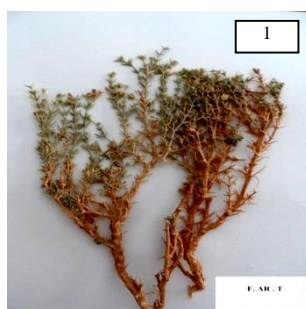
	Characters → ↓Species	Hair		Wax		Stomata	
		Density	Type	Density	Type	Length of Guard Cell μm	Stomatal Index
1	<i>F.arabica</i> v. <i>thilhoana</i>	4.	Tab.	++	B.Gr.	5.4	8.10
2	<i>F.arabica</i> v. <i>viscidissima</i> .	4.	Glan.	++	B.Gr.	5	8.08
3	<i>F.bruguieri</i>	4.	Glan.	+	B.Gr.	5.8	13.7
4	<i>F. cretica</i>	0.	-	+	S.Gr.	5.8	7.5
5	<i>F. glutinosa</i>	3.	Tab	+	B.Gr.	7	10.4
6	<i>F. indica</i>	3.	Tab.	-	-	5	10.8
7	<i>F. microphylla</i>	2.	Tab.	-	-	12.5	13.5
8	<i>F. sinaica</i> v. <i>pseudocretica</i>	1	Tab.	-	-	5.8	15.09
9	<i>F. sinaicav. longipes</i>	3	Glan.	-	-	8.3	13.4
10	<i>F. sinaicav. Kahirina</i>	2	Glan.	+	S.Gr	6.2	13.7
11	<i>F. schweinfurthii</i>	0.	-	-	-	6.6	15.2
12	<i>F. tenuifolia</i>	0	-	++	S.Gr	5.4	17.5
13	<i>F. thebaica</i>	3	Glan.	++	B.Gr.	5.8	10.9

**Table 6** Primary and secondary sculpture of the leaf surface**Key to table 6:** Iso = Isodiametric; El. = Elongated in one direction; STR= straight; UND= undulated.

	Characters → ↓Species	Wall thickness	Outline of cells	Cell shape	Anticlinal wall	Cell Boundary	Periclinal Wall	2ry. Sculpture
1	<i>F.arabica</i> v. <i>thilhoana</i>	Thin	Tetra & Penta	Iso	STR	Raised	Straight	Striate
2	<i>F.arabica</i> v. <i>viscidissima</i> .	Thin	Tetra & Penta	Iso	STR	Channelled	Convex	Striate
3	<i>F.bruguieri</i>	Thin	Hexa	Iso	STR	Raised	Straight	Papillate
4	<i>F.cretica</i>	Thick	Flattened	Iso	Wavy	Channelled	Convex	Smooth
5	<i>F.glutinosa</i>	Thick	Tetra	Iso	STR	Channelled	Convex	Striate
6	<i>F.indica</i>	Thick	Penta	Iso	STR	Raised	Straight	Granulate
7	<i>F.microphylla</i>	Thin	Penta	Iso	STR	Raised	Straight	Striate
8	<i>F.sinaica</i> v. <i>pseudocretica</i>	Thin	Flattened	El.	STR	Raised	Straight	Striate
9	<i>F.sinaica</i> v. <i>Longipes</i>	Thin	Flattened	El.	UND	Channelled	Convex	Granulate
10	<i>F.sinaica</i> .v. <i>kahirina</i>	Thin	Flattened	El.	UND	Channelled	Convex	Granulate
11	<i>F.schweinfurthii</i>	Thin	Penta	Iso	STR	Raised	Straight	Smooth
12	<i>F.tenuifolia</i>	Thin	Tetra	Iso	STR	Raised	Straight	Striate
13	<i>F.thebaica</i>	Thin	Hexa	Iso	STR	Channelled	Convex	Smooth

**Table 7** Recommended classification of the studied *Fagonia* sp.

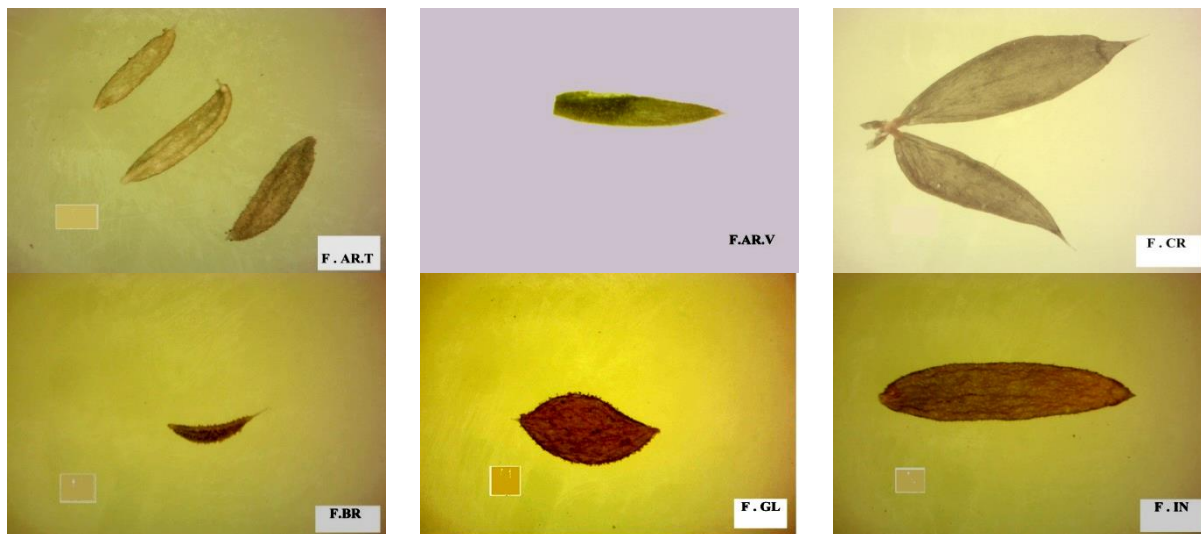
Group	I	II	III	IV
Character	Cylindrical stem	Quadrated Stem	Striate stem	Terete stem
Species	<i>F.indica</i>	<i>F.bruguieri</i> <i>F.cretica</i> <i>F.sinaica</i> <i>F.tenuifolia</i>	<i>F.arabica</i> v. <i>viscidissima</i> <i>F.microphylla</i> <i>F.schweinfurthii</i> <i>F.thebaica</i>	<i>F.arabica</i> v. <i>thilhoana</i> <i>F.glutinosa</i>

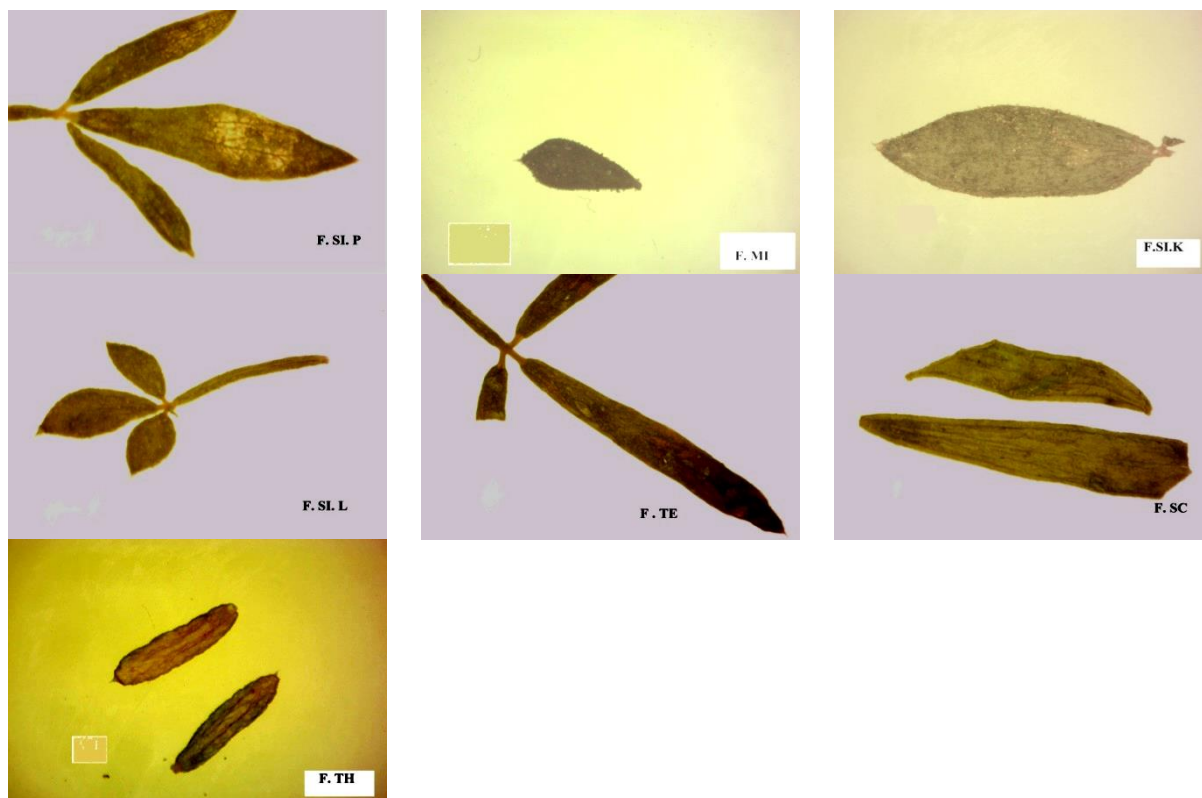




**Fig. 1** Photographs of the herbarium sheets of the studied *Fagonia* species

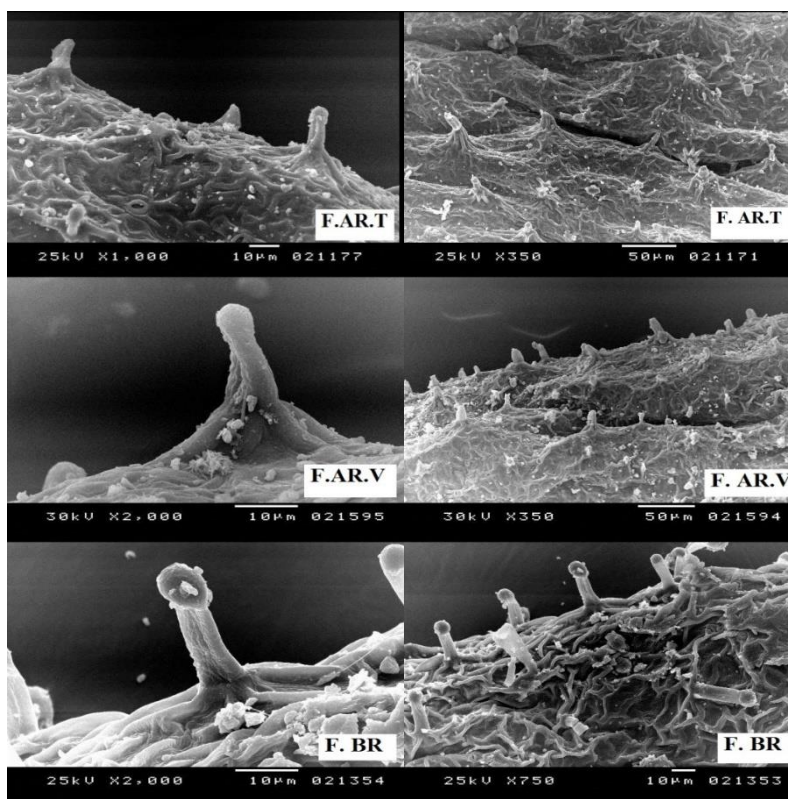
- |  |  |
|--|--|
| 1-F. AR. T = <i>Fagonia arabica</i> L. Var.thilhoana.  | 2-F.AR.V = <i>Fagonia arabica</i> L. var.viscidissima.     |
| 3-F.BR = <i>Fagonia bruguieri</i> DC.                  | 4-F.CR = <i>Fagonia cretica</i> L.                         |
| 5-F.GL= <i>Fagonia glutinosa</i> Delile                | 6-F.IN= <i>Fagonia indica</i> Burm.                        |
| 7-F.MI = <i>Fagonia microphylla</i> Pomel.             | 8-F.SLP = <i>Fagonias sinaica</i> Boiss var. Pseudocretica |
| 9- F.SLL = <i>Fagonia sinaica</i> Boiss .var.longipes. | 10-F.SL. K = <i>Fagonia sinaica</i> Boiss. var.kahirina.   |
| 11- F.SC = <i>Fagonia schweinfurthii</i> Hadidi.       | 12- F. TE = <i>Fagonia tenuifolia</i> Steud                |
| 13-F.TH = <i>Fagonia thebaica</i> Boiss.               |  |



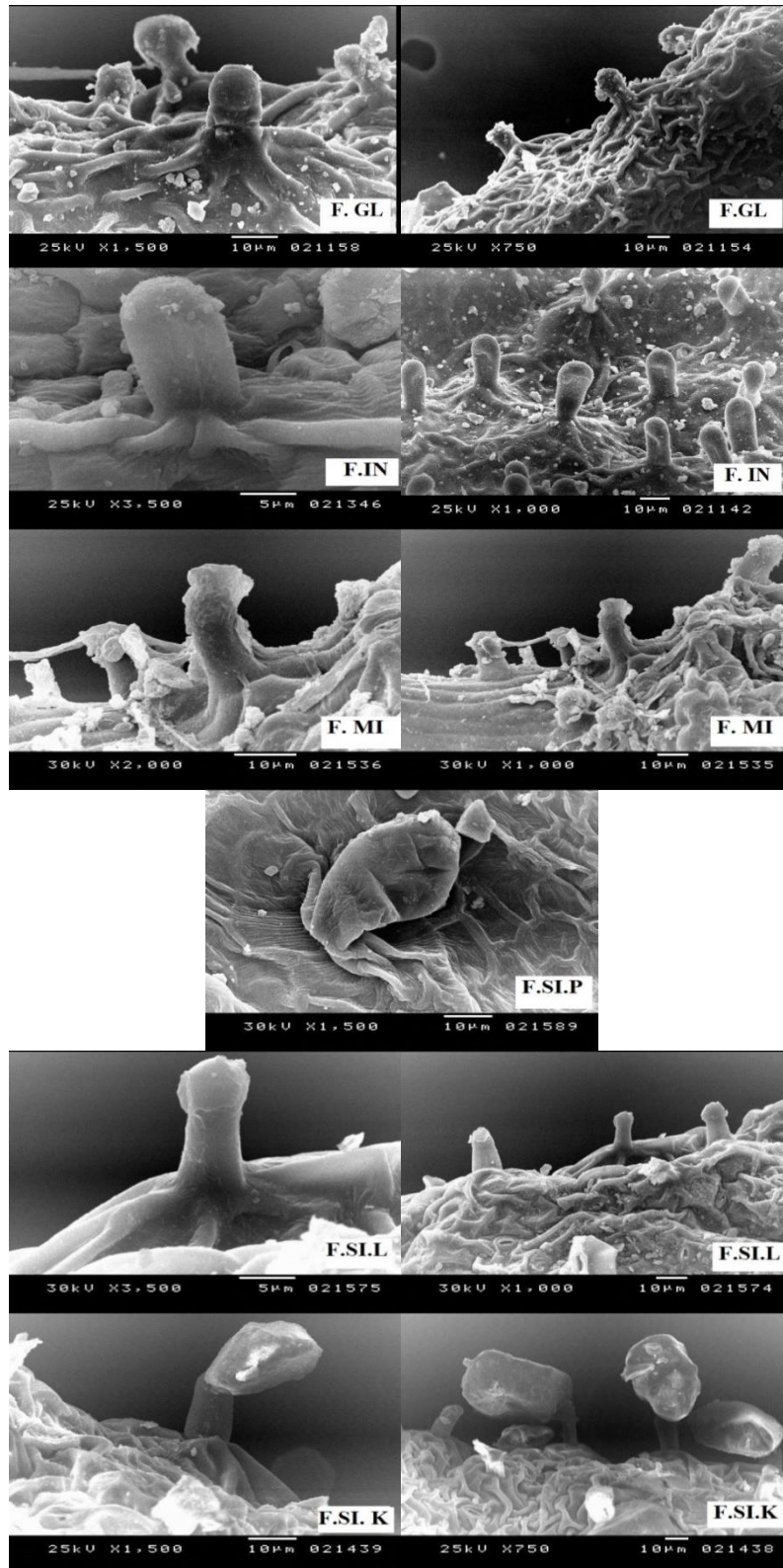


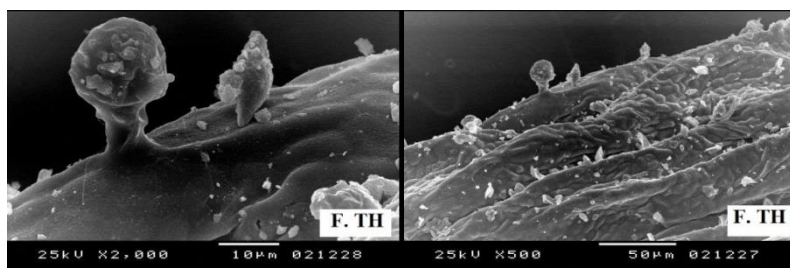
**Fig. 2:** Stereomicroscope photographs of Leaf shapes in the studied *Fagonia* species.

<b>F.AR.T</b> = <i>Fagonia arabica</i> L. var. <i>thilhoana</i>	<b>F.AR.V</b> = <i>Fagonia arabica</i> L. var. <i>viscidissima</i>
<b>F.BR</b> = <i>Fagonia bruguieri</i> DC	<b>F.CR</b> = <i>Fagonia cretica</i> L
<b>F.GL</b> = <i>Fagonia glutinosa</i> Delile	<b>F.IN</b> = <i>Fagonia indica</i> Burm.
<b>F.MI</b> = <i>Fagonia microphylla</i> Pomel	<b>F.SLP</b> = <i>Fagonia sinaica</i> Boiss var. <i>pseudocretica</i>
<b>F.SLL</b> = <i>Fagonia sinaica</i> Boiss var. <i>longipes</i>	<b>F.SLK</b> = <i>Fagonia sinaica</i> Boiss var. <i>kahirina</i> .
<b>F.SC</b> = <i>Fagonia schweinfurthii</i> Hadidi.	<b>F.TE</b> = <i>Fagonia tenuifolia</i> Steud.
<b>F.TH</b> = <i>Fagonia thebaica</i> Boiss.	

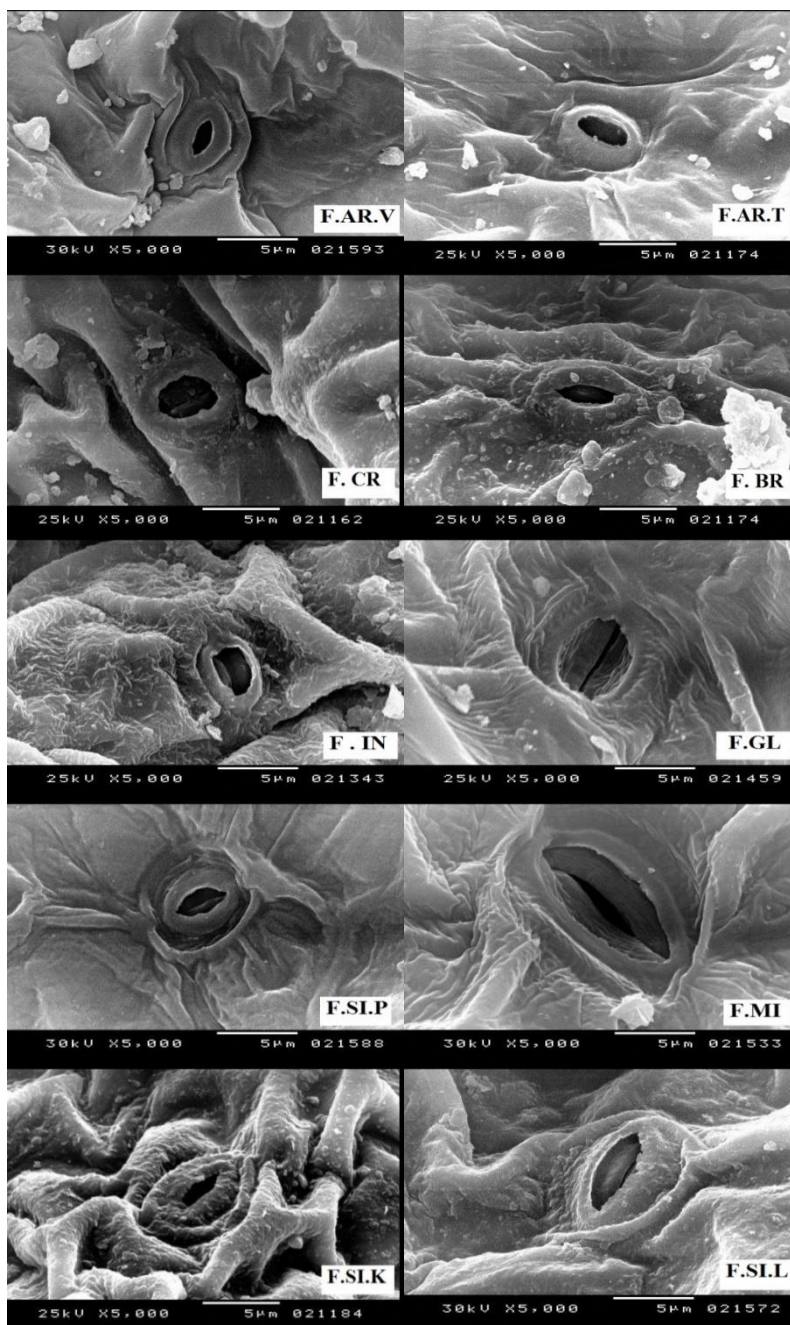


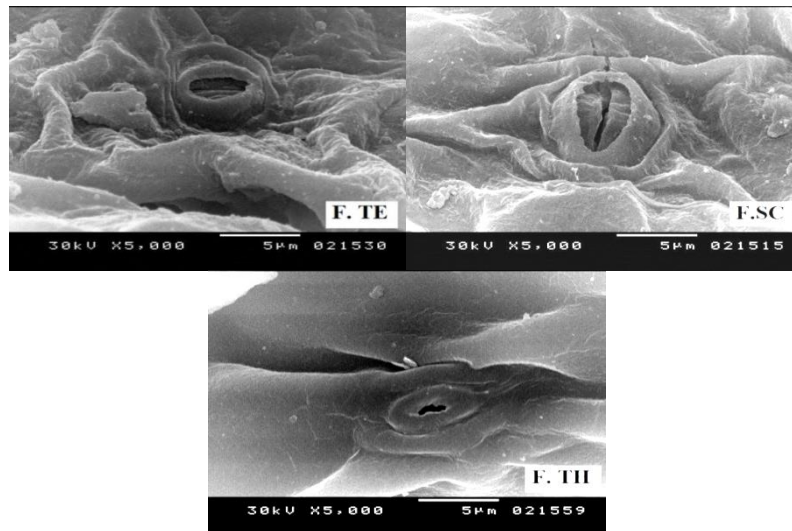






**Fig. 3 :** SEM micrographs showing hair characters of *Fagonia* species.

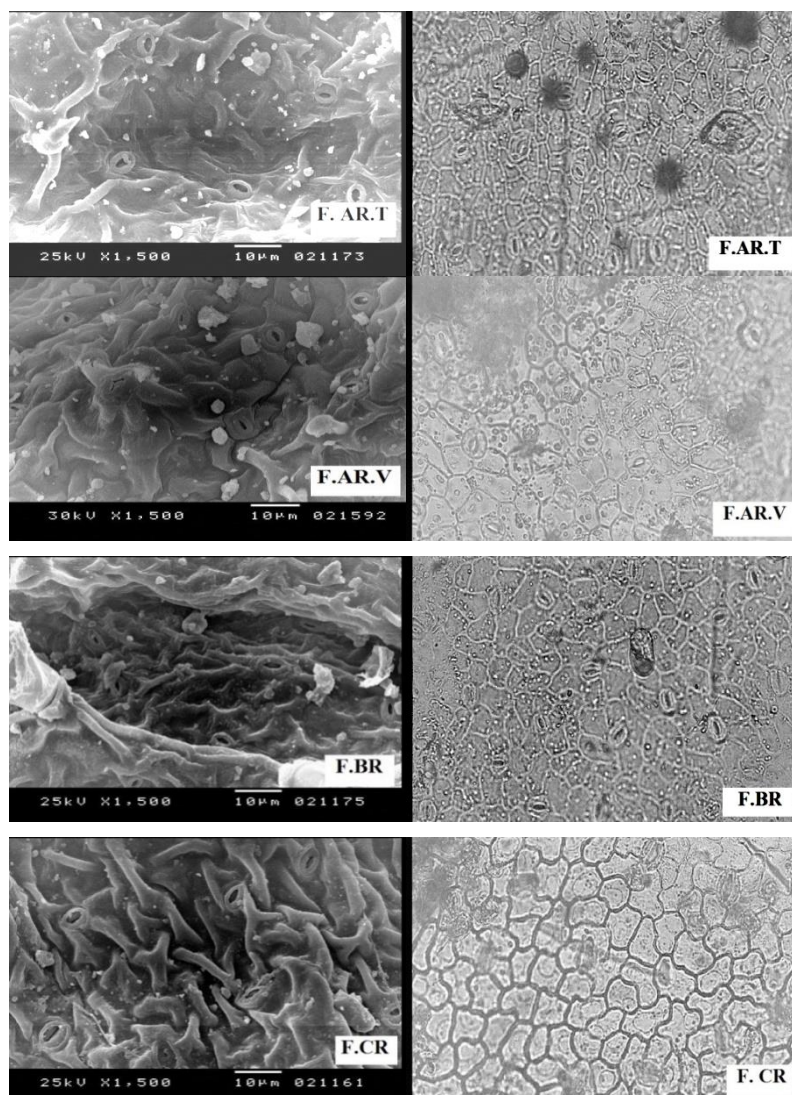


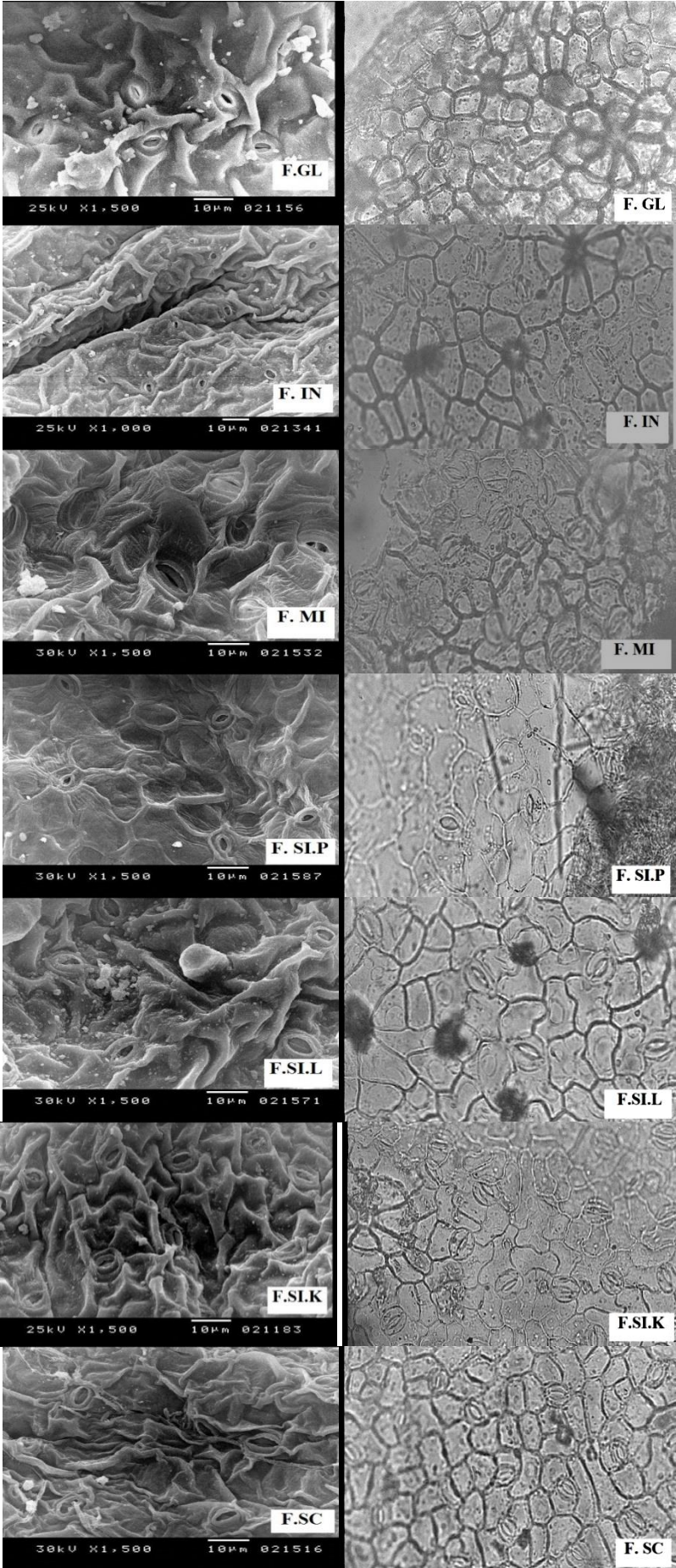


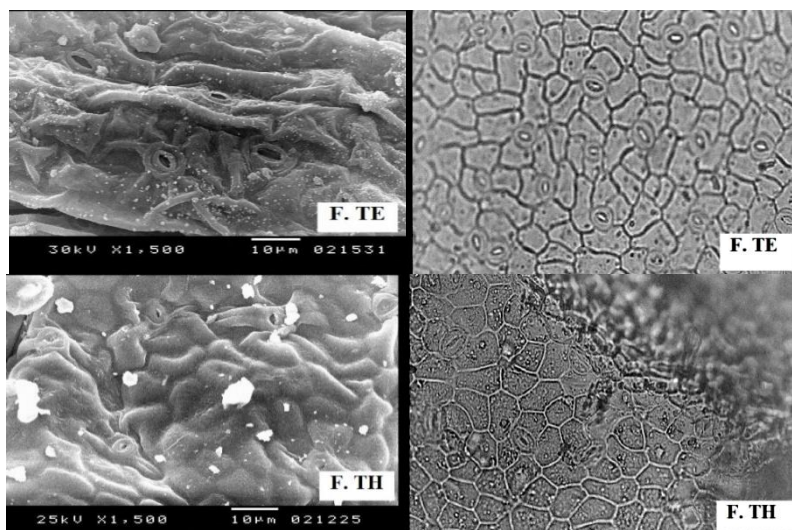
**Fig. 4:** SEM micrographs showing Stomata and guard cells variations of *Fagonia* species

**F.A.R.T**=*Fagonia arabica*L. var.*thilhoana*  
**F.BR** =*Fagonia bruguieri* DC.  
**F.GL** =*Fagonia glutinosa* Delile  
**F.MI** =*Fagonia microphylla* Pomel  
**F.SLL** =*Fagonia sinaica* Boiss var.*longipes*  
**F.SC**=*Fagonia schweinfurthii* Hadidi.  
**F.TH**=*Fagonia thebaica* Boiss.

**F.A.R.V**=*Fagonia arabica*L. var.*viscidissima*  
**F.CR** =*Fagonia cretica*L.  
**F.IN**=*Fagonia indica* Burm.  
**F.SLP** =*Fagonia sinaica* Boiss var. *pseudocretica*  
**F.SLK**=*Fagonia sinaica* Boiss var. *kahirina*.  
**F.TE**=*Fagonia tenuifolia* Steud.







**Fig. 5:** Leaf epidermal cell characters micrographs by both light and SEM of *Fagonia* species.

<b>F.A.R.T</b> = <i>Fagonia arabica</i> L. var. <i>thilhoana</i>	<b>F.A.R.V</b> = <i>Fagonia arabica</i> L. var. <i>viscidissima</i>
<b>F.BR</b> = <i>Fagonia bruguieri</i> DC.	<b>F.CR</b> = <i>Fagonia cretica</i> L.
<b>F.GL</b> = <i>Fagonia glutinosa</i> Delile	<b>F.IN</b> = <i>Fagonia indica</i> Burm.
<b>F.MI</b> = <i>Fagonia microphylla</i> Pomel.	<b>F.SLP</b> = <i>Fagonia sinaica</i> Boiss var. <i>pseudocretica</i>
<b>F.SLL</b> = <i>Fagonia sinaica</i> Boiss var. <i>longipes</i>	<b>F.SLK</b> = <i>Fagonia sinaica</i> Boiss var. <i>kahirina</i> .
<b>F.SC</b> = <i>Fagonia schweinfurthii</i> Hadidi.	<b>F.TE</b> = <i>Fagonia tenuifolia</i> Steud.
<b>F.TH</b> = <i>Fagonia thebaica</i> Boiss.	

*Identification key of the studied Fagonia species according to vegetative morphological characters*

- 1-Short spiny stipules, never exceed 5mm
  - 2-Uni-Tri-foliolate leaves
    - 3-Glabrous stem ----*F.tenuifolia*
    - 3-Hairy stem -----*F.glutinosa*
    - 3-Woolly stem -----*F.thebaica*
  - 2-Tri-foliolate leaves
    - 3-Sparsely hairy
      - 4-Leaves ovate----*F.microphylla*
      - 4-Leaves linear to lanceolate*F.cretica* & *F.sinaica*
- 1-Mid.spiny stipules
  - 2-Unifoliolate leaves -----*F.arabica* v.*thilhoana*
  - 2-Uni-Tri-foliolate leaves *F.bruguieri*
- 1-Long spiny stipules exceed 10mm
  - 2-Unifoliolate leaves
    - 3-Glabrous stem ----*F.indica*
    - 3- Woolly stem -----*F.arabica* v.*viscidissima*
  - 2-Trifoliolate leaves -----*F.schweinfurthii*

## Discussion

From the most important taxonomic works concerning genus *Fagonia* is that of Ozenda and Quezeel (1956) who revised the Zygophyllaceae of North Africa and Sahara desert. About 20

*Fagonia* species including several endemic species are known from this area. They proposed a classification of the genus according to vegetative morphological characters. This work was followed by Porter (1963) who pointed out that the North American species of *Fagonia* are distinct from the South American ones. Up to now, *Fagonia* is one of the critical genera of family Zygophyllaceae. Many species are very closely allied and are linked by intermediate forms, which make a species delimitation rather difficult. Radford (1986) stated that evidence from plant morphology provided the basic language for plant characterization, identification, classification and relationships. Thus, vegetative morphological characters; especially that of leaf; have been employed as a basis for classification since the early days of taxonomy. In fact, vegetative characters can be unreliable because of the similarity happened between unrelated species, but even so Davis and Heywood (1973) deplored the neglect of morphological characters as one of the most serious errors which delay the achievement of a natural system.

Vegetative morphological characters consider the first step in identification and classification in all the botanical works. Davis and Heywood (1963) indicated that whatever other evidence be employed in the construction of a classification, practical considerations demand that the characters used are expressed morphologically. In spite of the fact of the similarity between unrelated

genera in the morphological characters, we cannot neglect these characters in constructing the keys in the different floras and as first step in identification. According to the importance of the vegetative characters, the macro- and micro-morphological characters of the available Libyan species of *Fagonia* were studied in this work. From the results obtained we noticed that *F. sinaica*, with its three varieties, is the only species which has pink stem and can be easily identified in the field. The recognition of its varieties cannot be done without the aid of the micro characters of the leaves, and even so within limit. The outline of the stem can be an easy character in distinguishing the studied species into four categories as mentioned in table 7. This division does not coordinates with both El-Hadidi (1966) and Ozenda and Quezel (1956) revisions of the genus. Meanwhile, the results obtained revealed that the length of the spiny stipules can be of taxonomic importance in the delimitation of the studied taxa. This character divides the studied species into two groups, these groups can be further identified according to the types of leaves; unifoliate versus trifoliate; and the type and density of hairs. The leaf shape is mostly lanceolate, except in *F. arabica* v. *thilhoana*, *F. glutinosa*, *F. microphylla* and *F. sinaica* v. *lonipes* which have ovate leaf blades, beside the leaf margins and apices are of minor taxonomic importance in the delimitation of the studied taxa. This conclusion coordinates Porter (1963) opinion who state that □ absolute size is not always a reliable character a variation may accompany the change of climatic conditions e.g. precipitation□. He considered pubescence and stipular type to be more constant under such conditions.

Stace (1984) stated that leaf microcharacters are more conservative than the gross or macrocharacters, and hence more trustworthy as taxonomic indicators. Thus, the epidermal cells have been examined by both light and SEM to investigate the leaf microcharacters in the studied species. The epidermal cell characters are categorized into four categories according to Barthlott (1981). The arrangement and shape of cells (1<sup>st</sup>. Sculpture), the fine relief of the outer cell wall (2<sup>nd</sup>. Sculpture), thickness and pitting of the anticlinal and periclinal walls (3<sup>rd</sup>. Sculpture) and finally the phytoglyph which cover the full range of features to be seen on the leaf surface, this term was emphasized by Carr *et al.* (1971). Our results revealed that all the studied species are enriched by bicellular either tabular or glandular hairs with different densities, except

three species; *F. cretica*, *F. schweinfurhii* and *F. tenuifolia*; are glabrous. The surface of the leaves has wax depositions varied in densities and size of the granules and this may be an adaptive feature to the xeric conditions on the plants. All the species has anomocytic stomata with different stomatal indices, but the guard cells have different lengths mostly range from 5 to 8 µm, except *F. microphylla* which has guard cells more than 12 µm length. These variations can be attributed to the water availability and the different ecological factors. The epidermal cells, as appeared by the light microscope are homogenous, have thin or thick walls with undulate, wavy or straight periclinal walls. The cell shapes mostly tetra-, penta- or hexagonal or irregularly flattened in *F. cretica* and *F. sinaica* (three varieties). The cell boundaries, as seen by SEM, are raised with straight periclinal walls or channeled with concave periclinal walls. The secondary sculpture on the periclinal walls show some variations where it was smooth in *F. cretica*, *F. schweinfurhii* and *F. thebaica*, papillate in *F. bruguieri* and granulate or striate in the rest of the studied species.

This study has elucidated the importance of the vegetative macro characters in the taxonomy of the genus as first step in identification, especially the length of the spiny stipules and the type of leaf blade. Leaf or leaflet shape as well as margins and apices are of minor taxonomic importance. Microcharacters can be used to recess the identification and can be consider as the second step in identification.

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