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Palynological study of the genus *Fagonia* L. (Zygophyllaceae, Zygophylloideae) in Libya.

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Highlights

- **The genus Fagonia comprises nine species growing in different phytogeographical regions in Libya.**
- **Twelve Fagonia L. taxa, representing nine species and three varieties, collected from different locations in Libyan documented in details using light microscopy (LM) and scanning electron microscopy (SEM).**
- **The palynological results obtained revealed that the studied taxa have similar characters i.e. eurynopalynous.**

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ABSTRACT

The pollen morphology of twelve *Fagonia* L. taxa, representing nine species and three varieties, collected from different locations in Libya were subjected in this study and documented in detail using light microscopy (LM) and scanning electron microscopy (SEM). Pollen grains characters include shape (Polar axis, Equatorial axis), apertures type, colpus and pore length, colpus edge, and exine sculpture (surface) were studied and photographed. The obtained results revealed that palynological characters can help in the identification of the studied taxa. Polar axis, Equatorial axis, and pore length varied as well as within the studied taxa. The result of the ANOVA tests indicates that the colpus and pore lengths are significantly different within the studied taxa. An identification key, as well as clustering analyses, based on the results obtained, have been constructed. The results indicated that the pollen characters within the studied *Fagonia* taxa are eurypalynous discussed with the previous taxonomic works.

1. Introduction

Zygophyllaceae is a widespread family of about 27 genera classified over 285 species subdivided into five subfamilies (Sheahan & Chase 1996; 2000). The genus *Fagonia* is a member of Zygophyllaceae, subfamily Zygophiloideae that is included in the eurosid I clad (APG III, 2009). In Libya, the Zygophyllaceae comprises 8 genera and 25 species (Feng *et al.*, 2013). One of the important genera belonging to this family is genus *Fagonia.* The genus comprises nine species growing in different phytogeographical regions in Libya (Abdul Ghafoor, 1977). The taxonomy of the genus is very difficult mainly due to a high degree of phenotypic plasticity and adaptations to climatic conditions (Zohary 1972; Danin 1996). Accordingly, the taxonomy of the genus has been faced with many ideas. Ozenda and Quézel (1956) grouped the North African *Fagonia* species into four natural groups; which can be considered as sections according to Melbourne System of Nomenclature (2012); this division based mainly on 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, Batanouny and Batanouny (1970) and El Hadidi (1966) described 18 Egyptian species of *Fagonia* and constructed an artificial key for their identification based on the morphological characters of the species. El Hadidi (1966) divided the Egyptian *Fagonia* species into three groups according to variations in the internal structure.

The delimitation of species in *Fagonia* is known for being notoriously difficult and confusing. This is caused by the great variation in most morphological characters within many species. The first complete modern treatment of the genus has been done by Beier (2005). According to this revision, *Fagonia* is considered a genus of 34 species, distributed mainly in warm and arid areas all over the world, except Australia, with a great diversity of species in the Horn of Africa region and Baja California. Genus *Fagonia* is one of the critical genera of the Zygophyllaceae, as mentioned. Many species are very closely allied and are linked by intermediate forms, which make a species delimitation rather difficult. Previous works on the genus are based mainly on vegetative characters. Palynological investigations are few, and if present, concerning the whole family as that of Perveen and Qaiser (2006) who studied pollen morphology of 14 species representing five genera of the family Zygophyllaceae from Pakistan. Bukhari *et al.* (2014) studied the pollen morphology of *Zygophyllum simplex, Zygophyllum migahidii, Tribulus terrestris, Tribulus macropterus, Fagonia glutinosa* and *F.indica* in the species of Saudi Arabia. El-Atroush *et al.* (2015) studied the pollen morphology and protein bands of Egyptian *Nitraria* sp. including *Fagonia Arabica.* Recent work by Naghiloo *et al.* (2020) restricted the pollen biology of the Zygophyllaceae and its effect on forage activity.

This work aims to use the pollen character, as a modern taxonomical tool, to clarify the relationship between the *Fagonia* species recorded in the Libyan Flora. At the same time to clarify, the

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taxonomical variations presented in the pollen morphological characters within the Libyan *Fagonia* species.

2. Materials and methods

The study area extends from the eastern plains (Al-Gabal Al-Akhdar and Derna) in the east to Gabal Naffusah (Nalut, Giado, and Ghadames) in the west to Sebha and El-Kufra in the south, the name of 20 visited locations as shown in (Table1). Flowering specimens of the different species found in each location have been collected and used in this study.

Fagonia species grow in different phytogeographical regions with different environmental conditions. Table 2 shows the studied *Fagonia* species which were gathered and collected from the field and allocate in Benghazi and Tripoli university herbaria. These species prefer sandy or gravelly habitats and tolerate soil salinity. The names of the species are according to the World Checklist of Selected Plant Families (WCPF) the global species resources. Five individuals from each species, collected from different locations, have been subjected to this investigation.

Nine species and three varieties belonging to genus *Fagonia* (*F.arabica* L., *F.bruguieri* DC., *F.cretica* L., *F.glutinosa* Delile., *F.indica* Burm, *F.schweinfurthii* Hadidi, *F.sinaica* L., *F.tenuifolia* Steud., and *F.thebaica* Boiss.) were subjected in this study. The collection of specimens through field trips to different locations covering most of the habitats in Libya from Al-Jabal Nafusah to Al-Jabal Al-Akhdar (The Green Mountain) to Sebha in the south. The specimens were identified according to Jafri and El Gadi (1977) and Boulos (2000). The voucher specimens are kept at the herbaria of Botany Department, Faculty of Science, Alexandria University (ALEX).

Pollen grains, of five individuals from each species of *Fagonia*, collected from unopened anthers were acetolyzed according to Erdtman (1966) separately for light microscope investigation. Thirty pollen grain, from each species, have been examined, measured, and photographed by a Motic compound microscope allocated at the taxonomy Lab., Botany Department, Faculty of Science, Alexandria University.

For SEM studies, cleaned stubs were first labeled and the anthers were opened by the needles under a stereomicroscope and sputtered directly onto the cleaned stubs. The stubs were coated with 30 nm of gold in a polaron JFC-1100E coating unit, then examined and photographed with JEOL JSM-5300 SEM in the electron microscopes unit, Faculty of Science, Alexandria University, Egypt. At least 10 pollen grains, in each taxon, were examined by SEM. The terminology used in this work is generally based on that of Faegri (1956). All the measured characters are subjected to an ANOVA test.

Table 1

Name of 20 locations of the collected *Fagonia* species in Libya.

No	Location	Region	No	Location	Region
1	Gharian ,Gebel Nafousa	West	11	Wadi El-Aital	west
2	ShikShook,Giado,Gebel Nafousa	West	12	Sokna	Middle
3	Mesallata	west	13	Tagrenna, Jefren	West
4	Alkhums	west	14	Tazerbo	South
5	Wadi Malah, Nalut	west	15	Gebel Uwainat	South
6	Hun	Middle	16	Wazen	West
7	Wadi Derna	East	17	El-Soda mountain	South
8	Tobruk	East	18	Benghazi, Teka	East
9	Weshka	Middle	19	Al-Abidaa, Shahat, Ras El-Hellal	East
10	Brak, Sebha	South	20	Musaid	East

Table 2

Locations of *Fagonia* specimens used in present study.

No.	Name of taxa	Reference of the name after Tropicos	Location (s)
1	*Fagonia arabica* var. *thilhoana* Maire	Sp. Pl. 1: 386 (1753)	15
2	*Fagonia arabica* var.*viscidissima*Maire.	Sp. Pl. 1: 386 (1753)	8 , 10 , 14 , 15
3	*Fagonia bruguieri* DC.	Prodr. 1: 704(1824)	6 , 9 , 10
4	*Fagonia cretica* L.	Sp. Pl. 3: 86 (1753)	1, 2, 3, 4, 5, 6, 7, 8, 19
5	*Fagonia glutinosa* Delile.	Descr. Égypte, Hist. Nat. 230, t. 28. f. 2	2 , 6 , 9 , 17 , 10 ,16
6	*Fagon indica* Burm.	Fl. Indica 102(1768)	6, 10 , 18 , 15, 20
7	*Fagonia schweinfurthii* Hadidi	Webbia 33:38(1978)	9 , 6 , 17
8	*Fagonia sinaica* var. *longipes* Pamp.	Diagn. Pl. Orient., ser. 1, 1: 61 (1843)	1 , 2 , 5
9	*Fagonia sinaica* var. *pseudocretica*Maire.	Diagn. Pl. Orient., ser. 1, 1: 61 (1843)	9 , 11 , 12
10	*Fagonia sinaica* var. *kahirina* Boiss.	Diagn. Pl. Orient., ser. 1, 1: 61 (1843)	1 , 6 , 13
11	*Fagonia tenuifolia* Steud.	Fl. Orient. 1: 909 (1867)	5 , 6, 17 , 9
12	*Fagonia thebaica* Boiss.	Diagn. Pl. Orient. 8: 121 (1849)	15

3. Results

Pollen grains of the studied *Fagonia* species are monomorphic or dimorphic, symmetric, and isopolar with different shapes and sizes. The dimorphic pollen taxa have either two types of apertures, variations in Polar axis length, or both. The two types of apertures are tricolpate or tricolporate with lolongate pores and, mostly, syncolpate at the poles. Exine tectate with micoreticulate or foveolate tectum ornamentation (Table 3).

1- *F. arabica var.thilhoana* Maire.

The pollen grains show dimorphism phenomenon with two different shapes and sizes, and the surface ornamentation on pole.

These two forms donated the symbols "A" and "B". Pollen shape, in the two types, is subprolate to prolate. The polar axis from 9.7 to 18.2 µm, with a mean of 13.8 µm while the equatorial axis length from 8.2 to 9.44 µm, with a mean of 8.99 µm. The aperture type is tricolpate or tricolporate, colpus length from 7.7 to 14.1 µm (Table 3).

Type A (Fig. 1) pollen subprolate, tricolporate with apocolpate apertures and ornamented colpi margins. Pore 2 to 2.4 µm long. Exine has microreticulate tectum in both the mesocolpium region and poles (Fig. 2).

Type B (Fig. 3) pollen shape is prolate, tricolpate with long colpi, which merge at the poles giving a syncolpate aperture in the polar view. The colpi have ornamented margins. Exine has foveolate tectum throughout the whole pollen (Fig. 4).

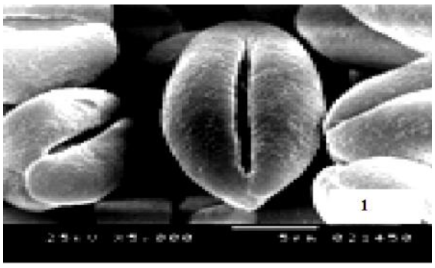

Fig. 1. F. *arabica* var. *thilhoana* Maire type A

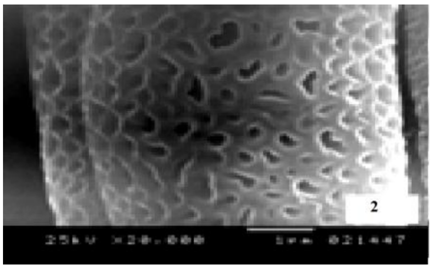

Fig. 2. F. *arabica* var.*thilhoana* Maire type A

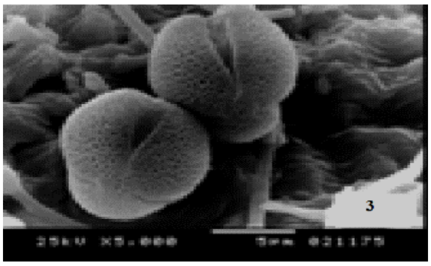

Fig. 3. F. *arabica* var.*thilhoana* Maire type B

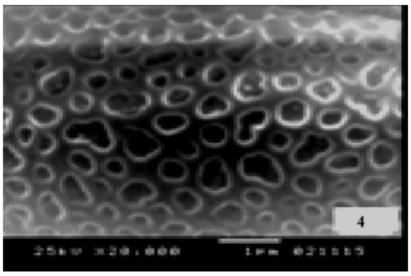

Fig. 4. F. *arabica* var.*thilhoana* Maire type B

2- *F.arabica var.viscidissima* Maire.

The pollen grains in this species show dimorphism, Pollen grains, perprolate to spheroidal. The polar axis 7.61 to 16.7 µm, with a mean of 11.8 µm while the equatorial axis 5.7 to 8.09 µm, with a mean of 6.92 µm. Tricolpate or tricolporate apertures with colpus length varies from 6.66 to 12.85 µm (Table 3).

Type A (Fig. 5) Pollen perprolate with tricolpate aperture. The colpi are shorter than the polar axis with ornamented margins. Exine has microreticulate tectum in both the mesocolpium region and poles (Fig. 6).

Type B (Fig. 7) pollen shape is spheroidal with tricolporate aperture. The colpi extend toward the poles where they merge giving a syncolpate colpi in the polar view with smooth margins. Exine has microreticulate tectum throughout the whole pollen grain (Fig. 8).

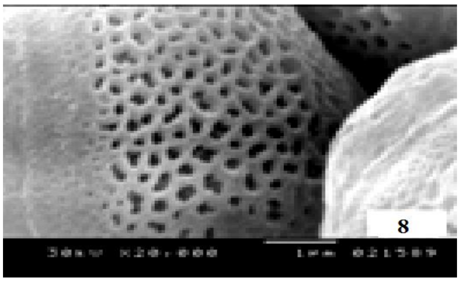

Fig. 5. F.*arabica* var.*viscidissima* Maire type A

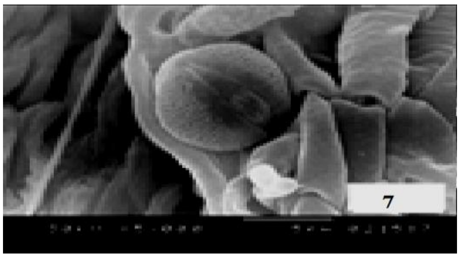

Fig. 6. F.*arabica* var.*viscidissima* Maire type A

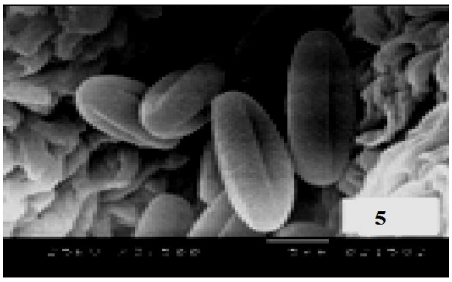

Fig. 7. F.*arabica* var.*viscidissima* Maire type B

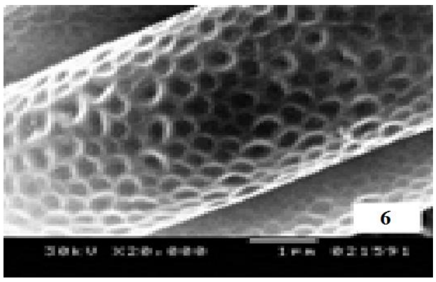

Fig. 8. F.*arabica* var.*viscidissima* Maire type B

3- *F. bruguieri* DC.

Pollen shape is subprolate. The polar axis from 9.1 to 14.5 µm, with a mean of 11.43 µm while the equatorial axis from 7.2 to 8.6 µm, with a mean of 7.77 µm (Fig. 9). Tricolporate aperture with long colpi, which merge at the poles giving a syncolpate colpi in the polar view, with smooth margins. Colpi length from 6.7 to 8.4 µm. Pore lolongate, 3.02 to 4.3 µm length (Table 3). Exine has microreticulate tectum throughout the whole pollen grain (Fig. 10).

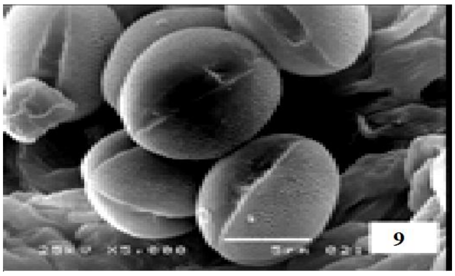

Fig. 9. F. *bruguieri* DC

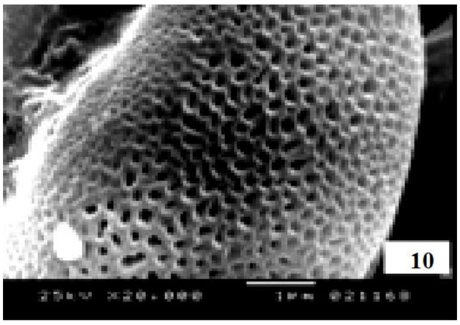

Fig. 10. F. *bruguieri* DC

4 - *F. cretica* L.

Pollen shape is prolate. The polar axis from 8.6 to 13.9 µm, with a mean of 11.64 µm while the equatorial axis from 7.1 to 8.9 µm, with a mean of 8.1 µm (Fig. 11). Tricolporate aperture with long colpi merge at the poles giving a syncolpate colpi in the polar view with smooth margins and length varies from 7 to 12.6 µm. Pore lolongate, from 3.5 to 4.7 µm length (Table 3). Exine has foveolate tectum throughout the whole pollen grain (Fig. 12).

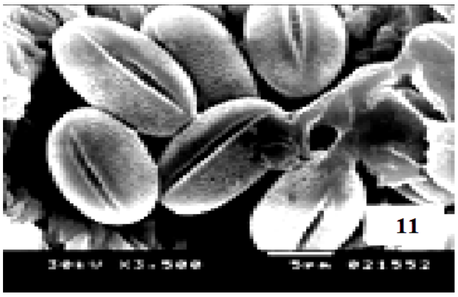

Fig. 11. F. *cretica L*

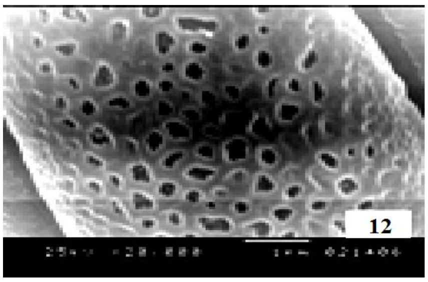

Fig. 12. F. *cretica L*

5 - *F. glutinosa* Delile.

The pollen grains show dimorphism. Pollen grains, in the two types, are symmetric, isopolar, prolate to subprolate. The polar axis from 9.6 to 14.3 µm, with a mean of 10.76 µm while the equatorial axis from 6 to 8.88 µm, with a mean of 7.71 µm. The aperture type is tricolpate or tricolporate with colpus length varies from 7 to 12.5 µm (Table 3).

Type A (Fig. 13) pollen shape is prolate with tricolpate aperture. The colpi shorter than the polar axis with ornamented margins. Exine has microreticulate tectum (Fig. 14).

Type B (Fig. 15) pollen shape is subprolate with tricolporate aperture. The colpi extend toward the poles where they merge giving a syncolpate colpi in the polar view with smooth margins. The pores lolongate, 2.2 to 2.8 µm in length. Exine has microreticulate tectum (Fig. 16).

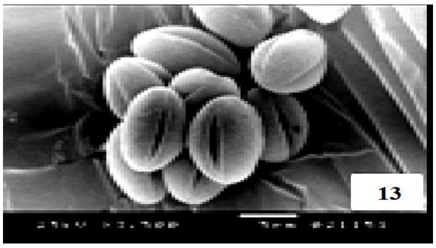

Fig. 13. F. *glutinosa* Delile. type A

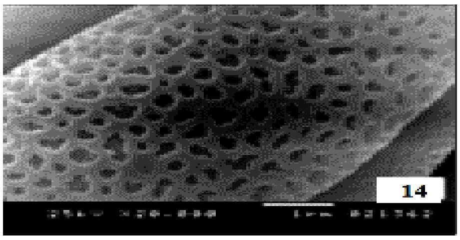

Fig. 14. F. *glutinosa* Delile. type A

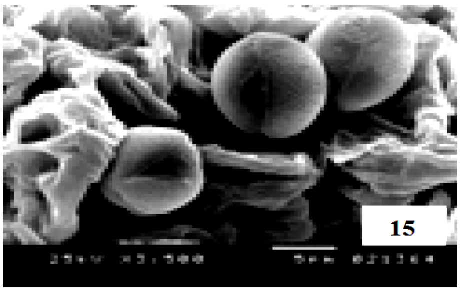

Fig. 15. F. *glutinosa* Delile. type B

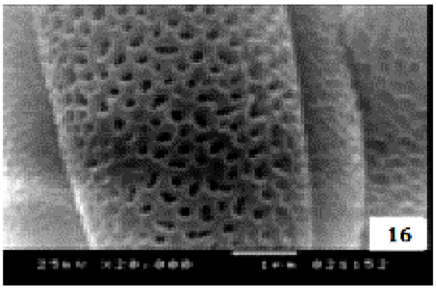

Fig. 16. F. *glutinosa Del*ile. type B

6 - *F. indica* Burm.

Pollen shape is subprolate. The polar axis from 7.77 to 11.3 µm, with a mean of 9.04 µm while the equatorial axis from 6.45 to 7.3 µm, with a mean of 6.81 µm (Fig. 17). Tricolporate aperture with long colpi which merge at the poles giving syncolpate colpi in the polar view with smooth margins and length varies from 6.11 to 9 µm. Pore lolongate, 1.14 - 2.91µm length (Table 3). Exine has microreticulate tectum (Fig. 18).

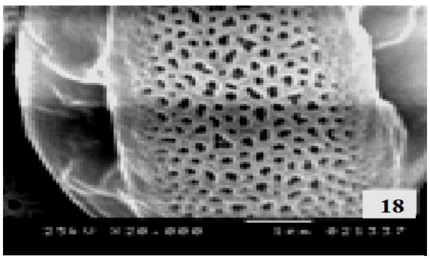

Fig. 17. F. *indica* Burm

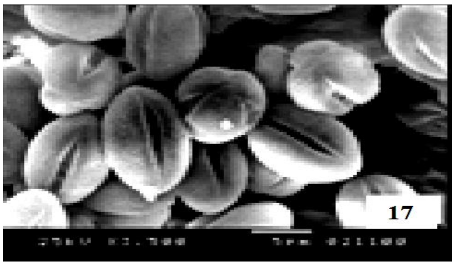

Fig. 18. F. *indica* Burm

7- *F. sinaica var. pseudocretica* Pamp.

Pollen shape is prolate. The polar axis from 10.33 to 11.6 µm, with a mean of 10.7 µm while the equatorial axis from 6.33 to 8.33 µm, with a mean of 7.26 µm (Fig. 19). Tricolporate aperture with long colpi which merge at the poles giving syncolpate colpi in the polar view with smooth margins and length from 9.33 to 11 µm. Pore lolongate, 2 to 3.33 µm length (Table 3). Exine has microreticulate tectum (Fig. 20).

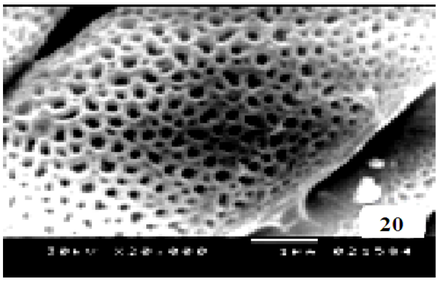

Fig. 19. F. *sinaica* var. *pseudocretica* Pamp

Fig. 20. F. *sinaica* var. *pseudocretica* Pamp

8 - *F. sinaica var. longipes* Maire.

Pollen shape is subprolate. The polar axis from 9.33 to 10.66 µm, with a mean of 9.88 µm while the equatorial axis from 7.33 to 8.09 µm, with a mean of 7.81 µm (Fig. 21). Tricolporate aperture with long colpi, which merge at the poles giving syncolpate colpi in the polar view with smooth margins. The colpi from 7 to 8.66µm long. Pore lolongate, from 2.38 to 3.33 µm length (Table 3). Exine has microreticulate tectum (Fig. 22).

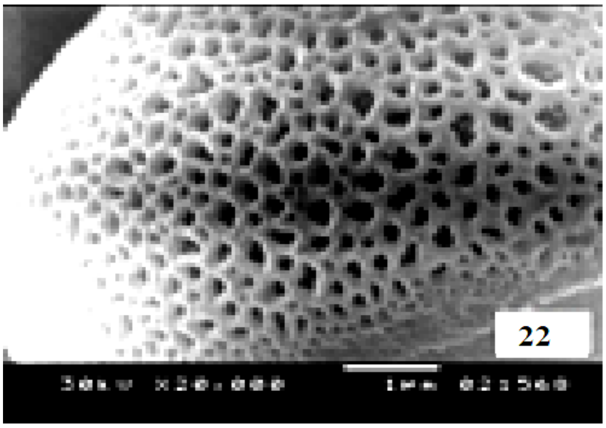

Fig. 21. F. *sinaica* var. *longipes* Maire

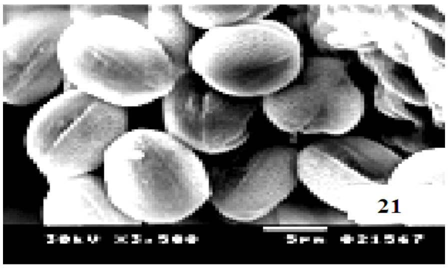

Fig. 22. F. *sinaica* var. *longipes* Maire

9 - *F. sinaica var. kahirina* Boiss.

Pollen shape is subprolate . The polar axis from 6.7 to 11.05 µm, with a mean of 9.26 µm. The equatorial axis from 6.57 to 8.5 µm, with a mean of 7.89 µm (Fig. 23). Tricolporate aperture with long colpi from 5.7 to 8.94 µm, which merge at the poles giving syncolpate colpi in the polar view with smooth margins. Pore lolongate, from 2 to 3.15 µm (Table 3). Exine with foveolate tectum (Fig. 24).

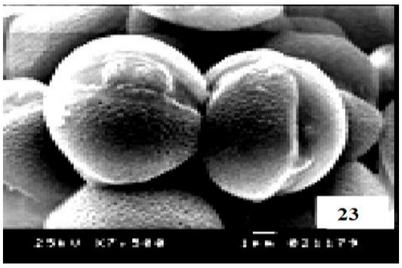

Fig. 23. F. *sinaica* var. *kahirina* Boiss

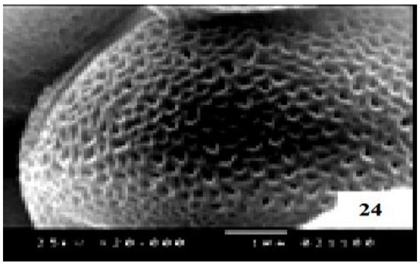

Fig. 24. F. *sinaica* var. *kahirina* Boiss

10- *F. schweinfurthii* Hadidi.

The pollen grains show dimorphism. Pollen grains, in the two types, symmetric, isopolar, subprolate to prolate. The polar axis from 8.33 to 11.6 µm, with a mean of 10.16 µm while the equatorial axis from 6.66 to 9 µm, with a mean of 7.66 µm. The aperture type is tricolpate or tricolporate with colpus from 7.33 to 9.66 µm long (Table 3).

Type A (Fig. 25) Pollen shape is subprolate with tricolporate aperture. The colpi 7.33 - 9.66 µm long with smooth margins and merge at the poles giving syncolpate colpi. The pore lolongate from 1.66-3.33µm. Exine has microreticulate tectum (Fig. 26).

Type B (Fig. 27) pollen shape is prolate with tricolpate aperture. The colpi of the same lengths and merge at the poles giving syncolpate colpi in the polar view with smooth margins. Exine has microreticulate tectum (Fig. 28).

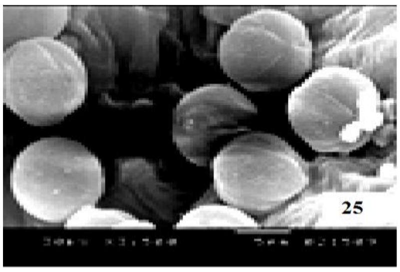

Fig. 25. F. *schweinfurthii Hadidi*. Type A

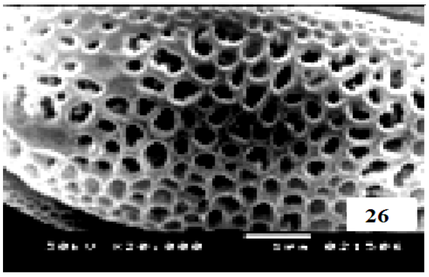

Fig. 26. F. *schweinfurthii Hadidi*. type A

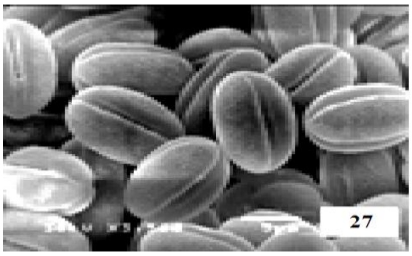

Fig. 27. F. *schweinfurthii Hadid*i. type B

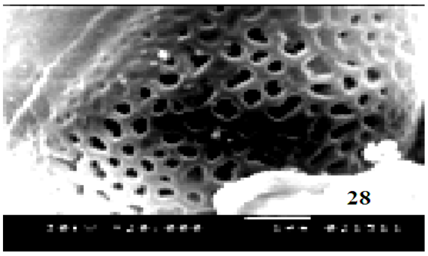

Fig. 28. F. schweinfurthii Hadidi. type B

11- *F. tenuifolia* Steud.

Pollen shape is subprolate. The polar axis from 8.66-10.33µm, with a mean of 9.52 µm while the equatorial axis from 7.33 - 8.83 µm, with a mean of 8.03 µm (Fig. 29). Tricolporate aperture with long colpi 6.66 to 7.83 µm long, which merge at the poles giving syncolpate colpi in the polar view with smooth margins. Pore lo-longate 1.66 - 3.66 µm (Table 3). Exine has micro reticulate tectum (Fig. 30).

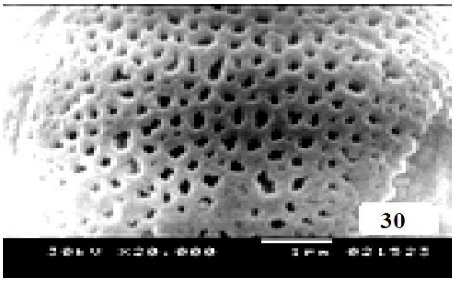

Fig. 29. F. *tenuifolia Steud*

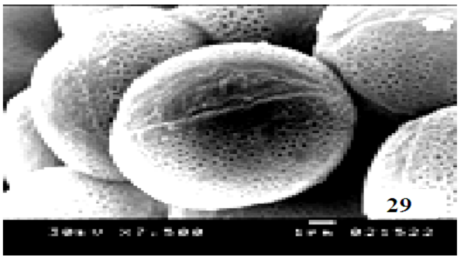

Fig. 30. F. *tenuifolia Steud*

12 - *F. thebaica* Boiss

The pollen grains show dimorphism. Pollen grains, in the two types, subprolate to prolate. The polar axis from 8.4 to 10 µm, with a mean of 9.21 µm while the equatorial axis length varies from 4.2 to 8.4 µm, with a mean of 6.41 µm. The aperture type was tricolpate or tricolporate with colpus length varies from 7.5 to 8.2 µm (Table 3).

Type A (Fig. 31) Pollen shape is subprolate, tricolporate with apocolpate apertures and ornamented colpi margins. Pore 2.5 to 3.8 µm length. The polar axis with smooth margins. Exine has foveolate tectum (Fig. 32).

Type B (Fig. 33) pollen shape is prolate, tricolpate with long colpi, which merge at the poles giving syncolpate aperture in the polar view. The colpi have ornamented margins. The polar axis with reticulate margins. Exine has foveolate tectum (Fig. 34).

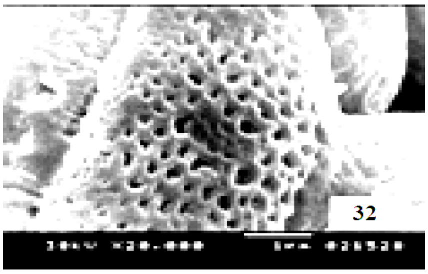

Fig. 31. F. *thebaica Boiss* type A

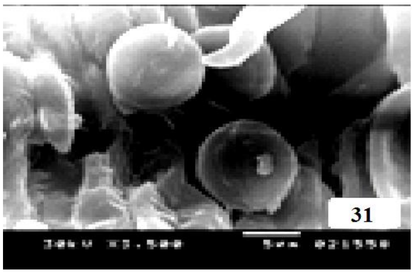

Fig. 32. F. *thebaica Boiss* type A

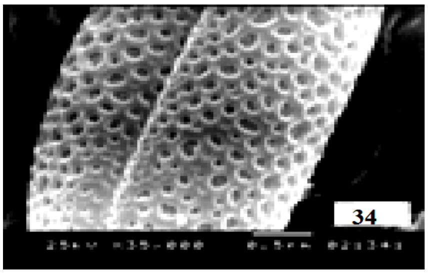

Fig. 33. F. *thebaica Boiss* type B

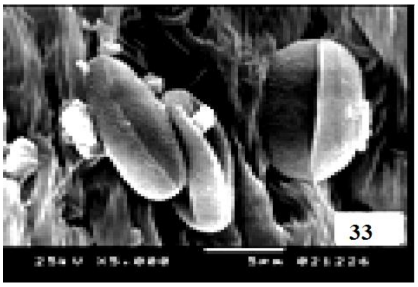

Fig. 34. F. *thebaica Boiss* type B

Table 3

Palynological characters investigated within the studied taxa

	Species	Polar axis (µm)	Equatorial axis (µm)	P/E Shape	Type apertures	Colpus Length (µm)	Pore Length (µm)	Col.edge	Ex.O.
1	***F.arabica v. thilhoana***	9.7–18.2 (13.8)±3.5	8.2–9.4 (9.0)±0.5	1.12 subprolate	Tr.Colp.	7.7–14.1 (10.4)±2.4	2.0–2.4 (2.2)±0.2	Orna	MR
				1.84 Prolate	Tr. Col.		-------	Orna	Fov.
2	***F.arabica v. viscidissima***	7.6–16.8 (11.9)±4.2	5.7–8.1 (6.9)±1.2	2.68 Per prolate	Tr.Col.	6.7–12.9 (9.5)±2.9	-------	Orna	MR
				1.00 spheroidal	Tr.Colp.		2.1–2.9 (2.5)±0.3	Sm.	MR
3	***F. bruguieri***	9.1–14.5 (11.4)±0.3	7.2–8.6 (7.8)±0.6	1.20 Sub prolate	Tr.Colp.	6.7–8.4 (7.8)±0.8	3.0–4.3 (3.6)±0.7	Sm.	MR
4	***F. cretica***	8.6–3.9 (11.6)±2.4	7.1–8.9 (8.1)±0.8	1.43 Prolate	Tr.Colp.	7–12.6 (9.4)±2.2	3.5–4.7 (4.0)±0.5	Sm.	Fov.
5	***F .glutinosa***	9.6–14.3 (10.8)±1.8	6.0–8.9 (7.7)±1.18	1.67 Prolate	Tr.Col.	7–12.5 (8.9)±2.0	-----	Sm.	MR
				1.18 Sub prolate	Tr.Colp.		2.2–2.8 (2.6)±0.3	Sm.	MR
6	***F. indica***	7.8–11.3 (9.0)±1.4	6.5–7.3 (6.8)±0.3	1.32 Sub Prolate	Tr.Colp.	6.1–9.0 (7.4)±1.1	1.1–2.9 (2.0)±0.7	Sm.	MR
7	***F. sinaica v. pseudocretica***	10.3–11.6 (10.7)±0.6	6.3–8.3 (7.3)±0.8	1.48 Prolate	Tr.Colp.	9.3–11.0 (10.3)±0.7	2.0–3.3 (2.5)±0.5	Sm.	MR
8	***F. sinaica v. longipes***	9.3–10.7 (9.9)±0.5	7.3–8.1 (7.8)±0.3	1.26 Sub-Prolate	Tr.Colp.	7-8.7 (7.7)±0.7	2.4–3.3 (2.9)±0.4	Sm.	MR
9	***F. sinaic v. kahirina***	6.7–11.1 (9.3)±1.7	6.6–8.5 (7. 9)±0.8	1.31 SubProlate	Tr.Colp.	5.7–8.9 (7.5)±1.5	2.0–3.2 (2.6)±0.416	Sm.	Fov.
10	***F. schweinfurthii***	8.3–11.6 (10.2)±1.3	6.7–9 (7.7)±0.7	1.53 Prolate	Tr.Colp.	7.3–9.7 (8.6)±0.7	1.7– 3.3 (2.8)±0.5	Sm.	MR
				1.04 spheroidal	Tr.Col.			Sm.	MR
11	***F. tenuifolia***	8.7–10.3 (9.5)±0.6	7.3–8.8 (8.0)±0.7	1.18 Sub-Prolate	Tr.Colp.	6.7–7.8 (7.4)±0.5	1.7–3.7 (2.5)±0.9	Sm.	MR
12	***F. thebaica***	8.4–10.0 (9.2)±0.6	4.2–8.4 (6.4)±1.9	1.09 Sub prolate	Tr.Colp.	7.5–8.2 (7.8)±0.2	2.5–3.8 (3.1)±0.6	Sm.	Fov.
				2 Prolate	Tr.Col.		------	Sm.	Fov.

Abbreviations: Col.=colpus, Tr.Colp.= tricolporate, Orna=ornamented, Sm.=smooth, Ex.O.=exine ornamentation, MR=microreticulate, Fov.=foveolate

3.1. Results of ANOVA Test

Table 4

Palynological characters Subjected to ANOVA Test.

No.	Characters	F value	P value	F critical	
1	**Polar axis**	0.414539	0.944093	1.952212	
2	**Equatorial axis**	0.9377321	0.51152	1.952212	
3	**Colpus length**	3.151916	0.002829	1.99458	*
4	**Pore length**	5,307631	2 E-05	1.99458	**

*: *Items are the significantly different characters*

**: *Items are the highly significantly different characters.*

All four measurable pollen grains characters were subjected to ANOVA test and listed in Table (4). One character, colpus length, was highly significantly different among the studied taxa, one character, pore length, was significantly different and only two characters, P.A. & E.A., were insignificantly different between the studied species.

3.2. Cluster analyses

The results of the clustering analyses are illustrated in Fig. 35, clustering analysis according to palynological characters, separated *F.arabica v.thilhoana* at similarity index of 3, while *F.cretica* has been separated at similarity index of 2.2 and the rest of the species separate *F.arabica v.viscidissima* at similarity index 1.5 and *F.glutinosa* at similarity index 1.2. The rest eight species were categorised into two categories. The first category gathers *F. bruguieri, F. sinaica v. longipes,* and *F.tenuifolia* as subgroup and *F. sinaica v. pseudocretica* and *F. schweinfurthii* in another subgroup. The second category has three species, *F. indica, F.thebaica,* and *F. sinaica v. kahirina*.

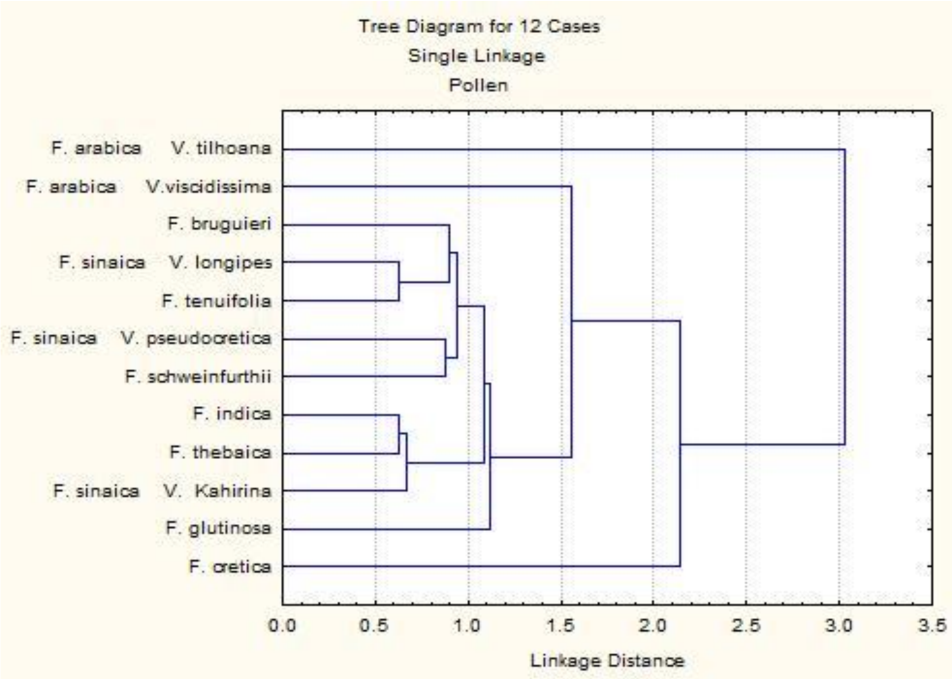

Fig. 35. Dendogram showing the relation of the studied species according to Palynological characters.

3.3. Identification key of the studied *Fagonia* species according to palynological characters

1- Dimorphic pollen grains with two aperture types

1.1- Colpi never exceed 8.5 µm *F.thebaica*

1.2- Colpi from 7.5-10 µm *F.schweinfurthii*

1.3- Colpi very long exceed 10 µm

1.3.1- Pollen grains prolate or subprolate *F.arabica var. thilhoana* & *F.glutinosa*

1.3.2-Pollen grains spherical or perprolate *F.arabica var.viscidissima*

2- Monomorphic pollen grains

2.1- Colpi length from 6-9 µm

2.1.1-Pollen grains subprolate

2.1.1.1- Pore length small never exceed 2.9 µm *F.indica*

2.1.1.2-Pore length from 2-3.5 µm *F.sinaica & F. tenuifolia*

2.1.1.3-Pore length 3.5-5.0 µm *F.bruguieri*

2.1.2-Pollen grains prolate *F.cretica*

4. Discussion

Genus *Fagonia* is one of the most difficult genera in his circumscription of the species belonging to it. This genus is objected to many taxonomic investigations to clarify the most significant relations between its species. The most important taxonomical studies are those of Quezel (1956) and El-Hadidi (1966), who classified the genus into groups based on morphological and some anatomical variations (Table 5). The morphological, floral, and anatomical investigations were done by (Taia *et al.* 2015, 2016 & 2017). They found that the spiny stipules beside the micromorphological characters could be of help in the recognition of some species. Meanwhile, the floral characters, especially the knee-like structure in the style add new characters in the delimitation of the taxa. Internal structures especially the pith shape can be of use in the grouping of the species as mentioned before by Boissier (1867). Palynological studies on this genus are few and did not give valuable opinions about the delimitation of the species. For that, this investigation has been done as a trial to clarify the pollen grain variations among the Libyan species.

Table 5

Quezel and El-Hadidi classification of *Fagonia* Sp.

	Char.	Group 1	Group 2	Group 3	Group 4
Quezel 1956	Morph.	*F. kahirina-cretica-flamandii*	*F. arabica-bruguieri*	*F. glutinosa-latifolia*	*F. microphylla*
El Hadidi 1966	Morph.& Anatomy	*arabica-bruguieri* group *F. arabica, F. bruguieri,F. myriacantha, F. hassasi, F. thebaica, F. boulosii, F. indica, F. taechholmiana* and *F. alba.*	*glutinosa* group *F. glutinosa, F.tristis, F. mollis,F. microphylla, F. latifolia* and *F. isotricha.*	*sinica* group *F. sinica, F. cretica* and *F. bisharorum.*	

The palynological results obtained revealed that the studied taxa have similar characters i.e. eurynopalynous. The studied taxa have either one type of aperture within their pollen grains or two types of apertures. This character grouped the studied taxa into two divisions. The first division, monomorphic, gathers *F.bruguieri, F.cretica, F.indica, F.sinaica* (3 varieties), and *F.tenuifolia*. The second division has the rest of the taxa. Colpi and pore lengths can help in the separation of some taxa, but within the limit. This result is in approval of Shiha (1984) and Perveen and Qaiser (2006).

The dendrogram resulted from the clustering analyses separate *F.arabica* var. *thilhoana* lineage distance 3, and the rest of the taxa grouped together. These taxa separate *F.cretica* at lineage distance 2.2 and *F.arabica* var. *viscidissima* at lineage distance 1.5, while *F.glutinosa* separated at lineage distance 1.2. The rest of the studied taxa are grouped in two categories. The first category has *F.sinaica* var. *kahirica, F.thebaica,* and *F.indica.* The second category has the rest of the studied taxa. This relation revealed that all the studied taxa are intermingled and have similar characters, that their separations according to pollen characters will be difficult. These similarities are due to the phenotypic plasticity of this genus as indicated by Zohary 1972 and Danin (1996). This palynological study is in partial accordance with Quezel (1956) in classifying the *Fagonia* species into four sections.

From this study, we can conclude that the pollen characters of genus *Fagonia* are of limited help in the taxonomy of the genus and we have to rely on the other morphological, floral, and anatomical characters. In addition, the taxa within that genus need further breeding experiments to investigate the delimitations within its taxa.

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