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An Illustrated Description of *Selaginella imbricata* and *Selaginella yemensis* from Saudi Arabia

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Abstract: *Selaginella imbricata* (Forssk) Spring and *Selaginella yemensis* (Swart) Spring, are described in detail in light of numerous recent collections from Saudi Arabia. The two species are recorded for the first time in El-Baha region and Shammaran and Muhayl valley of Asir region. The two species are investigated and compared with those of other countries. A key to the two species is providing. The presence of *Selaginella* species in five different localities in Saudi Arabia indicates that the species are native and not invasive plants.

Key words: Morphology, *Selaginella imbricate*, *Selaginella yemensis*, sporophytes

INTRODUCTION

The pteridoflora in the Saudi Arabia is mainly of tropical nature and is very poor in species. Finding of pteridophytes reported by Kürschner (1984, 1989), Basahy (1996) and Al-Turki (2004) from Asir and Jezan regions (Fayfa Mountains). A good record of pteridophytes flora was from Southwestern Saudi Arabia (Asir Mountains). Migahid (1978), Collenette (1985, 1998) and Al-Turki (2004) recorded the two species of *Selaginella*, *Selaginella yemensis* (Swart), *Selaginella imbricata* (Forssk) and other new fern allies, have received some attention but little information can be found in those contributing regarding palynological characteristics. Recently, Also Al-Shehri (2002) has been engaged in a survey of the fern flora of this tropical area. *Selaginella* is a single genus belongs to the clubmosses family Selaginellaceae, which has 750 species mainly in the tropics. Only four species recorded in Europe (Preston and Hill, 1999), also there are seven species native to Fiji are described and keyed (Gardner, 1997). *Selaginella* belongs to the order lycopsida. The *Selaginella* is a cosmopolitan genus of heterosporate lycophyta it produce sporangia in small cones and there are two different types of spores minute microspores and larger megaspores. The sporoderms of the megaspores of the genus *Selaginella* is composed of three layers, which are named intine, exine and perine. A mesine does not exist. The exine consists of a remarkable thin and quite homogenous membrane that until now has been regarded as the mesine or endoexine (Morbelli and Rowley, 1999; Rowley *et al*., 2002). A gap in the exospores and in mesospores is found to be a normal part of development of *Selaginella* megaspores (Morbelli *et al*., 2001, 2003). The outer part of the exospore is separated from the inner part of the exospore by a gap. In this study, sporophytes of the *Selaginella imbricata* and *Selaginella yemensis* are keyed and concisely described including new data from floral morphology, leaf architecture, spore morphology and stem anatomy are given here, using characters not discussed by the earlier researchers. In the present study, observation and new collections of the two species are described.

MATERIALS AND METHODS

The plants were collected in September 2004 from El-Baha region (more than 8200 ft. elevation) and in October 2005 from Asir region (Shammaran and Mahayel valley, ca. 1200 ft. elevation)

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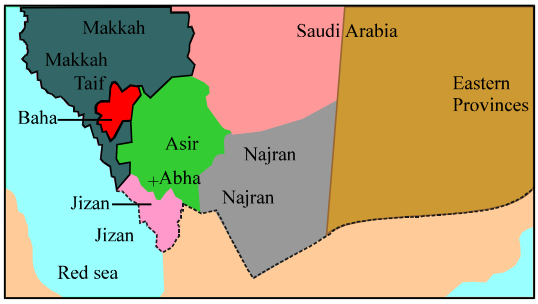

Fig. 1: Study area (Asir and Jizan are the previous study area. Baha and Asir are the present study area)

Table 1: The characteristic data and the dimensions of the two species of *Selaginella*

Taxa terms	*Selaginella imbricata*			*Selaginella yemensis*		
	Length	Width	Diameter	Length	Width	Diameter
Ventral foliage leaves	2.4-2.5 mm	1.6-1.7 mm		0.19-0.23 mm	1.6-1.7 mm	
Dorsal foliage leaves	1.7-2.4 mm	1.1-1.25 mm		0.13-1.4 mm	1.1-1.25 mm	
Megasporophyll	1.3-1.45 mm	0.9 mm		1.2-1.8 mm	0.9 mm	
Microsporophyll	0.4-0.6 mm	0.8-0.9 mm		1.95-1.7 mm	0.8-0.9 mm	
Megasporangia	0.35 mm	0.43-0.6 mm		0.95-1.1 mm	0.43-0.6 mm	
Microsporangia			0.6 mm			0.55-0.70 mm
Megaspores			200-300 µm			400-550 µm
Microspores			42-50 µm in E.V.			27.5-32.5 µm in E.V.
Stem diameter			0.45 mm			0.55-0.7 mm
Shoot length	2-6 cm	1.5-4 cm		10-30 cm		
No. of sporangia in strobilus	4-15 sporangia			7-15 sporangia		
No. of megaspores in megasporangium	3 spores			3 spores		
No. of microspores in microsporangium	Indefinite (many)			Indefinite (many)		
Strobilus length	7-25 mm	4-5 mm		7-20 mm	2.5-3.5 mm	

E.V.: Equatorial View

(Fig. 1). The fresh specimens were investigated by dissecting and light microscopes (LM). For light microscopy (LM) the leaves and spores were whole mounted in glycerin jelly. The dimensions are given in Table 1 and photographs have been taken under light microscopy and illustrated in Fig. 2 and 3. The materials are stored in Biological Department, Collage of Sciences, King Khaled University, Abha, Saudi Arabia.

RESULTS AND DISCUSSION

Selaginella yemensis and *Selaginella imbricata* have slender branching stems bearing pseudofronds in four rows, the later ones are larger, which gives the plant its characteristic flattened form. The characteristics data and measurements of the species are shown in the Table 1, 2 and in Fig. 2 and 3.

***Selaginella imbricata* (Forssk) Spring**

Syn.: *Lycopodium imbricata* Forssk

Plants terrestrial, seasonally green not creeping. Quite common on wet rocks on mountains. The plants less branching herb, with very bright green frond and blue sheen. The erect stem send up erect fronds with tiny pointed leaves. The fronds ascending axiliary opposite bipinnates (Fig. 2, a, b), ca

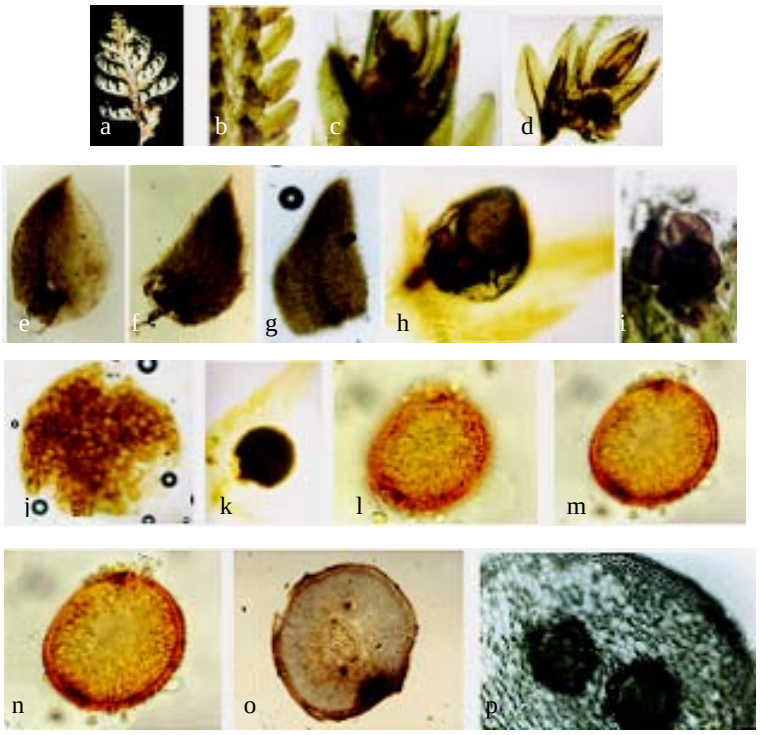

Fig. 2(a-p): *Selaginella imbricata* (Forssk) Spring:(a) Habit of sporophytes (40x), (b) Abaxial view of fertile branch (40x), (c) Strobilus (40x), (d) Microsporophyll and microsporangia (100x), (e) Foliage lateral leaf (100x), (f) Megasporophyll (100x), (g) Foliage dorsal leaf (100x), (h) Megasporangium with megaspores (100x), (i) megaspores (400x), (j) Ruptured microsporangium (100x), (k) Immature microsporangium (100x) (l, m, n) Immature microspores (1000x), (o) T.S. in aerial stem (100x) and (p) T.S. in rhizome (400x)

Table 2: Occurrence of *Selaginella* species in Saudi Arabia as recorded in previous studies and the present study

	Region						
	Present study				Previous study (Collenete, 1998; Al-Turki, 2004)		
	Asir				Asir		
Species	Muh.	Sham.	El-Baha	Jezan	Muh.	Sham.	Jezan (fayfa-1500 m)
Selaginella imbricata	-	+	+	-	+	-	-
Selaginella yemensis	+	-	-	+	-	+	+

+: Present, -: Absent, Muh.= Muhayl; Sham.= Shammaran

2-6 cm long (or more). They growing identity, without creeping rhizome or stolons. The rhizophore forked, hairy initiated from the base of the stem. The main stem slender, (0.45 mm diameter) and glabrous with a single vascular bundles (*Monostelic protostele*). But the rhizome has distelic vascular bundles. The vascular bundles connected with the outer cortex by transversely elongated cells (Fig. 2o, p). Apex of the main stem dark greenish with many branching and the primary lateral branches developing into the same shoot system. The leaves pinnately overlapped arranged in four rows (two ventrally and two in dorsal sides) and dimorphous- throughout. The surface glabrous, dorsiventral

Fig. 3a-o: *Selaginella yemensis* (Swart) Spring: (a) Habit of sporophytes (40x), (b) Abaxial view of fertile branch (40x), (c) Foliage lateral leaf (100x), (d) Microsporangium (40x), (e) Foliage dorsal leaf (median) (40x), (f) T.S. in stem (100x), (g) Microsporphylls (40x), (h) Microsporangia and microsporphylls (40x), (i) Megasporangium (100x), (j) Megasporophyll apex (100x), (k) Microspores tetrads (400x), (l) Megasporangium and megasporophyll (100x), (m, n) Microspores (1000x) and (o) Megasporophyll (40x).

flattened. The old leaves yellowish and the youngest one greenish, lanceolate and with acute apex (2.4-2.5×1.6-1.7 mm). Axiliary leaves (ventral leaves) on the main stem larger than those on the dorsal side (Fig. 2e). They ovate-shape and acute toothed apex. The margins asymmetrical, toothed until the base, left side white color and the right side green. The midrib very thin and ending below the apex (excurrent). The base peltate and not attenuate. Dorsal leaves (Fig. 2g) ovate or oblong-elliptic (1.7-2.4×1.1-1.3 mm). The margins denticulate (crenate), with one or few cilia or long spine and the apex acute or acuminate. The leaf base symmetrical (Fig. 2g). Strobili compact, tetragenous or slightly dors-ventrally complanate, solitary terminal in the apex of the aerial shoot (Fig. 2c), (7-25×4-5 mm). The sporangia produced at the bases of the sporophylls at the stem tips. The sporophylls (Fig. 2d, f) slightly toothed unlike the sterile leaves, heteromorphous, ovate and lanceolate. The margins crenate, white and the apex acuminate. The sporophylls ridged above and the ridges with some spines.

The Strobili (Fig. 2c) have megasporophylls at the base portion of lower side. The microsporophylls at the upper portion of the srobilus (Fig. 2d). They ovate shaped and with acuminate apex. The margins white color, toothed in both sides. The teeth smaller than in megasporophylls. The margin teeth long in mid margin and short at the apex. The midrib very thin, ending below the apex, and originated from the axis as leaf traces. The leaf base has a scar point of attachment to the main axis. Most of the microsporophylls have one microsporangium (Fig. 2j, k), with orange color, thick wall and with very short stalk. They have oil droplets or starch grains mixed with the spores. They attached to the leaf base in the point of initiation of the midrib. Each microsporangium (0.6 mm in diameter) has many microspores, orange to brownish or pale yellow in colour ca. 42-50 μm in diameter. The exine smooth at distal face and scabrate at proximal face (Fig. 2l, n). The sporoderm of the microspores composed of a thick homogenous exine and the trilete marker indistinct (or alete). The prine not clear and the sculpture of the exine has homobrochates ornamentation (microechnate elements). The megasporophylls (Fig. 2f) ovate shaped and with acute apex. The margins white or greenish and more toothed. The base very wide and has characteristic attached scare. The midrib very thin and sometimes not clear in the upper part of the leaf as same as microsporophylls. The megasporangia (0.4×0.4-0.6 mm) (Fig. 2h) larger than microsporangia, black or brownish in color rounded or circular in shape, thick wall and have approximately or almost only three megaspores. The megaspores (Fig. 2i) yellow, brownish or red in color and with thick sporoderm. The sporoderm folded and irregularly punctuate or scabrats. The distal face regulate and the proximal face has perine monolete or trilete suture. The exine thick and echinate or verrucate sculpture. Megaspores have dark central part at immature stage and ca. 200-300 μm in diameter (Fig. 2i).

***Selaginella yemensis* (Swart) Spring**
Syn.: ***Lycopodium sanguinolentum* Forssk**
***Lycopodium yemensis* Swart**

The plants terrestrial, seasonally green, creeping and bearing root like rhizophores. The branches axiliary, alternates and divided dichotomously into fronds (Fig.3a, b). The shoot ca. 10-30 cm long (or more), growing identity, with creeping rhizome or stolons. Apex of the main stem greenish and branching. The Rhizophores at intervals, throughout the length of creeping stem and branches, some time forked and form hairy-like roots and more than 22 mm long. The main stem slender, glabrous and ca. 0.5-0.70 mm in diameter (Fig. 3f), with a double vascular bundles (0.2 mm in diameter). This structure (bistelic protostele) connected with the outer cortex by transversely elongated cells (tuberculate endodermis) (Fig. 3f). The primary lateral branches bipinnates. The leaves pinnate, overlapped, arranged in four ranks (two ventrally and two in lateral sides) and dimorphous-throughout. The leaves surface glabrous and dorsiventral flattened. The old leaves yellowish and the youngest one greenish, lanceolate with acute apex. The lateral (axiliary) leaves (1.9-2.3×0.85-1.1 mm), on main stem larger than those on the dorsal (Fig. 3c). The lateral leaves ovate-shape and acute with toothed apex (Fig. 3e). The margins asymmetrical toothed until the base, one side white color, and the other side green. The midrib very thin and excurrent. The base peltate and not attenuate. Dorsal leaves (Fig. 3e) ovate or broadly elliptic (1.3-2.4×0.73-0.60 mm). The margins denticulate, (crenate) apex acute or acuminate and asymmetrical (Fig. 3c, e). The base symmetrical and has one or many long spines. Strobili (Fig. 3h, l) compact, tetragenous or slightly dors-ventrally complanate and terminal of the shoot apex (7-20×2.4-3.5 mm in size). The sporangia produced at the bases of the slightly toothed, large sporophylls. Sporophylls, heteromorphous, ovate lanculate and unlike the sterile leaves. The margin crenate and white colour in both sides. The apex acuminate. The Strobili at the apex of the shoot (Fig. 3b) with megasporophylls at the base portion of lower side and the microsporophylls at upper portion of it. Microsporophylls (1.7-1.95×0.9-1 mm) smaller than megasporophyll. They ovate shape, acuminate apex and margin white color and spiny (Fig. 3g). The spines long in mid margin and short at the apex. The midrib very thin and ending at apex. It originated from the main axis as leaf trace. The

leaf base has a scar point of attachment to the main axis. Most of each microsporophyll has one microsporangium (Fig. 3h) with orange, brownish colour. They have thick wall, very short stalk and attached to the leaf base in the point of initiation of the midrib. Each microsporangium (Fig. 3d) has many microspores (25-27.5 μm in polar view). Microspores pale yellow or orange in colour (27.5-32.5 μm in equatorial view). The exine psilate at distal face and scabrate at the proximal face (Fig. 3k, m, n). The sporoderm (2.5-5 μm thick) of the microspores composed of a thick homogenous exine and the trilete marker distinct. The perine distinct. The sculpture of the exine has homobrochates ornamentation (microechnate elements). The megasporophylls (Fig. 3j) ovate shape and with acuminate to aristate apex often backward. The margins white and toothed. The base very wide and has characteristic attached scare point. The midrib very thin and sometimes distinct in the upper part of the leaf (excurrent). The megasporangia (Fig. 3i) larger (0.95-1.1×0.95-1.3 mm in size) than microsporangia. They black or brownish in colour, rounded or circular in shape and thick wall. They have approximately only three megaspores. The megaspores (400-550 μm, in E.V.) brownish or red in colour with thick triletes marker (Fig. 3i). The sporoderm is folded. The exine thick and echinate or verrucate sculpture. Megaspores (Fig. 3i) are yellow or brownish. The sporoderm is irregularly punctuated or scabrats at the distal face indistrict at proximal face. The perine indistrict has monolete or trilete suture.

Key to Species of *Selaginella*

- Main stem erect and rhizophores from lower part of the stem, main stem branched and stem with monostelic protostele. Leaves white margined, lateral leaves oblong and exauriculate ..... *Selaginella imbricata*
- Main stem creeping and rhizophores up to middle or upper part of the stem and the main stem branched from lower parts. Stem with bistelic protostele leaves are white margined and lateral leaves are oblong or elliptic and auriculate ..... *Selaginella yemensis*

CONCLUSION

The present study investigated the *Selaginella imbricata* and *Selaginella yemensis* sporophytes according to the new field observations and the new collections from Saudi Arabia. These results are the first detail description of *Selaginella* sporophytes and spores in Saudi Arabia. The two species (*Selaginella yemensis* and *Selaginella imbricata*) have slender branching stems bearing pseudofronds in four rows, the later ones are larger, which gives the plant its characteristic flattened form. The morphology of heterosporous sporophytes are characteristic for the plants. The sporophytes are ripe in June to August. This agrees with the Britain species, which were fruiting in August (Philips, 1980). *Selaginella yemensis* sporophytes have distributed rhizophores and the main axis is branched from the lower part and upward. These characters are not present in the *S. imbricata* sporophytes, but these characters are comparable to *S. rolandi-princips* Alston, which recorded in Hainan Island in Eastern Asia (Zhang *et al*., 2005). *Selaginella imbricata* stem has single vascular bundle and the dorsal leaves on fronds are imbricate and it's comparable to *S. involves* (Sw.) Spring, (Zhang *et al*., 2005). *Selaginella imbricata* is characterized by a pinnate branching pattern in which the appearance of the main axis is visible in each subdivision of the frond, but not visible from the habit of *S. yemensis*. The presences of many rhizophores in fronds of *S. yemensis* indicate that it is truly creeping plants (Wong, 1983; Gardener, 1997; Brighigna *et al*., 2002). In addition, the pinnule of this species is usually widest near its base and may or may not be markedly tapered. The degree of this tapering varies somewhat between species and it could be much of taxonomic value (Morbelli *et al*., 2001). The microspores of these species have ornamentation that varies from granules and spines to alveoli. The ornamentation and the sporoderm thickness are different on proximal and distal faces of the two studied species.

The microspores of *S. marginata* and *S. sulcata* (Gardener, 1997; Zhang *et al*., 2005) however, have similar ornamentation with the two studied species on polar view surfaces. The dry microspores of *S. peruviana* and *S. sellowii* have an exospore that is peltate on the proximal face and in the section; they have a separation between the two portions of the exsospore as in the megaspores (Morbelli *et al*., 2003; Rowley *et al*., 2002). The above-mentioned characters are not clear in the studied species. Thus, it is necessary to collect data on, for example the chromosome number and DNA in order to corporate whether the species compared and represents different evolutionary lineages. We can conclude that the two species are recorded fore the first time in El-Baha region and Shammaran area (Asir region) (Table 2). The fruiting sporophytes were investigated for the first time from Saudi Arabia and they are comparable with those of other countries species. The presence of Selaginella in different localities in Saudi Arabia indicates that the species are native or endemic not invasive plants.

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