

Systematic studies on the Zygophyllaceae of Saudi Arabia: new combinations in *Tetraena* Maxim.

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Abstract: During 2013 and 2014, fresh material of *Tetraena hamiensis* (Schweinf.) Beier & Thulin was collected from four different localities in Saudi Arabia. Some morphological differences, especially in leaf, flower parts, and fruit characters, were observed among individuals of this species within the same location. Principal coordinates analysis and the unweighted pair group method with arithmetic algorithm clustering test split off individuals of *T. hamiensis* with these morphological varieties as three clusters; one comprises individuals with characters overlapping those of *T. hamiensis*, one comprises individuals with characters overlapping those of *T. qatarensis*, and one comprises individuals with characters overlapping those of *T. mandavillei*. Therefore, *T. hamiensis*, *T. qatarensis*, and *T. mandavillei* are herein considered as varieties of *T. hamiensis* (*T. hamiensis* var. *hamiensis*, *T. hamiensis* var. *qatarensis*, and *T. hamiensis* var. *mandavillei*). *Tetraena hamiensis* and its varieties are illustrated and morphological characters are supplied to differentiate among them.

Key words: Taxonomy, *Tetraena*, *Tetraena hamiensis*, Zygophyllaceae, PCoA, UPGMA, Saudi Arabia

1. Introduction

Zygophyllaceae is a widespread family of herbs, shrubs, and trees growing in arid and semiarid areas in the tropics and subtropics. Currently, it includes about 285 species and 27 genera subdivided into five subfamilies, namely Zygophylloideae, Tribuloideae, Seetzenioideae, Larreoideae, and Morkillioideae (Sheahan and Chase, 1996, 2000; Beier et al., 2003; Bellstedt et al., 2008). Zygophylloideae is the largest subfamily and currently consists of six genera, namely *Zygophyllum*, *Fagonia*, *Augea*, *Roepera*, *Tetraena*, and *Melocarpum* (Beier et al., 2003; Bellstedt et al., 2008). Until 2002, *Tetraena* was a monotypic genus, and its only species, *T. mongolica*, is endemic to western Inner Mongolia in China. Sheahan and Chase (1996, 2000) used the combination of morphological and anatomical characters together with *rbcL* DNA and *trnL-F* gene sequence data to investigate the phylogenetic relationships within the family Zygophyllaceae. Their results indicated that *Fagonia*, *Augea*, and *Tetraena* are nested within *Zygophyllum* to form a large Zygophylloideae clade. Similarly, Beier et al. (2003) used morphological characters and noncoding *trnL* plastid data to investigate the phylogenetic relationships within the subfamily Zygophylloideae. In that study, they morphologically

distinguished *Zygophyllum* from *Tetraena*, the fruit being a loculicidal capsule and the staminal appendages undivided in the former, whereas in the latter the fruit is a schizocarp and the staminal appendages sometimes split. However, they transferred 35 species from *Zygophyllum* to *Tetraena* as new combinations; these species are from Africa and Asia. Subsequently, many authors (e.g., Norton et al., 2009; Louhaichi et al., 2011; Mosti et al., 2012; Sakkir et al., 2012; Symanczik et al., 2014; Ghazanfar and Osborne, 2015) agreed with the new classification proposed by Beier et al. (2003) and used the new combinations proposed them. Thus, *Tetraena* currently has a distribution stretching from the Canary Islands in the west to South Africa in the south and China in the east.

Zygophyllum hamiense Schweinf., 1899; *Z. mandavillei* Hadidi, 1977; and *Z. qatarense* Hadidi, 1978 are known from the Arabian Peninsula and Saudi Arabia. *Zygophyllum mandavillei* is morphologically distinguished from other species of its section by its glabrous, large, long-stalked flowers and by its sausage-shaped capsules (El-Hadidi, 1977), while *Z. qatarense* is distinguished by its clavate or obconical leaflets (4–7 mm long), short-stalked flowers (2–3 mm), and small-sized fruits (8 × 3 mm) (El-Hadidi in Boulos, 1978). Several authors (Hosny, 1978, 1988;

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Batanouny, 1981; Collenette, 1985, 1999; Mandaville, 1986, 1990; Cornes and Cornes, 1989; Western, 1989; Thulin, 1993; Migahid, 1996; Sayed, 1996; Wood, 1997; Böer and Sargeant, 1998; Barth, 1999; Karim, 2002; Waly et al., 2011; Ksiksi et al., 2012) considered *Z. hamiense*, *Z. mandavillei*, and *Z. qatarense* as separate species, while other authors (e.g., Thomas and Chaudhary, 2001) considered them as varieties of *Z. hamiense* due to the morphological similarities of their leaflets and fruits. These species are among the 35 species transferred by Beier et al. (2003) from *Zygophyllum* to *Tetraena* and presently known as *T. hamiensis* (Schweinf.) Beier & Thulin, 2003; *T. mandavillei* (Hadidi) Beier & Thulin, 2003; and *T. qatarensis* (Hadidi) Beier & Thulin, 2003.

In this work *Tetraena hamiensis*, *T. mandavillei*, and *T. qatarensis* are considered as three varieties of *T. hamiensis* based on the morphological characters of leaflets and capsules, using their qualitative and quantitative morphological characteristics.

2. Materials and methods

During 2013 and 2014, 14 fresh specimens of *Tetraena hamiensis* (syn. *Zygophyllum hamiense*), each with leaves, flowers, and fruits, were collected in Saudi Arabia at four different localities: Khurais, Al Ahsa road; Al Ahsa, Qatar road; Al Ahsa, Qatar road (Alaudaidah, 10 km before Alaudaidah, 25 km before Alaudaidah); and Shedgum, next to the cement factory, Al Ahsa-Dammam road. Several duplicate herbarium specimens were made, and additional samples were preserved in 70% ethanol. Numerous specimens of *Tetraena hamiensis*, *T. mandavillei*, and *T. qatarensis* were examined from different herbaria: Riyadh, RIY, Saudi Arabia: Riyadh National Herbarium; Riyadh, KSU, Saudi Arabia: King Saud University Herbarium;

Cairo, CAI, Egypt: Cairo University Herbarium; Royal Botanic Gardens, Kew, K, UK; and Royal Botanic Garden, Edinburgh, E, UK. Drawings were based on both fresh and herbarium specimens (14 and 6 samples). Microscopic examinations and measurements of 29 (20 quantitative and 9 qualitative) morphological characteristics (Tables 1–3), including both vegetative and reproductive features, such as leaf, flower, and fruit characters, were estimated with the aid of a Novex AP-20 stereomicroscope and 10× hand lens. The average measurements for ten mature leaves, flowers, and fruits were taken for each sample. Measurements for leaves, flowers, and fruits of dried herbarium specimens were supplemented by rehydrating material in boiling in water. Measurements are given in millimeters, except where indicated. Conservation threat assessments follow the International Union for Conservation of Nature (IUCN, 2014). Voucher specimens are deposited in KAUH (proposed abbreviation), KSU, and RIY.

Qualitative and quantitative characters of *T. hamiensis* were analyzed by principal coordinates analysis (PCoA) and the unweighted pair group method with arithmetic algorithm (UPGMA) based on the similarity matrix generated using Gower's general similarity coefficient (Gower, 1966). Both analyses were performed using the package MVSP version 3.1 (Kovach, 1999).

3. Results

3.1. Morphological analyses

3.1.1. Principal coordinates analysis (PCoA)

Gower's general similarity coefficient (Gower, 1966) was used for PCoA based on morphological data as shown in Figure 1. The first three principal coordinate axes accounted for 42.277%, 12.421%, and 7.772% of the total variation in the data, respectively. The variance of the first

Table 1. Twenty quantitative morphological characters of 20 Saudi Arabian *Tetraena hamiensis* varieties.

No.	Characters	No.	Characters
1.	Length of petiole (mm)	11.	Length of long stamen
2.	Width of leaflet (mm)	12.	Length of short stamen
3.	Length of leaflet (mm)	13.	Length of appendage
4.	Length of flower (mm)	14.	Length of long filament
5.	Width of flower (mm)	15.	Length of short filament
6.	Length of flower pedicle (mm)	16.	Length of style
7.	Length of sepal (mm)	17.	Length of fruit pedicle
8.	Width of sepal (mm)	18.	Length of fruit
9.	Length of petal (mm)	19.	Width of upper end of fruit
10.	Width of petal (mm)	20.	Width of lower end of fruit

Table 2. Nine qualitative morphological characters and character states used in morphometric analysis of the *Tetraena hamiensis* varieties.

No.	Character	Character state	Code
1	Color of plant	Green	1
		Green with purple branches	2
		Reddish	3
		Yellowish green	4
Leaf character			
2	Leaf structure	1-foliolate	1
		1+2-foliolate	2
3	Leaf/leaflet shape	Cylindrical	1
		Globular	2
		Clavate	3
4	Leaf/leaflet surface	Pubescent	1
		Glabrous	2
5	Petiole surface	Pubescent	1
		Glabrous	2
Fruit character			
6	Fruit shape	Oblong obconical 5-angled	1
		Cylindrical sausage-shaped	2
		Oblong obovate 5-angled	3
7	Fruit apex	Conspicuously angled	1
		Sometimes ridged but not conspicuously angled	2
		Rounded	3
8	Fruit surface	Pubescent	1
		Glabrous	2
9	Fruit pedicle surface	Pubescent	1
		Glabrous	2

Table 3. Nine qualitative morphological characters and character code (Ch) of 20 Saudi Arabian *Tetraena hamiensis* varieties.

No. of sample	Taxon	Character code								
		Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6	Ch 7	Ch 8	Ch 9
1	<i>T. hamiensis</i> var. <i>hamiensis</i> 24	1	1	3	1	2	3	1	1	1
2	<i>T. hamiensis</i> var. <i>hamiensis</i> 18	1	1	3	1	2	3	1	1	1
3	<i>T. hamiensis</i> var. <i>hamiensis</i> 19	1	1	3	1	2	3	1	1	1
4	<i>T. hamiensis</i> var. <i>hamiensis</i> s.n.	1	1	3	1	2	3	1	1	1
5	<i>T. hamiensis</i> var. <i>qatarensis</i> 20	3	1	2	1	1	1	2	1	1
6	<i>T. hamiensis</i> var. <i>qatarensis</i> 21	3	1	2	1	1	1	2	1	1
7	<i>T. hamiensis</i> var. <i>qatarensis</i> 22	2	1	2	1	1	1	2	1	1
8	<i>T. hamiensis</i> var. <i>qatarensis</i> 16	2	2	2	1	1	1	2	1	1
9	<i>T. hamiensis</i> var. <i>qatarensis</i> s.n.	2	1	2	1	1	1	2	1	1
10	<i>T. hamiensis</i> var. <i>qatarensis</i> s.n.	2	1	2	1	1	1	2	1	1
11	<i>T. hamiensis</i> var. <i>qatarensis</i> s.n.	3	1	2	1	1	1	2	1	1
12	<i>T. hamiensis</i> var. <i>qatarensis</i> s.n.	2	1	2	1	1	1	2	1	1
13	<i>T. hamiensis</i> var. <i>qatarensis</i> s.n.	3	1	2	1	1	1	2	1	1
14	<i>T. hamiensis</i> var. <i>mandavillei</i> 13	4	1	1	2	2	2	3	2	2
15	<i>T. hamiensis</i> var. <i>mandavillei</i> 15	4	1	1	2	2	2	3	2	2
16	<i>T. hamiensis</i> var. <i>mandavillei</i> 17	4	1	1	2	2	2	3	2	2
17	<i>T. hamiensis</i> var. <i>mandavillei</i> 23	4	1	1	2	2	2	3	2	2
18	<i>T. hamiensis</i> var. <i>mandavillei</i> 25	4	1	1	2	2	2	3	2	2
19	<i>T. hamiensis</i> var. <i>mandavillei</i> 26	4	1	1	2	2	2	3	2	2
20	<i>T. hamiensis</i> var. <i>mandavillei</i> 30	4	1	1	2	2	2	3	2	2

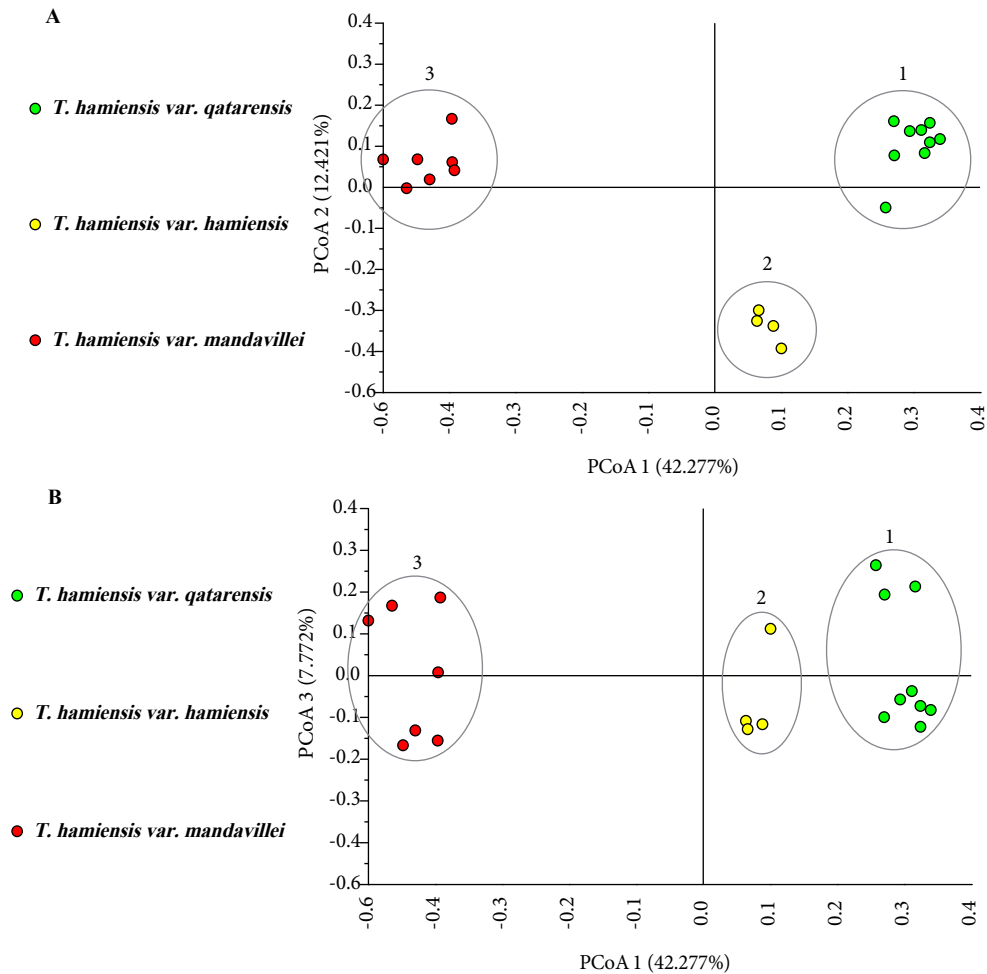


Figure 1. A) PCoA representation of morphological data of 20 accessions of Saudi Arabian *T. hamiensis* plants using Gower's general similarity coefficient (Gower, 1966). Principal coordinate axes 1 and 2. B) Principal coordinate axes 1 and 3. Different symbols correspond to different species as shown in the legend. Clusters are indicated by numbers.

two principal coordinates explained 54.698% of the total variation and the ordination of these two axes showed three groups (Figure 1A). The variance of the first and third principal coordinates accounted for 50.049% of the total variation and the two-dimensional plot of these two axes revealed three groups (Figure 1B).

3.1.2. Cluster analysis (UPGMA)

The relationships among the Saudi Arabian *Tetraena hamiensis* accessions were examined using UPGMA clustering based on Gower's general similarity coefficient (Gower, 1966). UPGMA separated Saudi Arabian *Tetraena hamiensis* into three clusters (Figure 2).

During field collection, some morphological varieties, especially in the leaf, flower parts, and fruit characters (Figures 3A–3F and 4A–4D; Table 4) were observed among *Tetraena hamiensis* individuals within the same location. PCoA and UPGMA tests displayed significant differences

for the qualitative and quantitative morphological characters studied. In the PCoA of morphological data, individuals of *Tetraena hamiensis* split off as three clusters in both the first two axes and in the first and third axes (Figures 1A and 1B); in cluster 1 nine individuals with characters partially overlapping those of *T. qatarensis* were grouped together, in cluster 2 four individuals with characters partially overlapping those of *T. hamiensis* were grouped together, and in cluster 3 seven individuals with characters partially overlapping those of *T. mandavillei* were grouped together. In the UPGMA dendrogram (Figure 2), individuals of *T. hamiensis* split off as three clusters; cluster I comprises individuals with characters entirely overlapping those of *T. qatarensis*, cluster II comprises individuals with characters entirely overlapping those of *T. hamiensis*, and cluster III comprises individuals with characters entirely overlapping those of *T. mandavillei*.

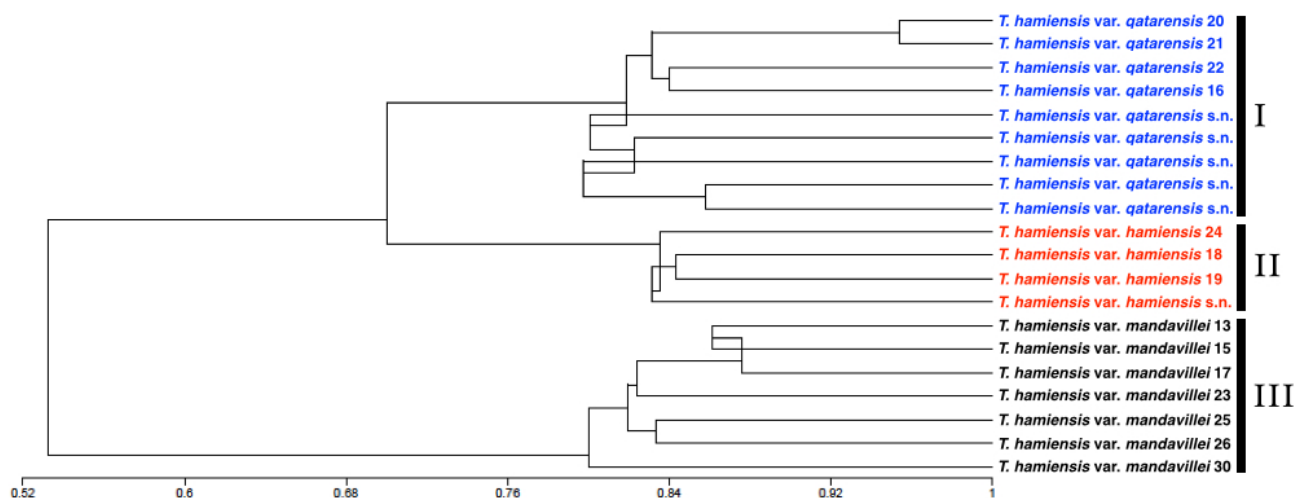


Figure 2. UPGMA resulting from morphological data of 20 accessions of Saudi Arabian *Tetraena* plants using Gower's general similarity coefficient (Gower, 1966). Roman numerals are used to identify the clusters.

3.2. Taxonomy

Tetraena hamiensis (Schweinf.) Beier & Thulin in Pl. Syst. Evol. 240 (1–4): 35 (2003).

Perennial shrubs, green or reddish or yellowish green, up to 80 cm high, 90 cm wide. Stems pubescent, with unicellular simple trichomes. Leaves: mostly 1-foliolate, sometimes 2-foliolate in upper branches, terete, globular or cylindrical or clavate, 4–9 mm long, 3–6 mm wide, fleshy, pubescent or glabrous, petiole equal or longer than leaflets up to 9 mm long, stipules triangular, herbaceous, 1 × 1.5 mm, pubescent. Flowers bisexual, solitary at each node, white, 4–6 × 3–5 mm, pedicel 3–5 mm long. Sepals 5, rounded-obtuse at the apex, herbaceous, yellowish green, obovate, 3–5 × 2–3 mm, pubescent, aestivation imbricate. Petals 5, white, spatulate, 4–6 × 1.5–2 mm, aestivation open. Stamens 10, 2–5 mm long, staminal appendages, undivided, 2–3 mm long, 1–1.5 mm wide, anther 2 lobes, yellow, dorsifixed, dehiscence longitudinally. Disc smooth. Ovary 5-locular, pubescent, single style, 0.5–1.5 mm long. Capsules a schizocarp, oblong-obovate, oblong-obconical, 5-angled or cylindrical, 8–20 × 2–5 mm, pubescent or glabrous, pedicel 5–10 mm long, pubescent or glabrous.

Tetraena hamiensis is distinguished from the other species of *Tetraena* by leaves mostly 1-foliolate, sometimes 2-foliolate, capsules oblong-obconical or cylindrical sausage-shaped (Table 4).

Key to the *Tetraena hamiensis* varieties in Saudi Arabia

1- Leaflets clavate, 6–9 × 3–5 mm, green; petiole up to 9 mm; pedicels up to 5 mm long; capsule oblong-obconical 5-angled, clear lobed, 10–13 × 3–4 mm, pubescent, fruiting pedicel up to 10 mm long var. *hamiensis*

2- Leaflets globular, 4–6 × 4–6 mm, reddish or olive green, petiole up to 8 mm; flowers pedicel up to 3 mm

long; capsule oblong-obovate 5-angled, 8–10 × 2–3 mm, pubescent, partly lobed, fruiting pedicel up to 7 mm long var. *qatarensis*

3- Leaflets cylindrical 7–9 × 3–5 mm; petiole up to 9 mm; flowering's pedicel up to 4 mm long; capsule cylindrical-sausage-shaped, 16–20 × 3–4 mm, glabrous, 16–20 mm long, fruiting pedicel up to 5 mm long var. *mandavillei*

Tetraena hamiensis* (Schweinf.) Beier & Thulin var. *hamiensis (Figures 3A, 3D, 4A, and 5)

Basionym: *Zygophyllum hamiense* var. *hamiense* Schweinf., Chaudhary, Flora of the Kingdom of Saudi Arabia 2: 502 (2001).

Isotype: El Hami, east Schehr. Schweinfurth 182 (W).

Synonyms: *Zygophyllum hamiense* Schweinf., in Bull. Herb. Boissier vii. App. II. 277 (1899); *Tetraena hamiensis* (Schweinf.) Beier & Thulin, Pl. Syst. Evol. 240 (1–4): 36 (2003).

Conservation status: In terms of current conservation status, *Tetraena hamiensis* var. *hamiensis* appears to be distributed in some localities in the eastern and south central regions of Saudi Arabia. At the international level, this species is evaluated as Least Concern (LC), since it also grows in the United Arab Emirates, Oman, Kuwait, Yemen, Iran, and Somalia (IUCN, 2014).

Habitat: Sands and saline soils.

Phenology: Flowering and fruiting from February to June and September to November.

Vernacular names (Arabic): Harm.

Distribution: Saudi Arabia: Eastern region and south central of Saudi Arabia (Figure 5); Worldwide: United Arab Emirates, Oman, Kuwait, Yemen, Iran, and Somalia.

Specimens examined: Saudi Arabia: Al Ahsa, Qatar road, 2 May 2013, 25°16'30"N, 49°41'09"E, Alzahrani D18

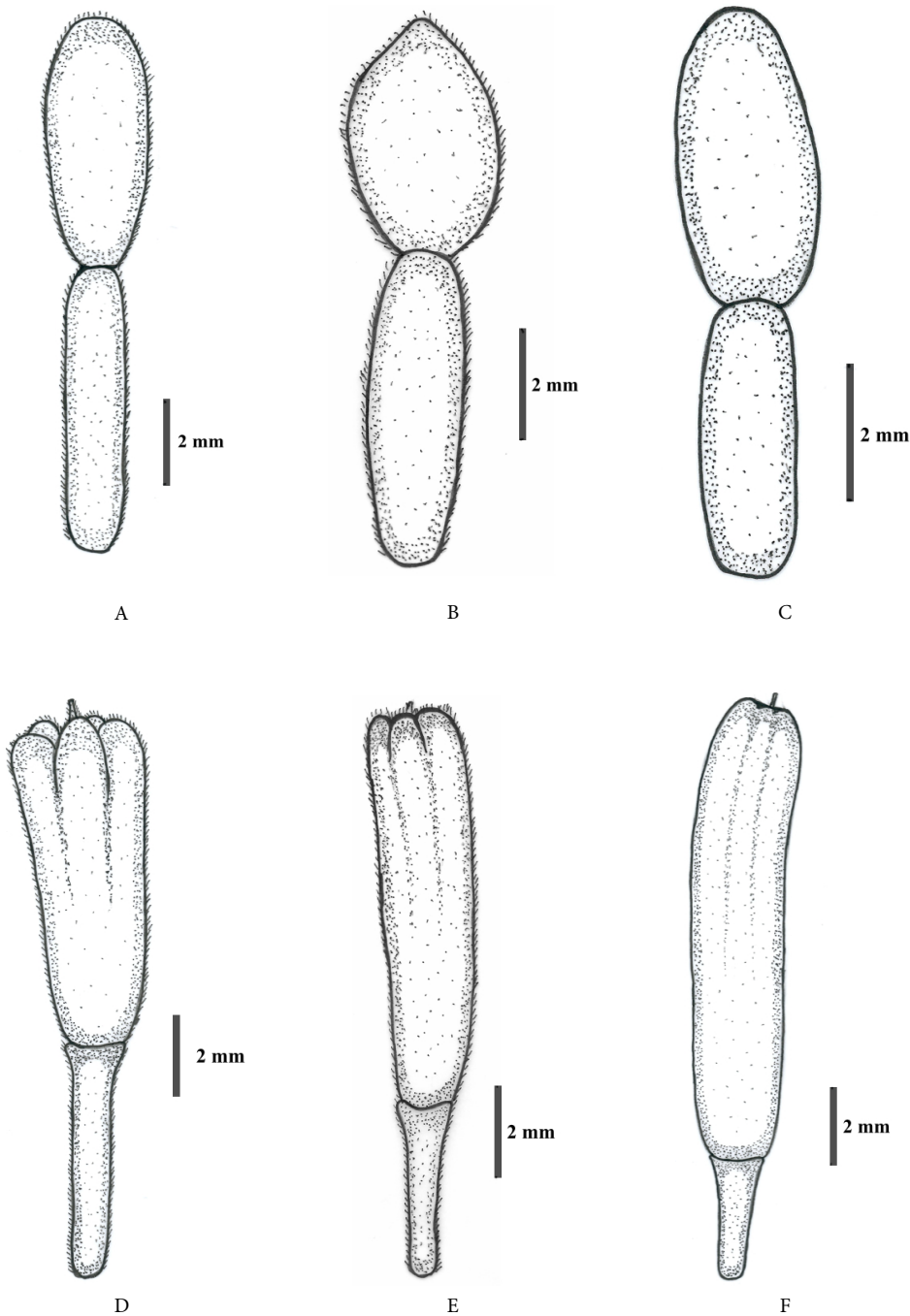
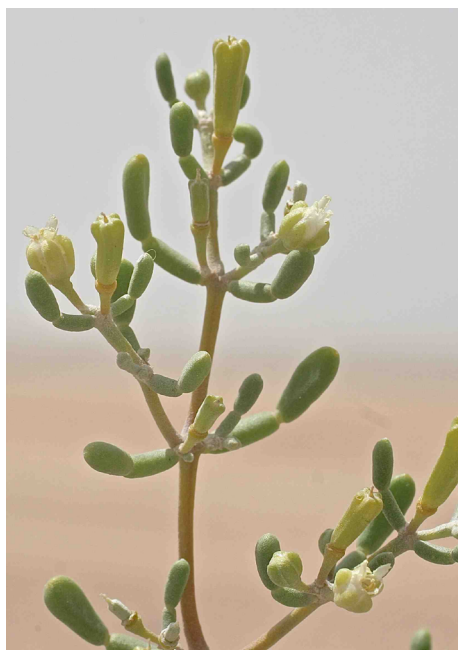


Figure 3. General leaf and fruit shape in line drawings. Leaf shape of *T. hamiensis* var. *hamiensis* (A), leaf shape of *T. hamiensis* var. *qatarensis* (B), leaf shape of *T. hamiensis* var. *mandavillei* (C), fruit shape of *T. hamiensis* var. *hamiensis* (D), fruit shape of *T. hamiensis* var. *qatarensis* (E), fruit shape of *T. hamiensis* var. *mandavillei* (F).

(KAUH*); Al Ahsa, Qatar road, 25 km before Salwa, 2 May 2013, 24°49'54"N, 50°40'25"E, *Alzahrani* D19 (KAUH); Al Ahsa, Qatar road, 10 km before Alaudaidah, 2 May 2013, 24°27'32"N, 51°02'52"E, *Alzahrani* D24 (KAUH); Al Ahsa, Dammam road, 3 May 2013, 25°37'33"N, 49°31'11"E,

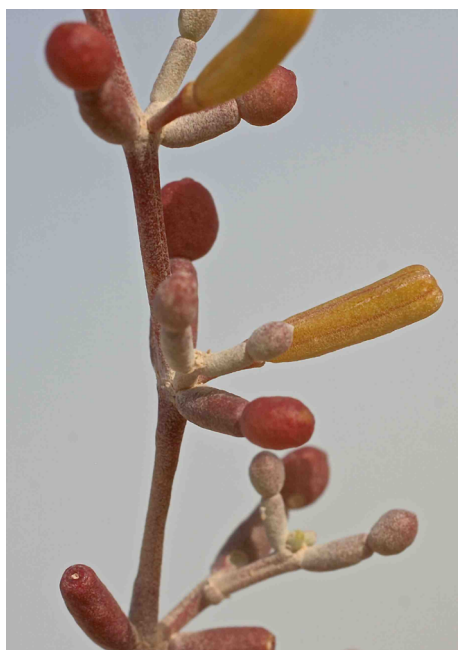
Alzahrani D28 (KAUH); Alqateef, Alsharqia, 7 July 1997, Atar 5723 (KSU); Aflag, Layla, 17 September 1998, Atar 5834 (KSU); Dhahran, 30 December 1953, Baker XI (K). UAE: West side of Jabal Hafit, 1 January 1983, *Brown* 439 (CAI). Oman: Nizwa Agricult Inst. Firg., 8 November



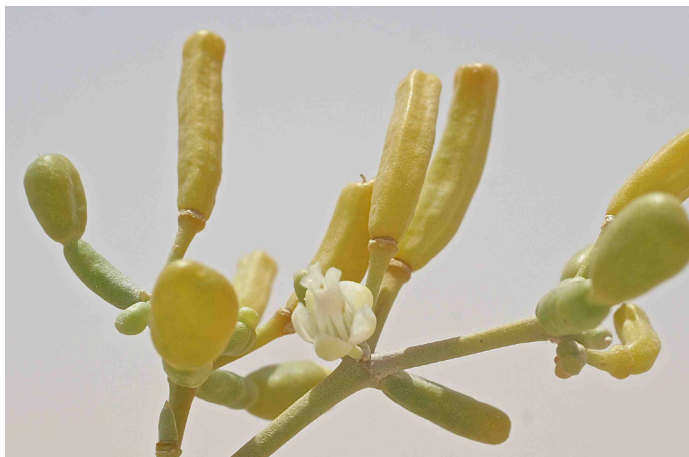
A



B



C



D

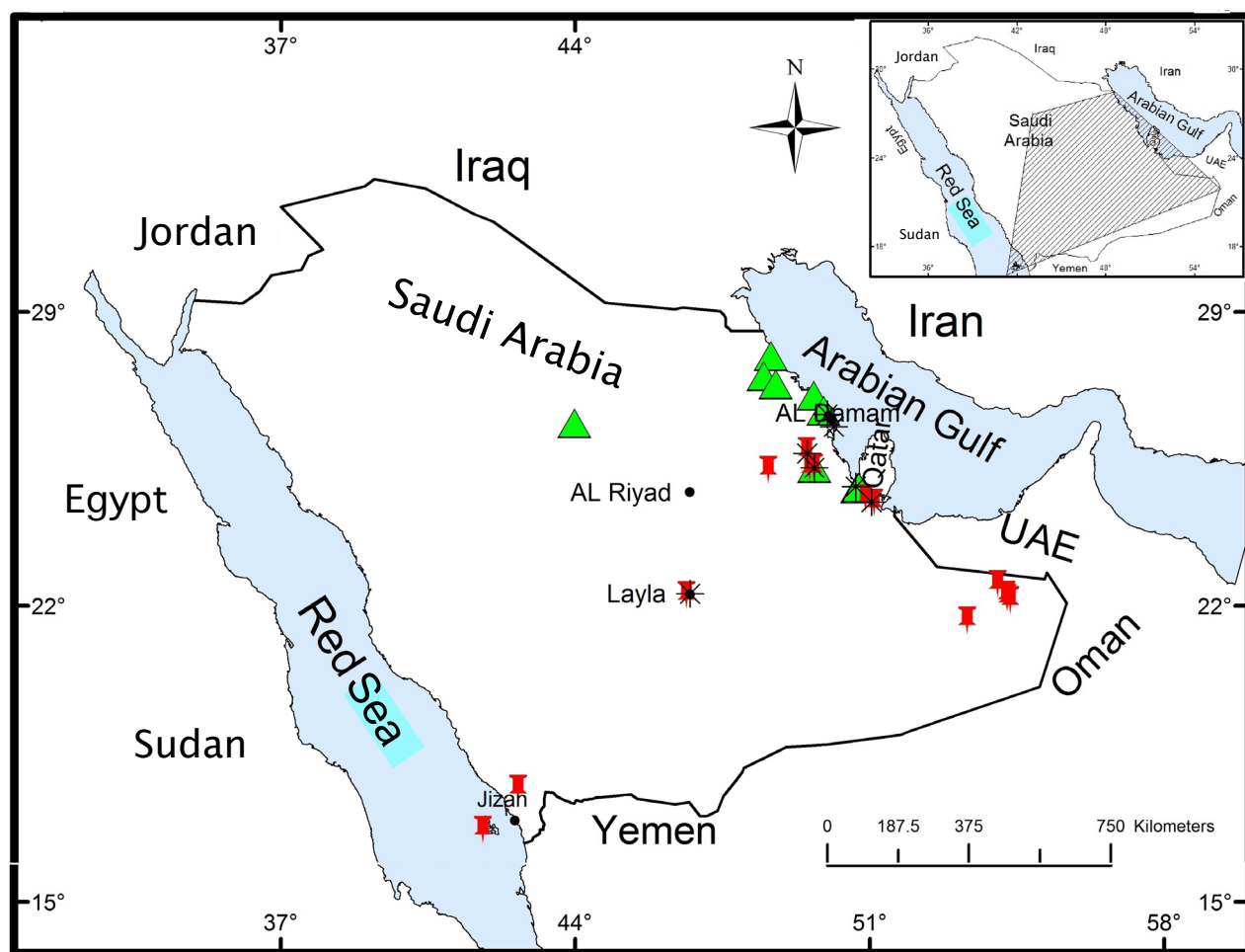
Figure 4. General leaves, flowers, and fruits of *T. hamiensis* varieties: *T. hamiensis* var. *hamiensis* (A), *T. hamiensis* var. *qatarensis* (B and C), *T. hamiensis* var. *mandavillei* (D).

1981, *Maconochie* 2948 (K); Bahala, 4 March 1976, *Radcliffe-Smith* 3790 (K); Dhufar: 50 km west of Mudhai, 13 September 1985, *Miller* 7621 (K). Yemen: Hadramout, Sayun outside the town, weeds in field and road sides, 16 June 1987, *Boulos, Rowaished, Gifri, Saeed & Hissein* 17042

(CAI); Wadi Hajr, 100 km W of Mukalla, Howtah 11 km N of Meifa Haga, 13 February 1989, *Miller, Guarino, Obadi, Hassan & Mohammed* M.8153 (K, E). Iran: Southeast Iran: Zahedan province, 24 miles of Rask road to Chah Bahar, 21 March 1971, *Grey-Wilson & Hewer* 262 (K).

Table 4. Principal morphological differences between *Tetraena hamiensis* varieties.

No.	Morphological characters	<i>T. hamiensis</i> var. <i>hamiensis</i>	<i>T. hamiensis</i> var. <i>qatarensis</i>	<i>T. hamiensis</i> var. <i>mandavillei</i>
1.	Color of plant	Green	Reddish or olive green	Yellowish green
2.	Leaflet shape	Clavate	Globular	Cylindrical
3.	Leaflet surface	Pubescent	Pubescent	Glabrous
4.	Leaflet size	6–9 × 3–5 mm	4–6 × 4–6 mm	7–9 × 3–5 mm
5.	Length of leaflet petiole	Up to 9 mm	Up to 8 mm	Up to 11 mm
6.	Length of flowers pedicle	Up to 5 mm	Up to 3 mm	Up to 4 mm
7.	Capsule shape	Oblong-obconical 5 angled, clearly lobed	Oblong-obovate 5 angled, partly lobed	Cylindrical sausage shape
8.	Capsule apex	Conspicuously angled	Sometimes ridged but not conspicuously angled	Rounded
9.	Capsule surface	Pubescent	Pubescent	Glabrous
10.	Capsule size	10–13 × 3–4 mm	8–10 × 2–3 mm	16–20 × 3–4 mm

**Figure 5.** A distribution map of *Tetraena hamiensis* varieties in Saudi Arabia:

T. hamiensis var. *hamiensis* (triangle), *T. hamiensis* var. *qatarensis* (asterisk), *T. hamiensis* var. *mandavillei* (pin).

***Tetraena hamiensis* (Schweinf.) Beier & Thulin var. *qatarensis* (Hadidi) Alzahrani & Albokhari, comb. nov.** (Figures 3B, 3E, 4B, 4C, and 5)

Basionym: *Zygophyllum qatarense* Hadidi, in *Webbia* 32 (2): 394 (1978).

Synonyms: *Zygophyllum hamiense* var. *qatarense* (Hadidi) Thomas & Chaudhary, *Flora of the Kingdom of Saudi Arabia* 2: 502 (2001); *Tetraena qatarensis* (Hadidi) Beier & Thulin, in *Pl. Syst. Evol.* 240 (1–4): 36 (2003).

Type: Qatar, Um slal Ali, c. 25 km N of Doha, March 1977, *Boulos* 10953, holotype (K!), isotype (CAI, FLO).

Conservation status: The current *Tetraena hamiensis* var. *qatarensis* is evaluated as Least Concern (LC) since its common in Qatar, Kuwait, Bahrain, the UAE, Oman, Socotra, Samha Isl., Abd-al-Kuri Isl., and Iraq (IUCN, 2014).

Habitat: In Saudi Arabia, found in saline sand, including beaches and coastal areas, and in rocky habitats.

Phenology: Flowering and fruiting from February to June and September to November.

Vernacular names (Arabic): Harm.

Distribution: Saudi Arabia (eastern region and north central Saudi Arabia (Figure 5); Qatar, Kuwait, Bahrain, UAE, Oman, Socotra, Samha Isl., Abd-al-Kuri Isl., and Iraq.

Specimens examined: Saudi Arabia: Al Ahsa, Qatar road, 2 May 2013, 25°16'29"N, 49°41'07"E, *Alzahrani* D16 (KAUH*); Al Ahsa, Qatar road, 2 May 2013, 24°48'40"N, 50°44'26"E, *Alzahrani* D20 (KAUH); Al Ahsa, Qatar road, 2 May 2013, 24°48'40"N, 50°44'26"E, *Alzahrani* D21 (KAUH); Al Ahsa, Qatar road, 2 May 2013, 24°48'40"N, 50°44'26"E, *Alzahrani* D22 (KAUH); Buraidah, 6 March 1997, *Alfarhan & Thomas* s.n. (KSU); Al-Ahsa, March 1996, *Thomas* 766 (KSU); Aljubail, Alsharqia, 7 July 1997, *Atar* s.n. (KSU); Alsafaneiyah, Dammam, February 1981, *Migahid & Alsheikh* s.n. (KSU); Alsafaneiyah, Dammam, 25 February 1981, *Migahid & Alsheikh* s.n. (KSU); Umm assahik, Alsharqia, 7 July 1997, *Atar* s.n. (KSU); Near Batha check point, Salwa region, 11 March 1990, *Chaudhary, Wutaid & Qahtani* s.n. (National Herbarium, RIY); Rocky coastal area near Batha check point, Salwa region, 11 March 1990, *Chaudhary, Wutaid & Qahtani* s.n. (National Herbarium, RIY); Dareen Island, 5 May 1987, *Chaudhary* s.n. (National Herbarium, RIY); Abqaiq-Hofuf road 87 km from Dhahran, 13 April 1982, *Podzorski* 811 (National Herbarium, RIY); Nairyah, 11 October 1983, *Jeha* s.n. (National Herbarium, RIY); 18 km N of Dammam, 7 February 1982, *Naylor* 5 (E). Qatar: Um slal Ali, c. 25 km N of Doha, 29 March 1977, *Boulos* 10953 (K!, holotype); Dukham, 22 September 1970, *Willoax* 3 (K); Abu Samra, South Qatar, 22 February 1979, *Batanouny* 2453 (K); Dukham Camp, 12 m waste ground, 29 December 1970, *Wilcox* 38 (K); Sheikh Khalifa Ibn Ali Al Thani Garden,

4 April 1977, *Boulos* 11179 (K); Al Khor outside town, 4 April 1977, *Boulos* 11168 (K). Kuwait: Al-Khiran, March 1983, *Rawi & Student* 1550 (CAI); Roadsides between Al-Ahmadi and mina Abdullah, 16 March 1995, *Mathew* 2531 (K). Bahrain: Sar, 26 April 1979, *Vije* 87 (K); Sar, April 1979, *Vije* 2 (K); Persian Gulf, Narch 1950, *Good* 67 (K); Near base of central hills of Bahrain main island, 26 April 1984, *Rezk* 103 (K); Jerdab, 1985, *Naguib* 404 (K); Dumeotin, 1985, *Naguib* 604 (K); Al-Areen Wild Life Park and Reserve, 20 April 1985, *Boulos & Hasan* 15687 (K). UAE: Abu Dhabi, 20 March 1981, *Western* BW 20 (K). Oman: Wahiba sands, 16 January 1986, *Cope* 36 (K); Wahiba sands, West of Ra's Jibsh, 17 January 1986, *Cope* 43 (K); Wahiba sands, 20 km south of Bilad Bani Bu Ali, 18 January 1986, *Cope* 46 (K); Wahiba sands, Wadi Al Batha between Al Mintirib and Bilad Bani Bu Hasan, 14 January 1986, *Cope* 20 (K); Nr Zukayt 10 km SSW of Izki, 18 September 1979, *Miller & Whitcombe* 2017 (K); Camp1, Ramlat As Sahwa, Alghaba, 5 March 1978, *Lawton* 1938 (K); Wahiba sands, 21 January 1985, *Muvton* 21/2 (E); Kuria Muria Island, Al Hallaniyah Island, February 1993, *McLeish* 1587 (E); Dhofar Wadi Ayn Beach, September 1993, *McLeish* 2464 (E). Iraq: 25 km SE by S of Zubair, 23 March 1957, *Ghiust, Rawi & Rechinger* 16871 (K); 25 km SE by S of Zubair, 23 March 1957, *Ghiust, Rawi & Rechinger* 16872 (K); Between Zubair and Safwan, 23 March 1966, *Alizzi* 34353 (K); c 10 km SE of Zubair, 12 February 1947, *Gillett & Rawi* 6010 (K); Near Safwan, 21 April 1967, *Alizzi & Sabah* 34959 (K).

***Tetraena hamiensis* (Schweinf.) Beier & Thulin var. *mandavillei* (Hadidi) Alzahrani & Albokhari, comb. nov.** (Figures 3C, 3F, 4D, and 5)

Basionym: *Zygophyllum mandavillei* Hadidi, in *Publ. Cairo Univ. Herb.* 7–8: 327 (1977).

Synonyms: *Zygophyllum hamiense* var. *mandavillei* (Hadidi) Thomas & Chaudhary, *Flora of the Kingdom of Saudi Arabia* 2: 502 (2001); *Tetraena mandavillei* (Hadidi) Beier & Thulin, in *Pl. Syst. Evol.* 240 (1–4): 36 (2003).

Type: Saudi Arabia, Rub' Al-Khali, Camp Shaybah 9, June 1970, *Mandaville*, 2892, holotype (BM!), isotype (CAI).

Conservation status: *Tetraena hamiensis* var. *mandavillei* is distributed in the eastern and southwest regions and northwest, northern, and eastern parts of ArRub al Khali in Saudi Arabia. At the international level, this species is evaluated as Least Concern (LC), since it is also found and not threatened in Oman, the United Arab Emirates, and Yemen.

Habitat: In Saudi Arabia found in red sands, gravels, or saline habitats.

Phenology: Flowering and fruiting from February to June and September to November.

Vernacular name (Arabic): Harm.

Distribution: Saudi Arabia (central, eastern, north, and eastern ArRub al Khali, Doshak Island, and southwest region of Saudi Arabia (Figure 5)); Oman, United Arab Emirates, and Yemen (Aden Desert).

Specimens examined: Saudi Arabia: Khurais, Al Ahsa road, 2 May 2013, 25°13'55"N, 48°36'16"E, *Alzahrani* D13 (KAUH*); Al Ahsa, Qatar road, 2 May 2013, 25°16'18"N, 49°34'59"E, *Alzahrani* D15 (KAUH); Al Ahsa, Qatar road, 2 May 2013, 25°16'29"N, 49°41'07"E, *Alzahrani* D17 (KAUH); Al Ahsa, Qatar road – 25 km before Alaudaidah, 2 May 2013, 24°32'55"N, 50°54'16"E, *Alzahrani* D23 (KAUH); Al Ahsa, Qatar road, 10 km before Alaudaidah, 2 May 2013, 24°27'32"N, 51°02'52"E, *Alzahrani* D25 (KAUH); Al Ahsa, Qatar road, Alaudaidah, 2 May 2013, 24°26'07"N, 51°07'01"E, *Alzahrani* D26 (KAUH); Shedgum, next to the cement factory, Al Ahsa-Dammam road, 3 May 2013, 25°40'07"N, 49°30'31"E, *Alzahrani* D30 (KAUH); Wadi Baysh, near Sabiya, 8 June 1999, *Farhan, Turki* and *Thomas* s.n. (KSU); Near Shabita, 23 February 1990, *Chaudhary, Wutaid & Qahtani* s.n. (National Herbarium, RIY); Doshak Island, 24 June 1988, *Chaudhary* s.n. (National Herbarium, RIY); Layla lakes, sol Layla, 2 March 1987, *Colletette* 6046 (National Herbarium, RIY, K); 10 km northwest of cam S-3, northeastern Rub' al-Khali, 3 February 1979, *Mandaville* 7085 (E); Rub' Al-Khali, Camp Shaybah 9, 22 June 1970, *Mandaville* 2892 (BM!, holotype). Oman: Near Wadi Tawsinat, north Dhofar, 12 May 1982, *Gallagher* 6464/26 (E). UAE: Sweehan, February 1996, *Boer* 103 (National Herbarium, RIY).

4. Discussion

Taxonomy must largely rely on morphological characters to define taxa. Problems in taxonomy arise when some taxa display a large amount of variability, due to phenotypic plasticity (van den Berg and Groendijk-Wilders, 1999). In the present study, some morphological varieties, especially in the leaf, flower parts, and fruit characters, were observed among individuals of *Tetraena hamiensis* inhabiting the same location. A considerable number of these characters were scored and numerical methods (PCoA and UPGMA) were applied to study their variation among individuals of *T. hamiensis*. The obtained PCoA plots and UPGMA dendrogram gave quite similar results. In both the first two axes and in the first and third axes of the PCoA (Figures 1A and 1B), individuals of *T. hamiensis* split off as three clusters; one comprises individuals with characters partially overlapping those of *T. hamiensis*, one comprises individuals with characters partially overlapping those of *T. qatarensis*, and one comprises

individuals with characters partially overlapping those of *T. mandavillei*. In the UPGMA (Figure 2) dendrogram, one comprises individuals with characters entirely overlapping those of *T. hamiensis*, one comprises individuals with characters entirely overlapping those of *T. qatarensis*, and one comprises individuals with characters entirely overlapping those of *T. mandavillei*. Therefore, *T. hamiensis*, *T. qatarensis*, and *T. mandavillei* are herein considered as varieties of *T. hamiensis* (*T. hamiensis* var. *hamiensis*, *T. hamiensis* var. *qatarensis*, and *T. hamiensis* var. *mandavillei*). These results strongly support the opinion of Thomas and Chaudhary (in Chaudhary, 2001) in recognizing varieties under *hamiensis*. In our opinion, UPGMA and PCoA analyses can be used to study the morphological variation among individuals of the same species, since these analyses give insight into the degree of similarity among individuals and clear distinctions between the different varieties.

In the original description of *Zygophyllum mandavillei* (*T. hamiensis* var. *mandavillei*, in this work), El-Hadidi (1977) stated that the flower pedicle (5 mm long) is longer than the capsule pedicle (2 mm long) and the ovary is glabrous. Controversially, Mandaville (1990) recorded flower pedicles of about 3 mm long and capsules pedicles of 3–5 mm long, i.e. the flower pedicle nearly equal to or shorter than the capsule pedicle. Examination of El-Hadidi's specimens, including the type specimens, revealed that the flower pedicle is up to 4 mm long, the capsule pedicle is up to 5 mm long, and the ovaries are pubescent. Also, in the original description of *Zygophyllum qatarensis* (*T. hamiensis* var. *qatarensis*, in this work), El-Hadidi in Boulos (1978) stated that the petiole length is as long as the leaflet, the ovary and capsule are glabrous, and the pedicle is 2–3 mm long. Examination of El-Hadidi's specimens, including the type specimens, revealed that the petiole length is up to 8 mm long, the leaflet is up to 6 mm long, the ovary is hairy, the capsule is pubescent, and the pedicle is up to 7 mm long.

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References

- Barth HJ (1999). Desertification in the eastern province of Saudi Arabia. *J Arid Environ* 43: 399-410.
- Batanouny KH (1981). Ecology and Flora of Qatar. Doha, Qatar: University of Qatar Press.
- Beier BA, Chase MW, Thulin M (2003). Phylogenetic relationships and taxonomy of subfamily Zygophylloideae (Zygophyllaceae) based on molecular and morphological data. *Plant Syst Evol* 240: 11-39.
- Bellstedt DU, Van Zyl L, Marais EM, Bytebier BL, De Villiers CA, Makwarela AM, Dreyer LL (2008). Phylogenetic relationships, character evolution and biogeography of southern African members of genus *Zygophyllum* (Zygophyllaceae) based on three plastid regions. *Mol Phylogenet Evol* 47: 932-949.
- Böer B, Sargeant D (1998). Desert perennials as plant and soil indicators in eastern Arabia. *Plant Soil* 199: 261-266.
- Boulos L (1978). Materials for a flora of Qatar. *Webbia* 32: 369-396.
- Chaudhary SA (2001). Flora of the Kingdom of Saudi Arabia (Part 3), Vol. 3. 1st ed. Riyadh, Saudi Arabia: Ministry of Agriculture and Water Press.
- Collenette IS (1985). An Illustrated Guide to the flowers of Saudi Arabia. London, UK: Scorpion Publishing Press.
- Collenette IS (1999). Wildflowers of Saudi Arabia. Riyadh, Saudi Arabia: NCWCD Press.
- Cornes MD, Cornes CD (1989). The Wild Flowering Plants of Bahrain. London, UK: IMMEL Publishing.
- El-Hadidi MN (1977). Two New *Zygophyllum* Species from Arabia. Cairo, Egypt: Cairo University Herbarium Press.
- Ghazanfar SA, Osborn J (2015). Typification of *Zygophyllum propinquum* Decne. and *Z. coccineum* L. (Zygophyllaceae) and a key to *Tetraena* in SW Asia. *Kew Bull* 70: 38.
- Gower JC (1966). Some distance properties of latent root and vector methods used in multivariate analysis. *Biometrika* 53: 326-338.
- Hosny AI (1978). Revision of *Zygophyllum* L. Sect. *Bipartita* and *Mediterranea* in Egypt and Arabia. MSc, Cairo University, Cairo, Egypt.
- Hosny AI (1988). Genus *Zygophyllum* L. in Arabia. *Taeckholmia* 11: 19-32.
- IUCN (2014). IUCN Red List of Threatened Species. Version 2014.1. Gland, Switzerland: IUCN.
- Karim FM (2002). Wild Flowering Plants of the United Arab Emirates. Abu Dhabi, UAE: Environmental Research and Wildlife Development Agency.
- Kovach WL (1999). MVSP – A Multivariate Statistical Package for Windows, Version 3.1. Pentraeth, UK: Kovach Computing Services.
- Ksiksi T, Guenaoui C, Fawzi N (2012). Early growth stages of the rare *Acridocarpus orientalis* in the UAE - a first step towards conservation. *Nat Resour J* 3: 1-5.
- Louhaichi M, Salkini AK, Estita HE, Belkhir S (2011). Initial assessment of medicinal plants across the Libyan Mediterranean coast. *Advances in Environmental Biology* 5: 359-370.
- Mandaville JP (1986). Plant life in the Rub' al-Khali (the Empty Quarter), south-central Arabia. *P Roy Soc Edinb B* 89: 147-157.
- Mandaville JP (1990). Flora of Eastern Saudi Arabia. London, UK: Kegoian Pul International Ltd.
- Migahid AM (1996). Flora of Saudi Arabia, Vol. 1, 4th ed. Riyadh, Saudi Arabia: Riyadh University Press.
- Mosti S, Raffaelli M, Tardelli M (2012). Contribution to the Flora of Central-Southern Dhofar (Sultanate of Oman). *Webbia* 67: 65-91.
- Norton J, Abdul Majid S, Allan D, Al Safran M, Böer B, Richer R (2009). An Illustrated Checklist of the Flora of Qatar. Gosport, UK: Browndown Publ.
- Sakir S, Kabshaw M, Mehairbi M (2012). Medicinal plants diversity and their conservation status in the United Arab Emirates (UAE). *J Med Plants Res* 6: 1304-1322.
- Sayed OH (1996). Adaptational responses of *Zygophyllum qatarense* Hadidi to stress conditions in a desert environment. *J Arid Environ* 32: 445-452.
- Sheahan MC, Chase MW (1996). A phylogenetic analysis of Zygophyllaceae based on morphological, anatomical and *rbcL* DNA sequence data. *Bot J Linn Soc* 122: 279-300.
- Sheahan MC, Chase MW (2000). Phylogenetic relationships within Zygophyllaceae based on DNA sequences of three plastid regions, with special emphasis on Zygophylloideae. *Syst Bot* 25: 371-384.
- Symanczik S, Blanzkowski J, Koegel S, Boller T, Wiemken A, Al-Yahya'ei M (2014). Isolation and identification of desert habituated arbuscular mycorrhizal fungi newly reported from the Arabian Peninsula. *J Arid Land* 6: 488-497.
- Thulin M (1993). Zygophyllaceae. In: Thulin M., editor. Flora of Somalia, Vol. 1. Kew, UK: Royal Botanic Gardens, pp. 176-189.
- Van den Berg RG, Groendijk-Wilders N (1999). Numerical analysis of the taxa of series *Circaeifolia* (*Solanum* section *Petota*). In: Nee M, Symon DE, Lester RN, Jessop JP, editors. Solanaceae IV: Advances in Biology and Utilization. Kew, UK: Royal Botanic Gardens, pp. 213-226.
- Waly NM, Al-Ghamdi FA, Al-Shamrani RI (2011). Developing methods for anatomical identification of the genus *Zygophyllum* L. (Zygophyllaceae) in Saudi Arabia. *Life Sci J* 8: 451-459.
- Western AR (1989). The Flora of the United Arab Emirates, an Introduction. Al Ain, UAE: United Arab Emirates University Press.
- Wood JR (1997). A Handbook of the Yemen Flora. Kew, UK: Royal Botanic Gardens.