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THE TAXONOMIC POSITION OF *PETINIOTIA PURPURASCENS* (*BRASSICACEAE*): A PHENETIC ANALYSIS

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Rechinger, in his 1968 *Flora Iranica* account, considered *Sterigmostemum* to contain nine species in Iran. In 1980 Léonard excluded *S. purpurascens* from *Sterigmostemum* and transferred it to the new genus *Petiniotia* as *P. purpurascens.* Subsequently, in 1988 Jacquemoud retained this species in *Sterigmostemum*, but as subgenus *Petiniotia.* In 2000 Sonboli *et al*. excluded *S. laevicaule* from *Sterigmostemum* and considered it to be a synonym of *Erysimum crassicaule*. Phenetic analysis of morphological and anatomical characters from herbarium and fresh specimens supports the recognition of five species in *Sterigmostemum* (*S. incanum*, *S. sulphureum*, *S. acanthocarpum*, *S. ramosissimum* and *S. longistylum*). The results of cluster analysis and ordination based on these characters confirm Léonard's exclusion of *S. purpurascens* and transfer to the genus *Petiniotia* as *P. purpurascens*. A key is provided to distinguish *Petiniotia* from *Sterigmostemum*, followed by descriptions of the two genera and a conspectus of species.

Keywords. Anatomy, *Brassicaceae*, *Cruciferae*, Iran, *Petiniotia*, phenetics, *Sterigmostemum.*

Introduction

Sterigmostemum M.Bieb. belongs to tribe *Hesperidae* of *Brassicaceae* (Rechinger, 1968). The genus was originally described by von Bieberstein (1819), and then recognized by subsequent authors. Rechinger (1968) reported nine species: *S. incanum* M.Bieb., *S. laevicaule* Bornm., *S. sulphureum* (Banks & Soland.) Bornm., *S. contortuplicatum* (Boiss.) Bornm., *S. acanthocarpum* (Fisch. & C.A.Mey.) Kuntze [as *S. acanthocarpum* Fisch. & C.A.Mey.], *S. ramosissimum* (O.E.Schulz) Rech.f., *S. longistylum* (Boiss.) Kuntze [as *S. longistylum* (Boiss.) Bornm.], *S. rhodanthum* Rech.f., Aell. & Esfand. and *S. purpurascens* (Boiss.) Parsa from Iran. Jafri (1973) considered *S. rhodanthum* to be a synonym of *S. purpurascens*. Léonard (1980) described the new genus *Petiniotia* J.Léonard based on *Sterigmostemum purpurascens* and considered *S. rhodanthum* a synonym. However, Jacquemoud (1988), in his monograph of *Sterigmostemum*, retained *S. purpurascens* in *Sterigmostemum*, but in the new subgenus *Petiniotia* (J.Léonard) Jacquemoud. Sonboli *et al*. (2000) excluded *S. laevicaule* from *Sterigmostemum* and considered it a synonym of *Erysimum*

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crassicaule (Boiss.) Boiss. Although the trichomes of *Sterigmostemum* were studied by Jacquemoud (1988), there is no report on stem and fruit anatomy in this genus. The present study describes the phenetic analysis of morphological and anatomical characters in Iranian *Sterigmostemum* s.l. with the following objectives:

1 To evaluate the taxonomic importance of anatomical characters and morphometry in species delimitation in the genus.
2 To assess the systematic position of *S. purpurascens*.

Materials and methods

Plant material

Specimens in Iranian herbaria and new collections from wild populations were examined. Details of localities and voucher specimens are given in Table 1.

Morphometry

For the morphological studies, a minimum of five specimens were examined from each of 23 localities or populations, the latter being treated as operational taxonomic units (OTUs). In total 28 quantitative and qualitative morphological characters were used for the phenetic analysis. Means were determined for quantitative characters and qualitative characters were treated as multistate and then coded (Table 2).

Anatomy

Mature stems and fruits from fresh as well as herbarium specimens were used for anatomical studies. Fresh material was fixed in FAA (formaldehyde 10ml:acetic acid 5ml:75% ethanol 85ml) and herbarium specimens were boiled in water, cooled and then fixed in FAA for 72 hours. Material was then transferred to 70% ethanol. Hand sections were cleared in parazone and stained with 2% carmine (10–15 min) followed by 1% methylene green (30 s) and mounted in glycerin. In total 10 anatomical characters were used for phenetic analysis (Table 3).

Phenetic analysis

In order to group OTUs with morphological and anatomical similarity, clustering and ordination based on principal components analysis (PCA) were performed. Different clustering methods using Single Linkage, UPGMA and WARD were used to find the true clusters (Ingrouille, 1986). For cluster analysis the variables were standardized (mean = 0, variance = 1; Chatfield & Collins, 1995). In order to determine the most variable characters among the species, factor analysis based on PCA was performed on standardized data. Varimax rotation was carried out after Kaiser

TABLE 1. Locality references of OTUs studied

OTUs	Locality
Sterigmostemum incanum	
1. Si–1	Urmia: Khoy, near Gheris, 10 vi 1997, *Sonboli & Zehzad* s.n. (HSBU)*
2. Si–2	Urmia: Darya road, Bashghale, 1300m, 14 vi 1997, *Sonboli* s.n. (HSBU)
3. Si–3	Maku: Kelisa-Kandy, 11 vi 1997, *Sonboli & Zehzad* s.n. (HSBU)
4. Si–4	Fars: Shiraz, Khane-zenian, Zakherd, 2050m, 11 vi 1992, *Mozaffarian* 71357 (TARI)**
S. sulphureum	
1. Ss–1	Tehran: Tehran–Firuzkuh, 40km to Firuzkuh, 14 v 1997, *Sonboli & Mansournia* s.n. (HSBU)
2. Ss–2	Tehran: 13km from Firuzkuh to Semnan, 2000m, 9 vi 1981, *Assadi & Mozaffarian* 35250 (TARI)
3. Ss–3	Azerbaijan: Tabriz, Kuh-e Sahand, Lighvan, 2400–2500m, 10 ix 1995, *Assadi* 73998 (TARI)
4. Ss–4	Bakhtiari: Borojen, Boldaji, Kabibak, 2250m, 3 vii 1986, *Mozaffarian* 57379 (TARI)
S. ramosissimum	
1. Sr–1	Shahroud: Khoshyeylagh, 2130m, 10 vi 1973, *Foroughi* 8944 (TARI)
2. Sr–2	Tehran: 30km NE of Firuzkuh, Veresk, 1600m, 8 v 1973, *Arazm & Bazargan* 6804 (TARI)
3. Sr–3	Gorgan: Golestan National Park, Almeh, 1700m, 7 vi 1997, *Sonboli* s.n. (HSBU)
S. acanthocarpum	
1. Sa–1	Zanjan: km 63 road of Zanjan–Mahneshan, 1900m, 14 v 1997, *Sonboli* s.n. (HSBU)
2. Sa–2	Qom: Qom–Tehran road, 23 iv 1973, *Babakhanloo & Amin* 6802 (TARI)
3. Sa–3	Qom: km 26 road of Tehran–Qom, 1000m, 23 iv 1973, *Babakhanloo & Amin* 6448 (TARI)
4. Sa–4	Khoy: Razi, 2050m, 9 vii 1991, *Mozaffarian* 69956 (TARI)
5. Sa–5	Tehran: Sorkhe-Hesar Park, Golgasht, 12 v 1997, *Sonboli & Hashemi* s.n. (HSBU)
S. longistylum	
1. Sl–1	Hormozgan: 50km from Hajiabad to Sirjan, 1600m, 5 v 1985, *Mozaffarian* 52621 (TARI)
2. Sl–2	Kerman: Mahan–Kerman, 1900m, 6 v 1977, *Assadi* 23250 (TARI)
3. Sl–3	Esfahan: Najafabad, protected area, 1600m, 7 v 1983, *Nowroozi* 1969 (TARI)
Petiniotia purpurascens	
1. Pp–1 (as *S. purpurascens*)	Hormozgan: Hajiabad, Golzar, 9 v 1997, *Sonboli & Zehzad* s.n. (HSBU)
2. Pp–2 (as *S. purpurascens*)	Hormozgan: Bandar-e Abbas–Hajiabad, Tangezagh, 7 v 1997, *Sonboli & Zehzad* s.n. (HSBU)
3. Pp–3 (as *S. rhodanthum*)	Baluchistan: 20km from Suran to Saravan, 1250m, 12 iv 1983, *Mozaffarian* 43892 (TARI)
4. Pp–4 (as *S. rhodanthum*)	Hormozgan: Lar, Kuh-e Shab, 500–900m, 19 iv 1983, *Assadi & Sardabi* 42031 (TARI)

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TABLE 2. Morphological characters included in the phenetic analyses

Character	Character states
1. Indumentum	Only non-glandular (1); Non-glandular plus setae on fruit (2); Glabrous plus setae on fruit (3); Long, thin-stalked glandular plus non-glandular (4); Sessile glandular with or without non-glandular (5); Long, intermediate-stalked glandular plus non-glandular (6); Strongly glandular plus non-glandular (7)
2. Pedicel length	(mm)
3. Pedicel orientation	Straight (1); Patent (2)
4. Sepal colour	Green (1); Whitish-pink or purple (2)
5. Sepal length	(mm)
6. Sepal width	(mm)
7. Petal colour	Yellow (1); Whitish-pink or purple (2)
8. Petal shape	Spatulate (1); Circular (2); Obovate (3)
9. Petal length	(mm)
10. Petal width	(mm)
11. Base of petal	Attenuate to a long (11mm) claw (1); With a short (1mm) claw (2); Cuneate (3)
12. Claw length	(mm)
13. Longer filaments	Connate in pairs (1); Free (2)
14. Longer filaments length	(mm)
15. Short filaments length	(mm)
16. Anther length	(mm)
17. Ovary shape	Linear (1); Ovoid, attenuate towards apex (2); Cylindrical (3)
18. Style length	(mm)
19. Style	Cylindrical, thinner than fruit (1); Cylindrical, as thick as fruit (2); Clavate, thickened towards apex (3)
20. Stigma	Deeply 2-lobed, lobes subcircinate (1); V-shaped (2); 2-lobed, lobes inclining (3)
21. Stigma lobes length	(mm)
22. Fruiting pedicel length	(mm)
23. Fruit dehiscence	Indehiscent (1); Longitudinally dehiscent from the base (2); Late dehiscent (3)
24. Articulations on fruit	2–3 articulate (1); Lomentum (2); More than 3 (3)
25. Setae on silique	Present (1); Absent (2)
26. Seeds per silique	Up to 8 (1); More than 8 (2)
27. Glandular hairs	Absent (1); Subsessile (2); Stalked (3)
28. Peduncle	Flexuous (1); Not flexuous (2)

TABLE 3. Anatomical characters included in the phenetic analyses

Character	Character states
1. Shape of stem epidermal cells	Subglobose (1); Square with sinuate walls (2); Square with straight walls (3)
2. Inner epidermal cell walls of stem	Thickened (1); Not thickened (2)
3. Shape of cortex cells	Subglobose with irregular walls (1); Globose with regular walls (2); Oblong with irregular walls (3)
4. Endodermis and pericycle	Both well differentiated (1); Only endodermis differentiated (2)
5. Pericycle fibres	Present as individual scattered cells (1); Present in 1–2 cell layers as bundle (2); Present in 2–3 cell layers as large bundle (3)
6. Glandular hairs length	(mm)
7. Width of glandular hairs stalk	(mm)
8. Glandular hairs length/width	(mm)
9. Non-glandular hairs length	(mm)
10. Abscission layer	Sclerenchymatous (1); Collenchymatous (2); Parenchymatous (3)

normalization (Manly, 1991). For the phenetic analyses SPSS version 9.0 was used (George & Mallery, 2000).

RESULTS AND DISCUSSION

Characters

Indumentum

Most of the taxa examined have non-glandular and glandular hairs, though sometimes the latter are absent. The non-glandular hairs are unicellular and dendroid, with minor differences between taxa (Fig. 1A–F). Glandular hairs are subsessile (Fig. 1I) or variously stalked with multicellular heads (Fig. 1G–K).

Anatomy

The inner epidermal cell walls of the stem are thickened in all taxa except for *P. purpurascens.* An endodermis and pericycle are present in all taxa except for *P. purpurascens* where only an endodermis is present. Pericycle fibres are variable in number of cell layers and density. They are mostly well differentiated, especially in *S. ramosissimum*, though weakly so in *P. purpurascens.*

The siliques consist of two subequal loculi separated by a linear septum. In all cases the pericarp is differentiated into three layers: epicarp, mesocarp and endocarp. The epicarp consists of a single layer of epidermal cells (round in *P. purpurascens* and square in *Sterigmostemum*) with thickened outer walls, under which are

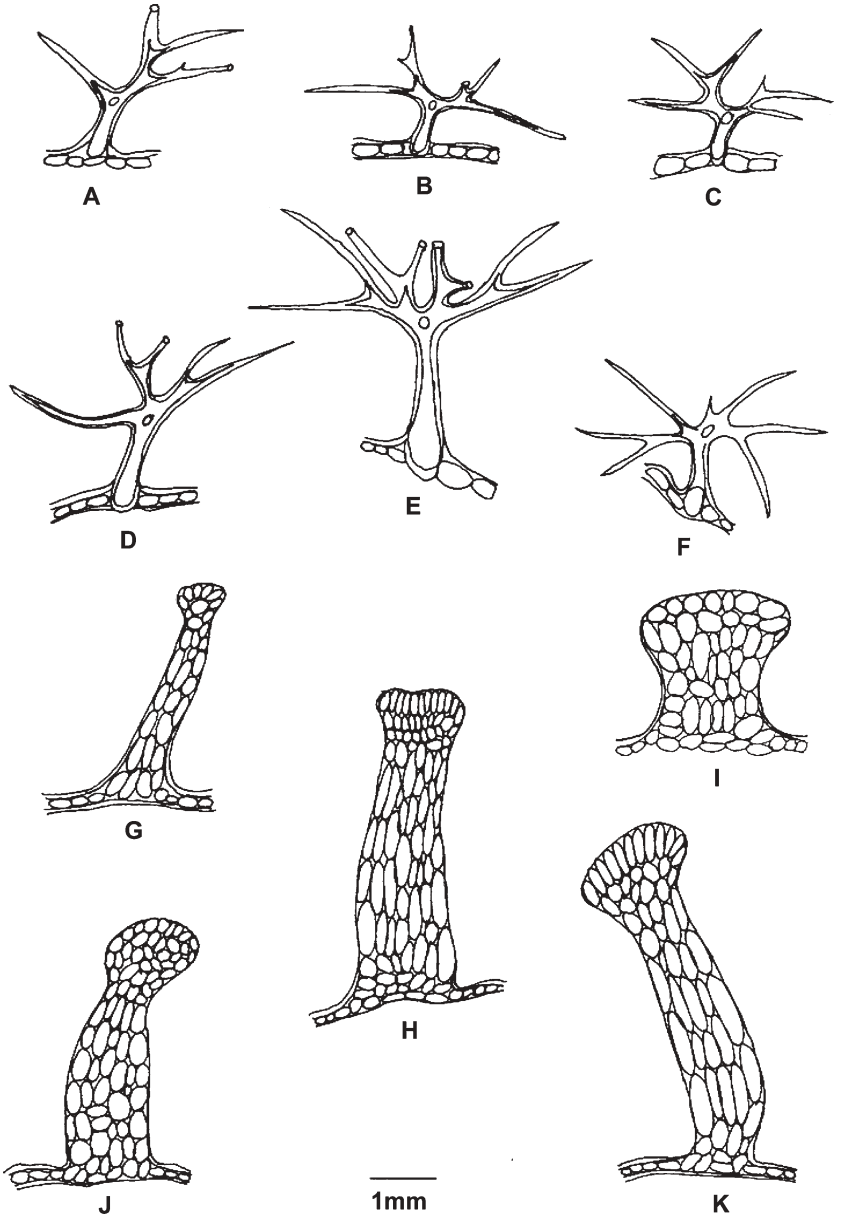

FIG. 1. Stem hairs of taxa studied. A–F: Non-glandular, dendroid. A, *Sterigmostemum ramosissimum*. B, *S. acanthocarpum.* C, *S. incanum.* D, *S. sulphureum.* E, *Petiniotia purpurascens.* F, *S. longistylum.* G–K: Glandular. G, *S. incanum.* H, *S. acanthocarpum.* I, *P. purpurascens.* J, *S. longistylum.* K, *S. ramosissimum*.

3–5 layers of parenchymatous cells. The mesocarp contains various sizes and numbers of parenchymatous cells in 1–3 layers. Lastly, the endocarp consists of 3–5 layers of sclerenchymatous cells. The abscission layer along the locules in early-dehiscent species (*P. purpurascens* and *S. longistylum*) and late-dehiscent species (*S. acanthocarpum* and *S. incanum*) consists of parenchymatous or collenchymatous cells, respectively, while in the indehiscent fruits in *S. ramosissimum* and *S. sulphureum* it is lignified. A data matrix of the qualitative morphological and anatomical characters is given in Table 4.

Phenetic analyses

Groupings of the OTUs, based on morphological and anatomical characters, are presented in Figs 2–5. In the cluster analysis of morphological data, two major clusters were obtained. The first major cluster comprises populations of *Petiniotia purpurascens* (group A in Fig. 2), while the remaining OTUs of *Sterigmostemum* form the second major cluster (group B in Fig. 2). Ordination of OTUs based on the first two PCA factors supported the clustering results (Fig. 3). Factor analysis of morphological data showed that the first three factors comprise about 73% of the total variance. The first factor comprises about 31% of total variance in which characters such as peduncle, sepal length, petal length and claw length showed the highest positive correlation (>0.7). The second factor comprises about 26% of total variance in which characters such as petal shape, base of petal, ovary shape and stigma possessed the highest correlation (>0.8). Factor 1 separates populations of *P. purpurascens* from other *Sterigmostemum* species, while factor 2 separates populations of *S. longistylum* from the other species of *Sterigmostemum.*

Cluster analysis and ordination of the anatomical characters also produced two major clusters similar to those from the morphological data (Figs 4, 5). Separation of *P. purpurascens* from other *Sterigmostemum* species is supported in both of these analyses. The results are similar to the morphological analyses. Factor analysis revealed that the first two factors comprise about 88% of the total variance. Factor 1 comprises 55% of total variance in which characters such as inner epidermal cell walls of stem, endodermis and pericycle, non-glandular hair length and abscission layer showed the highest correlation (>0.9). This factor separates *P. purpurascens* from *Sterigmostemum* species. Factor 2 comprises about 33% of total variance, with characters including glandular hair length, width of glandular hair stalk and glandular hair length/width possessing the highest correlation (>0.7). This factor also separates *S. sulphureum* from *Sterigmostemum*. The results obtained from phenetic analyses of morphological and anatomical characters support separation of *S. purpurascens* from the genus *Sterigmostemum* and its inclusion in the genus *Petiniotia* as suggested by Léonard (1980, 1988). This is further justified by the geographical distribution of these species. The monotypic genus *Petiniotia* is mainly from the Saharo-sindian region of Iran, while species in *Sterigmostemum* grow in the Irano-turanian region.

TABLE 4. Data matrix of qualitative morphological and anatomical characters of *Petiniotia* and *Sterigmostemum* species from Iran (Numbers refer to character states in Tables 2 and 3)

	OTUs					
Character	*P. purpurascens*	*S. incanum*	*S. sulphureum*	*S. ramosissimum*	*S. acanthocarpum*	*S. longistylum*
Pedicel orientation	1	2	2	2	2	2
Sepal colour	2	1	1	1	1	1
Petal colour	2	1	1	1	1	1
Petal shape	2	3	3	3	3	1
Base of petal	2	1	1	1	3	1
Longer filaments	2	1	1	1	1	1
Fruit dehiscence	2	3	1	1	3	3
Setae on silique	2	2	2	2	1	2
Seeds per silique	2	2	2	1	2	2
Glandular hairs	2	3	1	3	3	3
Peduncle	1	2	2	2	2	2
Shape of stem epidermal cells	1	2	3	3	3	2
Inner epidermal cell walls of stem	2	1	1	1	1	1
Endodermis and pericycle	2	1	1	1	1	1
Pericycle fibres	1	2	2	3	2	2
Abscission layer	1	2	1	1	2	1

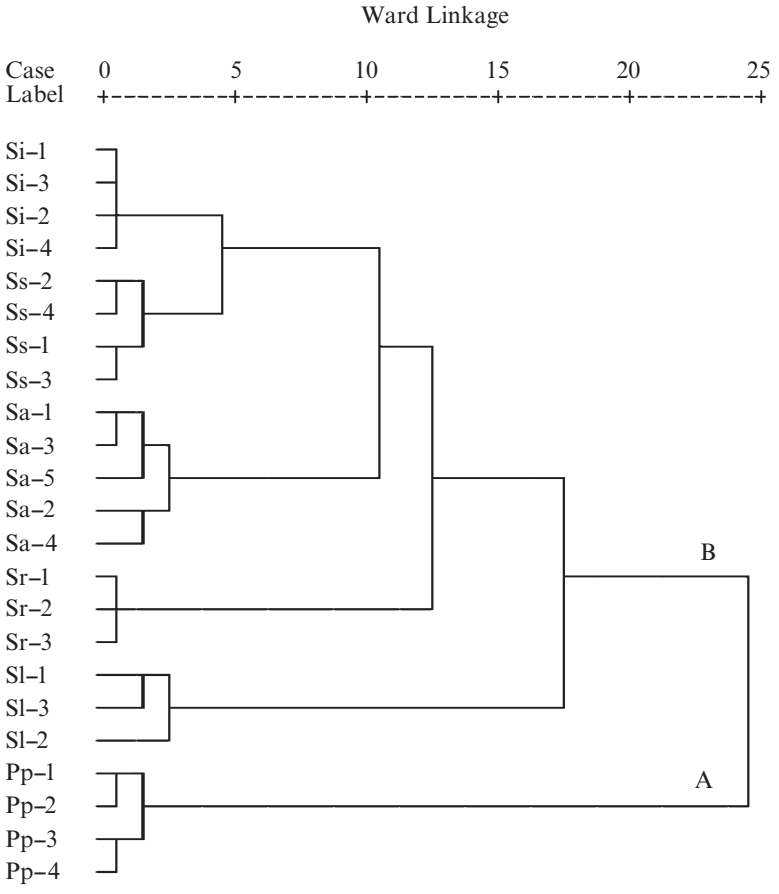

FIG. 2. Ward cluster analysis of 23 OTUs based on morphological characters (Case labels refer to OTUs in Table 1).

CONCLUSIONS

Samples from wild Iranian populations of *Sterigmostemum* s.l. were subjected to multivariate analyses to determine phenetic relationships in the genus. The results confirm the recognition of two separate genera, *Petiniotia* and *Sterigmostemum* s.s. Based on cluster analysis and principal components analysis of morphological and anatomical characters, *S. purpurascens* is treated in the separate genus *Petiniotia* as suggested by Léonard (1980) as *P. purpurascens* (Boiss.) J.Léonard with *S. rhodanthum* as a synonym.

No specimens identified as *Sterigmostemum contortuplicatum* have so far been found in Iranian herbaria, though there may be some elsewhere. Jacquemoud (1988) considered this species to be a synonym of *S. incanum*. *Sterigmostemum laevicaule* Bornm. has previously been excluded from this genus and has already been treated

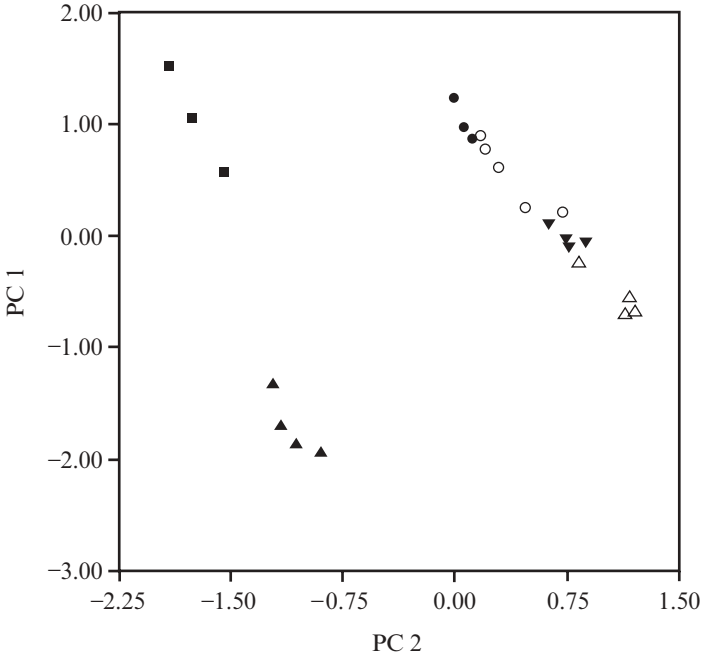

FIG. 3. Ordination of 23 OTUs based on morphological characters: *Petiniotia purpurascens* (▲), *Sterigmostemum incanum* (▼), *S. sulphureum* (△), *S. acanthocarpum* (○), *S. ramosissimum* (●), *S. longistylum* (■).

as a synonym of *Erysimum crassicaule* (Boiss.) Boiss. on the basis of morphological data (Sonboli *et al*., 2000). Our studies support the recognition of five *Sterigmostemum* species: *S. incanum*, *S. sulphureum*, *S. acanthocarpum*, *S. ramosissimum* and *S. longistylum* in Iran.

Key to distinguish Petiniotia *from* Sterigmostemum

1a. Petals yellow, obovate–spatulate, claw 1.5–6mm long; longer filaments connate in pairs; glandular hairs stalked ____ **Sterigmostemum**
1b. Petals whitish-pink or purple, circular, claw 0.5–1mm long; longer filaments free; glandular hairs subsessile, globose ____ **Petiniotia**

DESCRIPTION AND CONSPECTUS OF THE GENERA *STERIGMOSTEMUM* AND *PETINIOTIA*

Sterigmostemum M.Bieb., Fl. Taurico–Caucasica 3: 444 (1819).
Syn.: *Sterigma* DC., Syst. Nat. 2: 579 (1821), *comb. illeg*.
Var. orthogr.: *Sterigmostemon* A.L.Jussieu, Dict. Sci. Nat. 50: 521 (1827).

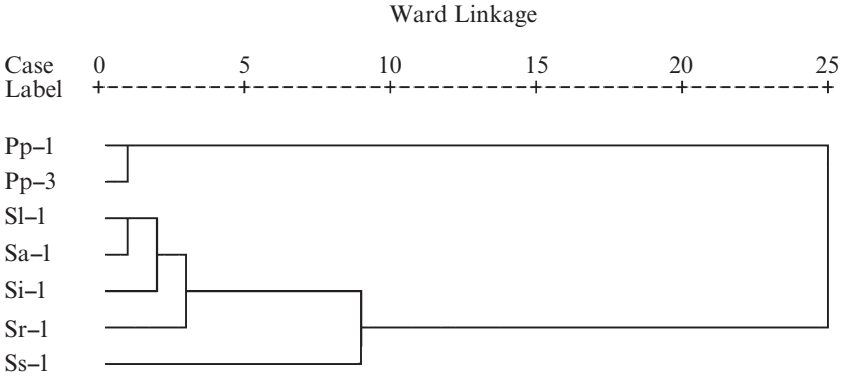

FIG. 4. Ward cluster analysis of taxa based on anatomical characters (Case labels refer to OTUs in Table 1).

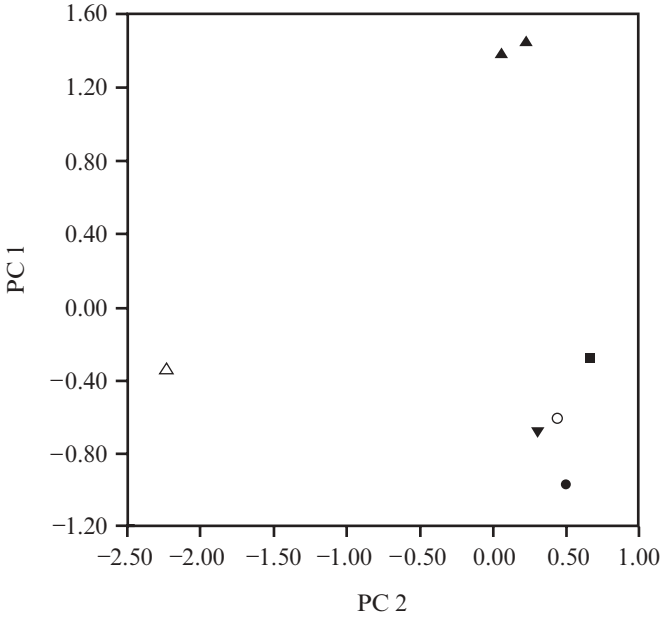

FIG. 5. Ordination of taxa based on anatomical characters: *Petiniotia purpurascens* (▲), *Sterigmostemum incanum* (▼), *S. sulphureum* (△), *S. acanthocarpum* (○), *S. ramosissimum* (●), *S. longistylum* (■).

Annual, biennial or perennial herbs, sometimes suffrutescent, with dendroid non-glandular and stalked multicellular glandular hairs (sometimes without the latter). Stems branched at base, rarely simple. Leaves lanceolate, oblong, pinnatisect or pinnatifid, sometimes entire or sinuate. Sepals erect, green, not saccate. Petals yellow,

obovate to spatulate, clawed. Stamens 6, the longer filaments connate in pairs. Style long or short. Stigma 2-lobed; lobes decurrent, divergent. Silique indehiscent or late dehiscent.

An identification key for *Sterigmostemum* species has already been published (Sonboli *et al.*, 2001). A brief conspectus of *Sterigmostemum* species follows.

1. Sterigmostemum incanum M.Bieb., Fl. Taurico–Caucasica 3: 444 (1819).
Syn.: *Cheiranthus torulosus* M.Bieb., Fl. Taurico–Caucasica 2: 121 (1808).
Sterigma torulosum (M.Bieb.) DC., Syst. Nat. 2: 580 (1821), *comb. illeg.*
Sterigmostemum torulosum (M.Bieb.) Stapf, Denk. Akad. Wiss. Wien Math. Nat. Kl. 51: 301 (1885), *comb. illeg.*
Sterigmostemum sulphureum (Banks & Soland.) Bornm. subsp. *glandulosum* Hub.-Mor. & Reese, Feddes Rep. 48: 273 (1940).

2. Sterigmostemum sulphureum (Banks & Soland.) Bornm., Beih. Bot. Centralbl. 28: 110 (1911).
Syn.: *Cheiranthus sulphureus* Banks & Soland., Russell. Nat. Hist. Aleppo 2: 257 (1794).
Sterigma sulphureum (Banks & Soland.) DC., Syst. Nat. 2: 580 (1821).

3. Sterigmostemum ramosissimum (O.E.Schulz) Rech.f., Fl. Ir. 57: 280 (1968).
Syn.: *Anchonium sterigmoides* Lipsky, Fl. USSR 8: 322 (1933).
A. ramosissimum O.E.Schulz, Bot. Jahrb. 60: 97 (1939).

4. Sterigmostemum acanthocarpum (Fisch. & C.A.Mey.) Kuntze, Rev. Gen. Pl. 1: 36 (1891).
Syn.: *Sterigma acanthocarpum* Fisch. & C.A.Mey., Ind. Sem. Hort. Petrop. 1: 38 (1835).
Sterigmostemon acanthocarpum (Fisch. & C.A.Mey.) Bornm., Bull. Herb. Boiss. 2: 1266 (1904), *comb. illeg.*

5. Sterigmostemum longistylum (Boiss.) Kuntze, Rev. Gen. Pl. 1: 36 (1891).
Syn.: *Sterigma longistylum* Boiss., Ann. Sci. Nat. Bot. 2: 387 (1842).
Sterigmostemon longistylum (Boiss.) Bornm., Beih. Bot. Centralbl. 28: 110 (1911).

Petiniotia J.Léonard, Bull. Jard. Bot. Natl. Belg. 50: 227 (1980).
Annual herb. Stem usually simple, sometimes branched near base. Indumentum of dendroid non-glandular and subsessile multicellular glandular hairs, sometimes glabrescent. Lower leaves lanceolate, oblong, pinnatisect; upper leaves entire or sinuate. Sepals erect, whitish-pink, not saccate. Petals whitish-pink or purple, circular, short-clawed, 0.5mm long. Stamens 6, longer filaments free. Style clavate. Stigma 2-lobed; lobes V-shaped. Silique longitudinally dehiscent from base.

1. Petiniotia purpurascens (Boiss.) Léonard, Bull. Jard. Bot. Natl. Belg. 50: 230 (1980).

Syn.: *Sterigma purpurascens* Boiss., Fl. Or. 1: 241 (1867).
Sterigmostemum purpurascens (Boiss.) Kuntze, Rev. Gen. Pl. 1: 36 (1891).
Sterigmostemum rhodanthum Rech.f., Aell. & Esfand., Phyton 3: 66 (1951).
Sterigmostemum purpurascens (Boiss.) Parsa, Fl. de l'Iran 1: 682 (1952), *comb. illeg*.

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