Annals of Agricultural Science 61 (2016) 165–173

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Annals of Agricultural Science

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# Taxonomic study on the wild species of genus *Solanum* L. in Egypt

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ARTICLE INFO

*Article history:*
Received 9 May 2016
Received in revised form 29 September 2016
Accepted 4 October 2016
Available online 28 December 2016

*Keywords:*
Solanaceae
*Solanum*
Taxonomic relationships
Morphological characters
Cluster analysis

ABSTRACT

A taxonomic revision of the genus *Solanum* L. in Egypt is presented. Nine native species are recognized, as well as the new recorded species *S. diphyllum* L. The work is devoted to study the morphological characters of each species, the nomenclature with synonyms, and the taxonomic relationships between the studied species. A key to *Solanum* species is given. The taxonomic relationships between the studied species are represented by the cluster analysis. The morphological variation measured by Euclidean distance process and phenogram was constructed. The phenogram showed that the studied species of genus *Solanum* can simply be divided into two groups. A phylogram was presented by using parsimony analysis of the morphological data. Both of phylogram and phenogram showed great similarity between *S. sinaicum* and *S. villosum*, suggesting that the two species can be considered as one species with two subspecies or varieties. The morphological characters showed highly significant role in the identification of the studied species.


## Introduction

Genus *Solanum* L. is the type genus of the family Solanaceae and comprises about 1500 species constituting the largest and most complex genus within this family, it distributed in the temperate and tropical regions of the world (Jennifer and James, 1997). In the Egyptian flora, the genus *Solanum* is represented by nine wild species, namely; *S. coagulans*, *S. elaeagnifolium*, *S. forskalii*, *S. incanum*, *S. nigrum*, *S. schimperianum*, *S. sinaicum*, *S. villosum* and *S. virginianum* (Boulos, 2009; Hepper, 2002), whereas *S. diphyllum* L. was suggested as a new record by Shaheen et al. (2004). The genus has an important economic value with many cultivated species as sources of edible vegetables and fruits (Muthoni et al., 2012), in addition to several medicinal ones (Pereira et al., 2014 and Rajathi et al., 2015). This genus has concerned many taxonomists due to its complexity. *Solanum* species are often confused as a result of diversity in their gross morphology and eco-geographical distribution (Bello et al., 2013; Levin et al., 2005). Consequently, taxonomists have experienced difficulty in the ordering of species within the genus. Species definitions are confounded by a number of factors, including similar morphologies between distinct species, high levels of hybridization followed by introgression, and phenotypic plasticity in variable environments (Spooner and van den Berg, 1992). D'Arcy (1972) divided genus *Solanum* L. into seven subgenera and numerous sections and series. D'Arcy (1991) made minor modifications to this system. Hunziker (2000) modified D'Arcy's system and provided descriptions and commentary for each recognized section. Jaeger (1985) and Jaeger and Hepper (1986) attempted a monographic revision of the entire genus in Africa. Lester et al. (2011) studied the *Solanum* species in Africa and edited D'Arcy's system. All of these classifications based on morphological characters. Some overall recommendations are made for taxonomic rearrangements within the genus *Solanum* based on molecular studies above the sectional level include the works of Levin et al. (2006) and Stern et al. (2010). These studies give information on major clades within genus *Solanum*, but none have sampled from all the subgenera documented by morphological systematists such as D'Arcy. Many taxonomist use various computer software for the better understating of phylogeny to solve the taxonomic problems which could not be resolved by morphological characters (Yousaf et al., 2010; Samuels, 2012).

The current study aimed to present the taxonomic review of genus *Solanum* in Egypt, based on comparative morphological studies of *Solanum* species, with a special focus on subgenus Solanum.

## Materials and methods

The present study was carried out on ten wild *Solanum* species found in Egypt. The specimens are collected from different locations and the major local herbarium CAIM of the Flora &

Peer review under responsibility of Faculty of Agriculture, Ain-Shams University.
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http://dx.doi.org/10.1016/j.aoas.2016.10.003
0570-1783/

**Table 1**
The taxonomic position of the studied species according to D'Arcy (1972, 1991) as well as its distribution in Egypt.

| Subgenus | Section | Species | Distribution in Egypt |
|---|---|---|---|
| Leptostemonum | Torva | *S. schimperianum* Hochst. (=*S. carense* Dunal) | Gebel Elba and the surrounding mountainous regions |
| | Melongena | *S. virginianum* L. (=*S. xanthocarpum* Schrad. & H. Wendl.) | The Red Sea coastal strip |
| | | *S. incanum* L. (=*Solanum bojeri* Dunal, *S. sanctum* L.) | The Nile region including the delta, and Gebel Elba and the surrounding mountainous regions |
| | Oliganthes | *S. forskalii* Dunal (=*S. albicaule* Kotschy ex Dunal; *S. sindicum* Prain) | Gebel Elba and the surrounding mountainous regions |
| | Monodolichopus | *S. coagulans* Forssk. (=*S. dubium* Fresen.) | The Red Sea coastal strip, Gebel Elba and the surrounding mountainous regions |
| | Leprophora | *S. elaeagnifolium* Cav. (=*Solanum dealbatum* Lindl.) | The Nile region including the delta and Rafah |
| Solanum | Solanum | *S. nigrum* L. (=*Solanum humile* Lam.)[a] | Over all Egypt |
| | | *S. sinaicum* Boiss.[b] | Sinai and Giza |
| | | *S. villosum* Mill. (= *S. miniatum* Bernh. ex Willd.) | The Nile region, the oases, the Mediterranean coastal strip, Gebel Elba |
| | Holophylla | *S. diphyllum* L. | Aswan and Giza |

[a] Some botanists have suggested that *S. nigrum* may be conspecific with *S. americanum*, www.theplantlist.org.
[b] The species *S. sinaicum* Boiss. Diagn. Pl. Orient., 1 (11):135. (1849) was found in Sinai. Lester et al. (2011) mentioned *S. sinaicum* may be conspecific with *S. retroflexum* Dunal, DC. Prodr., 13(1):50 (1850).

**Table 2**
Morphological characters and character states used in the numerical analysis.

| Characters | Taxa | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *S. coagulans* | *S. diphyllum* | *S. elaeagnifolium* | *S. forskalii* | *S. incanum* | *S. nigrum* | *S. schimperianum* | *S. sinaicum* | *S. villosum* | *S. virginianum* |
| 1 Habit: Herb 1/Shrub 2 | 1 | 2 | 1 | 2 | 2 | 1 | 2 | 1 | 1 | 2 |
| 2 Plant height (cm): Less than 1 m 1/1 m or more 2 | 2 | 2 | 1 | 2 | 2 | 1 | 2 | 1 | 1 | 1 |
| 3 Stem surface: Glabrous 1/ Pubescent2/Villous 3/Stellate-pubescent 4 | 4 | 1 | 4 | 4 | 4 | 2 | 4 | 3 | 3 | 4 |
| 4 Type of stem: Herbaceous 1/Woody 2 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 2 |
| 5 Stem Colour: Green 1/Grey-green 2 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 |
| 6 Stem armed or not: Unarmed 1/Armed 2 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 |
| 7 Leaves armed or not: Unarmed 1/Armed 2 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 |
| 8 Leaves: Mostly unequal-paired 1/Not so 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 9 Leaves: Coriaceous 1/Not so 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 |
| 10 Leaf outline: Ovate 1/Elliptic 2/Obovate 3/Oblong 4 | 1 | 2 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 11 Leaf apex: Acuminate 1/Acute 2/Obtuse 3 | 1 | 2 | 1 | 3 | 2 | 2 | 2 | 1 | 1 | 1 |
| 12 Leaf margin: Entire 1/Dentate 2/Undulate 3/Lobbed 4 | 3 | 1 | 3 | 1 | 3 | 2 | 1 | 2 | 2 | 4 |
| 13 Leaf base: Obtuse 1/Cuneate 2/Subcordate 3/Oblique 4 | 4 | 2 | 4 | 3 | 4 | 2 | 1 | 2 | 2 | 3 |
| 14 Leaf adaxial surface: Glabrous 1/Sparsely pubescent 2/Villous 3/Stellate-tomentose 4 | 4 | 1 | 4 | 4 | 4 | 2 | 4 | 3 | 3 | 4 |
| 15 Leaf abaxial surface: Glabrous 1/ Sparsely pubescent 2/Villous 3/ Stellate-tomentose 4 | 4 | 1 | 4 | 4 | 4 | 2 | 4 | 3 | 3 | 4 |
| 16 Leaf length: Up to 8 cm 1/Up to 12 cm 2 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 2 |
| 17 Leaf width in (cm): | 5 | 3 | 2 | 3 | 8 | 5 | 8 | 3 | 3 | 5 |
| 18 Petiole length in (cm): | 7 | 1 | 5 | 2 | 4 | 3 | 3 | 3 | 3 | 4 |
| 19 Petiole surface: Glabrous 1/Sparsely pubescent 2/Villous 3/Stellate-pubescent 4 | 4 | 1 | 4 | 4 | 4 | 2 | 4 | 3 | 3 | 4 |
| 20 Pedicel length: 0.5–1 cm 1/1.2–1.5 cm 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 |
| 21 Pedicel surface: Glabrous 1/Sparsely pubescent 2/Villous 3/Stellate-pubescent 4 | 4 | 1 | 4 | 4 | 4 | 2 | 4 | 3 | 3 | 4 |
| 22 Corolla colour: White 1/White with black midrib outside 2/Pale mauve-violet 3 | 3 | 1 | 3 | 3 | 3 | 1 | 3 | 2 | 1 | 3 |
| 23 Corolla diameter (cm): 0.5 cm 1/1 cm 2/1.5 cm 3/2–2.5 cm 4/up to 3.5 cm 5 | 4 | 1 | 5 | 4 | 4 | 2 | 3 | 3 | 2 | 4 |
| 24 Corolla sinus: Deep 1/Shallow 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| 25 Corolla surface outside: Glabrous 1/Pubescent 2/Stellate-pubescent 3 | 3 | 1 | 2 | 3 | 3 | 2 | 3 | 2 | 2 | 3 |

**Table 2** (*continued*)

| Characters | Taxa | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *S. coagulans* | *S. diphyllum* | *S. elaeagnifolium* | *S. forskalii* | *S. incanum* | *S. nigrum* | *S. schimperianum* | *S. sinaicum* | *S. villosum* | *S. virginianum* |
| 26 Calyx length in (mm) | 5 | 3 | 6 | 3 | 6 | 2 | 6 | 2 | 2 | 5 |
| 27 Calyx surface: Glabrous 1/Sparsely pubescent to pubescent 2/Stellate-pubescent 3 | 3 | 1 | 3 | 3 | 3 | 2 | 3 | 2 | 2 | 3 |
| 28 Calyx prickly or not: Unprickly 1/Prickly 2 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 |
| 29 Calyx sinus: Deep 1/Shallow 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| 30 Anther length in (mm) | 7 | 2 | 8 | 7 | 5 | 2 | 4 | 2 | 2 | 8 |
| 31 Style length: 5–6 mm 1/up to 1 cm 2 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 |
| 32 Style surface: Glabrous 1/Pubescent 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 |
| 33 Peduncle: Branched 1/Unbranched 2 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 |
| 34 Inflorescence: Subumbellate 1/Elongate 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 |
| 35 Inflorescence: Leaf-opposed 1/Not so 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 36 Number of flowers per inflorescence: (1–5) 1/(6–10) 2/(10–30) 3 | 2 | 2 | 2 | 2 | 1 | 2 | 3 | 1 | 1 | 1 |
| 37 Unripe fruit colour: Green 1/White mottled with green veins 2 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 |
| 38 Ripe fruit colour: Yellow - Orange 1/Red 2/Black 3 | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 1 | 1 | 1 |
| 39 Fruit diameter (Cm): 0.6–1 cm 1/Up to 1.2 cm 2/2 cm or more 3 | 1 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 3 |
| 40 Fruit shape: Globose (somewhat spherical) 1/Spherical 2 | 2 | 1 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 1 |
| 41 Fruit surface: Glabrous 1/Glabrescent 2 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 42 Seed colour: Yellow to bright brown 1/Black 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

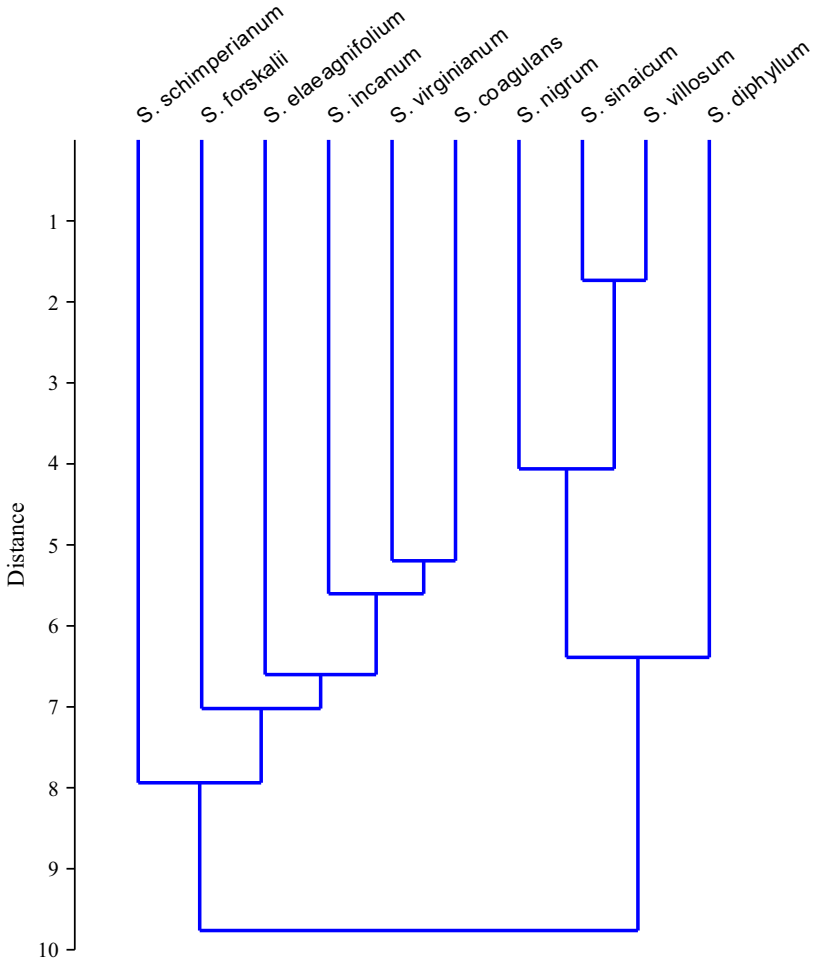
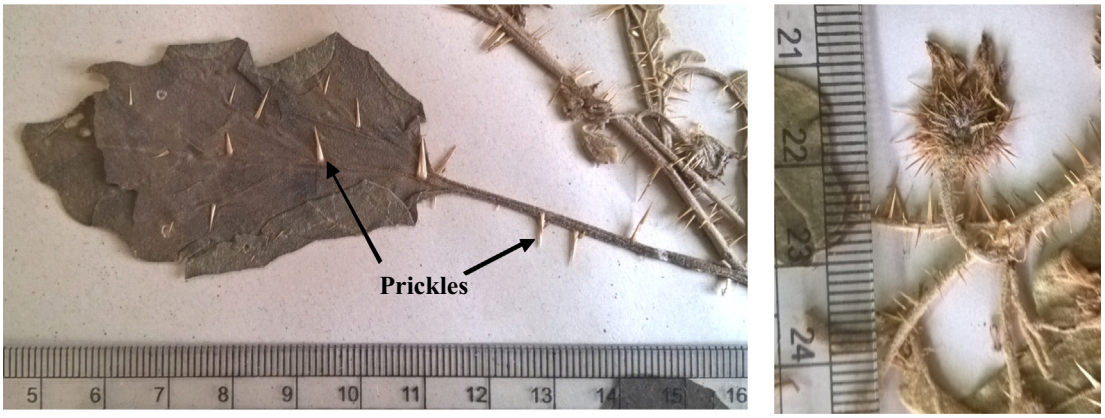



**Fig. 1.** Phenogram showing the taxonomic relationships within the genus *Solanum* in Egypt.

**Table 3**
Morphological variation between the studied species based on squared Euclidean distance.

| Taxa | *S. coagulans* | *S. diphyllum* | *S. elaeagnifolium* | *S. forskalii* | *S. incanum* | *S. nigrum* | *S. schimperianum* | *S. sinaicum* | *S. villosum* | *S. virginianum* |
|---|---|---|---|---|---|---|---|---|---|---|
| *S. coagulans* | 00 | | | | | | | | | |
| *S. diphyllum* | 12.72 | 00 | | | | | | | | |
| *S. elaeagnifolium* | 5.83 | 12.57 | 00 | | | | | | | |
| *S. forskalii* | 7.14 | 10.34 | 7.00 | 00 | | | | | | |
| *S. incanum* | 5.91 | 11.79 | 8.06 | 7.61 | 00 | | | | | |
| *S. nigrum* | 10.00 | 5.83 | 11.31 | 8.88 | 9.53 | 00 | | | | |
| *S. schimperianum* | 8.00 | 10.58 | 9.89 | 7.93 | 5.91 | 8.12 | 00 | | | |
| *S. sinaicum* | 8.88 | 6.85 | 9.64 | 7.34 | 9.05 | 4.12 | 8.18 | 00 | | |
| *S. villosum* | 9.27 | 6.48 | 10.00 | 7.86 | 9.32 | 4.00 | 8.48 | 1.73 | 00 | |
| *S. virginianum* | 5.19 | 12.12 | 5.91 | 6.32 | 5.29 | 10.14 | 7.93 | 8.94 | 9.32 | 00 |

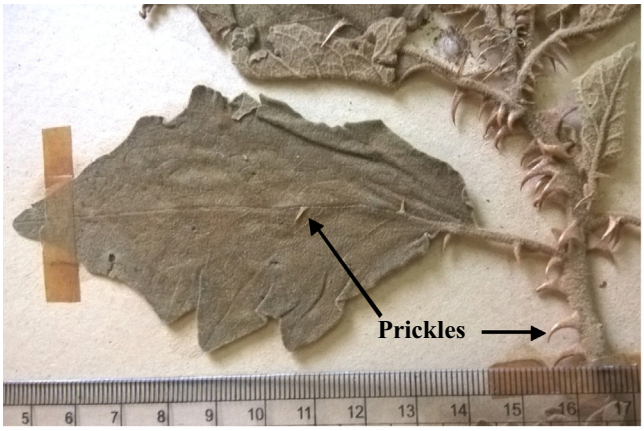


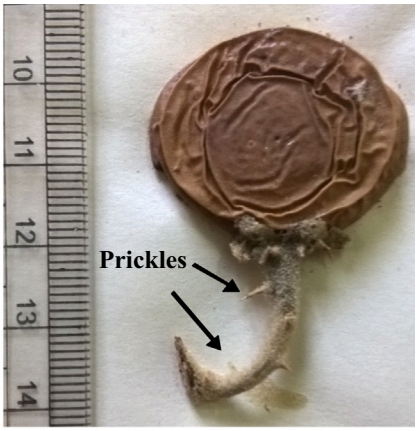

***S. coagulans*, prickly leaf and flowering branch.**


***S. elaeagnifolium*, flowering and fruiting branches.**


***S. forskalii*, flowering and fruiting branches.**

**Fig. 2.** Representative pictures showing morphological diversity of *Solanum* species within subgenus Leptostemonum in Egypt.




***S. incanum*, prickly leaf and fruit.**


***S. virginianum*, flowering branch.**

**Fig. 3.** Representative pictures showing morphological diversity of *Solanum* species within subgenus Leptostemonum in Egypt.

Phyto-taxonomy Researches Department, Agricultural Research Center, Giza, as well as information from the literatures. Nomenclature of all species was updated according to the two major online websites (www.tropicos.org and www.theplantlist.org). The herbarium vouchers and fresh materials subjected to detailed studies of the variation in several morphological parameters. Observations were made using a dissecting microscope on morphological characters, such as the variation in size, shape, hairiness and colour in the plant organs, *e.g.*, leaves, flowers, fruits and seeds. Full valid names of all studied species with their taxonomic position, as reported by (D'Arcy, 1972, 1991), are presented in Table 1. Key to differentiate between studied species was prepared.

Forty-two morphological characters recorded comparatively for the studied taxa are given in Table 2. Characters and character states were determined through examination of both fresh and herbarium specimens and were coded as multistate characters. The data matrix was subjected to cluster analysis using UPGMA (Unweighted pair group method with arithmetic mean) and a phenogram was constructed to show the relationship among the species (Fig. 1). The data matrix was exploited to cladistics analysis

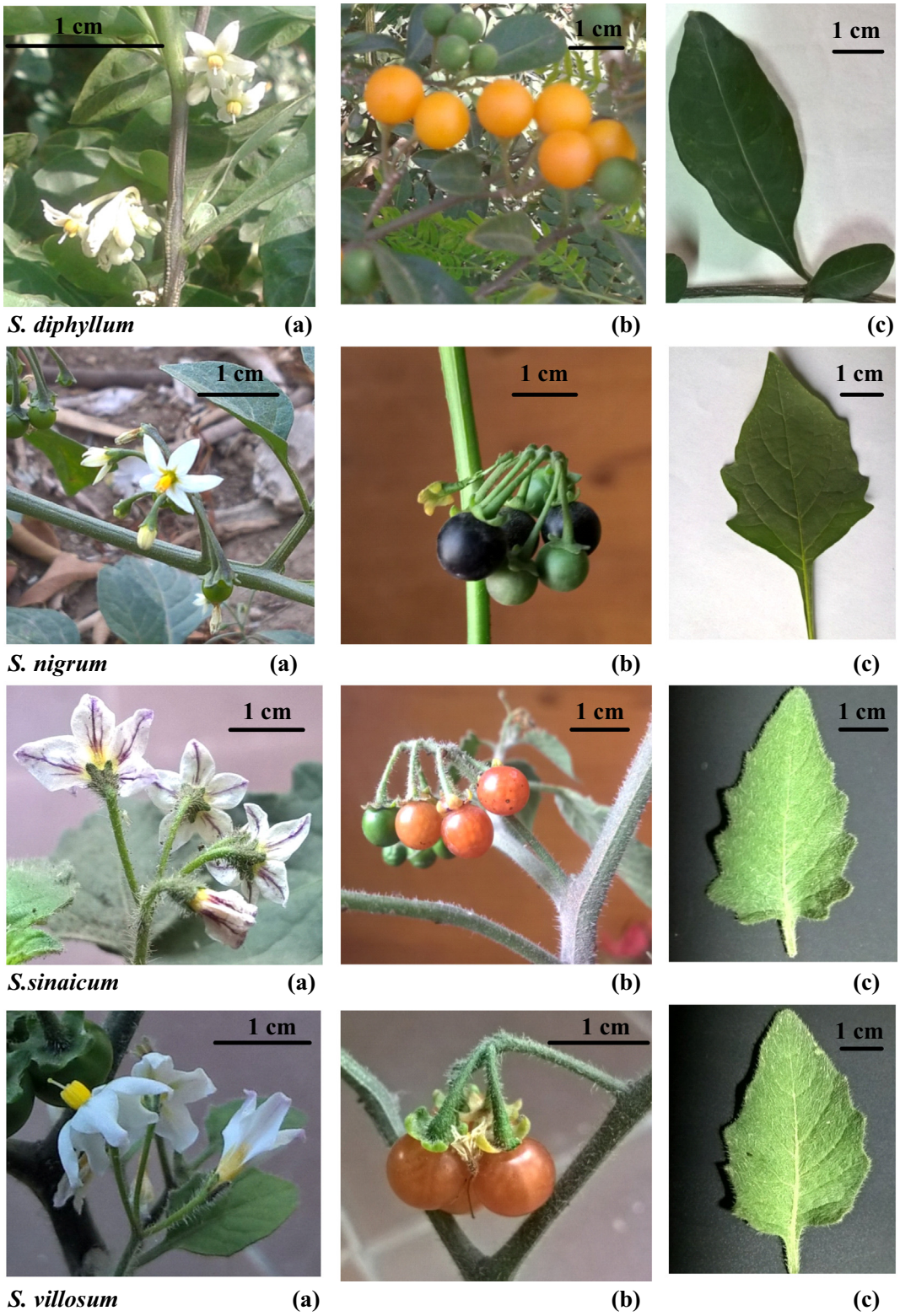



**Fig. 4.** Representative pictures showing morphological diversity of *Solanum* species within subgenus *Solanum* in Egypt. (a) Flowers, (b) Fruits and (c) Leaves.

(Parsimony analysis) and a phylogram was created to clear the inferred evolutionary relationships among the species (Fig. 6). Morphological variation between the studied species based on squared Euclidean distance was presented in Table 3. All analyses were carried out using the program Past (Version 2.17c) (Hammer et al., 2001).

## Results and discussion

Morphological characters provided essential source for the classification of *Solanum* species. Plant habits, stem structure, leaf; shape, margin, apex and base, petiole pubescence, flower structure and colour, fruit and seed are significantly helpful in

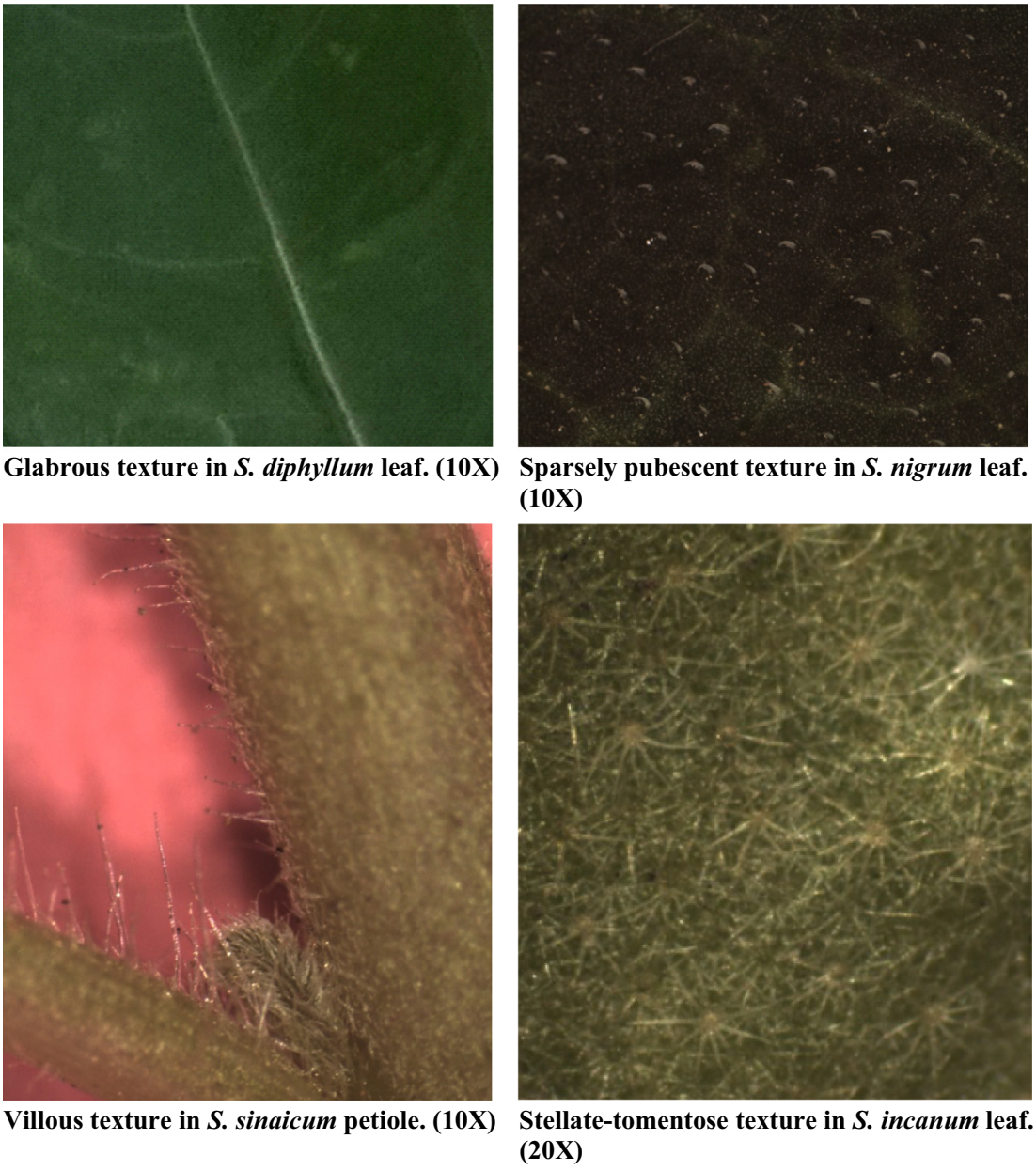



**Fig. 5.** Representative pictures showing diversity in plant textures (X for magnification).

the identification of the species (Pojarkova, 1997; Yousaf et al., 2010). Forty-two morphological characters are evaluated and used in the cluster analysis. The resulted phenogram (Fig. 1) divided the studied species into two groups; the first contains the species belong to subgenus Leptostemonum, the second includes those belong to subgenus *Solanum*. This result is supported the subgenera recognized by some botanists (D'Arcy, 1972, 1991; Lester et al., 2011; Edmonds, 2012). The species belonging to subgenus Leptostemonum characterized by the prescience of prickles (except *S. schimperianum*) and stellate hairs, pale mauve-violet flowers arranged in a subumbellate or elongate inflorescence, anthers relatively long and the fruits are yellow-orange or red (Figs. 2, 3 and 5). While, the species belonging to subgenus Solanum are characterized by lack of prickles and stellate hairs; white flowers and orange or black fruits arranged in a subumbellate pattern and the anthers relatively short.

Within the first group, subgenus Leptostemonum, *S. schimperianum* delimited early because of the unarmed nature of this species. This result agrees with Dunal (1852). He placed it in a separate series Subdulcamara, subsection dulcamara in his section Pachystemonum. Moreover Lester et al. (2011) placed it with the mostly unarmed shrubs in subsection Anomalum, Section Giganteiformia belonging to subgenus Leptostemonum. Vorontsova et al. (2013) presented phylogenetic reconstruction of African species of *Solanum* subgenus Leptostemonum and kept *S. schimperianum* in Giganteum clade.

Within the second group, subgenus Solanum, *S. diphyllum* separated leaving the more related species *S. nigrum*, *S. sinaicum* and *S. villosum* together. Morphologically these species are very much similar. *S. diphyllum* can easily distinguished by its coriaceous, glabrescent and mostly unequal-paired leaves (Figs. 4 and 5). *S. nigrum* can be distinguished from *S. sinaicum* and *S. villosum* by larger, dark green, glabrescent to sparsely pubescent leaves and black fruits (Figs. 4 and 5). On the otherhand, *S. sinaicum* and *S. villosum* characterized by white villous hairs on stems, leaves, petioles and calyx; fruits orange colored

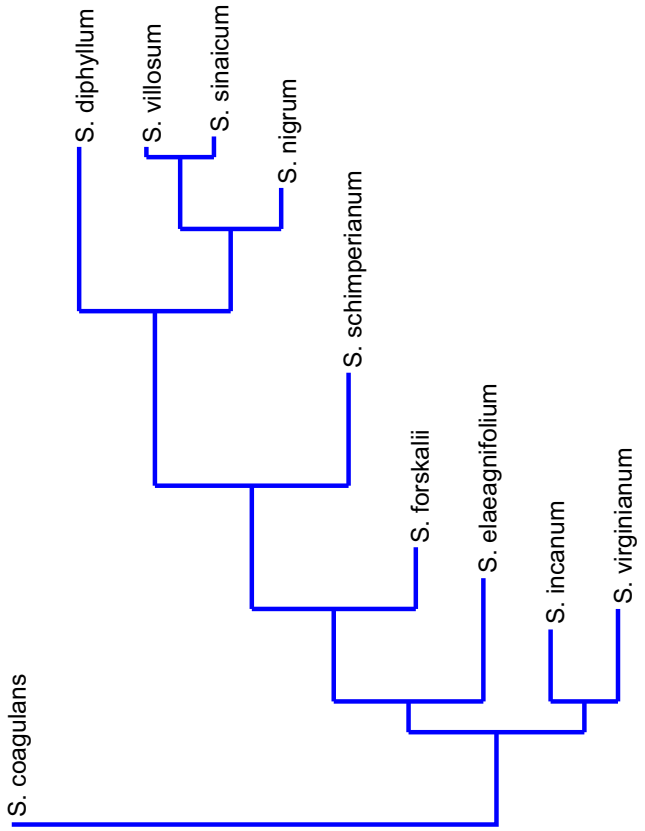



**Fig. 6.** Phylogram (parsimonious tree) showing the phylogeny within the genus *Solanum* in Egypt.

(Figs. 4 and 5). The three species arranged together belonging to section Solanum by D'Arcy (1972, 1991) and Lester et al. (2011). *S. sinaicum* highly similar to *S. villosum* as showed in cluster analysis and has the lowest morphological variation distance 1.73 (Table 3). *S. villosum* characterized by white petals and *S. sinaicum* by white petals with black-violet midrib outside (Fig. 4). This finding suggested that *S. sinaicum* may turn out to be an ecotype of the *S. villosum* or generated from it by hybridization. Natural hybridization is probably more widespread in section Solanum producing morphogenetically complex populations (Jennifer and James, 1997). Jaeger (1985) revised the genus *Solanum* in Africa and totally neglected the *S. sinaicum*. Lester et al. (2011) mentioned *S. sinaicum* may be a conspecific with *S. retroflexum*. Jennifer and James (1997) reported that if the two are conspecific, *S. retroflexum* then becoming a synonym of *S. sinaicum*. In contrary, *S. retroflexum* has black fruits and *S. sinaicum* has orange fruits. So, there is no chance to be a conspecific to each other.

The phylogram produced from the Parsimony analysis greatly supported the subgenera and sectional arrangement by D'Arcy (1972, 1991). The phylogenetic tree showed that *S. coagulans* has significant differences of all existing studied species. Moreover it showed the great similarity between *S. sinaicum* and *S. villosum* and the close relationship between both of them with *S. nigrum* by including them in one clade (Fig. 6). This result gives impression these three species are implied to have descended from a common ancestor. Jaeger (1985) mentioned that *S. villosum* is considered to be a likely progenitor of *S. nigrum* by hybridization with the diploid *S. americanum* and ignored *S. sinaicum*. Some botanists have suggested that *S. americanum* may be conspecific with *S. nigrum* (www.theplantlist.org). Täckholm (1974) and Nasir (1985) considered *S. villosum* a variety of *S. nigrum*. The difficulties encountered in the morphological differentiation of these three species may be caused by the natural hybridization that is probably more widespread in this section as recorded by Bello et al. (2013) and Poczai et al. (2014). In spite of the fact that the section Solanum has lately been studied extensively, taxonomy is still unsettled and debated because of inter- and intraspecific hybridization, phenotypic plasticity and polyploidization (Poczai and Hyvönen, 2011; Scaldaferro et al., 2012). Our findings suggested that the three species *S. nigrum*, *S. sinaicum* and *S. villosum* can be considered as one species with three subspecies or varieties. Otherwise at least, the two species *S. sinaicum* and *S. villosum* should be one species with two subspecies *sinaicum and villosum*.

**Key to species of the genus *Solanum* in Egypt:**

1. Plants armed as a whole or partly ……..……..**2**
   Plants unarmed.…….....……**6**
2. Fruit diameter about 2 cm or more……...……**3**
   Fruit diameter from 0.7 to 1.2 cm……..……...……**4**
3. Low shrub 20-40 cm height; leaves almost deeply pinnately lobed…..……***S. virginianum***
   Stout shrub 1-2 m height; leaves undulate or sinuately lobed……..……..……***S. incanum***
4. Leaves unarmed ……..…….....…..***S. forskalii***
   Leaves usually armed……..……..…..**5**
5. Leaves grey-tomentose on both surfaces, with large conspicuous prickles ……. ***S. coagulans***
   Leaves grey-green above, white-tomentose beneath, prickles inconspicuous …...……..……...
   ……..***S. elaeagnifolium***
6. Shrubs; leaves borne on woody stems……..……..……**7**
   Herbs, leaves borne on herbaceous shoots…….....…**8**
7. Leaves mostly unequal paired; pedicel less than 1 cm; fruits yellow to orange … ***S. diphyllum***
   Leaves all alike; pedicel more than 1 cm; fruits bright red……..…. ***S. schimperianum***
8. Mature fruit black, plant glabrescent-pubescent …….....…… ***S. nigrum***
   Mature fruit orange, plant villous..……..……..**9**
9. Corolla white with black or violet midrib outside…….……..…….. ***S. sinaicum***
   Corolla white……..……..…… ***S. villosum***

In conclusion, this study has succeeded in highlighting on number of morphological characters that can be used for taxonomic delimitation of *Solanum* species; the data attained could be taken along with data from other sources such as molecular techniques

to enhance proper taxonomic characterisation of the species of genus *Solanum*.

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