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Vegetative Morphological Variations within Some Egyptian *Amaranthus* L. Species

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Abstract

Leaf and stem vegetative morphological characters have been studied in ten Egyptian *Amaranthus* species. Macro-and micro-morphological characters besides leaf venation and architecture have been studied. Twenty-seven main variable characters have been subjected as OTU's to numerical analysis. The resulted dendrograms (nearest neighbor, group average and farthest neighbor) divided the studied species into two categories with different subdivisions. From the most important morphological characters within the studied taxa are the places of red spot on the leaf surfaces and the type of leaf venation. These characters divided the studied taxa into two main groups: 1- the red spot; on the middle versus on the lower part of the leaf blades, 2- the leaf venation; reticulodromus versus brochidodromous.

Keywords : *Amaranthus*, Clustering analysis, Leaf characters, Macro-morphology, Micro-morphology, Stem characters, Venation.

1. Introduction

Genus *Amaranthus* L. is one of the widely distributed genera grown mainly in temperate and tropical climates, belonging to Amaranthaceae Juss., subfamily Amaranthoideae, tribe Amarantheae. Genus *Amaranthus* is the largest and has 70 annual or short lived perennial monoecious or dioecious species with worldwide distribution. It grows in roadsides, gardens and disturbed habitats with great morphological diversity between the species and even between individuals of the same species in response to environmental variables. *Amaranthus* has been faced with many opinions concerning species delimitation and identification since a long time ago. Thellung, (1914), Sauer, (1955), Aellen, (1961 and 1972), Cavaco, (1962) and Townsend, (1974 and 1985) have been faced with many difficulties in recognizing the different taxa while studying the morphological characters of the genus. Linnaeus, (1753) divided the genus into two groups; *Pentandri* and *Triandri* according to the number of stamens in the flower (which is the same as the number of perianth segments). This division of the genus has been accepted by Adanson, (1763) and Tournefort, (1794), while Dumortier, (1827) reclassified the *Amaranthus* species into two sections *Amaranthotypus* and *Blitopsis*, the former has monoecious plants with pentamerous flowers arranged in lax or dense spikes or panicles and circumscissile fruits. While section *Blitopsis* has dioecious plants with trimerous or pentamerous flowers arranged in axillary glomerules and has irregular ruptured indehiscent capsules.

Gordon, (1853) raised the inflorescence type to be a priori character in distinguishing the taxa under the genus and reclassified it into two subgenera; *Albersia* and *Euamaranthus.* And this reclassification has been accepted by both Kirschleger, (1857) and Bentham and Mueller, (1870), but they divided subgenus *Albersia* into three sections *Amblogyne*, *Euamaranthus*, and *Euxolus* according to the fruit whether bursts transversely or in an irregular manner or indehiscent. Afterward, Uline and Bray, (1894) classified the *Amaranthus* species into four groups; Amblogyne, Scleropus, Pyxidium, and Mega according to fruit characters. While Beck (1909) regrouped the *Amaranthus* species into three sections and Rouy, (1910) return back to the old classification of the species into two sections but renamed them *Euamaranthus* and *Pentrius*. Sauer, (1955), previously classified genus *Amaranthus* into two subgenera, differentiating only between monoecious and dioecious species, viz. *Amaranthus* and *Acnida* (L.) Aellen ex K. R. Robertson

The classification of *Amaranthus* is obscure due to the shortage of scrappy quantitative species-defining characteristics, besides the wide range of phenotypic flexibility, as well as introgression and hybridization involving weedy and crop species. This phenotypic variability led to nomenclature disorder and misapplication of names as seen in Mosyakin and Robertson, (1996), Costea *et al*., (2001) and Iamonico, (2009). Accordingly, the previous trials of classifications of the genus were faced with many difficulties in distinguishing and circumscription of the *Amaranthus* species. Mosyakin and Robertson, (1996) found that all the *Amaranthus* species must be divided into three subgenera; 1- *Acnida* (L.) Aellen ex K. R. Robertson with three sections; 2- *Albersia* (Kunth) Gren. and Godr. with four sections; and 3- *Amaranthus* with three sections and two subsections (Figure 1).

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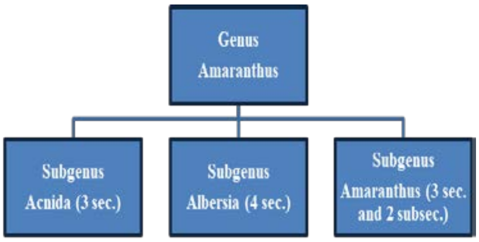


Figure 1. Mosyakin and Robertson (1996) division of *Amaranthus* species

Till now the classification of the genus is still a matter of controversy and faced with great arguments. This work has been carried out to investigate the variations within the *Amaranthus* species grown in Egypt. According to Täckholm, (1974) the genus was represented by fourteen annual species; El Hadidi and El Hadidi, (1980) reported 10 species with 5 subspecies and 5 varieties, while according to Boulos, (1999, 2009) the genus was represented by eleven annual, rarely perennial species and five subspecies. These taxa growing, either as weeds in the cultivated areas or wildly in the roadsides. Ten of these species can be obtained from the field and subjected to analysis in this study to increase knowledge about the morphological variability between the species in the local region.

2. Materials and Methods

Ten *Amaranthus* species were collected from the wild population in Alexandria and Cairo during the years 2015 and 2016. The ten studied species arranged according to the system of infra-generic classification of Mosyakin and Robertson, (1996), their different collection sources are cited in tables 1.and 2 The collected specimens were identified using Täckholm, (1974) and Boulos, (1999). Taxonomic authorities for Latin names and synonymy of the species investigated in this study were based on either the Australian plant name index (APNI), Gray card index (GCI) or Index Kewensis (IK). Voucher specimens were kept in the Faculty of Science, Alexandria University Herbarium (ALEX) for vegetative morphological measurements and any further inspection.

Table 1. *Infra-generic* classification of *Amaranthus* species used in the present study

Authors	Year	Characters	Ranks	Names	Further divisions
Linnaeus	1753	Perianth number	Groups	*Pentandri & Triandri*	--
Adanson	1763	Perianth number	Groups	*Pentandri & Triandri*	--
Tournefort	1794	Perianth number	Groups	*Pentandri & Triandri*	--
Dumortier	1827	Sex of plant	sections	*Amaranthotypus & Blitopsis*	--
Gorden	1855	Type of Inflorescence	Subgenera	*Albersia &Euamaranthus*	--
Kirschleger	1857	Type of Inflorescence & Fruit characters	Subgenera	*Albersia (3 sections) & Euamaranthus*	*Amblogene, Euamaranthus & Euxalus*
Bentham	1870	Type of Inflorescence & Fruit characters	Subgenera	*Albersia (3 sections) &Euamaranthus*	*Amblogene, Euamaranthus & Euxalus*
Uline and Bray	1894	Fruit	Sections	*Amblogyne, Scleropus, Pyxidium & Megea*	--
Beck	1909	Fruit	Sections	*Amblogene, Euamaranthus & Euxalus*	--
Rouy	1910	Perianth parts	Sections	*Euamaranthus & Pentrius*	--
Sauer	1955	Sex of plant	Subgenera	*Acnida & Amaranthus*	--
Mosyakin and Robertson	1996	Sex of plant & Inflorescence	Subgenera	*Acnida, Amaranthus & Albersia*	*Acnida* = 3 sections *Amaranthus* = 3 sections & 2 subsections *Albersia* = 4 sections

Table 2. Data of *Amaranthus* species collected in the present study and its taxonomic category after Mosyakin and Robertson, (1996)

No.	Species	Collection	Locations	Subgenus	Sections	Sub- Sections
1	*A. albus* L.	12 Jan. 2016,Wafaa Taia	Madinati,Cairo	*Albersia (Kunth) Gren. & Godr*	*Pyxdium oquin* in DC.	--
2	*A. blitiodes* S. Watson	11 Aug. 2015, Azza Shehata & Eslam El-Shamy	Fac. Agric., El-Shatby, Alexandria	*Albersia (Kunth) Gren. & Godr*	*Pyxdium oquin* in DC.	--
3	*A. caudatus* L.	11 Nov. 2015, Wafaa Taia	Madinet Nasr, Cairo.	*Amaranthus*	*Amaranthus*	*Amaranthus*
4	*A. graecizans* L.	12 Dec. 2015, Wafaa Taia	. Smouha, Alexandria	*Albersia (Kunth) Gren. & Godr*	*Pyxdium Moquin* in DC.	--
5	*A. hybridus* L.	15 Nov. 2015, Azza Shehata & Eslam El-Shamy	Fac. Of Sci., El-Shatby, Alexandria	*Amaranthus*	*Amaranthus*	*Hybrida*
6	*A. lividus* L.	1 Oct. 2015, Azza Shehata & Eslam El-Shamy	Fac. Of Sci., El-Shatby, Alexandria	*Albersia (Kunth) Gren. & Godr*	*Blitopsis Dumort*	--
7	*A. retroflexus* L.	14 Oct. 2015, Azza Shehata & Eslam El-Shamy	Fac. Of Sci., El-Shatby, Alexandria	*Amaranthus*	*Amaranthus*	*Amaranthus*
8	*A. spinosus* L.	22 Oct. 2015, Azza Shehata & Eslam El-Shamy	Al-Agamy, Alexandria	*Amaranthus*	*Centrusa Griseb*	--
9	*A. tricolor* L.	10 Jun. 2015, Wafaa Taia	Al-Saha Square, Madinet Nasr, Cairo.	*Albersia (Kunth) Gren. & Godr*	*Pyxdium Moquin* in DC.	--
10	*A. viridis* L.	1 Oct. 2015, Manaser Ibrahim	Smouha, Alexandria	*Albersia (Kunth) Gren. & Godr*	*Blitopsis Dumort*	--

Stem color and habits were noticed in the field. At least ten individuals were used in this study, for morphological measurements and examinations. The fourth interned leaves from ten individuals in each species were subjected to measurements. For epidermal cell investigation using LM, fresh leaves were collected from each plant samples, painted with fingernail polish on both the abaxial and adaxial surfaces and allowed to dry. After drying, short clear cellophane tape was firmly pressed over the dried nail polish on the surfaces according to the method of Mbagwu *et al.,* (2008). Epidermal strips were taken from the median portion of matured leaves stained in alcoholic safranin and mounted in 50% glycerin jelly for microscopic examination. Photographs of good preparations were taken at a magnification of X400 objective using the light microscope (Olympus CX 31 with its built in camera).

For leaf venation, fresh leaves were immersed in 70% ethyl alcohol for a few days with several changes of alcohol to remove chlorophyll pigments. Leaf samples were washed by water. Leaves were carefully brushed out to obtain leaf skeleton, examined and photographed using Olympus stereomicroscope. For SEM, dried leaves were fixed directly to the copper stub with double-sided adhesive tape at abaxial and adaxial surfaces and coated for 5 minutes with gold in polaron JFC-1100E coating unit, then examined and photographed with JEOL JSM-5300 SEM at the EM unit, Faculty of Science, Alexandria University. The terminology of the leaf was according to Stace, (1984), and Barthlot *et al.,* (1998) to describe the epidermal cell features and leaf venation.

The characters used for clustering analysis were chosen according to be of a fixed taxonomic value and not affected by any environmental conditions. Consequently, 27 characters represented in Appendix (1) have been subjected to this analysis using Systat 12 program.

3. Results

The general external morphology of the studied species was illustrated in plate 1. The results were summarized in tables 3, 4 and 5, plates 1, 2, 3 and 4. *Amaranthus* species are annuals; except *A. hybridus, A. lividus* and *A. viridis* are perennials. The stem takes different shades of green and sometimes tinged with pink; erect, procumbent or prostrate. The stem has different length and width, slender, angular or flattened with moderate to dense branches and either glabrous or covered with hairs in various densities (Table 3). The leaves are green, pale green or tinged with red or reddish purple; spiral or alternate. The leaves are ovate to lanceolate, with the broader part in the middle, except in both *A. hybridus A. lividus* and *A. viridis* the wider part in the lower part of the blade. All the studied species have hairy leaf surfaces with different densities; except *A. lividus* the leaves are glabrous. The hairs are mostly multicellular uniseriate glandular (Plate 4f), but in *A. blitoides* the hairs are multicellular uniseriate tabular (Plate 3e) and in *A. tricolor* the hairs are multicellular uniseriate pointed (Plate 4g). Multicellular biseriate hairs noticed in *A. retroflexus* only beside the multicellular uniseriate ones (table 4). The leaf blade venation is either reticulodromous or brochidodromous (Plate 2a and b), with different primary veins thickness. The secondary veins varied from 7 to 15, irregular or regular and in few species, they are wider at the leaf blade apex. The marginal veins are complete or incomplete with incomplete aeriolar veins except in *A. albus*, the aeriolar veins are closed (table 4).

Leaf micro-morphological characters were summarized in table 5. The epidermal cells as shown by LM and SEM have elongated and irregular shapes in the abaxial surfaces, while they are polygonal and irregular in the adaxial surfaces (plates 2, 3, and 4).

The anticlinal walls are straight and elevated in all the species, except in *A. graecizans, A. hybridus* and *A.*

tricolor the anticlinal walls are undulated (Plate 3g - j and Plate 4g and h). The ornamentation of the periclinal walls is mostly striate, rugate, wrinkled or papillate with few or dense epicuticular secretions, except in *A. graecizans, A. hybridus* and *A. lividus.* While in *A. blitoides* the periclinal walls are smooth with few granulate epicuticular secretions (Plate 3c and d). The stomata are anomocytic or anisocytic (Plate 2 c, d, f and g), raised in all the studied species in both the abaxial and adaxial surfaces, except in *A. blitoides* it is sunken in the adaxial surface (Plate 3d). Meanwhile, the stomata are diacytic (Plate 2e and h) and superficial in both the abaxial and adaxial surfaces in *A. lividus* (Plate 4a and b).

The most valuable morphological variations are subjected to numerical investigations by taking 27 characters as OUT's in the ten studies taxa and the obtained dendrograms showed that, the three dendrograms split the studied taxa into two groups (GI and GII) at dissimilarity matrix 3 in the farthest neighbor linkage (F.N.); 5.3 in group average (G.A.) and 3.5 in the nearest neighbor (N.N.). In the nearest neighbor linkage (Figure 2a) and farthest neighbor linkage (Figure 2c) the dendrograms coincide in the division of the taxa; as both of them gather the taxa number 5, 9, 7, 6, 10 and 3 in one group and the taxa number 2, 8, 1 and 4 in the second group at different dissimilarity matrices as shown in table 6. In group average linkage method (Figure 2b) the two taxa (9 and 5) were separated in a one group (GII) and the rest of the taxa in a second group (GI). The three dendrograms gathered both taxa (3 and 10) together at a similarity index 1.012. The F.N. and G.A. gathered the taxa 9 and 5 at dissimilarity index 1.745 and 2.292; and the taxa 2 and 8 at dissimilarity index 3.623 and 1.675, respectively (Table 6).

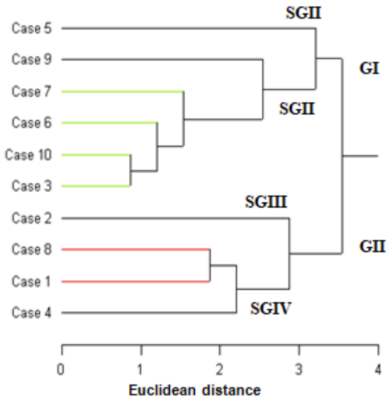


Figure 2a. Nearest neighbor linkage

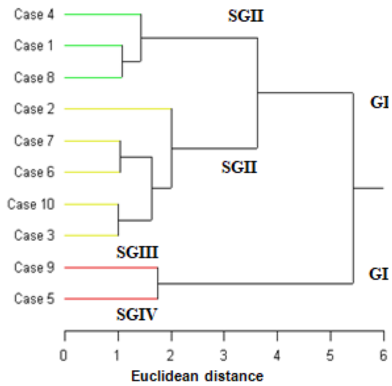


Figure 2b. Group average linkage

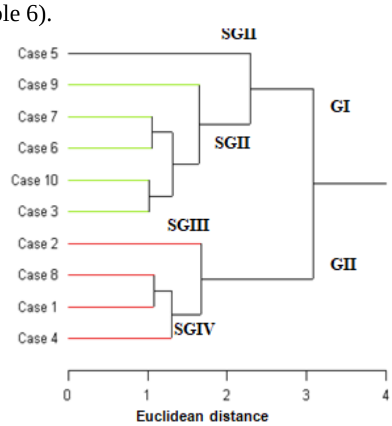


Figure 2c. Farthest neighbor linkage

Figures 2a, b and c: Dendrograms showing the three possible relationships among the ten studied *Amaranthus* species using Euclidean distance method and; **a.** Nearest neighbor linkage, **b.** Group average linkage and **c.** Farthest neighbor linkage methods. Cases studied: 1. *A. albus* ; 2. *A. blitiodes* ; 3. *A. caudatus* ; 4. *A. graecizans* ; 5. *A. hybridus* ; 6. *A. lividus* ; 7. *A. retroflexus* ; 8. *A. spinosus* ; 9. *A. tricolor* and 10. *A. viridis.*

Table 3. Stem morphological characters of the studied *Amaranthus* species

No.	Species	Characters							
		Habit	Type	Length (cm)	Width (mm)	Shape	Color	Density of branches	Density of hairs
1	*A. albus*	Annual	Erect	17-30 (23.5±5.44)	0.2 – 0.4 (0.32±0.09)	Slender	Light green	Dense	Hairy
2	*A. blitiodes* Watson	Annual	Prostrate	25-35 (28.6±3.78)	0.1 - 0.2 (0.15±0.05)	Flattened	Greenish white	Moderate	Hairy
3	*A. caudatus*	Annual	Erect	30-40 (36.6±2.07)	0.2 - 0.5 (0.35±0.12)	Angular	Purple	Moderate	Hairy
4	*A. graecizans*	Annual	Procumbent	14-30 (20.5±6.8)	0.2 - 0.4 (0.3±0.08)	Angular	Red	Moderate	Sparsely hairy
5	*A. hybridus.*	Perennial	Erect	40-55 (47.4±7.16)	0.2 - 0.4 (0.32±0.09)	Angular	Green	Dense	Hairy
6	*A. lividus*	Perennial	Procumbent	20-39 (34.8±5.67)	0.1 - 0.3 (0.2±0.08)	Flattened	Green	Moderate	Hairy
7	*A. retroflexus*	Annual	Erect	35-40 (36.8±1.92)	0.2 - 0.4 (0.3±0.08)	Slender	Light Green	Moderate	Hairy
8	*A. spinosus*	Annual	Erect	15-30 (25±7.07)	0.3 - 0.6 (0.45±0.12)	Flattened	Green	Dense	Hairy
9	*A. tricolor*	Annual	Erect	39-45 (41±2.54)	0.2 - 0.3 (0.22±0.05)	Slender	Red	Moderate	Glabrous
	A. viridis	Perennial	Procumbent	27-40 (36.2±6.37)	0.2 - 0.4 (0.3±0.08)	Angular	Green or tinged purple	Moderate	Sparsely hairy

± = Standard deviation values

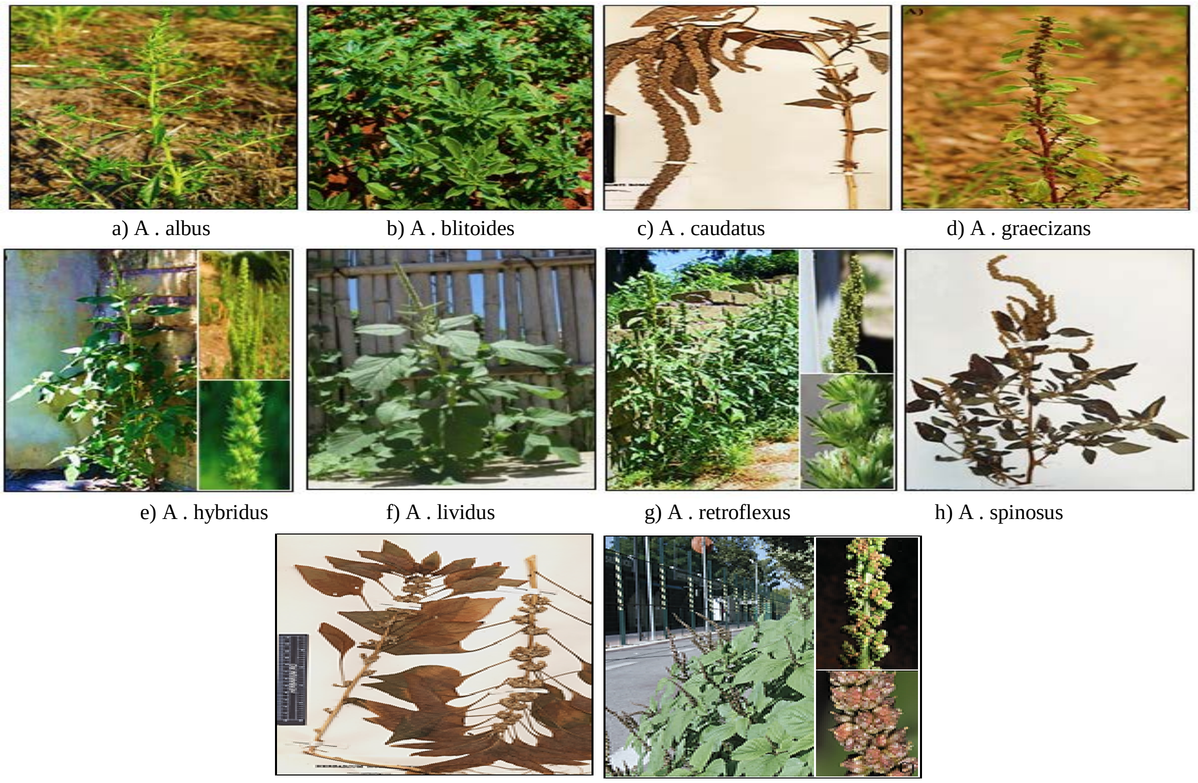
Table 4. Leaf macro-morphological characters of the studied *Amaranthus* species

No.	Species	Characters Arrangement	Color	Length (cm.)	Width (cm.)	Shape	Widest part	Spot	Surface	Hair type*
1	*A. albus*	Spiral	Pale Green	0.9-3.1 (2.25±1.02)	0.4-1.5 (0.97±0.45)	Lancolate	Middle	Middle	Sparsely hairy	MUG
2	*A. blitiodes* Watson	Alternate	Green with white spots	1-2.4 (1.94±0.65)	1-1.5 (1.32±0.16)	Ovate to Lancolate	Middle	Middle	Sparsely hairy	MUT
3	*A. caudatus*	Alternate	Green	4-4.5 (4.20±0.20)	1-2 (1.54±0.28)	Ovate to Lancolate	Middle	Middle	Hairy	MUG
4	*A. graecizans*	Alternate	Green tinged with red	1.8-3.8 (2.77±1.02)	1-1.9 (1.32±0.39)	Ovate to Lancolate	Middle	Middle	Sparsely hairy	MUG
5	*A. hybridus.*	Alternate	Green	2-5.9 (4.52±1.66)	1-4 (2.64±1.25)	Ovate	Lower	Lower	Wooly	MUG
6	*A. lividus*	Spiral	Green	1.5-4.5 (2.70±1.29)	1-3.5 (1.88±0.92)	Ovate	Lower	Lower	Glabrous	-
7	*A. retroflexus*	Alternate	Green tinged with red	3-3.5 (3.18±0.21)	1-1.5 (1.28±0.21)	Ovate to Lancolate	Middle	Middle	Hairy	MUG+ MBG
8	*A. spinosus*	Spiral	Green	2.5-6 (4.32±1.47)	2-3.8 (2.32±1.20)	Ovate to Lancolate	Middle	Middle	Hairy	MUG
9	*A. tricolor*	Alternate	Green or reddish purple	3-4 (3.54±0.36)	1-2 (1.54±0.36)	Ovate	Middle	Middle	Hairy	MUP
10	*A. viridis*	Alternate	Green tinged with purple	2-5.4 (3.60±1.47)	1-3.7 (2.58±0.94)	Ovate	Lower	Lower	Sparsely hairy	MUG

*****Hair types: MUG = Muticellular Uniseriate Glandular, MUT = Muticellular Uniseriate Tubular, MBG = Muticellular biseriate Glandular and MUP = Muticellular Uniseriate Pointed, ± = Standard deviation values.

Table 4 (Cont.) Leaf macro-morphological characters of the studied *Amaranthus* species

No.	Species	Characters					
		Types of venation	Size of 1^{ry} veins	Type of 2^{ry} veins		Marginal veins	Areolar Veins
				Spaces	No.		
1	*A. albus*	Reticulodromous	Moderate	Wide at apex	8	Incomplete	Closed
2	*A. blitiodes* Watson	Brochidodromous	Thin	Wide at apex	12	Incomplete	Incomplete
3	*A. caudatus*	Reticulodromous	Thick	Irregular	15	Incomplete	Incomplete
4	*A. graecizans*	Brochidodromous	Thick	Wide at base	7	Complete	Incomplete
5	*A. hybridus*	Brochidodromous	Thick	Wide at apex	11	Complete	Incomplete
6	*A. lividus*	Brochidodromous	Thick	Irregular	11	Incomplete	Incomplete
7	*A. retroflexus.*	Brochidodromous	Thick	Wide at apex	9	Complete	Incomplete
8	*A. spinosus*	Brochidodromous	Moderate	Irregular	11	Complete	Incomplete
9	*A. tricolor*	Reticulodromous	Thick	Irregular	8	Complete	Incomplete
10	*A. viridis*	Brochidodromous	Thick	Regular	14	Incomplete	Incomplete



a) A . albus b) A . blitoides c) A . caudatus d) A . graecizans
e) A . hybridus f) A . lividus g) A . retroflexus h) A . spinosus
i) A . tricolor j) A . viridis

Plate 1. (a-j) Photo-micrographs showing the general external morphological features of the ten studied *Amaranthus* species; a) *A. albus,* b) *A. blitoides*, c) *A. caudatus*, d) *A. graecizans*, e) *A. hybridus*, f) *A. lividus*, g) *A. retroflexus*, h) *A. spinosus*, i) *A. tricolor*and and j) *A. viridis*, respectively.

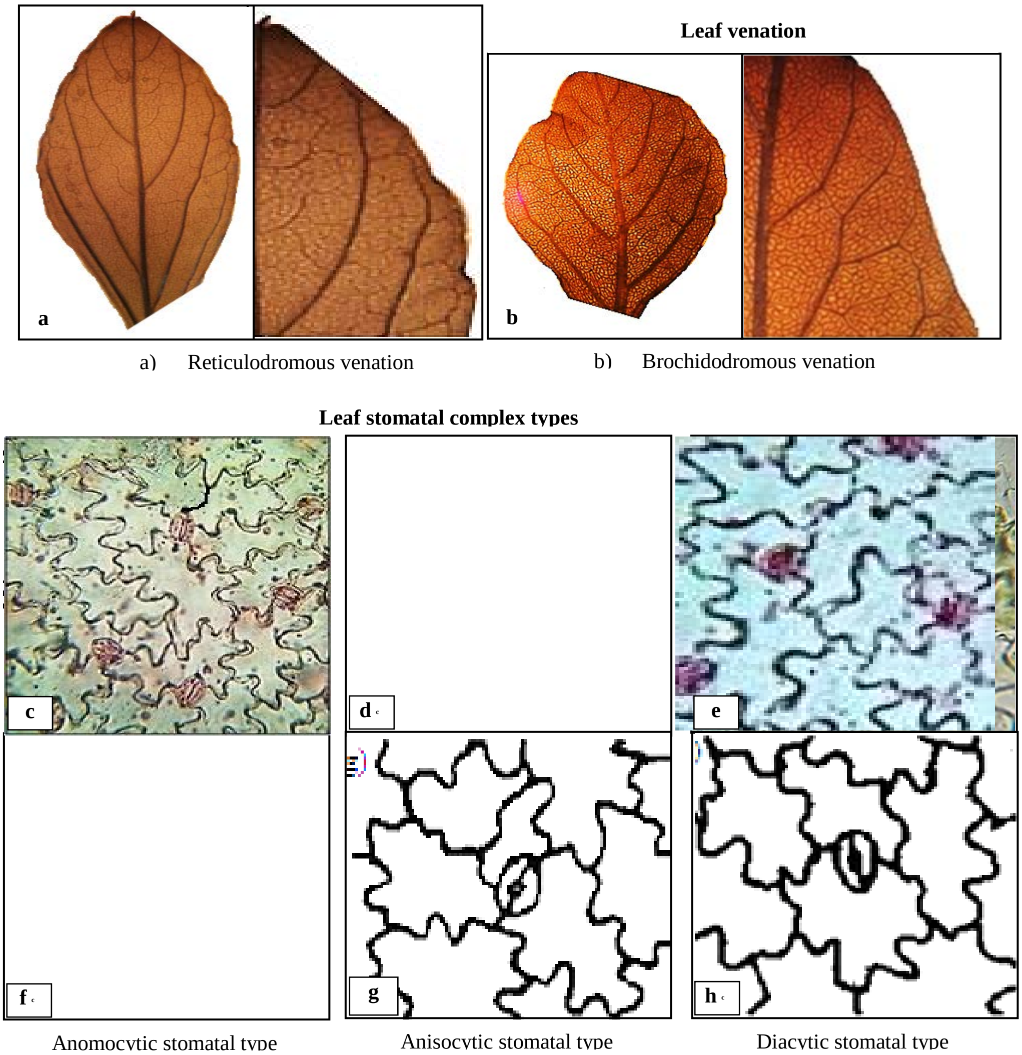


Plate 2. (a and b) Photo-micrographs showing the types of the leaf venation, (c-e) Photo-micrographs, (f-h) drawings showing the types of the leaf stomatal complex for the studied *Amaranthus* species**.**

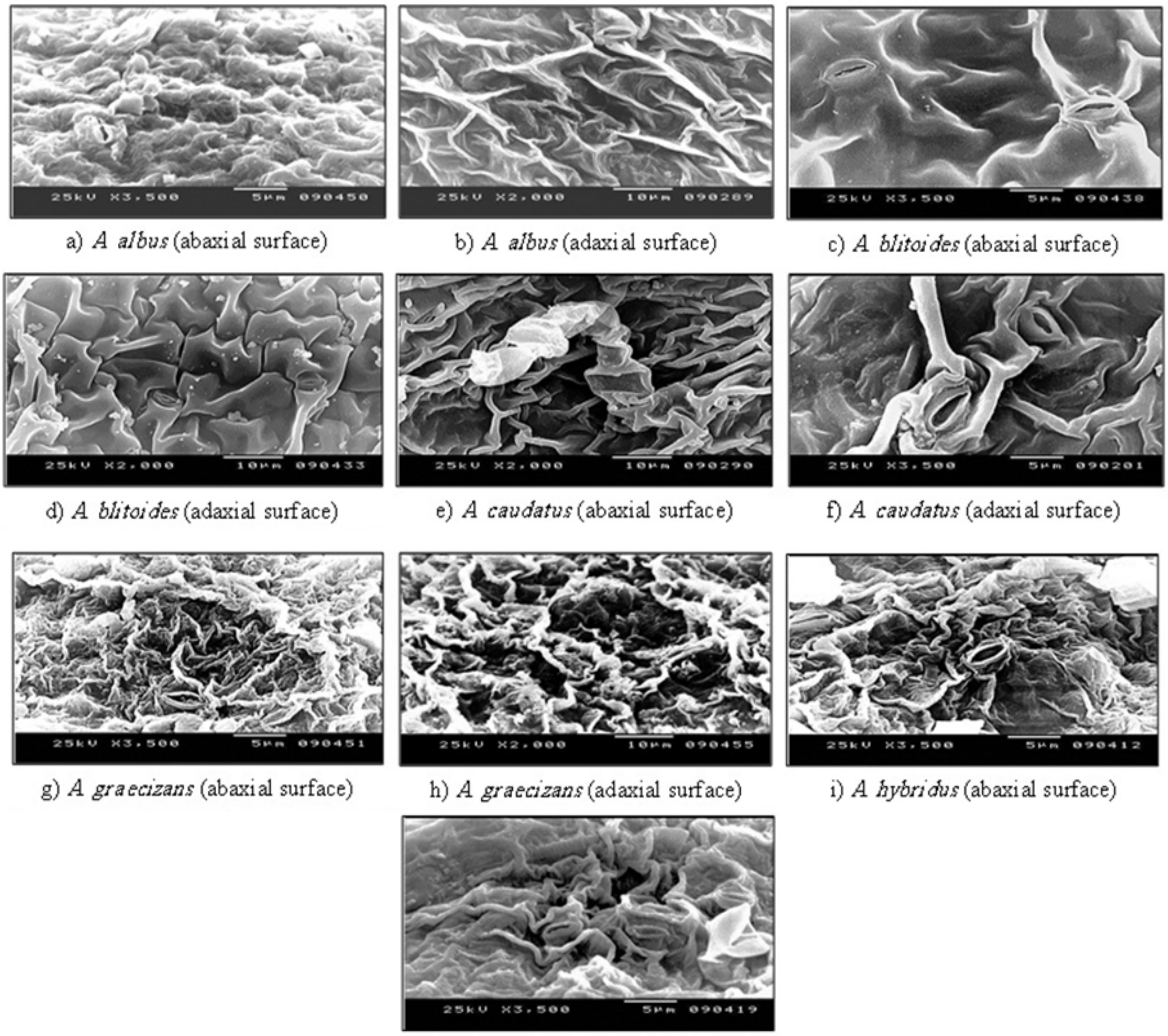
Table 5. Leaf micro-morphological characters of the studied *Amaranthus* species

No.	Species	Characters								
		Shape of epidermal cell		Epidermal wall pattern			Stomata type		Stomata level	
		Abaxial	Adaxial	Anticlinal wall	Periclinal wall	Epicuticuler secretion	Abaxial	Adaxial	Abaxial	Adaxial
1	*A. albus*	Elongated/ Irregular	Polygonal/ Irregular	Straight/ Elevated	Striate	Few granules	Anomo- Aniso- cytic	Anomo- Aniso-cytic	Raised	Raised
2	*A. blitiodes* Watson	Irregular	Polygonal/ Irregular	Straight/ Elevated	Smooth	Few granules	Anomo- Aniso- cytic	Anomo- Aniso-cytic	Raised	Sunken
3	*A. caudatus*	Sinuate/ Irregular	Polygonal/ Irregular	Straight/ Elevated	Rugate	Few granules	Anomo- Aniso- cytic	Anomo- Aniso-cytic	Raised	Raised
4	*A. graecizans*	Sinuate/ Irregular	Irregular	Undulate/ Elevated	Rugate	Absent	Anomo-cytic	Anomo-cytic	Raised	Raised
5	*A. hybridus*	Sinuate Irregular	Polygonal/ Irregular	Undulate/ Elevated	wrinkled	Absent	Anomo- Aniso- cytic	Anomo- Aniso- cytic	Raised	Raised
6	*A. lividus*	Elongated/ Irregular	Regular	Straight/ Elevated	Striate	Absent	Anomo- Aniso-Dia- cytic	Anomo- Aniso-Dia- cytic	Superficial	Superficial
7	*A. retroflexus*	Elongated	Isodiametric/ Irregular	Undulate/ Elevated	wrinkled	Dense granules	Anomo- Aniso-cytic	Anomo- Aniso- cytic	Raised	Raised
8	*A. spinosus*	Elongated	Polygonal/ Irregular	Undulate/ Elevated	Papillate	Dense granules	Anomo- Aniso-cytic	Anomo- Aniso- cytic	Raised	Raised
9	*A. tricolor*	Elongated/ Irregular	Elongated/ Irregular	Undulate/ Elevated	Striate	Dense granules	Anomo- Aniso-cytic	Anomo- Aniso- cytic	Raised	Raised
10	*A. viridis*	Elongated/ Irregular	Elongated/ Irregular	Straight/ Elevated	Striate	Few granules	Anomo- Aniso- cytic	Anomo- Aniso- cytic	Raised	Raised

Table 6. Joining Euclidean distances gathered for the ten studied *Amaranthus* species according to the linkage methods of data analysis using Systat 12 program

Nearest neighbor linkage method				Group average linkage method				Farthest neighbor linkage method			
Clusters Joining		Distance	No. of Members	Clusters Joining		Distance	No. of Members	Clusters Joining		Distance	No. of Members
Case 10	Case 3	1.012	2	Case 10	Case 3	1.012	2	Case 10	Case 3	1.012	2
Case 6	Case 10	1.043	3	Case 7	Case 6	1.049	2	Case 7	Case 6	1.049	2
Case 7	Case 6	1.049	4	Case 8	Case 1	1.081	2	Case 8	Case 1	1.081	2
Case 8	Case 1	1.081	2	Case 8	Case 4	1.302	3	Case 8	Case 4	1.437	3
Case 8	Case 4	1.167	3	Case 10	Case 7	1.313	4	Case 10	Case 7	1.632	4
Case 2	Case 8	1.297	4	Case 9	Case 10	1.653	5	Case 9	Case 5	1.745	2
Case 7	Case 9	1.357	5	Case 2	Case 8	1.675	4	Case 2	Case 10	2.011	5
Case 7	Case 2	1.432	9	Case 9	Case 5	2.292	6	Case 8	Case 2	3.623	8
Case 5	Case 7	1.745	10	Case 9	Case 2	3.088	10	Case 8	Case 9	5.422	10

Cases studied: 1. A . albus; 2. A . blitiodes; 3. A . caudatus; 4. A . graecizans; 5. A . hybridus; 6. A . lividus; 7. A . retroflexus; 8. A . spinosus; 9. A . tricolor and 10. A .viridis .



a) *A albus* (abaxial surface) b) *A albus* (adaxial surface) c) *A blitoides* (abaxial surface)
d) *A blitoides* (adaxial surface) e) *A caudatus* (abaxial surface) f) *A caudatus* (adaxial surface)
g) *A graecizans* (abaxial surface) h) *A graecizans* (adaxial surface) i) *A hybridus* (abaxial surface)
j) *A hybridus* (adaxial surface)

Plate 3. (a-j) SEM photo-micrographs showing types of stomata and shape of epidermal cells on both abaxial and adaxial surfaces of the leaf for *A. albus, A. blitoides, A. caudatus, A. graecizans,* and *A. hybridus***,** respectively.

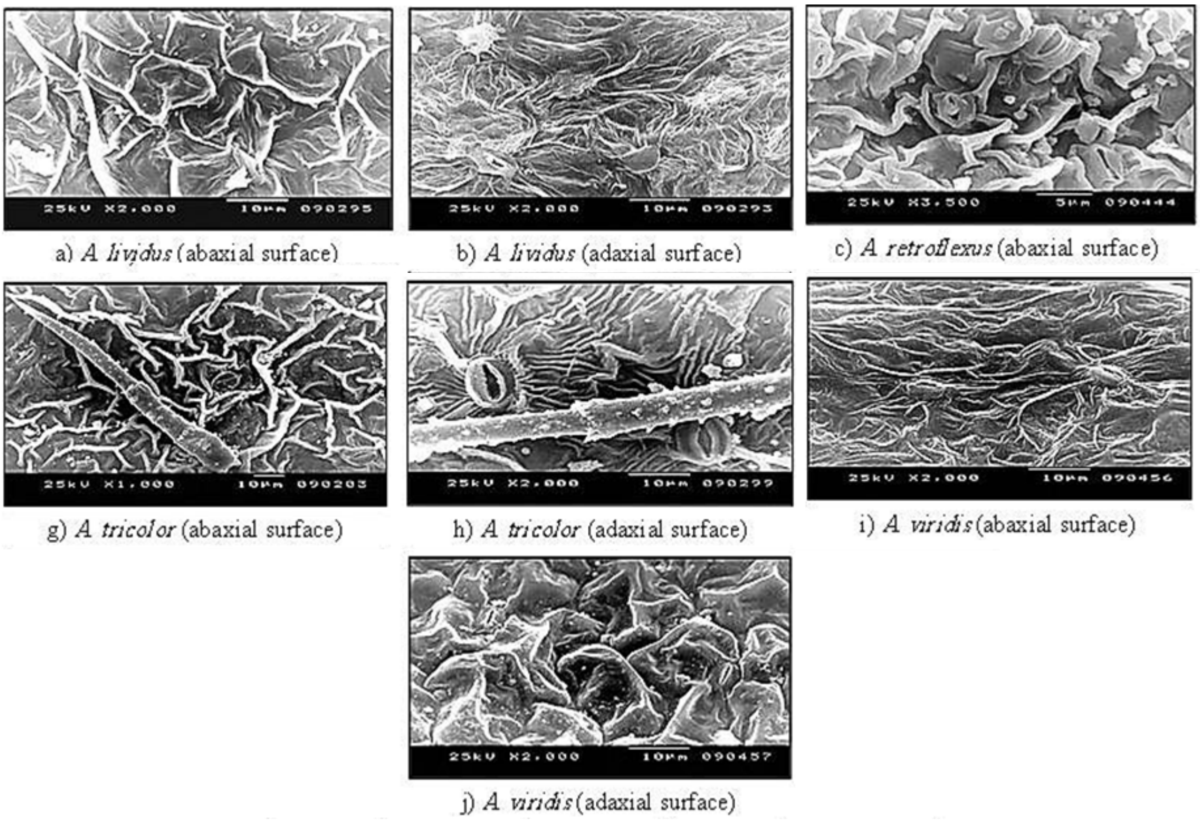


Plate 4. (a-j) SEM photo-micrographs showing types of stomata and shape of epidermal cells on both abaxial and adaxial surfaces of the leaf for *A. lividus, A. retroflexus*, *A. spinosus*, *A. tricolor* and *A. viridis*, respectively.

4. Discussion

Amaranthus is a cosmopolitan genus with annual monoecious or dioecious species. Species within this genus are under taxonomic investigations due to their high phenotypic variability (Mosyakin and Robertson, 2003; Iamonico, 2009 and 2015). The first comprehensive taxonomical division of the genus was that of Dumortier, (1827) who divided its species into two sections. Classification of the genus has been faced with many opinions and divisions afterward; from the most reasonable division is that of Mosyakin and Robertson, (1996). Accordingly, the vegetative morphological variation within the Egyptian *Amaranthus* has been investigated in this work. Davis and Heywood, (1973) pointed out that any stable character can be used in systematic. Subsequently, the most stable characters have been subjected to numerical analysis to investigate the relationship between the studied species.

According to Dumortier, (1827), the studied taxa were classified under the two sections; *Amaranthotypus* and *Blitopsis*; as follows: *A. caudus, A. hybridus, A. retroflexus,* and *A. spinosus* under section *Amaranthotypus*. While section *Blitopsis* includes *A. albus, A. blitoides, A. graecizans, A. lividus, A. tricolor* and *A. viridis*. The results found in the present study did not coincide with Dumortier's classification of the species. The obtained dendrograms divided the studied taxa into two groups in the three clustering methods (N.N., G.A. and F.N.). The three dendrograms put *A. albus* beside *A. spinosus* (1 and 8) at dissimilarity index 1.081, as well as *A. caudatus* beside *A. viridis* (3 and 10) at dissimilarity matrix 1.012. The species *A. lividus* and *A. retroflexus* (6 and 7) are closely met at dissimilarity matrix 1.049 in the three dendrograms. These gatherings of the species are logic due to the morphological similarities between every two species, in spite of gathering species between two different Dumortier's sections. This result may be in acceptance of Mosyakin and Robertson, (1996) who divided all the *Amaranthus* species into three subgenera; 1- *Acnida* (L.) Aellen ex K. R. Robertson with three sections; 2- *Albersia* (Kunth) Gren. and Godr. with four sections and 3- *Amaranthus* with three sections and two subsections.

As *Acnida* taxa were not represented in the flora of Egypt, accordingly the three resulted dendrograms revealed that the studied taxa can be divided into two subgenera, with many sections and *Acnida* is excluded. We can explain this division as it was according to the vegetative morphological characters only. From the most important morphological characters within the studied taxa are the places of red spot on the leaf surfaces and leaf venation, which divide the studied taxa into two groups, red spot on the leaf surfaces on the middle versus on the lower part of the leaf blades besides the leaf venation, reticulodromus versus brochidodromous. The species under these groups did not coincide with those of Dumortier, (1827). In spite of that, the results obtained were in partial acceptance with that of Waseltov *et al.,* (2018) who found that both *A. caudatus* and *A. hyvridus* were closed to each other in the phylogenetic tree, as well as *A. albus* and *A. blitoides*. Most of the taxonomical works on this genus were classified according to the floral characters and sex of the plants (Mosyakin and Robertson, 2003 and Iamonico, 2009 and 2015). As a conclusion the studied *Amaranthus* species can be divided into two main groups based on their vegetative morphological characters only.

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Appendix 1. Types of characters (OTU's) used in the numerical analysis and its ranking

No.		Characters	Ranking of Multistated Qualitative					
			1	2	3	4	5	6
1	Stem characters	Habit	Annual	Perennial				
2		Type	Erect	Procumbent	Prostrate			
3		Length (cm)	Multistated Quantitative					
4		Width (mm)						
5		Shape	Flattened	Angular	Slender			
6		Color	Light Green	Greenish white	Green	Green tinged with purple	Purple	Red
7		Density of branches	Moderate	Dense				
8		Density of hairs	Glabrous	Sparsely hairy	Hairy			
9	Leaf macro-characters	Arrangement	Alternate	Spiral				
10		Color	Pale green	Green	Green with white spots	Green tinged with red	Green tinged with purple	Green or reddish purple
11		Length (cm)	Multistated Quantitative					
12		Width (cm)						
13		Shape	Ovate	Ovate to Lancolate	Lancolate			
14		Widest part	Middle	Lower				
15		Spot	Middle	Lower				
16		Surface	Glabrous	Sparsely hairy	Hairy	Wooly		
17		Hair type*	MUP	MUT	MUG	MUG+MBG		
18		Types of venation	Reticulodromous	Brochidodromous				
19		Size of 1^{ry} veins	Thin	Moderate	Thick			
20		Type of 2^{ry} veins space	Regular	Wide at apex	Wide at base	Irregular		
21		Number of 2^{ry} veins	Multistated Quantitative					
22	Leaf micro-characters	Marginal veins	Complete	Incomplete				
23		Areolar veins	Closed	Incomplete				
24		Abaxial epidermal cells	Irregular	Elongated/Irregular	Sinuate/Irregular			
25		Adaxial epidermal cells	Irregular	Elongated/Irregular	Polygonal/Irregular	Isodiametric/Irregular	Polygonal/regular	
26		Abaxial stomatal type	Anomo-cytic	Anomo-Aniso-cytic	Anomo-Aniso- Dia-cytic			
27		Marginal veins	Complete	Incomplete				