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Family Boraginaceae: Hair Variations and their Significance in the Systematic of the Genera

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Abstract: Leaves of sixty six species distributed over twenty genus have been studied by using both the stereo and scanning electron microscopes to investigate the degree of hair density as well as the types of hairs and their characters. From this investigation four groups have been recognized as the result of subjecting the hair characters to cladistic analysis. The first group gathers all the glabrous species together which support their isolation in a new family, Ehretiaceae, as proposed before. The rest of the groups collect the rest of the species at different levels of variations which donot support further division of the genera. Species of *Heliotropium* are closely related to each others which, partly, support their separation as proposed before. Meanwhile some of the *Heliotropium* species resemble the other Boraginoideae species in their haircharacters. A postulated line of evolution has been drawn which start with the glabrous species as the more primitive ones and ended with the woolly species with either one raw or two rows basal cells and echinate, granulate or scaly hair walls in the other end.

Key words: Ehretiaceae, Boraginoideae, Heliotropoideae, hair characters, evolutionary line, taxonomical revision

INTRODUCTION

Family Boraginaceae Juss. is one of the widely distributed families. It has about one hundred genera and more than two thousand species distributed all over the world (Heywood, 1978). Members of the family have great variations in their morphological characters. They are trees, shrubs or lianas, annuals or perennials lacking essential oils. They are also inhabit different habitats, mountains, wadies or even disturbed habitats. Stems and leaves of the Boraginaceae characterized by the presence of hairs on their surfaces which may be glandular or eglandular (Metcalf and Chalk, 1979). The density of these hairs may be varied in the different habitats. Few taxa have glabrous leaves and this encouraged Hutchinson (1948) to isolate them in another new family Ehretiaceae. Family Boraginaceae had drawn the attention of many taxonomists since long time ago. Hallier (1912), Bessey (1915), Brand (1921), Lawrence (1963), Chopra (1971), Khalifa and Hamed (1982), Al-Nowaihi *et al.* (1987), Taia and Shiha (1999) are ones from those who gave great attention to the systematics of the family. According to the ovary, entire or lobed, genera of the Boraginaceae has been divided into four subfamilies. These subfamilies have been faced with many taxonomic opinions since long time ago. Svensson (1925), Pal (1963) and Di Fulvio (1978) transfer the three subfamilies Heliotropoideae (Schrad.) Arn., Cordioideae (R.Br.) Lindl. And Ehretioideae (Mart. Ex Lindl.) Arn. and gathered them in a separate family Heliotropiaceae. This conclusion has been supported by Hilger (1989), Ferguson (1999) and Diane *et al.* (2002) on

the basis of both fruit and flower development as well as molecular analysis data. The taxonomic status of the family according to different systems of classifications are listed in Table 1, while the main divisions of the family and their characters (Heywood, 1978) as well as the genera studied are listed in Table 2.

This study concerns with the variations in hair characters and density within 66 species distributed over 20 genus collected mainly from deferent habitats in Saudi Arabia. The aims of the study are to investigate how much these characters can affect the delimitation of the taxa and to determine whether they can reinforce the generic boundaries and clarify the evolutionary line between the taxa or not. The study based on both light and scanning electron microscopes, as well as vegetative examinations.

MATERIALS AND METHODS

Materials of the studied taxa and their locations are listed in Table 3. Leaves of the 66 species are collected either from field trips or from herbarium specimens allocated at the ministry of agriculture and water resources herbarium in El-Riyadh city. At least five specimens, from each species examined by the stereomicroscope firstly, before subjecting to softening. Chosen parts of the leaves were boiled softly in 10% nitric acid until the epidermises could be removed. Then both the abaxial and adaxial ones were examined by light microscope. Dry leaves from most of the taxa studied were mounted onto clean stubs and coated with gold and

Table 1: Systematic position of family Boraginaceae in the different systems of classification

Class./Authors	Engler	Cronquist	Thorne	Dahlgren	Takhtajan
Class	Dicotyledonae	Magnoliopsida	Magnoliopsida	Magnoliopsida	Magnoliopsida
Subclass	Sympetalae	Asteridae	Magnoliidae	Magnoliidae	Lamiidae
Superorder	-----	-----	Solananae	Solananae	Solananae
Order	Tubiflorae	Lamiales	Solanales	Boraginales	Boraginales
Suborder	Boraginineae	-----	-----	-----	-----
Family	Boraginaceae	Boraginaceae	Boraginaceae	Boraginaceae	Boraginaceae
Magnoliopsida	Magnoliopsida	Magnoliopsida	Dicotyledonae	Class	Magnoliopsida
Lamiidae	Magnoliidae	Magnoliidae	Sympetalae	Subclass	Asteridae
Solananae	Solananae	Solananae	-----	Superorder	-----
Boraginales	Boraginales	Solanales	Tubiflorae	Order	Lamiales
-----	-----	-----	Boraginineae	Suborder	-----
Boraginaceae	Boraginaceae	Boraginaceae	Boraginaceae	Family	Boraginaceae

Table 2: Taxonomic division of family Boraginaceae (Heywood, 1998)

Family	Subfamily	Main characters	Tribe	Genera studied
Boraginaceae	Ehretioideae	Ovary: entire Fruit: drupe	-----	<i>Ehretia</i>
	Heliotropoideae	Ovary: slightly lobed Fruit: simple nutlets		<i>Heliotropium</i>
	Cordioideae	Ovary: moderately lobed Fruit: simple nutlets		<i>Cordia</i> <i>Brandella</i>
	Boraginoideae	Ovary: deeply lobed Fruit: 4 nutlets	Boragineae	<i>Anchusa</i> <i>Alkana</i> <i>Buglossoides</i> <i>Gastrocotyle</i> <i>Hormuzakia</i> <i>Paracaryum</i> <i>Heterocaryum</i> <i>Microparacaryum</i> <i>Paracynoglossum</i> <i>Trichodesma</i>
			Cynoglosseae	<i>Echiachilon</i> <i>Lappula</i>
			Eritricheae	<i>Arnebia</i>
			Lithospermeae	<i>Molkiopsis</i> <i>Ogastemma</i>
			Echieae	<i>Echium</i>

Table 3: Studied taxa and their distribution in Saudi Arabia

Taxa	Distribution	Number of studied sheets
<i>Alkana orientalis</i> (L.) Boiss.	Abha, Sawdah mountain, Lauz mountain, Saraa	6669, 7591, 15574, 7661
<i>Anchusa aegyptiaca</i> (L.) DC.	Jeddah, Konfoudah, Tabuk	---, 1762, ---
<i>Anchusa milleri</i> Willd	Wadi Um Rimth, Tabuk, Buraydah, Medina, Yanbu, Hail	8045, 5274, 10041, 16563
<i>Anchusa unchulata</i> L.*	Wadi Arar	----
<i>Anchusa hispida</i> Forssk.	Tabuk, Buraydah, Al-Goof	----
<i>Arnebia asperima</i> L.*	Al-Taif	10165, ---
<i>Arnebia decumbens</i> (Vent.) Coss and Karl	Al-Harra, Al-Goof, Rumaih, Wadi Maarik, Hail, Skaka, Riyadh, Wadi Arar, Doumah El-Jondol.	11132, 5061, 9343, 8203, 8160, 10162, 7643
<i>Arnebia hispidissima</i> (Lehm.) DC.	Abha, Al-Kara, Riyadh, Al-Taif, Al-Lith, Unaiza, Al-Harik	10130, 10132, 10133, 1028, 8755, 12817, 10125
<i>Arnebia linearifolia</i> DC.	Al-Harra, Hail, Khurais, Sakaka	10889, E-509, 11133, 10203, 10202, 3438
<i>Arnebia tetrastigma</i> Forssk.	Al-Taif, Dahnaa desert, AL-Harra, Al-Goof	16743, 3017, ---, 11130
<i>Brandella erythraea</i> L.*	Sawdah mountain	1004, 7577, ----
<i>Buglossoides arvensis</i> (L.) I.M. Johnson *	Warjan mountain, Medinah	9964, ----
<i>Buglossoides tenuiflora</i> L.*	Wadi Baesha	16377, ----
<i>Cordia abyssinica</i> R.Br.	Gizan, Arar	10057, ---
<i>Cordia africana</i> L.*	Gizan	10055, 10063, ---
<i>Cordia myxa</i> L.	Riyadh	10123, ----
<i>Cordia ovalis</i> L.*	Abha	8921, ----
<i>Cordia gharaf</i> Forssk. Ehrln. ex Asch.*	Wadi Baesha, Tabuk, Yanbo	3037, ----
<i>Echiochilon propersicum</i> Burm. F.*	Nagran, Sakaka	7786, 16204, 7788, ---
<i>Echiochilon kotschyi</i> Bunge.*	Al-Kharj-Sulayil road	12491, ----
<i>Echium angustifolium</i> Mill.*	Sawdah mountain, Abha, Khamees Moushait	16214, ----
<i>Echium horridum</i> Batt.	Gizan	10120, ----
<i>Echium longifolium</i> Del.	Medinah, Shamansel mountain, El-Dammam	6638, ----
<i>Echium plantagineum</i> Del.*	Wadi Baesha	13232, ----
<i>Echium sericeum</i> L.*	Sakaka, Hail, Unayza	13233, 10153, 10262, 11881, ---
<i>Echium rauwolfii</i> Del.	El-Dammam, Rumaih, Kaisumah	,----

Table 3: Continue

Taxa	Distribution	Number of studied sheets
<i>Ehretia obtusifolia</i> Hochst.*	Abha, Sawdah mountain	14387, 966, 9982, ---
<i>Ehretia abyssinica</i> R.Br.*	Gizan, Hail	12313, ---
<i>Gastrocotyle hispida</i> (Forssk.) Bunge	Hail, Sakaka, Al-Kharj	1083, 11129, 10155, ---
<i>Heliotropium carbanense</i> Fres.	Abha, Gizan, Jeddah	6685, E-763, 918, 932
<i>Heliotropium bacciferum</i> Forssk.	Al-Badeia, Taif, Al-Riyadh, Unaiza, Hail, Al-Hofuf	10150, 13297, ---
<i>Heliotropium caleareum</i> Forssk.*	Wadi Baesha	16345, ---
<i>Heliotropium cinerascens</i> Steud.	Nagran, Sakaka	----
<i>Heliotropium crispum</i> L.*	Al-Kharj, Al-Riyadh, Taif, Hail, Hofuf, Unayza	10234, 3450, 6633, 6797, 3458, 10201, 6849, 10140, 3613
<i>Heliotropium curassavicum</i> Steud.*	Medinah, Jeddah	7816, 7750, ---
<i>Heliotropium digynum</i> (Forssk.) Asch.	Jeddah, Konfudah, El-Dammam, Rumaih, Unaiza	6746, 3678, 6747, 6751, ---
<i>Heliotropium europaeum</i> L.	Al-Kharj, Al-Riyadh, Sakaka, Gizan	3442, 3444, 10166, 6570, ---
<i>Heliotropium hirsutissimum</i> Grauer	Gizan, Arar	---
<i>Heliotropium kassasi</i> Tackh. et Boulos	Jeddah, Konfudah	8331, 8626, 10999, ---
<i>Heliotropium kotschyi</i> (Bunge) Gurke**	El-Zahrán	7777, 12759, ---
<i>Heliotropium lasiocarpum</i> L.*	Abha	8933, 8956, 1092, ---
<i>Heliotropium lignosum</i> Schweinf. ex Bunge	El-Dammam, El-Zahrán, Rumah	----
<i>Heliotropium longiflorum</i> (A.DC.) Steud et Hochst.	Taif-Jeddah road, Nagran	96635, 5893, 6959, ---
<i>Heliotropium pallens</i> Del.	Hail, Jeddah, Konfudah	774, 12937, ---
<i>Heliotropium pterocarpum</i> Hochst.	Gizan, Badr-Medinah road	6808, 3422, 3423, 3439, ---
<i>Heliotropium ramosissimum</i> (Lehm.) Siebu ex DC.**	El-Riyadh	3450, 3452, 3453, ---
<i>Heliotropium ramiflorum</i> Del.*	Said mountain near El-Medinah, Abha, Nagran	9043, 10511, ---
<i>Heliotropium strigosum</i> Willd.	Abha, Yanbua, Gizan	12969, 6744, E-764, 762, 6636, ---
<i>Heliotropium supinum</i> L.	Al-Kharj, Al-Riyadh	----
<i>Heterocaryum subsessile</i> Varke*	Al-Harra, Hail	11126, ---
<i>Hormuzakia aggregata</i> (Lehm.) Gusul.	Al-Riyadh	----
<i>Lappula spinocarpus</i> (Forssk.) Asch. ex Ktze.	Al-Hara, Hail, Skaka	10043, 10184, 10998, ----
<i>Lappula sinaica</i> (DC) Aschirs Schweif.*	warjan mountain in El-Medinah, Radwa mountain North Yanbua	9997, 12410, ---
<i>Microparacaryum intermedium</i> Boiss.*	Radwa mountain Yanbua	9999, 15571, 15572, ---
<i>Molkiopsis ciliata</i> (Forssk.) Johnst.	Dammam, Nifud desert, Rumaih, Buraida, Kaisumah	12260, E-776, 6551, 8211, E-777, 5059
<i>Ogastemma pusillum</i> Boiss.*	Thumamah, Rumah, Rowdat Al-Khuraim	165220, 15844, 8220, ---
<i>Paracaryum boissieri</i> Schweinf.	Radwa mountain North Yanbua	12411, 12412, 10244, ---
<i>Paracaryum intermedium</i> (Forssk.) Lipsky.	Tabuk, Shar mountain	10111, 10297, ---
<i>Paracaryum regulosum</i> L.*	Al-Harra, Hail	---
<i>Paracynoglossum bottae</i> DC.*	Sawda, North Abha	----
<i>Trichodesma africanum</i> (L.) R.Br.	Agga mountain, Hail, Jeddah	16088, 16078, 16561, ---
<i>Trichodesma ehrenbergii</i> Schweinf.	Medina, Shamansel mountain near El-Medina	12280, 16717, 10281, 13373, 16716 A
<i>Trichodesma pauciflorum</i> Bak.	Gizan, Arar	----
<i>Trichodesma trichodesmioides</i> Boiss.*	Gizan, Fayfa mountain, El-Hadda, Taif road	12970, 9729, 9725, 10217, --
<i>Trichodesma zeylanicum</i> (Burm. F.) R.Br.	Gizan, Arar, Asir mountain	10288, 10215, 10287, ---

species not recorded in the flora of Saudi Arabia (Migahid, 1996), **Species not recorded in the flora of Saudi Arabia (Migahid, 1996) but recorded by Zohary (1957)

examined by JEOL T-20 scanning electron microscope allocated at Alexandria University. Terminology used here are that of Al-Shammary and Gornall (1994).

RESULTS

The results obtained are summarized in Table 4 and illustrated in Fig. 1-56. From Table 4 we can notice that the genera *Ehretia* (Fig. 54), *Paracaryum boissieri* and *P.intermedium* (Fig. 56) are the only ones with glabrous leaves while the rest of the genera are either hairy or even woolly with deferent hair lengths. No variations in the density of hairs have been noticed between both the abaxial and adaxial surfaces. Few species only which are sparsely hairy, *Arnebia linearifolia*, *A. tetrastigma* (Fig. 41 and 42), *Cordia abyssinica* (Fig. 55), *C. africana* (Fig. 52), *C. myxa* (Fig. 24), *Echium horridum* (Fig. 20),

Lappula sinaica (Fig. 43), *Trichodesma africana* (Fig. 9) and *T. ehrenbergii* (Fig. 39). Few species have addressed hairs, *Echiochilon* sp. (Fig. 15 and 16), *Gastrocotyle hispida* (Fig. 46), *Heliotropium crispum* (Fig. 30), *H. kotschi* (Fig. 31), *H. lasiocarpum* (Fig. 45), *H. lignosum*, *H. ramosissimum* (Fig. 19), *H. ramiflorum* (Fig. 13), *H. strigosum* (Fig. 4 7), *Lappula sinaica* (Fig. 43) and *Ogastemma pusillum* (Fig. 18). Most of the species have distributed hairs allover the lamina except *Arnebia tetrastigma* (Fig. 42), *Brandella erythraea* (Fig. 22), *Cordia africana* (Fig. 52), *C. myxa* (Fig. 24), *C. ovalis* (Fig. 53), *Heliotropium curassavicum* (Fig. 49) and *Ogastemma pusillum* (Fig. 18) in which the hairs are restricted to the midrib area only. The types of hairs are mostly either unicellular pointed or multi-cellular pointed ones, branched hairs founded with multi-cellular ones in *Microparacaryum intermedium* only (Fig. 48). The

Table 4: Characters investigated in the studied taxa

Taxa	1	2	3	4	5	6	7	8
<i>Alkana orientalis</i> (L.) Boiss.	2	3	3	3	2	3	5	Fig. 8
<i>Anchusa aegyptiaca</i> (L.) DC.	2	3	3	3	2	3	5	---
<i>Anchusa mülleri</i> Willd	2	3	3	3	2	4	4	Fig. 1
<i>Anchusa undulata</i> L.*	2	3	3	3	2	4	4	---
<i>Anchusa hispida</i> Forssk.	2	3	3	3	2	4	4	----
<i>Arnebia asperima</i> L.*	2	4	3	3	2	4	3	Fig. 23
<i>Arnebia decumbens</i> (Vent.) Coss and Karl	2	3	3	3	2	4	5	Fig. 2
<i>Arnebia hispidissima</i> (Lehm.) DC.	2	2	3	3	2	4	3	Fig. 3
<i>Arnebia linearifolia</i> DC.	2	5	3	3	2	5	4	Fig. 41
<i>Arnebia tetrastigma</i> Forssk.	2	5	3	2	2	5	4	Fig. 42
<i>Brandella erythraea</i> L.*	2	2	3	2	2	2	4	Fig. 22
<i>Buglossoides arvensis</i> (L.) I.M. Johnson *	2	2	3	3	4	5	4	Fig. 21
<i>Buglossoides tenuiflora</i> L.*	2	4	3	3	2	2	4	Fig. 38
<i>Cordia abyssinica</i> R.Br.	2	5	3	3	2	5	4	Fig. 55
<i>Cordia africana</i> L.*	2	5	3	2	4	5	4	Fig. 52
<i>Cordia myxa</i> L.	2	5	3	2	2	5	3	Fig. 24
<i>Cordia ovalis</i> L.*	2	2	3	2	2	5	5	Fig. 53
<i>Cordia gharaf</i> Forssk. Ehrh. ex Asch.*	2	2	3	3	2	5	4	Fig. 40
<i>Echiochilon propersicum</i> Burm.F.*	2	4	2	3	2	4	4	Fig. 16
<i>Echiochilon kotschyi</i> Bunge.*	2	4	2	3	2	4	4	Fig. 15
<i>Echium angustifolium</i> Mill.*	2	3	3	3	4	4	4	Fig. 7
<i>Echium horridum</i> Batt.	2	5	3	3	2	4	4	Fig. 20
<i>Echium longifolium</i> Del.	2	2	3	3	2	3	4	Fig. 5
<i>Echium plantagineum</i> Del.*	2	3	3	3	2	3	5	Fig. 4
<i>Echium sericeum</i> L.*	2	3	3	3	2	5	4	Fig. 37
<i>Echium rauwolfii</i> Del.	2	3	3	3	2	3	4
<i>Ehretia obtusifolia</i> Hochst.*	1	1	1	1	1	1	1
<i>Ehretia abyssinica</i> R. Br.*	1	1	1	1	1	1	1	Fig. 54
<i>Gastrocotyle hispida</i> (Forssk.) Bunge	2	3	2	3	2	5	1	Fig. 46
<i>Heliotropium arbainense</i> Fres.	2	4	3	3	4	5	2	Fig. 27
<i>Heliotropium bacciferum</i> Forssk.	2	3	3	3	4	2	4	Fig. 32
<i>Heliotropium battae</i>	2	4	3	3	4	5	2	Fig. 29
<i>Heliotropium caleareum</i> Forssk.*	2	4	3	3	4	2	2	Fig. 26
<i>Heliotropium cinerascens</i> Steud.	2	3	3	3	4	2	4	Fig. 28
<i>Heliotropium crispum</i> L.*	2	4	2	3	4	5	2	Fig. 30
<i>Heliotropium curassavicum</i> Steud.*	2	3	3	2	2	5	2	Fig. 49
<i>Heliotropium digynum</i> (Forssk.) Asch.	2	4	3	3	2	5	2	Fig. 44
<i>Heliotropium europaeum</i> L.	2	4	3	3	4	2	5	Fig. 34
<i>Heliotropium hirsutissimum</i> Grauer	2	3	3	3	4	5	5	Fig. 36
<i>Heliotropium kassasi</i> Tackh. et Boulos	2	3	3	3	4	5	5	----
<i>Heliotropium kotschyi</i> (Bunge) Gurke**	2	4	2	3	4	5	4	Fig. 31
<i>Heliotropium lasiocarpum</i> L.*	2	4	2	3	2	5	4	Fig. 45
<i>Heliotropium lignosum</i> Schweinf. ex Bunge	2	4	2	3	4	5	5	----
<i>Heliotropium longiflorum</i> (A.DC.) Steud et Hochst.	2	4	3	3	4	2	5	Fig. 33
<i>Heliotropium pallens</i> Del.	2	4	3	3	4	2	5	Fig. 35
<i>Heliotropium pterocarpum</i> Hochst.	2	4	3	3	2	2	3	Fig. 25
<i>Heliotropium ramosissimum</i> (Lehm.) Siebu ex DC.**	2	4	2	3	2	5	4	Fig. 19
<i>Heliotropium ramiflorum</i> Del.*	2	4	2	3	2	3	3	Fig. 13
<i>Heliotropium strigosum</i> Willd.	2	4	2	3	4	5	3	Fig. 47
<i>Heliotropium supinum</i> L.	2	4	3	3	2	3	2	Fig. 14
<i>Heterocaryum subsessile</i> Varke*	2	2	3	3	2	3	4	Fig. 11
<i>Hormuzakia aggregata</i> (Lehm.) Gusul.	2	2	3	3	2	3	4	----
<i>Lappula spinocarpos</i> (Forssk.) Asch. ex Ktze.	2	3	3	3	2	3	4	Fig. 12
<i>Lappula sinaica</i> (DC) Aschirs Schweif.*	2	5	2	3	2	2	4	Fig. 43
<i>Microparacaryum intermedium</i> Boiss.*	2	4	3	3	3	5	3	Fig. 48
<i>Molkiopsis ciliata</i> (Forssk.) Johnst.	2	2	3	3	2	3	2	Fig. 17
<i>Ogastemma pusillum</i> Boiss.*	2	4	2	2	2	5	4	Fig. 18
<i>Paracaryum boissieri</i> Schweinf.	1	1	1	1	1	1	1	----
<i>Paracaryum intermedium</i> (Forssk.) Lipsky.	1	1	1	1	1	1	1	Fig. 56
<i>Paracaryum regulosum</i> L.*	2	2	3	3	2	3	4	Fig. 6
<i>Paracynoglossum bottae</i> DC.*	2	2	3	3	2	3	4	Fig. 10
<i>Trichodesma africanum</i> (L.) R.Br.	2	1	3	3	4	3	4	Fig. 9
<i>Trichodesma ehrenbergii</i> Schweinf.	2	1	3	3	4	2	4	Fig. 39
<i>Trichodesma pauciflorum</i> Bak.	2	4	3	3	2	5	4	Fig. 50
<i>Trichodesma trichodesmioides</i> Boiss.*	2	4	3	3	2	5	2	Fig. 51
<i>Trichodesma zeylanicum</i> (Burm F.) R. Br.	2	4	3	3	2	5	2	----

1-Hair presency: 1 = Absent, 2 = Present; 2-Hair density: 1 = Glabrous, 2 = Hairy, 3 = Densely hairy, 4 = Woolly, 5 = Sparse,
 3-Hair direction: 1 = Glabrous, 2 = Pressed on the leaf surface, 3 = Erect; 4-Hair location 1 = Glabrous, 2 = Restricted to the midrib,
 3 = Throughout the lamina; 5-Hair type: 1 = Absent, 2 = Multi-cellular pointed, 3 = Both, branched and pointed, 4 = Unicellular pointed;
 6-Basal stalk cell(s): 1 = Glabrous, 2 = One enlarged cell, 3 = Many-celled, one layer, 4 = Many-celled, two layers 5 = Absent;
 7-Hair wall: 1 = Glabrous, 2 = Granulate, 3 = Echinata, 4 = Scaly 5 = Smooth; 8-Figure number



Fig. 1: *Anchusa milleri* Willd



Fig. 2: *Arnebia decumbens* (Vent.)
Coss & Karl.



Fig. 3: *Arnebia hispidissima*
(Lehm.)DC.



Fig. 4: *Echium plantagineum* Del.



Fig. 5: *Echium longifolium* Del.

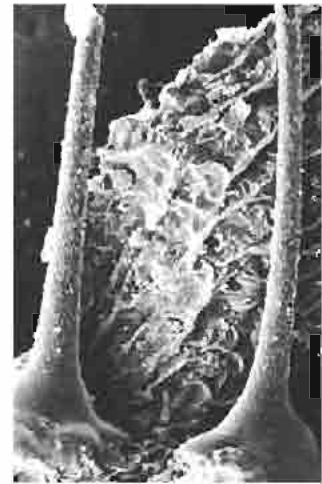


Fig. 6: *Paracaryum regulosum* L.



Fig. 7: *Paracaryum regulosum* L.



Fig. 8: *Alkana orientalis* (L.) Boiss.



Fig. 9: *Trichodesma africanum* (L.) R.Br.



Fig. 10: *Paracynoglossum bottae* DC.



Fig. 11: *Heterocaryum subsessile* Varke



Fig. 12: *Lappula spinocarpos* (Forssk.)
Asch.ex Ktze.



Fig. 13: *Heliotropium ramiflorum*
Del.



Fig. 14: *Heliotropium supinum* L.



Fig. 15: *Echiochilon kotschyi* Bunge.



Fig. 16: *Echiochilon propersicum* Burm.F.



Fig. 17: *Molleopsis ciliata* (Forssk.) Johnst.



Fig. 18: *Ogastemma pusillum* Boiss.



Fig. 19: *Heliotropium ramosissimum* (Lehm.) Siebu ex DC.



Fig. 20: *Echuus horridum* Batt.



Fig. 21: *Buglossoides arvensis* (L.) I.M.Johson



Fig. 22: *Brandella erythraea* L.



Fig. 23: *Arnebia asperma* L.



Fig. 24: *Cordia myxa* L.



Fig. 25: *Heliotropium pterocarpum* Hochst.



Fig. 26: *Heliotropium caleareum* Forssk.*



Fig. 27: *Heliotropium arbainense* Fres.



Fig. 28: *Heliotropium cinerascens* Steud.



Fig. 29: *Heliotropium battae*



Fig. 30: *Heliotropium crispum* L.



Fig. 31: *Heliotropium kotschyi* (Bunge) Gurke

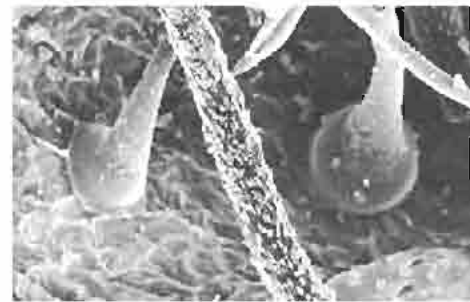


Fig. 32: *Heliotropium bacciferum* Forssk.



Fig. 33: *Heliotropium longiflorum* (A.DC.) Steud et Hochst.



Fig. 34: *Heliotropium europaeum* L.



Fig. 35: *Heliotropium pallens* Del.



Fig. 36: *Heliotropium hirsutissimum* Grauer



Fig. 37: *Echinum sericeum* L.



Fig. 38: *Buglossoides tenuiflora* L.



Fig. 39: *Trichodesma ehrenbergii* Schweinf.



Fig. 40: *Cordia gharaf* Forsk. Ehlbn.ex Asch.



Fig. 41: *Arnebia linearifolia* DC.



Fig. 42: *Arnebia tetrastigma* Forssk.



Fig. 43: *Lappula sinaica* (DC) Aschirs Schweif.



Fig. 44: *Heliotropium digynum* (Forssk.)Asch.



Fig. 45: *Heliotropium lasiocarpum* L.

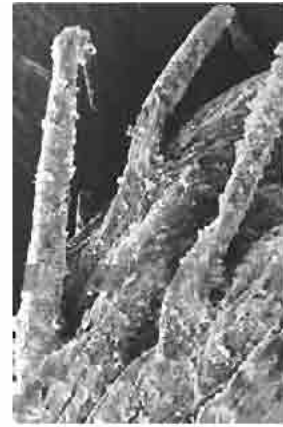


Fig. 46: *Gastrocotyle hispida* (Forssk.)Bunge

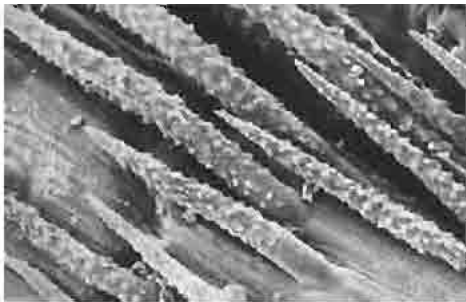


Fig. 47: *Heliotropium strigosum* Willd.

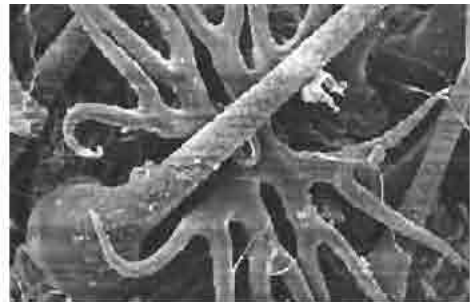


Fig. 48: *Microparacaryum intermedium* Boiss.



Fig. 49: *Heliotropium curassavicum* Steud.*



Fig. 50: *Trichodesma pauciflorum* Bak.



Fig. 51: *Trichodesma trichodesmioides* Boiss.



Fig. 52: *Cordia africana* L.



Fig. 53: *Cordia ovalis* L.



Fig. 54: *Ehretia abyssinica* R.Br.*



Fig. 55: *Cordia abyssinica* R.Br.



Fig. 56: *Paracaryum intermedium* (Forssk.) Lipsky.

presence of basal cell(s), considered most important in delimiting the taxa as most of the taxa have many, rosette-like, basal cells which are either one row or in many rows. Few taxa have either one enlarged basal cell (Fig. 22, 25, 26, 32-35, 38 and 39) or the hairs are without any differentiated basal cell. Hair walls are mostly covered with scales while echinate hair walls are present in *Arnebia asperma* (Fig. 23), *A. hispidissima* (Fig. 3), *Cordia myxa* (Fig. 24), *Heliotropium pterocarpum* (Fig. 25), *H. ramiflorum* (Fig. 13), *H. strigosum* (Fig. 47) and *Microparacaryum intermedium* (Fig. 43). Meanwhile few taxa have granulate or even smooth hair wall. Most of the taxa studied have either needle-shaped or granulated wax deposits on their surfaces and for that, we considerate as a common character in the family.

The characters studied are clustered in a similarity index dendrogram (Fig. 57) in order to evaluate them and to know the most correlated ones. From this dendrogram we found that all the studied characters are grouped in two categories. The first category comprise hair presence (1), hair location (4) and both of them are closely relay on hair direction (3). These three characters are tied together at similarity 95. The second group comprises hair type (5) and basal cell (6) in one branch and hair density (2) and hair wall (7) in another branch and all these four characters gathered at similarity index of 84. These two categories met together at similarity index of 74.

All the taxa studied are clustered together in another dendrogram (Fig. 58) to examine the most correlated species according to hair characters. From the resulted dendrogram, we found that all the taxa are divided into four groups at similarity index of 84. The most evaluated characters in grouping the taxa are hair presency (char. 1), hair density (char. 2), basal cell(s) (char. 6) and hair wall (char. 7), respectively.

Group 1: This group characterizes by having glabrous leaves and has the following species: *Ehretia obtusifolia*,

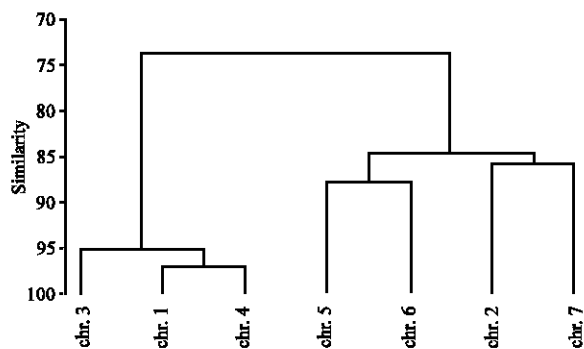


Fig. 57: Dendrogram showing the similarity between the studied characters

Ehretia abyssinica, *Paracaryum boissieri* and *Paracaryum intermedium*.

Group 2: This group characterizes by having densely hairy or even hairy leaves. The hairs are either without basal cell or with basal cells in one or two rows. This group is subdivided into two subgroups as follows:

Subgroup 2a: This subgroup has densely hairy leaves, with many-celled, one row basal cells. The hairs have smooth walls. It includes *Echium plantagineum*, *Alkana orientales*, *Anchusa aegyptiaca*, *Heliotropium supinum*, *Molkiopsis ciliata*, *Echium angustifolium*, *Heliotropium cinerascens*, *Heliotropium bacciferum*, *Heliotropium ramiflorum*, *Echiochilon propersicum*, *Echiochilon kotschi*, *Arnebia asperima*, *Arnebia hispidissima* and *Arenabia decumbens*.

Subgroup 2b: This subgroup characterizes by having hairy or densely hairy leaves with either many-celled, two layered basal cells or without basal cells at all. The hairs have scaly walls. It is subdivided again into two categories the first (2b 1) has densely hairy leaves with many-celled, two layered basal cells and includes the following species: *Echium hordium*, *Anchusa hispida*, *Anchusa milleri*, *Anchusa undulata*, *Echium rauwolfia*, *Lappula spinocarpus*, *hormuzakia aggregata*, *Paracaryum regulosum*, *Paracynoglossum bottae*, *Echium longifolium* and *Heterocaryum subsessile*.

Subgroup (2b 2): has hairy leaves without distinct basal cell and includes the species *Trichodesma africanum*, *Trichodesma ehrenbergii*, *Lappula sinaica*, *Arnebia linearifolia* and *Cordia abyssinica*.

Group 3: has sparsely hairy leaves, with the hairs restricted around the midrib only. The hairs without distinct basal cell and have scaly walls. This group has the species *Cordia africana*, *Arnebia tetrastigma*, *Cordia myxa*, *Buglossoides arvensis*, *Cordia gharaf*, *Brandella erythraea* and *Cordia ovalis*.

Group 4: This group characterizes by having densely hairy or even woolly leaves, with or without basal cells and either scaly, granulate or smooth walls. It is subdivided into two subgroups as follows:

Subgroup 4a: With many-celled, one layered basal cells and either granulate or scaly walls. It gathers most of the *Heliotropium* species as follows: *Heliotropium kotschi*, *H. strigosum*, *H. crispum*, *H. lignosum*, *H. caleareum*, *H. arabainense*, *H. battae*, *H. hirsutissimum*, *H. kassasi*, *H. pallens*, *H. europaeum* and *H. longiflorum*.

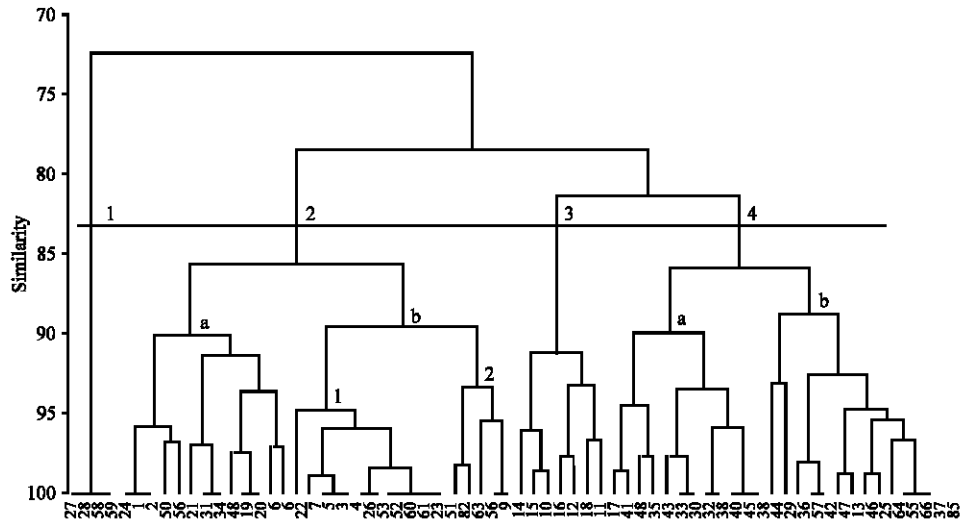


Fig. 58: Dendrogram showing the similarity between the studied taxa

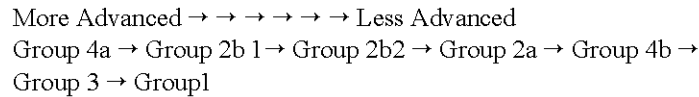


Fig. 59: Diagram shows the line of evolution within the Boraginaceae. According to hair characters

Subgroup 4b: Without basal cell and the hairs have smooth walls. It gathers the rest of the *Heliotropium* species with another taxa as follows: *Gastrocotyle hispida*, *Heliotropium hirsutissimum*, *Ogastema pusillum*, *Heliotropium lasiocarpum*, *Heliotropium ramosissimum*, *Buglossoides tenuiflora*, *Heliotropium pterocarpum*, *Echium sericeum*, *Trichodesma pauciflorum*, *Microparacaryum intermedium*, *Trichodesma zylanicum*, *Heliotropium digynum* and *Trichodesma trichodesmoides*.

DISCUSSION

From the results obtained, we can notice that hair characters support the isolation of the genus *Ehretia* as proposed by Hutchinson (1948), as the species studied of this genus have glabrous leaves. Genera within the Boraginaceae are mostly hairy or even woolly, except *Paracaryum* which show close affinity to the genus *Ehretia* and met together in group 1. Group 3 has seven species, four of *Cordia*, one of *Brandella* and the other two species are of *Arnebia* and *Buglossoides*. This group gathers, mainly, species of subfamily Cordioideae with the exception of the latest two species. Meanwhile, group 4a has most of the *Heliotropium* species. This means that hair characters of the *Heliotropium* species have close affinity to each other and do not support the isolation of

the three subfamilies Ehretioideae, Heliotropoideae and Cordioideae from the Boraginaceae and gather them in a single family as proposed by Svenson (1925), Pal (1963), Di Fulvio (1978), Hilger (1989), Ferguson (1999) and Diane *et al.* (2002). Meanwhile this data show that species of the genus *Heliotropium* can be isolated as a unique group. Group 4b collect the rest of the *Heliotropium* species with other species of subfamily Boraginoideae. Group 2, in spite of being divided into three categories, it does not differentiate between the Boraginoideae species as all the three categories have species from the five tribes. These mean that taxa within family Boraginaceae do not show any sharp variations in their hair characters, except those with glabrous leaves, Ehretioideae.

Endress (2004) mentioned that glabrous plants are more primitive than hairy ones and within the hairy plants the simple, unicellular hairs considered less advanced than the multi-cellular or branched hairs. According to our data, we can postulate a line of evolution within the studied genera according to hair characters. Thus, we can put group 1, with glabrous plants, in one end of the line while the other end will be group 4a which characterize by densely hairy or even woolly leaves, with multi-cellular hairs and multi-cellular and one-layered basal cells and granulate or scaly hair walls. Accordingly, species separated in family Ehretiaceae can be considered the less advanced ones while those within subfamily

Boraginoideae are the more advanced species (Fig. 59). Within the Boraginoideae there are levels of evolution within the genera as well. This conclusion, partly, coordinate with that obtained by Taia and Shiha (1999) on the basis of pollen characters as they considered species of the Boraginoideae the more advanced ones within the family. Meanwhile the data obtained supports the taxonomic position of the family in a separate order. Boraginales as proposed by Takhtajan (1974) and Dahlgren (1989) classifications (Table 1).

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