

LEAF ANATOMICAL STUDY OF THE GENUS *AMYGDALUS* L. (ROSACEAE) IN IRAN AND ITS TAXONOMICAL IMPLICATION

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In this survey, leaf anatomy (midrib and blade) of 22 species and hybrids of the genus *Amygdalus* L. (*Rosaceae*) in Iran is studied. Regarding to vegetative form, the species of *Amygdalus* are distributed as four forms in Iran: trees, shrubs with brachyblast (short shoots), shrubs without brachyblast and spiny shrubs. Forty-one characters were measured and among them, some characters were variable and taxonomically valuable. The most important characters includes: presence or absence of hair and hair type on midrib and blade, length of adaxial and abaxial epidermal cells in midrib and blade, presence or absence of spongy parenchyma and its thickness, number of palisade parenchyma layers and their thickness, the angle between two halves of blade, midrib shape, ratio of midrib length/width, presence or absence of fiber around phloem in midrib and its thickness, presence or absence of internal phloem in midrib, ratio of xylem length/width and phloem length/width, adxial and abaxial collenchyma thickness in midrib and adaxial and abaxial parenchyma thickness in midrib. One of the special characters in leaf anatomy of *Amygdalus* is the density of palisade parenchyma layers and the absence of spongy parenchyma in leaf in most species that is related to semi-arid ecological conditions. While leaf anatomical features of the genus *Amygdalus* are relatively reliable in specific level, they are not useful in subgeneric or sectional level.

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Key words. *Amygdalus*, leaf anatomy, *Rosaceae* family, Iran.

مطالعه ساختار تشریحی برگ در گونه‌های جنس بادام از خانواده گل سرخ در ایران و کاربرد تاکسونومیک آن

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در این تحقیق، ساختار تشریحی برگ شامل رگبرگ میانی و پهنک در ۲۲ گونه و هیبرید از گونه‌های جنس بادام در ایران مورد مطالعه واقع شد. از نظر فرم رویشی گونه‌های بادام به چهار فرم درختی، درختچه‌ای دارای براکی بلاست (شاخه‌های کوتاه)، درختچه‌ای فاقد براکی بلاست و درختچه‌ای خاردار تقسیم می‌شوند. مجموع ۴۱ صفت تشریحی مشخص و بررسی شد که از میان آنها تنها برخی صفات متغیر و دارای ارزش تاکسونومیک بودند که مهم‌ترین آنها عبارتند از: وجود یا عدم وجود کرک و نوع آن در رگبرگ میانی و پهنک، طول سلولهای اپیدرمی فوقانی و تحتانی در رگبرگ و پهنک، وجود یا عدم وجود پاراننشیم اسفنجی و ضخامت آن، تعداد لایه‌های پاراننشیم نردبانی و ضخامت آن، زاویه دو بخش پهنک، شکل رگبرگ میانی، نسبت طول به عرض رگبرگ، وجود یا عدم وجود فیبر در اطراف بافت آبکش در رگبرگ میانی و ضخامت آن، وجود یا عدم وجود فلوئم داخلی و ضخامت آن، نسبت طول به عرض چوب و آبکش، ضخامت کلانشیم فوقانی و تحتانی در رگبرگ میانی و ضخامت پاراننشیم فوقانی و تحتانی در رگبرگ. از ویژگیهای خاص تشریحی در گونه‌های جنس بادام، می‌توان به تراکم لایه‌های پاراننشیم نردبانی و عدم حضور پاراننشیم اسفنجی در پهنک بیشترین تعداد گونه‌ها اشاره کرد که مربوط به شرایط اکولوژیک نیمه خشک می‌باشد. درحالی که صفات تشریحی برگ شواهد نسبتاً مناسبی برای جداسازی گونه‌ها در جنس بادام هستند، این صفات برای جداسازی زیر جنسها یا بخشها مفید نیستند و نتایج این مطالعه آناتومیکی نمی‌تواند طبقه‌بندی کلاسیک در سطح زیر جنس یا بخش را تایید نماید.

INTRODUCTION

Amygdalus L. is one of the most difficult genera in *Rosaceae*. It was placed in subfamily *Amygdaloideae* (Cronquist 1981, Takhtajan 1997). This genus has ca. 45 species in the world. The species of *Amygdalus* are distributed in Irano-Turanian region in SW Asia and Middle Asia and few species are seen in E Asia. *Amygdalus* species are found in different environmental conditions from southern slopes of Elburz mountain to northern slope of Makran mountain in south of Iran. According to Flora Iranica (Browicz 1969), *Amygdalus* has 15 species and two hybrids in Iran and on the basis of studies of Khatamsaz (1993), it includes 21 species and six hybrids. In Flora of Turkey (Browicz 1972), *Amygdalus* includes 12 species and in Flora of U. S. S. R. (Shishkin & Yuzepchuk, 1941), it has 16 species. *Amygdalus* has been divided into two subgenera: subgen. *Amygdalus* and subgen. *Dodecandra* (Browicz 1969). The first subgenus has two sections: sect. *Amygdalus* and sect. *Spartioides* but the second subgenus has not been divided to sections. The species of *Amygdalus* are deciduous trees or shrubs that morphologically are divided into four morphological or vegetative forms: Trees, shrubs with brachyblasts, shrubs without brachyblasts and spiny shrubs. They are adapted to semi-arid environments. They grow in mountainous areas in elevations ranging from 500 m in Elburz mt. to 3800 m in Taftan mt. in Iran. They are found on rocky mountains or rocky-stony or limestone slopes (Browicz & Zohary 1996). While in eastern botanist's publications, *Amygdalus* was considered as a single genus, in most of western botanist's classifications, *Amygdalus* has been considered as a subgenus or as a section in *Prunus*. For example, Bentham and Hooker (1865) classified *Amygdalus* as a section in *Prunus* and Rehder (1940) identified five subgenera in *Prunus* that one of them is subgen. *Amygdalus* (Lee & Wen 2001). Hitherto there is no comparative anatomical study on *Amygdalus* except in anatomy of dicotyledones (Metcalf & Chalk 1957). *Amygdalus* has many taxonomical problems, high variation in morphology and high degree of interspecific hybridization. Therefore, delimitation of taxa and species in this genus based on morphological characters is difficult. The aim of this study is to use anatomical analysis in the taxonomy of the genus *Amygdalus*.

MATERIAL AND METHODS

Numerous specimens of 22 species and hybrids of *Amygdalus* were collected from different localities of Iran. A list of voucher specimens is presented in Table 1. The matured fresh or herbarium leaves in

fruiting stage were selected and fixed in alcohol-glycerin (60:40) for until used. Hand cross sections were made from middle part of the blade with a razor. These sections were stained with methyl green and bismark brown and then photographed by different magnifications of light microscopy Olympus model Lika and Nikon camera model 200M in three treatments and the characters were measured with the aid of the Measurepro software.

RESULTS

In this study, 41 anatomical characters of leaf including two parts: blade and midrib were studied and measured for comparing the species. Among these characters, 13 characters in midrib and eight characters in blade were variable between studied species. The results of this anatomical study are presented in Tables 2 and 3.

Blade (T. S.)

Important blade anatomical characters in this study are including:

- 1- Hair and hair type: Five species are hairy on the epidermis including: *A. carduchorum*, *A. haussknechtii* var. *pubescens*, *A. kotschyi*, *A. orientalis* and *A. elaeagnifolia* subsp. *elaegnifolia* (Figs. 4c, 5c, 6c and 9a). Hair type is similar to the midrib hairs including simple and glandular hairs. The first four species have two hair types and *A. elaeagnifolia* subsp. *elaegnifolia* has only one type of hairs.
- 2- Epidermis: includes adaxial and abaxial epidermis. The length of adaxial epidermal cells varies from 8-11 μm to 65-74 μm and the length of abaxial epidermal cells is in the range of 4.5-7.5 μm to 23-45 μm .
- 3- Mesophyll: includes dorsiventral or isobilateral types. The features of mesophyll that are variable among the species are: number of palisade parenchyma layers, adaxially or abaxially and their thickness, number of spongy parenchyma layers, usually abaxially and its thickness and the angle between two halves of blade. As the species of *Amygdalus* grow in semi-arid conditions, the mesophyll consists of palisade parenchyma in both surfaces, except in one population of *A. lycioides* var. *lycioides* (Ghorveh population) that includes dorsiventral mesophyll (two parenchyma types: spongy and palisade). This species has spongy parenchyma in abaxial surface with 3 layers and 70 μm thickness (Fig. 17c). Other species have only palisade parenchyma, and the mesophyll type is isobilateral. The layers of adaxial palisade parenchyma varies from two to five layers and the thickness of this layers is in the range of 35 μm to 145 μm . Regarding to layers of abaxial palisade parenchyma, the number of layers varies from 2 to 6-7 layers (Figs. 5c, 10c, 13c, 17c, 19c

and 22c) and the thickness varies from 37 μm to 135 μm . The angle varies from 70° to 180°.

Midrib

The measured characters are including:

1- Hair and hair types: The species studied are: *A. carduchorum*, *A. haussknechtii* var. *pubescens*, *A. kotschyi*, *A. orientalis* and *A. elaeagnifolia* subsp. *elaegnifolia* (Figs. 4a-b-c, 5a-b-c, 6a-b-c and 9a-b-c). The first four species have two hair types: simple and glandular hairs but *A. elaeagnifolia* subsp. *elaegnifolia* has only one type of hairs (Fig. 9a).

2- Epidermis: includes adaxial and abaxial epidermis. Regarding to the length of adaxial epidermal cells, variation is from 5-10 to 33-40 μm and the length of abaxial epidermal cells varies from 3.5-4 μm to 14-18 μm .

3- Midrib shape varies from truncate in *A. eburnea* to truncate-triangular, triangular, suborbicular, orbicular and broad orbicular (Table 2). Ratio of midrib length/width varies from 0.54 to 1.8. Collenchyma tissue includes adaxial and abaxial. Adaxial collenchyma thickness varies from 23 μm to 120 μm . It is necessary to mention that *A. eburnea* lack any subepidermal collenchyma (Figs. 14a-b). Abaxial collenchyma thickness is in the range from 16 μm to 110 μm . Adaxial parenchyma thickness is in the range of 6.5 μm to 110 μm and the abaxial parenchyma thickness in the range of 12 μm to 100 μm . Except *A. orientalis*, *A. reticulata*, *A. elaeagnifolia* subsp. *elaegnifolia*, *A. glauca*, three populations of *A. scoparia* (Dasht-e Ardzan, Yasuj and Bushehr) and *A. × yasujensis* that are without protective tissue (fibre) around phloem (Figs. 5a-b, 8a-b, 9a-b, 12a-b and 22a-b), other species have protective tissue with different thickness from 40-45 to 13 μm . Also in *A. trichamygdalus* there are sclerenchyma and fibre tissues (Figs. 2a-b). Ratio of xylem length/width varies from 1.5 to 5.95 and the ratio of phloem length/width from 2.22 to 6.85. Except *A. trichamygdalus*, *A. orientalis*, *A. carduchorum*, *A. pabotii*, *A. elaeagnifolia* subsp. *leiocarpa*, *A. nairica*, *A. spinosissima* subsp. *turcomanica* and *A. lycioides* var. *lycioides* (Ghorveh) that lack internal phloem (Figs. 2a-b, 5a-b, 7a-b, 10a-b, 16a-b and 17a-b), other studied species have this tissue in various thickness from 6 to 38 μm .

DISCUSSION

In Flora Iranica (Browicz 1969), *Amygdalus* was classified into two subgenera: subgen. *Amygdalus* and subgen. *Dodecandra*. Only the former subgenus was divided into two sections: sect. *Amygdalus* (with 12 species, three species are tree and nine species are shrubs with brachyblast or short shoots) and sect.

Spartioides (with three junciform species without brachyblast). The second subgenus has not divided to sections and includes six spiny shrubby species. *Amygdalus* is one of the most problematic genera in *Rosaceae* and boundaries between species are not clear. This genus deals with high variation in morphological characters under different ecological conditions and high degree of hybridization, so delimitation of taxa in this genus is difficult based on morphological characters only. Other data sources including micromorphological studies, anatomical survey and molecular studies could help to distinguish the taxonomical relationships between species. Present research is the first study of leaf anatomy of the genus *Amygdalus* in Iran. The main aims of this research include: 1) detailed study on anatomical characters of leaf and 2) then using the anatomical results for taxonomical evaluation. Results of leaf anatomical study in *Amygdalus* showed variation among closely related species within the sections. Also there are not distinctive anatomical characters for separating of two subgenera from each other or two sections in the first subgenus. For example, according to Flora of Iran (*Rosaceae* family) (Khatamsaz 1992), two sections in the first subgenus are known morphologically close to each other in some characters including absence of spiny species, shape of hypanthium and number of stamens but mainly differ from each other as follows: Species in sect. *Amygdalus* have brachyblast whereas in sect. *Spartioides*, there is no brachyblast. Regarding to anatomical characters, there is enough heterogeneity in each section especially in sect. *Amygdalus* in different aspects including: midrib shape, presence or absence of hair, length of epidermal cells, adaxial and abaxial collenchyma thickness, parenchyma thickness, thickness of palisade parenchyma, number of layers and the angle between two halves of blade. For example, *A. carduchorum* and *A. pabotii* are morphologically closely related but anatomically, are completely different or *A. elaeagnifolia* and *A. reticulata*, as two closely related species from morphological point of view, show various anatomical characters in the midrib and blade. While two subgenera of *Amygdalus* differ morphologically specially in presence of thick spines and cylindrical shape of hypanthium in *Dodecandra*, based on anatomical characters, we couldn't find any reliable anatomical character for separating these two subgenera. In the second subgenus (subgen. *Dodecandra*), there are six spiny shrubby species. With emphasize to results of this study, it is clear that, from anatomical point of view, this subgenus shows variations regarding to some aspects including: midrib

Table 1. Voucher *Amygdalus* specimens used in this study.

Species	Herbarium number	Locality	Collector(s)
<i>A. communis</i> L.	36333 - TUH	Kurdistan: Kamiaran to Marivan, Takht zangi village, 1550 m	Attar, Maroufi & Zamani
<i>A. trichamygdalus</i> (Hand.-Mazz.) Woronow	36331 - TUH	Kurdistan: Kamiaran to Marivan, Takht zangi village, 1560 m	Attar, Maroufi & Zamani
<i>A. wendelboi</i> Freitag	5420 - TUH	Kerman: Bam, Mij, 1900-2100 m	Mirtadzadini
<i>A. korshinskyi</i> (Hand.-Mazz.) Bornm.	36337 - TUH	Kurdistan: Marivan to Paveh, Dezli pass, 1430-1500 m	Attar, Maroufi & Zamani
<i>A. fenzliana</i> (Fritsch) Lipsky	37214 - TUH	East Azerbaijan: After Kaleibar, 1450 m	Attar & Zamani
<i>A. haussknechtii</i> (C. K. Schneider) Bornm. var. <i>pubescens</i> Bornm.	36336 - TUH	Kurdistan: ca. 15 km to Kamiaran, Lineh pass, 1490 m	Attar, Maroufi & Zamani
<i>A. orientalis</i> Duh.	37231 - TUH	Kermanshah: 35 km to Eyvan-e Gharb, 1700-1750 m	Attar, Vafadar & Zamani
<i>A. kotschyi</i> Boiss. & Hohen.	36029 - TUH	Kurdistan: 20 km to Sanandaj from Marivan, 1780 m	Attar, Vafadar & Zamani
<i>A. carduchorum</i> Bornm.	37235 - TUH	Kurdistan: Kamyaran to Marivan, against Palangan village, 1650 m	Attar, Vafadar & Maroufi
<i>A. pabotii</i> Browicz	37227 - TUH	West Azerbaijan: Mahabad to Sardasht, Zamziran pass, 1670 m	Attar, Maroufi & Vafadar
<i>A. reticulata</i> Runemark ex Khatamsaz	20390 - TUH	Fars: Bamou National Park, 1750-1850 m	Attar, Khatamsaz & Sheikh
<i>A. elaeagnifolia</i> Spach subsp. <i>elaeagnifolia</i>	36282 - TUH	Fars: Pass after Dasht-e Ardzan, 2000 m	Attar & Zamani
<i>A. elaeagnifolia</i> Spach subsp. <i>leiocarpa</i>	36275 - TUH	Kohgiluyeh and Boyer Ahmad: 39 km to Yasuj from Ardakan, 1955 m	Attar & Zamani
<i>A. glauca</i> Browicz	36299 - TUH	Fars: Kotal Pir-e Zan, 1940 m	Attar & Zamani
<i>A. arabica</i> Oliv.	36328 - TUH	Kurdistan: Near Saghez, Dulkero village, 1630 m	Attar, Maroufi & Zamani
<i>A. scoparia</i> Spach	36285 - TUH	Fars: Dasht-e Ardzan, 2100 m	Attar & Zamani
<i>A. scoparia</i>	20326 - TUH	Kohgiluyeh and Boyer Ahmad: Yasuj, Dogonbadan to Choram, 900-1100 m	Ghahreman, Attar & Sheikh
<i>A. scoparia</i>	36106 - TUH	Esfahan: between Neyzar and Salafchegan, 1890 m	Attar & Zamani
<i>A. scoparia</i>	36382 - TUH	Bushehr: Asaluyeh, 820 m	Attar
<i>A. eburnea</i> Spach	8621 - TUH	Fars: road of Nourabad, 1640 m	Mobayen
<i>A. nairica</i> Fed.	37219 - TUH	East Azerbaijan: 17 km after Ahar to Tabriz, 1710 m	Attar & Zamani
<i>A. spinosissima</i> Bge. subsp. <i>spinosissima</i>	27289 - TUH	Khorassan: Mashhad to Torbat-e Heydariyeh, Robot-e Sang, 1780 m	Ghahreman, Attar, Okhovvat & Mehdigholi
<i>A. spinosissima</i> Bge. subsp. <i>turcomanica</i> (Lincz.) Browicz	37181 - TUH	North Khorassan: ca. 10 km to Bojnourd from Shirvan, 1000 m	Attar & Zamani
<i>A. lycioides</i> Spach var. <i>lycioides</i>	36320 - TUH	Kurdistan: Hamadan to Ghorveh, ca. 30 km to Ghorveh, 1730 m	Attar, Maroufi & Zamani
<i>A. lycioides</i> var. <i>lycioides</i>	36319 - TUH	Esfahan: Fereidoonshahr: Vahdatabad village, mt. Pishkooch, 2000 m	Attar & Zamani
<i>A. lycioides</i> var. <i>horrida</i> (Spach) Browicz	19425 - TUH	Tehran: Kiasman, mts. Fasham, 1930 m	Mobayen
<i>A. × keredjensis</i> Browicz	37351 - TUH	Tehran: Karaj, Koohdashteh, 1470 m	Vafadar
<i>A. × kamiaranensis</i> Khatamsaz & Assadi	36328 - TUH	Kurdistan: Kamiaran, 1510 m	Attar, Maroufi & Zamani
<i>A. × yasujensis</i> Khatamsaz	23470 - TUH	Kerman: 110 km SW Kerman, Gughar village, 2550 m	Mirtadzadini

Table 2. Important and useful anatomical characters of midrib in *Amygdalus* species.

Abbreviations. L/W M: length/width of midrib, L/W X: length/width of Xylem, L/W Ph: length/width of phloem, Ad. C. Th: adaxial collenchyma thickness, Ab. C. Th: abaxial collenchyma thickness, Ad. P. Th: adaxial parenchyma thickness, Ab. P. Th: abaxial parenchyma thickness, I. Ph. Th: internal phloem thickness, Ph. P. T. Th: phloem protective tissue thickness, Ad. E. Th: adaxial epidermis thickness, Ab. E. Th: abaxial epidermis thickness, H/H.T: hair/hair kind (S: simple, G: glandular), M. Sh: midrib shape.

Species	Midrib Characters												
	L/W M	L/W X	L/W Ph	Ad. C. Th (µm)	Ab. C. Th (µm)	Ad. P. Th (µm)	Ab. P. Th (µm)	I. Ph. Th (µm)	Ph. P. T. Th (µm)	Ad. E. Th (µm)	Ab. E. Th (µm)	H / H. T	M. Sh
<i>A. communis</i>	1.07	3.08	4.12	110-117	100	34	14	30	Fibre-30-33	12-17	14-18	-	suborbicular
<i>A. trichamygdalus</i>	0.88	1.92	2.73	65	67	32	62	-	Fibre-25-30	12-25	8-12	-	triangular
<i>A. wendelboi</i>	1.33	5.51	6.85	53	79	33	12	18-20	Fibre-15-30	11-20	8	-	suborbicular
<i>A. korshinskyi</i>	1.03	3	5	120	110	36	100	10	Fibre-30	13-15	7-8	-	suborbicular
<i>A. fenzliana</i>	0.83	3.43	4.33	62	65	36	84	10	Fibre-26	15-30	6-8	-	suborbicular
<i>A. haussknechtii</i> var. <i>pubescens</i>	0.9	2.89	3.57	65	60	32	50	13	Fibre-30	15-17	8-9	+ / S, G	suborbicular
<i>A. orientalis</i>	0.89	2.63	4	30	30-35	50	40-45	-	-	12-20	5	+ / S, G	suborbicular
<i>A. kotschyi</i>	1.19	5.95	5	110	100	110	81	8-10	Fibre-30	10-19	6-7	+ / S, G	suborbicular
<i>A. carduchorum</i>	0.91	2.37	4.44	46	60	49	80	-	Fibre-15-20	11-13	8-10	+ / S, G	suborbicular
<i>A. pabotii</i>	1.07	4.66	4.41	50	45	26	65	-	Fibre-13-16	13-14	5-6	-	orbicular
<i>A. reticulata</i>	0.94	2.35	5	93	71	25	15	7.8	-	33-40	11-13	-	triangular
<i>A. elaeagnifolia</i> subsp. <i>elaeagnifolia</i>	0.95	4	3.06	62	64	47	26	15	-	13-23	6-9	+ / S	broad orbicular
<i>A. elaeagnifolia</i> subsp. <i>leiocarpa</i>	1.3	3.1	4.5	30	20	35	40-45	-	Fibre-20-25	15-22	4-5	-	broad triangular
<i>A. glauca</i>	0.81	1.5	4.16	78	66	33	36	18	-	24-25	5-6	-	broad orbicular
<i>A. arabica</i>	0.62	2.1	2.53	55	60	19	29	15	Fibre-25-30	9-12	12-13	-	triangular
<i>A. scoparia</i> (Dasht-e Ardzan)	0.67	2.16	3.72	82	100	40	63	6	-	15-17	9-13	-	triangular
<i>A. scoparia</i> (Yasuj)	0.75	3.75	3.33	75	70	42	65	35-40	-	12-14	11	-	triangular
<i>A. scoparia</i> (Esfahan)	0.89	2.22	3.44	23	22	18	16	38	Fibre-25	10-14	3.5-4.5	-	triangular
<i>A. scoparia</i> (Bushehr)	0.65	2.96	4.44	90	16	23	47	15	-	10-20	4.5-7	-	broad triangular
<i>A. eburnea</i>	0.66	3.85	4.6	-	23	6.5	12	13	Fibre-12-17	8-15	3.5-6	-	truncate
<i>A. nairica</i>	1.03	3.11	4.32	60	58	23	63	-	Fibre-21	8-14	9	-	suborbicular
<i>A. spinosissima</i> subsp. <i>spinosissima</i>	1.8	1.58	3.04	40	88	14	41	13	Fibre-40-45	23-25	12-17	-	triangular
<i>A. spinosissima</i> subsp. <i>turcomanica</i>	1.7	2.5	3.71	36	30	30-35	40	-	Fibre-17-22	12-15	5-6	-	broad triangular
<i>A. lycioides</i> var. <i>lycioides</i> (Ghorveh)	0.56	2.64	2.22	73	54	14	23	-	Fibre-10-13	13-23	10-14	-	suborbicular
<i>A. lycioides</i> var. <i>lycioides</i> (Esfahan)	0.84	5	4.47	42-45	50	17	19	10	Fibre-25	16	5.5-9	-	broad triangular
<i>A. lycioides</i> var. <i>horrida</i> (Tehran)	1	3.84	6	40	32	13	28	25	Fibre-15	5-10	3.5-4	-	triangular
<i>A. × keredjensis</i>	0.54	2.39	3.42	67	85	25	31	15	Fibre-15	20-31	10-11	-	triangular
<i>A. × kamarianensis</i>	0.90	2.45	3.43	68	76	30	27	10-12	Fibre-13.1	15-17	13-14	-	triangular
<i>A. × yasujensis</i>	0.6	2.5	2.88	68	50	33	21	25	-	25-35	5-10	-	triangular

Table 3. Important and useful anatomical characters of blade for distinguishing of *Amygdalus* species. Abbreviations. Ad. E. Th: adaxial epidermis thickness, Ab. E. Th: abaxial epidermis thickness, P. L/ P. Th: palisade parenchyma layers / palisade thickness, S. L/ S. Th: spongy parenchyma layers / spongy thickness, H/H.T: hair/hair kind (S: simple, G: glandular), A: angle between two halves of blade.

Speies	Blade					
	Ad. E. Th (μm)	Ab. E. Th (μm)	P. L/ P. Th (μm)	S. L/ S. Th(μm)	H / H. T	A
<i>A. communis</i>	20-35	8.5-16	3 - (3-4) / 85 - (75-80)	-	-	130°
<i>A. trichamygdalus</i>	15-24	20-26	3 - (3-4) / 90 - (85-90)	-	-	180°
<i>A. wendelboi</i>	30-33	17-20	3 - 5 / 80 - 70	-	-	145°
<i>A. korshinskyi</i>	22-31	12-13	3 - 3 100 - 80	-	-	135°
<i>A. fenzliana</i>	12-25	10-18	3 - 4 / 75 - 70	-	-	160°
<i>A. haussknechtii</i> var. <i>pubescens</i>	13-15	13	3 - 3 / 65 - 60	-	+ / S, G	170°
<i>A. orientalis</i>	20-23	13-20	(4-5) - (6-7) / 80 - 85	-	+ / S, G	120°
<i>A. kotschy</i>	22-24	24-37	(4-5) - (4-5) / (80-90) - (80-90)	-	+ / S, G	130°
<i>A. carduchorum</i>	13-14	9-16	2 - 3 / 40 - 42	-	+ / S, G	150°
<i>A. pabotii</i>	12-16	10-19	3 - 3 / 35 - 37	-	-	90°
<i>A. reticulata</i>	65-74	10-25	4 - 4 / 88 - 90	-	-	145°
<i>A. elaeagnifolia</i> subsp. <i>elaeagnifolia</i>	17-18	13-18	(3-4) - (5-6) / 90 - 100	-	+ / S	155°
<i>A. elaeagnifolia</i> subsp. <i>leiocarpa</i>	12-19	10-18	(4-5) - (6-7) / 100 - 80	-	-	115°
<i>A. glauca</i>	30-43	7.5-16	3 - (5-6) / 100 - 107	-	-	150°
<i>A. arabica</i>	23-26	12-25	3 - 3 / 75 - 77	-	-	155°
<i>A. scoparia</i> (Dasht-e Ardzan)	25-43	11-19	3 - (3-4) / 97 - 86	-	-	170°
<i>A. scoparia</i> (Yasuj)	32-50	11-14	3 - 5 / 145 - 115	-	-	170°
<i>A. scoparia</i> (Esfahan)	15-24	5-9	(3-4) - (6-7) / 75 - 66	-	-	135°
<i>A. scoparia</i> (Bushehr)	17-24	4.5-7.5	(4-5) - (4-5) / 95 - 80	-	-	175°
<i>A. eburnea</i>	13-16	8-12	(3-4) - (4-5) / 61 - 70	-	-	180°
<i>A. nairica</i>	23-25	12-21	3 - 3 / 74 - 68	-	-	130°
<i>A. spinosissima</i> subsp. <i>spinosissima</i>	24-32	15-28	3 - (4-5) / 110 - 135	-	-	160°
<i>A. spinosissima</i> subsp. <i>tuomanica</i>	10-20	8-15	(3-4) - (4-5) / 120 - 100	-	-	180°
<i>A. lycioides</i> var. <i>lycioides</i> (Ghorveh)	8-11	10-11	2 / 60	3 / 70	-	70°
<i>A. lycioides</i> var. <i>lycioides</i> (Esfahan)	17	12-13	4 - (5-6) / 68 - 62	-	-	175°
<i>A. lycioides</i> var. <i>horrida</i> (Tehran)	16-29	17-26	(4-5) - 2 / 95 - 105	-	-	160°
<i>A. × keredjensis</i>	15-28	9.5-16	3 - (4-5) / 110 - 103	-	-	170°
<i>A. × kamiaranensis</i>	34-43	23-45	4 - (3-4) / 100 - 110	-	-	170°
<i>A. × yasujensis</i>	21-32	8-23	5 - (4-5) / 110 - 97	-	-	120°

shape, ratio of midrib length/width, protective tissue in midrib, collenchyma thickness, the angle between two halves of blade and palisade parenchyma thickness. Also, one variety of *A. lycioides* (var. *lycioides*, Ghorveh population) includes dorsiventral mesophyll that is not observed in another variety of this species or in whole studied species. Consequently, anatomical data did not provide sufficient characters for taxonomic separating of subgenera or sections and couldn't confirm classic classification of *Amygdalus* based on Browicz (1969) and Khatamsaz (1992). *Amygdalus* species are distributed in semi-arid and arid environments in Iran, so they show anatomical characters of xerophyte's plants (Zarinkamar 1993, Zarinkamar & Dinarvand 2006). For example they include palisade parenchyma in both surfaces of blade (isobilateral mesophyll). In five studied species, we observed hair on the surface of epidermis in the midrib and in the blade. Because there is not any anatomical study about *Amygdalus* species in Iran and in the world, we should refer to anatomical features of the closest genus to *Amygdalus* that is *Prunus*. Also in most western botanist's classifications, *Amygdalus* is considered as a subgenus or as a section in *Prunus* (Lee and Wen 2001). As mentioned in Metclafe and Chalk (1957), the mesophyll in *Prunus* consists of two or more palisade layers. In *Amygdalus*, the number of palisade layers is in the range from two to five in adaxial surface and three to six-seven in abaxial surface.

In the first subgenus and first section (sect. *Amygdalus*), 12 species are included. The common morphological character of species in this section is the presence of brachyblast (short shoots). There is not any spiny species in this section but some species have more or less thin spines. Also the shape of hypanthium is campanulate. In this section, three species have tree habit include: *Amygdalus communis*, *A. trichamygdalus* and *A. wendelboi*. The height of these trees is in the range of 4-8 m. Nine species are shrubby species include: *A. fenzliana*, *A. korshinskyi*, *A. haussknechtii*, *A. orientalis*, *A. kotschyi*, *A. carduchorum*, *A. pabotii*, *A. elaeagnifolia* with two subspecies and *A. reticulata*. The height of these shrubs is in the range of 0.5-4 m. The first two tree species are distributed in W and NW Iran but *A. wendelboi* is found very far from two other related species in S Iran. According to results of this anatomical study, in some midrib characters including: ratio of midrib length/width, ratio of xylem length/width, ratio of phloem length/width, adaxial and abaxial collenchyma thickness, abaxial parenchyma thickness, internal phloem and midrib shape, these tree species are different from each other (Table 2) (Figs. 1a-b, 2a-b).

Regarding to blade characters, these species are distinguished by the following characters: the angle between two halves of blade and length of adaxial and abaxial epidermal cells (Table 3) (Figs. 1c, 2c).

Many shrubby species in sect. *Amygdalus* are distributed in W and NW Iran (seven species including: *A. fenzliana*, *A. korshinskyi*, *A. haussknechtii* var. *pubescens*, *A. orientalis*, *A. kotschyi*, *A. carduchorum* and *A. pabotii*) and two species are distributed in C and S Iran (*A. elaeagnifolia* with two subspecies and *A. reticulata*). Among these shrubby species, in *A. haussknechtii* var. *pubescens*, *A. orientalis*, *A. kotschyi*, *A. carduchorum* and *A. elaeagnifolia* subsp. *elaeagnifolia*, leaf surface is hairy (Figs. 4a-b-c, 5a-b-c, 6a-b-c and 9a-b). The density of hairs in *A. kotschyi* and *A. orientalis* is more than the other species. Also in *A. orientalis*, annual shoots are covered with dense short and white hairs. In *A. reticulata* that is distributed in limited area in Fars province, a special feature is observed. The length of adaxial epidermal cells in both midrib and blade is largest among all studied species, 33-40 μm (Figs. 8a-b-c). In this species, many crystals are seen in the mesophyll. Our results showed enough variation and heterogeneity among shrubby species in this section. Midrib shape, length of epidermal cells, presence or absence of protective tissue and internal phloem in midrib, thickness of collenchyma and parenchyma, angle between two halves of the blade and thickness of palisade parenchyma are variable anatomical characters among shrubby species in sect. *Amygdalus* (Tables 2, 3) (Figs. 3a-b-c, 4a-b-c, 5a-b-c, 6a-b-c, 7a-b-c, 8a-b-c and 9a-b-c). Our results showed that two subspecies of *A. elaeagnifolia* are different from each other in some anatomical characters such as: midrib shape, angle, number of palisade parenchyma layers and presence or absence of hair and presence or absence of fiber (Figs. 9a-b-c, 10a-b-c).

In sect. *Spartioides*, there are three junciform shrubby species including: *A. scoparia*, *A. glauca* and *A. arabica*. The main vegetative feature of these three species is the lack of brachyblasts. *A. scoparia* is one of the most widespread species of *Amygdalus* in Iran. *A. glauca* is distributed in a limited area in Fars province and *A. arabica* is distributed in W Iran especially in Kurdistan province. *A. scoparia* was studied for anatomy at population level. Midrib shape, presence or absence of protective tissue around phloem, thickness of collenchyma and parenchyma and the thickness of palisade parenchyma in blade are anatomical characters that show variation in this section (Figs. 11a-b-c, 12a-b-c, 13a-b-c). Different populations of *A. scoparia* show more or less differences in midrib and blade anatomical characters, especially in protective tissue around phloem, internal phloem thickness, adaxial and

abaxial collenchyma and parenchyma thickness and adaxial and abaxial palisade parenchyma thickness.

In subgen. *Dodecandra*, there is one group of species, spiny shrubs. *A. eburnea* in S and E Iran, *A. nairica* in NW Iran, *A. spinosissima* with two subspecies in E and NE Iran and *A. lycioides* with two varieties in many different localities in Iran as a widespread species. The last species was studied for anatomy at population level. Variable anatomical characters in this subgenus include: midrib shape, protective tissue around phloem, thickness of collenchyma and parenchyma and thickness of palisade parenchyma in blade (14a-b-c, 15a-b-c, 16a-b-c, 17a-b-c, 18a-b-c, 19a-b-c). In *A. lycioides* var. *lycioides* (Ghorveh population), we observed special anatomical feature. The mesophyll is dorsiventral includes palisade and spongy parenchyma (Fig. 17c). *A. spinosissima* subsp. *spinosissima* has a special state among the species in this subgenus, it has more fiber than other species with 40-45 μm thickness (Figs. 15a-b). Also *A. eburnea* lack adaxial collenchyma in midrib and the palisade parenchyma has penetrated from mesophyll in blade above the xylem (Figs. 14a-b). Two subspecies of *A. spinosissima* have more or less differences in midrib and blade anatomical characters and among different populations of *A. lycioides*, Ghorveh population is different from the two other populations.

Three hybrids of *Amygdalus* were studied in this research include: *A. × keredjensis*, *A. × kamiaranensis* and *A. × yasujensis*. The first hybrid is distributed in southern slope of mt. Elburz in the north of Iran, the second in W Iran and the third in C, C-W Iran. From anatomical point of view, presence or absence of protective tissue around phloem, ratio of length/width in midrib, thickness of collenchyma, angle in blade and thickness of palisade parenchyma are variable characters among studied hybrids (Figs. 20a-bc, 21a-b-c, 22a-b-c). Our results showed that *A. × yasujensis* is more different from the other two hybrids.

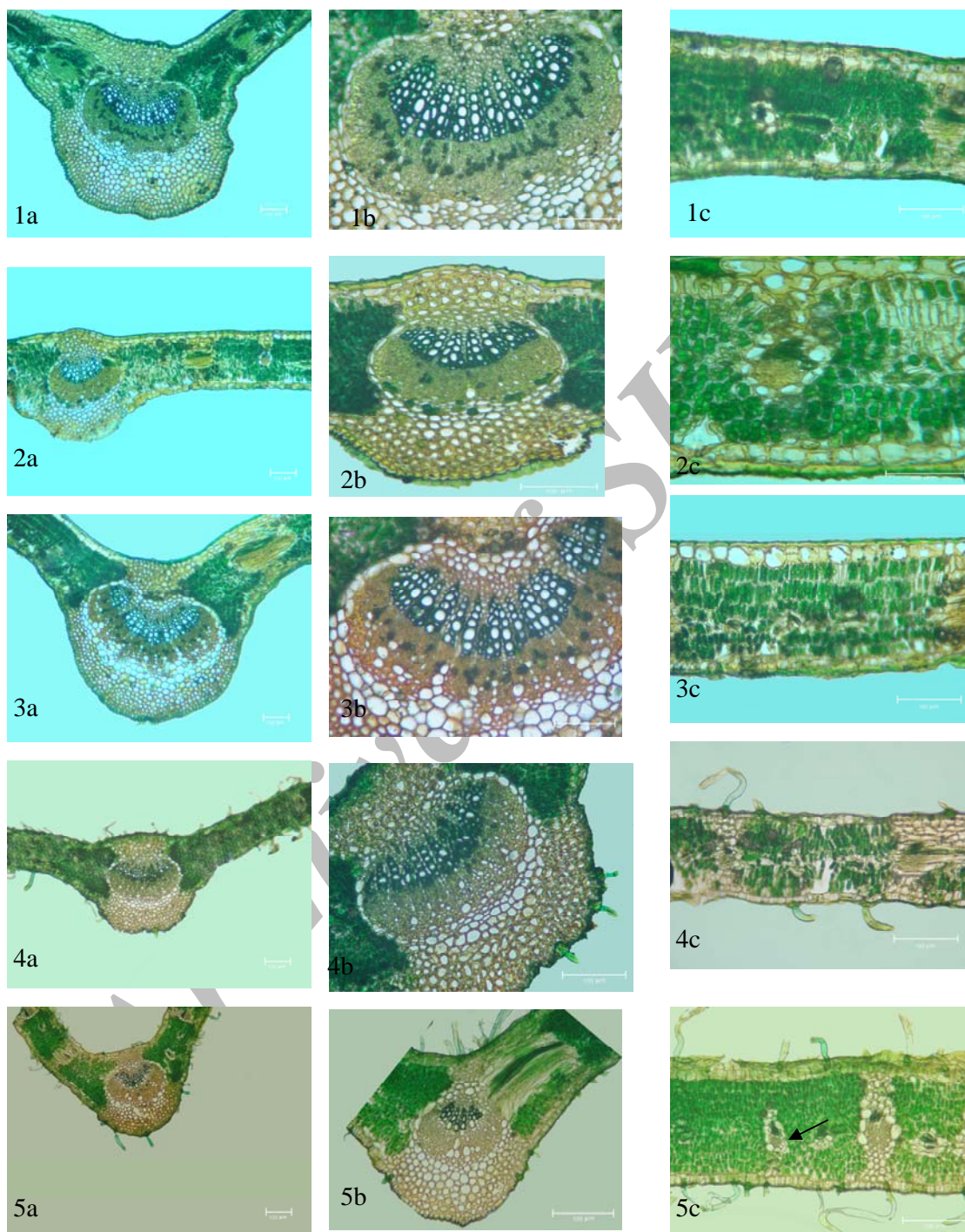
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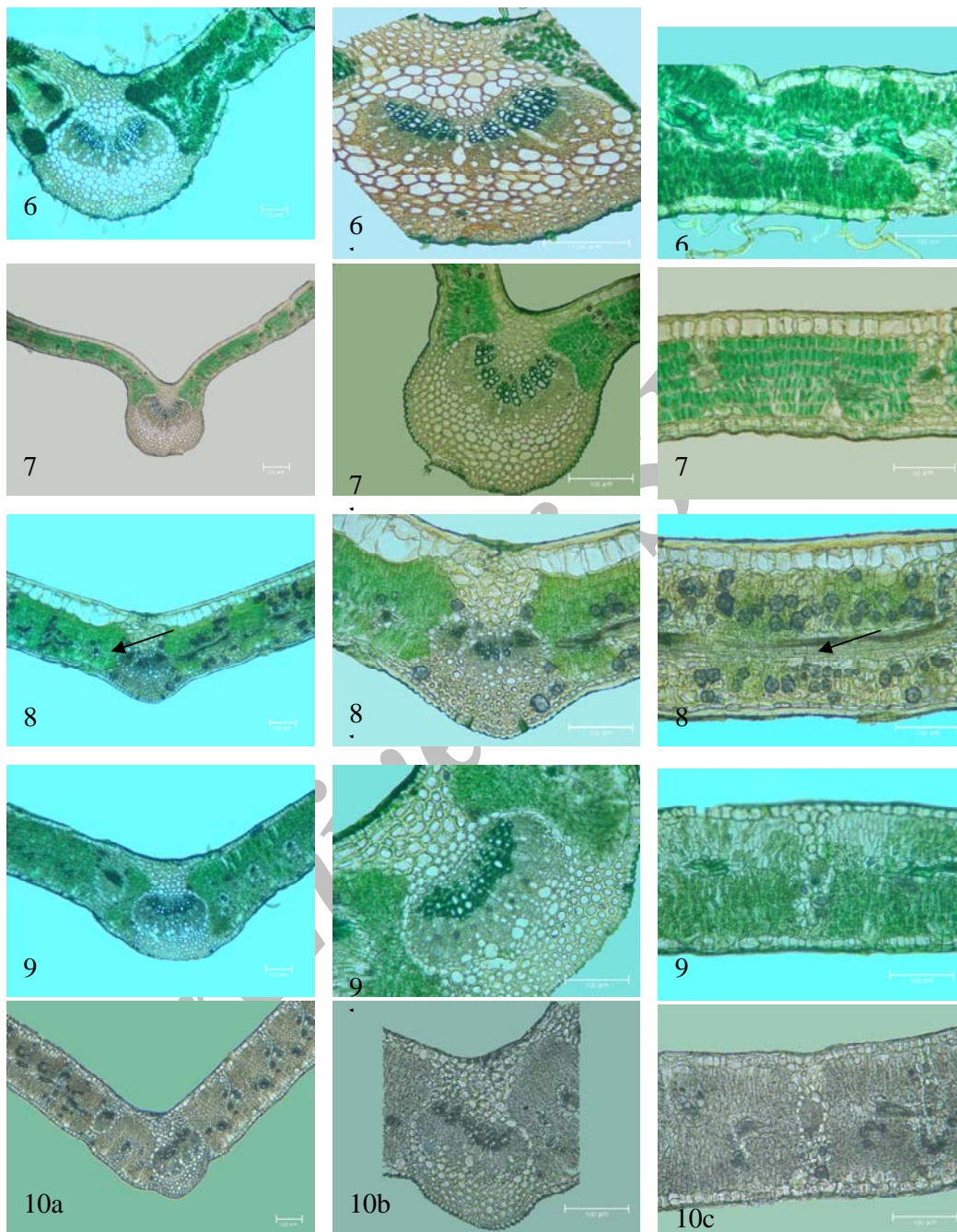
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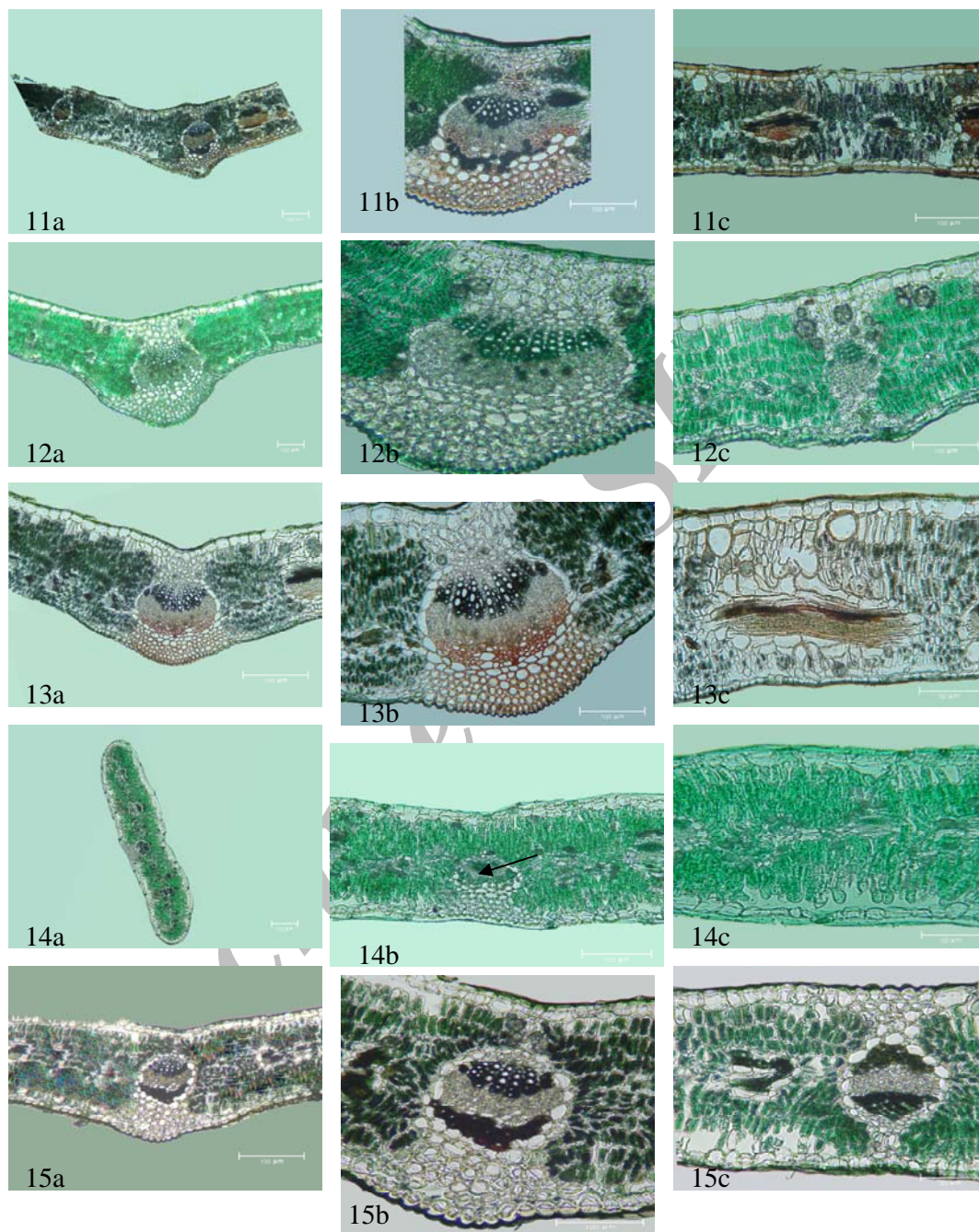
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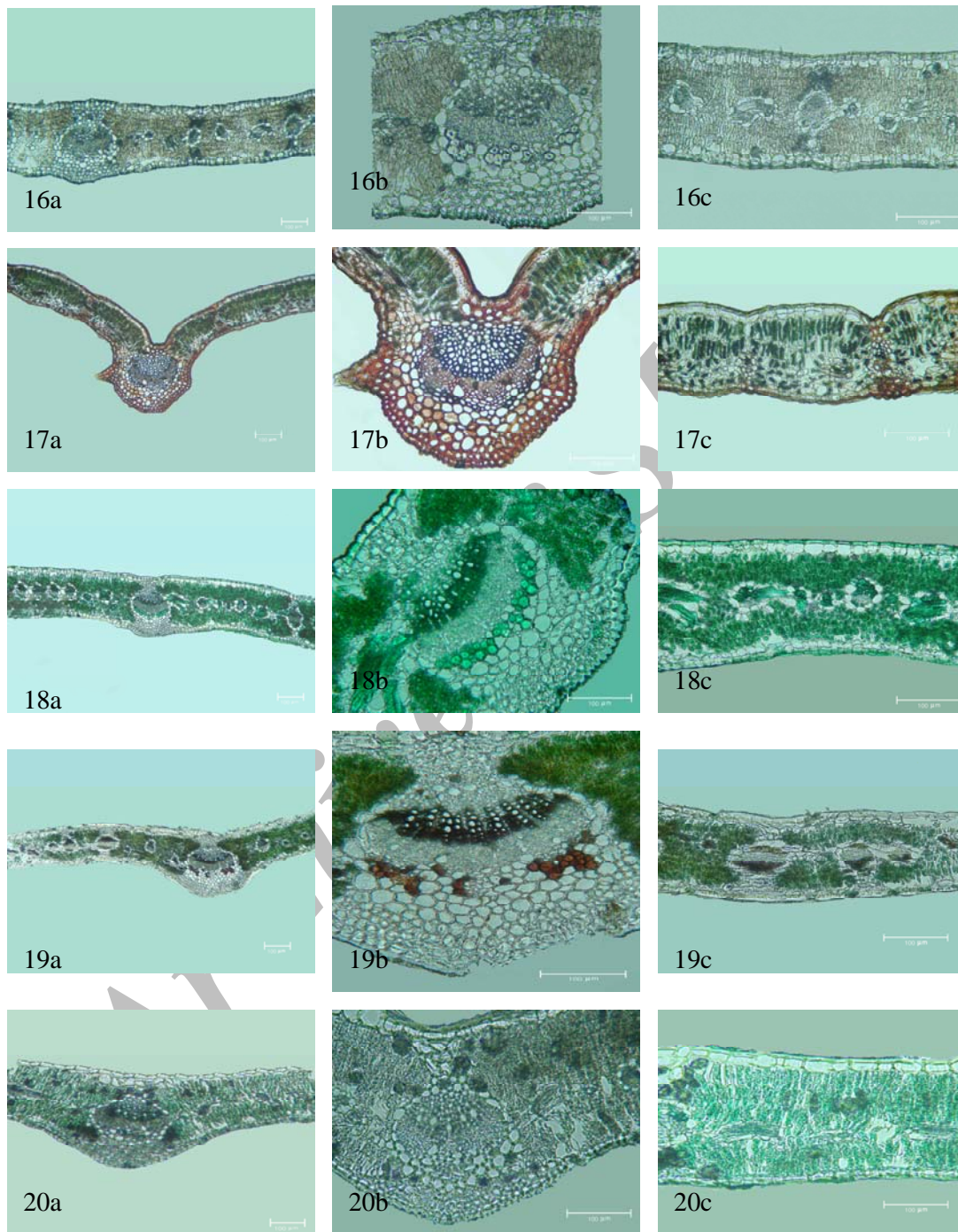
Figs. 1-5. Transversal sections of leaf of Iranian species of *Amygdalus*. The midrib (figs. A-b) includes: epidermis, with or without hair, collenchyma, parenchyma, protective tissue and vascular tissues. The blade (fig. c) includes: epidermis, with or without hair and mesophyll with palisade parenchyma in adaxial and abaxial surfaces. 1a-b-c: *A. communis*, 2a-b-c: *A. trichamygdalus*, 3a-b-c: *A. korshinskyi*, 4a-b-c: *A. haussknechtii* var. *pubescens*, 5a-b-c: *A. orientalis* (dense adaxial palisade parenchyma is shown.).



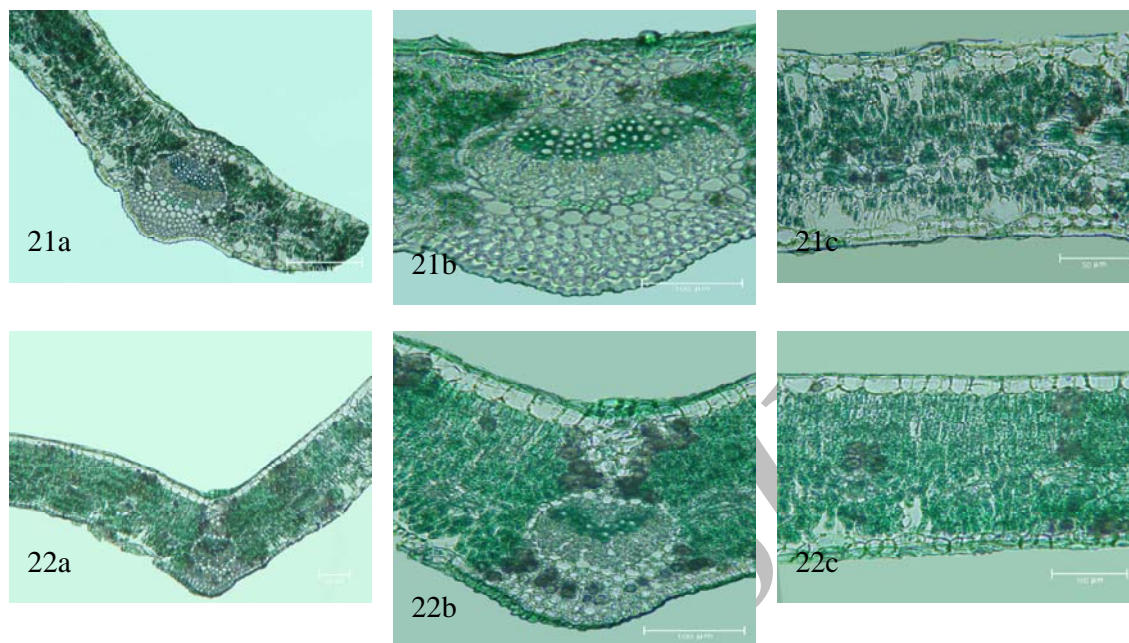
Figs. 6-10. Transversal sections of leaf of Iranian species of *Amygdalus* species. The midrib (figs. a-b) includes: epidermis, with or without hair, collenchyma, parenchyma, protective tissue and vascular tissues. The blade (fig. c) includes: epidermis, with or without hair and mesophyll with palisade parenchyma in adaxial and abaxial surfaces. 6a-b-c: *A. kotschyi*, 7a-b-c: *A. pabotii*, 8a-b-c: *A. reticulata* (large epidermal cells and numerous crystals in blade are shown.), 9a-b-c: *A. elaeagnifolia* subsp. *elaegnifolia*, 10a-b-c: *A. elaeagnifolia* subsp. *leiocarpa*.



Figs. 11-15. Transversal sections of leaf of Iranian species of *Amygdalus*. The midrib (figs. a-b) includes: epidermis, with or without hair, collenchyma, parenchyma, protective tissue and vascular tissues. The blade (fig.c) includes: epidermis, with or without hair and mesophyll with palisade parenchyma in adaxial and abaxial surfaces. 11a-b-c: *A. arabica*, 12a-b-c: *A. scoparia* (Dasht-e Ardzan)), 13a-b-c: *A. scoparia*(Esfahan), 14a-b-c: *A. eburnea* (absence of adaxial collenchyma and the penetration of palisade parenchyma, 15a-b-c: *A. spinosissima* subsp. *spinosissima* (dense fibre).



Figs. 16-20. Transversal sections of leaf of Iranian species of *Amygdalus*. The midrib (figs. a-b) includes: epidermis, with or without hair, collenchyma, parenchyma, protective tissue and vascular tissues. The blade (fig.c) includes: epidermis, with or without hair and mesophyll with palisade parenchyma in adaxial and abaxial surfaces. 16a-b-c: *A. spinosissima* subsp. *turcomanica*, 17a-b-c: *A. lycioides* (Ghorveh) (dorsiventral type of mesophyll), 18a-b-c: *A. lycioides* (Esfahan) (fibre), 19a-b-c: *A. lycioides* (Tehran), 20a-b-c: *A. × keredjensis*.



Figs. 21-22. Transversal sections of leaf of Iranian species of *Amygdalus*. The midrib (figs. a-b) includes: epidermis, with or without hair, collenchyma, parenchyma, protective tissue and vascular tissues. The blade (fig.c) includes: epidermis, with or without hair and mesophyll with palisade parenchyma in adaxial and abaxial surfaces. 21a-b-c: *A. × kamiaranensis*, 22a-b-c: *A. × yasujensis*.

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