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یافته‌های نوین در علوم زیستی
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اهمیت آرایه شناسی صفات ریختی در گل گندم (تیره کاسنیان)

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چکیده. ریخت‌شناسی فندقه در *Centaurea* در ۴۹ آرایه مطالعه شده است. در این بررسی برای جداسازی بخش‌ها، ۱۹ صفت تشخیصی ارائه شده است. بر اساس این صفات بعضی بخش‌ها، مانند بخش *Cyanus* با داشتن ناف کرک‌دار از بقیه بخش‌ها جدا می‌شوند. با وجود اختلافات زیاد، *C. leuzeoides* و *C. gilanica* در بخش *Psephelloideae* قرار گرفتند، که بخشی شامل گونه‌های با تفاوت‌های زیاد است. همچنین *C. albonitens* در مقایسه با سایر گونه‌های بخش *Phaeopappus* از ویژگی‌های متفاوتی برخوردار است، به عنوان مثال ویژگی‌هایی مانند رنگ پاپوس و نسبت طول پاپوس به طول فندقه از سایر گونه‌های بخش جدا شده است. همچنین در بخش *Cynaroides* اختلافات زیادی در صفات ریختی گونه *C. phlomoides* در مقایسه با دیگر گونه‌های *Centaurea* مشاهده شد. این گونه بر اساس صفاتی چون پاپوس کوتاه و طول ناف از بقیه گونه‌های این بخش جدا می‌شود. بنابراین، براساس یافته‌های این تحقیق، صفات ریختی فندقه فقط می‌توانند برای جدایی آرایه‌ها در سطح گونه مورد استفاده قرار گیرند. در این مقاله، کلید شناسایی بخش‌ها و همچنین عکس‌های فندقه در آرایه‌های انتخابی ارائه شده است.

واژه‌های کلیدی. ایران، پاپوس، فلورا ایرانیکا، کلیدشناسایی، مرکبان

Taxonomic significance of achene morphology in the genus *Centaurea* L. (Asteraceae)

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Abstract. Achene morphology of 49 taxa of the genus *Centaurea* L. was studied in terms of 19 different characteristics. On the basis of the variation in these features, some sections, such as sect. *Cyanus* with hairy hilum, were separated. Despite various differences, *C. leuzeoides and C. gilanica* were categorized in the section *Psephelloideae*, a section with lots of character variations within its species. Also, *C. albonitens* has different characteristics in comparison with other taxa within section *Phaeopappus*, for example features such as pappus color and the ratio of pappus length to that of achene separated the species from other members of the section. The last but not the least, highly different characteristics were observed in the achene morphology of *C. phlomoides* as compared with other species in section *Cynaroides*. Differences such as short pappus and hilum length were found to separate *C. phlomoides* from other members of sect. *Cynaroides*. In conclusion, on the basis of the findings of this research, most achene morphological characteristics can be appropriately used as key features for the differentiation of sections in the genus *Centaurea*. An identification key based on the features of the achene, images related to the achene of the studied species were also presented.

Keywords. Compositae, Flora Iranica, identification key, Iran, pappus

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INTRODUCTION

Centaurea L. (Asteraceae), with 350 to 600 species of herbaceous thistle-like plants in the world (Heywood, 1979; Hickey & King, 1981), is found only in the North of the equator, mostly in the Eastern hemisphere. The Middle-East and its surrounding regions are particularly species-rich with regard to the genus *Centaurea* (Davis *et al.*, 1988; Wagenitz, 1980). This genus belongs to subtribe *Centaurinae*, Tribe *Cardueae*, subfamily *Carduoideae* and family Asteraceae (Judd *et al.*, 2008; Bremer *et al.*, 2009). Based on Flora Iranica (Wagenitz, 1980), *Centaurea*, with 88 species in the Iranian plateau, is divided into 28 sections. The infrageneric classifications of the genus *Centaurea* were mainly based on features such as plant duration, characteristics of involucres (shape of phyllaries, cilias, terminal spine tipped or non spine tipped of bracts), and color of florets and position of leaves. Moreover, flower colors and heights were the other criteria considered to be taxonomically important. *Centaurea* is one of the largest genera in Iran with almost 89 species, of which 76 species are endemic (Wagenitz, 1980; Ghahreman & Attar, 1999; Shabestari *et al.*, 2013a, 2013b; Negaresh *et al.*, 2014). This genus is a bushy plant with ciliate (*C. depressa* M.Bieb.) or spiny (*C. kandavanensis* Wagenitz) phyllaries with white, yellow, pink or purple flowers. Some phyllaries overlapped in several rows, with tips variously spiny or mucronate and margins pinnate or entire. The stems of the plants are long and erect (*C. cheiranthifolia* Willd.), rarely acaulescent (*C. rhizantha* Tchich.), short (*C. aucheri* (DC.) Wagenitz) or prostrate (*C. incanescens* (DC.) Sch.Bip.). Leaves are entire, pinnatifid, pinnatisect, with different shapes, and are covered with gray hairs (gray-tomentose), rarely dense arachnoid (*C. luristanica* Rech.f.) or glabrous (*C. koeieana* Bornm.). Achenes are oblong, rarely triangular, 2.5-3.5 mm long, with apex flattened, tapered to a rounded, having a laterally notched base. Pappus are often white (colorful pappus is an exception, as seen in some species like *C. aucheri*), composed of unequal, stiff, minutely barbellate or tiny, flat scales (Fig. 1) (Wagenitz, 1980). As it was mentioned before, the achene characteristics have not been studied thoroughly, or rarely considered to be taxonomically important (Maleev, 1971; Boissier, 1875; Wagenitz, 1975, 1980; Shabestari *et al.*, 2013a, 2013b; Bona, 2014; Negaresh *et al.*, 2014; Ranjbar & Negaresh, 2014). In this paper, achene variation in 49 taxa (44 species and 5 subspecies) belonging to 24 sections was investigated. The criteria were highly focused on the achene and pappus characteristics, and the study has been concluded with achene-based identification key for the sections of the genus *Centaurea*.

MATERIALS & METHODS

Achenes of 44 species and five subspecies of 24 sections belonging to the genus *Centaurea* were collected from specimens preserved in the Central Herbarium of Tehran University (TUH), as shown in Table 1. The sections *Phalolepis* (Cass.) DC., *Grossheimia* (Sosn. & Takht.) Dittrich and *Czerniakovskya* (Czerep.) Wagenitz have been excluded from the study, since no proper specimens of these sections were available.

Then, achenes were studied and photos were taken by means of a Dinolite hand-held digital microscope with a magnification of 180x.

In order to investigate the characteristics of achene in the specimens studied, 19 criteria were sorted out. The selected characteristics included features such as appendage length and color, hilum length, achene length, pappus-achene connection length, color and shape of achene, pappus and inner pappus type, and ratio of the length of pappus to that of achene. The complete list of the characteristics studied is presented in Table 2.

RESULTS

As it is shown in Tables 2 and 3, 19 criteria were taken into consideration in characterizing and sorting out the differences among the 49 taxa studied (44 species and 5 subspecies). Some of these characteristics and their importance are explained below.

- Appendage of hilum: the first and the most important characteristic key which separates the taxa studied into two main parts, based on whether they have appendiculate hilum or exappendiculate hilum.
- Color of appendage: section *Stizolophus* (Cass.) DC. (*C. balsamita* Lam.) becomes distinct by red-brown appendage among all other sections.
- Achene's shape: it varies among the taxa studied; some are oblong (*C. behen* Lam.), fusiform (*C. amadanensis* Sch.Bip.) or urceolate (*C. kotschyi* (Boiss.) Hayek), while others are triangular (*C. glastifolia* L.), elliptic (*C. geluensis* Boiss. & Hausskn. ex Boiss.) or rectangular (*C. gaubae* (Bornm.) Wagenitz).
- Achene's size: most of the taxa studied have normal size (2.5-3.5 mm long), while some can be seen in inflated form, for example *C. zuvandica* (Sosn.) Sosn. in sect. *Psephellus* (Cass.) DC. and *C. incanescens* (Fisch. & C.A.Mey. ex DC.) Sosn. in sect. *Amblyopogon* Fisch. & C.A.Mey. ex DC.

Fig 1. Different types of achene and pappus. **A.** *Centaurea balsamita* subsp. *kermanensis* (Bornm.) Wagenitz. **B.** *C. iberica* Trevir. ex Spreng. **C.** *C. luristanica* Rech.f. **D.** *C. ustulata* DC. **E.** *C. albonitens* Turrill, **F.** *C. leuzeoides* Walp.

- Pappus length: pappus are shorter than the achene in the first group (*C. phlomoides* Boiss. & Hausskn. ex Boiss.), while in the second group the pappus are longer than the achene (*C. luristanica*), and in the third group the lengths of achene and pappus are equal (*C. bruguierana* Hand.-Mazz.). Differences in pappus length among different sections as well as within certain sections is also observed (*C. iberica* and

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Table 1. Voucher specimens used in achene characterization.

Species	Locality	Height (m)	Collector & Herbarium nummber
Centaurea lachnopus Rech.f.	Semnan: ca 15 from Semnan to Firouz kuh	1130	Ghahreman, Mozaffarian 5822 (TUH)
C. balsamita subsp. *balsamita* Lam.	Golestan: Golestan National Park	s.n.	Ghahreman, Mozaffarian, Attar 25438 (TUH)
C. balsamia subsp. *balsamita* Lam.	Azarbayejan: Marand to Evoghli, Kushksary to Erelan	1360	Ghahreman, Mozaffarian 9747 (TUH)
C. balamita subsp. *balsamia* Lam.	Azarbayejan; Urmieh, Balanesh	1350	Ghahreman, Attar 21319 (TUH)
C. balsamita subsp. *balsamita* Lam.	Kermanshah: 40 km, to Paveh	1550	Attar, Dadjou, Mehdigholi, Okhovat 14237 (TUH)
C. balsamita subsp. *kermanensis* (Bornm.) Wagenitz	Khorasan: Neishabour road, Mt. Binaloud Kouh	1250	Ghahreman, Attar 21916 (TUH)
C. balsamita subsp. *kermanensis* (Bornm.) Wagenitz	Fars: Shiraz, Psargad	1845	Ghahreman, Attar 22515 (TUH)
C. aggregata Fisch. & C.A.Mey.	Kermanshah: 5 km after Paveh to Nasoud	1550	Ghahreman, Attar, Mehdigholi 22376 (TUH)
C. aggregata Fisch. & C.A.Mey.	Kermanshah: 50 km Paveh	1550	Ghahreman, Attar 21202 (TUH)
C. aggregata Fisch. & C.A.Mey.	Kordestan: Ghorv: to Sanandaj: 45 km to Sanandaj	1500	Ghahreman, Attar 19647 (TUH)
C. aggregata Fisch. & C.A.Mey.	Kordestan: Marivan to Sanandaj from old road Gardane Geran	1320	Ghahreman, Mozaffarian 18303 (TUH)
C. ovina Pall. ex Willd.	Azarbayejan: Ardebil, 10 km to Ahar	1370	Attar, Dadjou 17237 (TUH)
C. ovina Pall. ex Willd.	Azarbayejan: Ardebil to Germi, 10 km to Germi	1860	Attar, Dadjou 14679 (TUH)
C. ammocyanus Boiss.	Alborz: Near Hashtgerd, 30 km WD Karaj	1250	Esfandiari 11445-TUH
C. pulchella Ledeb.	Azarbayejan: Tabriz on the road to Lighvan	2280	Ghahreman, Mozaffarian 17376 (TUH)
C. pulchella Ledeb.	Khorasan: mt. Kashmar	1060	Ghahreman, Attar 27324 (TUH)
C. hyrcanica Bornm.	Mazandaran: Nowshahr, Kheiroud forest	20	Syadati, Moradi 40196 (TUH)
C. hyrcanica Bornm.	Gilan: Ispili	1580	Syadati 18489 (TUH)
C. kotschyi (Boiss.) Hayek	Mazandara: road of Karaj - Chalous	40	Nazaryan 33460 (TUH)
C. kotschyi (Boiss.) Hayek	Tehran: Chalous road, slope of Kandavan	s.n.	Ghahreman, Mozaffarian 9780 (TUH)
C. ispahanica Boiss.	Isfahan: Shahreza, Samirom, Kouhravi,	2450	Ghahreman, Mozaffarian 18233 (TUH)
C. rhizantha Tchich.	Azarbayejan: Arasbaran, protected Area, Kouhe Kalan	1105	Attar, Dadjou 17671 (TUH)
C. rhizantha Tchich.	Azarbayejan: Marand, Zunuz, between Zunuzagh and Kuhkamar	1700	Ghahreman, Mozaffarian 17405 (TUH)
C. glastifolia L.	Azarbayejan: Marand road of Zunuz	1700	Ghahreman, Attar 21296 (TUH)
C. glastifolia L.	Azarbayejan: Khoy road of Ghotur, Razi, 2 km of bus station	1160	Ghahreman, Attar 21992 (TUH)
C. aucheri subsp. *aucheri* (DC.) Wagenitz	Kordestan: Sanandaj, 28 km to Divan Darreh	1840	Attar, Dadjou, Mehdigholi, Okhovat 14293 (TUH)
C. aucheri subsp. *aucheri* (DC.) Wagenitz	Hamadan: Kubardar Ahang to Ghohord, Keitou, Kouhe Keiton	1800	Mozaffarian 64603 (TUH)
C. aucheri subsp. *aucheri* (DC.) Wagenitz	Azarbayejan sharqi: N slopes of Mishov-Dagh, south of the road	1400	Podlesh, Zarre 55267 (TUH)
C. aucheri subsp. *szowittsii* (Boiss.) Wagenitz	Azarbayejan: Gardane Yam, Mishodagh	1400	Ghahreman, Aghostin, Sheikholeslami 11444 (TUH)
C. aucheri subsp. *szowittsii* (Boiss.) Wagenitz	Markazi: 70 km NW of Saveh village of Bandamir	1920	Ghaffari, 4681 (TUH)
C. aucheri-elbursensis Wagenitz	Azarbayejan: Myaneh, Bostanabad, 35 km Bostanabad	1740	Ghaffari, 11627 (TUH)
C. albonitens Turrill	Azarbayejan: Sirvan, from Yam to Tabriz	1900	Ghahreman, Aghostin, Sheikholeslami 11477 (TUH)
C.albonitens Turrill	Azarbayejan: Tabriz, 20 km to Marand	1360	Ghaffari, 6642 (TUH)
C.geluensis Boiss. & Hausskn. ex Boiss.	Lorestan: Khorramabad, Sefidkou	1720	Veis Karami 23715 (TUH)
C. gigantea Sch.Bip. ex Boiss.	Lorestan: Khoramabad, road of Sefid Dasht	1142	Ghahreman, Attar, Dadjou 21840 (TUH)

Table 1. continue …

Species	Locality	Height (m)	Collector & Herbarium nummber
C. imperialis Hausskn. ex Bornm.	Kordestan: Marivan to Baneh 50 km to Baneh	1540	Ghahreman, Attar 19667 (TUH)
C. phlomoides Boiss. & Hausskn. ex Boiss.	Kermanshah: Paveh	1550	Attar, Mirtadzadini 19857 (TUH)
C. amadanensis subsp. *gymnoclada* (Jaub. & Spach) Negaresh	Kordestan, Marivan, Ghamishlu	1320	Ghahreman, Attar 19650 (TUH)
C. amadanensis subsp. *amadanensis* Sch.Bip.	Lorestan: Khoramabad, 50 km after bifurcation of Khorramabad- Sefid Dasht	1142 m	Ghahreman, Attar, Ghaffari 21839 (TUH)
C. nemecii Náběl̆ek	Kordestan: Sanandaj, Salavat Abad pass	1700 m	Ghahreman, Mozaffarian 18295 (TUH)
C. koeieana Bornm.	Lorestan: Khorramabad, Delbar	1100 m	Veis Karami 23712 (TUH)
C. pabotii Wagenitz	Chaharmahal-e- Bakhtiari Lordegan to Dashte Armand	1585 m	Mozaffarian 54658 (TUH)
C. behen Lam.	Lorestan: Khorramabad, Cham-Divan, Chal-e-Ahmad	1440 m	Veis Karami 23713 (TUH)
C. solstitialis Asso	Azarbayejan: between Ardebil-Kivy	1480 m	Sheikholeslami 11510 (TUH)
C. pseudosinaica Czerep.	Hormozgan: Bandar Abbas, near Sarkhon, Radar site	75 m	Ghahreman, Mozaffarian 5357 (TUH)
C. iberica Trevir. ex Spreng.	Gilan: Langroud. Chamkhaleh	-26 m	Naghinezhad 27549 (TUH)
C. iberica Trevir. ex Spreng.	Gilan: Lngroud, Chamkhaleh	-26 m	Naghinezhad 27548 (TUH)
C. bruguierana Hand.-Mazz.	Khuzestan: Mahshahr		Ghahreman & Attar23340 (TUH)
C. bruguierana Hand.-Mazz.	Kordestan: inter Gilan e Gharb and Ghasre Shirin	360 m	Ghahreman 11456 (TUH)
C. sosnowskyi Grossh.	Gilan: between Ispili and Leih	1580 m	Saiydi 18490-(TUH)
C. kandavanensis Wagenitz	Golestan: before Nardin to Tange rah	465 m	Ghahreman, Attar 21930-(TUH)
C. luristanica Rech.f.	Khuzestan: Ize, Darre Sansan		Attar, Dadjou 17723-(TUH)
C. leuzeoides Walp.	Gorgan: Golestan National park, Almeh	-	Ghahreman, Mozaffarian 5903 (TUH)
C. gilanica Bornm.	Hamedan: Famenin; Ghorveh, Karafs, Mnts N.E of Karafs	1790 m	Mozaffarian 64542 (TUH)
C. zuvandica (Sosn.) Sosn.	Mazandaran: Kandavan road of Chalous-Haraz, Youssh	2230 m	Ghaffari 21229 (TUH)
C. phaeopappoides Bordz.	Azarbayejan: Siah cheshme Baron village, around Zarzor Chuch	1750 m	Mozaffarian 71130 (TUH)

C. hyalolepis Boiss. in section *Calcitrapa* DC.).

- Pappus color: most pappus are cream, brown or milky white, but species in section *Phaeopappus* (DC.) O.Hoffm. (except *C. albonitens*), *Psephelloideae* (Boiss.) Sosn. and *Xanthopsis* are distinguished by their purple or black pappus.

- Inner dense pappus: this characteristic can be seen in sections *Hyalea*, *Mesocentron* (*C. solstitialis*), *Tetramorphaea*, *Acrocentron*, *Psephelloideae* (*C. leuzeoides*), *Odontolophoideae*, *Xanthopsis* (DC.) Wagenitz & Hellwig and *Cyanus* (Miller) DC. (except *C. elbrusensis* Boiss. & Buhse).

Pappus form: pappus, either short or long, has different forms, most of which in ray form are separated from other taxa (*C. aucheri*), while some others are dense and straight (*C. ispahanica* Boiss.). Though *C. albonitens* in section *Phaeopappus* with broom-shaped pappus and *C. incanescens* in section *Amblyopogon* with short truncate and oblique pappus are very different among all species studied in other sections.

- Connection area of pappus to achene: it is mostly denticulate or rarely entire (*C. gilanica* Bornm.). The section *Cyanus* has hairy hilum area, except for the *C. elbursensis*.

As it is observed in Tables 2 and 3, there are differences in achene's characteristics among sections, even in one unique *C. lachnopus* Rech.f. in sect. *Centaurea* with distinct white appendage coming out of hilum (Fig. 2 A).

The members of sect. *Acrolophus* (Cass.) DC. & *Ammocyanus* Boiss. are similar in achene chracteristics, and based on Wagenitz (1980), these species have apparent similar morphology too (Fig. 2 D, E & F). Based on Tables 2 and 3, hilum in *C. hyrcanica* Bornm. in sect. *Jacea* (Miller) DC., is concave, semi-circular and no appendage can be seen in it (Fig. 2 H).

In sect. *Rhizocalathium* Tzvelev (Fig. 2 J, K & L) appendage is seen out of hilum (similar to sect. *Centaurea*), and a narrow brown margin is seen in the bottom of achene in hilum opening.

Sect. *Phaeopappus* (*C. aucheri* with three subspecies) are similar, especially in having purple pappus and the length of pappus in comparison with achene length (Fig. 3 N- P), while *C. albonitens* in the same section

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Table 2. Characterizations used for achene differentiation (measurement in mm).
Abbreviations: **App**=appendage, **App.L**=appendage length, **App.C**=appendage color, **H**=hilum, **H.L**=hilum length, **A.L**=achene length, **A.W**=achene width, **A.C**=achene color, **A.S**=achene shape, **int**=intangible, **-**=glabrous, **+/-**=pubsent, **+**=normal, **++**=fairly high, **+++**=highly.

Section	species	Hair	App.	App.L	App.C	H	H.L	A.L	A.W	A.C	A.S
Centaurea	*C. lachnopus*	-	+	1.3	white	+	1.3	7.4	1.6	light brown	oblong
Stizolophus	*C. balsamita* subsp. *balsamita*	-	+	0.7	red	+	0.7	4.4	1.5	dark brown	oblong-attenuate towards base
	C. balsamita subsp. *kermanensis*	-	+	0.7	red	+	0.7	3.9	1.3	light grey	oblong
Acrolophus	*C. ovina*	+/-	+	0.2	white	+	0.5	3.2	1.4	brown	oblong
	C.aggregata	+/-	+	0.3	white	+	0.6	2.8	1.4	brown	cup-shaped
Ammocyanus	*C. ammocyanus*	+/-	+	0.6	grey	+	0.6	2.9	1.2	golden cream	attenuate towards base
Hyalea	*C. pulchella*	+	-	-	-	+	0.1	2.7	1.1	greyish brown	attenuate to base
Jaceae	*C. hyrcanica*	+/-	-	-	-	+concave	1.03	3.12	½	cream	oblong-attenuate towards base
Cheirolepis	*C. kotschyi*	-	-	-	-	+	0.5	6.01	2.71	cream	urceolate
Rhizocalathium	*C. rhizantha*	-	+	0.6	white	+	0.6	6.1	1.9	yellow	urceolate
	C. ustulata	-	+	1.3	cream white	+	1.3	5.9	2.3	cream-gold	oblong
	C. ispahanica	-	+	2.2	dark brown	+	2.2	10.4	2.4	honey brown	oblong-attenuate towards base
Chartolepis	*C. glastifolia*	+	-	-	-	+	0.6	1.9	0.8	dark oblong	oblong
Phaeopappus	*C. aucheri* subsp. *aucheri*	-	+	1	white	+	1.15	5.8	3.1	light brown	oblong inflated
	C. aucheri subsp. *szowitsii*	-	+	1.1	white	+	1.19	7.3	2.7	light brown	Oblong-attenuate towards base
	C.aucheri subsp. *elbursensis*	-	+/-	-	-	-	-	6.9	1.7	light brown	oblong
	C. albonitense	-	+	0.6	white	+	0.6	2.9	1.09	dark brown	oblong
Cynaroides	*C. regia*	-	-	-	-	+	0.9	7.9	3.03	shiny cream	oblong
	C. imperialis	+/-	+	0.9	white	+	0.5	5.4	1.8	dark brown	rectangular
	C. gigantea	+/-	-	-	-	+	0.9	5.8	3	shiny cream	oblong
	C. phlomoides	+	+	1.4	white	+	2.4	7	2.7	brown	rectangular
	C. geluensis	++	-	-	-	+	1.1	4.1	1.16	grayish cream	fusiform
Paraphysis	*C. amadanensis*	-	+	1.3	white	+	1.3	6.9	2.8	yellowish cream	rectangular
	C. nemecii	+	+	0.8	white	+	0.8	5.6	3.3	shiny white	oblong
Microlophus	*C. behen*	+	-	-	-	+	0.7	4.5	1.89	small & cream	oblong
	C. pabotii	++	-	-	-	+	0.8	4.4	2.03	cream	oblong
	C. koeieana	++	-	-	-	+	1.1	2.1	0.4	gray brown	urceolate
Mesocentron	*C. solstitialis*	-	-	-	-	+	0.5	2.5	1.2	cream with black spot	oblong
	C. pseudosinaica	-	+	1	yellow	+	1	2.8	1.4	cream	oblong
Calcitrapa	*C. iberica*	+	-	-	-	+	0.6	3.3	1.4	yellow cream	oblong
	C. hyalolepis	+	-	-	-	+	int	2.5	0.9	yellow cream	oblong

Table 2. continue …

Section	species	Hair	App.	App.L	App. C	H	H.L	A. L	A. W	A.C	A.S
Tetramorphaea	*C. bruguierana*	+	-	-	-	+	0.3	2	0.9	yellow caramel	oblong
Acrocenteron	*C. sosnowskyi*	++	-	-	-	+	1.5	5.4	2.3	amber colored	oblong
	C. kandavanensis	+++	-	-	-	+	1.2	5.4	2.3	amber colored	oblong
	C. luristanica	+++	-	-	-	+	1.05	6.2	2.5	amber colored	oblong
Psephelloideae	*C. leuzeoides*	-	-	-	-	+	1.07	8.1	2.9	shiny white	fatty oblong
	C. gilanica	+/-	+	1.01	white	+	1.01	6.8	2.7	yellow honey	oblong
Psephellus	*C. zuvandica*	+	+	1.4	white	+	1.4	5.3	2.6	yellow cream	urceolate
Amblyopogon	*C. incanescens*	-	-	-	-	+	2.5	7.3	4.17	cream white	urceolate
Odontolophoideae	*C. phaeopappoides*	+ pilose	+	0.7	white	+	0.8	3.8	1.6	light brown	elliptic
Uralepis	*C. gaubea*	+ pilose	+	1.2	white	+	1.2	2.8	1.3	yellow honey	rectangular
Xanthopsis	*C. xanthocephala*	-	+	1.2	white	+	1.3	6.8	2.5	amber colored	elliptic
Cyanus	*C. cyanus*	+	+	2	white	+	2.3	4.6	2.4	yellow brown	triangular
Cyanus	*C. cheiranthifolia*	-	+	1.1	white	+	1.5	4.4	2.08	yellow cream	oblong
	C. depressa	+	+	2.9	white	+	2	4.9	2.6	light brown	oblong
	C. elbursensis	+	+	1.9	white	+	2.1	5.6	1.7	brown	oblong
	C. triumfetti	+	+	1.4	white	+	1.5	4.8	1.9	black yellow	oblong

Fig. 2. **A.** *Centaurea. lachnopus*. **B.** *C. balsamita* subsp. *balsamita*. **C.** *C. balsamita* subsp. *kermanensis*. **D.** *C. aggregate*. **E.** *C. ovina*. **F.** *C. ammocyanus*. **G.** *C. pulchella*. **H.** *C.hyrcanica*. **I**. *C. kotschyi*. **J.** *C. rhizantha*. **K.** *C. ustulata*. **L.** *C. ispahanica.*

is observed to have white cream pappus (Fig. 3 Q). Moreover, outer pappus are shorter in comparison with the inner part.

C. nemecii Nábělek in sect. *Paraphysis* (DC.) Wagenitz has bright milky achene, and similar color in short outer pappus and long inner pappus (Fig. 3 X). Sect. *Microlophus* (Cass.) DC. is noticeable in terms of the angled form of its hilum (Fig. 4 A & B). Achene of *C. koeieana* in sect. *Microlophus* is covered with dense hairs (Fig. 4 C). *C. iberica* in sect. *Calcitrapa* is distinguished by short and scarce hairs on its hilum (Fig. 4 F).

Species belong to sect. *Acrocentron* (Cass.) DC. are fully covered with soft hairs and have inner dense pappus (I.D.P) which is observable in all of the three species of the section, especially in *C. sosnowskyi* Grossh. which has scaly inner dense pappus (Fig. 4 I). *C. zuvandica* (Fig. 5 N) in sect. *Psephellus* is similar to members of sects. *Centaurea* and *Rhizocalathium* in that it has clear appendage, out of hilum, and similar to the members of section *Microlophus* in that it has truncate hilum.

C. leuzeoides (Fig. 4 L) in sect. *Psephelloideae* has black pappus, shiny white achene and inner dense pappus.

The achene in *C. incanescens* is large and inflated with a concave semi-circular hilum, short, dense, truncate and oblique pappus (Fig. 5 O). *C. phaeopappoides* (Fig. 5 P) in sect. *Odontolophoideae* is similar to the members of the sect. *Centaurea*, *Rhizocalathium* and *Psephellus* as its appendage is out of hilum.

Three sects. *Phaeopappus*, *psephelloideae* (*C. gilanica*, Fig. 5 M) and *Xanthopsis* have purple pappus. As it was mentioned above, species in sect. *Cyanus*, especially *C. cheiranthifolia*, *C. triumphetti*, and *C. depressa* have hairs on their hilum (Fig. 5 S, U and V), while the presence of hairs on the hilum is scarce in other sections.

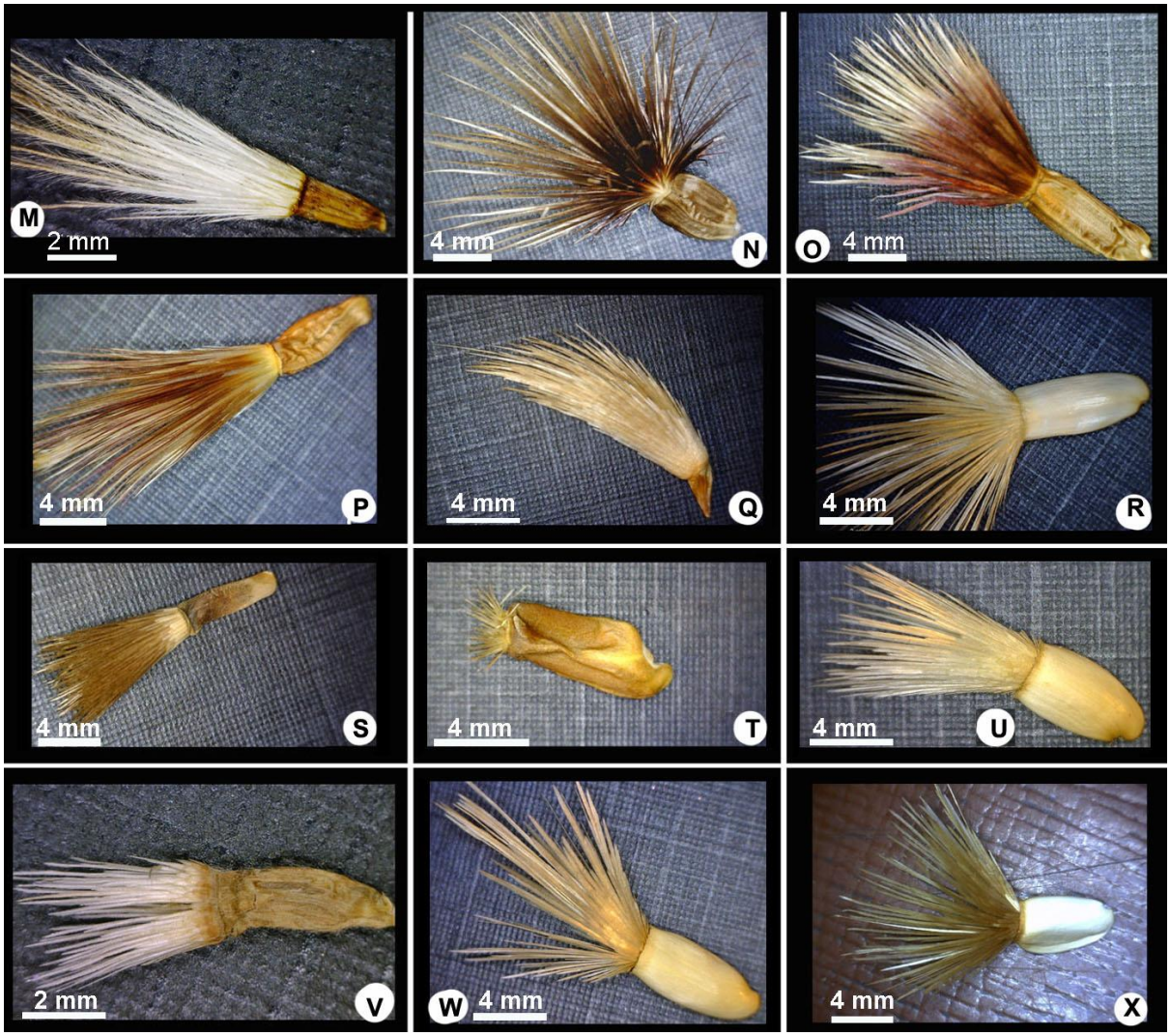

Fig. 3. M. *Centaurea glastifolia*. **N.** *C. aucheri* subsp. *aucheri*. **O.** *C. aucheri* subsp. *szowitsii*. **P.** *C. aucheri* subsp. *elburzensis*. **Q.** *C. albonitens*. **R.** *C. regia*. **S.** *C. imperialis.* **T.** *C. phlomoides*. **U.** *C. gigantea*. **V.** *C. geluensis*. **W**. *C. amadanensis*. **X**. *C. nemeci.*

Table 3. Characteristics used for achene differentiation (measurement in mm).
Abbreviations: **P.L**=pappus length, **P.C**= pappus color, **P.F**=pappus form, **P.T**=pappus type, **I.D.P**=inner dense pappus,**ND**= not denticulate, **Co.L**= connection length, **Co.C**=connection color, **Co.F**=connection form, **P.L/A.L**=pappus length/achene length, **S**=scabrous, **D**=denticulate, **P**= plumose, **-** = glabrous, **+/-**=pubsent, **+**=normal, **++**=fairly high, **+++**=highly.

Section	species	P.L	P.C	P.F	P.T	I.D.P	Co.L	Co.C	Co.F	P.L/ A.L
Centaurea	*C. lachnopus*	11	milky white	straight	S	-	2.3	dark brown, margined	D	1.5
Stizolophus	*C. balsamita* subsp. *balsamita*	4.3	brownish cream	straight	S	-	1.5	light cream, margined	D	0.9
	C. balsamita subsp. *kermanensis*	2.7	Brownish golden	straight	S	-	1.2	light cream, margined	D	0.7
Acrolophus	*C. ovina*	0.9	white	straight	S	-	1.12	light cream no margin	D	0.2
	C.aggregata	3.1	white	straight	S	-	1.2	brown margined	D	1.1
Ammocyanus	*C. ammocyanus*	3.4	white	straight	S	-	1.05	golden cream margined	D	1.1
Hyalea	*C. pulchella*	4.2	shining white	straight	S	+	1.1	no margin	D	1.9
Jaceae	*C. hyrcanica*	1.3	yellow	short& straight	S	-	0.9	no margin	D	0.4
Cheirolepis	*C. kotschyi*	13.01	brown	ray form	P	-	2.2	cream margin	D	2.1
Rhizocalathium	*C. rhizantha*	1.86	white	straight	S	-	1.3	no margin	D	0.3
	C. ustulata	2.4	honey brown	short & ray form	S	-	1.6	no margin	D	0.4
	C. ispahanica	3.9	honey brown	short & straight	S	-	2.1	no margin	D	0.4
Chartolepis	*C. glastifolia*	9.3	cream white	straight	highly P	-	0.6	brown margin	D	4.8
Phaeopappus	*C. aucheri/ aucheri*	12	brown purple	highly ray form	P	-	2.3	cream margin	D	2
	C. aucheri/ szowitsii	12.02	cream, purple	ray form	P	-	2.3	brown margin	D	1.6
	C.aucheri/ elbursensis	15.4	cream purple	straight spreading	S	-	1.8	dark brown margin	D	2.2
	C. albunitense	13	white	broom shape	S	-	1.4	white brown margin	D	4.5
Cynaroides	*C. regia*	11.5	cream	ray form	S	-	2.9	no margin	D	1.5
	C. imperialis	9	white, inner	straight	S	-	1.7	dark margin	D	1.6
Cynaroides	*C. gigantea*	9.2	white	straight	S	-	2.5	no margin	D	1.5
	C. phlomoides	2.2	white honey	short & ray form	S	-	1.5	yellow margined	D	0.3
	C. geluensis	4.2	cream white	ray form	S	-	1.08	red brown margined	D	1.02
Paraphysis	*C. amadanensis*	11	cream	ray form	S	-	2.5	dark brown margined	D	1.5
	C. nemecii	10.4	golden honey	ray form	S	-	2.4	golden margined	D	1.8
Microlophus	*C. behen*	6.5	white	semi straight	S	-	1.6	no margin	D	1.5
	C. pabotii	5.3	white	straight	S	-	1.6	no margin	D	1.2
	C. koeieana	5.5	white	straight	S	-	1.5	brown margined	D	2.6
Mesocentron	*C. solstitialis*	4.6	white	ray form	S	+	1.1	no margin	D	1.8
	C. pseudosinaica	3.6	honey color	semi ray form	S	_	1.2	no margin	D	1.2
Calcitrapa	*C. iberica*	1.16	white	short & semi ray	S	-	1.01	dark brown margined	D	0.3
	C. hyalolepis	3.2	white	semi ray	S	-	0.9	yellow margin	D	1.3

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Table 3. continue …

Section	species	P.L	P.C	P.F	P.T	I.D.P	Co.L	Co.C	Co.F	P.L/ A.L
Tetramorphaea	*C. bruguierana*	2.2	white	semi ray	S	+	0.2	brown margin	D	1.08
Acrocenteron	*C. sosnowskyi*	8	honey cream	ray form	S	+	1.93	no margin	D	1.48
	C. kandavanensis	8.3	white	semi ray form	S	+	1.81	no margin	D	1.5
	C. luristanica	17.8	milky white	semi ray	S	+	2.3	no margin	D	2.8
Psephelloideae	*C. leuzeoides*	10	black	ray form	S	+	2.7	no margin	D	1.2
	C. gilanica	7.7	cream purple	semi ray form	S	-	2.1	brown margin	ND	1.1
Psephellus	*C. zuvandica*	0.5	yellow	too short & ray form	S	-	1.6	brown margin	D	0.1
Amblyopogon	*C. incanescens*	1.7	white	dense & diagonal	S	-	2.2	black, brown margin	D	0.2
Odontolophoideae	*C. phaeopappoides*	2.2	brown honey	ray form	S	+	1.6	honey margin	D	0.5
Uralepis	*C. gaubea*	7.4	white	semi ray form	S	-	1.6	red brown margin	D	2.6
Xanthopsis	*C. xanthocephala*	2.2	purple	short& semi ray form	S	+	1.3	black margin	D	0.3
Cyanus	*C. cyanus*	6.4	white	ray form	S	+	2.1	cream margin	D	1.3
Cyanus	*C. cheiranthifolia*	1.3	amber colored	short & semi ray form	S	+	1.7	red brown margin	D	0.3
	C. depressa	6.2	white	semi ray form	S	+	2.1	cream margin	D	1.3
	C. elbursensis	18	cream white	semi ray form	S	-	2.2	dark brown margin	D	3.2
	C. triumphetti	1.5	amber colored	short & straight	S	+	1.6	light margin	D	0.3

DISSCUSION

The character states used for achene characterization in different species of the genus *Centaurea* are thoroughly investigated, and some of them were found to be major key features. Character states derived from the presence of hair on the achene, the presence of appendage, the length and color of the appendage, the length of hilum, the length of achene and its color, the length of pappus, especially in comparison with the length of achene, the presence of inner dense pappus as well as the color and form of the connection area of hilum were found to be important.

Due to the Flora Iranica (Wagenitz, 1980), the identification key generated for the separation of the groups (A-I) were based on characters such as the form and color of appendage and bracts, the number of cilia, the form of leaves, the presence or absence of terminal spine and the duration of the plant. In this paper, the identification key for 24 sections of the genus *Centaurea* is constructed on the basis of the achene specifications. Three groups are considerably distinct and recognized. Group A is distinguished by having the achene with large and highly observable prominent appendage coming out of hilum. Group B is specified by having the achene with appendage enclosed by the hilum. Moreover, Group C is specified by the absence of appendage in achene's hilum.

Group A: Achene with large and highly prominent appendage out of hilum

1. Hilum appendage red……..sect. *Stizolophus*
 - Hilum appendage white……2
2. Achene with margin in connection to pappus ….3
 - Achene with no margin in connection to pappus.5
3. Achene hairy on its surface……..4
 - Achene glabrous……...sect. *Centaurea*

4. Inner pappus dense and scale like……..
….……..…sect. *Odontolophoideae*
- Inner pappus loose……sect. *Psephellus*
5. Pappus shorter than the achene ……..
……...sect. *Rhizocalathium*
- Pappus longer than the achene ……
……...…sect. *Mesocentron = C. pseudosinaica*

Group B: Achene with small appendage, but not prominent in coming out of hilum
1. Achene with margin in connection to pappus…..2
- Achene without margin in connection to pappus…
……...…sect. *Acrolophus = C. ovina*
2. Pappus length / achene length more than 1…… 3
- Pappus length / achene length less than 1…….. 4
3. Hilum truncate……..sect. *Uralepis*
- Hilum round.……5
4. Achene denticulate in pappus connection area….6
- Achene not as above…..sect. *Cyanus = C. cyanus*
5. Hilum scabrous……7
- Hilum smooth ……..8
6. Pappus with inner dense row……
……..……sect. *Cynaroides = C. depressa*
- Pappus without inner dense row……
…….sect. *Cyanus = C. elbursensis*
7. Pappus with inner dense row……sect. *Xanthopsis*
- Pappus without inner dense……
……sect. *Cynaroids = C. phlomoides*
8. Achene hairy……...10
- Achene glabrous……...9
9. Pappus purple……...sect. *Phaeopappus*
- Pappus not purple…….....
……...…sect. *Paraphysis = C. amadanensis*
10. Pappus purple..sect. *Psephelloideae = C. gilanica*
- Pappus not purple…….....11
11. Achene shiny white...sect. *Paraphysis = C. nemecii*
- Achene Brown ……12
12. Pappus length more than 5 mm……
……sect. *Cynaroides = C. imperialis*
- Pappus length less than 5 mm……13
13. pappus with inner dense row……
……sect. *Cyanus = C. cheiranthifolia*
- Pappus with no inner dense…….……
...sect. *Ammocyanus*, sect. *Acrolophus=C. aggregate*

Group C: Achene without appendage
1. Pappus with inner dense row……2
- Pappus with no inner dense row.……5
2. Achene scarcely hairy…….sect. *Hyalea*
- Achene glabrous……...3
3. Achene margined on pappus connection area……sect. *Tetramorphaea*
- Achene no margined……4
4. Achene white, pappus black……
……..sect. *Psephelloideae = C. leuzeoides*
- Achene cream-colored, pappus white……
……..sect. *Mesocentron = C. solstitialis*
5. Achene hairy ……6
- Achene glabrous…....sect. *Cynaroides = C. regia*
6. Hilum hairy……...sect. *Calcitrapa*
- Hium glabrous ……7
7. Achene margined on pappus connection area…..9
- Achene no margined……8
8. Hilum concave……10
- Hilum angled.……sect. *Microlophus*
9. Achene-pappus small opening……sect. *Jaceae*
- Achene-pappus large opening……
……sect. *Cynaroides = C. gigantean*
10. Pappus longer than the achene ……11
- Pappus shorter than the achene or the same…..12
11. Achene hairy……..sect. *Chartolepis*
- Achene glabrous……..sect. *Cheirolepis*
12. Pappus truncate-oblique.…....sect. *Amblyopogon*
- Pappus not as above……
…….sect. *Cynaroides = C. geluensis*

According to Tables 2 and 3, some differences are observed in some species among sections. In sect. *Acrolophus*, in *C. ovina* (Fig. 2 E) no margin is seen in achene pappus connection area, while *C. aggregata* (Fig. 2 D) has a brown margin. Moreover, based on Tables 2 and 3, in *C. ovina*, pappus length is shorter than the achene length, while in *C. aggregata* pappus is longer. Therefore, the ratio of pappus length to achene length is more than 1. One important point to mention is that the similarity between sects. *Acrolophus* and *Ammocyanus*, based on the features studied in Flora Iranica (Wagenitz 1980), is mirrored in the high similarity between *C. ammocyanus* (Fig. 2 F) and *C. aggregata* in the section mentioned, in the features studied here (Tables 2 & 3). In sect. *Phaeopappus*, despite the categorization of *C. albonitens* with *C. aucheri* in the mentioned section, white broom form pappus is seen (Fig. 3 Q), though the other subspecies are interesting and recognized by having ray form purple pappus (Fig. 3 N, O & P). Moreover, pappus in *C. albonitens* is much longer in comparison with achene length.

Sect. *Cynaroides* is one of the most varied sections, as many different character states were observed among its five species. *C. regia* is the only species among all others with no hairs on its achene surface (Fig. 3 Q), while the others have hairs as *C. imperialis* (Fig. 3 R) and *C. gigantea* (Fig. 3 T) are specified by having scarce hairs and *C. phlomoides* (Fig. 3 R) and *C. geluensis* (Fig. 3, V) are fully covered with hairs on their achene surface.

In sect. *Cynaroides*, the species *C. phlomoides* has distinct morphological differences in the characters studied compared with other species of the section.

In addition, different bracts and capitulum size are additional morphological traits to convince us to separate *C. phlomoides* from the other members of this section and treat it as a new section.

Three species namely *C. regia*, *C. geluensis* and *C. gigantea* have no appendage, while the other species do. Moreover, *C. regia* and *C. gigantea* have no margin. In all species in sect. *Cynaroides*, pappus is obviously longer than the achene, however, pappus length in *C. phlomoides* is much shorter than the achene length. Furthermore, according to Tables 2 and 3, hilum length in *C. phlomoides* is much longer than the others. The ratio of pappus length to achene length is less than one in the mentioned species, while in others it is more than 1.

In sect. *Paraphysis*, *C. amadanensis* has no hairs on the achene (Fig. 3 W), and the color of the achene is creamy, but in *C. nemecii* achene is hairy and white (Fig. 3 X). These two species are morphologically close to each other, however, they are separated on the basis of the presence of pedicel in *C. amadanensis* or the lack of pedicel in *C. nemesi*.

In sect. *Microlophus,* achenes in species *C. behen*, *C. pabotii* and *C. koeieana* (Fig. 4 A, B and C) were thoroughly investigated. In all these three species, the surface of achene is hairy, but achene in *C. koeieana* is overwhelmingly hairy. Also, in the two species mentioned first, the form of hilum is corner angled, while hilum in *C. koeieana* is scanned. Moreover, the length of

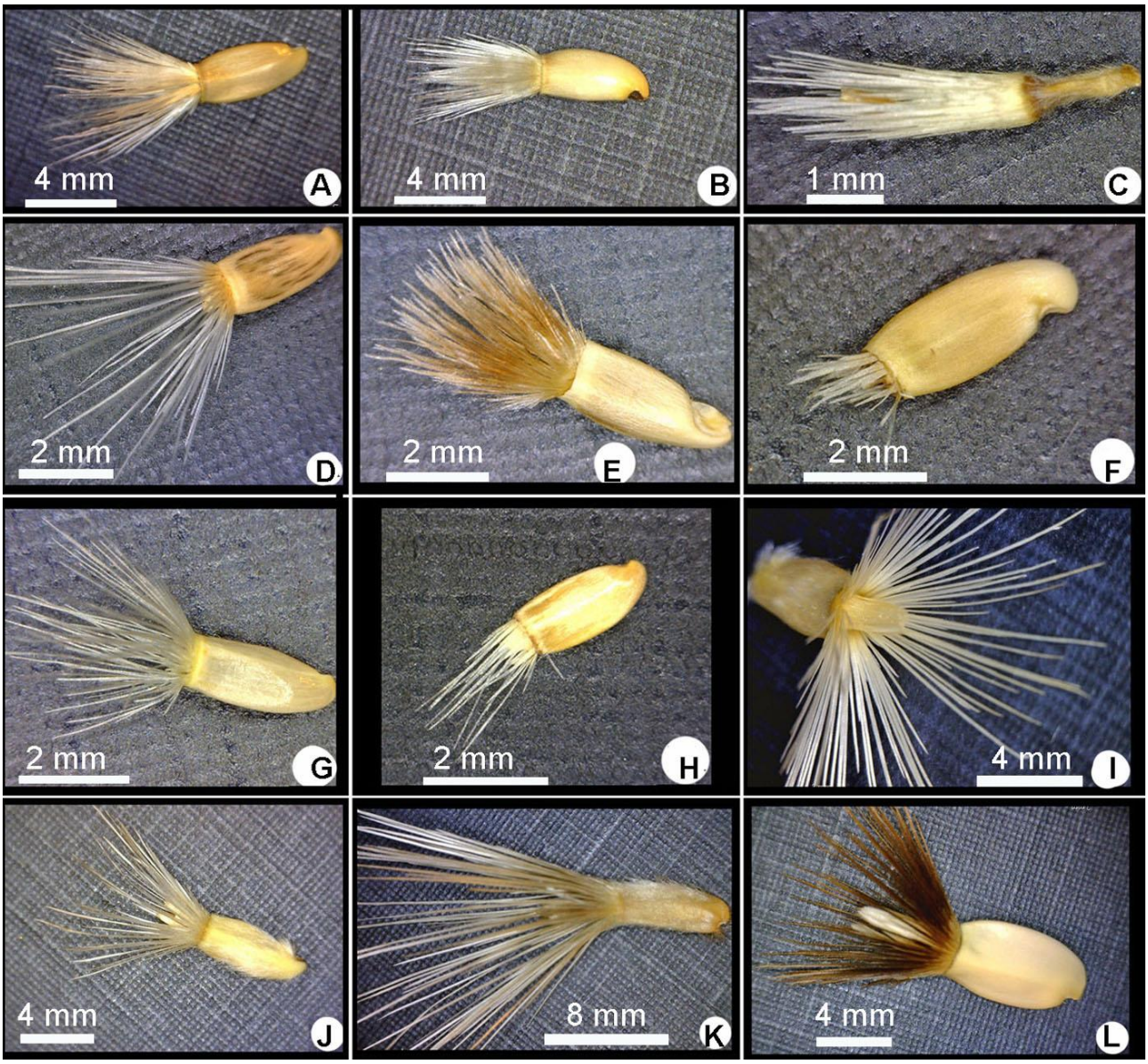

Fig. 4. A. *Centaurea behen*. **B**. *C. Pabotii*. **C**. *C. Koeiana*. **D**. *C. solstitialis* subsp. *solstitialis*. **E**. *C. pseudosinaica*. **F**. *C. iberica*. **G**. *C. hyalolepis*. **H**. *C. bruguierana*. **I**. *C. sosnowskyi*. **J**. *C. kandavanensis*. **K**. *C. luristanica*. **L**. *C. leuzeoides.*

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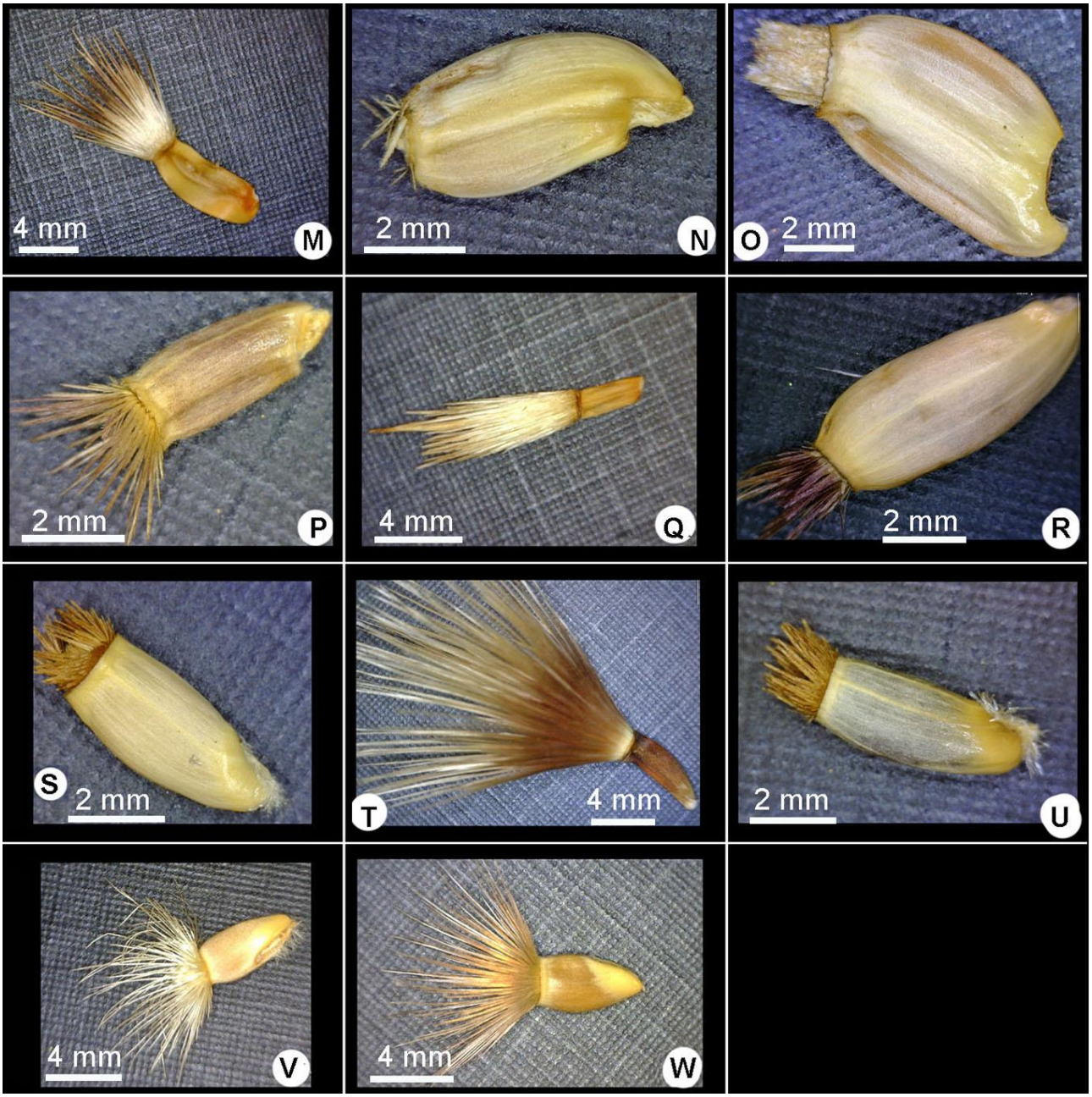

Fig. 5. M. *Centaurea gilanica*. **N**. *C. zuvandica*. **O**. *C. incanescens*. **P**. *C. phaeopappoides*. **Q**. *C. gaubae*. **R**. *C. xantocephala*. **S**. *C. cheiranthifolia*. **T**. *C. elburzensis*. **U**. *C. triumfettii*. **V**. *C. depressa*. **W**. *C. cyanus.*

pappus is almost 3 times more than achene length. This section is homogenous in the characters studied. The appendage of bracts is without hilum and all flowers are yellow. Their achenes are also very similar.

In sect. *Mesocentron*, an interesting reversed relation is seen in the presence of inner dense pappus and appendage. It means that, in *C. solstitialis* (Fig. 4 D), no appendage is seen but the inner dense pappus is obvious with white achene, while *C. pseudosinaica* (Fig. 4 E) is seen with prominent appendage, no inner dense pappus and brown achene. These two species are similar in that they have yellow flowers and 'bract appendage' that leads to long acute spines, but different because of their geographical distribution, as the first one is an Irano-Turanian element while the second one is a Sahara-Sindian element. Their achenes are completely different.

In sect. *Calcitrapa*, two species namely *C. iberica* (Fig. 4 F) and *C. hyalolepis* (Fig. 4 G) are thoroughly investigated. The most important criteria to be used in the comparison between these two is the length of pappus. This means that, in the first species, the length of pappus is shorter than that of the achene, while in *C. hyalolepis* the pappus is longer. Therefore, the ratio is more than 1 in the former, but less than 1 in the latter. In addition, short

amount of hairs can be seen in hilum area of *C. iberica*.

Sect. *Psephelloideae*, is a group with a lot of differences among its species. *C. leuzeoides* (Fig. 4 l): 1-lacks hairs on achene, 2-lacks appendage, 3-shiny white achene, 4- has black pappus, 5-lacks margin in pappus-achene connection area, 6- has denticulate pappus-achene connection form,7- has inner dense pappus

C. gilanica (Fig. 5 M): 1. has hairs on achene surface, 2. has appendage, 3. the achene color is yellow brown, 4. has cream-colored purple pappus, 5. has brown margin in pappus-achene connection area, 6. Achene-pappus connection is not denticulate, 7. lacks inner dense pappus.

Sect. *Amblyopogon* with only one species, *i.e. C. incanescens*, have the largest hilum as compared with all other sections, short, dense and in diagonal form pappus (Fig. 5 O).

Sect. *Xanthopsis*, besides *phaeopappus*, is famous for its purple pappus.

The other interesting section is *cyanus*: the species thoroughly observed included *C. cheiranthifoli*, *C. depressa*, *C. cyanus*, *C. elbursensis and C. triumfettii*. The prominent differences investigated were addressed as follows.

In *C. cheiranthifolia* (Fig. 5 S) no hairs were seen on achene, while the others have hairs on their achene.

Hilum length in *C. cyanus* (Fig. 5 W) is the biggest in comparison with other species in this section. The achene shape in *C. cyanus* (Fig. 5 W) is triangular while others have oblong shape. *C. elbursensis* (Fig. 5 T) is the only species in this group without inner dense central pappus, while others have the feature. Pappus in *C. cheiranthifolia* (Fig. 5 S) and *C. triumfetti* (Fig. 5 U) are shorter than the achene, while in other species of the mentioned section, pappus are long enough to consider. Interestingly, in *C. elbursensis*, pappus is much longer in comparison with achene length.

Based on the discussion, despite the fact that each section contains a lot of species with many similarities in achene's morphology, many differences in species in many of those sections have been observed.

Based on the studied morphological traits, especially the morphology of achene, these traits are useful for the delimitation of the species. Although a new key has been provided for categorizing the sections, achene morphological traits were found to be inadequate. In each section type, achenes are different among some species even when similarities were observed in other morphological traits.

Morphologically, some traits such as the presence or absence of appendage of bracts, central bract appendage form, the number of cilias around appendage, the color of cilias and the color of flowers can be useful for the delimitation of sections. In addition, achene characteristics can be useful for the delimitation of the species in the genus *Centaurea*.

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