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Review paper

ESSENTIAL-OIL COMPOSITION OF PLANT SPECIES OF THE GENUS *BUPLEURUM*

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Abstract. *This review summarizes the current knowledge on the essential-oil analysis of the forty plant species belonging to the genus Bupleurum, ten of which are annual, and thirty are perennial. The analysis covers the chemical composition of essential oils isolated from various plant organs, oil yields, and the percentage of identified components. The main constituents of the essential oils are outlined, and the structures of the most prevalent monoterpenes, sesquiterpenes, phenylpropanoids, aldehydes, alcohols, esters, etc., are given. Tables comparing the chemical composition are included for essential oils that underwent multiple analyses.*

Key words: *essential oil, Bupleurum, chemical composition, terpenes*

1. INTRODUCTION

Essential oils are mixtures of volatile organic compounds, obtained by hydrodistillation, steam distillation, or microwave-assisted dry distillation (Fokou et al., 2020). Essential oils and natural volatiles are among the most used and thriving products in the industry. They find extensive use as flavoring agents, in the cosmetic industry (in lotions and shampoos, and in preparations for revitalizing skin and hair), and can be used as antipathogenic agents in agriculture (Raveau et. al, 2020). They are also utilized in the industry of perfumes, candles, soaps, and sterilizing liquids, and play an important role in both conventional and medical aromatherapy. The distinctive flavor, odor, or scent of an aromatic plant originates from essential oils. Essential oils represent a mixture of a large

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number of structurally diverse compounds, which are typically divided into different classes based on their chemical structure and biosynthetic origin (terpenes and phenylpropanoids).

Established by Linnaeus in 1735, the genus *Bupleurum* constitutes a diverse collection of flowering plants within the Apiaceae family, commonly known as the carrot or parsley family. Globally, it includes approximately 248 recognized species, widely dispersed across the Northern Hemisphere. The genus name, *Bupleurum*, traces its origins to the Latin term "boupleuron," where "bous" signifies "ox" and "pleura/on" pertains to "rib." This nomenclature is attributed to the distinctive shape of the roots, a frequently utilized part of the plants.

The roots of several different plant species are mentioned under the name Chaihu in traditional Chinese medicine for the treatment of the common cold, four of which belong to *Bupleurum* (Pan, 2020). *B. falcatum* and *B. chinense* have the greatest ethnopharmacological application, so today they are extensively cultivated in China, Japan, and Korea. Until now, extracts of various species of the genus *Bupleurum* have been most often chemically investigated, which resulted in the isolation of a large number of chemically diverse compounds (Ashour & Wink, 2010). Saikosaponins are the principal ingredient of the roots of *Bupleurum* species (up to 7% of the total dry weight of roots), showing a plethora of different biological properties (hepatoprotective, antipyretic, anti-inflammatory, antivirus, sedative, antidepressive, etc.) Lignans represent the second most abundant group of secondary metabolites of this genus, with more than 50 distinct compounds identified, and can be distinguished into four groups, depending on the way the two phenylpropanoid units are bridged. The most frequently encountered compounds are dibenzylbutyrolactone derivatives, arylnaphthalenes, aryltetralinelactones, and tetrahydrofurofuranes. In addition to saikosaponins and lignans, a large number of structurally different polyacetylenes, coumarins, and flavonoids were also identified in the extracts of plant species of this genus. The chemical composition of essential oils derived from these plant species has been insufficiently explored. The following is a review of the current knowledge in this area.

2. Composition Of The Essential Oil of Different Plant Species of the Genus *Bupleurum*

The following section summarizes the results of previous studies on the chemical composition of essential oils from different taxa within the genus *Bupleurum* (Table 1). According to Neeves & Watson (2004), ten infrageneric classification systems were published since the early days, chronologically: Grenier & Godron (1848), Boissier (1872), Briquet (1897), Drude (1898), Calestani (1905), Wolff (1910), Koso-Poljanski (1913), Cerceau-Larrival (1962), Tutin (1968), and Cauwet-Mark (1976). The first comprehensive and thorough revision by Wolff (1910) (including the sections, subsections, and series) is still among the most widely used ones (Neeves & Watson, 2004). Therefore, Table 1 follows Wolff's infrageneric classification system of the genus *Bupleurum*, while for the species described after this publication, infrageneric categories reflect the classification system suggested in the relevant literature (marked with an asterisk in Table 1). Subgenus category is annotated for the species included in the recent revisions by Neeves & Watson (2004) and Wang et al. (2011).

The summarized research, detailed in Table 1, encompasses essential-oil compositions derived from different plant organs, including roots, leaves, flowers, fruits, and entire aerial parts. Various extraction methods were employed, such as hydrodistillation, steam distillation, microdistillation, and solvent-free microwave extraction, among others. Notably, the yield of essential oil and its composition varied based on the plant species, the plant organ subjected to isolation and isolation method, and all available results are comprehensively presented in Table 1.

The main components of the essential oils of species from the genus *Bupleurum*, isolated from the aerial parts, belong to the class of mono- and sesquiterpenes. The most abundant monoterpene hydrocarbons identified in the essential oils of plants from this genus are *α*- and *β*-pinene, p-cymene, limonene, sabinene, *α*- and *β*-phellandrene, *γ*-terpinene, etc. (Fig. 1). The most dominant oxygenated monoterpenes are 1,8-cineole, terpinen-4-ol, cryptone, dihydrocarveol, etc. (Fig. 2).

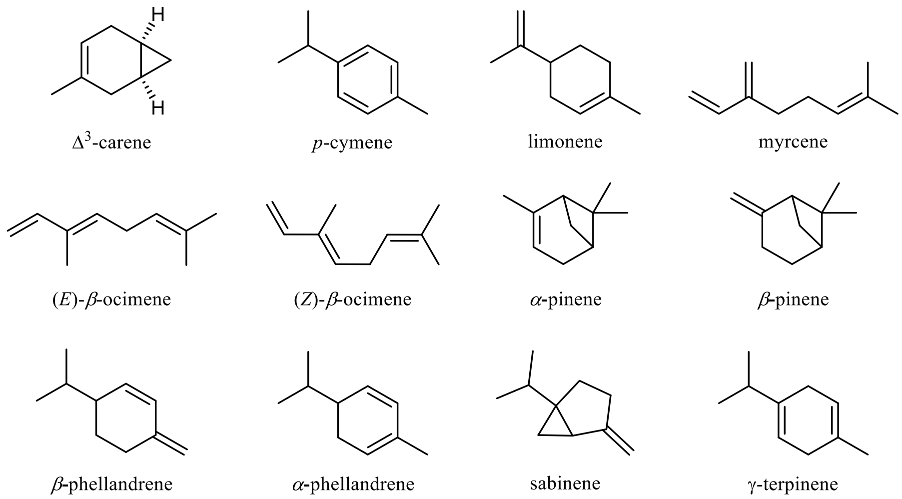

Fig. 1 Main monoterpene hydrocarbons found in the essential oils of *Bupleurum* species

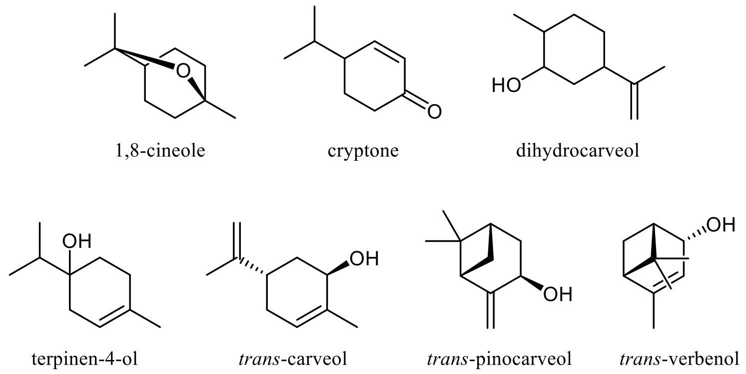

Fig. 2 Main oxygenated monoterpenes found in the essential oils of *Bupleurum* species

Sesquiterpene hydrocarbons and oxygenated sesquiterpenes detected in the essential oils are germacrene D, bicyclogermacrene, calarene, *α*-copaene, bulnesol, elemol, caryophyllene oxide, torilenol, etc. (Fig. 3).

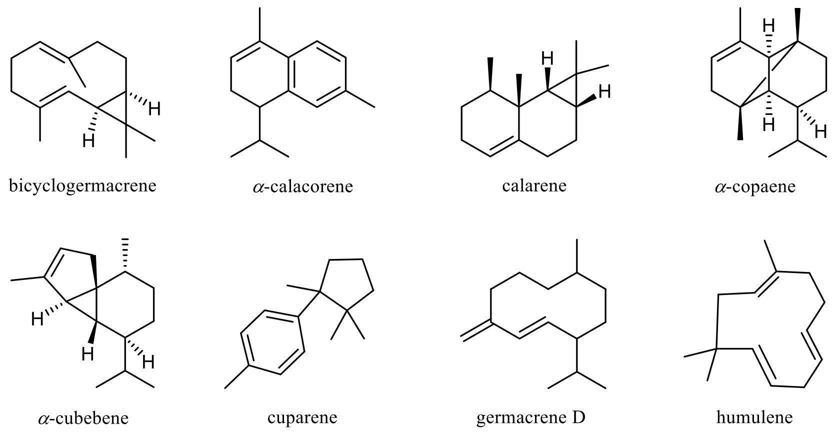

Fig. 3 Main sesquiterpene hydrocarbons found in the essential oils of *Bupleurum* species

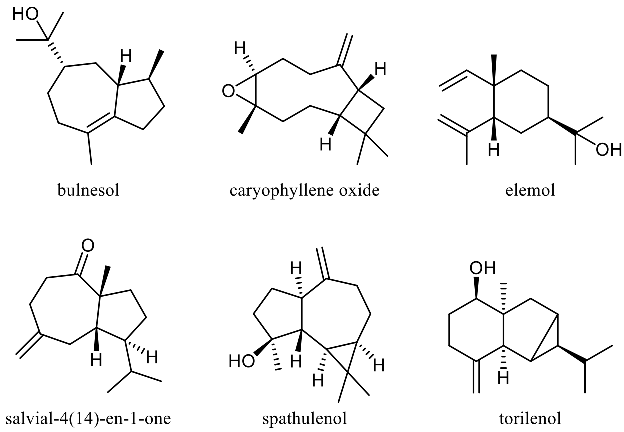

Fig. 4 Main oxygenated sesquiterpene and related compounds found in the essential oils of *Bupleurum* species

On the other hand, the root essential oils are rich in aldehydes (hexanal, heptanal, furfural), hydrocarbons (undecane), long-chain alcohols (1-hexadecanol), and acids (dodecanoic and hexadecanoic acid) and esters (geranyl acetate, citronellyl acetate, isoamyl valerate, Fig. 5). Phenylpropanoids have been detected in the essential oils but in significantly lower percentages, with the most abundant being methyleugenol and estragole (Fig. 6).

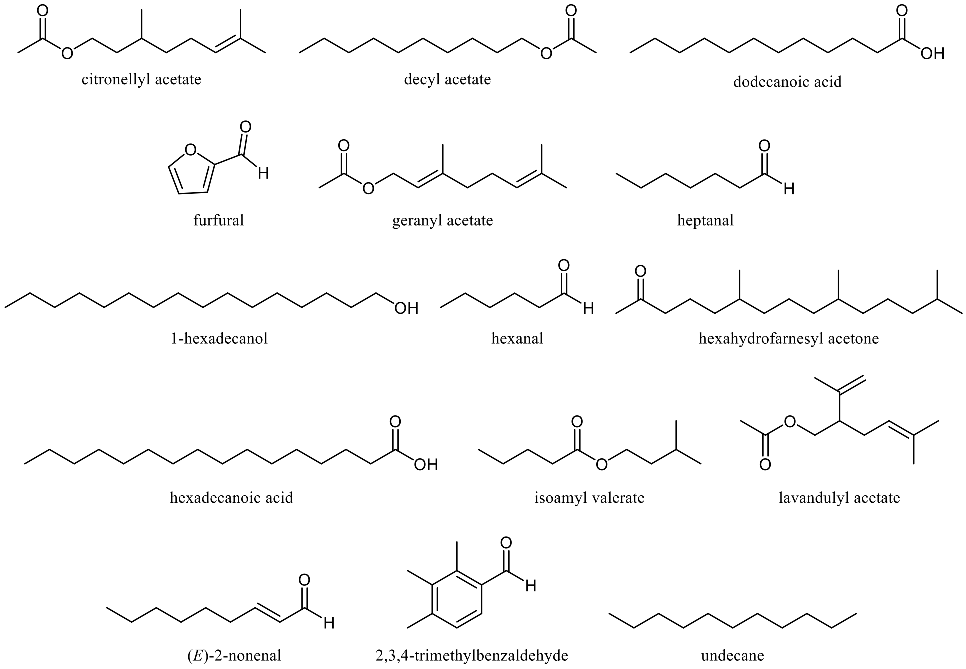

Fig. 5 Main aldehydes, alcohol, acids, hydrocarbons, and esters found in the essential oils of *Bupleurum* species

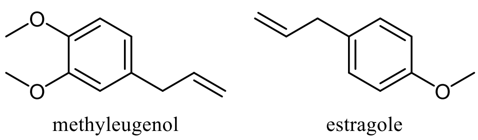

Fig. 6 Main phenylpropanoids found in the essential oils of *Bupleurum* species

Table 1 Data on the investigated *Bupleurum* taxa for the content of essential oils

Plant species[a]	Subgenus[b] Section[c] Subsection Series	Plant parts	Location	Collection time	Yield (%)	Const. Iden.[d] (%)	Reference
B. aureum Fisch. ex Hoffm.	*Bupleurum* *Longifolia* Wolff. - -	Stems[e]	Krasnoyarsk, Russia	Flowering phase 2013	0.07	99.0	Zykova et al., 2013
		Leaves[e]			0.12	96.0	
		Flowers[e]			0.22	99.6	
		Fruits[e]			-	77.3	
		Roots[e]			-	82.7	
B. bicaule Helm	*Bupleurum* *Eubupleura* Briq. *Nervosa* Godr. ex pte. *Falcata* Wolff.	Roots[f]	Hailar, China	August 2016	0.04 (*v*/*w*)	85.5	Wei et al., 2018
		Roots[e]	Neimeng, Mongolia	October 2003	0.081 (*w*/*w*)	-	Li et al., 2007
B. candollei Wall. ex DC.	*Bupleurum* *Eubupleura* Briq. *Nervosa* Godr. ex pte. *Falcata* Wolff.	Aerial parts[f]	Nainital, India	-	0.2 (*v*/*w*)	91.8	Joshi and Pande, 2008
B. cappadocicum Boiss.	- *Eubupleura* Briq. *Juncea* Briq. -	Flowers[g]	Karaman, Turkey	May–August 2009	-	96.8	Saraçoğlu et al., 2012
		Fruits[e]			-	94.3	
		Roots[e]			-	96.6	
B. chinense DC.	*Bupleurum* *Eubupleura* Briq. *Nervosa* Godr. ex pte. *Falcata* Wolff.	Roots[e]	Liaoning, China	October 2003	0.055 (*w*/*w*)	-	Li et al., 2007
Radix Bupleuri Chinensis		Leaves[f]	Sichuan Province, China	-	-	-	Meng et al., 2014
		Flowers[f]			-	-	
		Stems[f]			-	-	
		Roots[f]			-	-	
		Fruits[f]			-	-	

B. chinense DC. f. vanheurckii (Muell.-Arg.) Shan et Y.Li (syn. *B. chinense* DC.)	*Bupleurum* *Eubupleura* Briq. *Nervosa* Godr. ex pte. *Falcata* Wolff.	Plant parts used for the preparation of decocts[f]	Kunyu Mountain, China	August 2010	-	93.3	Ze-Kun et al., 2012
B. croceum Fenzl	- *Perfoliata* Godr. *Laevia* Briq. -	Flowers[e]	Konya, Turkey	May–August 2009	-	96.3	Saraçoğlu et al., 2012
		Fruits[e]			-	84.1	
		Roots[e]			-	93.6	
B. falcatum L.	*Bupleurum* *Eubupleura* Briq. *Nervosa* Godr. ex pte. *Falcata* Wolff.	Aerial parts[e]	Semnan Fullad Mahaleh, Iran	April–June 2011	-	98.8	Abolfazl et al., 2013, 2014
		Aerial parts[e]	Talaghan area, Iran	June 2007	0.2 (*w*/*w*)	90.0	Rustaiyan et al., 2010
		Flowers[e]	Semnan, Fullad mahaleh, Iran	April–June 2011	-	98.8	Mohammadi et al., 2014
B. falcatum L. subsp. *cernuum* (Nyman) Arcang.	*Bupleurum* *Eubupleura* Briq. *Nervosa* Godr. ex pte. *Falcata* Wolff.	Flowers[g]	Konya, Turkey	May–August 2009	-	85.2	Saraçoğlu et al., 2012
		Fruits[g]			-	89.5	
		Roots[e]			-	88.8	
		Aerial parts[e]	Khorasan province, Iran	May 2004	0.1	97.3	Sajjadi, 2008
B. fruticosum L.	*Penninervia* S.S.Neves & M.F.Watson *Coriacea* Godr. - -	Stems, leaves and flowers[f]	Mt. Parnon, Greece	-	14.91 ml/kg	-	Evergetis et al., 2014
		Leaves and flowering umbels[e]	Cerca de Santa Comba, Portugal	During flowering	0.8	99.0	Maxia et al., 2011
		Leaves and umbels containing ripe fruits[e]		During fruiting	1.1	96.9	
		Leaves[e]	Baunei, Italy	Before flowering	1.0	96.3	
		Leaves and flowering umbels[e]		During flowering	1.8	92.3	
		Leaves and umbels containing ripe fruits[e]		During fruiting	2.6	96.1	

	Aerial parts[f]	Corsica, France	-	-	97.8	Liu et al., 2009
	Flowers[e]		-	1.1	95.9-97.9	
	Leaves and stems[e]		-	1.6		
	Flowers[e]		-	1.3		
	Leaves and stems[e]		-	2.2		
	Aerial parts[e]		-	1.71	92.6-96.6	
	Aerial parts[h]		-	0.21		
	Aerial parts[e]		-	1.86		
	Aerial parts[h]		-	0.25		
	Aerial parts[e]		May 2005	1.2		
	Aerial parts[e]		July/September 2005	2.9		
	Aerial parts[e]		November 2005	2.6		
	Aerial parts[e]		May 2005	0.8		
	Aerial parts[e]		July/September 2005	2.4		
	Aerial parts[e]		November 2005	2.4		
	Fruits[e]	Villeneuve les Corbieres, France	August 2000	2.5 (*v*/*w*)	98.2	Chizzola, 2008
	Stems[e]	Botanical Garden of the University of Urbino, Faculty of Pharmacy, Italy	April 2000	1.8 (*v*/*w*)	90.0	Bertoli et al., 2004
	Leaves[e]			3.0 (*v*/*w*)	98.4	
	Micropropagated plants[e]			0.1 (*v*/*w*)	99.3	
	Upper portions of blooming[e]	Ras-el-Hylal area, Libya	April 1993	3 ml/ 120 g	-	Giamperi et al., 1998
	Stems[e]	Cultivated in the garden of the Institute of Botany (University of Urbino, Italy)	August 1991	3.6 (*v*/*w*)	-	Manunta et al., 1992
	Leaves[e]			2.3 (*v*/*w*)	-	

		Fruiting apexes[e]	Sierra Cogollos mountains, Spain	September 1985	1.85 (*v/w*)	-	Lorente et al., 1989
		Leaves[e]	Tuscan population, Italy	Winter 2019	0.52	100	Roma-Marzio et al., 2020
		Stems[e]			0.07	99.9	
		Fruits[e]			0.26	100	
		Leaves[e]		Summer 2019	0.82	100	
		Steems[e]			Very low yield	100	
		Fruits[e]			Very low yield	99.3	
		Fruits[e]			0.10 (*w/w*)	81.2	
B. fruticescens L.	*Bupleurum* *Eubupleura* Briq. *Rigida* Drude. -	Flowering apexes[e]	Sierra Baza mountains, Spain	May 1989	0.055 (*w/w*)	-	Martin et al., 1993
B. gerardi All.	*Bupleurum* *Eubupleura* Briq. *Juncea* Briq. -	Flowers[g]	Konya, Turkey	May–August in 2009	-	81.2	Saraçoğlu et al., 2012
		Fruits[g]			-	83.0	
		Roots[g]			-	83.2	
		Aerial parts[e]	Bojnourd, Iran	June 2006	0.25 (*w/w*)	96.2	Rustaiyan et al., 2010
		Aerial parts[i]	Şaban village, Turkey	June 2013	-	91.7	Kiliç, 2014
B. gibraltaricum Lam.	*Penninervia* S.S.Neves & M.F.Watson *Coriacea* Godr. - -	Leaves[f]	El Zumbel area, Jaén, Spain	May 1996	1.2	-	Fernandez-Oscana et al., 2006
		Stems[f]			0.3	-	
		Aerial parts[f]			1.0	-	
		Leaves[f]		July 1996	0.8	-	
		Stems[f]			0.5	-	
		Umbels[f]			3.7	-	
		Aerial parts[f]			0.9	-	
		Leaves[f]		September 1996	1.8	-	
		Stems[f]			0.7	-	

		Umbels[f]			2.2	-	
		Aerial parts[f]			1.9	-	
		Leaves[f]		November 1995	1.1	-	
		Stems[f]			0.5	-	
		Umbels[f]			3.4	-	
		Fruits[f]			4.0	-	
		Aerial parts[f]			0.8	-	
		Aerial parts[f]	Jaén, Spain	September 1996	1.91	93.6	Fernandez-Oscana et al., 2004
		Aerial parts[e]	Puente de la Sierra, Jaén, Spain	November 1995	1.3 mL %	95.9	Velasco-Negueruela et al., 1998
		Umbel rays[e]			2.0	95.8	
		Stems[e]			0.4	96.8	
		Leaves[e]			1.6	98.3	
		Fruits[e]			2.2	98.9	
		Aerial parts[e]	Sierra Cazulas, Spain	August 1985	2.80 (*w*/*w*)	-	Ocete et al., 1989
B. hamiltonii N.P.Balakr.	*Bupleurum* *Eubupleura* Briq. *Nervosa* Godr. ex pte. *Falcata* Wolff.	Aerial parts[f]	Nainital, Uttarakhand, India	August 2009	0.2–0.3 (*v*/*w*)	92.8	Pande et al., 2012
B. heldreichii Boiss. & Balansa	- *Perfoliata* Godr. *Rugosa* Briq. -	Flowers[e]	Konya, Turkey		-	97.5	Saraçoğlu, 2011
		Fruits[e]			-	96.1	
		Roots[e]			-	98.2	
B. intermedium Steud. (syn. *B. subovatum* Link ex Spreng.)	- *Perfoliata* Godr. *Rugosa* Briq. -	Flowers[g]	Karaman, Turkey	May–August in 2009	-	93.6	Saraçoğlu et al., 2012
		Fruits[e]			-	94.0	
		Roots[g]			-	89.1	

B. lancifolium Hornem.	*Bupleurum*	Flowers[e]	Karaman, Turkey	May–August in 2009	-	89.8	Saraçoğlu et al., 2012
	**Bupleurum*	Fruits[e]			-	90.4	
	**Bupleurum*	Roots[e]			-	91.2	
	-						
B. longicaule Wall. & DC. var. *giraldii* H.Wolff	*Bupleurum* *Eubupleura* Briq. *Nervosa* Godr. ex pte. *Ranunculoidea* Wolff.	Roots[e]	Qinghai, China	October 2003	0.049 (*w/w*)	-	Li et al., 2007
B. longiradiatum Turcz.	*Bupleurum* *Longifolia* Wolff. - -	Roots[e]	crude drug market in Xi'an Shaanxi Province China	-	0.02 (*w/w*)	99.3	Shi et al., 2010
B. lycaonicum Snogerup	**Agostana*[j]	Flowers[g]	Konya, Turkey		-	88.4	Saraçoğlu, 2011
	-	Fruits[e]			-	88.2	
	-	Roots[e]			-	81.2	
	-						
B. malconense R.H.Shan & Yin Li	*Bupleurum*[k] - - -	Roots[e]	Sichuan, China	October 2003	0.014 (*w/w*)	-	Li et al., 2007
B. marginatum Wall. ex DC.	*Bupleurum* *Eubupleura* Briq. *Nervosa* Godr. ex pte. *Falcata* Wolff.	Roots[e]	Anhui, China	October 2003	0.020 (w/w)	-	Li et al., 2007
		Aerial parts[e]	Commercially obtained aerial parts	-	0.053	94.29	Ashour et al., 2009
		Aerial parts[e]		-	0.094	-	
B. microcephalum Diels	*Bupleurum* *Eubupleura* Briq. *Nervosa* Godr. ex pte. *Falcata* Wolff.	Roots[e]	Sichuan, China	October 2003	0.010 (*w/w*)		Li et al., 2007

B. montanum Coss. & Durieu	*Bupleurum* *Eubupleura* Briq. *Rigida* Drude. -	Aerial parts[e]	Megress Mountain, Algeria	May 2008	0.3	98.6	Laouer et al., 2009
B. multinerve DC.	*Bupleurum* *Eubupleura* Briq. *Nervosa* Godr. ex pte. *Ranunculoidea* Wolff.	Aerial parts[e]	Terelj, Hentii mountains, Mongolia	August–September 2010	0.35 (*w*/*w*)	-	Altantsetseg et al., 2012
B. odontites L.	*Bupleurum* *Eubupleura* Briq. *Glumacea* Boiss. *Fenestrata* Wolff.	Flowers[e]	Accia, Sicily, Italy	June 2014	0.12 (*w*/*w*)	96.6	Casiglia et al., 2016
		Fruits[e]			0.10 (*w*/*w*)	81.2	
B. pauciradiatum Fenzl	- *Bupleurum[1] *Juncea -	Flowers[e]	Karaman, Turkey		-	94.9	Saraçoğlu, 2011
		Fruits[e]			-	92.8	
		Roots[e]			-	93.0	
B. plantagineum Desf.	*Bupleurum* *Eubupleura* Briq. *Rigida* Drude. -	Leaves[i]	-	December 2016	-	91.1	Mékaoui et al., 2020
		Stems[i]			-	76.0	
		Roots[i]			-	88.0	
		Aerial parts[e]			0.18	98.8	
		Aerial parts[e]	Cap Carbon site, Algeria	May 2008	0.21	99.8	Laouer et al., 2009
B. praealtum L.	*Bupleurum* *Eubupleura* Briq. *Juncea* Briq. -	Air-dried plant material[f]	Sokobanja-Ozren, Serbia	June 2003	-	86.5	Kapetanos et al., 2008
B. rigidum L. subsp. *paniculatum* (Brot.) H. Wolff.	*Penninervia* *S.S.Neves & M.F.Watson* *Eubupleura* Briq. *Marginata* Godr. ex pte. -	Aerial parts[e]	Montes de Toledo, Spain	June 1996	0.94	97.6	Pala-Paul et al., 1999

B. rotundifolium L.	*Bupleurum Perfoliata* Godr. *Laevia* Briq.	Aerial parts[i]	Dikme plateau, Turkey	June 2013	-	90.8	Kiliç, 2014
	-	Roots[e]	-	-	-	74.2	Nageswara et al., 2012
		Flowers[e]			-	81.5	
		Fruits[e]			-	83.6	
		Roots[e]	Konya, Turkey	June and July 2009	-	74.2	Akin et al., 2012
		Flowers[e]			-	81.9	
		Fruits[e]			-	83.8	
B. scorzonerifolium Willd.	*Bupleurum Eubupleura* Briq. *Nervosa* Godr. ex pte. *Falcata* Wolff.	Aerial parts[e]	Sotnikovo village, Russia	June 2014–August 2017	1.66 (*v/w*)	-	Tykheev et al., 2018
					0.3	-	
					0.62	-	
			Ivolga village, Russia		0.38	-	
			Zagustay arbor, Russia		0.80	-	
			Georgievka village, Russia		0.18	-	
			Oninoborsk village, Russia		0.33	-	
			Shiringa village, Russia		0.31	-	
			Nyzhniy Tsasuchey village, Russia		0.32	-	
			Bayan Ulaan Uul mountain, Russia		0.31	-	
					0.51	-	
			Berkh territory, Russia		0.38	-	
					0.51	-	
			Berkh territory, Russia		0.33	-	
			Huh nuur Lake, Russia		0.34	-	
		Roots[e]	Dongbei, China	October 2003	0.068 (*w/w*)	-	Li et al., 2007

		Aerial parts[e]	Terelj, Hentii mountains, Mongolia	August–September 2010	0.15 (*w*/*w*)	-	Altantsetseg et al., 2012
B. sibiricum Vest ex Roem. & Schult.	*Bupleurum* *Eubupleura* Briq. *Nervosa* Godr. ex pte. *Ranunculoidea* Wolff.	Aerial parts[e]	Zuunharaa, Turkey	August–September 2010	0.24 (*w*/*w*)	-	Altantsetseg et al., 2012
B. sibthorpianum Sm.	- *Eubupleura* Briq. *Nervosa* Godr. ex pte. *Falcata* Wolff.	Air-dried plant material[f]	Kopaonik, Serbia	June 2003	-	91.2	Kapetanos et al., 2008
B. smithii H.Wolff. var. *parvifolium* R.H.Shan & Yin Li	*Bupleurum*[k] - -	Roots[e]	Neimeng, China	October 2003	0.052 (*w*/*w*)	-	Li et al., 2007
B. sulphureum Boiss. & Balansa	- *Eubupleura* Briq. *Glumacea* Boiss. *Aristata* Godr.	Flowers[e]	Konya, Turkey		-	91.0	Saraçoğlu, 2011
		Fruits[e]			-	77.3	
		Roots[e]			-	82.7	
B. turcicum Snogerup	- *Eubupleura* Briq. *Trachycarpa* Lange. -	Flowers[e]	Konya, Turkey			93.8	Saraçoğlu, 2011
		Fruits[e]				94.9	
		Roots[e]				93.0	
B. wenchuanense R.H.Shan & Yin Li	*Bupleurum*[k] - - -	Roots[e]	Sichuan, China	October 2003	0.015 (*w*/*w*)	-	Li et al., 2007
B. yinchowense R.H.Shan & Yin Li	*Bupleurum*[k] - - -	Roots[e]	Shanxi, China	October 2003	0.050 (*w*/*w*)	-	Li et al., 2007

[a]The names are harmonized with the World Flora Online (worldfloraonline.org); [b]Neves and Watson, 2004; [c]Wolff, 1910; [d]constituents identified; [e]essential oil was obtained by hydrodistillation; [f]essential oil was obtained by steam distillation; [g]essential oil was obtained by microdistillation; [h]essential oil was obtained by solvent-free microwave extraction; [i]essential oil was obtained by head-space solid phase microextraction; [j]Tykheev et. al, 2020; [k]Wang et. al, 2011; [l]Snogerup and Snogerup, 2001.

It has been shown that in the flowering phase of *B. aureum*, the essential oil of leaves and flowers predominantly consists of sesquiterpene hydrocarbons, oxygen-containing compounds are contained mainly in the essential oil of the leaves of *B. aureum*, while the most abundant compounds in the essential oil of stems are monoterpenes and hydrocarbons (Zykova et al., 2013). The main components of the essential oil of the stems are *β*-pinene (9.0%), *β*-caryophyllene (18.7%), and undecane (12.4%), in the leaf essential oil *β*-caryophyllene (19.6%) and bicyclosesquiphellandrene (8.5%). *β*-Caryophyllene (28.0%), *β*-pinene (10.6%), and *n*-undecane (8.4%) are the main components of the essential oil of *B. aureum* flowers.

The root essential oil of *B. bicaule* was analyzed twice, from different localities, China and Mongolia (Wei et al., 2018, Li et al., 2007).

Saraçoğlu and co-workers investigated the chemical composition of the fruit, flower, and root essential oil of *B. cappadocicum* (Saraçoğlu et al., 2012). Heptanal (46.5%) and undecane (36.6%) were the main components in the flower oil of *B. cappadocicum*, while in the fruit oil, undecane (50.3%) and spathulenol (7.4%) were the predominant constituents. In the essential oil isolated from roots, the main constituents were undecane (23.1%) and hexadecanoic acid (14.2%).

The results of the analysis of the essential oil of the roots (Li et al., 2007) and the whole plant (Ze-Kun et al., 2012) of *B. chinense* are available in the literature. While the oil isolated from the roots contained mostly hexanal (29.5%), furfural (7.3%), and hexanoic acid (7.4%), one of the predominant constituents in the essential oil isolated from the whole plant was germacrene D (14.8%).

In total, 38 (flower), 29 (fruit), and 12 (root) constituents were identified and quantified in the various parts of *B. croceum*, respectively. In the flower oil of *B. croceum*, germacrene D (12.7%) and *α*-pinene (9.0%) were the main constituents. The flower essential oil was comprised of sesquiterpene hydrocarbons (26.2%), oxygenated sesquiterpenes (21.5%), alkanes (21.0%), monoterpene hydrocarbons (19.1%), 'others' (7.5%) and oxygenated monoterpenes (1.0%). As for the fruit oil of *B. croceum*, the main constituents were undecane (13.0%) and tetradecanoic acid (11.9%). Furthermore, the fruit essential oil was composed of alkanes (23.9%), fatty acid esters (20.1%), monoterpene hydrocarbons (13.4%), 'others' (13.2%), oxygenated sesquiterpenes (8.5%), sesquiterpene hydrocarbons (2.8%), diterpenes (1.3%), and oxygenated monoterpenes (0.9%). In the root oil of *B. croceum*, hexadecanoic acid (34.8%) and heptacosane (19.8%) were the main constituents. The root essential oil was comprised of alkanes (50.8%), fatty acid esters (36.6%), 'others' (3.9%), and oxygenated sesquiterpenes (2.6%).

A comparison of the chemical composition of the essential oils isolated from aerial parts (Abolfazl et al., 2013, 2014; Rustaiyan et al., 2010) and flowers (Mohammadi et al., 2014) of *B. falcatum* from Iran is presented in Table 2. Abolfazl and co-workers noted torilenol (39.1%), spathulenol (19.6%), and *α*-cubebene (8.1%), while the most abundant compounds in the essential oil analyzed by Rustaiyan were *α*-pinene (29.4 %) and spathulenol (27.7 %), although the percentage of identified constituents was lower (Table 1). The flower essential oil was chemically the same (Mohammadi et al., 2014) as the one described by Abolfazl (2013, 2014).

Table 2 The major constituents in the essential oil of *B. falcatum*

Constituent	Aerial parts		Flowers	Fruits	Roots	Flowers
α-Calacorene	2.4	0.8	2	1.9	5.4	2.4
Caryophyllene oxide	-	6.1	-	-	-	-
α-Copaene	-	0.6	-	6.8	3.9	-
α-Cubebene	8.1	-	4.3	0.3	-	8.1
Cuparene	2.8	-	2.2	2.9	1.4	2.8
(*E*,*E*)-2,4-Decadienal	-	-	-	-	6.9	-
Heptanal	4.2	-	4.3	7.3	2.1	4.2
Hexanal	-	-	-	2.9	7.1	-
3-(*Z*)-Hexenyl benzoate	-	4.8	-	-	-	-
Lavandulyl acetate	-	6.7	-	-	-	-
2-Pentylfuran	-	-	-	0.8	23.1	-
α-Pinene	3.5	29.4	41.2	42.4	1.7	3.5
trans-Pinocarveol	4.1	-	2.8	1.2	-	4.1
Spathulenol	19.6	27.7	10.4	8.5	7.2	19.6
Torilenol	39.1	-	-	-	-	39.1
Reference	Abolfazl et al., 2013, 2014	Rustaiyan et al., 2010	Saraçoğlu et al., 2012			Mohammadi et al., 2014

The essential oil of *B. fruticosum* has been analyzed numerous times (Table 3). Liu and co-workers investigated the relationship between the plant's vegetative development and the oil composition (Liu et al., 2009). No significant variation in the chemical composition was observed; all essential oils were rich in *β*-phellandrene (over 70%) and contained significant amounts of *α*-phellandrene, limonene, and *α*-pinene.

The essential oils from Italian *B. fruticosum* were characterized by high amounts of *β*-phellandrene (57.8-71.4%) and sabinene (12.1-13.9%). Significant quantitative variations were observed in the oils from Sardinian species during different vegetative phases, with an increase in *β*-phellandrene and sabinene (Maxia et al., 2011). In contrast, the chemical composition of Portuguese *B. fruticosum* differed significantly, with *α*-pinene and *β*-pinene constituting over 70% of the total oil. Sardinian and Portuguese *B. fruticosum* were found to belong to different chemotypes, with the former showing similarities to oils from other Mediterranean regions, while the latter aligned with *α*-pinene/*β*-pinene chemotypes reported in Spain (Lorente et al., 1989).

Table 3 The major constituents in the essential oil of *B. fruticosum*

Sample[a]	*trans*-Carveol	1,8-Cineole	Citronellyl acetate	Cryptone	*p*-Cymene	Estragole	Geranyl acetate	Limonene	Myrcene	(*Z*)-*β*-Ocimene	*α*-Phellandrene	*β*-Phellandrene	*α*-Pinene	*β*-Pinene	Sabinene	*γ*-Terpinene	*α*-Thujene
A[b]	0.6	-	-	4.3	1.7	0.2	3.0	-	1.8	-	1.0	57.8	1.4	0.1	12.1	0.4	-
B[b]	-	-	-	0-2	0.9-2.7	0-tr	-	-	2.2-2.6	0.9-1.0	0.1-1.2	7.8-68.5	1.5-37.3	0-33.0	1.0-12.2	0-1.7	0-1.3
C[b]	-	-	-	-	0.7-2.7	-	-	-	1.6-2.4	-	0.1-1.7	6.2-71.4	1.4-42.7	0-33.5	2.5-13.9	0.5-1.4	-
D[c]	-	-	-	-	-	4.8-6.6	1.7-2.3	5.5	2.0	-	3.0	71.3-71.8	1.5-1.6	-	1.0-2.5	-	-
E[c]	-	-	-	-	-	tr	1.2-2.4	5.7-6.0	2.3	-	3.3-3.4	77.3-79.1	1.9-2.0	-	1.1-1.5	-	-
F[c]	-	-	-	-	0.2-0.3	-	0.8-1.6	6.1	2.3-2.4	-	3.3-3.4	79.1-79.7	2.1	0.3-0.4	1.0	-	-
G[c]	-	-	-	-	2.8-3.5	-	1.2-2.5	5.9-6.1	2.0	-	2.8-3.5	76.8-77.5	1.1-1.3	0.2-0.3	0.7-0.9	-	-
H[c]	-	-	-	0.3-0.8	0.3	-	1.2-1.8	5.6-5.8	2.1-2.3	-	2.6-3.0	72.8-75.7	1.9-2.0	-	1.5-7.3	0.1-0.3	-
I[c]	-	-	-	-	0.1-0.2	-	1.5-1.6	5.4-5.8	2.1-2.3	-	3.0-3.5	73.6-78.3	1.8-2.0	-	1.2-6.0	0.1-0.3	-
J[c]	-	-	-	0.2-2.1	0.5-0.6	-	1.9-2.1	5.4-5.9	2.0-2.2	-	2.3-2.5	70.4-71.6	1.8-1.9	-	1.2-8.2	0.2-1.4	-
K[d]	-	-	-	tr	0.9	-	-	-	1.9	0.3	0.2	7.4	35.4	39.1	-	0.6	2.3
L[e]	2.7	-	3.8	-	0.9	-	tr	tr	tr	0.75	18.3	1.6	0.3	-	7.1	49.8	tr
M[e]	tr	-	0.3	-	0.9	-	0.3	3.0	2.9	0.1	2.9	41.7	1.9	0.6	35.7	0.8	tr
N[e]	tr	-	0.8	-	2.9	-	0.7	tr	2.1	0.8	2.6	60.9	0.1	0.5	12.8	1.4	0.1
O[f]	-	-	4.2	-	2.0	-	-	-	-	1.3	12.2	-	-	-	12.0	48.8	-
P[f]	-	-	-	-	-	-	-	5.0	2.5	-	-	38.7	2.6	0.4	39.7	-	-
Q[g]	-	4.1	-	-	2.9	tr	-	4.1	3.1		3.1	-	41.2	35.9	-	2.5	-
R[h]	-	-	-	-	0.2	-	-	0-tr	1.0-1.1	2.4-3.9	0.1-0.2	7.9-11.2	35.6-41.4	35.1-37.5	2.1-2.2	0.5-0.8	1.2-1.3
S[h]	-	-	-	-	0.8-1.1	-	-	0-tr	0.8-1.1	0-tr	0-0.4	8.9-20.6	30.7-33.6	35.4-39.9	2.8-2.9	0.8	0.9-1.0
T[h]	0-0.1	-	-	0-0.7	1.2-2.9	-	-	0-tr	1.1-1.4	13.5-19.2	0.5-0.7	15.4-19.3	15.9-22.2	18.4-22.0	2.1-2.2	1.7-3.0	0.7-0.9

[a]A-Leaves; B-Leaves and flowering umbels; C-Leaves and umbels containing ripe fruits; D-Flowers; E-Leaves and stems; F-Aerial parts (hydrodistillation); G-Aerial parts (solid phase microextraction); H-Aerial parts (before flowering); I-Aerial parts (during flowering); J-Aerial parts after flowering; K-Fruits; L-Stems; M-Leaves; N-Aerial parts; O-Stems; P-Leaves; Q-Fruiting apexes; R-Leaves; S-Fruits; T-Stems;
[b]Maxia et al., 2011; [c]Liu et al., 2009; [d]Chizzola, 2008; [e]Bertoli et al., 2004; [f]Giamperi et al., 1998; [g]Lorente et al., 1989; [h]Roma-Marzio et al., 2020.

The essential oil of *B. fruticescens* was only analyzed once previously (Martin et al., 1993), and the major constituents were determined to be *β*-caryophyllene (30.5%) and *α*-pinene (16.9%).

All the essential oils of *B. gerardii*, whether isolated from the aerial parts or from individual plant organs, were characterized by a high content of undecane (Table 4). When comparing the compositions of oils from different parts of the plants, the most notable difference is observed in the content of hexanal, which is significantly higher in the root compared to the essential oils from flowers and fruits. Additionally, it is worth noting that *α*-pinene was not detected in the latter ones (Saraçoğlu et al., 2012). Furthermore, there is a significant disparity in the content of *α*-pinene, hexanal, and germacrene D between oils originating from Iran (Rustaiyan et al., 2010) and Turkey (Kiliç, 2014).

Table 4 The major constituents in the essential oil of *B. gerardii*

Constituent	Flowers	Fruits	Roots	Aerial parts	Aerial parts
Bicyclogermacrene	-	-	-	5.3	-
Calarene	2	-	3.9	-	-
Caryophyllene oxide	5.8	3.8	-	-	1.7
Germacrene D	-	-	-	11.1	2.7
Hexahydrofarnesyl acetone	8.8	9.6	-	-	-
Hexanal	8.2	6.1	21.7	-	19.9
Limonene	5.4	1.8	1	0.8	2.5
α-Pinene	-	-	17.9	0.7	15.8
β-Pinene				2.3	-
Spathulenol	2.5	2.3	2.9	3.9	0.4
Undecane	36.9	49.2	16.6	62.9	38.3
trans-Verbenol	-	-	3.3	-	-
Reference	Saraçoğlu et al., 2012			Rustaiyan et al., 2010	Kiliç, 2014

The investigation of Fernandez-Oscana and co-workers was focused on determining the yield and composition of essential oils derived from various parts of *B. gibraltaricum* throughout different vegetative stages, including pre-flowering, full flowering, late flowering, and fruiting periods (Fernandez-Oscana et al., 2006, Table 5). The highest oil content in the leaves (0.8–1.8% yield) and stems (0.3–0.7%) was observed during the late flowering period, while the oil yield of umbel rays (2.2–3.7%) reached its peak during full flowering. In the leaf oils, the predominant components were sabinene (12.0–33.9%), and limonene (7.8–23.4%), while the sabinene levels reached a minimum during full flowering and a maximum in the fruiting period. Stem oils featured sabinene (4.7–21.6%) and 2,3,4-trimethylbenzaldehyde (9.3–13.6%) as the main components, with sabinene being at a minimum in the pre-flowering and peaking in full flowering period. Umbel ray oils consistently had sabinene (20.7–43.1%) as the most abundant component across all phenological periods, followed by *α*-pinene (7.3–28.2%). Both monoterpenes increased

Table 5 The major constituents in the essential oil of *B. gibraltaricum*

Constituent	Leaves	Stems	Umbels	Fruits	Aerial parts	Aerial parts	Aerial parts	Aerial parts	Umbel rays	Stems	Leaves	Fruits
Bulnesol	0.9-4.0	3.2-6.2	0.2-0.9	-	1.3-2.2	1.3	-	2.1	0.3	3.4	0.1	-
Δ^3-Carene	-	-	-	-	-	0.1	33	tr	tr	-	tr	0.2
Elemol	1.8-2.1	1.3-7.2	0.1-1.0	-	1.4-4.3	1.4	-	4.3	0.6	5.5	0.5	0.1
Guaiol	1.1-3.5	2.8-5.8	0.3-1.7	-	3.1-6.2	3.6	-	5.3	0.6	5.4	0.3	0.1
Guaiol isomer	1.1-3.6	2.7-5.5	-	-	-	1.2	-	0.6	0.6	5.1	0.3	tr
Limonene	7.8-23.4	3.3-11.2	4.8-6.7	9	5.5-26.8	7.3	8.2	6.5	7.3	7.2	10	9
Myrcene	1.5-3.4	-	-	-	-	2.3	3.5	0.5	1.1	1.6	3.2	1.6
α-Pinene	5.6-11.7	1.0-7.0	7.3-28.2	42.7	4.9-15.6	15.6	10.5	5.9	17.6	6	13	42.7
Sabinene	12.0-33.9	4.7-21.6	20.7-43.1	28.3	7.4-31.1	31.1	-	9.2	33.8	21.8	50	28.3
Terpinen-4-ol	0.6-3.6	0.9-2.4	2.4-3.8	1.7	0.7-4.6	2.4	9	5.1	2.9	2.5	2.3	1.7
2,3,4-Trimethyl benzaldehyde	7.6-14.5	9.3-13.6	3.3-15.3	4.5	10.9-18.1	10.9	-	17.2	8.4	10.7	3.4	4.5
Reference	Fernandez-Oscana et al., 2006					Fernandez-Oscana et al., 2004	Ocete et al., 1989	Velasco-Negueruela et al., 1998				

during the late flowering and decreased to minimum levels in the fruiting stage. The biggest difference in the composition of the oil of the aerial parts was observed in the content of Δ^3-carene (0-33%, Table 5). The dominant constituents in the oil from the aerial parts, analyzed by Velasco-Negueruela, were found to be: 2,3,4-trimethylbenzaldehyde (17.2%), sabinene (9.2%), and limonene (6.5%). The major components of the umbel ray oil were: sabinene (33.8%), *α*-pinene (17.6%), and 2,3,4-trimethylbenzaldehyde (8.4%). The stem oil was characterized by the presence of *α*-pinene (6.0%), sabinene (21.8%), limonene (7.2%), 2,3,4-trimethylbenzaldehyde (10.7%), guaiol isomer (5.1%), elemol (5.5%), and guaiol (5.4%). The leaf oil had as the main components *α*-pinene (13.0%), sabinene (50%), and limonene (10.0%), whereas in the oil from the fruits, *α*-pinene (42.7%), sabinene (28.3%), and limonene (9.0%) were found to be the most important ones. If the composition of the oils from different parts of the plant were compared, it would be worth mentioning that sabinene was the most common component of all investigated oils, as well as that the stems contained a significantly higher amount of α-pinene compared to other parts of the plant (42.7%, Velasco-Negueruela et al., 1998).

The essential oil of the aerial parts of *B. hamiltonii* Balak (syn. *B. tenue* Buch.) from India consisted mainly of sesquiterpene hydrocarbons (61.9%), followed by monoterpene hydrocarbons (16.6%), oxygenated sesquiterpenes (7.9%) and oxygenated monoterpenes (6.2%). The most abundant constituents of this essential oil were determined to be germacrene D (17.8%), *trans-β*-farnesene (14.7%), and *trans*-caryophyllene (13.1%, Pande et al., 2012). An earlier report showed the presence of *α*-terpineol (21.02%), geranyl acetate (9.78%), and santene (8.70%) as the dominant constituents in the essential oil of *B. tenue* fruits from Pakistan (Ahmad et al., 1987).

The essential oil of *B. heldreichii* has been previously analyzed only once. Saraçoğlu gave a comparison of the composition of oils isolated from flowers, fruits, and roots. Germacrene D was the most dominant compound in the essential oils of the flowers and fruits, while it was not detected in the root essential oil, which was rich in hexadecanoic and tetradecanoic acids (Saraçoğlu, 2011).

In the literature, a comparison of the composition of the essential oil isolated from various plant organs of *B. lancifolium* has been provided (Saraçoğlu et al., 2012). The flower oil consisted of spathulenol (15.4%) and α-pinene (10.8%) as the main constituents. The most abundant constituents of fruit essential oil were hexacosane (13.0%), and pentacosane (12.0%). The root essential oil was comprised mostly of alkanes (43.3%), and fatty acid esters (21.2%), with the most dominant being hexadecanoic acid (13.9%) and heptacosane (12.0%).

The essential oil isolated from the flowers of *B. intermedium* was rich in methyl linoleate (21.2%) and germacrene D (16.4%), while the fruit oil comprised mostly of sesquiterpene hydrocarbons: germacrene D (25.9%) and *β*-caryophyllene (19.1%). Undecane (62.8%) and hexanal (8.1%) were the most abundant compounds in the essential oil isolated from the roots (Saraçoğlu et al., 2012).

Nineteen compounds were identified and quantified in the oil of *B. longicaule*, with hexanal (15.1%), and furfural (15.6%) as the main constituents (Li et al., 2007).

The analysis of the root essential oil of *B. longiradiatum* revealed the presence of 51 compounds, constituting 99.3% of the overall oil composition (Shi et al., 2010). Notably, the most abundant components of the oil were thymol (7.0%), butylidene phthalide (6.8%), heptanal (5.3%), and 4-hydroxy-2-methylacetophenone (5.3%).

Thirty-seven compounds were identified in the essential oil obtained from the flowers of *B. lycaonicum*, with tridecane (14.9%), spathulenol (8.0%), hexanal (6.3%), and germacrene D (6.2%) being the major components. In the essential oil isolated from the fruits, thirty-four compounds were identified, with spathulenol (14.4%), 1,5-epoxysalvial 4(14)-ene (7.3%), hexahydrofarnesyl acetone (6.2%), tridecane (4.8%), and caryophyllene oxide (4.8%) being the main constituents. The essential oil from the roots contained twelve compounds, with tridecane (37.3%), hexanal (23.8%), undecane (5.1%), and pentadecane (2.7%) identified as the major components. Oxygenated sesquiterpenes (29.3%–40.5%) were found in the essential oil from the flowers and fruits of *B. lycaonicum*, while alkanes (47.6%) were predominant in the essential oil from the roots (Saraçoğlu, 2011).

The essential oil of the roots of *B. malconense* has been previously analyzed only once, and furfural (13.2%) and *p*-cymenene (7.5%) were identified as the main components (Li et al., 2007).

The essential oil of *B. marginatum* has been analyzed twice so far. Li et al. (2007) identified seventeen components in the root oil of Chinese origin, with the most abundant being *p*-cymenene (9.2%), *p*-cymene (8.4%), and *cis*-linalool oxide (5.4%). Ashour and co-workers isolated the oil from the aerial parts of the commercially available plant material by hydrodistillation during either 6 or 24 hours, resulting in a significant difference in the yield of the essential oil (Table 1). The composition was provided only for the oil isolated after 6 hours, characterized by a high content of alkanes, with undecane (10.4%), tridecane (13.2%), and pentadecane (8.7%) being the most prevalent (Ashour et al., 2009).

Sixteen compounds were identified in the root oil of *B. microcephalum*, with cyperol (15.6%) and heptanal (6.4%) as the main constituents (Li et al., 2007).

The essential oil of the aerial parts of *B. montanum* from Algeria was characterized by a high content of megastigma-4,6-(*E*),8(2)-triene (25.3%), myrcene (17.2%), *α*-pinene (12.1%) and benzyl tiglate (7.7%).

Hydrodistillation of aerial parts of *B. multinerve* from Mongolia resulted in the isolation of the essential oil in moderate yield (0.35%, Altantsetseg et al., 2012). The oil was rich in monoterpenes, with (*E*)-*β*-ocimene (18.6%), myrcene (9.1%), and limonene (7.8%) being the most abundant ones.

Casiglia and co-workers provided a comparison of the composition of the essential oil of *B. odontites* (syn. *B. fontanesii*) isolated from flowers and fruits (Casiglia et al., 2016). Notably, the flower oil contained significant amounts of oxygenated sesquiterpenoids, accounting for 55.5%. Among them, *α*-elemol (16.7%) and caryophyllene oxide (16.4%) were predominant, along with noteworthy amounts of spathulenol (10.4%), and bulnesol (4.9%). Hydrocarbons also made up a significant proportion (39.6%) of the oil, with heptacosane (15.9%), undecane (9.7%), and tricosane (8.9%) as the major components. On the other hand, the fruit oil differed from the flower oil by the absence of long-chain hydrocarbons and a higher quantity of oxygenated sesquiterpenes (78.0%), which constituted nearly the entirety of the identified components (81.2%). In this case, spathulenol (16.8%) was the principal compound identified, followed by caryophylladienol I (13.2%), not present in the oil isolated from the flowers, *α*-elemol (12.8%), bulnesol (9.7%), caryophyllene oxide (9.6%), and ledol (8.2%).

In the essential oil obtained from the flowers of *B. pauciradiatum*, among the thirty-five compounds identified, germacrene D (46.4%), β-caryophyllene (18.1%), spathulenol

(5.4%), and bicyclogermacrene (4.2%) were the main components (Saraçoğlu, 2011). Conversely, in the essential oil derived from the fruits, among the fifty-nine compounds identified, *β*-pinene (20.9%), germacrene D (18.8%), *α*-pinene (16.1%), and spathulenol (6.1%) were the most abundant ones. The analysis of the essential oil from the roots of *B. pauciradiatum* revealed the presence of twelve compounds, with spathulenol (17.3%), hexacosane (13.3%), pentacosane (11.0%), and hexadecanoic acid (10.2%) identified as the major components. Sesquiterpene hydrocarbons (75.0%) were found in the highest relative amounts in the essential oil from the flowers of *B. pauciradiatum*, while monoterpene hydrocarbons (42.8%) were dominant in the essential oil from the fruits, and alkanes (56.8%) were most abundant in the essential oil from the roots.

The essential oil of *B. plantagineum* has been analyzed twice, both studies stating a similar yield (0.18 and 0.21%, respectively; Mékaoui et al., 2020, Laouer et al., 2009). Both essential oils were characterized by a high content of monoterpenes but in different relative proportions. The most abundant constituents of the oil described by Laouer et al. were *α*-pinene (31.9%), myrcene (24.8%), and *cis*-chrysanthenyl acetate (28.2%). The oil analyzed by Mékaoui et al. was composed of *α*-pinene (19.3%), myrcene (14.9%), limonene (10.2%), *cis*-chrysanthenyl acetate (33.0%), and *β*-caryophyllene (5.0%). Mékaoui et al. also compared the chemical composition of the volatiles trapped by headspace solid-phase microextraction from different plant organs. The essential oil of stems and leaves contained the same most prevalent components (*α*-pinene, *α*-*trans*-bergamotene, and *cis*-chrysanthenyl acetate). In addition to *α*-pinene and *α*-*trans*-bergamotene, the root essential oil was comprised of a significant amount of sesquiterpene hydrocarbons, such as amorpha-4,11-diene, *α*-acoradiene, and *γ*-muurolene. There was a clear prevalence of sesquiterpene hydrocarbons in the analyzed volatiles (45.6, 32.0, and 70.3% from leaves, stems, and roots, respectively), compared to the oxygenated compounds and monoterpene hydrocarbons.

The essential oil of *B. praelatum* from Serbia predominantly contained (+)-spathulenol (17.7%), (-)-(*E*)-caryophyllene oxide (6.1%), octyl 2-methylbutanoate (5.8%), and hexahydrofarnesyl acetone (5.1%, Kapetanos et al., 2008).

The essential oil of *B. rigidum* subsp. *paniculatum* contained high amounts of monoterpene hydrocarbons (Pala-Paul et al., 1999), with the most abundant representatives being *β*-pinene (26.7%), *α*-pinene (26.4%), myrcene (26.2%), and limonene (12.2%).

Bupleurum rotundifolium is a representative of the annual species of this genus, and the literature provides the chemical composition of the essential oil isolated from the aerial parts (Kiliç, 2014), as well as for individual plant organs (Nageswara et al., 2012, Akin et al., 2012). Interestingly, the volatiles from the aerial parts, captured by headspace solid-phase microextraction, predominantly were comprised of spathulenol (25.6%), *α*-pinene (29.7%), and germacrene D (18.4%), which were either absent or present in much smaller quantities in the oils from individual plant organs, isolated by hydrodistillation (Table 6). The root essential oil was rich in alkanes, more specifically in undecane (26.4%) and tridecane (12.3%) content. Hexadecanoic acid was present in high amounts in the flower essential oil (12.2%) but was not detected in the root and fruit oils.

Table 6 The major constituents in the essential oil of *B. rotundifolium*

Constituents	Aerial parts	Roots	Flowers	Fruits
Decyl acetate	-	4.4	-	-
Hexadecanol	-	7.9	-	2.7
Hexadecanoic acid	0.2	-	12.2	-
Hexahydrofarnesyl acetone	-	4.2	2.5	2.2
Germacrene D	18.4	-	7.4	5
Limonene	2.5	0.6	2.4	5.4
β-Phellandrene	-	0.4	7.2	6.1
α-Pinene	29.7	-	8.7	11.1
Salvial-4(14)-en-1-one	2.4	-	0.7	1.7
Spathulenol	25.6	0.2	3.9	2.6
Tridecane	-	12.3	1.4	1.6
Undecane	2.5	26.4	4.9	10.4
Reference	Kiliç, 2014	Nageswara et al., 2012, Akin et al., 2012		

The effect of environmental factors on the chemical composition of the essential oil of *B. scorzonerifolium* was investigated by Tykheev et al. (2018). It was concluded that the samples from the Irkutsk region lacked germacrene-type sesquiterpenes, while the Republic of Buryatia, Trans–Baikal region, Krasnoyarsk region, and Mongolia samples were devoid of guaiane-type sesquiterpenes. The more continental regions exhibited elevated levels of humulane, caryophyllane, muurolane sesquiterpenes, as well as monocyclic and bicyclic sesquiterpenes with a cyclopropane ring. The Krasnoyarsk samples were notable for high concentrations of cadinane and bisabolane sesquiterpenes, along with alcohols, phenylpropanoids, and acyclic and thujane monoterpenes. Meanwhile, the Irkutsk region samples predominantly featured guaiane-type sesquiterpenes (Tykheev et al., 2018). The essential-oil composition of the plants originating from Mongolia, given by another group of authors, was in accordance with the previously described compositions (Table 7, Altantsetseg et al., 2012).

Heptanal (22.8%), 2-pentylfuran (4.7%), and (-)-(*E*)-caryophyllene oxide (4.9%) were found to be the most abundant constituents in the essential oil of *B. sibthorpianum* from Serbia (Kapetanos et al., 2008).

Thirty-nine compounds have been identified in the essential oil obtained from the flowers of *B. sulphureum* (Saraçoğlu, 2011). Among them, undecane (14.0%), spathulenol (9.9%), α-pinene (9.3%), and 1,5-epoxysalvial-4(14)-ene (8.7%) were found as the main components. Whereas for the essential oil extracted from the fruits, thirty-seven compounds were identified, with undecane (20.2%), spathulenol (6.0%), *α*-pinene (5.8%), and hexahydrofarnesyl acetone (4.5%) being the main compounds. The analysis of the essential oil from the roots revealed nineteen compounds, with calarene (26.9%), undecane (23.8%), bornyl acetate (8.2%), and aristolene (3.7%) identified as the major constituents. The essential oil from the flowers of *B. sulphureum* was characterized by the highest content of oxygenated sesquiterpenes (33.2%), while the essential oil from the fruits had the highest proportion of alkanes (22.7%), while the root essential oil was rich in sesquiterpene hydrocarbons (32.0%).

Table 7 The major constituents in the essential oil of *B. scorzonerifolium*

Constituents	Aerial parts											Aerial parts	Roots
	1[a]	2[b]	3[c]	4[d]	5[e]	6[f]	7[g]	8[h]	9[i]	10[j]	11[k]		
Bicyclogermacrene	1.6-3.5	3.6	4.9	1.8	1.2	1.1	0.5	3.6-6	3.5-5.2	-	7.6	-	-
Caryophyllene	5.1-5.8	11.4	9.6	4.3	3.6	5.6	2.5	7.4-8.1	3.9-10.6	12.8	8.3	2	-
Caryophyllene oxide	0-1.5	5.2	1.6	1	6.9	5.8	0.9	0.7-0.9	1.2-7.3	1.1	2.2	2.5	-
p-Cymene	0.5-1.6	0.4	-	5.3	21.7	20.4	12.8	1.5-10.6	0.2-7.8	6.3	2	11.5	0.8
Dodecanoic acid	-	-	-	-	-	-	-	-	-	-	-	-	5.7
Furfural	-	-	-	-	-	-	-	-	-	-	-	-	8.1
Germacrene D	26.8-36.8	35.7	41.8	17.9	11.4	9.5	5.1	15.8-31.6	15.6-24.7	41.3	25.7	4.1	-
Heptanal	-	-	-	-	-	-	-	-	-	-	-	tr	9.3
Hexanal	0-0.2	0.6	-	-	-	-	1.4	0-0.1	-	-	-	0.6	12.4
Humulene	0.9-1.4	2.9	1.8	1.7	2.3	1.7	1.6	2.6-5.7	1.7-14.7	2.5	3.2	0.8	-
Limonene	6.1-8.4	2.9	2.1	10.8	9.7	7.7	6.3	2.6-4.4	6.2-7.1	6.1	5.6	15.2	-
Myrcene	10.9-13.8	2.6	3.6	14.2	13.8	13.1	3.5	0.6-5.3	3-8.5	8	8.4	8.1	-
2-Nonenal	-	-	-	-	-	-	-	-	-	-	-	-	4.9
cis-*β*-Ocimene	2.5-18.6	2.3	1.1	2	0.6	1.1	1.6	7.7-12.3	0.4-3.3	8.5	9.2	1	-
trans-*β*-Ocimene	2.1-14.8	-	11.3	12.6	5.9	7	0.4	1.4-2.3	0.5-3.1	0.6	0.9	10.5	-
α-Pinene	0.8-4.5	-	0.5	1.2	1.9	4.7	5.9	0.1-1.2	2.7-3.7	1.7	5.6	6.3	-
β-Pinene	1.1-2	0.4	0.5	1.2	2.5	3.6	1.6	1.5-8.1	1.9-3.1	0.9	1.1	3.1	-
Sabinene	1.8-4.1	0.9	1.7	4.8	2.1	1.8	0.3	0.9-3.9	0-0.6	-	0.2	6.6	-
Spathulenol	0.5-1.3	6.6	1.2	0.9	4.4	3	10.4	0.9-1	0.6-7.4	-	1.1	2.7	-
γ-Terpinene	1.2-2.3	-	0.5	5.4	2.5	5.7	1.3	0.1-2.5	0-1.6	2.3	1.7	0.1	-
Reference	Tykheev et al., 2018											Altantsetseg et al., 2012	Li et al., 2007

[a]Samples collected near the Sotnikovo village, Ivolginsky district, Buryatia (altitude 490 m); [b]Sample collected near the Ivolga village, Ivolginsky district, Buryatia (altitude 645 m); [c]Sample collected near the Zagustay arbor, Selenginsky district, Buryatia (altitude 572 m); [d]Sample collected near the Georgievka village, Khorinsk district, Buryatia (altitude 769 m); [e]Sample collected near the Oninoborsk village, Khorinsk district, Buryatia (altitude 772 m); [f]Sample collected near the Shiringa village, Eravninsky district, Buryatia (altitude 926 m); [g]Samples collected near the Nyzhniy Tsasuchey village, Ononsky district, Trans–Baikal region (altitude 811 m); [h]Samples collected near the Bayan Ulaan Uul mountain, Khentii aimag (altitude 1327 m); [i]Samples collected near the Berkh territory, Khentii aimag (altitude 1091 m); [j]Sample collected 20 km to northeast from the Berkh territory, Khentii aimag (altitude 1015 m); [k]Sample collected near the Huh nuur Lake, Khentii aimag (altitude 1670 m).

Among the thirty-nine compounds identified in the essential oil obtained from the flowers of *B. turcicum*, heptanal (33.2%), pentadecane (19.6%), and undecane (6.6%) were the main components (Saraçoğlu, 2011). While for the essential oil derived from the fruits, the identified thirty-nine compounds included heptanal (23.5%), pentadecane (13.4%), undecane (8.9%), and (*E*)-geranyl acetone (7.7%) as the most dominant constituents. The root essential oil was characterized by high amounts of pentacosane (9.0%), 1-undecanol (8.8%), hexacosane (8.0%), 1-dodecanol (6.3%), and spathulenol (6.3%).

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HEMIJSKI SASTAV ETARSKIH ULJA BILJNIH VRSTA RODA *BUPLEURUM*

U ovom radu dat je pregled rezultata dosadašnjih istraživanja na temu analize sastava etarskog ulja četrdeset biljnih vrsta koje pripadaju rodu Bupleurum, od kojih je deset jednogodišnjih, a trideset višegodišnjih. Prikazan je hemijski sastav etarskih ulja dobijenih iz različitih biljnih organa, dati su prinosi etarskih ulja i procenat identifikovanih sastojaka. Navedeni su najzastupljeniji sastojci svih etarskih ulja, i date strukture najzastupljenijih monoterpena, seskviterpena, fenilpropanoida, kao i alifatičnih aldehida, alkohola, estara, itd. Takođe, poređenje hemijskog sastava etarskih uja koja su više puta analizirana, dato je u vidu tabela.

Ključne reči: *Bupleurum, etarsko ulje, hemijski sastav, terpeni*