Component composition of essential oil in the North American *Pinus* L. species introduced to the Southern Coast of Crimea

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Background. Studying essential oils in conifers is of great scientific and practical interest due to their high bactericidal properties. Their volatiles play an important role in combating pathogenic microflora and removing harmful microorganisms from the air, thus benefiting human health. Conifers are highly effective as part of parklands and urban landscaping.
Materials and methods. *Pinus radiata* D. Don, *P. sabiniana* Douglas and *P. coulteri* D. Don grown on the Southern Coast of Crimea were studied. Essential oil was extracted from pine needles by hydrodistillation on Ginsberg devices, and its component composition was analyzed using gas–liquid chromatography on a 6890N system with a 5973N mass selective detector.
Results. Among the studied species, *P. radiata* manifested high essential oil content in needles: 0.15% on the wet weight basis (0.36%, dry weight). Under the conditions of the southern coast of Crimea, the major essential oil components in *P. radiata* were *β*-pinene (29.5% of the total essential oil), *α*-pinene (21.2%) and limonene (12.4%); in *P. sabiniana*, phenylethyl butyrate (20.5%), limonene (15.2%) and *α*-pinene (13.7%); in *P. coulteri*, *β*-pinene (11.6%), *δ*-cadinene (11.0%) and *α*-pinene (10.6%). In the essential oil of *P. radiata* monoterpenes dominated (74.9%); in *P. sabiniana*, monoterpenes (38.7%) and their derivatives – alcohols (25.3%) and esters (20.5%); in *P. coulteri*, sesquiterpenes (38.2%) and monoterpenes (28.8%).
Conclusion. The essential oils of *P. radiata* and *P. sabiniana* under different climate conditions contained mostly monoterpenes (*β*-pinene in *P. radiata*, and *α*-pinene in *P. sabiniana*) and their derivatives. The component composition of *P. coulteri* essential oil was the most variable, with a general tendency towards the predominance of sesquiterpenes and diterpenes; the ratio between those groups and the qualitative composition of sesquiterpenes both varied.

Key words: conifers, introduction, hydrodistillation, gas–liquid chromatography.

Компонентный состав эфирного масла североамериканских видов рода *Pinus* L., интродуцированных на Южном берегу Крыма

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Актуальность. Изучение эфирных масел хвойных растений представляет большой научно-практический интерес, поскольку они обладают высокими бактерицидными свойствами, играют важную роль в активном воздействии летучих выделений на патогенную микрофлору и очищении воздуха от болезнетворных микроорганизмов, охране здоровья человека, высокой эффективности хвойных насаждений в формировании парковых сообществ и озеленении городов.
Материалы и методы. Для исследования использовали древесные растения *Pinus radiata* D. Don, *P. sabiniana* Douglas и *P. coulteri* D. Don, культивируемые на Южном берегу Крыма (ЮБК). Эфирное масло из хвои извлекали методом гидродистилляции на аппаратах Гинзберга, компонентный состав эфирного масла исследовали методом газожидкостной хроматографии с использованием прибора 6890N (Agilent Technologies, США) и масс-спектрометрического детектора 5973N (Agilent Technologies, США).
Результаты. Среди изученных видов *P. radiata* характеризовалась высоким содержанием эфирного масла в хвое – 0,15% от сырой массы (0,36% на абсолютно сухой вес). В условиях ЮБК основными компонентами эфирного масла *P. radiata* были β-пинен (с удельным содержанием 29,5%), α-пинен (21,2%) и лимонен (12,4%); *P. sabiniana* – фенилэтилбутират (20,5%), лимонен (15,2%) и α-пинен (13,7%); *P. coulteri* – β-пинен (11,6%), δ-кадинен (11,0%) и α-пинен (10,6%). В эфирном масле *P. radiata* преобладали монотерпены (74,9%); у *P. sabiniana* – монотерпены (38,7%) и их производные (спирты 25,3%) и сложные эфиры (20,5%); у *P. coulteri* – сесквитерпены (38,2%) и монотерпены (28,8%).
Заключение. *P. radiata* и *P. sabiniana*, произрастающие в разных климатических условиях, содержат в основном монотерпены (*P. radiata* – β-пинен, *P. sabiniana* – α-пинен) и их производные. Компонентный состав эфирного масла *P. coulteri* характеризуются наибольшей изменчивостью: при общей тенденции преобладания сесквитерпенов и дитерпенов в эфирном масле соотношение этих групп варьирует, как и качественный состав сесквитерпенов.

Ключевые слова: хвойные растения, интродукция, гидродистилляция, газожидкостная хроматография.

Introduction

Studying essential oils extracted from woody conifers is of great scientific and practical interest, since they possess high bactericidal properties. They play an important role in the effective impact of conifer volatiles on pathogenic microflora and harmful microorganisms in the atmosphere, thus benefiting human health. They contribute to the high efficiency of coniferous tree plantations in the formation of parklands and urban landscaping (Shpak et al., 2008). Volatile phytoncides of essential oils are regulators of physical and chemical properties of the air and increase the concentration of health-friendly light negative ions. They supply atmospheric air with biologically active oxygen, promote the deposition of dust particles, create a unique fragrance and freshness of the air, which favorably affects the emotional state of a human being. Also, considerable interest is shown in the essential oils of coniferous species in the search for new substances required by perfumery and medicine (Ekundayo, 1988).

The composition and properties of essential oils in conifers are a complex mixture of terpene hydrocarbons and their derivatives (α- and β-pinene, limonene, borneol, bornyl acetate, cadinene, etc.) produced under the conditions of plant life and determining their biological characteristics, resistance to frost and drought, and to fungal diseases (Kolesnikova et al., 1977; Lawless, 2000; Konopleva, Deynenko, 2006; Narchuganov et al., 2011; Kolesnikova et al., 2018). Insecticidal properties of essential oils are a leading factor in the resistance of conifers to damage caused by insects and pathogens (Gijzen et al., 1993). As reported by a number of scientists, essential oils play a protective role in the physiological processes occurring in the plant under various stressful situations (Zauralov, 1975), while changes in the content and composition of terpenoids in essential oil depend on environmental factors (especially pollutions) and may be indicators of the stand's state (Judzentiene et al., 2007).

Obtaining detailed information about the composition of essential oils in pine species not only allows us to expand knowledge about their silvicultural and biological significance (resistance of plantings to pests and diseases) or the biosynthesis of terpenes and the importance of essential oil composition for the chemosystematics of the genus (Savory, 1962; Mirov, 1967; Bardyshev et al., 1968; Podgorny, Akimov, 1975), but also makes it possible to justify recommendations on the practical use of certain oil components (Konopleva, Deynenko, 2006).

Of particular interest to researchers are terpenoids in the essential oils of coniferous plants belonging to the genus *Pinus* L.: in their quantitative and qualitative composition they are superior to many other types of compounds found in medicinal plants. Substances of the terpenoid group obtained from plant raw materials of pine trees, due to their unique pharmacological properties, are increasingly used in the treatment of various pathological states (Hong et al., 2004). Pine essential oils exhibit antioxidant, antiviral, analgesic, anti-inflammatory, cytotoxic and/or antimicrobial activity (Cho et al., 2000; Kolayli et al., 2009; Yesil-Celiktas et al., 2009). In addition, they are characterized by high biological activity – antifungal, acaricidal and antithrombotic (Kolayli et al., 2009; Tognolini et al., 2006).

The ability of woody plants to develop and accumulate bioactive compounds is a dynamic process that changes at different stages of ontogenesis and under the influence of various environmental factors. It is known that the synthesis of turpentine oils is genetically determined, and their composition is subject to individual, geographical and species variability, which can serve as one of the additional ways to address issues of species taxonomy, since pine species are characterized by a clearly expressed chemical identity (Kolesnikova et al., 2018). The high degree of genotypic variability observed in the genus *Pinus* is reflected in its biochemical variability, which is usually studied at the levels of molecular markers, terpene composition, and isoenzyme variation. Volatile terpenes are often used as chemosystematic markers, based on the fact that terpenoid biosynthesis is under strict genetic control and is not significantly affected by environmental factors (Baradat, Yazdani, 1988; Inserti et al., 2013). The importance of terpenes and their effectiveness as genetic markers in studies into biodiversity, geographical variability, evolution, and taxonomy in Pinales is discussed in detail by J. W. Hanover (1992).

The analysis of the published data on the variability in the component composition of essential oils shows that such composition depends on the species, place of growth, type of raw material, season (Von Rudloff, 1967, 1975), climate, and environmental factors (Gut, Krinitsky, 1989; Chernodubov, 1990).

Modern research into the component composition of essential oils of the genus *Pinus* are mainly dedicated to native and some introduced species, but the available published descriptions of the essential oil composition in coniferous species growing in the Russian Federation are far from being complete and require detailed consideration (Zykova, Efremov, 2012).

The purpose of this study was to examine the characteristics of the content and component composition of essential oil in three North American *Pinus* spp. (*P. radiata* D. Don, *P. sabiniana* Douglas, and *P. coulteri* D. Don) growing on the southern coast of Crimea (SCC) and maintained in the dendrological collection of the Nikita Botanical Gardens (NBG).

Materials and methods

Studies were conducted in August 2018 on *P. radiata*, *P. sabiniana* and *P. coulteri* model trees (60–70 years of age) growing in Montedor Park, NBG. The content of essential oil was assessed in needles by hydrodistillation on Ginsberg devices (Karpacheva, 1972) with subsequent measurement of its volume. Organoleptic evaluation of essential oil was performed using the method proposed by V. P. Isikov et al. (2009). The component composition of essential oils was studied using a 6890N chromatograph (Agilent Technologies, USA) with a 5973N mass selective detector (Agilent Technologies, USA). The components of essential oil were identified by search results and comparing the data obtained during chromatography of chemical mass spectra with the data from the NIST 02 Mass Spectral Library (more than 174,000 compounds). Retention indices (RI) of components were calculated according to the results produced by the control analyses of essential oils with the addition of normal alkanes (Karpacheva, 1972).

Results and discussion

In the environments of the SCC, *P. radiata* contained 0.15% of essential oil on the wet weight basis (WW), or 0.36%, dry weight (DW), while *P. sabiniana* and *P. coulteri* had 0.03% WW (0.07–0.06% DW) (Table 1). Judging from the dominant tinge of essential oils in the studied *Pinus* spp., they belong to the following flavor groups: conifer-fruit (*P. radiata*), flower-conifer (*P. sabiniana*), and wood-resin-balsamic (*P. coulteri*) (Table 1).

Table 1. Mass fraction and organoleptic evaluation of essential oils in *Pinus* L. spp.

Таблица 1. Массовая доля и органолептическая оценка эфирного масла видов рода *Pinus* L.

Species	Weight ratio of essential oil, %:		Flavor group	Dominant tinge of flavor
	Wet weight	Dry weight		
Pinus radiata D. Don	0.15	0.36	intermediate, pleasant with light tones	conifer-fruit
Pinus sabiniana Douglas	0.03	0.07		flower-conifer
Pinus coulteri D. Don	0.03	0.06	pleasant	wood-resin-balsamic

The composition of essential oils in the studied species differed in quantitative and qualitative indicators. Sixty-four components were identified in the essential oil of *P. radiata*, 43 in *P. sabiniana*, and 60 in *P. coulteri* (Table 2). For *P. radiata*, the major components were *β*-pinene (29.57% of the total essential oil), *α*-pinene (21.2%) and limonene (12.41%); for *P. sabiniana,* phenylethyl butyrate (20.58%), limonene (15.23%) and *α*-pinene (13.69%); for *P coulteri*, *β*-pinene (11.64%), *δ*-cadinene (11.07%) and *α*-pinene (10.67%) (Table 2).

The essential oil of *P. radiata* also contained *α*-terpeniol, *β*-myrcene, pinocarveol, myrtenol, *δ*-cadinene, germacrene D, and *γ*-3-carene. In *P. sabiniana* there was a significant amount of estragole (6.39%), *α*-terpeniol (5.72%) and *β*-pinene (2.06%), as well as *β*-myrcene, *cis*-ocimene, epoxyterpenolene, citronellol, tridecanal, and manoyl oxide. Characteristic differences in the component composition of *P. coulteri* essential oil, when compared to that of other species, were the significant specific amount of carvone (6.98%), *τ*-muurolol (4.46%), *α*-muurolene (4.02%), and dodecanal (4%),

Table 2. The composition of essential oils in *Pinus* L. spp. under the conditions of the Southern Coast of Crimea

Таблица 2. Компонентный состав эфирного масла видов рода *Pinus* L. в условиях Южного берега Крыма

Component	RI	*Pinus radiata* D. Don	*Pinus sabiniana* Douglas	*Pinus coulteri* D. Don
		Quantitative content (% rel.) of the identified components in essential oil		
ethanol	819	3.01	6.80	3.12
tricyclene	931	0.17	0.04	0.06
α-thujene	934	0.05	0.04	0.09
***α*-pinene**	940	**21.20**	**13.69**	**10.67**
camphene	947	0.80	0.32	0.34
1-isopropyl-4-methylenebicyclo[3.1.0]hex-2-ene	950	0.12	0.04	0.04
sabinene	966	0.12	0.03	0.07
***β*-pinene**	970	**29.57**	2.06	**11.64**
β-myrcene	981	1.84	2.16	0.61
γ-3-carene	996	2.05	0.06	0.07
α-terpinene	1001	0.14	0.04	0.11
p-cymene	1004	0.18	0.10	0.21
β-phellandrene	1010	0.79	0.71	1.74
limonene	1013	**12.41**	**15.23**	2.10
cis-ocimene	1020	–	2.39	0.48
trans-ocimene	1030	0.85	0.13	–
γ-terpinene	1038	0.13	0.13	0.07

Table 2. Continued
Таблица 2. Продолжение

Component	RI	*Pinus radiata* D. Don	*Pinus sabiniana* Douglas	*Pinus coulteri* D. Don
		Quantitative content (% rel.) of the identified components in essential oil		
limonene oxide	1046	0.11	0.16	–
terpinolene	1065	0.75	0.27	0.22
α-thujone	1072	0.33	0.71	–
epoksiterpinolen	1076	0.71	1.05	0.35
β-thujone	1083	0.07	0.09	–
fenchol	1086	0.36	0.14	–
α-campholenal	1090	0.29	0.63	0.41
pinone	1092	0.27	–	–
camphor	1103	0.14	0.34	0.10
pinocarveol	1108	1.86	0.53	0.26
exo-methylcamphenylol	1116	–	–	0.17
verbenol	1116	0.43	–	–
pulegol	1116	–	0.70	–
citronellal	1121	–	0.72	–
isopulegol	1127	–	0.21	–
pinocamphone	1133	0.25	–	–
isoborneol	1136	0.64	0.78	0.23
terpinen-4-ol	1148	0.46	0.48	0.39
myrtenal	1152	0.83	0.43	0.20
dihydrocarvone	1158	–	–	0.16
α-terpineol	1161	4.51	5.72	1.45
myrtenol	1167	1.50	–	–
estragole	1175	–	6.39	0.60
decanal	1175	–	–	2.14
phenyl acetate	1191	0.12	–	–
carvone	1203	–	–	6.98
methylthymol	1204	0.18	–	–
citronellol	1208	–	3.49	–
undec-2-en-1-ol	1249	–	–	0.53
bornyl acetate	1254	0.14	–	–
1,1-diethoxyoctane	1270	–	0.30	–
myrtenyl acetate	1292	0.10	–	–
dihydrocarvil acetate	1298	–	–	0.09

Table 2. Continued
Таблица 2. Продолжение

Component	RI	*Pinus radiata* D. Don	*Pinus sabiniana* Douglas	*Pinus coulteri* D. Don
		Quantitative content (% rel.) of the identified components in essential oil		
carvacrol	1303	–	0.19	–
α-ylangene	1330	0.10	–	–
α-cubebene	1330	–	–	1.92
α-copaene	1354	0.21	–	3.62
β-bourbonene	1361	0.05	–	0.35
β-cubebene	1366	0.06	–	0.47
β-elemene	1368	0.11	–	1.83
dodecanal	1378	–	–	4.00
tridecanal	1379	–	3.00	–
trans-caryophyllene	1392	1.04	–	0.85
phenylethyl butyrate	1400	–	**20.58**	–
bergamotene	1412	0.23	–	0.77
cubebene	1420	0.10	–	0.62
humulene	1423	0.22	–	–
farnesene	1435	–	–	0.41
β-cadinene	1443	0.14	–	1.27
germacrene D	1448	2.48	–	3.15
β-selinene	1453	–	–	0.69
bicyclosesquiphellandrene	1456	0.24	–	1.72
1,1-diethoxydecane	1460	–	0.89	–
α-selinene	1462	–	–	1.34
germacrene B	1462	0.56	–	–
α-muurolene	1470	0.42	–	4.02
α-amorphene	1478	0.30	–	1.23
γ-cadinene	1480	0.24	–	–
calamenene	1482	0.20	–	2.02
***δ*-cadinene**	1488	1.14	–	**11.07**
cadina-1,4-diene	1495	0.12	–	0.87
nerolidol	1526	0.14	–	1.12
spathuenol	1529	0.55	–	–
torreyol	1531	–	–	1.02
caryophyllene oxide	1531	0.27	–	–
N/A	1541	–	–	0.45

Table 2. The end
Таблица 2. Окончание

Component	RI	*Pinus radiata* D. Don	*Pinus sabiniana* Douglas	*Pinus coulteri* D. Don
		Quantitative content (% rel.) of the identified components in essential oil		
cubenol	1575	0.24	–	–
cubenol (isomer)	1576	-	–	2.45
τ-muurolol	1586	1.23	–	4.46
α-cadinol	1595	1.10	–	2.10
N/A	1650	–	0.48	–
manoyl oxide	1778	0.58	4.52	0.32
defined / identified		**64/64**	**42/41**	**60/59**

Note: RI – component retention index, N/A – not identified
Примечание: RI – индекс удерживания, N/A – не идентифицировано

as well as α-copaene, germacrene D, limonene, decanal, and cubenol.

Within the essential oil fractions there were significant differences in the content of individual components. Among the organic compounds in the essential oil of *P. radiata*, monoterpenes predominated (74.9% of the total organic compounds); in the essential oil of *P. sabiniana*, monoterpenes (38.7%) and their derivatives – alcohols (25.37%) and esters (20.58%) – prevailed, while in the essential oil of *P. coulteri* the main part was occupied by sesquiterpenes (38.23%), and the content of monoterpenes was only 28.87%. There were no sesquiterpenes in *P. sabiniana* essential oil. The alcohol content in *P. coulteri* and *P. radiata* essential oils was 17.88% and 13.03%, respectively. Oxides, aldehydes, ketones, acetals and phenols were represented in all the studied oils in trace amounts (Figure).

Proceeding from the premise that the synthesis of turpentine oils is genetically determined and their composition is subject to individual, geographical and species variability, we conducted a comparative analysis of the component composition of essential oils for the studied pine species growing in different natural and climatic environments.

P. radiata, as a representative of subsect. *Attenuatae*, sect. *Trifoliae*, gen. *Pinus*, is characterized by a predominance of monoterpenes in essential oil, in particular α- and β-pinenes, with a large specific weight of the latter. Thus, when cultivated in Greece and Ecuador, the amount of pinenes was 56.6% (Ioannou et al., 2014) and 57.1% (Sacchetti et al., 2005), respectively (Table 3).

This trend can also be seen in the results of our research (under the conditions of the SCC, the amount of pinenes was 50.77%) and is consistent with the data obtained

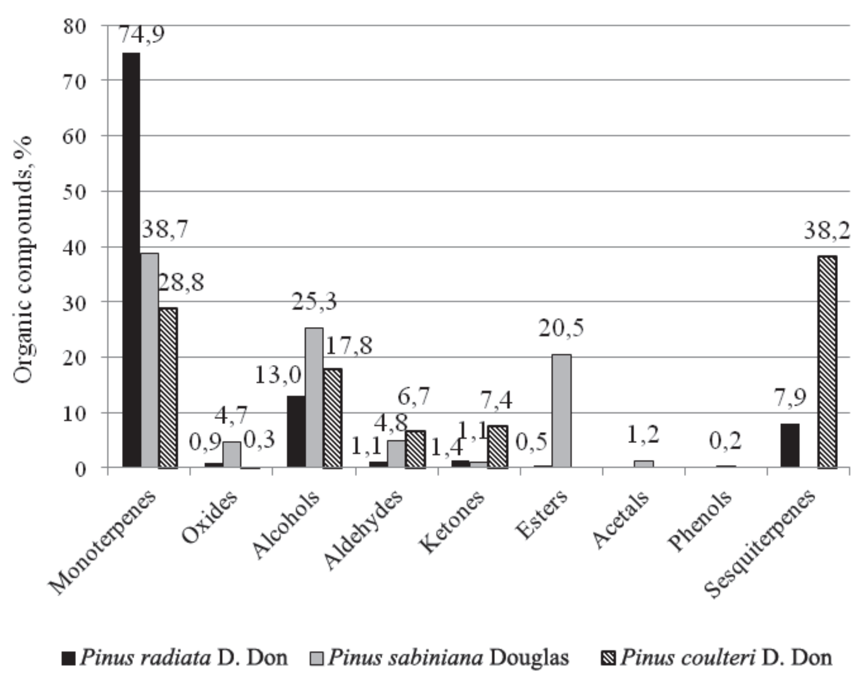

Figure. The ratios of organic compounds (%) in essential oils of *Pinus* L. spp.
Рисунок. Соотношение органических веществ (%) эфирного масла видов рода *Pinus* L.

Table 3. **The main components in essential oils of *Pinus* L. spp. under different climatic conditions**
Таблица 3. **Основные компоненты эфирного масла видов рода *Pinus* L. в различных климатических условиях**

Component	*Pinus radiata* D. Don			*Pinus sabiniana* Douglas			*Pinus coulteri* D. Don		
	Greece [*]	Ecuador [**]	SCC	Greece [*]	California [***]	SCC	Greece [*]	Tunisia [****]	SCC
ethanol	–	–	3.01	–	–	6.80	–	–	3.1
α-pinene	**18.9**	**21.9**	**21.2**	**61.6**	**39.1**	**13.7**	**13.6**	**10.8**	**10.7**
β-pinene	**38.7**	**35.2**	**29.6**	4.7	3.3	2.1	1.1	**11.3**	**11.6**
β-myrcene	1.3	1.0	1.8	2.0	3.6	2.1	-	1.0	0.6
β-phellandrene	5.0	12.6	0.8	2.0	**10.4**	0.7	**6.2**	-	1.7
α-phellandrene	–	–	–	–	–	–	–	**5.1**	–
limonene	–	–	**12.4**	–	**10.5**	**15.2**	–	-	2.1
cis-ocimene	3.8	–	–	5.2	4.6	2.4	1.6	0.1	0.4
methyl chavicol	–	–	–	1.4	4.5	–	1.9	0.2	–
terpinolene	–	2.2	0.7	–	–	–	–	0.2	–
α-copaene	–	–	0,2	–	–	–	–	–	3.6
citronellol	–	1.9	–	–	–	3.5	–	–	–
dodecanal	–	–	–	–	1.0	–	–	–	4.0
α-terpineol	–	3.0	4.5	–	–	5.7	–	–	1.4
estragole	–	–	–	–	–	6.4	–	–	–
carvone	–	–	–	–	–	-	–	–	**6.9**
tridecanal	–	–	–	–	–	3.0	–	–	–
phenylethyl butyrate	–	–	–	–	–	**20.5**	–	–	–
4-epi-isocembrol	–	–	–	–	–	–	**17.7**	–	–
ß-caryophyllene	–	–	–	–	–	–	–	**21.3**	–
germacrene D	**6.4**	–	2.5	–	–	–	**8.8**	6.2	–
α-muurolene	–	–	0.4	–	–	–	–	–	**4.0**
bicyclosesquiphellandrene	4.7	–	0.2	–	–	–	–	–	1.7
manoyl oxide	–	–	–	-	–	4.5	–	–	–
(E)-calamenene	–	–	–	–	–	–	–	**15.2**	–
δ-cadinene	3.6	–	1.1	–	–	–	3.6	0.1	**11.0**
α-cadinol	2.7	–	1.1	–	–	–	4.7	–	2.1
τ-muurolol	–	–	1.2	–	–	–	–	**5.3**	**4.4**

Note: SCC – Southern Coast of Crimea; * – Ioannou et al., 2014; ** – Sacchetti et al., 2004;
*** – Adams and Wright, 2012; **** – Hanana et al., 2014
Примечание: SCC – Южный берег Крыма; * – Ioannou et al., 2014; ** – Sacchetti et al., 2004; *** – Adams and Wright, 2012;
**** – Hanana et al., 2014

by other authors (Petraskis et al., 2001). The peculiarity of *P. radiata* essential oil under the conditions of the SCC was the presence of limonene (12.41%), which determines a stronger coniferous smell of the essential oil. Diterpenes and sesquiterpenes in *P. radiata* essential oil were present in small amounts under different environmental conditions. Having compared the available data, we can conclude that the component composition of this type of essential oil is quite stable.

In the essential oil of *P. sabiniana*, as a representative of subsect. *Ponderosae*, sect. *Trifoliae*, gen. *Pinus*, monoterpenes also predominated but, in contrast to *P. radiata*, they were *α*-pinenes. In the analysis presented by R. P. Adams and J. W. Wright (2012), when pines were grown *in vivo* (California), *α*-pinene was the most common metabolite (39.1%), with moderate amounts of limonene (10.5%) and *β*-phellandrene (10.4%). With pines grown in Greece, the content of *α*-pinene was twice as high (Ioannou et al., 2014), compared to natural habitats, and on the SCC it was twice as low (13.7%). Limonene is present in sufficient quantities in pine essential oil from natural habitats and rivers. The dominant component in the essential oil of *P. sabiniana*, which grows on the SCC, as mentioned above, is the monoterpene alcohol phenylethyl butyrate.

Thus, the dominant role of monoterpenes (namely *α*-pinene) and their derivatives, whose quantitative ratio varies depending on the growing conditions, as well as the almost complete absence of diterpenes and sesquiterpenes, is characteristic of this species.

The highest variability in the component composition of essential oil was observed in *P. coulteri*. This species is characterized by a predominance of sesquiterpenes and diterpenes. However, the qualitative composition of this group varied greatly in different environments. In Greece, the content of monoterpenes was 26.7%, diterpenes 28.6%, and sesquiterpenes 48% (Ioannou et al., 2014). The main component is the diterpene alcohol 4-epi-isocembrol (17.7%) and sesquiterpene germacrene D (8.8%).

In Tunisia, the essential oil of *P. coulteri* contained 29.2% of monoterpenes and 55.4% of sesquiterpenes. Among the latter, *β*-caryophyllene (21.3%) and (E)- calamenene (15.2%) predominated, and *α*-phellandrene (5.1%) was also present (Hanana et al., 2014). The share of sesquiterpenes decreased to 38% on the SCC, while the share of monoterpenes and their derivatives increased to 37.5%. Among sesquiterpenes, *δ*-cadinene played a leading role under the conditions of the SCC (11.0%).

Conclusion

In the environments of the SCC, the yield of essential oil in *Pinus radiata* was 0.15% WW (0.36% DW), while *P. sabiniana* and *P. coulteri* showed 0.03% WW (0.07–0.06% DW).

In the context of the dominant flavor tone, the oils belong to the conifer-fruit (*P. radiata*), flower-conifer (*P. sabiniana*) and wood-resin-balsamic (*P. coulteri*) groups of tinges.

The major components of *P. radiata* essential oil are *β*-pinene (29.57%), *α*-pinene (21.2%) and limonene (12.4%); for *P. sabiniana*, they are phenylethyl butyrate (20.5%), limonene (15.2%) and *α*-pinene (13.7%); for *P. coulteri*, *β*-pinene (11.6%), *δ*-cadinene (11.0%) and *α*-pinene (10.6%).

Among the organic compounds in the essential oil of *P. radiata*, monoterpenes predominate (74.9% of the total organic compounds). In the essential oil of *P. sabiniana* monoterpenes (38.7%) and their derivatives – alcohols (25.3%) and esters (20.5%) – are prevailing. In the essential oil of *P. coulteri* the main part is occupied by sesquiterpenes (38.2%), while the content of monoterpenes is 28.8%.

A comparative analysis of the component composition in the essential oils of the studied pine species under different natural and climatic conditions showed the following results. The component composition of *P. radiata* essential oil is quite stable under different conditions; it is characterized by a predominance of monoterpenes, in particular *β*-pinene. A specific feature of *P. radiata* essential oil in the environments of the SCC is the presence of limonene. The essential oil of *P. sabiniana* is also dominated by monoterpenes (in particular α-pinene) and their derivatives, whose quantitative ratios vary depending on the growing conditions. The dominant component in the essential oil of *P. sabiniana*, growing on the SCC, as mentioned above, is the monoterpene alcohol phenylethyl butyrate. These species are characterized by almost complete absence of diterpenes and sesquiterpenes.

The highest variability in the component composition of essential oil is observed in *P. coulteri*. With the general tendency towards the predominance of sesquiterpenes and diterpenes in essential oil, the ratio between these groups changes, as does the qualitative composition of sesquiterpenes. For example, the proportion of monoterpenes and their derivatives increases significantly (by 10%, on average), compared to other areas where this species grows. Among sesquiterpenes, the leading role under different conditions can be played by the diterpene alcohol 4-epi-isocembrol (Greece), sesquiterpene *β*-caryophyllene (Tunisia), and *δ*-cadinene (SCC).

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