Original Research Paper

Natural Product Communications
Volume 18(3): 1–12

DOI: 10.1177/1934578X231161186
journals.sagepub.com/home/npx

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The Essential Oils of Rubber Rabbitbrush (*Ericameria nauseosa*) from North-Central Utah and Southwestern Idaho

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Abstract

Background: Rabbitbrush (*Ericameria nauseosa*) is a conspicuous member of plant communities in the deserts of western North America. The plant is an important winter forage for several ungulates in the region and has been used in Native American ethnopharmacology. **Methods:** Several specimens were collected from North Central Utah (8 samples) and Southwestern Idaho (6 samples). The essential oils were obtained by hydrodistillation and analyzed by gas chromatographic techniques. The data were analyzed using agglomerative hierarchical cluster analysis (HCA), principal component analysis (PCA), and Pearson correlation analysis. **Results:** Essential oil yields ranged from 0.030% to 2.011%. The major components in the essential oils were β-phellandrene (1.8%-56.5%), β-pinene (0.%3-23.3%), limonene (0.7%-22.3%), and (*Z*)-β-ocimene (0.0%-29.3%). With the exception of 1 sample from Utah, the essential oils showed greater than 50% similarity in composition. There were significant differences in percentages of some components, however. Sabinene, β-phellandrene, cosmene, 1,3,8-*p*-menthatriene, terpinen-4-ol, and β-eudesmol concentrations were higher in the Idaho samples while myrcene, limonene, geranyl acetate, (*E*)-β-caryophyllene, γ-curcumene, germacrene D, α-muurolene, γ-cadinene, and δ-cadinene concentrations were significantly higher in the Utah samples. Chiral gas chromatography–mass spectrometry showed the chiral monoterpenoids to be dominated by the (−)-enantiomers, but there were some differences in enantiomeric distribution in the essential oils from Utah compared to those from Idaho. **Conclusion:** The essential oil compositions in this work are qualitatively similar to those reported previously. However, there were quantitative differences in chemical composition and enantiomeric distributions between the Utah samples and the Idaho samples. Additional research is needed to compare essential oil composition from other geographical locations in western North America.

Keywords

essential oils, chemical composition, enantiomeric distribution, multivariate analysis, β-phellandrene, β-pinene, limonene, (Z)-β-ocimene

Received: January 27th, 2023; Accepted: February 15th, 2023.

Introduction

Ericameria nauseosa (Pursch) G.L. Nesom & G.I. Baird [syn. *Chrysothamnus nauseosus* (Pall. ex Pursh) Britton], rubber rabbitbrush (Asteraceae) is a shrub that grows in arid regions of western North America from around 102° west longitude to the Pacific coast.[1] The plant serves as winter forage for mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), and pronghorn (*Antilocapra americana*).[2] The Cheyenne Native Americans used a decoction of the aerial parts as a wash to treat sores and skin eruptions; an infusion of the inflorescences was taken to treat coughs.[3] The plant has been considered as a substitute source of rubber.[4] Currently, *E. nauseosa* is made up of 2 subspecies (subspp. *nauseosa* and *consimilis*) and 22 varieties.[5,6]

The phytochemistry of *E. nauseosa* has been previously investigated (as *Chrysothamnus nauseosus*). A chloroform extract of *E. nauseosa* has yielded polyacetylenes[7] and grindelane diterpenoids.[8] There have been several investigations into the volatile phytochemistry of *E. nauseosa*.[9–12] Major compounds reported in the essential oils were monoterpene hydrocarbons, β-phellandrene (18.0%-26.0%), β-pinene (9.2%-30.3%),

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Table 1. Chemical Composition (%) of Aerial Parts Essential oil of *Ericameria nauseosa* subsp. *nauseosa* from North-Central Utah.

			Sample number							
RI_{calc}	RI_{db}	Compound	UT#1	UT#2	UT#3	UT#4	UT#5	UT#6	UT#7	UT#8
925	927	α-Thujene	0.3	0.1	0.2	0.2	0.2	tr	0.1	—
932	932	α-Pinene	1.0	0.3	0.6	0.8	0.7	0.1	0.2	—
972	971	Sabinene	7.6	3.6	5.4	1.3	2.6	tr	0.2	—
978	978	β-Pinene	23.3	10.0	15.2	9.0	11.3	2.2	3.4	0.3
988	989	Myrcene	4.7	10.9	12.9	5.9	7.2	0.8	0.7	—
1006	1006	α-Phellandrene	0.2	0.1	0.2	1.1	1.2	0.6	0.4	—
1008	1008	δ-3-Carene	—	—	—	0.3	0.3	—	—	—
1016	1017	α-Terpinene	0.7	0.6	0.8	1.1	1.1	0.7	0.7	—
1025	1025	*p*-Cymene	—	0.1	0.1	0.4	0.2	0.6	0.2	—
1029	1030	Limonene	15.4	8.1	8.9	22.3	13.9	5.6	1.7	0.9
1031	1031	β-Phellandrene	35.9	25.2	26.3	15.8	26.4	14.4	14.3	1.8
1035	1034	(*Z*)-β-Ocimene	—	0.2	0.2	0.1	0.1	12.9	6.8	—
1045	1045	(*E*)-β-Ocimene	3.9	7.7	6.8	5.4	4.0	0.9	0.5	—
1057	1057	γ-Terpinene	1.1	1.0	1.1	2.2	1.9	1.6	1.4	—
1085	1085	Terpinolene	0.3	0.3	0.3	1.1	0.9	0.6	0.4	—
1113	1113	(*E*)-4,8-Dimethylnona-1,3,7-triene	—	0.1	0.1	tr	—	0.1	0.1	—
1119	1119	*endo*-Fenchol	—	—	—	tr	—	0.1	—	—
1122	—	Cosmene	—	0.2	—	tr	—	tr	0.1	—
1124	1124	*cis-p*-Menth-2-en-1-ol	—	tr	tr	0.1	0.1	0.2	0.1	—
1129	1128	*allo*-Ocimene	—	—	—	—	—	0.6	0.4	—
1130	1129	1,3,8-*p*-Menthatriene	—	1.3	0.7	0.6	0.4	0.1	0.2	—
1142	1142	*trans-p*-Menth-2-en-1-ol	—	—	—	tr	—	0.1	0.1	—
1171	1170	Ethyl benzoate	—	—	—	tr	—	—	—	—
1180	1180	Terpinen-4-ol	0.8	0.4	0.3	0.5	1.2	1.4	0.6	3.0
1184	1187	Hex-(3*Z*)-enyl butanoate	—	tr	—	—	—	—	—	—
1184	1188	Naphthalene	—	tr	tr	tr	—	—	—	—
1186	1185	Dill ether	—	—	—	tr	—	—	—	—
1187	1187	Cryptone	—	—	—	0.1	—	0.2	0.1	0.6
1190	1195	Hexyl butyrate	—	0.1	—	—	—	—	—	—
1192	1190	Methyl salicylate	—	0.1	tr	0.1	—	0.1	—	—
1195	1195	α-Terpineol	—	0.1	tr	0.1	0.2	0.4	0.2	1.7
1197	1196	*cis*-Piperitol	—	—	—	tr	—	0.2	—	—
1209	1208	*trans*-Piperitol	—	—	—	tr	—	0.1	—	—
1211	1214	Octyl acetate	—	0.3	0.2	0.2	0.1	0.5	0.4	—
1230	1231	Hex-(3*Z*)-enyl 2-methylbutanoate	—	0.1	tr	tr	—	—	—	—
1243	1242	Cuminal	—	—	tr	tr	—	0.1	tr	—
1253	1254	Piperitone	—	tr	tr	0.1	0.1	0.1	—	—
1268	1268	Ethyl salicylate	—	—	—	0.1	—	0.1	0.1	—
1278	1277	Phellandral	—	tr	0.1	0.1	0.1	0.9	0.6	—
1345	1345	α-Cubebene	—	0.1	0.1	0.1	0.1	0.1	0.2	—
1348	1350	Citronellyl acetate	—	0.6	0.4	0.5	0.4	0.2	0.2	3.4
1358	1361	Neryl acetate	—	0.1	tr	0.1	—	0.1	0.1	—
1369	1367	Cyclosativene	—	—	tr	0.1	—	—	—	—
1374	1374	α-Copaene	—	0.2	0.2	0.2	0.2	0.3	0.3	0.3
1377	1378	Geranyl acetate	—	3.2	2.0	1.3	0.9	0.4	0.3	3.0
1378	1382	Hex-(3*Z*)-enyl hexanoate	—	0.1	tr	—	—	—	—	—
1379	—	*cis*-Myrtanyl acetate	—	—	—	—	—	0.2	0.2	—
1380	1376	Methyl (*E*)-cinnamate	—	0.2	0.1	0.1	0.3	—	—	—
1384	1390	Hexyl hexanoate	—	0.1	0.1	—	—	—	—	—
1384	1382	*trans*-Myrtenyl acetate	—	—	—	—	—	0.8	0.7	—
1387	1390	7-*epi*-Sesquithujene	—	0.3	0.2	0.4	0.4	0.6	0.9	0.2
1389	1389	*trans*-β-Elemene	—	0.3	0.2	0.2	0.2	—	0.1	1.6
1400	1403	Methyleugenol	—	0.9	0.6	0.3	0.3	0.6	0.4	0.5
1418	1417	(*E*)-β-Caryophyllene	1.6	4.1	2.8	1.9	1.7	6.2	7.0	2.8
1430	1430	β-Copaene	—	0.1	0.1	0.1	0.1	0.1	0.2	—
1433	1433	*trans*-Cadina-1,4-diene	—	—	—	—	—	0.2	—	—

(Continued)

Table 1. Continued

			Sample number							
RI_{calc}	RI_{db}	Compound	UT#1	UT#2	UT#3	UT#4	UT#5	UT#6	UT#7	UT#8
1433	1432	*trans*-α-Bergamotene	—	0.1	0.1	0.1	0.2	0.4	0.3	—
1435	1435	Perillyl acetate	—	—	—	—	—	—	0.1	—
1444	1448	*cis*-Muurola-3,5-diene	—	tr	0.1	0.1	0.1	—	0.2	—
1444	1443	Prenyl benzoate	—	0.1	tr	0.1	—	—	—	—
1447	1453	*trans*-Muurola-3,5-diene	—	0.1	0.1	—	—	—	—	—
1453	1452	(*E*)-β-Farnesene	—	tr	tr	0.1	0.1	0.2	0.2	—
1455	1453	α-Humulene	—	0.2	0.1	0.2	0.2	0.2	0.2	0.4
1459	1458	*allo*-Aromadendrene	—	tr	0.1	0.1	—	—	0.1	0.4
1461	1461	4,6,8,10-Tetramethyltridecane	—	—	—	—	—	—	0.1	—
1461	1463	*cis*-Cadina-1(6),4-diene	—	0.1	0.2	0.1	—	—	0.1	—
1464	1463	γ-Decalactone	—	—	—	0.2	0.3	—	—	—
1469	1469	Ethyl (*E*)-cinnamate	—	—	—	0.1	—	0.9	0.8	—
1472	1472	*trans*-Cadina-1(6),4-diene	—	0.2	0.2	0.1	0.1	0.2	0.2	0.4
1475	1475	γ-Muurolene	—	0.4	0.3	0.6	0.6	0.7	0.7	0.9
1478	1478	γ-Curcumene	0.4	1.7	1.0	3.4	4.2	8.2	8.3	1.0
1482	1482	*ar*-Curcumene	—	—	—	—	—	6.6	2.9	—
1482	1484	Germacrene D	2.2	4.6	2.8	4.5	4.5	—	5.1	3.0
1485	1483	*trans*-β-Bergamotene	—	—	—	—	—	—	0.1	—
1489	1492	*trans*-Muurola-4(14),5-diene	—	—	—	—	—	—	—	0.5
1489	1489	β-Selinene	—	0.1	0.1	0.2	0.1	0.2	0.2	1.0
1491	1490	γ-Amorphene	—	0.2	0.2	0.3	0.3	0.3	0.4	—
1493	1497	α-Selinene	—	—	—	—	0.1	—	—	0.7
1494	1496	α-Zingiberene	—	0.1	—	0.1	0.1	0.4	0.8	—
1495	1497	*epi*-Cubebol	—	0.1	0.2	0.2	—	—	0.1	—
1498	1497	α-Muurolene	—	0.7	0.6	0.7	0.6	0.8	1.0	2.2
1502	1506	δ-Amorphene	—	—	—	0.1	0.2	—	0.1	—
1504	1503	β-Himachalene	—	—	—	—	—	0.3	—	—
1507	1508	β-Bisabolene	—	0.1	tr	0.2	0.2	0.6	0.8	—
1509	1509	β-Curcumene	—	0.3	0.2	0.5	0.6	1.4	1.5	—
1513	1512	γ-Cadinene	—	0.8	0.6	0.8	0.9	1.3	1.2	2.2
1518	1518	δ-Cadinene	0.6	2.9	2.3	3.1	2.4	2.8	3.4	10.5
1521	1520	(*E*,*Z*)-Matricaria ester	—	0.1	—	0.3	0.1	0.3	0.8	—
1523	1523	β-Sesquiphellandrene	—	—	—	—	—	—	0.7	—
1525	1527	(*Z*,*E*)-Matricaria ester	—	0.1	—	0.3	0.2	2.6	1.9	—
1531	1533	*trans*-Cadina-1,4-diene	—	0.1	0.1	0.1	0.1	—	—	0.3
1534	1537	Italicene ether	—	—	—	—	—	0.3	—	—
1537	1537	α-Cadinene	—	0.1	0.1	0.2	0.1	0.2	—	0.5
1540	1541	α-Calacorene	—	0.1	0.1	—	—	0.1	—	0.3
1561	1560	(*E*)-Nerolidol	—	—	—	0.5	0.3	2.0	2.6	—
1568	1573	Hex-(3*Z*)-enyl benzoate	—	0.1	—	—	—	—	—	—
1574	1574	Germacrene D-4-ol	—	—	—	—	—	—	—	0.3
1577	1577	Spathulenol	—	—	—	—	0.1	—	—	—
1582	1582	Caryophyllene oxide	—	0.3	0.3	0.2	0.1	0.4	1.1	1.1
1594	1594	Viridiflorol	—	0.3	0.2	0.3	0.1	0.4	0.4	2.9
1596	1596	Fokienol	—	—	—	—	—	0.2	0.3	—
1603	1600	α-Oplopenone	—	0.6	0.4	0.1	—	0.2	0.4	5.0
1615	1614	1,10-di-*epi*-Cubenol	—	—	—	0.1	—	0.1	—	0.2
1624	1624	Muurola-4,10(14)-dien-1β-ol	—	—	—	—	—	—	—	0.3
1627	1628	1-*epi*-Cubenol	—	0.1	tr	0.2	0.1	0.3	0.2	1.0
1639	1638	τ-Cadinol	—	0.6	0.4	1.1	0.6	1.1	1.2	5.9
1644	1644	τ-Muurolol	—	0.8	0.4	1.1	0.8	1.5	1.5	8.1
1646	1644	α-Muurolol (= δ-Cadinol)	—	0.2	0.1	0.4	0.2	0.4	0.5	2.4
1656	1655	α-Cadinol	—	1.6	0.8	2.3	1.4	2.5	2.5	21.7
1656	1658	Selin-11-en-4α-ol (= Kongol)	—	—	—	—	—	—	—	0.5
1671	1671	β-Bisabolol	—	—	—	0.1	—	0.5	0.8	—
1685	1688	α-Bisabolol	—	—	—	0.2	—	0.2	0.5	—

(Continued)

Table 1. Continued

			Sample number							
RI_{calc}	RI_{db}	Compound	UT#1	UT#2	UT#3	UT#4	UT#5	UT#6	UT#7	UT#8
1688	1685	Germacra-4(15),5,10(14)-trien-1α-ol	—	—	—	—	—	—	—	0.6
1731	1735	Oplopanone	—	—	—	—	—	—	—	0.4
1831	1832	(2Z,6E)-Farnesyl acetate	—	—	—	0.1	—	—	—	0.3
1833	1836	Neophytadiene	—	—	0.1	0.1	0.1	—	—	—
1840	1841	Phytone	—	0.3	0.2	0.2	0.1	0.3	1.5	0.6
1958	1958	Palmitic acid	—	—	—	—	—	—	—	0.4
1994	1993	Ethyl palmitate	—	—	—	—	—	0.2	1.0	—
2013	2015	13-*epi*-Manoyl oxide	—	—	—	—	—	0.1	—	—
2085	2086	Abietadiene	—	—	—	—	—	0.1	0.2	—
2100	2100	Heneicosane	—	—	—	—	—	0.1	—	—
2109	2109	Phytol	—	—	—	0.3	—	0.3	1.8	1.1
2160	2159	Incensole	—	—	—	—	—	—	—	0.5
2160	2164	Ethyl linoleate	—	—	—	—	—	0.1	0.7	—
2166	2169	Ethyl linolenate	—	—	—	—	—	0.3	1.4	—
2200	2200	Docosane	—	—	—	—	—	0.1	—	—
2300	2300	Tricosane	—	0.2	0.2	0.2	—	0.6	1.9	—
2500	2500	Pentacosane	—	—	—	—	—	—	0.4	—
		Monoterpene hydrocarbons	94.3	69.5	79.6	67.6	72.6	41.8	31.6	3.0
		Oxygenated monoterpenoids	0.8	4.4	2.8	2.8	3.0	5.4	3.2	11.7
		Sesquiterpene hydrocarbons	4.9	17.8	12.7	18.6	18.2	32.6	37.1	29.5
		Oxygenated sesquiterpenoids	0.0	4.4	2.8	6.7	3.7	10.1	11.8	50.7
		Benzenoid aromatics	0.0	1.3	0.7	0.7	0.6	1.7	1.3	0.5
		Diterpenoids	0.0	0.0	0.1	0.4	0.1	0.4	2.1	1.6
		Others	0.0	1.6	0.8	1.4	0.9	5.5	10.7	1.0
		Total identified	100.0	99.0	99.4	98.2	99.1	97.4	97.7	98.0

— = not detected.
Abbreviations: RI_{calc}, retention index determined with respect to a homologous series of *n*-alkanes on a ZB-5 ms column; RI_{db}, reference retention index obtained from the databases; tr, trace (<0.05%).

limonene (4.7%-33.2%), (*Z*)-β-ocimene (trace-14.6%), myrcene (0.9%-10.5%), and (*E*)-β-ocimene (0.3%-9.1%).[11,12] The purpose of this work was to examine the essential oil compositions of *E. nauseosa* subsp. *nauseosa* from several locations in southwestern Idaho and north-central Utah.

Results and Discussions

Essential oil Composition

Hydrodistillation of *E. nauseosa* aerial parts gave colorless essential oils in yields ranging from 0.030% to 0.294% (Utah samples) and 0.763% to 2.011% (Idaho samples). The essential oil compositions for the Utah and the Idaho samples are compiled in Tables 1 and 2, respectively.

The total number of compounds identified in the essential oils from Idaho ranged from 31 (ID#3) to 53 (ID#1), accounting for ≥99% of the total compositions. The major components in *E. nauseosa* essential oils from Idaho were β-phellandrene (29.4%-56.5%), β-pinene (4.2%-13.7%), (*Z*)-β-ocimene (0.2%-29.3%), and sabinene (2.0%-8.8%), with monoterpene hydrocarbons, in general (84.7%-92.1%), dominating the compositions. In contrast, the essential oils from Utah showed higher percentages of sesquiterpene hydrocarbons (4.9%-37.1%) and oxygenated sesquiterpenoids (0.0%-50.7%). In the Utah essential oils, β-phellandrene (1.8%-35.9%%), β-pinene (0.3%-23.3%), (*Z*)-β-ocimene (0.1%-12.9%), and sabinene (0.2%-7.6%) were major monoterpene components, along with myrcene (0.7%-12.9%) and limonene (0.9%-22.3%). The dominant sesquiterpenoid components in the Utah samples were α-cadinol (0.8-21.7%), δ-cadinene (0.6-10.5%), and *ar*-curcumene (2.9-6.6%). The essential oil compositions reported by Chao et al.[11] (collected near Salt Lake City, Utah; coordinates not reported) and by Tabanca et al.[12] (collected from Blaine County, Idaho; coordinates and elevation not reported) are similar in composition to those found in Utah samples UT#1, UT#2. UT#3, UT#4, and UT#5 in this present study.

Multivariate Analysis

In order to investigate the phytochemical relationships between the *E. nauseosa* essential oil samples, the percentages of the major components were subjected to agglomerative hierarchical cluster analysis (HCA) (Figure 1). The HCA shows that most of the *E. nauseosa* samples show >50% similarity in essential oil compositions. The lone exception was sample UT#8, which was collected in March 2021, from Pleasant Grove, Utah.

A principal component analysis (PCA) was carried out to verify the interrelation between the major components in the essential oils (Figure 2). The PCA shows most of the *E. nauseosa* essential

Table 2. Chemical Composition (%) of Aerial Parts Essential Oil of *Ericameria nauseosa* subsp. *nauseosa* from Southwestern Idaho.

			Sample number					
RI_{calc}	RI_{db}	Compound	ID#1	ID#2	ID#3	ID#4	ID#5	ID#6
926	927	α-Thujene	0.2	0.4	0.3	0.2	0.2	0.5
932	933	α-Pinene	0.2	0.6	0.5	0.6	0.6	0.6
941	940	α-Myrcene	—	—	—	tr	—	—
947	948	α-Fenchene	—	tr	—	—	—	—
949	950	Camphene	—	tr	tr	tr	tr	tr
961	959	Benzaldehyde	—	tr	—	—	tr	—
966	967	2,2-Dimethyl-3-heptanone	—	—	tr	—	—	—
970	970	2,6-Dimethyl-4-heptanone	—	—	tr	—	—	—
972	972	Sabinene	2.0	5.2	6.8	7.5	8.8	5.8
978	978	β-Pinene	4.2	13.7	13.4	13.0	12.6	12.2
990	989	Myrcene	1.2	1.3	1.1	1.2	1.5	1.3
991	990	2,3-Dehydro-1,8-cineole	0.1	tr	0.1	0.1	0.1	0.1
999	1003	Ethyl hexanoate	—	tr	tr	tr	tr	—
1005	1004	*p*-Mentha-1(7),8-diene	—	—	—	—	tr	—
1006	1006	3-Ethenyl-1,2-dimethyl-1,4-cyclohexadiene	0.9	0.2	0.2	0.3	0.3	0.1
1007	1007	α-Phellandrene	0.1	0.3	0.3	0.2	0.2	0.2
1017	1017	α-Terpinene	0.5	0.9	0.8	0.3	0.4	0.9
1025	1025	*p*-Cymene	0.1	0.2	0.1	0.1	0.1	tr
1030	1030	Limonene	5.8	0.7	0.8	0.8	0.8	2.6
1032	1031	β-Phellandrene	29.4	36.6	37.4	53.0	48.5	56.5
1036	1034	(*Z*)-β-Ocimene	29.3	19.5	19.5	0.2	0.3	0.3
1044	1045	Phenylacetaldehyde	—	—	tr	tr	0.1	tr
1046	1045	(*E*)-β-Ocimene	2.1	4.3	1.9	3.7	4.5	3.9
1059	1057	γ-Terpinene	0.8	1.5	1.3	0.6	0.7	1.5
1071	1069	*cis*-Sabinene hydrate	0.2	0.4	0.5	0.3	0.4	0.7
1082	1082	*p*-Mentha-2,4(8)-diene	tr	—	—	—	—	—
1087	1086	Terpinolene	0.2	0.5	0.3	0.2	0.2	0.3
1096	1097	α-Pinene oxide	tr	—	—	—	—	—
1101	1101	Linalool	tr	0.1	tr	tr	—	tr
1102	1101	*trans*-Sabinene hydrate	0.1	0.3	0.4	0.3	0.3	0.7
1106	1105	α-Thujone	—	—	—	0.1	0.1	—
1111	1111	Phenethyl alcohol	—	—	—	—	tr	—
1113	1113	(*E*)-4,8-Dimethylnona-1,3,7-triene	—	tr	tr	—	tr	tr
1122	—	(3*Z*,5*E*)-2,6-Dimethyl-1,3,5,7-octatetraene (= Cosmene)	3.5	0.7	0.6	1.2	1.5	0.6
1124	1124	*cis*-*p*-Menth-2-en-1-ol	0.3	0.7	0.8	0.4	0.6	0.6
1127	1127	(*E*,*Z*)-*allo*-Ocimene	1.9	—	—	—	—	—
1130	1129	1,3,8-*p*-Menthatriene	4.0	3.9	4.2	9.0	7.1	3.8
1139	1139	(*E*)-Myroxide	tr	—	—	—	—	—
1140	1139	(*E*,*E*)-*allo*-Ocimene	tr	—	—	—	—	—
1142	1142	*trans*-*p*-Menth-2-en-1-ol	0.2	0.5	0.5	0.3	0.4	0.3
1146	1145	Camphor	—	—	—	—	0.1	—
1151	1151	Citronellal	tr	—	tr	tr	—	tr
1163	1162	β-Artemisyl acetate	tr	—	—	—	—	—
1172	1171	*p*-Mentha-1,5-dien-8-ol	tr	—	tr	tr	—	tr
1182	1180	Terpinen-4-ol	2.2	3.3	3.2	1.3	1.5	2.7
1188	1187	Cryptone	0.1	0.3	0.1	0.3	0.5	0.1
1192	1192	Methyl salicylate	—	tr	tr	0.1	tr	—
1196	1195	α-Terpineol	0.2	0.4	0.4	0.2	0.2	0.2
1198	1198	*cis*-Piperitol	0.1	0.1	0.2	0.1	0.1	0.1
1201	—	(3*Z*)-Octenyl acetate	tr	tr	tr	tr	tr	tr
1208	1207	(3*E*)-Octenyl acetate	0.1	tr	tr	tr	tr	0.1
1209	1209	*trans*-Piperitol	0.1	0.2	0.2	0.2	0.3	0.2
1227	1227	Citronellol	0.3	0.1	0.2	tr	tr	0.2
1230	1231	(3*Z*)-Hexenyl 2-methylbutanoate	—	—	—	—	tr	—
1238	1238	Neral	tr	—	—	—	—	—
1241	1242	Cuminal	—	—	—	—	tr	—

(Continued)

Table 2. Continued

			Sample number					
RI_{calc}	RI_{db}	Compound	ID#1	ID#2	ID#3	ID#4	ID#5	ID#6
1255	1254	Piperitone	0.1	0.1	tr	tr	0.1	0.1
1261	1267	δ-Octenolactone	—	—	—	—	—	tr
1270	1268	Ethyl salicylate	—	—	—	—	tr	—
1277	1277	Perilla aldehyde	—	—	—	tr	—	—
1279	1280	Phellandral	—	tr	tr	tr	0.1	tr
1288	1287	α-Terpinen-7-al	—	tr	tr	tr	tr	—
1294	1291	*p*-Cymen-7-ol	—	—	—	—	tr	—
1311	1309	*p*-Vinylguaiacol	—	—	tr	—	—	0.2
1337	1335	*cis*-Piperityl acetate	—	—	tr	—	—	—
1340	1339	3-Oxo-*p*-menth-1-en-7-al	—	tr	tr	tr	tr	tr
1347	1348	α-Xubebene	tr	—	—	—	—	—
1351	1350	Citronellyl acetate	—	—	tr	tr	—	tr
1353	1356	Eugenol	—	—	—	—	0.1	—
1360	1358	4aα-7α-7aα-Nepetalactone	0.1	—	tr	—	—	—
1378	1377	α-Copaene	tr	—	—	tr	tr	tr
1383	1382	Modheph-2-ene	—	—	—	—	0.1	—
1384	1382	*trans*-Myrtanyl acetate	—	—	—	tr	tr	—
1387	1387	7-*epi*-Sesquithujene	tr	—	—	—	—	—
1389	1390	*trans*-β-Elemene	0.1	—	—	—	—	—
1390	1385	α-Isocomene	—	—	—	—	0.1	—
1396	1394	Vanillin	—	—	—	tr	—	—
1404	1405	Methyl eugenol	—	—	—	—	tr	—
1407	1406	α-Gurjunene	tr	—	—	—	—	—
1412	1411	β-Isocomene	—	—	—	—	0.1	—
1423	1424	(*E*)-β-Caryophyllene	tr	tr	—	tr	0.1	tr
1430	1430	β-Copaene	tr	—	—	—	—	—
1446	1447	Geranyl acetone	tr	—	tr	—	—	0.1
1449	1448	*cis*-Muurola-3,5-diene	tr	—	—	—	—	—
1452	1452	(*E*)-β-Farnesene	tr	—	—	tr	tr	—
1454	1454	α-Humulene	tr	—	—	tr	tr	tr
1460	1458	*allo*-Aromadendrene	0.1	—	—	—	—	—
1462	1463	*cis*-Cadina-1(6),4-diene	tr	—	—	—	—	—
1462	1463	γ-Decalactone	0.2	tr	tr	0.1	0.2	tr
1472	1472	*trans*-Cadina-1(6),4-diene	tr	—	—	—	—	—
1474	1475	γ-Muurolene	0.1	—	—	—	—	tr
1477	1482	γ-Curcumene	0.1	0.1	tr	0.2	0.2	tr
1479	1480	Germacrene D	0.1	—	—	—	—	—
1479	1480	*ar*-Curcumene	—	tr	tr	0.1	0.2	tr
1485	1490	γ-Amorphene	tr	—	—	—	—	—
1487	1489	δ-Selinene	tr	—	—	—	—	—
1489	1492	β-Selinene	tr	—	—	—	—	—
1491	1493	*trans*-Muurola-4(14),5-diene	0.1	—	—	—	—	—
1494	1497	Bicyclogermacrene	0.1	tr	tr	tr	tr	tr
1497	1497	α-Muurolene	0.2	—	—	tr	—	tr
1507	1508	β-Bisabolene	—	—	—	tr	tr	tr
1509	1509	β-Curcumene	tr	—	—	tr	tr	tr
1513	1512	γ-Cadinene	0.2	tr	—	—	—	tr
1515	1515	Cubebol	tr	—	—	—	—	tr
1518	1518	δ-Cadinene	1.4	tr	tr	0.1	0.1	0.1
1523	1526	Zonarene	tr	—	—	—	—	—
1532	1533	*trans*-Cadina-1,4-diene	tr	—	—	—	—	—
1536	1536	α-Cadinene	tr	—	—	—	—	—
1545	1548	Elemicin	—	—	—	—	—	0.1
1548	1549	α-Elemol	1.5	0.6	1.2	1.3	0.5	—
1559	1560	Lachnophyllum ester C	tr	0.1	tr	0.2	0.4	0.1
1561	1562	(*E*)-Nerolidol	—	—	—	—	tr	—

(Continued)

Table 2. Continued

RI_{calc}	RI_{db}	Compound	Sample number					
			ID#1	ID#2	ID#3	ID#4	ID#5	ID#6
1574	1574	Lachnophyllum ester D	—	—	—	—	tr	—
1576	1575	Germacra-1(10),5-dien-4β-ol	0.4	—	—	—	—	tr
1577	1576	Spathulenol	—	tr	tr	tr	tr	—
1579	1580	*trans*-Sesquisabinene hydrate	—	tr	tr	tr	tr	—
1582	1587	Caryophyllene oxide	—	—	—	tr	0.1	—
1586	1590	Globulol	tr	tr	—	—	—	—
1594	1594	Viridiflorol	tr	—	—	—	—	tr
1596	1593	Guaiol	0.1	—	—	—	—	—
1604	1605	Ledol	tr	—	—	—	—	—
1606	1607	5-*epi*-7-*epi*-α-Eudesmol	tr	—	—	—	—	—
1610	1613	Copaborneol	—	—	tr	tr	—	0.1
1613	1612	5-*epi*-7-*epi*-β-Eudesmol	tr	—	—	—	—	—
1614	1614	1,10-di-*epi*-Cubenol	tr	—	—	—	—	—
1615	1615	Zingiberenol	—	—	—	tr	—	—
1624	1624	*epi*-γ-Eudesmol	tr	—	tr	tr	—	—
1627	1628	1-*epi*-Cubenol	0.1	—	—	—	—	—
1631	1631	Eremoligenol	—	—	—	—	0.1	tr
1632	1632	γ-Eudesmol	0.4	0.3	0.3	0.2	0.1	0.1
1641	1639	Capillin	—	—	—	—	—	—
1642	1641	Agarospirol I (= Hinesol)	—	tr	tr	tr	tr	tr
1642	1640	τ-Cadinol	0.4	tr	—	—	—	0.1
1644	1644	τ-Muurolol	0.5	tr	—	—	—	0.1
1648	1651	α-Muurolol (= δ-Cadinol)	0.2	tr	—	—	—	tr
1655	1655	α-Cadinol	2.1	—	—	—	—	—
1658	1656	β-Eudesmol	—	1.7	1.7	2.3	4.1	1.5
1670	1670	*epi*-β-Bisabolol	—	tr	—	—	tr	—
1673	1674	β-Bisabolol	—	tr	tr	tr	tr	tr
1677	1681	γ-Dodecalactone	—	tr	—	tr	tr	tr
1686	1686	*epi*-α-Bisabolol	—	tr	—	—	0.1	—
1696	1695	Shyobunol	1.1	tr	—	—	—	0.1
1769	1769	Benzyl benzoate	—	—	—	—	tr	—
1842	1841	Phytone	—	—	—	—	tr	—
2107	2109	Phytol	—	tr	tr	0.1	0.2	tr
2300	2300	Tricosane	—	tr	—	—	tr	—
2500	2500	Pentacosane	—	—	—	—	tr	—
2700	2700	Heptacosane	—	—	—	—	0.1	—
		Monoterpene hydrocarbons	84.7	90.4	89.3	92.1	88.2	91.1
		Oxygenated monoterpenoids	6.0	6.6	6.4	3.4	4.6	6.0
		Sesquiterpene hydrocarbons	2.4	0.1	0.0	0.3	0.9	0.1
		Oxygenated sesquiterpenoids	6.7	2.7	3.2	3.8	5.0	2.0
		Diterpenoids	—	tr	tr	0.1	0.2	tr
		Benzenoid aromatics	0.0	0.0	0.0	0.1	0.1	0.3
		Acetylenes	tr	0.1	0.0	0.2	0.4	0.1
		Others	0.2	0.0	0.0	0.1	0.3	0.1
		Total identified	100.0	99.8	98.9	100.0	99.8	99.7

— = not detected.

Abbreviations: RI_{calc}, retention index determined with respect to a homologous series of *n*-alkanes on a ZB-5 ms column; RI_{db}, reference retention index obtained from the databases; tr, trace (<0.05%).

oils positively correlate with the monoterpene hydrocarbons β-phellandrene, β-pinene, limonene, and (*Z*)-β-ocimene, while sample UT#8 correlated with sesquiterpenoid concentrations.

In order to examine the potential correlation between chemical composition and geographical location (elevation, latitude, and longitude) and season (date of collection), a Pearson correlation analysis was carried out. Based on the Pearson correlation analysis (Table 3), the elevation of the collection site showed a positive and statistically significant correlation ($p < 0.05$) with bisabolane sesquiterpenoids ($r = 0.864$, $p < 0.0001$), and caryophyllane sesquiterpenoids ($r = 0.870$, $p < 0.0001$), and negative correlation with thujane monoterpenoids ($r =$

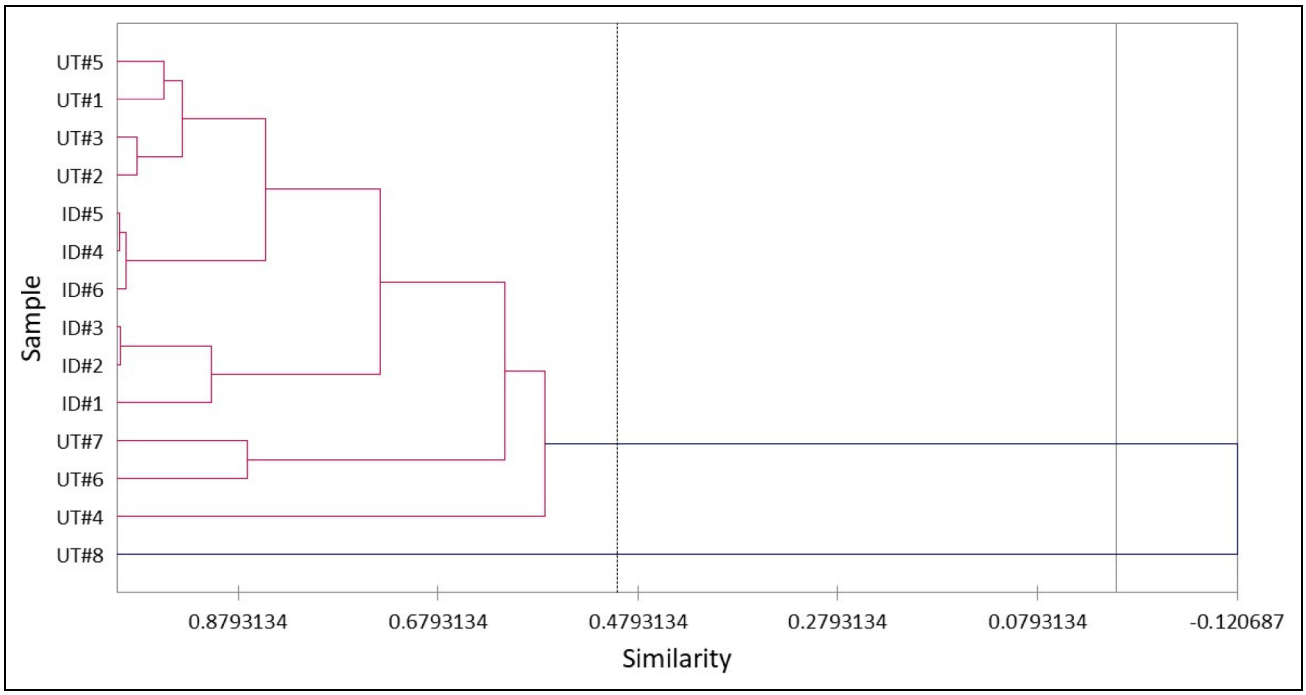

Figure 1. Dendrogram representing the similarities of the essential oil compositions of *Ericameria nauseosa*.

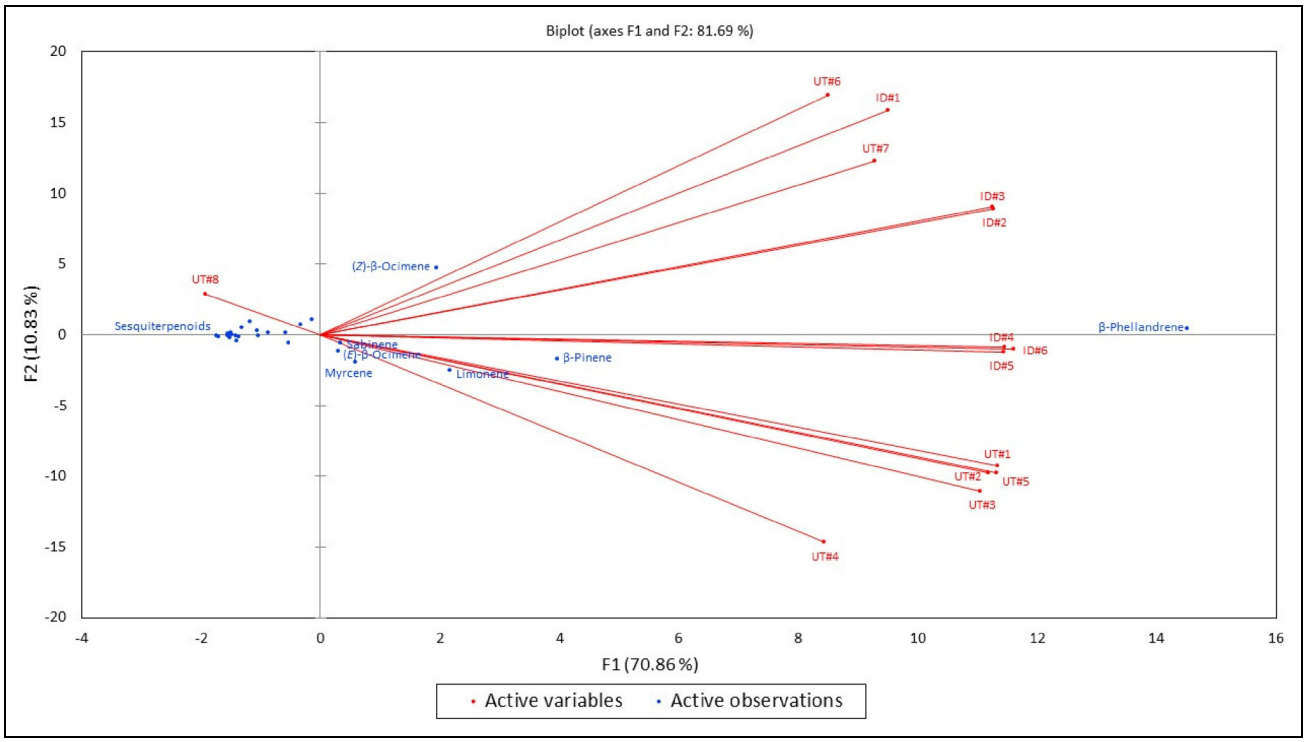

Figure 2. Principal component analysis (PCA) of the essential oils of *Ericameria nauseosa*.

−0.545, $p = 0.044$) and menthane monoterpenoids ($r = -0.539$, $p = 0.047$). The thujane and menthane monoterpenoids had a positive correlation with both latitude ($r = 0.639$, $p = 0.014$; $r = 0.593$, $p = 0.026$) and longitude ($r = 0.653$, $p = 0.011$; $r = 0.616$, $p = 0.019$). There was a negative correlation between caryophyllane sesquiterpenoids and latitude ($r = -0.807$, $p = 0.0005$) and longitude ($r = -0.797$, $p = 0.001$). These correlations are consistent with the higher concentrations

Table 3. Pearson Correlation (*p*-values in Parentheses) Between *Ericameria nauseosa* Essential Oil Component Classes and Sample Collection Parameters.

Variables	Thujanes	Pinanes	Menthanes	Gerananes	Bisabolanes	Cadinanes	Caryophyllanes	Germacranes
Elevation (m asl)	−0.545 (0.044)	−0.361 (0.205)	−0.539 (0.047)	−0.364 (0.200)	0.864 (< 0.0001)	0.272 (0.348)	0.870 (< 0.0001)	0.410 (0.145)
Latitude (°N)	0.639 (0.014)	0.148 (0.615)	0.653 (0.011)	0.163 (0.577)	−0.503 (0.067)	−0.478 (0.084)	−0.752 (0.002)	−0.807 (0.0005)
Longitude (°W)	0.593 (0.026)	0.134 (0.649)	0.616 (0.019)	0.245 (0.398)	−0.492 (0.074)	−0.470 (0.090)	−0.740 (0.002)	−0.797 (0.001)
Collection date	0.519 (0.057)	0.545 (0.044)	0.672 (0.009)	−0.052 (0.860)	−0.132 (0.653)	−0.689 (0.006)	−0.390 (0.169)	−0.490 (0.075)

of monoterpene hydrocarbons observed for the Idaho samples and the higher concentrations of sesquiterpenoids found in the Utah samples. The Utah collections sites were higher in altitude, but lower in both latitude and longitude. The geographical site of collection had an important effect on the chemical compositions of the essential oils. There were also positive correlations between collection date (ie, seasonal variation) and pinane ($r = 0.545$, $p = 0.044$) and menthane ($r = 0.672$, $p = 0.009$) monoterpenoids. Conversely, a negative correlation was found for cadinane sesquiterpenoids and collection date ($r = -0.689$, $p = 0.006$). That is, pinane and menthane concentrations apparently increased during the season, while cadinane concentrations decreased.

In order to further compare the *E. nauseosa* essential oil samples collected from Utah with those from Idaho, the concentrations of the major components were subjected to two-sample *t*-test for each compound. The average (± standard deviations) concentrations of the major components are listed in Table 4. The concentrations of the monoterpenoids, sabinene, β-phellandrene, 1,3,8-*p*-menthatriene, and terpinene-4-ol were significantly higher in the Idaho samples compared to the Utah samples. Conversely, several sesquiterpenoids, (*E*)-β-caryophyllene, γ-curcumene, germacrene D, α-muurolene, γ-cadinene, and δ-cadinene, had higher concentrations in the Utah samples.

Table 4. Comparison of Concentrations of Major Components of *Ericameria nauseosa* Essential Oils Collected from North-Central Utah and Southwestern Idaho.

	Average concentration (%) ± standard deviation		
Compound	Utah	Idaho	*p*-value
α-Pinene	0.5 ± 0.4	0.5 ± 0.2	0.768
Sabinene	2.6 ± 2.8	6.0 ± 2.3*	0.029
β-Pinene	9.3 ± 7.6	11.5 ± 3.6	0.497
Myrcene	5.4 ± 4.8*	1.3 ± 0.1	0.046
α-Terpinene	0.7 ± 0.3	0.6 ± 0.2	0.656
Limonene	9.6 ± 7.3*	1.9 ± 2.1	0.022
β-Phellandrene	20.0 ± 10.5	43.6 ± 10.7*	0.002
(*Z*)-β-Ocimene	2.6 ± 4.8	11.5 ± 12.8	0.155
(*E*)-β-Ocimene	3.6 ± 2.9	3.4 ± 1.1	0.833
γ-Terpinene	1.3 ± 0.7	1.1 ± 0.4	0.459
Cosmene	0.0 ± 0.1	1.3 ± 1.1*	0.037
1,3,8-*p*-Menthatriene	0.4 ± 0.4	5.3 ± 2.2*	0.003
Terpinen-4-ol	1.0 ± 0.9	2.4 ± 0.9*	0.015
Citronellyl acetate	0.7 ± 1.1	0.0 ± 0.0	0.125
Geranyl acetate	1.4 ± 1.2*	0.0 ± 0.0	0.016
(*E*)-β-Caryophyllene	3.5 ± 2.1*	0.0 ± 0.0	0.002
γ-Curcumene	3.5 ± 3.2*	0.1 ± 0.1	0.019
Germacrene D	3.3 ± 1.7*	0.0 ± 0.0	0.001
ar-Curcumene	1.2 ± 2.4	0.1 ± 0.1	0.225
α-Muurolene	0.8 ± 0.6*	0.0 ± 0.1	0.011
γ-Cadinene	1.0 ± 0.6*	0.1 ± 0.1	0.005
δ-Cadinene	3.5 ± 3.0*	0.3 ± 0.5	0.020
α-Oplopenone	0.8 ± 1.7	0.0 ± 0.0	0.212
τ-Cadinol	1.4 ± 1.9	0.1 ± 0.2	0.101
τ-Muurolol	1.8 ± 2.6	0.1 ± 0.2	0.117
α-Cadinol	4.1 ± 7.1	0.4 ± 0.9	0.186
β-Eudesmol	0.0 ± 0.0	1.9 ± 1.3*	0.017

*Significantly higher concentration (*t*-test), $p < 0.05$.

Terpenoid Enantiomeric Distributions

Several of the *E nauseosa* essential oils were analyzed by chiral gas chromatography-mass spectrometry (GC-MS) in order to determine the enantiomeric distributions of monoterpenoids (Table 5).

(−)-α-Thujene was the dominant enantiomer in all samples, and showed a higher proportion in the samples from Idaho compared to the samples from Utah, but the differences were not significant (*t*-test, $p = 0.072$). Although variable, (−)-α-pinene predominated over (+)-α-pinene in all samples, ranging from 59.5% to 90.1% for the Utah samples and 78.0%-90.6% for the Idaho samples. (−)-Sabinene was the exclusive enantiomer in the Utah samples but showed variation (74.4%-81.0%) in the Idaho samples. (−)-β-Pinene was the major enantiomer in all samples, ranging from 89.6% to 99.6%. (−)-α-Phellandrene was dominant in the Idaho samples (average 96.0%), but was variable in the Utah samples (31.1%-94.8%). Interestingly, limonene was nearly racemic in the Utah samples with an average of 40.9% (−)-limonene and 59.1% (+)-limonene, but (−)-limonene dominated in the Idaho samples (average 94.5%). (−)-β-Phellandrene was the dominant enantiomer in the samples from Utah (average 99.1%), but was the exclusive enantiomer in the samples from Idaho. (−)-*cis*-Sabinene hydrate (average 78.9%) and (−)-*trans*-sabinene hydrate (average 78.3%) were the major enantiomers in the Idaho samples but were not detected in the samples from Utah. (−)-Terpinen-4-ol was the major enantiomer in all samples and ranged from 65.8% to 68.6%.

Table 5. Enantiomeric Distribution of Monoterpenoid Components in *Ericameria nauseosa* Essential Oils from Utah and Idaho.

Compound	RT	UT#2	UT#3	UT#4	UT#5	ID#1	ID#2	ID#3	ID#4	ID#5	ID#6
(+)-α-Thujene	13.92	21.2	21.2	22.2	21.8	19.9	16.9	20.7	0.0	0.0	17.4
(−)-α-Thujene	13.99	78.8	78.8	77.8	78.2	80.1	83.1	79.3	100.0	100.0	82.6
(−)-α-Pinene	15.92	90.1	59.5	60.6	88.3	71.2	90.6	87.5	81.1	78.0	89.6
(+)-α-Pinene	16.40	9.9	41.5	39.4	11.7	28.8	9.4	12.5	18.9	22.0	10.4
(+)-Sabinene	19.74	0.0	0.0	0.0	0.0	25.6	20.9	23.3	20.4	19.0	21.4
(−)-Sabinene	20.60	100.0	100.0	100.0	100.0	74.4	79.1	76.7	79.6	81.0	78.6
(+)-β-Pinene	20.27	0.4	0.5	0.5	0.6	0.6	0.8	3.1	10.4	9.3	0.9
(−)-β-Pinene	20.62	99.6	99.5	99.5	99.4	99.4	99.2	96.9	89.6	90.7	99.1
(−)-α-Phellandrene	22.59	83.2	32.6	31.1	94.8	87.2	94.0	96.5	98.2	100.0	100.0
(+)-α-Phellandrene	22.81	16.8	67.4	68.9	5.2	12.8	6.0	3.5	1.8	0.0	0.0
(−)-Limonene	25.06	41.4	41.3	40.5	40.2	88.9	95.5	95.8	95.8	95.6	95.3
(+)-Limonene	25.99	58.6	58.7	59.5	59.8	11.1	4.5	4.2	4.2	4.4	4.7
(−)-β-Phellandrene	26.15	99.5	98.9	98.8	99.4	100.0	100.0	100.0	100.0	100.0	100.0
(+)-β-Phellandrene	26.88	0.5	1.1	1.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0
(+)-*cis*-Sabinene hydrate	40.70	nd	nd	nd	nd	22.7	19.8	21.9	21.2	20.0	20.9
(−)-*cis*-Sabinene hydrate	41.25					77.3	80.2	78.1	78.8	80.0	79.1
(+)-*trans*-Sabinene hydrate	46.15	nd	nd	nd	nd	nd	20.9	21.9	21.8	22.1	21.7
(−)-*trans*-Sabinene hydrate	46.84						79.1	78.1	78.2	77.9	78.3
(+)-Terpinen-4-ol	54.64	31.4	32.8	32.8	31.6	34.0	33.0	33.2	34.2	33.0	33.8
(−)-Terpinen-4-ol	54.93	68.6	67.2	67.2	68.4	66.0	67.0	66.9	65.8	67.0	66.2
(−)-α-Terpineol	59.73	100.0	100.0	100.0	100.0	73.3	82.5	76.9	67.3	67.3	77.3
(+)-α-Terpineol	60.58	0.0	0.0	0.0	0.0	26.7	17.5	23.2	32.7	32.7	22.7

Abbreviations: nd, not detected; RT, retention time (min).

Table 6. Collection Details for *Ericameria nauseosa* subsp. *nauseosa*.

Code	Date	Coordinates	Elevation (m)	Biomass (g)	Yield EO (g)
Utah samples					
UT#1	September 18, 2019	40°19′41″N, 111°38′00″W	1509	197.32	0.059
UT#2	May 20, 2020	40°21′39″N, 111°44′37″W	1409	207.95	0.160
UT#3	May 20, 2020	40°21′39″N, 111°44′37″W	1409	177.10	0.520
UT#4	June 4, 2020	40°21′39″N, 111°44′37″W	1409	356.98	0.500
UT#5	June 4, 2020	40°21′39″N, 111°44′37″W	1409	346.98	1.113
UT#6	June 22, 2020	40°35′07″N, 111°14′27″W	2409	423.36	0.478
UT#7	June 22, 2020	40°35′07″N, 111°14′27″W	2409	147.35	0.098
UT#8	March 29, 2021	40°21′39″N, 111°44′37″W	1409	139.11	0.326
Idaho samples					
ID#1	July 27, 2021	43°31′43″N, 116°28′18″W	792	54.24	0.417
ID#2	June 28, 2022	43°14′46″N, 116°22′46″W	701	136.15	1.517
ID#3	June 28, 2022	43°14′45″N, 116°22′47″W	704	164.55	1.255
ID#4	June 28, 2022	43°24′20″N, 115°17′33″W	1426	108.01	2.172
ID#5	June 28, 2022	43°24′20″N, 115°17′33″W	1426	102.75	1.615
ID#6	September 10, 2022	43°14′47″N, 116°22′45″W	701	81.43	1.064

(−)-α-Terpineol was the exclusive enantiomer in the samples from Utah, and although the major enantiomer in the Idaho samples, the concentration was significantly lower (average 74.1%). Thus, the enantiomeric distributions show significant differences between the Utah and the Idaho samples.

Conclusions

Eight essential oil samples of *E. nauseosa* subsp. *nauseosa* were collected from North Central Utah and 6 samples were collected from Southwestern Idaho. The essential oil compositions are qualitatively similar to those previously reported by Chao et al.[11] and Tabanca et al.[12]; corroborating the results of these previous reports and suggesting generally consistent chemical profiles for this plant. Nevertheless, subtle quantitative differences between the Utah samples and the Idaho samples were observed. The enantiomeric distributions of monoterpenoids are reported here for the first time and do reveal interesting differences and similarities between the Utah and Idaho collections. In order to more fully delineate the volatile phytochemistry of *E. nauseosa*, additional research is needed to examine essential oil compositions from other geographical locations

and different seasons in western North America to verify the trends observed.

Materials and Methods

Plant Material

Aerial parts of *E. nauseosa* subsp. *nauseosa* were collected from several plants growing in north-central Utah and southwestern Idaho (Table 6). The plants were identified by B. G. Platt and W. N. Setzer using published botanical descriptions[5,6] and by comparison with samples from the New York Botanical Garden Virtual Herbarium (https://sweetgum.nybg.org/science/vh/, accessed on May 3, 2022). A voucher specimen (WNS-Enn-0049) has been deposited in the University of Alabama in Huntsville Herbarium. The fresh-frozen (−20 °C) plant materials were hydrodistilled using either a Clevenger apparatus (Utah samples) or a Likens-Nickerson apparatus (Idaho samples) to give the essential oils as colorless oils with a pungent aroma.

Gas Chromatography

The essential oils of *E. nauseosa* subsp. *nauseosa* were analyzed by gas chromatographic techniques, including gas chromatography-mass spectrometry (GC-MS), gas chromatography-flame ionization detection (GC-FID), and chiral GC-MS as previously described.[13] Retention index (RI) values were determined with respect to a homologous series of *n*-alkanes on a ZB-5 ms column using the linear equation of van den Dool and Kratz.[14] The essential oil components were identified by comparison of the mass spectral fragmentation patterns and by comparison of RI values available in the Adams,[15] Mondello,[16] NIST20,[17] and our own in-house database.[18] The identification of enantiomers was determined by comparison of retention times with authentic samples obtained from Sigma-Aldrich (Milwaukee, WI, USA).

Statistical Analysis

The HCA, using Pearson correlation to measure similarity, and the unweighted pair group method with arithmetic average (UPGMA) for cluster definition, was used to analyze the similarity of the oil samples based on the distribution of the 27 components with the highest concentrations (average > 0.5%: β-phellandrene, β-pinene, limonene, (*Z*)-β-ocimene, sabinene, (*E*)-β-ocimene, myrcene, 1,3,8-*p*-menthatriene, α-cadinol, δ-cadinene, γ-curcumene, (*E*)-β-caryophyllene, germacrene D, terpinen-4-ol, γ-terpinene, τ-muurolol, geranyl acetate, τ-cadinol, β-eudesmol, α-terpinene, *ar*-curcumene, γ-cadinene, cosmene, citronellyl acetate, α-pinene, α-muurolene, and α-oplopenone). The PCA was utilized to verify the interrelation in the essential oil major components (see above). A Pearson correlation analysis was carried out to determine the phytochemical relationships with the collection parameters (elevation, latitude, longitude, and collection date). The HCA, PCA, and Pearson correlation analyses were performed using XLSTAT v. 2018.1.1.62926 (Addinsoft). Statistical significance was determined by two-sample *t*-test ($p < 0.05$) using Minitab® 18 (Minitab Inc., State College).

Acknowledgments

This work was carried out as part of the activities of the Aromatic Plant Research Center (APRC, https://aromaticplant.org/). We are grateful to Prof. Dr. Joyce K. R. da Silva (Programa de Pós-Graduação em Biotecnologia, Universidade Federal do Pará) for helpful discussions regarding statistical analysis.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Ethical Approval

Ethical approval is not applicable for this article.

Statement of Human and Animal Rights

This article does not contain any studies with human or animal subjects.

Statement of Informed Consent

There are no human subjects in this article and informed consent is not applicable.

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