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Research Article

Characterization of the volatiles of *Ericameria linearifolia* from southwestern Utah

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Abstract

Ericameria linearifolia, the narrowleaf goldenbush, is a conspicuous shrub growing in mountain and desert areas of California, southern Nevada, northwestern Arizona, and southwestern Utah. The purpose of this study was to obtain and chemically characterize the essential oil of this plant. Aerial parts of *E. linearifolia* were collected from southwestern Utah and hydrodistilled to give yellow essential oils in 1.290-1.817% yield, which were analyzed by gas chromatographic methods. The essential oils were dominated by monoterpene hydrocarbons (68.7-73.2%) and oxygenated monoterpenoids (16.2-18.7%). The major components were sabinene (13.2-14.3%), β-pinene (4.0-13.4%), β-phellandrene (0.3-13.9%), myrcene (6.0-12.2%), terpinen-4-ol (6.3-8.1%), limonene (1.5-15.8%), (*Z*)-β-ocimene (4.6-6.1%), (*E*)-β-ocimene (3.3-7.5%), and α-pinene (4.5-8.2%). Enantioselective GC/MS revealed the (+)-enantiomers to predominate for α-thujene, sabinene, *cis*-sabinene hydrate, *trans*-sabinene hydrate, and terpinen-4-ol, while the (–)-enantiomers predominated for β-phellandrene and verbenone. However, the enantiomeric distributions were not consistent for α-pinene, β-pinene, limonene, or α-terpineol, while linalool was virtually racemic.

1. Introduction

The genus *Ericameria* Nutt. (Asteraceae) contains 41 species, which are found in southwestern and western North America [1, 2]. *Ericameria linearifolia* (DC.) Urbatsch & Wussow (narrow-leaf golden bush) (syn. *Happlopappus linearifolius* DC.) is a shrub, 40-150 cm tall, the leaves are 12-55 mm long and 0.5-3 mm wide; the flower heads appear in spring and early summer and contain 3-18 ray florets and 16-60 disc florets (Fig. 1) [3, 4]. The native range of the plant includes California, southern Nevada, southwestern Utah, western Arizona, and northern Baja California (Fig. 2) [3], and grows in rocky or sandy soils on mountainsides, dry creek beds, deserts, and mesas [4]. The Kawaiisu people of California have used *E. linearifolia* in their traditional medicine [5]. A decoction of leaves and flowers was applied to limbs to treat rheumatism and applied externally to relieve soreness.

Labdane diterpenoids (18α-succinyloxy-labd-7-en-15-oic acid and 8,17*H*-7,8-dehydropinifolic acid) [6] and flavonoids (kaempferol, 3-methylkaempferol, 3,4′-dimethylkaempferol, quercetin, 3-methylquercetin, 3′-methylquercetin, and 3,3′-dimethylquercetin) [7] have been isolated and characterized from *E. linearifolia*. As far as we are aware, however, there have been no previous investigations on the essential oil of *E. linearifolia*. Apparently, only two other species of *Ericameria* have been analyzed in terms of essential oil composition, *Ericameria nauseosa* (Pursh) G.L.Nesom & G.I.Baird [8–10] and *Ericameria laricifolia*

Figure 1. *Ericameria linearifolia* (DC.) Urbatsch & Wussow (narrowleaf goldenbush). **A:** Photograph of the plant at the time of collection by K. Swor. **B:** Scan of the pressed plant by W.N. Setzer.

(A.Gray) Shinners [11]. As part of our continuing interest in the essential oils of Great Basin Asteraceae, the purpose of this study is to obtain and chemically characterize the essential oil of *E. linearifolia*.

Figure 2. Native range of *Ericameria linearifolia* (based on Urbatsch & Wussow, 1979 [3]).

2. Materials and methods

2.1. Plant material

Three different samples (three different plants) of *E. linearifolia* were collected on 26 April 2023 near Toquerville, Utah (37°17′9″ N, 113°18′21″ W, 1180 m asl). The plant was identified in the field by W.N. Setzer using a field guide [12] and later verified by comparison with herbarium samples from the New York Botanical Garden [13]. A sample of the plant was vouchered with the University of Alabama in Huntsville herbarium (WNS-El-6980). The fresh plant material was frozen (–20 °C) until distillation. The aerial parts of each plant were hydrodistilled using a Likens-Nickerson apparatus for 3 h with continuous extraction of the distillate with dichloromethane to give yellow essential oils (Table 1).

2.2. Gas chromatographic analysis

The essential oils from the aerial parts of *E. linearifolia* were analyzed by gas chromatography (GC/MS and GC-FID) as previously described [14]. Retention indices (RI) were determined using the linear equation of van den Dool and Kratz [15]. The essential oil components of *E. linearifolia* were identified by comparing their RI values (within ten RI units) and their MS fragmentation patterns (> 80% similarity)

Table 1. Details of hydrodistillation of *Ericameria linearifolia*.

Sample No.	Mass aerial parts (g)	Mass essential oil (g)	Yield (%, w/w)
#1	109.65	1.4144	1.290%
#2	117.04	1.8910	1.616%
#3	180.98	3.2888	1.817%

with those reported in the Adams [16], FFNSC3 [17], NIST20 [18], and Satyal [19] databases. The compound percentages were calculated from raw peak integration without standardization. Enantioselective GC/MS was carried out as described previously [14]. The individual enantiomers were determined by comparison of RI values with authentic samples (Sigma-Aldrich, Milwaukee, WI, USA), which are compiled in our in-house database. Enantiomeric distributions were calculated from raw peak areas.

3. Results and discussion

Hydrodistillation of three different plant samples of *E. linearifolia* from southwestern Utah gave yellow essential oils in yields of 1.290-1.817% (w/w). Gas chromatographic analysis (GC/MS, GC-FID) allowed for the identification of 122 components accounting for 99.1-99.6% of the total compositions (Table 2).

The major components in *E. linearifolia* essential oils were sabinene (13.2-14.3%), β-pinene (4.0-13.4%), β-phellandrene (0.3-13.9%), myrcene (6.0-12.2%), terpinen-4-ol (6.3-8.1%), limonene (1.5-15.8%), (*Z*)-β-ocimene (4.6-6.1%), (*E*)-β-ocimene (3.3-7.5%), and α-pinene (4.5-8.2%). As far as we are aware, there are only two previous reports on the essential oils of *Ericameria* species, *E. laricifolia* [11] and *E. nauseosa* [8–10]. The major components identified in *E. laricifolia* were β-phellandrene (24.3%), limonene (22.5%), β-pinene (17.5%), α-phellandrene (5.3%), and α-pinene (4.3%); while the major components (averages) in *E. nauseosa* were β-phellandrene (30.1%), β-pinene (10.3%), limonene (6.3%), (*Z*)-β-ocimene (6.4%), sabinene (4.1%), myrcene (3.6%), and (*E*)-β-ocimene (3.5%). Thus, there are qualitative similarities in the essential oils of the three *Ericameria* species, but quantitative differences. α-Pinene concentrations (average 5.9%) were higher in *E. linearifolia* than those reported for *E. laricifolia* (4.3%) or *E. nauseosa* (average 0.6%). Similarly, sabinene concentrations (average 13.8%) were also higher in *E. linearifolia* than those for *E. laricifolia* (not observed) or *E. nauseosa* (average 3.9%). β-Pinene concentrations were generally high in the *Ericameria* essential oils, *E. linearifolia* (average 10.0%), *E. laricifolia* (17.5%), and *E. nauseosa* (average 12.2%). Likewise, limonene concentrations were generally high in all three *Ericameria* essential oils, *E. linearifolia* (average 6.3%), *E. laricifolia* (22.5%), and *E. nauseosa* (average 9.0%). However, the concentration of β-phellandrene was lower in *E. linearifolia* (average 8.8%) than either *E. laricifolia* (24.3%) or *E. nauseosa* (average 27.7%). Terpinen-4-ol levels were high in *E. linearifolia* (average 7.0%), but lower in *E. laricifolia* (2.4%) and *E. nauseosa* (average 1.9%).

Several of the major components of *E. linearifolia* essential oil have shown relevant biological activity [20, 21]. For example, α-pinene has shown anti-inflammatory and antinociceptive activities in rodent models [22–25], while β-pinene has shown antinociceptive actions in rats [26]. Myrcene has also shown anti-inflammatory and analgesic effects in rodent models [27, 28]. Terpinen-4-ol has demonstrated antioxidant and anti-inflammatory activities as well as anti-arthritic effects attributed to the downregulation of the pro-inflammatory cytokines, IL-1ß, TNFα, IRAK, and NF-κB [29]. The anti-inflammatory and analgesic effects of the major components in *E. linearifolia* may account for the traditional use of this plant to treat rheumatism and other pains.

Enantioselective GC/MS was carried out to evaluate the enantiomeric distributions of chiral monoterpenoids (Table 3). The (+)-enantiomers predominated for α-thujene, sabinene, *cis*-sabinene hydrate, *trans*-sabinene hydrate, and terpinen-4-ol, while the (–)-enantiomers predominated for β-phellandrene and verbenone. Curiously, the enantiomeric distributions were not consistent between the three samples for α-pinene, β-pinene, limonene, and α-terpineol; the dominant enantiomers are switched for sample #1 compared to samples #2 and #3. Linalool was virtually racemic in the essential oils. In contrast, the essential oils of *E. nauseosa* showed (–)-α-thujene, (–)-α-pinene, (–)-sabinene, (–)-β-pinene, (–)-β-phellandrene, (–)-*cis*-sabinene

Table 2. Chemical composition (percent of total) of the essential oil from the aerial parts of *Ericameria linearifolia*.

RI_{calc}	RI_{db}	Compounds	Sample numbers		
			#1	#2	#3
925	925	α-Thujene	0.6	0.9	0.9
933	933	α-Pinene	4.5	5.1	8.2
949	950	Camphene	tr	tr	tr
953	953	Thuja-2,4(10)-diene	0.2	0.2	0.3
973	972	Sabinene	13.2	13.8	14.3
978	978	β-Pinene	4.0	12.7	13.4
990	989	Myrcene	12.2	6.4	6.0
1006	1006	3-Ethenyl-1,2-dimethylcyclohexa-1,4-diene	tr	tr	0.1
1007	1007	α-Phellandrene	tr	0.1	0.1
1017	1017	α-Terpinene	1.2	2.0	1.5
1025	1025	*p*-Cymene	1.3	1.1	1.2
1030	1030	Limonene	15.8	1.5	1.6
1032	1031	β-Phellandrene	0.3	13.9	12.3
1035	1034	(*Z*)-β-Ocimene	4.6	5.7	6.1
1047	1046	(*E*)-β-Ocimene	7.5	4.8	3.3
1058	1058	γ-Terpinene	2.4	3.6	2.8
1070	1069	*cis*-Sabinene hydrate	0.9	0.7	0.7
1085	1086	Terpinolene	0.6	0.9	0.8
1086	1086	*trans*-Linalool oxide (furanoid)	0.1	0.1	0.2
1090	1091	*p*-Cymenene	0.2	0.1	0.1
1096	1098	6-Camphenone	tr	-	-
1098	1098	Perillene	tr	-	-
1100	1101	Linalool	0.6	0.3	0.5
1101	1101	*trans*-Sabinene hydrate	0.6	0.5	0.4
1110	1112	Rose oxide	0.1	0.1	-
1122	1122	Chrysanthenone	0.1	0.1	0.1
1125	1124	*cis-p*-Menth-2-en-1-ol	0.4	0.6	0.4
1127	1127	α-Campholenal	0.2	0.2	0.5
1128	1128	(4*E*,6*Z*)-*allo*-Ocimene	0.2	0.2	0.2
1139	1139	Nopinone	0.1	tr	tr
1141	1141	*trans*-Pinocarveol	0.3	0.2	0.4
1142	1141	*cis*-Verbenol	0.3	0.3	0.7
1143	1142	*trans-p*-Menth-2-en-1-ol	0.3	0.3	0.1
1146	1146	*trans*-Verbenol	1.5	1.1	2.3
1149	1149	*iso*-Pulegol	0.1	0.1	-
1151	1154	*p*-Mentha-1(7),2-dien-8-ol	0.2	0.2	0.4
1152	1152	Citronellal	0.2	0.2	0.1
1156	1156	Menthone	tr	0.1	-
1157	1157	Sabina ketone	tr	tr	0.1
1158	1157	*iso*-Isopulegol	0.1	0.1	-
1162	1164	Pinocarvone	0.1	0.1	0.2
1173	1171	*p*-Mentha-1,5-dien-8-ol	0.5	0.5	1.0
1176	1176	Nonanol	0.3	tr	-
1178	1178	Octanoic acid	0.1	1.4	0.2

Table 2. *(Continued)*

RI_{calc}	RI_{db}	Compounds	Sample numbers		
			#1	#2	#3
1182	1180	Terpinen-4-ol	6.8	8.1	6.3
1188	1188	*p*-Cymen-8-ol	0.4	0.5	0.8
1196	1195	α-Terpineol	0.5	0.7	0.7
1197	1195	Myrtenol	0.3	0.1	0.3
1198	1198	*cis*-Piperitol	0.1	0.1	0.1
1208	1208	Verbenone	0.8	0.6	1.5
1210	1209	*trans*-Piperitol	0.1	0.2	0.1
1220	1218	*trans*-Carveol	0.1	0.1	0.2
1227	1227	Citronellol	0.1	0.1	0.1
1243	1242	Cuminal	tr	tr	tr
1244	1246	Carvone	tr	tr	0.1
1250	1249	Geraniol	0.2	0.1	0.2
1269	1270	*iso*-Piperitenone	0.1	0.1	0.1
1273	1276	2,3-Pinanediol	0.1	0.1	0.2
1277	1277	Phellandral	-	tr	tr
1293	1294	*p*-Cymen-7-ol	-	-	0.1
1331	1330	Bicycloelemene	-	0.1	0.1
1346	1348	α-Cubebene	0.2	-	-
1349	1349	Citronellyl acetate	0.1	0.1	-
1371	1372	Decanoic acid	2.0	1.4	0.8
1375	1375	α-Copaene	tr	-	0.1
1387	1387	β-Cubebene	0.1	-	-
1389	1390	*trans*-β-Elemene	0.1	0.1	0.1
1419	1417	(*E*)-β-Caryophyllene	0.1	0.6	0.3
1429	1433	β-Copaene	-	-	tr
1432	1432	*trans*-α-Bergamotene	-	tr	tr
1437	1438	Aromadendrene	tr	tr	tr
1449	1452	Cadina-3,5-diene	0.1	tr	-
1452	1452	(*E*)-β-Farnesene	tr	0.1	tr
1456	1454	α-Humulene	tr	tr	tr
1460	1457	*allo*-Aromadendrene	0.1	0.2	0.1
1465	1463	γ-Decalactone	tr	-	tr
1472	1472	*trans*-Cadina-1(6),4-diene	0.1	tr	tr
1475	1478	γ-Muurolene	0.1	0.1	0.1
1478	1478	γ-Curcumene	0.3	0.1	0.5
1481	1480	Germacrene D	0.9	0.4	1.2
1489	1489	β-Selinene	-	tr	-
1491	1491	Viridiflorene	tr	0.1	0.1
1492	1490	γ-Amorphene	0.2	tr	tr
1496	1497	Bicyclogermacrene	0.4	0.2	0.3
1496	1497	*epi*-Cubebol	0.3	-	-
1498	1500	α-Muurolene	0.1	0.2	0.1
1507	1508	β-Bisabolene	0.1	tr	0.1
1509	1509	β-Curcumene	tr	-	tr

Table 2. *(Continued)*

RI_{calc}	RI_{db}	Compounds	Sample numbers		
			#1	#2	#3
1513	1510	1,11-Oxidocalamenene	-	-	0.1
1513	1512	γ-Cadinene	0.1	0.2	0.1
1516	1515	Cubebol	0.3	tr	-
1518	1518	δ-Cadinene	1.4	0.8	0.4
1522	1519	*trans*-Calamenene	0.1	-	-
1523	1521	Zonarene	0.1	-	-
1533	1533	*trans*-Cadina-1,4-diene	0.1	tr	-
1537	1538	α-Cadinene	tr	tr	tr
1542	1541	α-Calacorene	0.1	0.1	0.1
1563	1560	Dodecanoic acid	0.2	0.1	0.1
1578	1576	Spathulenol	0.7	0.4	0.5
1583	1584	10-*epi*-Juneol	0.1	-	0.1
1583	1587	Caryophyllene oxide	-	0.2	-
1587	1590	Globulol	0.1	0.1	0.1
1588	1590	Gleenol	tr	-	-
1595	1594	Viridiflorol	0.1	0.1	0.1
1605	1605	Ledol	tr	tr	tr
1607	1609	Rosifoliol	tr	-	tr
1616	1616	1,10-di-*epi*-Cubenol	-	tr	-
1629	1628	1-*epi*-Cubenol	0.4	0.1	0.1
1633	1629	*iso*-Spathulenol	0.1	0.1	0.1
1643	1643	τ-Cadinol	0.4	0.4	0.5
1645	1645	τ-Muurolol	0.4	0.5	0.2
1647	1645	α-Muurolol (= δ-Cadinol)	0.2	0.1	0.1
1656	1655	α-Cadinol	0.9	1.2	0.7
1686	1688	α-Bisabolol	2.1	0.1	0.1
1694	1687	Shyobunol	0.3	0.3	0.1
1733	1735	Oplopanone	0.1	0.1	0.1
1840	1841	Phytone	tr	tr	tr
2105	2106	Phytol	tr	tr	tr
2300	2300	Tricosane	0.2	0.1	0.1
2400	2400	Tetracosane	0.1	tr	tr
2500	2500	Pentacosane	0.1	0.1	0.1
2700	2700	Heptacosane	0.1	tr	0.1
Compound Classes					
Monoterpene hydrocarbons			68.7	73.2	73.1
Oxygenated monoterpenoids			16.2	16.4	18.7
Sesquiterpene hydrocarbons			4.6	3.1	3.6
Oxygenated sesquiterpenoids			6.6	3.7	2.9
Diterpenoids			tr	tr	tr
Others			3.0	3.2	1.4
Total identified			**99.1**	**99.6**	**99.6**

RI_{calc} = Retention index determined using a homologous series of *n*-alkanes on a ZB-5ms column. RI_{db} = Reference retention index from the databases. tr = trace (< 0.05%). - = not detected.

Table 3. Enantiomeric distribution (%) of chiral monoterpenoids in *Ericameria linearifolia* essential oils.

Compounds	RI_{db}	RI_{calc}	Sample numbers		
			#1	#2	#3
(+)-α-Thujene	950	952	100.0	88.8	85.6
(–)-α-Thujene	951	954	0.0	11.2	14.4
(–)-α-Pinene	976	975	35.6	68.3	77.9
(+)-α-Pinene	982	981	64.4	31.7	22.1
(+)-Sabinene	1021	1016	92.6	73.7	71.6
(–)-Sabinene	1030	1027	7.4	26.3	28.4
(+)-β-Pinene	1027	1022	73.0	16.1	23.4
(–)-β-Pinene	1031	1030	27.0	83.9	76.6
(–)-α-Phellandrene	1050	1051	-	72.1	-
(+)-α-Phellandrene	1053	1053	-	27.9	-
(–)-Limonene	1073	1073	2.3	76.3	82.8
(+)-Limonene	1081	1078	97.7	23.7	17.2
(–)-β-Phellandrene	1083	1080	-	100.0	100.0
(+)-β-Phellandrene	1089	-	-	0.0	0.0
(+)-*cis*-Sabinene hydrate	1199	1198	86.4	71.0	69.4
(–)-*cis*-Sabinene hydrate	1202	1201	13.6	29.0	30.6
(–)-Linalool	1228	1227	47.1	44.5	43.5
(+)-Linalool	1231	1230	52.9	55.5	56.5
(+)-*trans*-Sabinene hydrate	1231	1229	93.5	73.2	73.0
(–)-*trans*-Sabinene hydrate	1235	1234	6.5	26.8	27.0
(+)-Terpinen-4-ol	1297	1291	73.1	55.0	62.9
(–)-Terpinen-4-ol	1300	1296	26.9	45.0	37.1
(–)-α-Terpineol	1347	1346	29.2	64.1	58.5
(+)-α-Terpineol	1356	1354	70.8	35.9	41.5
(–)-Verbenone	1368	1369	-	96.2	96.4
(+)-Verbenone	1380	1374	-	3.8	3.6

RI_{db} = Retention index from our in-house database. RI_{calc} = Calculated retention index based on a homologous series of *n*-alkanes on a Restek B-Dex 325 capillary column. - = compound not detected.

hydrate, (–)-*trans*-sabinene hydrate, (–)-terpinen-4-ol, and (–)-α-terpineol to be the dominant stereoisomers, while (+)-limonene predominated in *E. nauseosa* essential oils from Idaho, but (–)-limonene was the major isomer from Utah. Thus, there are no apparent consistencies in enantiomeric distributions of monoterpenoids in *Ericameria* essential oils.

4. Conclusions

There is a paucity of information regarding the essential oil compositions of *Ericameria*. Nevertheless, there seem to be some notable components common to the genus, namely β-phellandrene (up to 13.9% in *E. linearifolia* and abundant in other *Ericameria* species), α-pinene (4.5-8.2% in *E. linearifolia* and abundant in other *Ericameria* species), β-pinene (4.0-13.4% in *E. linearifolia* and abundant in other *Ericameria* essential oils), limonene (up to 15.8% in *E. linearifolia* and abundant in other *Ericameria* species), and terpinen-4-ol. Enantioselective GC/MS, however, showed the enantiomeric distributions of chiral monoterpenoids to be inconsistent, both between *Ericameria* species as well as within *E. linearifolia*. There are 41 species of *Ericameria*, but apparently only three species have had the essential oils examined, *E. nauseosa* (three different investigations), *E. laricifolia* (one investigation from 1977), and *E. linearifolia* (this present work). Thus, there are ample opportunities for future investigations on *Ericameria* essential oils, which would serve to better characterize the volatile phytochemistry of this genus.

Authors' contributions

Conceptualization, W.N.S.; Methodology, P.S. and W.N.S.; Software, P.S.; Validation, W.N.S., Formal Analysis, A.P., P.S., and W.N.S.; Investigation, K.S., A.P., P.S., and W.N.S.; Resources, P.S. and W.N.S.; Data Curation, W.N.S.; Writing – Original Draft Preparation, W.N.S.; Writing – Review & Editing, K.S., A.P., P.S., and W.N.S.; Project Administration, W.N.S.

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Availability of data and materials

All data will be made available on request according to the journal policy.

Conflicts of interest

The authors declare no conflict of interest.

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