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Research Article

Essential oil compositions of two sagebrush species from the Sawtooth Valley, Idaho: *Artemisia tridentata* subsp. *vaseyana* and *Artemisia cana* subsp. *viscidula*

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Abstract

Sagebrush species, including *Artemisia tridentata*, *Artemisia ludoviciana*, *Artemisia frigida*, and *Artemisia cana*, are conspicuous features of the intermountain western region of North America. As part of our interest in the volatile phytochemistry of aromatic and medicinal plants, including sagebrush, of the western United States, we obtained and analyzed the essential oils of *Artemisia tridentata* subsp. *vaseyana* and *Artemisia cana* subsp. *viscidula* from the Sawtooth Valley of central Idaho. Essential oils were obtained by hydrodistillation and analyzed by gas chromatography – mass spectrometry. The essential oil of *A. tridentata* subsp. *vaseyana* was dominated by fragranol (55.8-70.0%) and fragranyl acetate (24.1-30.0%). The major components of *A. cana* subsp. *viscidula* were (2*E*)-1,3,7-trimethyl-2,6-octadienyl acetate (33.7-38.2%) and ethyl *trans*-chrysanthemumate (7.8-26.3%), along with two major unidentified components (4.8-12.1% and 6.1-8.5%). The essential oil compositions of these two sagebrush species are remarkably different from those previously published and illustrate the complexity and variability of sagebrush volatile components.

1. Introduction

A major ecoregion in the intermountain western United States is the sagebrush steppe (sagebrush-dominated semiarid high desert), which covers about 62.7 million hectares of the Great Basin and Colorado Plateau [1]. The region is characterized by cold winters, relatively low annual precipitation, and dominance of sagebrush (*Artemisia* species) cover and perennial grasses [2]. Common sagebrush species include *Artemisia tridentata* Nutt., *Artemisia tripartita* Rydb., *Artemisia arbuscula* Nutt., and *Artemisia cana* Pursh. Other common plant species in this ecoregion include shrubs, such as rabbitbrush (*Ericameria nauseosa* (Pursch) G.L. Nesom & G.I. Baird, *Chrysothamnus viscidiflorus* Nutt.) and bitterbrush (*Purshia tridentata* (Pursh) DC.) and forbs, such as balsamroot (*Balsamorhiza sagittata* (Pursh) Nutt.), yarrow (*Achillea millefolium* L.), *Lomatium* species, and *Eriogonum* species [1].

There are four subspecies of *Artemisia tridentata* Nutt. (big sagebrush, Asteraceae) currently recognized by World Flora Online (WFO): *A. tridentata* subsp. *tridentata* (Great Basin sagebrush), *A. tridentata* subsp. *vaseyana* (Rydb.) Beetle (mountain big sagebrush), *A. tridentata* subsp. *wyomingensis* Beetle & A.L. Young (Wyoming sagebrush), and *A. tridentata* subsp. *parishii* (A. Gray) H.M. Hall & Clem. (Parish sagebrush, Mojave sagebrush) [3]. Each *A. tridentata* subspecies occupies a distinct environment; however, hybridization can occur in intermediate zones [4, 5].

Mountain big sagebrush (*A. tridentata* subsp. *vaseyana*) ranges from British Columbia, Canada, south through Washington, Idaho, Montana, Oregon, Wyoming, California, Nevada, Utah, and Colorado, and into northern Arizona and New Mexico [6]. The plant is generally found in montane meadows and forests at elevations of 2000-2800 m. It is a medium-sized shrub, around 0.4-0.8 m tall. The leaves are 12-35 mm long, 2-3 mm wide, with three shallow lobes; the flower stalks are prominent paniculiform arrays, 10-15 cm long [6] (Fig. 1).

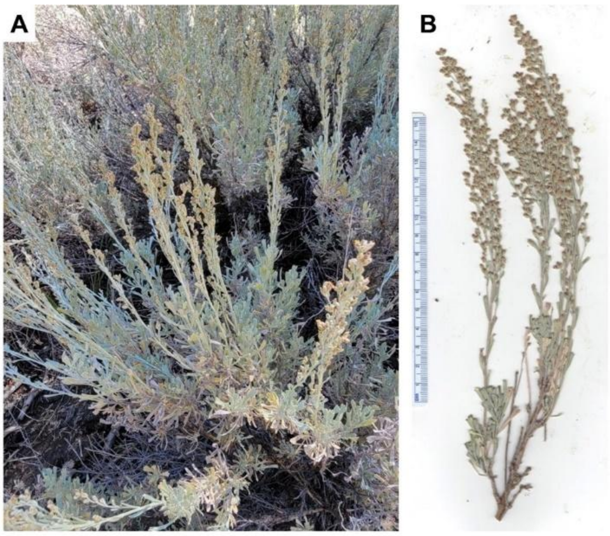

Figure 1. *Artemisia tridentata* subsp. *vaseyana* (Rydb.) Beetle. **A:** Photograph of the plant taken at the time of collection. **B:** Scan of a pressed sample.

Volatiles from *A. tridentata* subsp. *vaseyana* have been previously studied in southwestern Montana (major components α-pinene, 1,8-cineole, camphor, and two unidentified monoterpenoids) [7], central Utah (major components 1,8-cineole, *trans*-3-(1-oxo-2-methyl-2-propenyl)-2,2- dimethylcyclopropylmethanol, 2,2-dimethyl-6-isopropenyl-2*H*-pyran, 2,3-dimethyl-6-isopropyl-4*H*-pyran, thujone, sabinol, chrysanthemol, chrysanthemyl acetate, fragranyl acetate, fragranol, and 2-isopropenyl-5-methylhexa-(*E*)-3,5-dien-1-ol) [8], north-central Wyoming (major components, α-pinene, camphene, 1,8-cineole, camphor, fragranol, and grandisol) [9], and southwestern Idaho (major components 1,8-cineole, α-thujone, and camphor) [10]. The present study represents the first collection and analysis of *A. tridentata* subsp. *vaseyana* from the Sawtooth Valley of central Idaho. We hypothesized that the geographical remoteness of this collection from those from Utah or Montana likely exhibited a different chemical profile from previous reports.

Artemisia cana Pursh (silver sagebrush, Asteraceae) is an aromatic shrub found in the grasslands, floodplains, and montane forests of the western United States and Canada [6, 11, 12]. There are three subspecies of *A. cana*: *A. cana* subsp. *cana* (plains silver sagebrush), *A. cana* subsp. *bolanderi* (A. Gray) G.H. Ward (Bolander's silver sagebrush), and *A. cana* subsp. *viscidula* (Osterh.) Beetles (mountain silver sagebrush) [3]. Plains silver sagebrush is generally found east of the Continental Divide, including western Canada (Manitoba, Saskatchewan, Nebraska, Alberta and British Columbia) and the northwestern United States (North Dakota, South Dakota, Nebraska, Montana, Wyoming, Colorado). The range of Bolander's silver sagebrush is generally restricted to the enclosed basins of central Oregon and eastern California. Mountain silver sagebrush inhabits mountainous regions (approximately 1,800 m or higher) of southern Idaho, southwestern Wyoming, eastern Nevada, south along the Continental Divide, northern New Mexico and northern Arizona [13]. The plant generally grows 0.1-0.3 m tall, with linear-oblanceolate, entire leaves measuring 1-5 mm wide and up to 7 cm long, and covered with a silvery-white pubescence. The flower heads are arranged into congested, leafy panicles, sometimes reduced to a raceme or spike-like inflorescence [6, 11, 12] (Fig. 2).

Previous investigations of *Artemisia cana* subsp. *cana* have shown that the essential oils are dominated by 1,8-cineole and camphor [9,14,15]. Gundawardena and co-workers isolated and identified santolina triene, artemisia triene, artemiseole, 1,8-cineole,

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Figure 2. *Artemisia cana* subsp. *viscidula* (Osterh.) Beetle. **A:** Photograph of the plant taken at the time of collection. **B:** Scan of a pressed sample.

camphor, α-pinene, lyratal, isolyratol, lyratol, chrysanthemol, *trans*-chrysanthemal, chrysanthemyl acetate, fragranyl acetate, fragranol, 2-isopropenyl-5-methyl-(*E*)-hexa-3,5-dien-1-ol, 2,2-dimethyl-6-isopropenyl-2*H*-pyran, 2,3-dimethyl-6-isopropyl-4*H*-pyran, 2,4-diisopropenyl-5*H*-furan, and rothrockene from a pentane extract of *A. cana* subsp. *viscidula* [8]. However, the volatile chemical composition was not quantified. To the best of our knowledge this is the first report on the essential oil composition of *A. cana* subsp. *viscidula* growing in the Sawtooth Valley of central Idaho. We hypothesized that the chemical composition would differ from that of *A. cana* subsp. *cana*. As part of our interest in the volatile phytochemistry of aromatic and medicinal plants, we obtained and analyzed the essential oils from *Artemisia tridentata* subsp. *vaseyana* and *Artemisia cana* subsp. *viscidula*, which were growing in the Sawtooth Valley of central Idaho, and compared and contrasted the essential oil compositions with previous reports on these sagebrush species.

2. Materials and methods

2.1. Plant Material

The aerial parts of *A. tridentata* subsp. *vaseyana* and *A. cana* subsp. *viscidula* were collected from several plants growing in the Sawtooth Valley of Idaho on 11 October, 2025, in the early afternoon (Table 1). *Artemisia tridentata vaseyana* samples #1-3 were collected at 1:50, 1:55, and 1:58 pm, respectively. *Artemisia cana viscidula* samples #1-4 were collected at 1:53, 2:03, 2:12, and 2:53 pm, respectively. The plants were identified in the field by W.N. Setzer and verified by comparison with herbarium samples from the New York Botanical Garden [16]. Voucher specimens (WNS-Atv-2544 and WNS-Acv-5680) were deposited in the University of Alabama in Huntsville Herbarium. The fresh plant material was frozen after collection and stored frozen (–20 °C) until processed. For each plant sample, the fresh/frozen plant material was chopped and then hydrodistilled using a Likens-Nickerson apparatus for four hours with continuous extraction of the distillate with dichloromethane. The solvent was evaporated from the distillate using a stream of warm air to obtain the essential oils (Table 1).

2.2. Gas Chromatographic Analysis

The *A. tridentata* subsp. *vaseyana* and *A. cana* subsp. *viscidula* essential oils were analyzed by GC-MS using a Shimadzu GC-MS-QP2010 Ultra (Shimadzu Scientific Instruments, Columbia, MD, USA), fitted with a Zebron ZB-5ms fused silica capillary column (60 m × 0.25 mm × 0.25 μm film thickness) (Phenomenex, Torrance, CA, USA). The MS detector was operated in the electron impact (EI) mode with an electron energy of 70 eV, scan range of 40–400 atomic mass units, and scan rate of 3.0 scans/s. The injector, interface, and ion source temperatures were 260 °C. The GC oven was programed with an initial temperature of 50 °C, ramped at 2 °C/min to 260 °C, and held at 260 °C for 5 min. Each sample (0.1 μL of a 5% solution of essential oil in dichloromethane) was injected using a split mode (24.5:1). Retention indices were determined based on a series of homologous C_8-C_{26} *n*-alkanes (Sigma-Aldrich, St. Louis, MO, USA) using the arithmetic method described by van den Dool and Kratz [17]. The identification of the essential oil components were determined by comparison of retention indices (within 5 RI units) and mass spectral fragmentation (similarity index > 80%) with those in the databases of Adams [18], Satyal [19], Mondello [20], NIST20 [21],and W23N23 [22]. The percentages of the essential oil components were calculated based on peak integration without standardization.

2.3. Multivariate Analyses

Hierarchical cluster analysis (HCA) and principal

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Table 1. Collection and hydrodistillation details of *Artemisia tridentata* subsp. *vaseyana* and *Artemisia cana* subsp. *viscidula*.

Sample	Location	Mass plant material (g)	Mass essential oil (g)	Essential oil color	Yield (%, w/w)
Artemisia tridentata subsp. *vaseyana*					
#1	44°2′46″ N, 114°51′12″ W, 2054 m asl	52.80	2.40	pale yellow	4.55
#2	44°2′48″ N, 114°51′13″ W, 2050 m asl	93.17	3.81	pale yellow	4.09
#3	44°2′48″ N, 114°51′14″ W, 2050 m asl	39.53	2.07	greenish-yellow	5.24
Artemisia cana subsp. *viscidula*					
#1	44°2′47″ N, 114°51′13″ W, 2053 m asl	44.33	1.69	pale yellow	3.81
#2	44°2′48″ N, 114°51′11″ W, 2050 m asl	71.03	2.82	yellow	3.98
#3	44°2′33″ N, 114°50′28″ W, 2057 m asl	79.14	3.69	yellow	4.67
#4	44°2′33″ N, 114°50′29″ W, 2057 m asl	82.01	3.14	yellow	3.83

component analysis (PCA) were performed using XLSTAT v. 2018.1.1.62926 (Addinsoft, Paris, France). For the HCA, 18 *A. tridentata* subsp. *vaseyana* essential oil compositions from this study and previous publications [9,10] were treated as operational taxonomic units, and the percentages of the 14 most abundant essential oil components (α-pinene, camphene, artemiseole, 1,8-cineole, α-thujone, β-thujone, grandisol, chrysanthenone, *trans*-pinocarveol, camphor, *trans*-chrysanthemol, fragranol, ethyl *trans*-chrysanthemumate, and fragranyl acetate) were used to define the chemical associations between the *A. tridentata* subsp. *vaseyana* essential oil samples. Dissimilarity was used to determine clusters, considering the Euclidean distance, and Ward's method was used to define agglomeration. PCA was performed for the visual verification of the essential oil interrelationships of the different *A. tridentata* subsp. *vaseyana* samples using 14 major components as variables with a Pearson correlation matrix. Both HCA and PCA for *A. cana* subspecies *cana* [9, 14, 15] and *viscidula* (this work) were carried out as described above using 10 major components (α-pinene, camphene, artemiseole, 1,8-cineole, santolina alcohol, *cis*-chrysanthemal, camphor, *trans*-chrysanthemol, ethyl *trans*-chrysanthemumate, and (2*E*)-1,3,7-trimethyl-2,6-octadienyl acetate).

3. Results and discussion

3.1. Chemical Composition of Artemisia tridentata subsp. vaseyana

The essential oils of *A. tridentata* subsp. *vaseyana* were obtained by hydrodistillation using a Likens-Nickerson apparatus, with yields of 4.09-5.24% (w/w). The Likens-Nickerson simultaneous distillation extraction method generally gives higher essential oil yields [23–26] and higher yields of volatile monoterpene hydrocarbons [23] that are prone to escape due to the high temperatures of boiling water [27] and water-soluble components [24, 28, 29] that would otherwise partition into the hydrosol [29]. Thus, the Likens-Nickerson method is appropriate for small amounts of plant material [26] and is often the best method to obtain the most representative oil with the highest overall recovery [29]. Gas chromatographic analysis of the essential oils identified 76 components, which accounted for 98.0-98.4% of the total composition. The essential oil compositions are compiled in Table 2. The essential oils were dominated by oxygenated monoterpenoids, predominantly fragranol (55.8-70.0%) and fragranyl esters (25.0-31.6%). A representative chromatogram of *A. tridentata* subsp. *vaseyana* is shown in *Supplementary Fig. S1*. Oxygenated monoterpenoids have generally dominated the essential oils of *Artemisia tridentata* [10, 30], including *A. tridentata* subsp. *vaseyana* [9,10], although the individual compositions are highly variable. Other sagebrush species, e.g., *Artemisia ludoviciana* Nutt [9, 14, 31–34], *Artemisia frigida* Willd [14, 35–40], and *Artemisia longifolia* Nutt. [9] are also rich in oxygenated monoterpenoids (Table 2).

Fragranol, (1*S*,2*S*)-1-(2-hydroxyethyl)-2-isopropenyl-1-methylcyclobutane, was first isolated from *Artemisia fragrans* Willd. [41]. The compound has also been found in the essential oils of other members of the Asteraceae, including *Achillea nobilis* subsp. *neilreichii*

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Table 2. Essential oil compositions (percent of total composition) of *Artemisia tridentata* subsp. *vaseyana* from Sawtooth Valley, Idaho.

RI_{calc}	RI_{db}	Compounds	Area %		
			#1	#2	#3
766	774	Isobutyric acid	tr	tr	tr
829	830	Isovaleric acid	tr	tr	tr
840	840	2-Methylbutanoic acid	tr	tr	tr
848	846	(*Z*)-Salvene	tr	tr	-
850	850	Propyl isobutyrate	-	-	tr
850	850	(2*E*)-Hexenal	tr	tr	tr
880	878	3-Methyl-3-buten-1-yl acetate	tr	tr	tr
914	913	Isobutyl isobutyrate	tr	tr	tr
920	920	Prenyl acetate	tr	tr	tr
923	923	Tricyclene	-	tr	tr
926	927	α-Thujene	tr	tr	tr
933	932	α-Pinene	tr	0.1	0.1
949	953	Butyl isobutyrate	-	-	tr
949	950	Camphene	tr	0.1	tr
961	960	Benzaldehyde	tr	tr	tr
972	972	Sabinene	0.1	0.2	tr
978	978	β-Pinene	tr	0.1	tr
989	989	Myrcene	-	tr	tr
990	990	Dehydro-1,8-cineole	tr	0.1	tr
1017	1018	α-Terpinene	tr	tr	tr
1022	1022	Ethyl 3-methylbut-3-enyl carbonate	tr	tr	tr
1025	1025	*p*-Cymene	tr	tr	tr
1029	1030	Limonene	tr	tr	tr
1031	1031	2-*sec*-Butylthiazole	tr	-	tr
1032	1032	1,8-Cineole	2.1	3.2	1.9
1043	1043	Phenylacetaldehyde	0.1	tr	tr
1052	1055	Prenyl isobutyrate	-	tr	tr
1058	1058	γ-Terpinene	tr	0.1	tr
1070	1069	*cis*-Sabinene hydrate	tr	tr	tr
1085	1086	Terpinolene	tr	tr	tr
1105	1104	Nonanal	tr	-	tr
1107	1105	α-Thujone	2.9	4.4	0.1
1111	1112	*cis*-Rose oxide	tr	0.1	0.1
1111	1113	Phenethyl alcohol	tr	-	-
1118	1118	β-Thujone	0.3	0.4	-
1119	1118	Dehydrosabina ketone	tr	tr	-
1126	1127	*trans*-Rose oxide	tr	tr	0.1
1127	1123	Grandisol	tr	tr	0.1
1137	1138	Benzeneacetonitrile	tr	tr	tr
1138	1140	3-Methylbutenyl 2-methylbutyrate	-	tr	-
1138	1139	Nopinone	tr	-	-
1140	1140	*trans*-Sabinol	tr	0.1	-
1141	1141	*trans*-Pinocarveol	tr	0.1	-
1147	1145	Camphor	-	0.3	tr
1151	1152	Nerol oxide	tr	-	-
1162	1164	Pinocarvone	tr	tr	tr

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Table 2. *(Continued).*

RI_{calc}	RI_{db}	Compounds	Area %		
			#1	#2	#3
1170	1170	δ-Terpineol	tr	tr	tr
1172	1173	Borneol	-	0.2	-
1180	1180	Terpinen-4-ol	0.1	0.2	0.1
1194	1199	3,9-Epoxy-*p*-mentha-1,8(10)-diene	tr	-	-
1195	1195	α-Terpineol	-	0.1	tr
1220	1212	Fragranol	64.3	55.8	70.0
1284	1285	Bornyl acetate	-	0.2	tr
1288	1286	*trans*-Sabinyl acetate	tr	0.1	-
1320	1325	Dihydrocarvyl acetate	tr	0.1	tr
1346	1345	Fragranyl acetate	26.7	30.0	24.1
1354	1361	Neryl acetate	0.1	0.2	0.1
1380	1375	α-Copaene	0.1	tr	0.1
1388	1391	β-Bourbonene	-	-	tr
1423	1424	(*E*)-β-Caryophyllene	0.3	0.1	tr
1441	1441	Fragranyl propionate	0.3	1.0	0.4
1445	1448	Neryl propionate	-	tr	tr
1481	1482	γ-Curcumene	0.1	0.1	0.1
1484	1484	Fragranyl isobutyrate	0.2	0.2	0.4
1484	1480	Germacrene D	0.2	0.2	0.2
1499	1497	Bicyclogermacrene	tr	0.1	0.1
1499	1497	α-Selinene	-	-	tr
1507	1507	Geranyl isobutyrate	-	0.1	0.1
1521	1518	δ-Cadinene	tr	0.1	tr
1574	1575	Fragranyl 2-methylbutyrate	0.2	0.3	0.1
1578	---	Fragranyl isovalerate[a]	tr	0.1	tr
1580	1576	Spathulenol	0.1	0.1	0.1
1584	1587	Caryophyllene oxide	0.1	tr	tr
1628	1632	Muurola-4,10(14)-dien-1β-ol	0.1	0.1	-
1658	1655	α-Cadinol	tr	tr	tr
1951	1960	(*E*)-Tibetin spiroether	tr	-	-
		Compound classes			
		Monoterpene hydrocarbons	*0.1*	*0.6*	*0.1*
		Oxygenated monoterpenoids	*97.1*	*97.2*	*97.5*
		Sesquiterpene hydrocarbons	*0.6*	*0.5*	*0.4*
		Oxygenated sesquiterpenoids	*0.2*	*0.1*	*0.1*
		Benzenoid aromatics	*0.1*	*0.0*	*0.0*
		Aliphatic esters	*tr*	*tr*	*tr*
		Others	*tr*	*tr*	*tr*
		Total identified	***98.2***	***98.4***	***98.0***

RI_{calc} = Experimentally determined retention index using the arithmetic formula of van den Dool and Kratz [17]. RI_{db} = Reference retention index from the databases [18–22]. tr = trace (< 0.05%). [a] A reference RI for fragranyl isovalerate was not available, but by homology with fragranyl isobutyrate, it should be around 1580.

(A. Kern.) Velen. [42], *Achillea lingulata* Waldst. & Kit. (syn. *Aspilia cachimboensis* H. Rob.) [43], *Achillea wilhelmsii* K. Koch (syn. *Achillea santolinoides* subsp. *wilhelmsii* (K. Koch) Greuter) [44], *Pentzia incana* (Thunb.) Kuntze [45], *Artemisia pontica* L. [46], and *Artemisia cana* Pursh [47], in addition to *Artemisia tridentata* subsp. *vaseyana* [9]. Fragranol is also the sex pheromone of the papaya mealybug, *Paracoccus marginatus* Williams & Granara de Willink [48]. The epimer of fragranol, grandisol, (1*R*,2*S*)-1-(2-hydroxy-

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ethyl)-2-isopropenyl-1-methylcyclobutane, is the sex pheromone of the boll weevil, *Anthonomus grandis* Boheman [49] and the aggregation pheromone of the deodar weevil, *Pissodes nemorensis* Germar [50]. Grandisol has also been reported in the essential oils of *Artemisia chamaemelifolia* Vill. [51] and *A. tridentata* subsp. *vaseyana* [9].

The presence of both fragranol and grandisol in *A. tridentata* subsp. *vaseyana* from the Sawtooth Valley of Idaho (this study) indicates a qualitative similarity to several accessions of *A. tridentata* subsp. *vaseyana* from the Bighorn Mountains, Wyoming [9]. However, there are major quantitative differences between the two. Grandisol was only detected in small amounts in the present study, while some accessions from Wyoming showed high concentrations (8.8-36.2%), while other accessions showed none. Conversely, fragranyl esters were abundant in the Idaho samples, but were not detected in the samples from Wyoming. Interestingly, Zheljazkov and co-workers [9] observed profound differences in grandisol and fragranol concentrations in *A. tridentata* subsp. *vaseyana*, which were collected from different locations in the Bighorn Mountains of Wyoming, as well as in different months of the year. Likewise, there were substantial differences in the essential oil compositions of two sites in the Boise National Forest, Idaho [10]. The essential oil from one site was dominated by 1,8-cineole and α-thujone, whereas—that from the other site was rich in artemiseole and camphor. Neither fragranol nor fragranyl acetate was detected in these essential oils. These differences, coupled with the differences observed in the Sawtooth Valley, Idaho, collection, suggest that the phytochemical composition of this plant species and subspecies might be affected by geographical location and seasonality, resulting in different chemotypes [52]. Other factors that may contribute to the ecological plasticity include herbivory [53], co-dominant plant associations, soil texture [54, 55], and disturbance (e.g., fire, grazing) [56, 57].

Multivariate analyses (HCA, and, PCA) were carried out in order to visualize the differences in volatile chemical profiles of *A. tridentata* subsp. *vaseyana* (Figs. 3 and 4). The HCA shows five groupings: (1) a camphor-rich group, (2) an α-pinene/*trans*-pinocarveol group, (3) an α-thujone type with only one sample, (4) an ethyl *trans*-chrysanthemumate/grandisol group, and (5) a fragranol/fragranyl acetate group (samples from this study). The PCA corroborated the HCA and indicated correlations between the individual samples and their major components (Fig 3).

3.2. Chemical Composition of Artemisia cana subsp. viscidula

Hydrodistillation of the fresh/frozen aerial parts of *A. cana* subsp. *viscidula* yielded pale-yellow to yellow essential oils with yields of 3.81-4.67% (w/w). Gas chromatographic analysis led to identification of a total of 56 components in the essential oils, which accounted for only 67.4-79.1% of the total composition. Five unidentified components had concentrations greater than 1% (Table 3).

The major components in the essential oils of *A. cana* subsp. *viscidula* were *cis*-chrysanthemal 1.8-5.8%), *trans*-chrysanthemol (0.5-4.6%), ethyl *trans*-chrysanthemumate (7.8-26.3%), and (2*E*)-1,3,7-trimethyl-2,6-octadienyl acetate (33.7-38.2%), along with the major unidentified components RI 1212 (4.8-12.1%), RI 1303 (2.9-5.3%), and RI 1417 (6.1-8.5%). A representative chromatogram of *A. cana* subsp. *viscidula* is shown in *Supplementary Fig. S2.*

The chemical composition of *A. cana* subsp. *viscidula* is remarkably different from that of *A. cana* subsp. *cana* [9, 14, 15], which was dominated by camphene (as high as 11.3% [9]), 1,8-cineole (up to 30.5% [9]), and camphor (as much as 55.2% [15]). Multivariate analyses (HCA and PCA) illustrated the striking differences in the essential oil compositions between the two subspecies of *A. cana*. The major component in *A. cana* subsp. *viscidula*, (2*E*)-1,3,7-trimethyl-2,6-octadienyl acetate, was previously observed, albeit in small quantities, in *Artemisia ludoviciana* (4.4%) [31], *A. tridentata* subsp. *tridentata* (0.1%) [30], *A. tridentata* subsp. *wyomingensis* (0.2%) [10], and *Achillea millefolium* var. *occidentalis* (0.4%) [58]. Because (2*E*)-1,3,7-trimethyl-2,6-octadienyl acetate is rarely observed in essential oils and its identification was not confirmed using an authentic standard or an orthogonal technique, its identification is only tentative at this time (Figs. 5 and 6).

McArthur and co-workers [59] evaluated the genetic diversity of *A. cana* using randomly amplified

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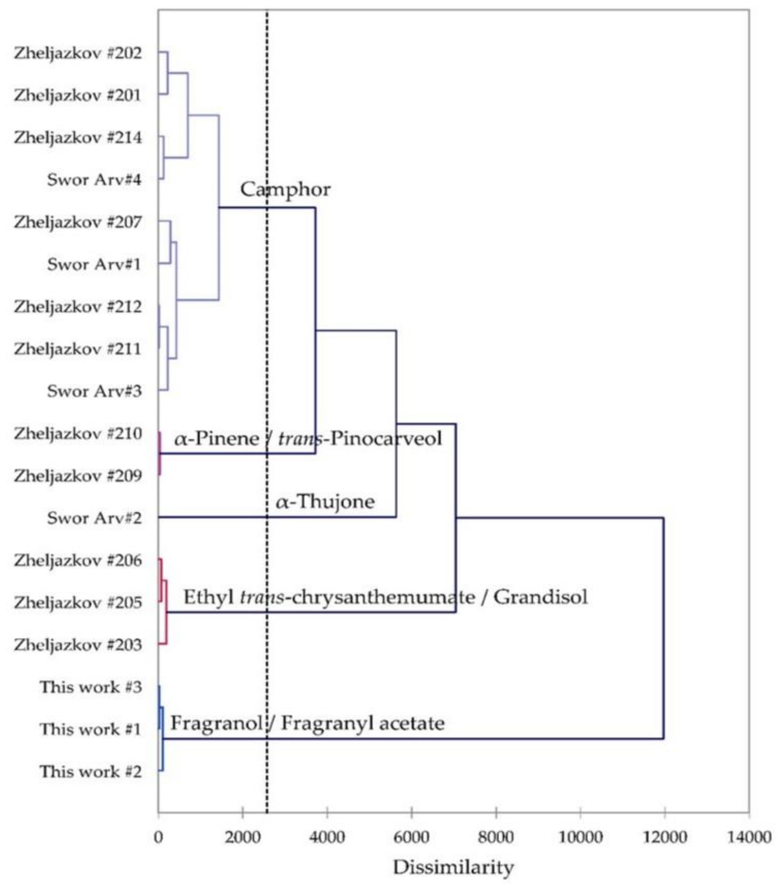

Figure 3. Dendrogram based on hierarchical cluster analysis of chemical compositions of *Artemisia tridentata* subsp. *vaseyana*. Zheljazkov [9], Swor [10].

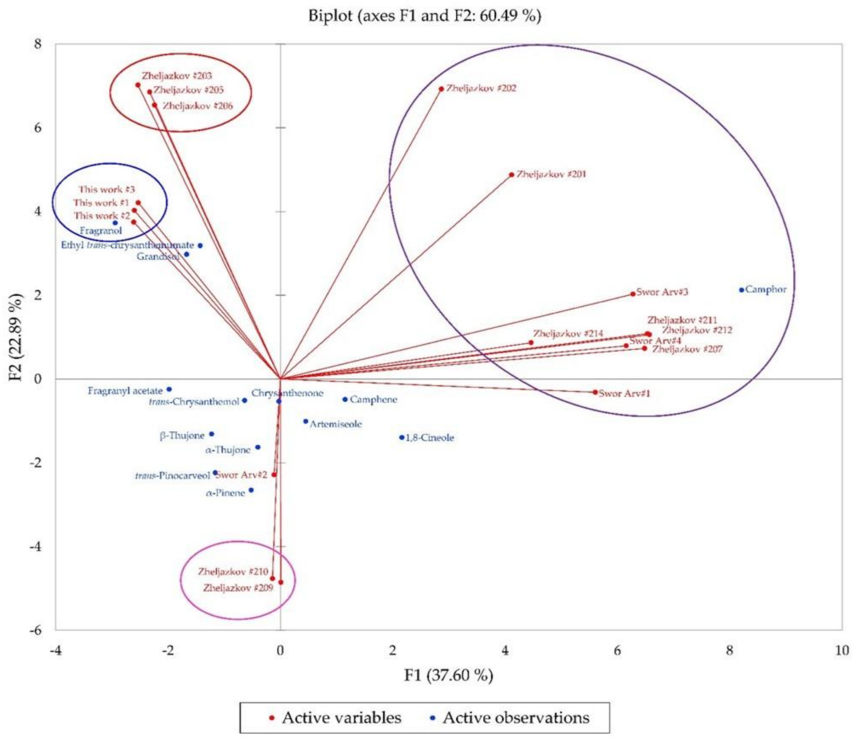

Figure 4. Biplot based on principal component analysis of *Artemisia tridentata* subsp. *vaseyana* chemical compositions. Zheljazkov [9], Swor [10].

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Table 3. Essential oil compositions (percent of total composition) of *Artemisia cana* subsp. *viscidula* from Sawtooth Valley, Idaho.

RI_{calc}	RI_{db}	Compounds	Area %			
			#1	#2	#3	#4
756	740	3-Methyl-3-buten-1-ol	tr	tr	0.1	tr
803	802	Hexanal	tr	tr	tr	0.1
850	850	(2*E*)-Hexenal	tr	tr	tr	0.1
879	878	3-Methyl-3-buten-1-ol acetate	0.1	0.1	0.2	0.1
932	932	α-Pinene	0.4	0.4	0.9	0.6
990	992	(3*E*)-2,6-Dimethyl-3,5-heptadien-2-ol	0.2	0.2	0.3	0.5
994	994	Yomogi alcohol	0.8	0.5	0.7	0.3
1021	1022	Ethyl 3-methylbut-3-enyl carbonate	0.1	-	0.1	tr
1031	1032	1,8-Cineole	0.8	0.6	1.5	0.9
1037	---	(2*E*,4*E*)-Hexadienyl acetate	0.2	0.1	0.2	0.1
1057	1057	γ-Terpinene	tr	tr	tr	0.1
1078	1079	Artemisia alcohol	0.1	tr	0.1	tr
1100	1098	Perillene	0.5	0.7	0.7	1.0
1105	1104	Nonanal	-	-	-	0.1
1139	---	*cis*-Chrysanthemal	4.3	5.8	6.1	1.8
1153	1153	*trans*-Chrysanthemal	0.3	0.4	0.4	0.1
1157	1155	*trans*-Chrysenthemol	4.6	1.6	2.3	0.5
1162	1164	Pinocarvone	0.1	0.1	0.3	0.4
1164	1165	Lavandulol	0.1	-	0.1	-
1180	1180	Terpinen-4-ol	0.3	0.2	0.5	0.5
1195	1195	α-Terpineol	0.1	-	0.2	-
1212	---	Unidentified[a]	4.8	12.1	11.0	11.4
1228	---	Unidentified[b]	1.3	1.2	0.9	1.3
1278	1280	Ethyl *trans*-chrysanthemumate	26.3	15.3	17.6	7.8
1284	1284	Lavandulyl acetate	0.9	0.6	0.6	0.2
1290	1289	*trans*-Verbenyl acetate	0.5	0.5	0.5	0.6
1303	---	Unidentified[c]	2.9	3.5	3.1	5.3
1375	1375	α-Copaene	0.1	0.3	0.1	0.3
1382	1382	β-Bourbonene	-	tr	-	0.1
1398	1396	(2*E*)-1,3,7-Trimethyl-2,6-octadienyl acetate[d]	37.0	37.7	33.7	38.2
1412	---	Unidentified[e]	1.8	1.9	1.7	1.9
1417	---	Unidentified[f]	7.6	8.7	6.1	8.5
1432	1432	*trans*-α-Bergamotene	0.1	0.1	0.1	0.3
1439	1439	(*Z*)-β-Farnesene	-	-	tr	0.1
1452	1452	(*E*)-β-Farnesene	-	tr	0.1	0.2
1477	1482	γ-Curcumene	0.5	0.7	0.8	2.8
1479	1480	Germacrene D	0.3	0.9	1.4	2.6
1482	1483	*trans*-β-Bergamotene	-	-	-	0.3
1494	1497	Bicyclogermacrene	tr	0.1	0.1	0.2
1497	1500	*trans*-Chrysanthemyl 2-methylbutanoate	tr	0.1	0.2	0.3
1508	1509	β-Curcumene	-	-	-	0.1
1516	1518	δ-Cadinene	tr	0.2	0.1	0.3
1540	1541	α-Calacorene	-	0.1	tr	0.1
1559	1560	(*E*)-Nerolidol	-	-	-	0.1
1575	1576	Spathulenol	tr	0.1	0.1	0.2
1581	1587	Caryophyllene oxide	tr	0.1	0.1	0.1
1622	1623	Humulane-1,6-dien-3-ol	tr	0.2	0.1	0.3

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Table 3. *(Continued).*

RIcalc	RIdb	Compounds	Area %			
			#1	#2	#3	#4
1625	1624	Muurola-4,10(14)-dien-1β-ol	-	0.3	0.1	0.4
1627	1631	1-*epi*-Cubenol	tr	0.1	tr	tr
1639	1642	Methyl (*Z*)-jasmonate	0.2	0.1	0.3	-
1643	1644	τ-Muurolol	-	0.1	0.1	0.1
1650	1651	α-Muurolol	-	-	-	0.2
1655	1655	α-Cadinol	-	0.1	0.1	0.2
1670	1671	β-Bisabolol	-	-	-	0.2
1670	1669	Methyl *epi*-(*Z*)-jasmonate	0.1	-	0.1	-
1683	1686	*epi*-α-Bisabolol	-	-	-	0.1
1917	1925	(*Z*)-Tibetin spiroether	-	-	0.2	0.3
1950	1960	(*E*)-Tibetin spiroether	0.2	0.6	2.9	3.6
2300	2300	Tricosane	tr	tr	tr	tr
2500	2500	Pentacosane	tr	tr	tr	0.1
2700	2700	Heptacosane	tr	tr	tr	0.1
		Compound classes				
		Monoterpene hydrocarbons	0.4	0.4	0.9	0.7
		Oxygenated monoterpenoids	39.7	26.5	31.8	14.5
		Sesquiterpene hydrocarbons	1.0	2.3	2.7	7.3
		Oxygenated sesquiterpenoids	tr	0.9	0.6	1.8
		Others	38.0	39.0	38.1	43.2
		Total identified	***79.1***	***69.1***	***74.0***	***67.4***

RIcalc = Retention index calculated with respect to a homologous series of *n*-alkanes on a ZB-5ms column. RIdb = Reference retention index from the databases. tr = trace (< 0.05%). [a] MS(EI): 137(29%), 123(8%), 97(46%), 69(77%), 43(34%), 41(100%). [b] MS(EI): 110(27%), 97(18%), 95(34%), 81(13%), 67(16%), 55(11%), 43(100%), 41(24%). [c] MS(EI): 137(100%), 123(12%), 109(13%), 95(20%), 81(22%), 79(14%), 69(33%), 67(31%), 55(22%), 43(81%), 41(67%). [d] Tentatively identified based on MS and RI. [e] MS(EI): 150(4%), 135(6%), 122(14%), 107(39%), 69(100%), 43(69%), 41(56%). [f] MS(EI): 154(2%), 137(5%), 94(70%), 79(100%), 59(64%), 43(65%), 41(12%).

polymorphic DNA (RAPD) and found a similarity of 45% between the subspecies *A. cana* subsp. *cana* and *A. cana* subsp. *viscidula*. That is, the two subspecies are genetically separable as well as geographically separated by the North American Continental Divide, which is consistent with the pronounced volatile phytochemical differences.

4. Conclusions

This project has provided evidence for a new chemotype of *A. tridentata* subsp. *vaseyana*. Based on the results of this study, samples of *A. tridentata* subsp. *vaseyana* from the Sawtooth Valley of Idaho represent a fragranol/fragranyl acetate chemotype (63.4 ± 7.1% fragranol; 26.9 ± 3.0% fragranyl acetate), which is remarkably different from previously reported samples. The essential oil of *A. cana* subsp. *viscidula* from the Sawtooth Valley of central Idaho can be described as a chemotype dominated by (2*E*)-1,3,7-trimethyl-2,6-octadienyl acetate (36.7 ± 2.0%) and ethyl *trans*-chrysanthemumate (16.7 ± 7.6%), which is significantly different from the camphor / 1,8-cineole chemotype found for *A. cana* subsp. *cana*. The remarkable differences in the essential oil compositions of these samples compared to previously published essential oil compositions likely reflect the effects of geographical location and other abiotic and biotic factors. Additional research on these *Artemisia* species as well as other sagebrush species from other geographical locations in western North America is needed to fully appreciate the phytochemical diversity of members of this genus.

Disclaimer (artificial intelligence)

Authors hereby state that no generative AI tools such as Large Language Models (ChatGPT, Copilot, etc.) and text-to-image generators were utilized in the preparation or editing of this manuscript.

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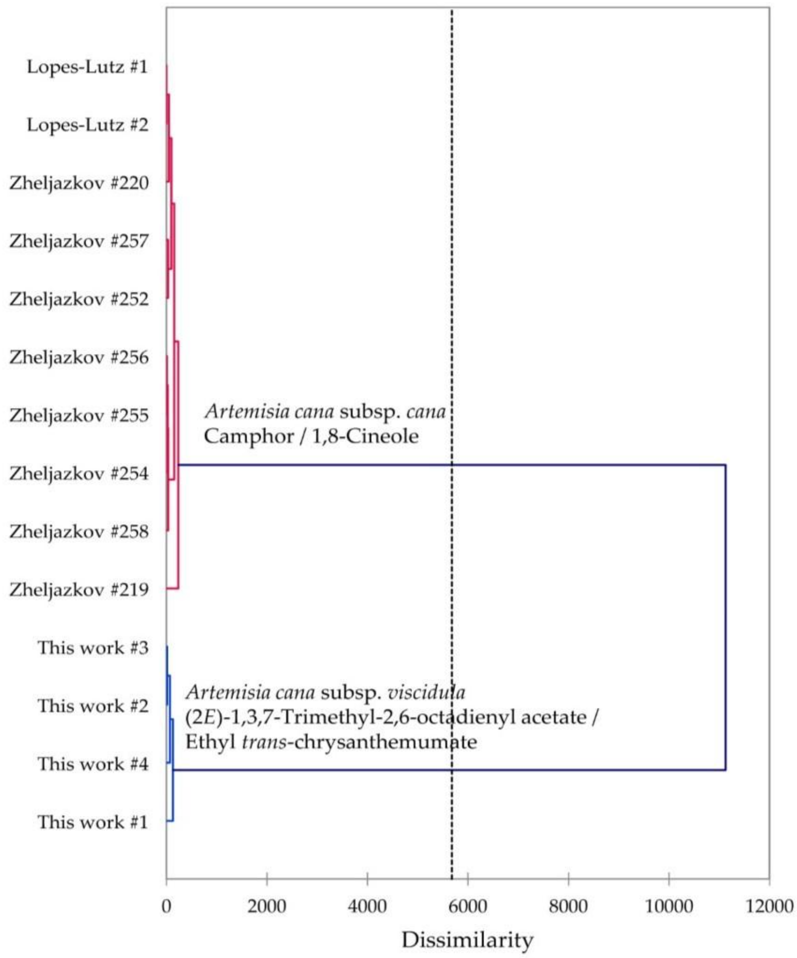

Figure 5. Dendrogram based on hierarchical cluster analysis of chemical compositions of *Artemisia cana*. Lopes-Lutz #1 [15], Lopes-Lutz #2 [14], Zheljazkov [9].

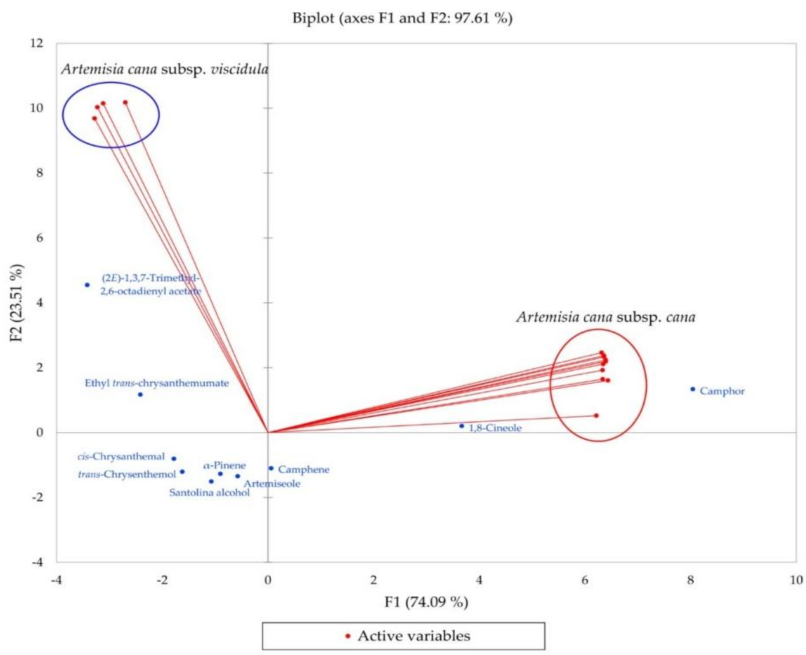

Figure 6. Biplot based on principal component analysis of *Artemisia cana* subsp. *viscidula* and subsp. *cana* chemical compositions.

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Supplementary materials

Figure S1. Chromatogram of *A. tridentata* subsp. *Vaseyana.*

Figure S2. Chromatogram of *A. cana* subsp. *viscidula.*

Supplementary material to this article can be found online at https://www.currentsci.com/images/articlesFile/supplementary.1785418208.pdf

Authors' contributions

Conceptualization, W.N.S.; methodology, P.S., W.N.S.; software, P.S.; validation, P.S., W.N.S.; formal analysis, A.P., P.S., W.N.S.; investigation, K.S., A.P., P.S., W.N.S.; resources, P.S., W.N.S.; data curation, W.N.S.; writing—original draft preparation, W.N.S.; writing—review and editing, K.S., A.P., P.S.; visualization, W.N.S.; supervision, P.S., 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.

References

1. Johnston, K.M. Evaluation of Linear Fuel Break Systems and Using Remote Sensing Data to Estimate Live Fuel Moisture Content in South-Central Idaho, Ph.D. Dissertation, University of Idaho, 2024.
2. Doherty, K.; Theobald, D.M.; Bradford, J.B.; Wiechman, L.A.; Bedrosian, G.; Boyd, C.S.; Cahill, M.; Coates, P.S.; Creutzburg, M.K.; Crist, M.R.; et al. A Sagebrush Conservation Design to Proactively Restore America's Sagebrush Biome; U.S. Geological Survey: Reston, Virginia, USA, 2022.
3. World Flora Online, W.F.O. An Online Flora of All Known Plants. Available online: https://www.worldfloraonline.org/ (accessed on 26 May 2026).
4. McArthur, E.D.; Welch, B.L.; Sanderson, S.C. Natural and artificial hybridization between big sagebrush (*Artemisia tridentata*) subspecies. J. Hered. 1988, 79, 268–276. https://doi.org/10.1093/oxfordjournals.jhered.a110508
5. Richardson, B.A.; Page, J.T.; Bajgain, P.; Sanderson, S.C.; Udall, J.A. Deep sequencing of amplicons reveals widespread intraspecific hybridization and multiple origins of polyploidy in big sagebrush (*Artemisia tridentata*; Asteraceae). Am. J. Bot. 2012, 99, 1962–1975. https://doi.org/10.3732/ajb.1200373
6. Shultz, L.M. Monograph of *Artemisia* subgenus *Tridentatae* (Asteraceae-Anthemideae). Syst. Bot. Monogr. 2009, 89, 1–131.
7. Dunkel, F.V.; Sears, L.J. Fumigant properties of physical preparations from mountain big sagebrush, *Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle for stored grain insects. J. Stored Prod. Res. 1998, 34, 307–321. https://doi.org/10.1016/S0022-474X(98)00015-0
8. Gunawardena, K.; Rivera, S.B.; Epstein, W.W. The monoterpenes of *Artemisia tridentata* ssp. *vaseyana*, *Artemisia cana* ssp. *viscidula* and *Artemisia tridentata* ssp. *spiciformis*. Phytochem. 2002, 59, 197–203. https://doi.org/10.1016/S0031-9422(01)00438-1
9. Zheljazkov, V.D.; Cantrell, C.L.; Jeliazkova, E.A.; Astatkie, T.; Schlegel, V. Essential oil yield, composition, and bioactivity of sagebrush species in the Bighorn Mountains. Plants. 2022, 11, 1228. https://doi.org/10.3390/plants11091228
10. Swor, K.; Satyal, P.; Poudel, A.; Setzer, W.N. Chemical characterization of three *Artemisia tridentata* essential oils and multivariate analyses: A preliminary investigation. Nat. Prod. Commun. 2023, 18, 1934578X231154965. https://doi.org/10.1177/1934578X231154965
11. Howard, J.L. *Artemisia cana*, Silver Sagebrush. Available online: https://research.fs.usda.gov/feis/species-reviews/artcan (accessed on 24 May 2026).
12. McArthur, E.D.; Taylor, J.R. *Artemisia cana* Pursh, silver sagebrush. In Wildland Shrubs of the United States and Its Territories: Thamnic Descriptions: Volume 1; Francis, J.K., Ed.; U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry: San Juan, Puerto Rico, pp. 57–59, 2004.
13. Harvey, S.J. Life History and Reproductive Strategies in *Artemisia*, M.S. Thesis, Montana State University, 1981.
14. Lopes-Lutz, D.; Alviano, D.S.; Alviano, C.S.;

Kolodziejczyk, P.P. Screening of chemical composition, antimicrobial and antioxidant activities of *Artemisia* essential oils. Phytochemistry 2008, 69, 1732–1738. https://doi.org/10.1016/j.phytochem.2008.02.014

15. Lopes-Lutz, D.; Mckay, T.; Kolodziejczyk, P.P. Distribution of volatiles in *Artemisia cana*. Pharm. Biol. 2008, 46, 373–376. https://doi.org/10.1080/13880200802055792
16. New York Botanical Garden, N.Y.B.G. C. V. Starr Virtual Herbarium. Available online: https://sweetgum.nybg.org/science/vh/ (accessed on 6 March 2026).
17. van den Dool, H.; Kratz, P.D. A generalization of the retention index system including linear temperature programmed gas-liquid partition chromatography. J. Chromatogr. A 1963, 11, 463–471. https://doi.org/10.1016/S0021-9673(01)80947-X
18. Adams, R.P. Identification of Essential Oil Components by Gas Chromatography/Mass Spectrometry, 4th ed.; Allured Publishing: Carol Stream, Illinois, USA, 2007; ISBN 978-1-932633-21-4.
19. Satyal, P. Development of GC-MS Database of Essential Oil Components by the Analysis of Natural Essential Oils and Synthetic Compounds and Discovery of Biologically Active Novel Chemotypes in Essential Oils, Ph.D. Dissertation, University of Alabama in Huntsville, Huntsville, AL, USA, 2015.
20. Mondello, L. FFNSC 3; Shimadzu Scientific Instruments: Columbia, Maryland, USA, 2016.
21. NIST20; National Institute of Standards and Technology: Gaithersburg, Maryland, USA, 2020.
22. W23N23; Wiley Registry/NIST Mass Spectral Library; John Wiley & Sons, Inc: Hoboken, New Jersey, USA, 2023.
23. Chen, F.; Zu, Y.; Yang, L. A novel approach for isolation of essential oil from fresh leaves of *Magnolia sieboldii* using microwave-assisted simultaneous distillation and extraction. Sep. Purif. Technol. 2015, 154, 271–280. https://doi.org/10.1016/j.seppur.2015.09.066
24. Jesionek, A.; Zabiegała, B.; Buciński, A.; Łuczkiewicz, M. From harvesting to distillation – effect of analytical procedures on the yield and chemical composition of *Rhododendron tomentosum* (*Ledum palustre*) essential oil. Acta Pol. Pharm. - Drug Res. 2019, 76, 83–92. https://doi.org/10.32383/appdr/93932
25. Kokotkiewicz, A.; Badura, A.; Tabaczyńska, Ż.; Lorenc, A.; Buciński, A.; Luczkiewicz, M. Optimization of distillation conditions for improved recovery of phthalides from celery (*Apium graveolens* L.) seeds. Polish J. Food Nutr. Sci. 2021, 71, 197–210. https://doi.org/10.31883/pjfns/137612
26. Hasanvandi, S.; Neisi, E.; Meshkat, M.H. Comparative analysis of essential oils from two *Satureja* species; extraction methods, chemical composition, and antimicrobial activities. Biocatal. Agric. Biotechnol. 2023, 50, 102731. https://doi.org/10.1016/j.bcab.2023.102731
27. Faria, J.M.S.; Figueiredo, A.C.; Teixeira, D.M.; Inácio, M.L. Infection of in vivo and in vitro pines with the pinewood nematode *Bursaphelenchus xylophilus* and isolation of induced volatiles. J. Vis. Exp. 2024, 211, e67149. https://doi.org/10.3791/67149
28. Au-Yeung, C.Y.; MacLeod, A.J. A comparison of the efficiency of the Likens and Nickerson extractor for aqueous, lipid/aqueous, and lipid samples. J. Agric. Food Chem. 1981, 29, 502–505. https://doi.org/10.1021/jf00105a016
29. Eikani, M.H.; Golmohammad, F.; Rowshanzamir, S.; Mirza, M. Recovery of water-soluble constituents of rose oil using simultaneous distillation-extraction. Flavour Fragr. J. 2005, 20, 555–558. https://doi.org/10.1002/ffj.1482
30. Swor, K.; Satyal, P.; Timsina, S.; Setzer, W.N. Chemical composition and terpenoid enantiomeric distribution of the essential oil of *Artemisia tridentata* subsp. *tridentata* from southwestern Idaho. Nat. Prod. Commun. 2022, 17, 1934578X2211174. https://doi.org/10.1177/1934578x221117417
31. Swor, K.; Poudel, A.; Satyal, P.; Setzer, W.N. The essential oil compositions of *Ambrosia acanthicarpa* Hook., *Artemisia ludoviciana* Nutt., and *Gutierrezia sarothrae* (Pursh) Britton & Rusby (Asteraceae) from the Owyhee Mountains of Idaho. Molecules. 2024, 29, 1383. https://doi.org/10.3390/molecules29061383
32. Baldemir, A.; Karaman, Ü.; İlgün, S.; Kaçmaz, G.; Demirci, B. Antiparasitic efficacy of *Artemisia ludoviciana* Nutt. (Asteraceae) essential oil for *Acanthamoeba castellanii*, *Leishmania infantum* and *Trichomonas vaginalis*. Indian J. Pharm. Educ. Res. 2018, 52, 416–425. https://doi.org/10.5530/ijper.52.3.48
33. Anaya-Eugenio, G.D.; Rivero-Cruz, I.; Bye, R.; Linares, E.; Mata, R. Antinociceptive activity of the essential oil from *Artemisia ludoviciana*. J. Ethnopharmacol. 2016, 179, 403–411. https://doi.org/10.1016/j.jep.2016.01.008
34. Collin, G.; St-Gelais, A.; Turcotte, M.; Gagnon, H. Composition of the essential oil and of some extracts of the aerial parts of *Artemisia ludoviciana* var. *latiloba* Nutt. Am. J. Essent. Oils Nat. Prod. 2017, 5, 1–11.
35. Setzer, W.N.; Satyal, P.; Poudel, A. Chemical composition of *Artemisia frigida* Willd. from southwestern Idaho. Am. J. Essent. Oils Nat. Prod. 2025, 13, 38–44.
36. Dylenova, E.P.; Zhigzhitzhapova, S. V.; Gulyaev, S.M.; Taraskin, V. V.; Randalova, T.E.; Radnaeva, L.D.

Artemisia frigida Willd. of the Baikal Region (Siberia): Essential oils, tincture, and antiradical activity. J. Herb. Med. 2023, 42, 100781. https://doi.org/10.1016/j.hermed.2023.100781
37. Korolyuk, E.A.; Tkachev, A.V. Chemical composition of the essential oil from two wormwood species *Artemisia frigida* and *Artemisia argyrophylla*. Russ. J. Bioorganic Chem. 2010, 36, 884–893. https://doi.org/10.1134/S1068162010070162
38. Liu, X.C.; Li, Y.; Wang, T.; Wang, Q.; Liu, Z.L. Chemical composition and insecticidal activities of essential oil of *Artemisia frigida* Willd (Compositae) against two grain storage insects. Trop. J. Pharm. Res. 2014, 13, 587–592. https://doi.org/10.4314/tjpr.v13i4.15
39. Zhang, Z.; Pang, X.; Guo, S.; Cao, J.; Wang, Y.; Chen, Z.; Feng, Y.; Lei, N.; Du, S. Insecticidal activity of *Artemisia frigida* Willd. essential oil and its constituents against three stored product insects. Rec. Nat. Prod. 2019, 13, 176–181. https://doi.org/10.25135/rnp.91.18.06.114
40. Zhigzhitzhapova, S.V.; Randalova, T.E.; Radnaeva, L.D.; Dylenova, E.P.; Chen, S.; Zhang, F. Chemical composition of essentials oils of *Artemisia frigida* Willd. (Asteraceae) grown in the North and Central Asia. J. Essent. Oil-Bearing Plants 2017, 20, 915–926. https://doi.org/10.1080/0972060X.2017.1377113
41. Bohlmann, F.; Zdero, C.; Faass, U. Natürlich Vorkommende Terpenderivate, XXVI. Über Die Inhaltsstoffe von *Artemisia fragrans* Willd. Chem. Ber. 1973, 106, 2904–2909. https://doi.org/10.1002/cber.19731060919
42. Demirci, F.; Demirci, B.; Gürbüz, I.; Yeşilada, E.; Başer, K.H.C. Characterization and biological activity of *Achillea teretifolia* Willd. and *A. nobilis* L. subsp. *neilreichii* (Kerner) Formanek essential oils. Turkish J. Biol. 2009, 33, 129–136. https://doi.org/10.3906/biy-0808-1
43. Čulum, D.; Čopra-Janićijević, A.; Muratović, E.; Siljak-Yakovlev, S.; Maksimović, M.; Vidic, D. Essential oil composition and antioxidant activity of endemic *Achillea lingulata* Waldst. & Kit. compared to common *A. millefolium* L. Rec. Nat. Prod. 2022, 16, 335–345. http://doi.org/10.25135/rnp.285.2107.2143
44. Ghavam, M.; Castangia, I.; Manconi, M.; Bacchetta, G.; Manca, M.L. Chemical composition and antimicrobial activity of a newly identified chemotype of *Achillea wilhelmsii* K.Koch from Kashan, Iran. Sci. Rep. 2024, 14, 22655. https://doi.org/10.1038/s41598-024-73284-0
45. Hulley, I.M.; Sadgrove, N.J.; Tilney, P.M.; Özek, G.; Yur, S.; Özek, T.; Başer, K.H.C.; van Wyk, B.E. Essential oil composition of *Pentzia incana* (Asteraceae), an important natural pasture plant in the Karoo Region of South Africa. African J. Range Forage Sci. 2018, 35, 137–145. https://doi.org/10.2989/10220119.2018.1495265
46. Radulović, M.; Rajčević, N.; Gavrilović, M.; Novaković, J.; Stešević, D.; Marin, P.D.; Janaćković, P. Five wild-growing *Artemisia* (Asteraceae) species from Serbia and Montenegro: Essential oil composition and its chemophenetic significance. J. Serbian Chem. Soc. 2021, 86, 1281–1290. https://doi.org/10.2298/JSC210803088R
47. Schepetkin, I.A.; Özek, G.; Özek, T.; Kirpotina, L.N.; Khlebnikov, A.I.; Klein, R.A.; Quinn, M.T. Neutrophil immunomodulatory activity of farnesene, a component of *Artemisia dracunculus* essential oils. Pharmaceuticals. 2022, 15, 642. https://doi.org/10.3390/ph15050642
48. Sugawara, Y.; Uesato, T.; Tabata, J. Sex pheromone of the papaya mealybug. J. Chem. Ecol. 2025, 51, 22. https://doi.org/10.1007/s10886-025-01574-6
49. Tumlinson, J.H.; Hardee, D.D.; Gueldner, R.C.; Thompson, A.C.; Hedin, P.A.; Minyard, J.P. Sex pheromones produced by male boll weevil: Isolation, identification, and synthesis. Science 1969, 166, 1010–1012. https://doi.org/10.1126/science.166.3908.1010
50. Phillips, T.W.; West, J.R.; Foltz, J.L.; Silverstein, R.M.; Lanier, G.N. Aggregation pheromone of the deodar weevll, *Pissodes nemorensis* (Coleoptera: Curculionidae): Isolation and activity of grandisol and grandisal. J. Chem. Ecol. 1984, 10, 1417–1423. https://doi.org/10.1007/BF00990312
51. Malaspina, P.; Polito, F.; Mainetti, A.; De Feo, V.; Cornara, L. Anatomical, micromorphological and phytochemical characterization of *Artemisia chamaemelifolia*, a rare plant in the western Italian Alps. Plant Biosyst. 2025, 159, 1050–1061. https://doi.org/10.1080/11263504.2025.2522717
52. Curado, M.A.; Oliveira, C.B.A.; Jesus, J.G.; Santos, S.C.; Seraphin, J.C.; Ferri, P.H. Environmental factors influence on chemical polymorphism of the essential oils of *Lychnophora ericoides*. Phytochem. 2006, 67, 2363–2369. https://doi.org/10.1016/j.phytochem.2006.08.002
53. Rabelo, R.S.; Dyer, L.A.; Yamaguchi, L.F.; Diniz, I.; Simbaña, W.; Kussano, A.J.M.; Kato, M.J.; Massad, T.J. Plasticity in plant defense and the role of phytochemical dissimilarity in limiting specialist herbivory. Front. Ecol. Evol. 2023, 11, 1175590. https://doi.org/10.3389/fevo.2023.1175590
54. Pu, X.; Lam, L.; Gehlken, K.; Ulappa, A.C.; Rachlow, J.L.; Forbey, J.S. Antioxidant capacity of Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) varies spatially and is not related to the presence of a sagebrush dietary specialist. West. North Am. Nat. 2015, 75, 78–87. https://doi.org/10.3398/064.075.0109
55. da Fonseca, S.T.D.; Pereira, A.M.S.; Lopes, N.P. Secondary metabolite plasticity in *Eclipta prostrata* (L.) L. (Asteraceae) under environmental and biological

stressors. ACS Omega. 2025, 10, 62916–62926. https://doi.org/10.1021/acsomega.5c08697

56. Qu, K.; Cheng, Y.; Gao, K.; Ren, W.; Fry, E.L.; Yin, J.; Liu, Y. Growth-defense trade-offs induced by long-term overgrazing could act as a stress memory. Front. Plant Sci. 2022, 13, 917354. https://doi.org/10.3389/fpls.2022.917354
57. 13. Siqueira, C.S.; Dos Santos, V.S.; Carollo, C.A.; Damasceno-Junior, G.A. Unraveling the adaptive chemical traits of *Rhamnidium elaeocarpum* Reissek in response to fire in Pantanal wetlands. Sci. Rep. 2023, 13, 11860. https://doi.org/10.1038/s41598-023-38725-2
58. Poudel, A.; Satyal, P.; Swor, K.; Setzer, W.N. The essential oil characterization of *Achillea millefolium* var. *occidentalis* DC . from the Great Basin of North America. J. Essent. Oil Plant Compos. 2024, 2, 130–142. https://doi.org/10.58985/jeopc.2024.v02i02.53
59. Mcarthur, E.D.; Mudge, J.; Van Buren, R.; Andersen, W.R.; Sanderson, S.C.; Babbel, D.G. Randomly amplified polymorphic DNA analysis (RAPD) of *Artemisia* subgenus *Tridentatae* species and hybrids. Gt. Basin Nat. 1998, 58, 12–27.

https://doi.org/10.58985/jeopc.2026.v04i02.84