Original Article

Natural Product Communications
July 2019: 1–7
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DOI: 10.1177/1934578X19866307
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The Chemical Composition of *Boswellia occulta* Oleogum Resin Essential Oils

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Abstract

Frankincense is an aromatic oleogum resin that has been traded for thousands of years for medicine and incense and is today frequently distilled into essential oils for aromatherapy and perfume. A new species of frankincense, *Boswellia occulta* Thulin, DeCarlo, & S.P. Johnson, was recently described from Somaliland (northern Somalia), but pure essential oils from this species have not yet been described. Samples of resin were collected directly from 12 individual *B. occulta* trees, hydrodistilled, and analyzed via GC-MS, GC-FID, and agglomerative hierarchical clustering. This revealed a significant level of methyl ethers in all samples (34.5%-62.6%), especially 1-methoxydecane (26.6%-47.9%) and 1-methoxyoctane (3.6%-8.6%). All samples were similar, but 3 groups were defined: (**1**) a methoxydecane/serratol/methoxyoctane group with 26.6% to 47.4% 1-methoxydecane, 14.5% to 31.8% serratol, and 3.6% to 8.6% 1-methoxyoctane; (**2**) a methoxydecane/di-*epi*-guaiol/serratol group with 26.6% to 29.1% 1-methoxydecane, 11.1% to 15.1% 4,10-di-*epi*-guaiol, and 10.3% to 16.8% serratol; and (**3**) a methoxydecane/methoxyoctane/di-*epi*-guaiol group with 38.9% to 47.9% 1-methoxydecane, 7.0% to 9.2% 1-methoxyoctane, and 2.2% to 12.3% 4,10-di-*epi*-guaiol.

Keywords

essential oil, frankincense, olibanum, methoxydecane, methoxyoctane, Somaliland, *Boswellia occulta*

Received: May 29th, 2019; Accepted: June 25th, 2019.

The *Boswellia* genus is made up of around 20 species; however, this number is in dispute.[1] *Boswellia* species are well known for producing frankincense, an aromatic oleogum resin. Frankincense has been used in traditional medicine and cultural and religious ceremonies for thousands of years. More recently, essential oils derived from frankincense resins have become popular in complementary and alternative medicine and in aromatherapy and have shown notable biological activities.[1]

Boswellia sacra Flueck., native to southern Oman, Yemen, Somaliland, and Somalia, yields an oleogum resin essential oil made up largely of α-pinene, α-thujene, limonene, sabinene, myrcene, β-caryophyllene, and *p*-cymene.[1] Although generally considered botanically synonymous, the African populations of *B. sacra* have often in the literature been considered a separate species, *B. carteri* Birdw., and essential oils from these resins are also rich in α-pinene, limonene, myrcene, α-thujene, *p*-cymene, and β-caryophyllene.[1] *Boswellia frereana* Birdw., endemic to Somalia, also yields an oleogum resin essential oil dominated by α-pinene with lesser amounts of *p*-cymene, α-thujene, sabinene, and β-caryophyllene. *Boswellia papyrifera* Hochst, which grows primarily in Ethiopia, Eritrea, and Sudan, has a very different volatile chemical profile of oleogum resin essential oil. The essential oil is composed largely of octyl acetate with smaller amounts of octanol.[1]

Recently, a new species of *Boswellia*, *B. occulta* Thulin, DeCarlo & S. P. Johnson, has been described[2] and identified as the source of a methoxyalkane-rich oleogum resin essential oil which has been contaminating commercial *B. carteri* essential oils; as the Somali harvesters consider *B. occulta* and *B. carteri* to be the same tree, they frequently mix the resins of the 2 species.[3] Methoxyalkanes in the frankincense resin coming from Somaliland are of considerable interest to the aromatics industry, which initially suspected them to be synthetic contaminants[4] (pers. comm. with industry). Several analytical investigations have been conducted on methoxyalkane-containing resins, but all on commercial samples.[4,5] In this work, we present a characterization of pure *B. occulta* oleogum resin

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Table 1. Chemical Composition of the Oleogum Resin Essential Oils of *Boswellia occulta*.

RI[a]	Compound	A	B	C	D	E	F	G	H	I	J	K	L
820	1-Methoxyhexane	-	-	-	-	-	tr[b]	tr	tr	tr	-	-	tr
920	1-Methoxyheptane[c]	tr	0.2	0.1	0.1	tr	tr	0.2	0.1	0.1	0.1	0.1	0.2
921	α-Thujene	0.1	0.4	0.2	0.6	0.6	0.5	0.3	0.3	0.3	0.4	0.1	0.2
928	α-Pinene	tr	0.3	0.7	0.2	0.2	0.9	0.1	0.1	2.4	0.2	0.1	0.4
945	Camphene	-	tr	tr	-	-	tr	-	-	tr	tr	-	-
967	Sabinene	0.1	1.8	0.7	6.3	3.0	5.5	3.4	3.2	4.1	8.3	1.1	4.6
973	β-Pinene	tr	tr	tr	tr	tr	tr	tr	tr	0.1	tr	tr	tr
984	Myrcene	-	tr	-	tr	tr	tr	0.1	tr	0.1	0.1	tr	tr
1003	α-Phellandrene	-	tr	-	tr	-	-	-	-	-	1.2	tr	tr
1011	1,4-Cineole	-	tr	-	-	-	-	-	-	-	-	-	-
1013	α-Terpinene	tr	0.1	tr	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2
1020	*p*-Cymene	0.1	0.5	0.3	0.8	0.4	0.1	0.2	0.1	0.1	0.4	0.1	0.1
1021	1-Methoxyoctane[c]	5.0	7.0	8.6	6.3	9.2	7.7	8.3	6.2	6.9	4.3	3.6	4.1
1025	Limonene	tr	tr	0.1	tr	0.1	0.1	tr	tr	0.1	0.1	tr	tr
1027	β-Phellandrene	-	tr	-	tr	tr	tr	tr	tr	tr	0.2	tr	tr
1053	γ-Terpinene	tr	0.2	tr	0.4	0.2	0.2	0.2	0.1	0.2	0.4	0.1	0.3
1065	*cis*-Sabinene hydrate	-	0.1	tr	-	0.2	0.1	tr	tr	tr	tr	tr	tr
1065	1-Octanol	0.2	-	0.2	-	-	-	-	-	-	-	-	-
1071	Dihydromyrcenol	0.9	0.3	0.1	0.4	0.1	0.1	0.2	0.1	tr	0.1	0.4	tr
1081	Terpinolene	-	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
1088	(*Z*)-4,8-Dimethylnona-1,3,7-triene	-	-	-	-	-	0.1	-	-	-	-	-	-
1095	Linalool	tr	tr	-	tr	0.1	tr	tr	tr	tr	tr	tr	tr
1097	*trans*-Sabinene hydrate	-	tr	tr	tr	0.1	0.1	0.1	tr	tr	tr	tr	tr
1100	Undecane	-	-	tr	-	-	-	-	-	-	-	-	-
1108	(*E*)-4,8-Dimethylnona-1,3,7-triene	tr	tr	tr	-	0.2	1.4	0.4	0.3	0.3	0.2	-	0.8
1122	1-Methoxynonane[c]	0.8	1.9	2.3	1.1	1.5	1.1	2.3	1.0	1.4	0.8	0.9	1.8
1125	Isobutyl hexanoate	-	-	-	-	-	tr	-	-	-	-	-	-
1176	Terpinen-4-ol	tr	0.4	0.2	0.6	0.5	0.2	0.2	0.1	0.1	0.3	0.1	0.3
1187	Hexyl butanoate	0.2	tr	0.2	0.1	0.1	0.1	-	0.1	tr	tr	tr	tr
1191	α-Terpineol	-	-	-	tr	tr	tr	-	tr	tr	tr	-	-
1202	(4*Z*)-1-Methoxydec-4-ene	0.2	0.1	0.3	tr	0.2	0.2	0.4	0.1	0.3	0.1	0.1	0.1
1205	Octyl acetate	0.2	-	-	-	-	-	-	-	-	-	-	-
1210	(4*E*)-1-Methoxydec-4-ene	0.2	0.2	0.2	0.3	0.4	0.2	0.3	0.3	0.3	0.2	0.3	0.3
1214	1-Methoxydecene[d]	0.3	0.3	0.4	0.5	0.9	0.3	0.7	0.4	0.4	0.2	0.6	0.5
1218	1-Methoxydecene[d]	tr	tr	tr	tr	0.1	tr	tr	tr	tr	tr	tr	tr
1223	1-Methoxydecane[c]	35.6	38.9	47.4	26.6	46.7	29.1	47.9	29.4	37.6	28.5	26.7	26.6
1231	Hexyl 2-methylbutanoate	-	-	0.1	-	-	-	-	-	-	-	-	-
1237	(2*E*)-1-Methoxydec-2-ene	0.4	0.6	0.6	0.5	0.7	0.5	1.3	0.8	1.0	0.6	1.1	0.8
1249	Piperitone	-	-	-	tr	-	-	-	tr	-	tr	-	tr
1263	(2*E*)-Decen-1-ol	-	-	-	-	-	tr	tr	tr	tr	tr	tr	-
1267	1-Decanol	5.3	0.8	1.0	0.4	2.3	3.2	2.7	0.8	1.6	1.4	1.1	0.7
1279	Bornyl acetate	-	-	-	-	-	-	-	-	tr	-	-	-
1314	1-Methoxyundecene[d]	0.1	0.2	0.1	0.4	0.1	tr	tr	tr	tr	-	tr	tr
1318	Methyl decanoate	tr	tr	0.1	tr	tr	-	tr	tr	tr	tr	-	-
1321	1-Methoxyundecane[c]	0.1	0.3	0.4	0.2	0.3	0.1	0.4	0.2	0.3	0.1	0.3	0.7
1324	1-Undecanol	0.1	-	tr	-	-	-	-	-	-	-	-	-
1341	α-Cubebene	tr	0.1	0.2	0.5	0.1	tr	tr	0.4	0.2	tr	tr	0.2
1357	Decanoic acid	0.3	tr	tr	-	0.3	0.2	0.1	tr	0.1	-	-	tr
1363	Cyclosativene	tr	0.2	tr	0.5	0.1	0.2	0.2	0.4	0.2	0.2	0.1	0.5
1370	α-Copaene	0.1	0.8	1.1	0.4	1.3	0.4	0.4	3.2	1.4	0.5	0.8	1.6

(Continued)

Table 1. Continued

RI[a]	Compound	A	B	C	D	E	F	G	H	I	J	K	L
1378	β-Bourbonene	0.5	0.3	0.5	2.7	0.9	-	0.1	1.9	0.3	tr	tr	1.2
1379	Hexyl hexanoate	0.4	0.2	0.5	tr	0.2	0.6	tr	-	0.1	0.2	0.2	-
1382	β-Cubebene	-	tr	tr	0.2	0.3	-	tr	0.5	0.2	tr	0.1	0.3
1382	α-Bourbonene	-	-	-	0.3	-	-	-	-	-	-	-	-
1383	Octyl butanoate	0.1	-	tr	-	-	0.3	-	-	-	-	-	-
1384	β-Elemene	-	tr	-	0.2	-	-	tr	0.3	0.1	tr	0.1	0.3
1386	Sativene	-	-	-	tr	-	-	-	-	tr	-	-	tr
1399	(*Z*)-Caryophyllene	-	-	0.1	0.1	-	-	-	-	-	-	-	-
1401	α-Gurjunene	-	-	-	0.2	-	-	-	0.3	0.2	-	tr	0.3
1402	Dodecanal	-	0.3	0.2	0.1	0.3	tr	0.1	tr	tr	tr	tr	0.1
1403	Decyl acetate	2.2	-	-	-	-	-	-	-	-	-	-	-
1406	1-Methoxydodecene[d]	0.1	-	0.1	tr	0.1	tr	0.1	tr	0.1	tr	0.1	0.2
1412	β-Ylangene	tr	tr	tr	0.3	0.1	-	tr	0.2	0.1	-	-	0.2
1414	β-Caryophyllene	0.0	0.2	0.2	0.8	0.5	0.2	0.1	1.3	0.5	0.2	0.4	0.7
1421	1-Methoxydodecane	0.1	0.1	0.1	tr	0.2	tr	0.1	0.1	0.2	0.1	0.1	0.4
1424	β-Copaene	0.1	tr	0.1	0.4	0.1	-	tr	0.3	0.1	-	tr	0.2
1435	Guaia-6,9-diene	-	-	-	-	-	-	-	-	-	-	0.1	-
1435	γ-Elemene	-	-	-	tr	-	-	-	0.1	tr	tr	-	tr
1439	*iso*-Germacrene D	-	-	-	0.1	-	-	-	-	-	-	-	-
1440	Dihydrocurcumene	-	-	-	0.1	-	-	-	-	-	-	-	-
1443	*cis*-Muurola-3,5-diene	-	tr	tr	0.1	0.1	tr	tr	0.2	0.1	tr	0.1	tr
1446	(*E*)-β-Farnesene	-	-	-	-	tr	tr	tr	-	tr	tr	tr	tr
1450	α-Humulene	-	tr	0.1	0.3	0.2	tr	tr	0.5	0.2	tr	0.1	0.2
1454	*allo*-Aromadendrene	-	tr	0.1	0.3	0.1	tr	tr	0.3	0.1	tr	0.1	0.2
1463	*cis*-Cadina-1(6),4-diene	-	tr	-	tr	-	-	-	tr	tr	-	-	tr
1466	Dauca-5,8-diene	-	tr	-	-	-	-	-	tr	tr	-	tr	tr
1468	9-*epi*-(*E*)-Caryophyllene	-	-	-	-	-	0.1	-	-	-	-	-	-
1469	*trans*-Cadina-1(6),4-diene	0.1	0.1	0.1	tr	0.3	tr	0.1	1.2	0.5	0.1	0.2	0.8
1469	γ-Muurolene	-	-	-	1.1	-	-	-	-	-	-	-	-
1476	Germacrene D	tr	0.1	-	3.9	1.0	0.1	0.5	8.0	4.0	0.1	0.5	7.5
1483	β-Selinene	tr	-	-	tr	-	-	-	tr	tr	-	-	tr
1486	*trans*-Muurola-4(14),5-diene	tr	tr	tr	0.3	0.1	tr	tr	0.6	0.2	tr	0.1	0.3
1489	*epi*-Cubebol	tr	0.2	0.4	1.0	0.3	tr	tr	0.7	0.2	0.1	0.2	0.3
1492	α-Muurolene	tr	tr	0.1	0.6	0.1	tr	tr	0.7	0.3	tr	0.1	0.4
1496	Epizonarene	-	-	-	tr	-	-	-	tr	tr	tr	-	tr
1499	β-Dihydroagarofuran	-	0.2	-	-	tr	0.2	0.1	-	-	0.2	0.1	0.1
1500	1-Pentadecene	-	-	-	-	-	0.3	0.3	tr	0.2	0.1	0.1	0.1
1502	Tridecanal	0.1	0.2	-	-	-	-	-	-	-	-	-	-
1507	γ-Cadinene	0.1	tr	tr	0.3	0.1	tr	tr	0.3	0.1	tr	tr	0.1
1509	Cubebol	tr	0.9	1.7	3.9	1.3	0.1	0.1	4.0	1.3	0.2	0.8	1.3
1511	δ-Cadinene	0.2	0.4	0.6	2.1	0.7	0.1	0.1	2.0	0.8	0.1	0.4	1.1
1514	1-Methoxytridecane	0.7	0.8	0.4	1.3	0.5	0.6	0.8	1.9	1.4	1.1	0.7	0.9
1515	*trans*-Calamenene	-	tr	tr	tr	0.1	-	-	tr	-	-	tr	tr
1517	Methyl dodecanoate	-	-	-	-	-	-	tr	-	-	-	-	-
1523	Kessane	-	0.3	-	-	0.1	0.4	0.3	-	-	0.3	0.2	0.3
1526	*trans*-Cadina-1,4-diene	-	tr	-	tr	0.1	tr	tr	0.2	0.1	tr	tr	tr
1530	*iso*-Kessane	-	0.3	-	-	0.1	0.3	0.2	-	-	0.2	0.2	0.3
1530	α-Cadinene	tr	-	-	tr	-	-	-	tr	tr	-	-	-
1535	α-Calacorene	tr	-	-	-	tr	tr	-	tr	tr	tr	tr	tr
1541	Elemol	-	2.1	-	-	0.3	2.0	1.2	0.1	-	2.0	2.0	1.5
1554	(*E*)-Nerolidol	1.7	-	1.7	-	3.0	0.8	0.6	-	-	0.5	-	0.5
1555	10-*epi*-Liguloxide[c]	-	4.2	-	-	1.1	4.5	3.1	0.3	-	3.5	2.6	3.3

(Continued)

Table 1. Continued

RI[a]	Compound	A	B	C	D	E	F	G	H	I	J	K	L
1555	Dodecanoic acid	0.8	-	-	0.3	-	-	-	0.8	0.8	-	0.3	-
1564	Palustrol	-	-	-	0.2	-	-	-	0.1	0.1	-	-	tr
1566	1,10-Decanediol	-	-	-	-	-	-	-	-	0.2	0.4	0.4	tr
1568	Longipinanol	-	-	-	0.3	-	-	-	-	-	-	-	-
1570	Germacrene D-4-ol	-	-	-	0.2	tr	-	-	0.3	0.3	-	0.2	0.2
1575	Octyl hexanoate	0.2	-	0.2	-	0.1	0.5	-	-	-	0.1	0.1	-
1575	Caryophyllene oxide	-	-	-	tr	-	-	-	-	-	-	-	-
1581	Decyl butanoate	0.1	-	tr	-	-	0.1	-	-	-	-	-	-
1582	*allo*-Hedycaryol	-	-	-	-	-	-	-	0.1	tr	-	-	-
1590	Guaiol	-	tr	-	-	tr	0.1	0.1	-	-	0.1	0.1	tr
1598	Ledol	-	tr	tr	0.3	tr	-	-	0.2	0.1	-	tr	tr
1601	Dodecyl acetate	0.1	-	-	-	-	-	-	-	-	-	-	-
1603	Copaborneol	-	0.4	-	0.5	-	-	-	1.1	0.2	-	tr	0.4
1607	4,10-di-*epi*-Guaiol[c]	-	12.3	-	-	2.2	15.1	9.4	1.2	-	13.6	12.3	11.1
1621	1-*epi*-Cubenol	-	-	-	0.1	tr	-	-	-	-	-	-	-
1624	Eremoligenol	-	0.1	-	-	-	-	tr	-	-	tr	tr	tr
1625	γ-Eudesmol	-	0.1	-	-	tr	0.1	tr	-	-	0.1	0.1	tr
1635	τ-Cadinol	0.2	-	-	-	-	-	-	-	-	-	-	-
1636	Cubenol	-	-	-	0.2	tr	-	-	0.3	tr	-	-	-
1637	Hedycaryol	-	0.2	-	-	tr	0.2	0.1	-	-	0.2	0.2	0.2
1637	τ-Muurolol	-	-	-	0.1	-	-	-	-	-	-	-	-
1639	α-Muurolol	-	-	-	0.4	-	-	-	0.3	0.1	-	tr	tr
1643	Agarospirol	-	0.1	-	-	-	0.1	0.1	-	-	0.1	0.1	tr
1646	Hinesol	-	2.7	-	-	0.4	2.9	1.7	0.2	-	2.7	2.6	2.1
1648	α-Cadinol	-	-	-	0.2	-	-	-	0.1	tr	-	-	-
1649	α-Eudesmol	-	1.7	-	-	0.3	1.2	0.9	tr	-	1.1	1.3	0.9
1668	Bulnesol	-	0.5	-	-	tr	0.5	0.3	tr	-	0.5	0.5	0.3
1690	Tridecenyl acetate[d]	0.1	-	-	-	-	-	-	-	-	-	-	-
1772	Decyl hexanoate	0.1	-	0.1	-	-	0.1	-	-	-	-	-	-
1944	(3*E*)-Cembrene A	2.8	1.9	1.7	2.7	2.5	2.4	1.6	2.3	2.9	2.7	3.4	2.0
1953	(3*Z*)-Cembrene A	0.1	-	0.1	-	-	-	-	-	-	-	-	-
1989	α-Pinacene	0.4	0.4	0.3	0.7	0.5	0.6	0.4	0.6	0.7	0.7	1.0	0.5
2002	Verticilla-4(20),7,11-triene	1.9	0.2	2.2	1.3	0.5	0.3	0.8	2.2	5.4	1.2	1.8	3.0
2058	Manool	0.2	-	0.1	-	-	-	-	-	-	-	-	-
2124	Neocembrene A	3.4	1.4	2.1	2.2	1.4	0.9	0.5	1.2	1.4	1.5	2.5	0.8
2136	Incensole	-	6.7	-	-	6.5	-	-	-	-	-	-	-
2139	Serratol	31.8	2.7	20.1	21.8	3.6	11.2	6.4	14.5	16.1	16.8	25.9	10.3
2143	Incensyl acetate	0.5	-	0.4	0.3	-	-	-	-	-	-	-	-
	Monoterpene hydrocarbons	0.3	3.2	2.0	8.5	4.5	7.3	4.3	3.9	7.4	11.6	1.5	5.7
	Oxygenated monoterpenoids	0.9	0.8	0.3	1.0	1.0	0.4	0.4	0.2	0.1	0.4	0.5	0.3
	Sesquiterpene hydrocarbons	1.2	2.2	3.2	16.0	6.2	1.2	1.4	23.0	9.7	1.2	3.1	16.1
	Oxygenated sesquiterpenoids	1.9	26.5	3.8	7.4	9.0	28.6	18.2	9.2	2.2	25.3	23.4	22.7
	Diterpenoids	41.1	13.4	27.0	28.9	14.9	15.5	9.6	20.9	26.6	22.9	34.6	16.8
	Fatty methyl ethers	43.6	50.8	60.9	37.1	60.9	39.8	62.6	40.6	50.0	36.1	34.5	36.8
	Fatty alcohols	5.6	0.8	1.2	0.4	2.3	3.2	2.7	0.8	1.8	1.8	1.6	0.7
	Fatty aldehydes	0.1	0.4	0.2	0.1	0.3	tr	0.1	tr	tr	tr	tr	0.1
	Fatty acids	1.1	tr	tr	0.3	0.3	0.2	0.1	0.8	0.9	0.0	0.3	tr
	Fatty esters	3.6	0.2	1.0	0.1	0.4	1.7	0.0	0.1	0.1	0.3	0.3	0.0
	Others	tr	tr	tr	0.0	0.2	1.7	0.7	0.3	0.4	0.3	0.1	0.9
	Total identified	99.4	98.3	99.7	99.9	100.0	99.7	100.0	99.7	99.2	99.8	99.8	100.0

(Continued)

Table 1. Continued

RI[a]	Compound	A	B	C	D	E	F	G	H	I	J	K	L

[a]RI, retention index determined with respect to a homologous series of *n*-alkanes on a ZB-5 column.
[b]tr, trace (<0.05%).
[c]Ayubova et al.[4]
[d]Correct isomer not determined.

essential oils collected from individual trees located in the Sanaag region of Somaliland.

Results

The *B. occulta* oleogum resin essential oils from 12 different individual trees were obtained by hydrodistillation in yields of 2.68% to 5.45% (w/v) as colorless to pale yellow oils. The chemical compositions of the essential oils are compiled in Table 1. All of the essential oils were dominated by methyl ethers (34.5%-62.6%), in particular 1-methoxydecane (26.6%-47.9%) and 1-methoxyoctane (3.6%-8.6%). Other major components included the diterpene alcohol serratol (2.7%-31.8%) and the sesquiterpene alcohol 4,10-di-*epi*-guaiol (up to 15.1%). Monoterpene hydrocarbons and oxygenated monoterpenoids made up a very small portion of the essential oil compositions (0.3%-11.6% and 0.1%-1.0%, respectively). Sesquiterpenoids were slightly higher in concentration with 1.2% to 23.0% sesquiterpene hydrocarbons and 1.9% to 28.6% oxygenated sesquiterpenoids.

A hierarchical cluster analysis has been carried out and reveals the *B. occulta* essential oil chemical profiles to be very similar. There are, however, 3 clearly defined groups (Figure 1): (**1**) a methoxydecane/serratol/methoxyoctane group with 26.6% to 47.4% 1-methoxydecane, 14.5% to 31.8% serratol, and 3.6% to 8.6% 1-methoxyoctane; (**2**) a methoxydecane/di-*epi*-guaiol/serratol group with 26.6% to 29.1% 1-methoxydecane, 11.1% to 15.1% 4,10-di-*epi*-guaiol, and 10.3% to 16.8% serratol; and (**3**) a methoxydecane/methoxyoctane/di-*epi*-guaiol group with 38.9% to 47.9% 1-methoxydecane, 7.0 to 9.2% 1-methoxyoctane, and 2.2% to 12.3% 4,10-di-*epi*-guaiol.

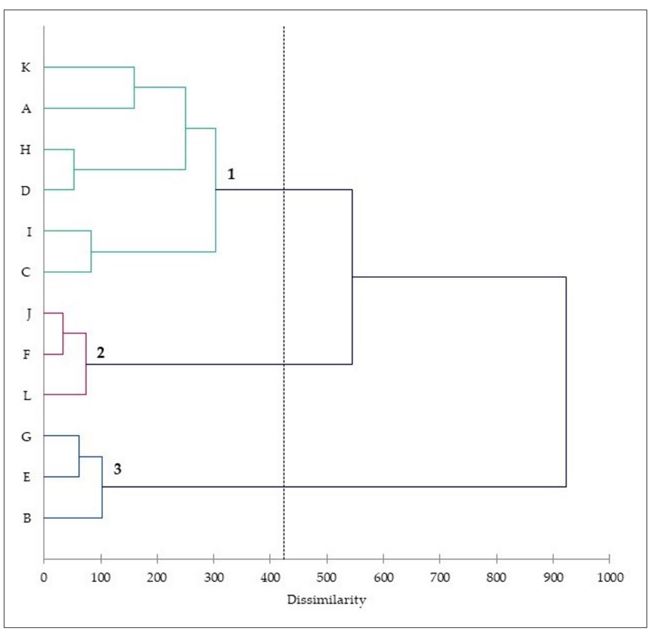

Figure 1. Dendrogram obtained from the agglomerative hierarchical cluster analysis of 12 *Boswellia occulta* oleogum resin essential oil compositions collected from Somaliland.

Discussion

The chemical compositions of *B. occulta* oleogum resin essential oils are markedly different from those derived from other *Boswellia* species (Table 2). Methoxyalkanes are exceedingly rare as natural products; they have never been reported as a plant product, to our knowledge, but have been isolated from spider silk,[6,7] millipedes,[8] and potentially microbes.[9,10] Previous work confirmed that the methoxyalkanes come from the resin itself, suggesting that the tree itself is producing these compounds, a botanical first.[4,5] The methoxyalkane *Boswellia* was originally believed to be a chemotype of *B. carteri* based on oleogum resins collected from Somaliland and Puntland,[5,11] but has since been shown to be a separate species, *B. occulta*, based on oleogum resins collected from specific trees.[3] *Boswellia carteri* oleogum resin essential oils by contrast are generally rich in α-pinene,[11–13] with 3 α-pinene-rich subgroups thus far defined: Group 1 (an α-pinene/myrcene/limonene group), Group 2 (an α-pinene/limonene group), and Group 3 (a limonene/α-pinene group). There is another distinct chemotype of *B. carteri*, a chemotype rich in α-thujene and *p*-cymene.[11,13] Very recently, Ayubova et al reported the chemical compositions of essential oils derived from oleogum resins purchased in the Sanaag region of Somaliland and reported by harvesters to be *B. occulta*; their compositions are qualitatively similar to the compositions of *B. occulta* found in this present study.[4] The oleogum resin essential oils reported by Ayubova et al showed 1-methoxydecane (23.1%-30.0%), 1-methoxyoctane (6.0%-8.2%), 4,10-di-*epi*-guaiol (2.5%-6.6%), and serratol as the major components. Thus, the oleogum resins obtained by this group are indeed most likely derived from *B. occulta*.

Boswellia sacra oleogum resin essential oils from Oman are dominated by α-pinene with an average content of 68.5%[14-16] (unpublished results from our laboratories). Van Vuuren et al have reported commercial *B. sacra* essential oils with lower concentrations of α-pinene (18.3% and 22.5%) along with larger

Table 2. Comparison of the Monoterpenoid Concentrations (Average % and Range) of *Boswellia carteri* (From Somalia), *Boswellia sacra* (From Oman), and *Boswellia frereana* (From Somalia).

	Boswellia carteri					*Boswellia frereana*	
Monoterpene	Chemotype 1	Chemotype 2	Chemotype 3	Chemotype 4	*Boswellia sacra*	Chemotype 1	Chemotype 2
α-Pinene	36.3 (15.6-48.9)	22.8 (12.0-31.8)	26.1 (19.9-32.3)	7.5 (2.3-14.8)	68.5 (46.8-79.6)	48.6 (24.7-67.9)	2.3 (2.0-2.6)
α-Thujene	2.3 (0.0-7.7)	7.4 (1.6-14.0)	3.2 (0.1-12.8)	43.0 (32.9-52.4)	0.6 (0.1-1.0)	17.5 (0.0-34.7)	44.4 (33.1-51.3)
β-Pinene	1.6 (1.1-2.0)	1.2 (0.0-3.3)	1.1 (0.9-1.3)	0.4 (0.2-0.8)	2.1 (1.3-2.4)	2.8 (1.3-4.5)	0.3 (0.2-0.3)
Sabinene	7.9 (1.4-25.7)	3.9 (0.0-9.9)	3.7 (0.4-4.9)	7.1 (5.6-10.9)	2.4 (0.0-7.8)	3.6 (2.2-7.0)	6.9 (5.1-8.3)
Myrcene	14.7 (2.5-25.7)	3.9 (0.0-9.9)	2.8 (0.0-4.2)	1.5 (0.0-4.0)	2.8 (0.2-7.5)	0.2 (0.0-2.1)	0.3 (0.0-0.9)
Limonene	11.4 (0.8-18.6)	13.3 (7.0-20.4)	34.3 (28.0-50.6)	2.1 (1.0-4.8)	5.8 (0.8-15.9)	1.7 (0.9-3.1)	1.5 (0.8-2.5)
p-Cymene	3.1 (0.7-5.3)	6.2 (3.6-11.8)	2.9 (1.0-4.1)	11.1 (3.4-19.7)	1.4 (0.7-2.7)	7.1 (2.1-12.3)	14.0 (9.9-16.9)

Table 3. *Boswellia occulta* Collection Sites, Sanaag Region of Somaliland, Near the Town of Ceel Dibir.

Sample	GPS coordinates	Elevation (m)
A	10°30.658' N, 46°24.890' E	409
B	10°30.703' N, 46°24.907' E	438
C	10°30.716' N, 46°24.904' E	443
D	10°30.742' N, 46°24.893' E	449
E	10°30.807' N, 46°24.841' E	449
F	10°30.870' N, 46°15.579' E	572
G	10°30.879' N, 46°15.556' E	570
H	10°30.880' N, 46°15.556' E	570
I	10°30.882' N, 46°15.471' E	578
J	10°30.877' N, 46°15.417' E	585
K	10°30.902' N, 46°15.343' E	597
L	10°30.828' N, 46°15.433' E	586

concentrations of limonene (13.1% and 11.2%).[13] However, these essential oils were obtained from "herbal shops or pharmacies" so the geographical origin was unknown. Furthermore, there is some debate regarding the taxonomy of *B. carteri* and *B. sacra*. Although both are generally considered by botanical taxonomists to be conspecific (*B. sacra*), others have considered the African populations to be *B. carteri* and the Arabian populations to be *B. sacra*.[1,11]

There seem to be 2 chemotypes of *B. frereana* from Somaliland (unpublished results from our laboratory). One chemotype is rich in α-pinene and α-thujene, and the other chemotype is dominated by α-thujene and *p*-cymene. These compositions are consistent with those reported by Van Vuuren et al for commercial *B. frereana* essential oil.[13]

Boswellia occulta oleogum resin essential oils are thus highly unique both for their unusual chemical composition and for their distinct scent profiles. Although it has thus far largely reached the market as a contaminant of *B. carteri* essential oils,[3] this species individually has value by enriching the range of materials used in the fragrance and complementary medicine industries.

Materials and Methods

Collection of Oleogum Resins

Oleogum resins from individual *B. occulta* trees were collected by Ahmed Mohamed Dhunkaal from the Sanaag region of Somaliland, near the town of Ceel Dibir, during October 2018 (summer) (Table 3 and Figure 2). The resins were sealed in plastic bags and shipped to the Aromatic Plant Research Center (Lehi, UT, USA) for analysis. The trees were photographed and a voucher specimen was collected and deposited in the University of Hargeisa Herbarium (HARG No. 000189). The voucher specimen was identified by Dr Mats Thulin and described as *B. occulta*.[2]

Hydrodistillation of Oleogum Resins

Hydrodistillations of the oleogum resin samples of *B. occulta* were carried out using an all-glass Clevenger apparatus as previously described.[11]

Gas Chromatography-Mass Spectrometry

The *B. occulta* oleogum resins were analyzed by GC-MS with a Shimadzu GCMS-QP2010 Ultra with ZB-5 capillary column as previously described.[11] Identification of the chemical components was carried out by comparison of the retention indices determined with respect to a homologous series of normal alkanes and our comparison of their mass spectra with those reported in the literature[17] and our own in-house library.[18]

Gas Chromatography-Flame Ionization Detection

Quantitative analysis of the *B. occulta* oleogum resin essential oils by GC-FID was carried out using a Shimadzu GC 2010 equipped with flame ionization detector, a split/splitless injector, and Shimadzu autosampler AOC-20i, with a ZB-5 capillary column as previously described.[19]

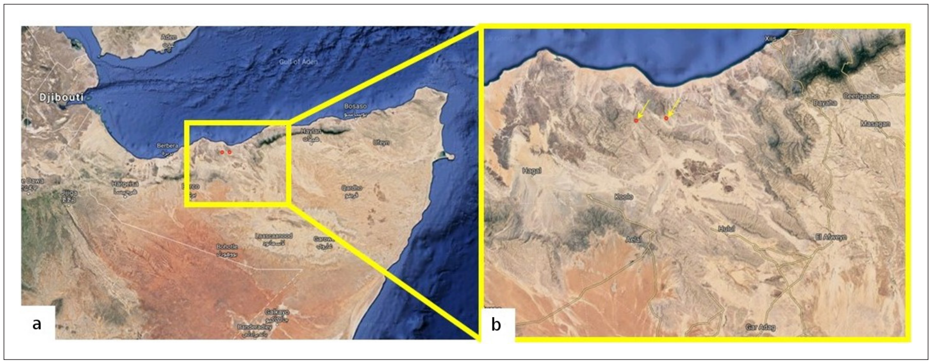

Figure 2. *Boswellia occulta* collection sites. (a) Somaliland. (b) Enlarged map showing collection sites.

Acknowledgments

We gratefully acknowledge the efforts of Ahmed Mohamed Dhunkaal in collecting the resin samples and voucher specimen. This work was carried out as part of the activities of the Aromatic Plant Research Center (https://aromaticplant.org/).

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.

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