The Chemical Composition of Single-Tree

Boswellia frereana Resin Samples

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Abstract
Frankincense is an aromatic terpenoid oleo-gum resin produced by trees in the genus Boswellia. It has been used for medicinal and religious purposes for millennia, and is today an important component in perfume and aromatherapy. The resin of Boswellia frereana is especially prized, and has been found to contain a high proportion of monoterpenes. However, previous studies have relied on commercial samples; in this study, we characterize the compositions of essential oil and DCM extract samples from 12 individual B frereana trees. The triterpenoid fraction was largely consistent between samples, with lupeol (14.7%-32.5%), α-amyrin (13.0%-25.2%), 3-epi-lupeol (6.4%-14.2%), and β-amyrin (5.3%-8.0%) as the primary constituents. The essential oil showed more intersample diversity, but still represented a single, variable chemotype characterized by a moderate to high level of α-thujene (14.5%-43.9%) and a varying, often significant, level of α-pinene (3.0%-63.0%).

Keywords
essential oil, frankincense, olibanum, Boswellia frereana, maydi, Somaliland

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Introduction
Frankincense is an aromatic tree exudate, composed of 3 principal fractions: a volatile, typically monoterpenic-rich essential oil, a complex polysaccharide gum, and a nonvolatile triterpene-based resin.1 It has been used in traditional medicine, perfumery, and religious ceremonies for thousands of years. More recently, frankincense has become popular in aromatherapy and other types of alternative and complementary medicine.2 Frankincense is produced by members of the genus Boswellia (Burseraceae), which is composed of small trees that specialize on arid conditions, often with exfoliating bark, compound leaves, and wind-dispersed seeds. There are ~24 species in the genus, although the exact number has been subject to recent changes.3

The oleo-gum resin essential oils of Boswellia vary significantly from species to species. Boswellia papyrifera Hochst., found in Ethiopia, Eritrea, and Sudan, yields an essential oil dominated by octyl acetate and to a lesser degree octanol.4-7 Boswellia sacra Flueck. (syn. Boswellia carteri Birdw.) from Oman, Yemen, Somaliland, and Somalia, is variably dominated by α-pinene, α-thujene, or limonene, often with significant amounts of myrcene, sabinene, viridiflorol, β-caryophyllene, or p-cymene.5-9 Most other Boswellia species, such as B neglecta S. Moore, B serrata Roxb. ex. Colebr., B dalzielii Hutch., B rivae Engl., and the Socotran Boswellia, are similarly rich in these mono- and sesquiterpenes.5,6,10-14 By contrast, Boswellia oculus Thulin, DeCarlo, & S.P. Johnson is dominated by methoxydecane and methoxyoctane, unusual components for a plant essential oil.15,16

Boswellia frereana Birdw., endemic to Somaliland and Somalia, is one of the most commonly traded frankincense species. It is known for its large tears of resin, commonly used as chewing gum in the Arab world, and more recently has become popular for its essential oil.2 Previous investigations on the essential oil of this species have all been on commercial samples, with mixed results: The different studies show varying levels of α-pinene, α-thujene, p-cymene, sabinine, and β-caryophyllene, possibly indicating multiple chemotypes.6,12 Some commercial B frereana essential oils also contain methoxylkanes, particularly methoxydecane (decyl methyl ether), and one study found resin

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that visually appeared to be \textit{B. frereana} contained methoxylalkanes.\textsuperscript{11} In this study, we therefore aim to clarify the chemotypes of \textit{B. frereana} by presenting a characterization of the oleogum resin essential oils from samples taken directly from individual trees in Somaliland.

### Results

The \textit{B. frereana} oleogum resin essential oils from 12 different individual trees were obtained by hydrodistillation in yields around 13\% (w/w) as pale-yellow oils. Resin samples from 7 trees were also extracted using dichloromethane.

All essential oils were dominated by \(\alpha\)-pinene (3.0\%-63.0\%) and \(\alpha\)-thujene (14.5\%-43.9\%) (Table 1). Other major components included sabine (3.3\%-8.0\%), \(\beta\)-cymene (1.7\%-13.0\%), and \(\beta\)-pinene (0.3\%-4.1\%). One sample also contained a significant quantity of \(\alpha\)-phellandrene (6.0\%) and its dimers (10.0\%). Three groups were determined by the agglomerative hierarchical clustering (AHC) analysis (Figure 1): (1) one group represented by a single sample and defined by high levels of \(\alpha\)-thujene; (2) a group comprising samples with high \(\alpha\)-pinene (52.6\%-63.0\%) and moderate \(\alpha\)-thujene (14.5\%-17.4\%), and (3) a group comprising samples with significant levels of both \(\alpha\)-pinene (34.0\%-53.5\%) and \(\alpha\)-thujene (21.4\%-33.0\%).

While the chemotypic groups of the essential oils were defined by monoterpenes, the extract groups were defined by the triterpenes (Figure 2). While 3 groups were identified, all samples were highly similar, with major components including lupeol (14.7\%-32.5\%), \(\alpha\)-amyrin (13.0\%-25.2\%), 3-epi-lupeol (6.4\%-14.2\%), \(\alpha\)-pinene (0.4\%-13.9\%), \(\alpha\)-thujene (3.6\%-12.9\%), and \(\beta\)-amyrin (5.3\%-8.0\%) (Table 2).

#### Table 1. Major Constituents (% Area >1) of Essential Oils Distilled From \textit{Boswellia frereana} Individual Tree Oleo-gum Resin Samples.

| Compound          | A   | B    | C    | D    | E    | F    | G    | H    | I    | J    | K    | L    |
|-------------------|-----|------|------|------|------|------|------|------|------|------|------|------|
| \(\alpha\)-Thujene| 43.9| 25.5 | 16.2 | 33.1 | 31.5 | 32.9 | 25.9 | 17.4 | 14.5 | 27.3 | 21.4 | 16.2 |
| \(\alpha\)-Pinene | 3.0 | 37.3 | 63.0 | 44.8 | 34.0 | 34.5 | 42.7 | 60.9 | 58.4 | 53.5 | 43.5 | 52.6 |
| Thujadiene        | 1.3 | 0.4  | 0.4  | 0.8  | 2.2  | 0.9  | 1.0  | 0.1  | 0.3  | 0.7  | 0.4  | 0.7  |
| Camphene          | 0.1 | 0.8  | 0.2  | 0.7  | 0.9  | 0.8  | 1.1  | 1.0  | 1.8  | 0.9  | 1.2  | 1.5  |
| Sabine            | 8.0 | 5.9  | 3.3  | 5.3  | 6.6  | 6.9  | 6.1  | 3.9  | 3.3  | 4.8  | 5.1  | 4.2  |
| \(\beta\)-Pinene  | 0.3 | 2.8  | 3.3  | 2.2  | 2.4  | 2.7  | 3.5  | 3.4  | 4.1  | 2.9  | 3.4  | 3.9  |
| \(\alpha\)-Phellandrene | 6.0 | 4.6  | 0.3  | 0.1  | 0.2  | 2.9  | 1.7  | 2.5  | 0.0  | 0.3  | 2.6  | 0.2  |
| \(\beta\)-Cymene  | 13.0| 5.7  | 3.3  | 1.9  | 6.5  | 5.7  | 5.1  | 2.2  | 3.2  | 1.7  | 5.5  | 5.2  |
| Limonene          | 2.7 | 1.8  | 1.1  | 0.5  | 1.0  | 1.1  | 1.3  | 1.1  | 1.1  | 0.6  | 2.1  | 1.6  |
| \(\beta\)-Phellandrene | 2.5 | 1.3  | 0.3  | 0.2  | 0.3  | 1.1  | 1.0  | 0.7  | 0.1  | 0.3  | 1.0  | 0.2  |
| 1,8-Cineole       | 0.3 | 0.8  | 0.5  | 1.1  | 0.5  | 0.4  | 0.2  | 0.7  | 0.1  | 0.4  | 0.3  | 0.9  |
| \(\beta\)-Thujone  | 0.5 | 0.3  | 0.1  | 0.5  | 1.2  | 0.6  | 0.3  | 0.0  | 0.3  | 0.2  | 0.2  | 0.4  |
| Terpinen-4-ol     | 1.5 | 0.6  | 0.4  | 1.8  | 1.1  | 1.2  | 0.7  | 0.4  | 1.0  | 0.4  | 0.5  | 0.7  |
| Bornyl acetate    | 0.2 | 1.3  | 1.2  | 0.7  | 1.3  | 1.0  | 1.5  | 1.0  | 1.7  | 1.0  | 1.5  | 1.9  |
| \(\beta\)-Bourbonene | 0.0 | 0.0  | 0.7  | 0.0  | 0.0  | 0.1  | 0.0  | 2.2  | 1.2  | 0.0  | 0.0  | 0.0  |
| \(\alpha\)-Phellandrene dimer A (RI 1792) | 7.5 | 3.6  | 0.6  | 0.0  | 0.3  | 0.8  | 1.9  | 1.1  | 0.1  | 0.1  | 4.6  | 0.7  |
| \(\alpha\)-Phellandrene dimer B (RI 1798) | 1.3 | 0.6  | 0.1  | 0.0  | 0.0  | 0.1  | 0.3  | 0.2  | 0.0  | 0.0  | 0.9  | 0.0  |
| \(\alpha\)-Phellandrene dimer C (RI 1826) | 1.2 | 0.5  | 0.1  | 0.0  | 0.0  | 0.1  | 0.3  | 0.1  | 0.0  | 0.0  | 0.7  | 0.0  |

### Discussion

In this study, we aimed to clarify the chemical composition of the oleogum resin essential oils produced by \textit{Boswellia frereana} (frankincense) trees in Somaliland (northern Somalia). Consistent with previous studies, the oleo-gum resin essential oils were found to contain large amounts of \(\alpha\)-pinene and \(\alpha\)-thujene, with smaller amounts of sabine, \(\beta\)-cymene, and \(\alpha\)-phellandrene dimers.\textsuperscript{6,9,12} However, while the samples showed a range of variation, they were not dissimilar enough to be considered separate chemotypes; rather than 2 distinct chemotypes, one dominated by \(\alpha\)-pinene and one dominated by \(\alpha\)-thujene, as we expected, most samples contained appreciable levels of both monoterpenes. We conclude that the samples in this study show only a single essential oil chemotype, characterized by a moderate to high level of \(\alpha\)-thujene and a varying, often significant, level of \(\alpha\)-pinene.

Methoxylalkanes were not detected, even as trace components, in any of the samples tested. This is particularly interesting given that we sampled \textit{B. frereana} trees sympatric to the \textit{B. occulta} trees known to produce methoxylalkanes.\textsuperscript{18} Methoxylalkanes are extremely rare as natural products, having been reported botanically only from \textit{B. occulta} and one cultivar of Chinese tree peony.\textsuperscript{18,19} However, \textit{B. occulta} resin is commonly mixed with other frankincense resin from \textit{B. sacra} and \textit{B. frereana} in Somaliland, leading to commercial essential oils sold as \textit{B. sacra} (or \textit{B. carteri} which are in fact a mixture of \textit{B. sacra} and \textit{B. occulta}).\textsuperscript{16} Our results do not preclude the possibility that \textit{B. frereana} may produce methoxylalkanes, but we conclude that it is more likely that commercial \textit{B. frereana} essential oils containing methoxyldecane or methoxylalkanes are in fact mixtures of \textit{B. frereana} and \textit{B. occulta}.

We found very little variation in the triterpenoid components from tree to tree, even between trees that have relatively
different essential oil compositions. Our results were largely consistent with other studies performed on commercial resin samples. As with previous studies, we found no boswellic acids or lupeolic acids, which are common in other Boswellia species. This is not surprising, however, considering that these components may not be volatile enough to be detected by GC-MS. Previous work has identified lupeol and 3-epi-lupeol as the major triterpenoid components of B. frereana resin; we likewise found significant levels of lupeol and 3-epi-lupeol. However, we also found α-amyrin and to a lesser degree β-amyrin to be present in significant quantities, components that have been previously reported from B. frereana but not in significant quantities.

We thus conclude that the samples in this study show a single, somewhat variable chemotype rich in α-thujene, α-pinene, lupeol, and α-amyrin. However, further sampling across the species’ range may reveal additional chemotypes, especially with regard to the triterpenoids.

Methods and Materials

Collection of Resins

Resins from individual B. frereana trees were collected by Ahmed Mohamed Dhunkaal from the Sanaag region of Somaliland (northern Somalia), near the town of Ceel Dibir, during October 2019 (Table 3, Figure 3). 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 (Voucher #HARG000497). The voucher specimen was identified by Faisal Jama.
Figure 2. Dendrogram obtained from agglomerative hierarchical cluster analysis of the dichloromethane extracts obtained from 7 *Boswellia frereana* individual tree oleo-gum resin samples from Somaliland.

Table 2. Major Constituents (% Area >1) of Dichloromethane Extracts Obtained From 7 *Boswellia frereana* Individual Tree Oleo-gum Resin Samples.

| Compound                  | RI   | A    | B    | C    | D    | E    | F    | G    |
|---------------------------|------|------|------|------|------|------|------|------|
| α-Thujene                 | 926  | 9.6  | 6.3  | 4.6  | 5.8  | 3.6  | 12.9 | 7.4  |
| α-Pinene                  | 934  | 0.4  | 9.9  | 13.0 | 9.0  | 13.9 | 2.0  | 12.8 |
| Sabinene                  | 972  | 1.2  | 1.0  | 0.8  | 1.0  | 0.7  | 0.7  | 1.1  |
| α-Phellandrene            | 1007 | 1.8  | 0.8  | 0.2  | 0.0  | 0.0  | 0.1  | 0.3  |
| p-Cymene                  | 1024 | 1.5  | 0.7  | 0.5  | 0.2  | 0.3  | 0.3  | 0.9  |
| α-Phellandrene dimer A    | 1798 | 3.1  | 2.1  | 0.4  | 0.0  | 0.1  | 0.3  | 0.8  |
| β-Amyrin$^a$              | 3345 | 8.0  | 5.4  | 6.4  | 5.8  | 6.1  | 5.5  | 5.3  |
| Unidentified lanostane    | 3373 | 1.7  | 1.6  | 1.7  | 1.3  | 1.6  | 1.6  | 1.7  |
| α-Amyrin$^b$              | 3395 | 15.2 | 13.0 | 17.4 | 13.6 | 16.2 | 13.1 | 25.2 |
| Lupeol$^b$                | 3402 | 32.5 | 30.0 | 24.0 | 32.4 | 26.6 | 27.9 | 14.7 |
| Unidentified ursane       | 3404 | 0.4  | 1.2  | 2.2  | 1.3  | 2.3  | 1.8  | 2.0  |
| 3-epi-Lupeol$^b$          | 3413 | 6.4  | 11.8 | 12.5 | 10.3 | 13.1 | 14.2 | 12.1 |
| α-Amyrin acetate$^a$      | 3499 | 1.3  | 1.4  | 2.0  | 1.1  | 1.9  | 2.4  | 1.6  |
| Unidentified triterpenoid  | 3649 | 3.7  | 3.3  | 2.7  | 4.6  | 2.0  | 3.4  | 3.3  |

$^a$Identification of triterpenoids is tentative only and largely based on mass spectral fragmentation; there are few retention data reported in the literature for comparison.
Hydrodistillation of Resins

Hydrodistillations of the resin samples of *B. frereana* were carried out using an all-glass Clevenger apparatus as previously described.\(^8\)

Dichloromethane Extraction of Resins

Resin samples from 7 individual trees were extracted with dichloromethane at room temperature, filtered, and evaporated to give the *B. frereana* extracts.

Gas Chromatography-Mass Spectrometry

The *B. frereana* resins were analyzed by GC-MS with a Shimadzu GCMS-QP2010 Ultra with ZB-5 capillary column as previously described.\(^8\) 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\(^23\) and our own in-house library.\(^24\)

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Table 3. *Boswellia frereana* Sample Collection Sites Near the Town of Ceel Dibir in the Sanaag Region of Somaliland.

| Sample | GPS coordinates          | Elevation (m) |
|--------|--------------------------|---------------|
| A      | 10.51675N, 46.25948E    | 551           |
| B      | 10.51680N, 46.26018E    | 547           |
| C      | 10.51790N, 46.26057E    | 538           |
| D      | 10.51820N, 46.26072E    | 535           |
| E      | 10.47090N, 46.39307E    | 389           |
| F      | 10.47030N, 46.39248E    | 399           |
| G      | 10.40785N, 46.34010E    | 429           |
| H      | 10.41140N, 46.32222E    | 559           |
| I      | 10.42993N, 46.31598E    | 598           |
| J      | 10.43165N, 46.31735E    | 595           |
| K      | 10.40020N, 46.34263E    | 439           |
| L      | 10.51617N, 46.25983E    | 556           |
| M      | 10.58250N, 47.18528E    | 518           |

Figure 3. Map showing area where *B. frereana* samples were collected (circle).

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Declarations of Conflicting Interests
The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: S. Johnson declares a business interest in a company producing products from B. frereana; it is not expected that this paper will affect that company. The rest of the authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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