MONO- AND SESQUITERPENOIDS OF THE OLEORESIN OF *Pinus koraiensis* AND *P. pumila*.
CRYSTAL STRUCTURE OF 1β,4αH,7αH,10βH-GUAIANE-5α,14-DIOL

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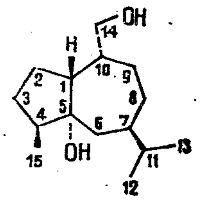
The composition of the mono- and sesquiterpenoids of the oleoresin of two species of conifers of the *Pinaceae* family has been studied. In the oleoresin of *Pinus koraiensis* Sieb. et Zucc. 10 oxidized monoterpenoids, 18 sesquiterpene hydrocarbons, and six sesquiterpene alcohols have been identified. In theoleoresin of *Pinus pumila* (Pall.) Rgl. 10 monoterpene hydrocarbons, six oxidized monoterpenoids, 14 sesquiterpene hydrocarbons, and four sesquiterpene alcohols have been found. The structure of 1β,4αH,7αH,10βH-guaiane-5α,14-diol, one of the hydroboration-oxidation products of an unidentified sesquiterpene alcohol isolated from both oleoresins, has been determined by x-ray structural analysis.

We have previously reported the composition of the mono- and sesquiterpene hydrocarbons of the oleoresins of the Korean pine (*Pinus koraiensis* Sieb. et Zucc.) [1] and the Japanese stone pine (*Pinus pumila* (Pall.) Rgl., island of Sakhalin) [2]. In the present communication we consider the results of an investigation of the mono- and sesquiterpenoids of the oleoresins of the Korean and Japanese stone pines growing on the northern shores of Lake Baikal.

In the oleoresin of the Korean pine, in addition to the α-longipinene, longifolene, caryophyllene, α-humulene, γ-cadiene, γ-muurolene, and cadalene isolated previously, we have identified δ-cadiene, α-muurolene, β-farnesene, γ-elemene, γ-amorphene, α-cadinene, ε-muurolene, β-bisabolene, cyclosativene, calamenene, and calacorene. The main components of the sesquiterpene hydrocarbon fractions are caryophyllene (25%), β-bisabolene (15%), and longifolene (14%).

Of the oxidized mono- and sesquiterpenoids in the oleoresin of the Korean pine we have identified α-terpineol, terpineol-4, borneol, linalool, pinocampheol, pinocarveol, pinan-1-ol, sabinene hydrate, α-terpenyl acetate, bornyl acetate, δ-cardinol, bisabolol, cubebol, epicubebol, and epicubenol, and also koraiaol (I) — a sesquiterpene alcohol with a new type of carbon skeleton. The structure of the last-mentioned compound has been determined by x-ray structural analysis [3]. Bisabolol is the main component of the fraction of oxidized mono- and sesquiterpenoids. Gas–liquid chromatography and thin-layer chromatography showed the presence of small amounts of several more alcohols, of which we isolated three unidentified sesquiterpene alcohols denoted by the letters A, B, and C.

Alcohol A is a labile sesquiterpene compound (mol. wt. 220) with two double bonds: trisubstituted (5.56 ppm, 1 H) and exocyclic (4.72 ppm, 2 H; ν = 890, 3080 cm^{-1}). The spectral characteristics indicate the presence of a tertiary hydroxyl (3605 cm^{-1}) and of three methyl groups (1.0 ppm, doublet, J = 8 Hz, 6H; 1.22 ppm, 3 H). The hydroboration-oxidation of alcohol A gave a mixture of products from which we separated by chromatography previously undescribed 1β,4αH,7αH,10βH-guaiane-5α,14-diol. The structure (2) and the conformation (Fig. 1) of this diol were determined by x-ray structural analysis.



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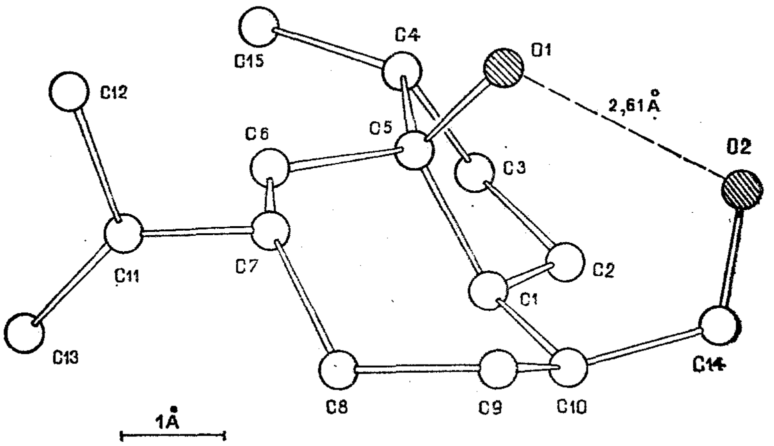

Fig. 1. Conformation of the molecule of 1β,4αH,7αH,10βH-guaiane-5α,14-diol.

Alcohol B also belongs to the group of sesquiterpene alcohols (mol. wt. 222). The IR and PMR spectra show the presence of a tertiary hydroxyl (3610 cm^{-1}) and of a secondary methyl group (0.82 ppm, 3 H, doublet, J = 5.5 Hz), of a $CH_3-\overset{|}{\underset{|}{C}}-OH$ fragment (1.18 ppm, 3 H), and of an exocyclic double bond (4.61 ppm, 2 H, ν = 890, 3080 cm^{-1}).

Alcohol C (mol. wt. 220) contains two exocyclic double bonds (4.75 ppm, 2 H; 4.92 ppm, 1 H; 5.02 ppm, 1 H; ν = 890, 910, 3080 cm^{-1}), geminal methyl groups (1.0 ppm, 6 H; 1360, 1374 cm^{-1}), and a tertiary hydroxy group (3610 cm^{-1}).

The oleoresin of the Japanese stone pine from the northern shores of Lake Baikal differs in relation to the composition of the mono- and sesquiterpene hydrocarbons from the oleoresin of this species of pine that we investigated previously, which was collected on the island of Sakhalin [2]. Thus, the new oleoresin lacks α-thujene and contains considerably less β-phellandrene while the content of α-pinene, thedominating component of the monoterpene hydrocarbon fraction, has increased somewhat.

The sesquiterpene hydrocarbons of these oleoresins differ mainly by the presence of α-bisabolene in the oleoresin under investigation. Furthermore, in this fraction we identified cyclosativene, longicyclene, longifolene, sibirene, caryophyllene, γ-elemene, α-humulene, α-muurolene, δ- and γ-cadinenes, β-bisabolene, ar-curcumene, and calacorene. The main components of the sesquiterpene hydrocarbons are longifolene (34%), α-bisabolene (30%), and β-bisabolene (14%).

In the fraction of oxidized mono- and sesquiterpenoids, bisabolol predominates (42%), and together with this we have found cubebol and epicubebol, koraiol, the unidentified alcohol A, α-terpineol, terpineol-4, borneol, bornyl acetate, sabinene hydrate, and linalool. This fraction was also found to contain a labile alcohol which, on chromatography, gave as decomposition products a mixture of δ- and γ-cadinenes.

The dominating position of compounds of the bisabolane series (α- and β-bisabolenes, bisabolol) among the sesquiterpenoids of the oleoresin of the Japanese stone pine from Lake Baikal must be noted.

EXPERIMENTAL

For instruments and methods, see the literature [4].

The oleoresin of the Korean pine was collected in 1976 in Khabarovsk territory, and the oleoresin of the Japanese stone pine was obtained from open resin blazes on the north eastern shores of Lake Baikal, also in 1976.

For chromatography we used air-dry silica gel or silica gel impregnated with 10% $AgNO_3$ (SiO_2 + $AgNO_3$) activated at 100°C for 3 h. The eluent for the chromatography of the hydrocarbons on SiO_2 was petroleum ether, and on SiO_2 + $AgNO_3$ petroleum ether with the addition of 2-10% of diethyl ether.

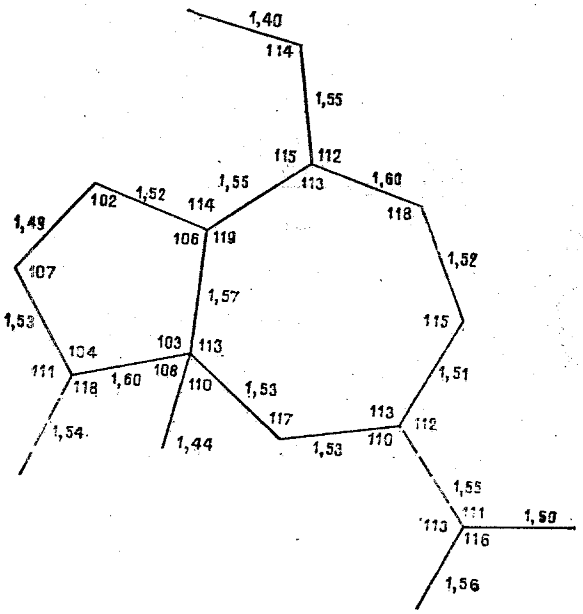

Fig. 2. Average values of the bond lengths and valence angles of the molecule of 1β,4αH,7αH,10βH-guaiane-5α,14-diol.

From 1 kg of the oleoresin of the Korean pine we obtained 162 g (16%) of monoterpene hydrocarbons, 7.1 g (0.7%) of sesquiterpene hydrocarbons, and 8.3 g (0.8%) of oxidized mono- and sesquiterpenoids, and from 1 kg of the oleoresin of the Japanese stone pine 142 g (14%), 8.7 g (0.9%), and 6.2 g (0.6%), respectively.

The composition of the monoterpene hydrocarbons was determined by the GLC method. α-Pinene (90.4%), β-pinene (2.9%), camphene (3.5%), myrcene (0.5%), limonene (0.6%), and β-phellandrene (1.0%) were found in the monoterpene fraction of the oleoresin of the Japanese stone pine. Terpinolene, 3-carene, γ-terpinene, and p-cymene were detected in trace amounts.

The sesquiterpene hydrocarbons of the Korean pine (3 g) were separated by chromatography on SiO_2 + $AgNO_3$ (100 g) into fractions 1 (0.6 g), 2 (1.2 g), 3 (0.26 g), and 4 (1.2 g).

By preparative GLC, fraction 1 yielded longifolene, α-longipinene, δ-cadinene, and α-muurolene.

The chromatography of fraction 2 (1.2 g) on SiO_2 (40 g) yielded β-bisabolene (0.34 g), γ-cadinene (0.06 g) and γ-muurolene (0.08 g).

The chromatography of fraction 3 (0.24 g) on SiO_2 (15 g) yielded β-farnesene.

The chromatography of fraction 4 (1.2 g) on SiO_2 (40 g) gave caryophyllene (0.6 g) and α-humulene (0.18 g).

The IR spectra of the compounds isolated were identical with those given in the literature [5]. Their PMR spectra coincided with those of authentic samples.

The minor components were identified from their relative retention times in capillary columns (GLC).

From the fraction of sesquiterpene hydrocarbons of the Japanese stone pine, longifolene, α-bisabolene, and β-bisabolene were isolated by preparative GLC. The remaining components were identified by GLC.

Identification of the Oxidized Compounds. Chromatography of the oxidized mono- and sesquiterpenoids of the oleoresin of the Korean pine (8 g) on SiO_2 (220 g) gave 13 fractions. Fractions 1 (0.4 g), 7 (0.41 g), and 9 (0.4 g) were chromatographed on SiO_2 + $AgNO_3$ with a ratio of substance to sorbent of 1:30.

Fraction 1 yielded bornyl acetate (0.25 g), $[\alpha]_D^{20}$ −18.9° (in the pure form) and α-terpenyl acetate (0.12 g).

Fraction 2 (0.6 g) yielded a mixture of terpineol-4 and linalool (8:1; PMR).

Fraction 3 (0.32 g) yielded a mixture of terpineol-4 and bisabolol (2:1; PMR).

TABLE 1. Coordinates of the Atoms (in fractions of the cell) of the Two Crystallographic Molecules of Guaianediol (the corresponding standard deviations are shown in parentheses)

Atom	$x\times10^3$	$y\times10^4$	$z\times10^4$	b, Å$^2\times10$	$x\times10^3$	$y\times10^4$	$z\times10^4$	b, Å$^2\times10$
	Molecule A				Molecule B			
C1	205(2)	4176(8)	4658(11)	37	200(2)	4161(9)	9699(10)	35
C2	309(2)	4190(9)	5513(11)	57	309(2)	4334(9)	10529(11)	53
C3	191(3)	4031(14)	5892(14)	80	188(3)	4223(10)	10939(10)	60
C4	071(3)	3471(9)	5406(10)	52	096(2)	3551(9)	10605(9)	50
C5	084(2)	3543(9)	4556(9)	30	092(2)	3523(9)	9738(9)	32
C6	−085(2)	3664(8)	3915(11)	46	−081(2)	3537(8)	9117(10)	45
C7	−092(3)	3666(11)	3072(11)	55	−095(3)	3404(10)	8277(11)	59
C8	016(3)	4231(10)	2938(10)	61	−001(3)	3499(12)	7978(11)	62
C9	196(3)	4053(10)	3219(14)	62	185(3)	3791(10)	8298(14)	66
C10	301(3)	4232(9)	4096(14)	50	294(3)	4144(9)	9127(13)	47
C11	−271(3)	3748(13)	2506(11)	82	−281(2)	3379(11)	7753(11)	71
C12	−355(2)	4412(10)	2593(10)	86	−355(2)	4129(9)	7606(10)	68
C13	−367(2)	3103(10)	2459(13)	86	−306(3)	2951(10)	7023(10)	86
C14	−097(3)	3540(11)	5487(10)	80	−070(2)	3511(10)	10733(11)	73
C15	466(3)	3848(11)	4364(11)	65	470(2)	3832(11)	9470(11)	54
O1	158(1)	2920(5)	4407(6)	43	175(1)	2888(5)	9658(6)	41
O2	455(1)	3124(6)	4399(8)	79	471(1)	3 36(6)	9705(8)	72

Fraction 4 (2.8 g) yielded bisabolol $[\alpha]_D^{20}$ +49.4° (in the pure form).

Fraction 5 (0.35 g) yielded a mixture of bisabolol and borneol (1:1.2; PMR).

Fraction 6 (0.4 g) yielded borneol, $[\alpha]_D^{20}$ +27.1° (c 26; $CHCl_3$).

Fraction 7 yielded pinocarveol (0.04 g), pinocampheol (0.06 g), a mixture of cubebol and epicubebol (0.12 g), and epicubenol (0.04 g).

Fraction 8 (0.11 g) yielded the unidentified alcohol A. IR spectrum, cm^{-1}: 890, 1380, 1465, 1645, 3080, 3610. Mass spectrum: 220 (M^+), 202, 187, 162, 159, 147.

Fraction 9 yielded alcohol A (0.08 g), pinan-1-ol (0.04 g), and the unidentified alcohols B (0.14 g) and C (0.10 g). IR spectrum of compound B, cm^{-1}: 894, 1375, 1460, 1642, 3074, 3605. IR spectrum of the compound C, cm^{-1}: 895, 910, 1374, 1440, 1650, 3085, 3610.

Fraction 10 (0.4 g) yielded δ-cadinol, $[\alpha]_D^{20}$ +28.5° (c 3.5; $CHCl_3$).

Fraction 11 (0.8 g) yielded α-terpineol, $[\alpha]_D^{20}$ −25.5° (in the pure form).

Fraction 12 (0.3 g) yielded koraiol, $[\alpha]_D^{20}$ +31.7° (c 22, CHCl), mp 89-90°C.

Fraction 13 (0.35 g) yielded sabinene hydrate, $[\alpha]_D^{20}$ −19.4° (in the pure form).

From the oxidized mono- and sesquiterpenoids of the oleoresin of the Japanese stone pine (5 g) in a similar manner we isolated bornyl acetate (0.06 g) terpineol-4 (0.16 g), borneol (0.11 g), δ-terpineol (0.18 g), linalool (0.06 g), a mixture of cubebol and epicubebol (0.09 g), koraiol (0.16 g), bisabolol (2.1 g), $[\alpha]_D^{20}$ −57.2° (in the pure form), δ-cadinol (0.11 g), sabinene hydrate (0.14 g), and the unidentified alcohol A (0.04 g).

When a mixture of terpineol-4 and the unknown compound (0.3 g; 2:1; PMR) was chromatographed, terpineol-4 and a mixture of δ- and γ-cadinenes (0.07; 1:1; PMR) was isolated.

The IR and PMR spectra of the oxidized compounds that were identified agreed with the spectra of authentic samples.

Hydroboration-Oxidation of the Alcohol A. To 0.2 g of alcohol A in 2 ml of diethyl ether was added 5 ml of a solution of diborane in THF (11 mg/ml). The mixture was kept at 0°C for 16 h, the excess of diborane was decomposed with ice, 3 ml of 4 N NaOH and 3 ml of 30% H_2O_2 were added, and the mixture was stirred at 40°C for 2 h. The reaction product was extracted with 10 ml of diethyl ether and, after the solvent had been distilled off, the residual mixture (0.2 g) was chromatographed on SiO_2 (8 g). Diethyl ether with the addition of 30% of acetone eluted 1β,4αH,7αH,10βH-guaiane-5α,14-diol (0.04 g), mp 91-92°C.

X-Ray Structural Analysis. The x-ray structural experiment was performed on a Syntex $P2_1$ instrument using Mo radiation with a graphite monochromator. The crystals of the guaianediol (2) were monoclinic with a = 8.769(2) Å, b = 19.205(5) Å, c = 18.484(5) Å, β = 110.98(2)°; z = 8; sp. gr. $P2_1/a$. The intensities of the reflections were measured from a crystal with dimensions of 1.1 and 0.3 × 0.1 mm^3 by the $2\theta/\omega$ scanning method in the range $2\theta < 40°$. No corrections were introduced for absorption. The calculations were performed with 1303 reflections having $I > 4\sigma$ from the 2701 measured. The structure was found by the direct method by a modified MULTAN program [5], the correct variant of the signs having NQEST = −0.65. The structure was refined in the anisotropic approximation to R = 0.098. The corodinates of the atoms of the molecules are given in Table 1.

The elementary cells consists of two independent molecules of the guaianediol (2) with practically identical geometries. The conformation of the molecules is shown in Fig. 1. The values of the bond lengths and valence angles averaged over the two molecules are given in Fig. 2. The geometry of the molecules is the usual one. The cycloheptane ring has a conformation close to the C_2 twist-chair form (the approximate twofold axis passes through the C_{10} atom). This form of the seven-membered ring is the usual one for perhydroazulene sesquiterpenoids [6]. The averaged torsional angles in the ring ($\varphi_{1,5}83$, $\varphi_{5.6}-70$, $\varphi_{6.7}59$, $\varphi_{7.8}-76$, $\varphi_{8.9}86$, $\varphi_{9.10}-33$, $\varphi_{10.1}-40°$) are close to those calculated theoretically (97, −76, 53, −76, 97, −41, and −41°, respectively [7].

The five-membered ring trans-linked to the seven-membered ring has an envelope conformation in which the C2 atom departs by 0.61 Å from the C1, C3, C4, C5 plane. Such a form of the ring is fairly common, for example, in the related molecule of florilenalin, the derivation of the C1 atom is 0.71 Å [8].

The molecule of the guaianediol (2) has a intramolecular hydrogen bond with an average O1····O2 distance of 2.61 Å. In addition to this, in the crystal the molecules are bound into infinite chains along the *a* axis by O1····O2' hydrogen bonds (x − 1/2, 1/2 − y, z) with a length of 2.67 Å.

SUMMARY

The composition of the mono- and sesquiterpenoids of the oleoresin of the Korean and Japanese stone pines have been studied.

In the oleoresin of the Japanese stone pine among the sesquiterpenoids, compounds of the bisabolane series predominate.

The structure of 1β,4αH,7αH,10βH-guaiane-5α,14-diol, a sesquiterpenoid not previously described that is produced by the hydroboration-oxidation of an alcohol isolated from both oleoresins, has been determined.

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