Diterpenoids from the Aerial Parts of *Plectranthus ornatus*

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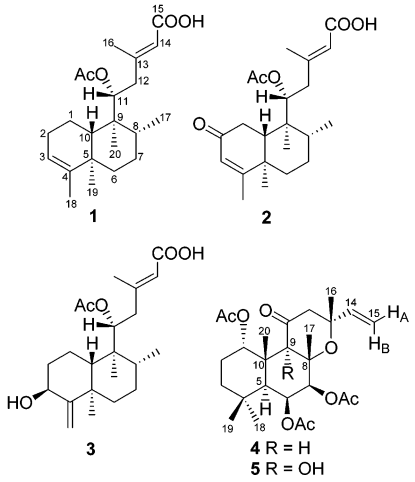
Phytochemical investigation of a hexane extract of the aerial parts of *Plectranthus ornatus* yielded three new neoclerodane diterpenoids (**1**−**3**), two labdane diterpenes (**4** and **5**) obtained for the first time as natural products, and several previously known substances. The structures and relative stereochemistry of **1**−**5** were established mainly on the basis of NMR spectroscopic studies and by comparison with related compounds.

In a continuation of our investigation of the chemistry of folk medicinal plants, we have examined the composition of *Plectranthus ornatus* Codd. (syn. *Coleus comosus* Hochst. ex Güerke), which belongs to the Lamiaceae family.[1,2] This plant, according to an ethnopharmacological survey, is often used for stomach and liver diseases as a substitute for *Plectranthus barbatus* and also has analgesic, anti-inflammatory, antipyretic, and diuretic activities.[3] From species of the Lamiaceae, nearly 100 diterpene carbon skeletons[4] have been elucidated, in agreement with its high evolutionary index.[5,6] From the genus *Plectranthus*, the majority of the diterpenes so far obtained possess the abietane skeleton, but in addition some phyllocladanes and *ent*-kauranes have been isolated.[7] The present phytochemical study of *P. ornatus* has led to the isolation of three new neoclerodane diterpenoids (**1**−**3**) and two labdane derivatives (**4** and **5**) obtained for the first time as natural products.[8,9]



1 **2** **3**

The hexane extract of aerial parts of *P. ornatus* was fractionated by column chromatography (silica gel), followed by treatment with active charcoal, and purified by either Sephadex LH-20 or silica gel-$AgNO_3$ (5%) column chromatography, to afford diterpenoids **1**−**5**, together with another labdane, 1α,6*β*-diacetoxy-8,13*R**-epoxy-14-labden-11-one (plectrornatin C), previously isolated from the same source,[10] a mixture of *β*-sitosterol and stigmasterol,[11] 3*β*-acetyl-α-amyrin,[12,13] and friedelin.[13] To identify the clerodane skeleton of diterpenoids **1**−**3**, REGRAS, a program developed for the specialist system SISTEMAT,[14] was used. This program permitted the analysis of ^{13}C NMR spectra by comparing data for a given compound to a database of molecules of a specific class. On the basis of data matches, the program showed a list of the most probable skeletons for the inputted data.[15]

The ^1H NMR spectrum of compound **1** ($C_{22}H_{34}O_4$) exhibited two olefinic protons (*δ* 5.19 and 5.67), an oxymethine (*δ* 5.44), an acetoxyl group (*δ* 2.02), two tertiary methyl groups (*δ* 0.77 and 1.05), a secondary methyl group (*δ* 0.98), and two olefinic methyl groups (*δ* 1.56 and 2.16). The ^1H and ^{13}C NMR spectra (Tables 1 and 2) of **1** were very similar to those reported for kolavenic acid.[16,17] However, the main differences observed in the chemical shifts are compatible with the presence of an acetoxyl substituent at the C-11 position. The presence of this group caused downfield shifts of the C-11 α-carbon and of the C-9 and C-12 *β*-carbons, and an upfield shift of the C-13 and C-20 *γ*-carbons, as a result of the steric compression of the *γ*-gauche interaction.[10,18] Unambiguous and complete assignments of the ^1H and ^{13}C NMR signals of **1** (Tables 1 and 2, Figure 1) were achieved with COSY, HMQC, HMBC, and NOESY experiments.

The relative stereochemistry of **1** was revealed by the NOESY spectrum shown in Figure 1. NOESY correlations of Me-19/H-1α/H-6α and H-10/H-1*β* suggested a *trans*-fused A/B ring. The *cis*-arrangement of Me-17 and Me-20 was suggested by the additional NOESY correlations observed between Me-20/Me-19 and Me-20/Me-17. The chemical shift of the methyl and vinyl protons allowed the assignment of the C-9 side chain of **1** as part of an *E*-olefin,[16−22] rather than a *Z*-olefin.[22−24] Thus, compound **1** was identified as 11-acetoxyneocleroda-3,13*E*-dien-15-oic acid.

Compound **2** was determined as $C_{22}H_{32}O_5$ on the basis of elemental analysis. Its ^1H and ^{13}C NMR spectra indicated the presence of six methyl groups, including an acetoxyl group (δ_H 2.01, δ_C 20.7 and 170.7), and an α,*β*-unsaturated ketone (δ_H 5.75, δ_C 199.2, 125.5 and 172.2). The ^{13}C NMR spectrum exhibited three carbonyl groups (*δ* 170.4, 170.7, and 199.2) and two trisubstituted olefins

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Table 1. ^{13}C NMR (100 MHz) Spectral Data for Compounds **1**–**5** in $CDCl_3$[a]

carbon	**1**		**2**		**3**		**4**		**5**	
1	19.5	(CH_2)	35.9	(CH_2)	21.4	(CH_2)	74.7	(CH)	74.0	(CH)
2	27.3	(CH_2)	199.2	(C)	37.6	(CH_2)	21.6	(CH_2)	23.2	(CH_2)
3	120.6	(CH)	125.5	(CH)	69.4	(CH)	36.7	(CH_2)	37.1	(CH_2)
4	144.6	(C)	172.2	(C)	161.6	(C)	33.7	(C)	33.9	(C)
5	38.8	(C)	40.1	(C)	40.5	(C)	47.2	(CH)	43.1	(CH)
6	36.9	(CH_2)	35.5	(CH_2)	37.4	(CH_2)	69.2	(CH)	69.4	(CH)
7	28.3	(CH_2)	27.6	(CH_2)	27.9	(CH_2)	78.5	(CH)	76.6	(CH)
8	36.2	(CH)	36.2	(CH)	36.5	(CH)	77.0	(C)	81.7	(C)
9	43.4	(C)	43.4	(C)	43.9	(C)	57.3	(CH)	81.5	(C)
10	47.5	(CH)	46.0	(CH)	49.2	(CH)	40.6	(C)	43.5	(C)
11	76.0	(CH)	74.4	(CH)	75.5	(CH)	205.0	(C)	205.2	(C)
12	42.2	(CH_2)	42.0	(CH_2)	42.0	(CH_2)	49.0	(CH_2)	48.8	(CH_2)
13	160.1	(C)	158.6	(C)	159.3	(C)	74.6	(C)	75.7	(C)
14	118.1	(CH)	118.3	(CH)	117.9	(CH)	146.3	(CH)	145.9	(CH)
15	171.7	(C)	170.4	(C)	170.6	(C)	112.8	(CH_2)	110.4	(CH_2)
16	19.1	(CH_3)	19.0	(CH_3)	19.0	(CH_3)	31.7	(CH_3)	31.1	(CH_3)
17	17.9	(CH_3)	17.6	(CH_3)	17.8	(CH_3)	23.9	(CH_3)	23.2	(CH_3)
18	18.3	(CH_3)	19.1	(CH_3)	99.9	(CH_2)	32.6	(CH_3)	32.7	(CH_3)
19	20.5	(CH_3)	18.7	(CH_3)	21.4	(CH_3)	22.8	(CH_3)	23.4	(CH_3)
20	12.1	(CH_3)	12.2	(CH_3)	11.9	(CH_3)	17.2	(CH_3)	19.7	(CH_3)
1α-OAc							169.3	(C)	168.4	(C)
							21.2	(CH_3)	20.8[b]	(CH_3)
6β-OAc							169.7	(C)	169.8	(C)
							20.8	(CH_3)	21.4	(CH_3)
7β-OAc							170.2	(C)	169.9	(C)
							21.2	(CH_3)	21.7[b]	(CH_3)
11-OAc	171.0	(C)	170.7	(C)	170.7	(C)				
	21.0	(CH_3)	20.7	(CH_3)	20.8	(CH_3)				

[a] Multiplicities were obtained from DEPT experiments. [b] Assignments may be interchanged.

Table 2. ^1H NMR (400 MHz) Spectral Data of Compounds **1**–**5** in $CDCl_3$[a]

position	**1**	**2**	**3**	**4**	**5**
1	β 1.87 m	β 2.60 dd (3.6, 17.5)	β 1.93 m	β 5.50 t (2.7)	β 5.56 m
	α 1.55 m	α 2.50 dd (13.5, 17.5)	α 1.71,m		
2	2.10 m		2.27,m	β 1.73 qd (3.6, 12.3)	β 2.06 m
	1.99 m		1.31 m	α 1.91 m	α 1.63 m
3	5.19 br s	5.75 br s	4.33 dd (5.6, 11.7)	β 1.14 td (3.3, 13.4)	β 1.57 m
				α 1.47 m	α 1.17 m
5				α 1.62 d (2.2)	α 2.43 d (2.9)
6	β 1.19 dd (3.6, 9.2)	β 1.38 ddd (4.1, 12.1, 13.0)	1.58 m	α 5.75 dd (2.4, 3.7)	α 5.81 dd (2.9, 4.6)
	α 1.73 m	α 1.33 m			
7	1.45 m	1.51 m	1.50 m	α 5.11 d (4.0)	α 5.55 d (4.6)
8	1.55 m	1.54 m	1.52 m		
9				α 3.33 s	α 4.74 s (OH)
10	1.40 m	1.98 dd (3.6, 13.5)	1.13 dd (1.8, 12.2)		
11	5.44 dd (1.3, 9.8)	5.29 dd (2.6, 9.9)	5.35 dd (1.7, 10.5)		
12	B 2.44 d (13.2)	B 2.37 dd (2.6, 13.2)	2.27 m	β 2.66 d (18.8)	β 3.15 d (16.5)
	A 2.28 m	A 2.30 dd (9.9, 13.2)		α 2.60 d (18.8)	α 2,44 d (16.5)
14	5.67 br s	5.66 br s	5.65 br s	5.95 dd (10.8, 17.4)	5.92 dd (10.7, 17.2)
15				B 5.28 dd (0.9, 17.4)	B 5.21 dd (1.0, 17.2)
				A 5.07 dd (0.9, 11.4)	A 4.94 dd (1.0, 10.7)
16	2.16 d (1.2)	2.14 d (1.3)	2.12 d(1.1)	1.23 s	1.35 s
17	0.98 d (6.4)	1.01 d (5.7)	0.99, d, (5.6)	1.52 s	1.64 s
18	1.56 s	1.90 d(1.1)	4.95 d (1.6)	0.99 s	1.05 s
			4,74 br s		
19	1.05 s	1.16 s	1.09s	0.96 s	0.97 *s*
20	0.77 s	0.87 s	0.77 s	1.45 s	1.53 s
1α-OAc				1.97 s	2.02 s
6β-OAc				2.09 s	2.10 s[b]
7β-OAc				2.08 s	2.03 s[b]
11-OAc	2.02 s	2.01 s	2.00 s		

[a] Chemical shift values are in ppm relative to TMS. [b] Assignments may be interchanged.

(δ 172.2, 158.6, 125.5, and 118.3). The spectroscopic data of diterpenoid **2** (Tables 1 and 2) were very similar to those reported for 11*R*-acetoxy-2-oxo-kolavenic methyl ester.[10] However, the fragment peak at *m/z* 205 (100%) in the mass spectrum was derived from the loss of the C-9 side chain of **2**. This was used to establish that this diterpene possesses a carboxylic acid group at C-15. The *trans*-fused A/B ring was shown in the NOESY spectrum. The *cis*-arrangement of Me-17, Me-20, and Me-19 was also suggested by the NOESY correlations between these groups. The *E* configuration of C-13 and the C-14 olefinic double bond was suggested by the signal of H-16 (δ 2.14, d, J = 1.3 Hz) coupled to a vinylic proton H-14 (δ 5.66), which showed a characteristic chemical shift and coupling constant.[21] Thus, compound **2** was identified as 11-acetoxy-2-oxo-neocleroda-3,13*E*-dien-15-oic acid.

Compound **3** ($C_{22}H_{34}O_5$) exhibited an oxymethine proton at C-3 (δ 4.33) and an exocyclic methylene proton at C-18 (δ 4.95 and 4.74). The NMR data of **3** (Tables 1 and 2) were similar to those of **1** and **2**, except for the protons around

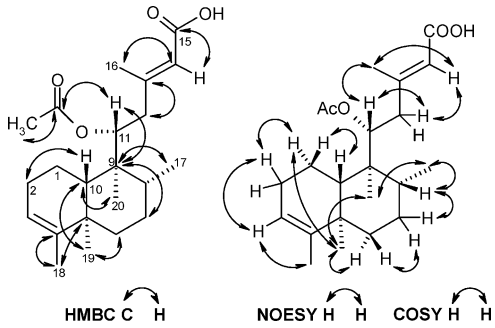

Figure 1. Main HMBC, COSY, and NOESY correlations of **1**.

ring A. The *trans*-fused nature of the A/B rings was indicated by NOE correlations between Me-19/Me-20 and Me-19/H-1α and H-10/H-1β. The configuration of the hydroxyl group at C-3 should be β-equatorial. The axial nature of proton H-3 was suggested because it appeared as a doublet of doublets with $J_{(H-3\alpha/H-2\beta ax)} = 11.7$ Hz and $J_{(H-3\alpha/H-2\alpha eq)} = 5.6$ Hz.[17,25] The three methyl groups (Me-17, Me-19, and Me-20) and H-3 were *cis* correlated. Therefore, the structure of **3** was deduced as 11-acetoxy-3β-hydroxyneocleroda-4(18),13*E*-dien-15-oic acid.

The stereochemistry of the C-11 stereogenic center of the neo-clerodane diterpenoids (**1**−**3**) was not ascertained. However, we propose that they have the *R** configuration, because the ^{1}H and ^{13}C NMR data corresponding to the C-9 side chain of the compounds were very similar to those reported for 11*R*-acetoxy-2-oxokolavenic acid methyl ester.[10]

Compound **4** ($C_{26}H_{38}O_8$) showed eight methyl groups in its ^{1}H and ^{13}C NMR spectra, including three acetoxyl groups, two protons adjacent to carbonyl (δ 2.66 and 2.60), three oxymethines (δ 5.50, 5.75, and 5.11), and a vinyl group linked to a fully substituted carbon (ABX system, δ_A 5.07, δ_B 5.28, and δ_X 5.95). Comparison of the data of **4** to those of other related 8,13-epoxy-14-labdene compounds[26−29] indicated that it is the 7-acetoxy derivative of plectrornatin C.[10] This was evidenced by the ^{1}H and ^{13}C NMR data (Tables 1 and 2), which showed a downfield shift of the H-7 proton of **4** (δ 5.11) with respect to the values reported in the literature (δ_α 1.91 and δ_β 2.27), and an additional acetoxyl group in **4** (δ_H 2.08, δ_C 170.2 and 21.2). NOESY data allowed the detailed stereochemical analysis of **4**. Several NOE correlations confirmed the relative configuration to be in the normal-labdane series, like forskolin and related substances.[10,26,27] The axial proton H-9α showed NOESY correlations with H-5α and H-7α, while H-6α exhibited a NOE with H-5α and Me-18. The NOE observed between H-1β/Me-20/Me-19 suggested the *cis*-arrangement of these groups. Additional correlations of H-12α/H-14 and H-15$_B$ and of H-12β with Me-16 and Me-17 established that these groups are on the same side of the molecular plane. The NOE observed between H-12β and Me-17 suggests the flagpole interaction (1→ 4), which is possible if the C ring is in the boat configuration.[29] On the basis of ^{1}H−^{1}H COSY and ^{1}H−^{13}C correlations, the ^{1}H and ^{13}C NMR signals were assigned unambiguously. Thus, compound **4** was identified as 1α,6β,7β-triacetoxy-8,13*R**-epoxy-14-labden-11-one.

The ^{1}H and ^{13}C NMR spectra of compound **5** ($C_{26}H_{38}O_9$) were very similar to those of **4**. In fact, the main difference between these compounds was the absence of signals for H-9, which indicated that compound **5** has a hydroxyl group at this position. This was supported by the presence of a signal of a nonprotonated hydroxylated carbon (δ 81.5) in the ^{13}C NMR spectrum. The stereochemistry of **5** was similarly established on the basis of the NOE correlations observed, suggesting that the hydroxyl group at C-9 has an α-axial orientation and that the C ring is in the boat conformation. Therefore, compound **5** was identified as 1α,6β,7β-triacetoxy-9-hydroxy-8,13*R**-epoxy-14-labden-11-one. Compounds **4** and **5** are previously known as semisynthetic products.[8,9]

Experimental Section

General Experimental Procedures. Melting points were obtained on a Mettler FP 80 HT instrument. Specific rotations were measured with a Perkin-Elmer 341 polarimeter. IR spectra were obtained with a Shimadzu/IR-408 spectrophotometer. ^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ solution on a Bruker DRX 400 Avance NMR spectrometer operating at 400 and 100 MHz, respectively. TMS was used as a internal standard for protons, and the solvent signal (δ $CDCl_3$ 77.0) as a internal standard for carbons. To determine the skeletal type, ^{13}C NMR data (chemical shift and multiplicity) were used as input for the REGRAS program with a 2717-diterpene database (program available from authors by e-mail: gilberto@coltec.ufmg.br). Mass spectra were registered in the positive EI mode on a VG Auto Spec mass spectrometer (70 eV) and by negative-ion mode ESI on a LCQ Advantage ion trap spectrometer. Elemental analyses were determined on a Carlo Erba EA 1108 apparatus. Silica gel 60 (70−230 mesh, Merck) and Sephadex LH-20 (Pharmacia Biotech AB, Uppsala, Sweden) were used for column chromatography, and silica gel 60 F_{254} plates (Merck) were used for TLC.

Plant Material. *Plectranthus ornatus* Codd. was cultivated on campus at Universidade do Vale do Rio Doce in Governador Valadares, MG, Brazil. The aerial parts of this species were collected in September 2002, and a voucher specimen was deposited in the Herbarium of the Department of Botany of Instituto de Ciências Biológicas, Universidade Federal de Minas Gerais, Brazil (ref. BHCB No. 57175). Botanists José R. Stehmann and Beatriz G. Brasileiro identified the plant.

Extraction and Isolation. Dried and powdered *P. ornatus* aerial parts (3.8 kg) were extracted with hexane at room temperature for 2 weeks. After filtration and evaporation of the solvent under reduced pressure and at low temperature (40 °C), a crude extract (38.0 g) was produced. Part of the hexane extract (30.0 g) was fractionated by column chromatography on silica gel (Merck) and eluted by solvents of increasing polarity. The three main fractions collected were treated with charcoal in MeOH. Repeated column chromatography (silica gel; hexane−EtOAc, as a gradient) of the fraction eluted with CH_2Cl_2 afforded **1** (1.0 g, 0.0263% on dry plant material). The fraction eluted with CH_2Cl_2−EtOAc (9:1) was rechromatographed (silica gel eluted with a gradient of hexane−EtOAc) and yielded the following compounds in order of increasing chromatographic polarity: a mixture of β-sitosterol and stigmasterol (365.0 mg, 0.00960%),[11] 3β-acetyl-α-amyrin (44.0 mg, 0.00115%),[12,13] and friedelin (30.0 mg, 0.000789%).[13] The fraction eluted with CH_2Cl_2−EtOAc (7:3) was subjected to column chromatography (silica gel; hexane−EtOAc, as a gradient) and purified by Sephadex LH-20 ($CHCl_3$−MeOH, 1:1), to afford compounds **2** (20.0 mg, 0.000526%) and **3** (29.0 mg, 0.000763%). The hexane−CH_2Cl_2 (1:1) fraction rechromatographed over silica gel using the same eluent system yielded 1α,6β-diacetoxy-8,13*R**-epoxy-14-labden-11-one (plectrornatin C, 69.3 mg, 0.00182%)[10] and a mixture of **4** and **5**. Final purification by column chromatography ($AgNO_3$−silica gel, 5:95; CH_2Cl_2 with an increase in EtOAc) yielded pure **4** (143.0 mg, 0.00376%) and **5** (20.0 mg, 0.000526%).

11*R-Acetoxyneocleroda-3,13*E*-dien-15-oic acid (11*R**-acetoxykolavenic acid) (1):** colorless crystalline solid ($CHCl_3$); mp 124.2−124.6 °C; $[\alpha]^{25}_D$ −73.3° (*c* 1.7, $CHCl_3$); IR (KBr) ν_{max} 3450 (OH), 1736, 1263 (OAc), 1684 (α,β-unsaturated COOH), 1644, 1434, 1302, 1210, 947 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz), see Table 2; ^{13}C NMR ($CDCl_3$, 100 MHz), see Table 1; negative-ion mode ESIMS *m/z* 361 [M − H] $^-$ (100), 347 (4), 333 (6),

325 (5), 307 (2), 276 (2), 249 (5), 191 (5), 141 (4), 113 (71); *anal.* C 72.90%, H 9.77%, calcd for $C_{22}H_{34}O_4$, C 72.93%, H 9.39%.

11*R-Acetoxy-2-oxo-neocleroda-3,13*E*-dien-15-oic acid (11*R**-acetoxy-2-oxokolavenic acid) (2):** colorless thick oil ($CHCl_3$); $[\alpha]_D^{25}$ −82.1° (*c* 1.6, $CHCl_3$); IR (KBr) ν_{max} 3300 (OH), 1720, 1225 (OAc), 1685 (α,β-unsaturated COOH), 1660 (α,β-unsaturated ketone), 2825, 1420, 1360, 1020, 970 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz), see Table 2; ^{13}C NMR ($CDCl_3$, 100 MHz), see Table 1; EIMS *m/z* 376 $[M]^+$ (1), 317 (13), 280 (1), 235 (24), 205 (100), 191 (45), 163 (14), 149 (20), 135 (60), 121 (73), 177 (18), 109 (79), 95 (57), 83 (32), 69 (36), 55 (51); *anal.* C 70.63%, H 8.65%, calcd for $C_{22}H_{32}O_5$, C 70.21%, H 8.51%.

11*R-Acetoxy-3β-hydroxyneocleroda-4(18),13*E*-dien-15-oic acid (3):** colorless thick oil ($CHCl_3$); $[\alpha]^{25}_D$ −83.3° (*c* 0.7, $CHCl_3$); IR (KBr) ν_{max} 3450 (OH), 1725, 1233 (OAc), 1692 (α,β-unsaturated COOH), 1642, 915 (vinyl group), 2851, 1425, 1150, 900 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz), see Table 2; ^{13}C NMR ($CDCl_3$, 100 MHz), see Table 1; EIMS *m/z* 318 (4), 300 (11), 285 (11), 207 (20), 189 (100), 177 (6), 175 (22), 163 (6), 161 (14), 111 (15), 95 (42), 83 (31), 71 (35), 60 (16); *anal.* C 70.11%, H 9.08%, calcd for $C_{22}H_{32}O_5$, C 69.84%, H 8.99%.

1α,6β,7β-Triacetoxy-8,13*R-epoxy-14-labden-11-one (4):** colorless crystalline solid ($CHCl_3$); mp 179.4−181.6 °C; $[\alpha]_D^{25}$ −47.0° (*c* 1.7, $CHCl_3$); IR (KBr)ν_{max} 1750, 1245 (OAc), 1714 (ketone), 3090, 1618, 948 (vinyl group), 2845, 1400, 1380, 1215, 905 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz), see Table 2; ^{13}C NMR ($CDCl_3$, 100 MHz), see Table 1; *anal*. C 64.80%, H 8.03%, calcd for $C_{26}H_{38}O_8$, C 65.13%, H 7.93%.

1α,6β,7β-Triacetoxy-9-hydroxy-8,13*R-epoxy-14-labden-11-one (5):** colorless amorphous solid ($CHCl_3$); mp 182.9−183.6 °C; $[\alpha]_D^{25}$ −77.7° (*c* 1.7, $CHCl_3$); IR (KBr) ν_{max} 3598 (OH), 1736, 1235 (OAc), 1710 (ketone), 3080, 1638, 950 (vinyl group), 2975, 1436, 1039, 999 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz), see Table 2; ^{13}C NMR ($CDCl_3$, 100 MHz), see Table 1; *anal*. C 63.09%, H 7.91%, calcd for $C_{26}H_{38}O_9$, C 63.15%, H 7.69%.

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