Five New Modified 6,7-Secolabdane Diterpenoids from *Cluytia richardiana*

Jaber S. Mossa,* Ilias Muhammad, Mohammed A. Al-Yahya, Humayun H. Mirza, Farouk S. El-Feraly, and Andrew T. McPhail*,†

Medicinal, Aromatic and Poisonous Plants Research Center (MAPPRC) and Department of Pharmacognosy, College of Pharmacy, King Saud University, P.O. Box 2457, Riyadh 11451, Saudi Arabia, and Department of Chemistry, Paul M. Gross Chemical Laboratory, Duke University, P.O. Box 90346, Durham, North Carolina 27708-0346

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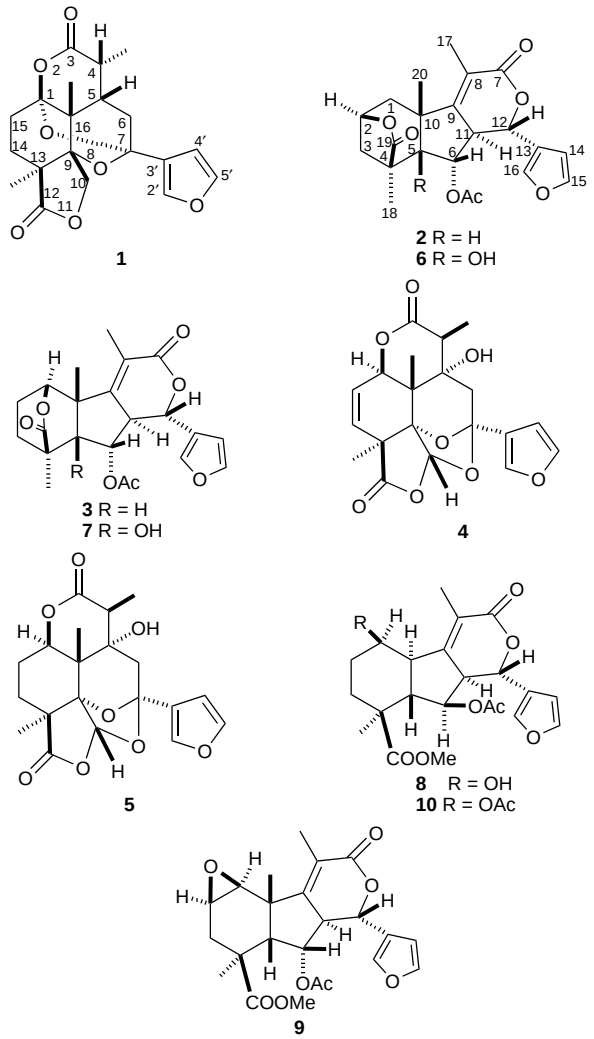
The aerial parts of *Cluytia richardiana* yielded five new modified 6,7-secolabdane diterpene derivatives, saudinolide (**4**), dihydrosaudinolide (**5**), 5β-hydroxyrichardianidin 1 (**6**), and 5β-hydroxyrichardianidin 2 (**7**), and the 6,7-seco-6,11-cyclo-20-norlabdane cluytene F (**8**). The structural assignments of the diterpenoids were based on their spectral data, including 2D NMR experiments, and chemical derivatization. X-ray crystallographic analyses provided unambiguous characterization of the structures and relative stereochemistries of **4**, **6**, **7**, and 1-*O*-acetylcluytene F (**10**).

In our previous reports,[1,2] we described the structures of five new modified labdane diterpenoids, namely, the 6(7),9(10)-biseco-6(11),1(9)-bicyclolabdanes, cluytenes A and C, and the 6,7-seco-6,11-cyclolabdanes, cluytenes B, D, and E, isolated from the aerial parts of *Cluytia richardiana* L. (Euphorbiaceae). Earlier investigations have reported on the isolation of other 6,7-secolabdanes, including saudin (**1**),[3] richardianidin 1 (**2**), and richardianidin 2 (**3**);[4] the structures of **1** and **2** were unambiguously established by X-ray crystallography. Furthermore, saudin (**1**) was found to possess a significant hypoglycemic effect in nonalloxanized rather than alloxanized fasted mice.[3,5] Examination of the same source[1,2] has now led to the isolation and characterization of five additional structurally related new diterpenoids, namely, the two saudin derivatives, saudinolide (**4**) and its dihydro derivative **5**, the 5β-hydroxyrichardianidin derivatives **6** and **7**, as well as the 6,7-seco-6,-11-cyclo-20-norlabdane, cluytene F (**8**) (Chart 1).

Chart 1



Results and Discussion

The EtOAc precipitate, obtained from the defatted EtOAc extract of *C. richardiana* (see the Experimental Section)[1,2] was flash chromatographed over Si gel to give, in crystalline form, the major diterpenoids **4** and **5** in 0.03% and 0.015% yields, respectively. Saudinolide (**4**), $C_{20}H_{20}O_8$, was found to have a γ-lactone (ν_{max} 1780 cm^{-1}; δ_C 174.7) and a δ-lactone (ν_{max} 1720 cm^{-1}; δ_c 172.7); a monosubstituted furan ring, as previously encountered in all diterpenoids isolated from this plant, was also present. The ^{1}H- and ^{13}C-NMR spectral data (Table 1) were generally similar to those of the earlier reported 6,7-secolabdane diterpene saudin (**1**),[3] except for signals indicating the presence of a hydroxyl group at C-5 (ν_{max} 3520 cm^{-1}; δ_C 72.5, s), a disubstituted double bond at C-14(15) ($\delta_{C\text{-}14}$ 126.2, $\delta_{C\text{-}15}$ 132.3), and an oxide bridge at C-7(10) ($\delta_{C\text{-}7}$ 108.4; $\delta_{C\text{-}10}$ 100.6). Since the ^{1}H- and ^{13}C NMR data of **1** were unambiguously assigned,[3] the placement of the tertiary hydroxyl group at C-5 was straightforward, as the ABC system due to the methylene group at C-6 in saudin (**1**) [δ 1.82, dd, J = 3.0 and 13.6 Hz (H6a); δ 2.44, dd, J = 10.8 and 13.6 Hz (H6b)] was replaced in **4** by an AB system as a dd

* Address correspondence to this author at King Saud University. Tel: (966) 1-467-7249. Fax: (966) 1-467-6383. E-mail: F30H002(%)-SAKSUOO. BITNET@VTBIT.CC.VT.EDU.

† Address correspondence to this author at Duke University. Tel.: (919) 660-1500. Fax: (919) 660-1605. E-mail: chem@chem.duke.edu.

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Table 1. ^{1}H- and ^{13}C-NMR Chemical Shift Values (in ppm) for Diterpenes **4** and **5**[a]

proton/ carbon	**4**		**5**	
	^{1}H	^{13}C	^{1}H	^{13}C
1	5.93[b]	73.0 d[c]	5.58 brt (8.6, 9.9)	71.6 d
3		172.7 s		172.9 s
4	2.9 dq (1.3, 8.0)[d]	47.7 d	2.86 dq (1.3, 8.1)	47.2 d
5		72.5 s		72.7 s
6	2.61 d (15.0)	42.3 t	2.59 d (15.1)	42.6 t
	2.54 d (15.0)		2.52 d (15.1)	
7		108.4 s		108.6 s
9		89.7 s		91.1 s
10	5.93 s[b]	100.6 d	6.11 s	100.1 d
12		174.7 s		176.1 s
13		44.3 s		40.7 s
14	5.91 d (3.9)	126.2 d	1.98 m	25.2 t
			1.84 m	
15	6.22 dd (3.9, 8.0)	132.3 d	2.44 m	20.5 t
			1.84 m	
16		48.8 s		46.2 s
2′	7.68 br d (1.0)	141.9 d	7.66 br d (1.0)	141.9 d
3′		124.3 s		124.5 s
4′	6.52 dd (1.0, 1.8)	108.7 d	6.50 dd (1.0, 1.9)	108.8 d
5′	7.48 t (1.8)	144.4 d	7.46 t (1.9)	144.4 d
C(4)-Me	1.41 d (8.0)	15.5 q	1.39 d (8.1)	15.4 q
C(13)-Me	1.19 s	19.6 q	1.29 s	17.4 q
C(16)-Me	1.46 s	16.5 q	1.45 s	15.7 q
OH	4.10 d (1.3)		4.0 d (1.3)	

[a] Spectra recorded for **4** and **5** at 300 MHz (^{1}H) and 75 MHz (^{13}C). [b] Signal superimposed on each other, *J* unresolved. [c] Multiplicities of the carbon signals were determined by APT and DEPT experiments, also aided by 2D NMR COSY and HETCOR experiments. [d] Values in the parentheses are coupling constants, in Hz.

centered at δ 2.58, J = 15 Hz. Furthermore, a COSY 2D NMR experiment suggested the presence of the system −CH═CHCH(O)− in **4**, and this was confirmed by a 2D NMR HETCOR experiment and other ^{13}C NMR data, which showed signals at δ_C 73.0 (d), 44.3 (s), 126.2 (d), 132.3 (d), and 48.8 (s) assigned to C-1, C-13−15, and C-16, respectively. Moreover, the NMR data of **4** did not show the oxygenated methylene of **1** at C-10. A higher degree of oxygenation at this center in **4** was indicated by the fact that the resonances for position 10 of **1** were replaced by a low-field methine signal (δ_H 5.93, s; δ_c 100.6). This last piece of information, together with the fact that the C-7 signal occurred at δ_C 108.4, indicating the same level of oxygenation as in **1**, suggested the gross structure of saudinolide (**4**). X-ray crystallographic analysis established the complete structure and relative stereochemistry of **4**. Non-hydrogen atom fractional coordinates are listed in Table 2. Bond lengths are in accord with expectations.[6] A view of the solid-state conformation is presented in Figure 1 [endocyclic torsion angles ωij (σ 0.3−0.5°) about the bonds

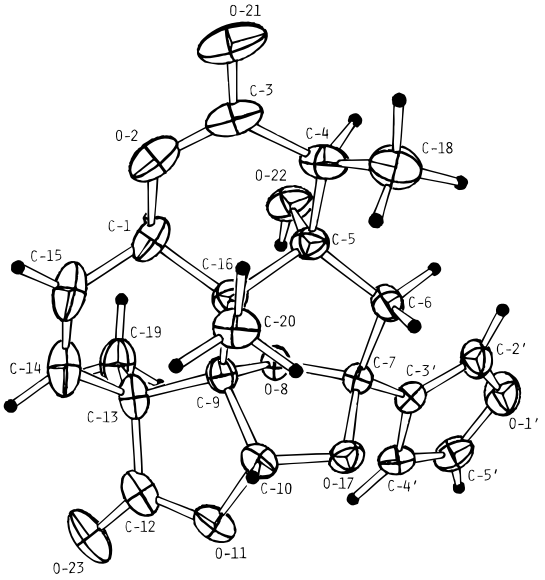

Figure 1. ORTEP diagram (40% probability ellipsoids) showing the crystallographic atom numbering scheme and solid-state conformation of saudinolide (**4**); small filled circles represent hydrogen atoms.

between atoms *i* and *j* follow: $\omega_{1,2}$ 34.7, $\omega_{2,3}$ −7.1, $\omega_{3,4}$ 8.6, $\omega_{4,5}$ −37.2, $\omega_{5,16}$ 64.7, $\omega_{16,1}$ −62.7° in δ-lactone ring A; $\omega_{5,6}$ 49.2, $\omega_{6,7}$ 10.3, $\omega_{7,8}$ −71.5, $\omega_{8,9}$ 73.3, $\omega_{9,16}$ −12.1, $\omega_{16,5}$ −48.2° in tetrahydropyran ring B; $\omega_{1,16}$ 57.5, $\omega_{16,9}$ −21.9, $\omega_{9,13}$ −24.4, $\omega_{13,14}$ 38.9, $\omega_{14,15}$ −2.1, $\omega_{15,1}$ −48.7° in cyclohexene ring C; $\omega_{7,8}$ 45.5, $\omega_{8,9}$ −47.5, $\omega_{9,10}$ 32.7, $\omega_{10,17}$ −5.7, $\omega_{17,7}$ −23.9° in 1,3-dioxalane ring D; $\omega_{9,10}$ 27.0, $\omega_{10,11}$ −27.1, $\omega_{11,12}$ 16.0, $\omega_{12,13}$ 1.8, $\omega_{13,9}$ −17.5° in γ-lactone ring E; $\omega_{1',2'}$ −0.6, $\omega_{2',3'}$ −0.2, $\omega_{3',4'}$ 0.3, $\omega_{4',5'}$ −0.7, $\omega_{5',1'}$ 0.8° in furan ring F]. Ring A approximates to an envelope (1,2-diplanar, half-boat) form with C-16 as the out-of-plane atom while ring B has a distorted boat (1,4-diplanar) form. Ring C is best described as being intermediate between 1,3- and 1,4-diplanar (boat) forms. Rings D and E both have envelope conformations with O-8 and C-10, respectively, as the out-of-plane atoms; ring F is essentially planar. The hydroxyl group at C-5 is intramolecularly hydrogen bonded to O−8[O-22···O-8 = 2.613(4) Å]. While structure **1** for saudin was assumed to depict its absolute stereochemistry, solely on a biogenetic basis,[3] noteworthy differences of stereochemistry at positions 4 and 7 of **1** and **4** are apparent despite their overall structural similarities.

Dihydrosaudinolide (**5**), $C_{20}H_{22}O_8$, possesses a γ- and δ- two-lactone system (ν_{max} 1780 cm^{-1}, 1725 cm^{-1}; δ_c 176.1, 172.9) and a furan ring, as found in **4**. Compari-

Table 2. Non-Hydrogen Atom Fractional Coordinates for Saudinolide (**4**), with Estimated Standard Deviations in Parentheses

atom	*x*	*y*	*z*	atom	*x*	*y*	*z*
C-1	0.2585(4)	0.3279(1)	−0.1153(5)	C-15	0.1429(4)	0.3599(2)	−0.1968(7)
O-2	0.2725(4)	0.2841(1)	−0.2270(4)	C-16	0.4018(4)	0.3546(1)	−0.1140(4)
C-3	0.3976(5)	0.2587(1)	−0.2281(6)	O-17	0.6093(3)	0.4380(1)	0.0112(3)
C-4	0.5370(5)	0.2767(1)	−0.1323(5)	C-18	0.6633(6)	0.2756(1)	−0.2759(7)
C-5	0.5137(4)	0.3220(1)	−0.0116(4)	C-19	0.1583(4)	0.4079(2)	0.2276(6)
C-6	0.6490(3)	0.3511(1)	0.0404(4)	C-20	0.4461(4)	0.3657(1)	−0.3252(4)
C-7	0.6038(3)	0.3979(1)	0.1441(4)	O-21	0.3952(5)	0.2210(1)	−0.3107(5)
O-8	0.4518(2)	0.3959(1)	0.1912(3)	O-22	0.4526(3)	0.3028(1)	0.1634(3)
C-9	0.3846(3)	0.4007(1)	0.0042(4)	O-23	0.1682(3)	0.5052(1)	0.0597(5)
C-10	0.4727(4)	0.4432(1)	−0.0700(4)	O-1′	0.8415(3)	0.4087(1)	0.5661(4)
O-11	0.3980(3)	0.4849(1)	0.0047(4)	C-2′	0.7930(4)	0.3852(1)	0.4057(5)
C-12	0.2568(4)	0.4749(1)	0.0314(5)	C-3′	0.6871(3)	0.4102(1)	0.3203(4)
C-13	0.2293(4)	0.4204(1)	0.0304(5)	C-4′	0.6669(4)	0.4525(1)	0.4329(5)
C-14	0.1313(4)	0.4038(2)	−0.1296(6)	C-5′	0.7631(4)	0.4498(1)	0.5775(5)

Table 3. ^{1}H-NMR Chemical Shift Values (in ppm) and Coupling Constants (in Hz, in Parentheses) for Diterpenes **6**−**8** and **10**[a]

proton	**6**	**7**	**8**	**10**
1	2.55 m	4.68 m	4.68 m	5.58 m
	2.19 m			
2	4.81 m	2.01 m	1.81 m	2.15 m
		1.67 m	1.70 m	1.60 m
3	2.49 td (2.8, 15.1)	1.96 m	2.26 m	1.98 dd (4.1, 13.6)
	1.92 dd (1.7, 15.1)	1.84 m	1.41 td (2.8, 4.0, 13.5)	1.45 dd (2.7, 13.6)
5			2.97 dd (10.1, 14.3)	2.93 dd (10.3, 14.0)
6	5.29 d (8.7)	5.0 d (8.3)	5.41 t (10.1, 10.2)	5.43 t (10.3, 10.3)
10			2.49 dd (1.7, 14.3)	2.58 br dd (1.3, 14.0)
11	3.18 qdd (2.5, 8.7, 11.8)	3.31 qdd (2.5, 8.3, 8.4)	3.29 qdd (2.0, 10.2, 12.8)	3.30 br qdd (2.0, 10.3, 12.5)
12	5.12 d (11.8)	4.99 d (8.3)	5.26 d (12.8)	5.27 d (12.5)
14	6.45 br d (1.3)	6.49	6.40 dd (1.0, 1.8)	6.39 dd (1.2, 1.8)
15	7.41 t (1.6)	7.45 m	7.37 t (1.8)	7.38 t (1.8)
16	7.49 br s	7.48 m	7.44 br s	7.45 br s
17	2.08 d (2.5)	2.06 d (2.5)	2.12 d (2.0)	1.86 d (2.0)
18	1.18 s	1.21 s	1.23 s	1.25 s
20	1.57 s	1.53 s		
OAc	1.75 s	1.72 s	1.53 s	2.12, 1.56 (2 × s)
OMe			3.59 s	3.60 s
OH	2.65 br s			

[a] Spectra for **6**−**8** and **10** recorded at 300 MHz.

Table 4. ^{13}C-NMR Spectral Data for Diterpenoids **6**−**8** and **10**[a]

	compound			
carbon	**6**	**7**	**8**	**10**
1	39.9 t[b]	79.3 d	64.8 d	68.2 d
2	75.0 d	24.9 t	29.1 t	25.1 t
3	41.6 t	23.4 t	29.6 t	30.3 t
4	47.0 s	47.6 s	44.2 s	43.7 s
5	84.2 s	83.5 s	46.6 d	48.0 d
6	80.5 d	82.2 d	72.1 d	68.6 d
7	165.9 s	165.1 s[c]	165.7 s	165.3 s
8	121.2 s[d]	121.4 s	119.8 s	120.1 s
9	159.2 s	155.0 s	152.4 s	151.0 s
10	50.9 s	53.4 s	45.5 d	43.5 s
11	49.1 s	47.7 d	42.7 d	42.5 d
12	74.4 d	75.2	69.1 d	71.9 d
13	121.6 s[d]	122.0 s[c]	122.8 s	122.7 s
14	108.7 d	109.0 d	109.3 d	109.2 d
15	143.7 d	144.0 d	143.5 d	143.6 d
16	142.3 d	141.3 d	141.5 d	141.5 d
17	12.9 q	13.8 q	11.9 q	11.9 q
18	16.2 q	15.5 q	13.4 q	13.4 q
19	179.2 s	173.7 s	176.4 s	176.3 s
20	25.0 q	18.4 q		
OAc	168.4 s	172.3 s	169.5 s	170.1, 169.3 (2 × s)
	25.0 q	20.0 q	19.9 q	21.3, 19.9 (2 × q)
OMe			51.9 q	52.0 q

[a] Spectra recorded for **6**−**8** and **10** at 75 MHz. [b] Multiplicities of the carbon signals of all compounds were determined by APT and DEPT experiments, also aided by 2D-NMR COSY and HETCOR experiments. [c,d] Interchangeable signals.

son of the ^{1}H- and ^{13}C-NMR spectral data of **4** and **5** (Table 1) suggested that **5** was likely to be the C-14-(15)-dihydro derivative of **4**, since a 2D NMR COSY experiment established the system $-CH_2CH_2CH(O)-$ in **5**. Chemical correlation with **4** confirmed the structure and relative stereochemistry of **5**. Thus, hydrogenation of **4**, using $Pd/CaCO_3$ as a catalyst, afforded the corresponding dihydro derivative **5** in 85% yield.

In addition, three minor diterpenoids **6**−**8** were isolated in crystalline form in 0.003%, 0.004%, and 0.007% yields, respectively. One of these, 5β-hydroxyrichardianidin 1 (**6**), $C_{22}H_{24}O_8$, was found to contain a γ-lactone (ν_{max} 1770 cm^{-1}; δ_c 179.2), an α,β-unsaturated δ-lactone (ν_{max} 1700 cm^{-1}; δ_c 165.9), and a furan ring. The ^{1}H- and ^{13}C-NMR spectra of **6** (Tables 3 and 4) were found to be generally similar to those reported for richardianidin 1 (**2**),[4] save for the differences associated with the presence of a tertiary hydroxyl group at C-5 (ν_{max} 3400 cm^{-1}; δ_C 84.2, s). Therefore, the presence of the C-2(4)-γ-lactone was inferred from the spectroscopic data ($\delta_{C\text{-}2}$ 75.0, $\delta_{C\text{-}19}$ 179.2; versus $\delta_{C\text{-}2}$ 75.2, $\delta_{C\text{-}19}$ 180.2 in **2**). The COSY 2D NMR spectrum suggested the presence of the systems $-CH(OAc)CHCH(O)-$ and $-CH_2CH(O)CH_2-$ in **6**, and this was confirmed by a 2D NMR HETCOR experiment (Tables 3 and 4). In addition, the ^{13}C-NMR spectrum revealed the deshielding of C-4, -6, and -10 to δ_C 47.0, 80.5, and 50.9, respectively (versus corresponding values of δ_C 41.8, 71.9, and 44.9 for **2**), due to the presence of the hydroxyl group at C-5. X-ray crystallographic analysis of **6** confirmed the overall structure and determined the relative stereochemistry at C-5. The asymmetric crystal unit consists of two independent molecules for which non-hydrogen atom fractional coordinates are listed in Table 5. Corresponding bond lengths in each of the molecules do not differ significantly and, in general, lie close to the expected values.[6] Bond strain is, however, reflected in several elongated bonds involving C-5 and C-10 [C-1−C-10 = 1.568(6), 1.567(7) Å; C-5−C-6 = 1.567(7), 1.567-(6) Å; C-5−C-10 = 1.588(7), 1.590(6) Å in the pair of molecules]. A view of the solid-state conformation of one molecule is illustrated in Figure 2. Corresponding torsion angles in the pair of crystallographically independent molecules are very similar (Δ_{max} = 5.0°; Δ_{mean} = 1.3°), and thus, their conformations do not differ significantly. Endocyclic torsion angles characterizing ring conformations are summarized in Table 6. The C-2(4)-bridged cyclohexane ring A has a chair conformation flattened around C-10, the cyclopentane ring B is in an envelope form with C-9 as the out-of-plane atom, the δ-lactone ring C approximates more closely to a 1,2-diplanar (half-boat, envelope) than to a 1,3-diplanar form, and the furan ring D is planar. Torsion angles (σ 0.4−0.5°) in the γ-lactone ring [values for the unprimed molecule, with corresponding values for the primed molecule in parentheses follow: $\omega_{2,3}$ −42.2 (−43.4), $\omega_{3,4}$ 39.2 (40.4), $\omega_{4,19}$ −24.2 (−25.1), $\omega_{19,24}$ −2.6 (−2.1), $\omega_{24,2}$ 28.9 (29.1)°] are related by an approximate mirror plane of symmetry passing through C-3 and the mid-point of the C-19−O-24 bond and, accordingly, this ring has an envelope conformation. Molecules of **6** are associated in the solid state by an O−H···O hydrogen bond. The hydroxyl hydrogen atom of each molecule is disordered

Table 5. Non-Hydrogen Atom Fractional Coordinates for the Two Molecules of 5β-Hydroxyrichardianidin 1 (**6**) in the Asymmetric Crystal Unit, with Estimated Standard Deviations in Parentheses

atom	*x*	*y*	*z*	atom	*x*	*y*	*z*
C-1	0.3427(3)	−0.1615(5)	0.6094(4)	C-1′	0.0141(3)	0.4016(5)	0.2799(4)
C-2	0.4177(3)	−0.1004(5)	0.6918(4)	C-2′	−0.0642(3)	0.3411(5)	0.2070(5)
C-3	0.4701(3)	−0.0375(5)	0.6156(4)	C-3′	−0.0475(3)	0.2743(5)	0.0964(4)
C-4	0.4152(3)	0.0735(5)	0.5741(4)	C-4′	−0.0009(3)	0.1631(5)	0.1603(4)
C-5	0.3362(3)	0.0354(4)	0.4767(4)	C-5′	0.0876(2)	0.2028(4)	0.2329(4)
C-6	0.3514(3)	−0.0080(4)	0.3497(4)	C-6′	0.1480(2)	0.2439(4)	0.1505(4)
C-7	0.1630(3)	−0.2659(5)	0.2416(4)	C-7′	0.2931(3)	0.5036(5)	0.3813(5)
C-8	0.1762(3)	−0.1994(5)	0.3613(4)	C-8′	0.2215(3)	0.4394(5)	0.4154(4)
C-9	0.2481(3)	−0.1386(4)	0.4005(4)	C-9′	0.1686(2)	0.3757(4)	0.3274(4)
C-10	0.2843(3)	−0.0709(4)	0.5206(4)	C-10′	0.0874(3)	0.3104(4)	0.3285(4)
C-11	0.3115(3)	−0.1336(4)	0.3227(4)	C-11′	0.1827(2)	0.3673(4)	0.1991(3)
C-12	0.2736(3)	−0.1491(4)	0.1857(4)	C-12′	0.2728(3)	0.3830(5)	0.1935(5)
C-13	0.3366(3)	−0.1774(5)	0.1129(4)	C-13′	0.2827(3)	0.4111(5)	0.0667(5)
C-14	0.3953(3)	−0.2750(6)	0.1342(5)	C-14′	0.2458(3)	0.5103(6)	−0.0083(4)
C-15	0.4415(4)	−0.2643(8)	0.0526(6)	C-15′	0.2673(4)	0.4986(7)	−0.1160(5)
C-16	0.3523(4)	−0.1149(8)	0.0191(5)	C-16′	0.3243(4)	0.3469(7)	−0.0037(6)
C-17	0.1059(3)	−0.2160(7)	0.4252(5)	C-17′	0.2172(4)	0.4603(7)	0.5474(5)
C-18	0.4591(3)	0.1859(5)	0.5343(5)	C-18′	−0.0001(3)	0.0487(5)	0.0824(5)
C-19	0.3859(3)	0.1019(6)	0.6917(5)	C-19′	−0.0532(3)	0.1387(6)	0.2551(5)
C-20	0.2183(3)	−0.0206(5)	0.5865(4)	C-20′	0.0820(3)	0.2602(5)	0.4563(4)
O-21	0.4171(3)	−0.1656(6)	−0.0209(4)	O-21′	0.3153(3)	0.3986(6)	−0.1151(4)
O-22	0.2156(2)	−0.2522(4)	0.1679(3)	O-22′	0.3096(2)	0.4858(4)	0.2708(3)
O-23	0.1072(2)	−0.3404(4)	0.2091(4)	O-23′	0.3364(2)	0.5752(4)	0.4477(4)
O-24	0.3901(2)	0.0000(−)[a]	0.7600(3)	O-24′	−0.0906(2)	0.2427(4)	0.2784(3)
O-25	0.3591(3)	0.1969(4)	0.7189(4)	O-25′	−0.0625(3)	0.0432(4)	0.3063(4)
O-26	0.2840(2)	0.1423(3)	0.4463(3)	O-26′	0.1237(2)	0.0943(3)	0.2967(3)
O-27	0.4368(2)	−0.0168(3)	0.3426(3)	O-27′	0.1132(2)	0.2543(3)	0.0208(3)
C-28	0.4653(3)	0.0569(5)	0.2642(5)	C-28′	0.1425(3)	0.1795(5)	−0.0559(4)
O-29	0.4236(3)	0.1405(5)	0.2092(4)	O-29′	0.1871(3)	0.0936(4)	−0.0219(4)
C-30	0.5502(3)	0.0218(7)	0.2547(6)	C-30′	0.1103(4)	0.2174(7)	−0.1864(5)

[a] The *y*-coordinate of O-24 was held constant throughout the least-squares parameter refinement to define the space group origin in this direction.

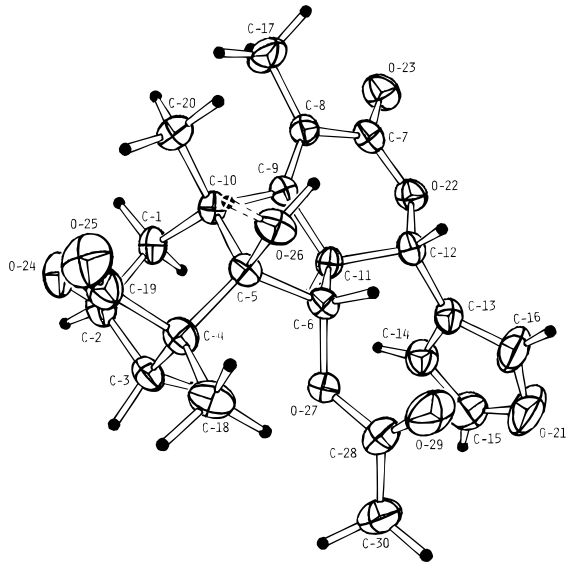

Figure 2. ORTEP diagram (40% probability ellipsoids) showing the crystallographic atom numbering scheme and solid-state conformation of the unprimed molecule of 5β-hydroxyrichardianidin (**6**); the hydroxyl hydrogen atom is disordered over two positions. Small filled circles represent hydrogen atoms.

over two orientations such that it is involved (1:1) in intramolecular [O(25)···O(26) = 3.069(5) Å, O(25′)···O(26′) = 3.147(6) Å] and intermolecular [O(26)···O(26′) = 2.836(4) Å] hydrogen bonds.

The ^{1}H- and ^{13}C-NMR spectral data (Tables 3 and 4) for the second minor diterpenoid, 5β-hydroxyrichardianidin 2 (**7**), $C_{22}H_{24}O_8$, were remarkably similar to those of **6** but lacked signals associated with the C-2(4)-γ-lactone ring. Instead, **7**, like **3**, was concluded to have a C-1(4)-δ-lactone group, as suggested by its ^{13}C-NMR spectral data ($\delta_{C\text{-}1}$ 79.3, $\delta_{C\text{-}19}$ 173.7 versus $\delta_{C\text{-}1}$ 78.07, $\delta_{C\text{-}19}$ 175.63 in **3**). A 2D NMR COSY experiment established the system $-CH_2CH_2CH(O)-$ in ring A of **7**, and this was confirmed by a 2D NMR HETCOR

Table 6. Endocyclic Torsion Angles[a] (ω_{ij}, deg) about the Bonds between Atoms *i* and *j* in **6**, **7**, and **10**; Estimated Standard Deviations are in Parentheses

	6			
	unprimed molecule	primed molecule	**7**	**10**
cyclohexane ring A				
$\omega_{1,2}$	−59.3(6)	−59.0(5)	57.5(3)	53.4(3)
$\omega_{2,3}$	75.4(5)	74.9(5)	4.9(3)	−57.9(3)
$\omega_{3,4}$	−72.4(4)	−71.7(4)	−61.9(2)	56.6(3)
$\omega_{4,5}$	54.8(5)	55.1(5)	56.4(2)	−56.0(2)
$\omega_{5,10}$	−32.7(5)	−34.0(5)	2.5(2)	56.1(2)
$\omega_{10,1}$	34.3(5)	35.1(5)	−61.1(2)	−52.2(2)
cyclopentane ring B				
$\omega_{5,6}$	−0.8(5)	1.6(4)	−25.6(2)	25.8(1)
$\omega_{6,11}$	21.7(5)	19.2(4)	28.8(2)	−0.8(1)
$\omega_{11,9}$	−35.8(5)	−34.3(4)	−20.8(2)	−25.4(2)
$\omega_{9,10}$	34.7(5)	34.1(4)	4.9(2)	41.0(2)
$\omega_{10,5}$	−19.9(5)	−21.2(4)	12.5(2)	−41.1(2)
α,β-unsaturated δ-lactone ring C[b]				
$\omega_{7,8}$	−8.8(7)	−8.0(8)	−19.1(3)	−8.5(3)
$\omega_{8,9}$	2.7(7)	1.4(7)	0.5(3)	−1.1(3)
$\omega_{9,11}$	25.8(6)	25.8(6)	37.6(3)	29.6(2)
$\omega_{11,12}$	−46.5(5)	−44.8(5)	−57.1(2)	−47.1(2)
$\omega_{12,22}$	43.4(6)	41.4(6)	43.0(3)	41.6(2)
$\omega_{22,7}$	−16.4(7)	−15.3(7)	−4.8(3)	−13.8(3)
furan ring D				
$\omega_{13,14}$	0.0(7)	0.1(7)	−0.3(4)	0.9(3)
$\omega_{14,15}$	0.2(8)	0.1(7)	0.5(4)	−0.2(3)
$\omega_{15,21}$	−0.3(8)	−0.3(8)	−0.6(4)	−0.5(3)
$\omega_{21,16}$	0.2(8)	0.4(8)	0.4(4)	1.1(3)
$\omega_{16,13}$	−0.1(7)	−0.3(7)	−0.0(4)	−1.3(3)

[a] The torsion angle A−B−C−D is defined as positive if, when viewed along the B−C bond, atom A must be rotated clockwise to eclipse atom D. [b] ΔC_S(1,2-diplanar) = $|\omega_{7,8}| + |\omega_{8,9}| + |\omega_{9,11} + \omega_{22,7}| + |\omega_{11,12} + \omega_{12,22}|$ = 24.0° and 23.3°, respectively, for the unprimed and primed molecules of **6**; = 30.9° for **10**; ΔC_2(1,3-diplanar) = $|\omega_{8,9}| + |\omega_{22,7}| + |\omega_{9,11} - \omega_{12,22}|$ = 36.7° and 32.3° for, respectively, the unprimed and primed molecules of **6**, = 26.9° for **10**.

Table 7. Non-Hydrogen Atom Fractional Coordinates for 5β-Hydroxyrichardianidin 2 (**7**) with Estimated Standard Deviations in Parentheses

atom	*x*	*y*	*z*	atom	*x*	*y*	*z*
C-1	0.3290(3)	0.44916(7)	−0.2387(3)	C-16	0.6738(4)	0.29015(7)	0.2196(5)
C-2	0.2272(3)	0.41712(9)	−0.3224(3)	C-17	0.7226(3)	0.43496(7)	−0.4106(4)
C-3	0.1289(3)	0.39779(7)	−0.1654(3)	C-18	0.0316(3)	0.40513(9)	0.1713(4)
C-4	0.1539(2)	0.41929(6)	0.0220(3)	C-19	0.1143(3)	0.46110(6)	−0.0242(3)
C-5	0.3380(2)	0.41833(5)	0.0836(3)	C-20	0.5564(3)	0.46932(7)	−0.0132(5)
C-6	0.4157(2)	0.37824(5)	0.1203(3)	O-21	0.6107(3)	0.25469(5)	0.2594(4)
C-7	0.7429(3)	0.36435(7)	−0.3370(4)	O-22	0.7291(2)	0.33457(4)	−0.2147(3)
C-8	0.6678(3)	0.40207(6)	−0.2890(3)	O-23	0.8197(2)	0.35892(5)	−0.4820(3)
C-9	0.5498(2)	0.40248(5)	−0.1555(3)	O-24	0.2152(2)	0.47706(5)	−0.1547(3)
C-10	0.4475(3)	0.43591(5)	−0.0812(3)	O-25	0.0041(2)	0.47993(5)	0.0392(3)
C-11	0.5002(2)	0.36562(5)	−0.0605(3)	O-26	0.3543(2)	0.43832(4)	0.2580(2)
C-12	0.6520(3)	0.34090(6)	−0.0312(3)	O-27	0.3000(2)	0.34963(4)	0.1772(2)
C-13	0.6182(3)	0.30255(6)	0.0523(4)	C-28	0.3129(3)	0.33423(6)	0.3536(3)
C-14	0.5127(4)	0.27297(7)	−0.0192(5)	O-29	0.4135(3)	0.34384(6)	0.4657(3)
C-15	0.5140(5)	0.24512(8)	0.1103(7)	C-30	0.1807(5)	0.30480(9)	0.3829(6)

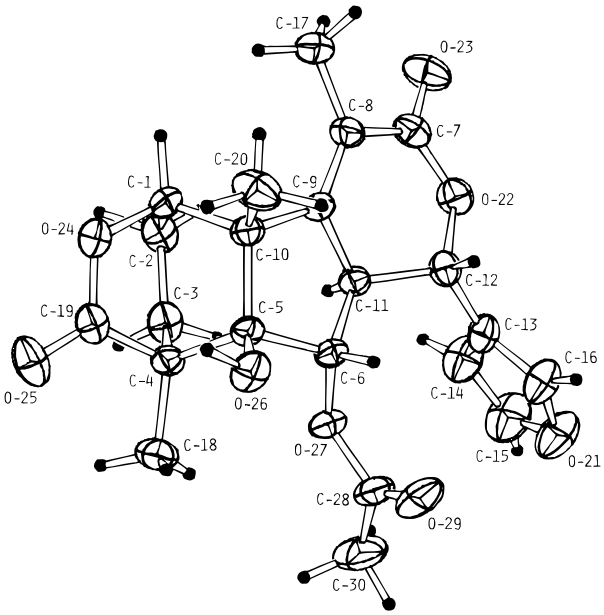

Figure 3. ORTEP diagram (40% probability ellipsoids) showing the crystallographic atom numbering scheme and solid-state conformation of 5β-hydroxyrichardianidin 2 (**7**); small filled circles represent hydrogen atoms.

experiment and other ^{13}C NMR data, which revealed signals at δ_C 79.3, 24.9, 23.4, 47.6, and 53.4 assigned to C-1-4 and C-10, respectively. On the basis of the foregoing data, this minor diterpenoid was formulated as **7**. The relative stereochemistry at C-5 was confirmed by X-ray crystallography. Carbon and oxygen atom fractional coordinates are listed in Table 7. Bond lengths, other than the elongated C-5−C-10 bond at 1.590(3) Å, are not unusual.[6] A view of the solid-state conformation is presented in Figure 3, while endocyclic torsion angles characterizing the shapes of rings A−D are provided in Table 6. The C-1(4)-bridged cyclohexane ring A has a boat conformation, while the cyclopentane ring B is intermediate between an envelope form with C-6 as the out-of-plane atom and a half-chair form with its C_2-symmetry axis passing through C-10 and the midpoint of the C-6−C-11 bond. The δ-lactone ring C has a 1,3-diplanar form; the furan ring D is planar. In the solid state, an O−H···O hydrogen bond [O-26···O-24 = 3.060(2) Å] associates molecules of **7** related by the 2_1 screw axis along the *c*-direction.

The third minor diterpenoid cluytene F (**8**), $C_{22}H_{26}O_8$, was found to have an acetate group (δ_C 169.5, 19.9), a methyl ester function (δ_C 176.4, 51.9), an α,β-unsaturated δ-lactone group (δ_C 165.7), and a furan ring. Comparison of the spectral data of **8** (Tables 3 and 4) with those of cluytene D (**9**)[2] led to the conclusion that **8** contained the 6,7-seco-6,11-cyclo-20-norlabdane skeletal backbone with the additional presence of a secondary hydroxyl group (δ_C 64.8; C-1) and a methine proton (δ_C 45.5; C-10) instead of the C-1(2)-epoxide and the Me-20 group, respectively, in **9**. On acetylation, **8** afforded the corresponding acetate **10** (δ_C 170.1, 21.3), with the ^{1}H NMR spectrum showing the anticipated deshielding of H-1 to a multiplet at δ 5.58 (versus $\delta_{H\text{-}1}$ 4.68 in **8**), thus confirming the presence of a hydroxyl group at C-1 in **8**. A 2D NMR COSY experiment showed that the signal at δ 4.68 (H-1) was coupled to two C-2 protons at δ 1.81 and 1.70 and the methine proton at δ 2.49 (H-10), with the latter showing additional coupling with H-5 (δ 2.97), suggesting the presence of the system $-CH_2CH(OH)CHCH-$ in **8**. Furthermore, the placement of the OAc group at C-6 (δ 5.41, t, J = 10.1 and 10.2 Hz, H-6) was also corroborated from the 2D NMR COSY experiment, which established the system $-CHCH(OAc)CHCH(O)-$ in **8**, as well as in its monoacetate **10**. Both systems were further confirmed by the 2D NMR HETCOR experiments on **8** and **10** and by ^{13}C NMR data of earlier compounds,[1,2] which helped formulate structure **8** for cluytene F. X-ray crystallographic analysis of **10** unambiguously established the structure and relative stereochemistry of compound **8**, which did not crystallize in a suitable form. Fractional coordinates for the carbon and oxygen atoms are listed in Table 8. A view of the solid-state conformation is illustrated in Figure 4. Bond lengths are in good agreement with expected values.[6] Endocyclic torsion angles (Table 6) indicate that the cyclohexane ring A has a chair conformation, the cyclopentane ring B is in an envelope form with C-10 as the out-of-plane atom, the δ-lactone ring C is intermediate between 1,2- and 1,3-diplanar forms, and the furan ring D is planar.

It is noteworthy that the stereochemistry of the acetate-bearing carbon of **8**, namely, C-6, is inverted as compared to that of **6**, **7**, and other related cluytenes previously isolated from the same source. Furthermore, the ^{1}H-NMR chemical shift values and multiplicities of H-6 in **8** and other related cluytenes are only marginally different.[2,4] Therefore, without X-ray crystallographic analysis, a prejudicial assignment of the stereochemis-

Table 8. Non-Hydrogen Atom Fractional Coordinates for 1-*O*-Acetylcluytene F (**10**) with Estimated Standard Deviations in Parentheses

atom	*x*	*y*	*z*	atom	*x*	*y*	*z*
C-1	0.3068(1)	0.2484(2)	0.5086(2)	C-18	0.3921(2)	0.1668(2)	0.1999(3)
C-2	0.3814(2)	0.2933(2)	0.4272(2)	C-19	0.2663(2)	0.2563(2)	0.1031(2)
C-3	0.3452(2)	0.3143(2)	0.2968(2)	O-21	−0.0641(1)	−0.1278(1)	0.1843(2)
C-4	0.3104(2)	0.2312(1)	0.2278(2)	O-22	0.0234(1)	0.0070(1)	0.5228(1)
C-5	0.2323(1)	0.1881(1)	0.3101(2)	O-23	0.0243(1)	0.0367(1)	0.7209(1)
C-6	0.1854(1)	0.1014(1)	0.2666(2)	O-24	0.2237(2)	0.3342(1)	0.1038(2)
C-7	0.0598(2)	0.0512(1)	0.6208(2)	O-25	0.2654(2)	0.2096(1)	0.0133(2)
C-8	0.1412(2)	0.1124(1)	0.6036(2)	C-26	0.1775(3)	0.3619(2)	−0.0103(3)
C-9	0.1848(1)	0.1138(1)	0.4933(2)	O-27	0.1058(1)	0.1259(1)	0.1894(1)
C-10	0.2674(1)	0.1667(1)	0.4431(2)	C-28	0.0931(2)	0.0814(2)	0.0809(2)
C-11	0.1536(1)	0.0536(1)	0.3886(2)	O-29	0.1412(2)	0.0208(1)	0.0483(2)
C-12	0.0481(2)	0.0326(1)	0.3959(2)	C-30	0.0106(2)	0.1198(2)	0.0121(2)
C-13	0.0177(2)	−0.0442(1)	0.3173(2)	O-31	0.2280(1)	0.3097(1)	0.5281(1)
C-14	0.0598(2)	−0.1308(2)	0.3139(3)	C-32	0.2381(2)	0.3694(2)	0.6197(2)
C-15	0.0084(2)	−0.1783(2)	0.2327(3)	O-33	0.3079(2)	0.3731(1)	0.6859(2)
C-16	−0.0567(2)	−0.0462(2)	0.2395(3)	C-34	0.1538(3)	0.4288(2)	0.6291(3)
C-17	0.1678(2)	0.1623(2)	0.7194(2)				

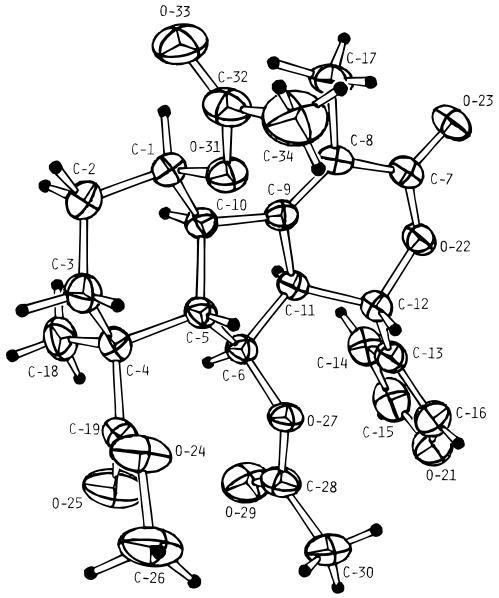

Figure 4. ORTEP diagram (40% probability ellipsoids) showing the crystallographic atom numbering scheme and solid-state conformation of 1-*O*-acetylcluytene F (**10**); small filled circles represent hydrogen atoms.

try at C-6 on the basis of biogenetic grounds would have led to the wrong conclusion.

Experimental Section

General Experimental Procedures. Melting points were recorded on an Electrothermal 9100 instrument. UV spectra were obtained in MeOH, using a Varian DMS 90 spectrophotometer, and IR spectra were taken as KBr disks on a Perkin-Elmer 5808 spectrophotometer. The NMR spectra were taken on a Varian VXR 300 instrument at 300 MHz (^{1}H) and 75 MHz (^{13}C) in $CDCl_3$, using tetramethylsilane (TMS) as internal standard. Spectral editing (APT and DEPTGL) and 2D NMR spectra (COSY and HETCOR) were obtained using standard Varian software. CIMS were recorded on a Finnigan MAT 300 mass spectrometer, using CH_4 as ionizing gas. Optical rotations were recorded in $CHCl_3$, unless otherwise stated, at ambient temperature using a Perkin-Elmer 241 MC polarimeter. TLC was performed on Si gel 60 F 254, using $CHCl_3$−Me_2CO (9:1) as solvent, with visualization using 1% vanillin/H_2SO_4 spray reagent.

Plant Material. The aerial parts of *C. richardiana*[7] were collected in Abha, Saudi Arabia, in June 1991. A voucher specimen (no. 10362) is deposited at the herbarium of MAPPRC, College of Pharmacy, King Saud University, Riyadh, Saudi Arabia.

Extraction and Isolation of Diterpenoids. The initial isolation procedure for the diterpenoids obtained from cold defatted EtOAc extract of *C. richardiana* was as previously described.[1,2] Elution with petroleum ether (60−80 °C)−EtOAc (8.5:1.5) from a Si gel column yielded saudinolide (**4**) as granules [1.05 g; R_f 0.59, solvent $CHCl_3$−Me_2CO (9:1)], followed by dihydrosaudinolide (**5**) as plates (509 mg; R_f 0.50). Further elution with petroleum ether−EtOAc (4:2) gave 5β-hydroxyrichardianidin 2 (**7**) as plates (130 mg; R_f 0.31), followed by 5β-hydroxyrichardianidin 1 (**6**) as needles (91 mg; R_f 0.30) and cluytene F (**8**) as colorless granules (235 mg; R_f 0.29).

Saudinolide (4): colorless granules from petroleum ether/EtOAc and (off-white) needles from hot EtOAc: mp 231−35 °C; $[\alpha]_D$ +98° (*c* 0.142, $CHCl_3$); UV (MeOH) λ_{max} (log ϵ) 220 (4.30), 265 (3.90) nm; IR (KBr) ν_{max} 3520 (OH), 1780 (γ-lactone), 1720 (δ-lactone), 1510, 1450, 1380 (br), 1200, 1190, 1050, 970, 860, 830, 735 cm^{-1}; ^{1}H and ^{13}C NMR, see Table 1; CIMS *m*/*z* $[M + 29]^+$ 417 (20), $[MH]^+$ 389 $[C_{20}H_{20}O_8 + H]^+$ (100), 371 ($[MH]^+ - H_2O$) (25), 343 (5), 215 (5), 154 (10).

Dihydrosaudinolide (5): plates from petroleum ether/EtOAc; mp 262−64 °C; $[\alpha]_D$ +73° (*c* 0.118, $CHCl_3$); UV (MeOH) λ_{max} (log ϵ) 218 (4.32), 258 (3.00) nm; IR (KBr) ν_{max} 3515 (OH), 1780 (γ-lactone), 1725 (δ-lactone), 1510, 1470, 1390 (br), 1200, 1190, 1050, 970, 860, 735 cm^{-1}; ^{1}H and ^{13}C NMR, see Table 1; CIMS *m*/*z* $[M + 29]^+$ 419 (5), $[MH]^+$ 391 ($[C_{20}H_{22}O_8 + H]^+$, 100), 373 ($[MH]^+ - H_2O$, 20), 301 (5).

5β-Hydroxyrichardianidin 1 (6): colorless needles from petroleum ether/EtOAc: mp 246−47 °C; $[\alpha]_D$ +42° (*c* 0.05, $CHCl_3$); UV (MeOH) λ_{max} (log ϵ) 220 (4.15), 275 (3.90) nm; IR (KBr) ν_{max} 3400 (OH), 1770 (γ-lactone), 1745 (OAc), 1700 (α,β-unsaturated δ-lactone), 1505, 1465, 1370, 1220, 1075, 1015, 820, 710 cm^{-1}; ^{1}H and ^{13}C NMR, see Tables 3 and 4, respectively; CIMS *m*/*z* $[M + 29]^+$ 445 (5), $[MH]^+$ 417 $[(C_{22}H_{24}O_8 + H)^+]$ (5), 399 $[(MH)^+ - H_2O]$ (10), 385 (20), 357 $[(MH)^+ - 60]$ (100), 339 (*m*/*z* 357 − H_2O) (58), 302 (5).

5β-Hydroxyrichardianidin 2 (7): colorless plates

from petroleum ether/EtOAc; mp 298−300 °C; $[\alpha]_D$ +17° (*c* 0.067, $CHCl_3$); UV (MeOH) λ_{max} (log ϵ) 220 (4.18), 273 (3.92) nm; IR (KBr) ν_{max} 3520 (OH), 1750 (δ-lactone), 1740 (OAc), 1705 (α,β-unsaturated δ-lactone), 1500, 1465, 1370, 1220, 1065, 1010, 815, 710 cm^{-1}; ^1H and ^{13}C NMR, see Tables 3 and 4, respectively; CIMS *m/z* $[M + 29]^+$ 445 (10), $[MH]^+$ 417 $[(C_{22}H_{24}O_8 + H)^+]$ (55), 399 $[(MH)^+ - H_2O]$(5), 385 (15), 357 $[(MH)^+ - 60]$ (100), 339 (*m/z* 357 − H_2O) (5), 311 (5).

Cluytene F (8): colorless granules from petroleum ether/EtOAc; mp 216−18 °C; $[\alpha]_D$ −58° (*c* 0.16, EtOH); UV (MeOH) λ_{max} (log ϵ) 218 (4.24), 268 (3.98) nm; IR (KBr) ν_{max} 3440 (OH), 1740 and 1730 (COOMe and OAc), 1690 (α,β-unsaturated-δ-lactone), 1500, 1320, 1230 (br), 1140, 1120, 1020, 860, 750 cm^{-1}; ^1H and ^{13}C NMR, see Tables 3 and 4, respectively; CIMS *m/z* $[M + 29]^+$ 447 (5), $[MH]^+$ 419 ($[C_{22}H_{26}O_8 + H]^+$, 45), 399 (5), 387 (20), 359 ($[MH]^+ - 60$, 100), 341 (*m/z* 359 − H_2O,-25), 262 (5), 245 (5).

Hydrogenation of Saudinolide (4) to 5. Compound **4** (100 mg) in MeOH (10 mL) was stirred for 3 h under H_2 at 0.5 psi, using $Pd/CaCO_3$ as catalyst. The resulting mixture was filtered through Celite and dried *in vacuo* to leave a residue (85 mg), from which the major product (**5**) was obtained by crystallization (petroleum ether/EtOAc) as colorless plates (65 mg): mp 263−65 °C; $[\alpha]_D$ +66° (*c* 0.118, $CHCl_3$). The physical (mp, $[\alpha]_D$, and mmp) and spectroscopic (NMR, IR, CIMS) data were indistinguishable from those of the natural product **5**.

Acetylation of Cluytene F (8). Compound **8** (100 mg) was dissolved in pyridine and treated with Ac_2O at room temperature for 12 h. Regular workup gave a single product, **10** (95 mg), which was purified by recrystallization (petroleum ether/EtOAc) to give colorless needles (80 mg): mp 235−37 °C; $[\alpha]_D$ + 30° (*c* 0.13, $CHCl_3$); IR (KBr) ν_{max} 1750, 1720 (br, COOMe, OAc), 1700 (α,β-unsaturated δ-lactone), 1500, 1430, 1370, 1240, 1220, 1190, 1115, 1070, 1010, 870, 810, 770, 735 cm^{-1}; ^1H and ^{13}C NMR, see Tables 3 and 4, respectively; CIMS *m/z* $[MH]^+$ 461 (22), 401 $[(MH)^+ - 60]$ (100), 341-(45).

X-ray Crystal Structure Analysis of Saudinolide 1 (4), 5β-hydroxyrichardianidin 1 (6), 5β-hydroxyrichardianidin 2 (7), and 1-*O*-acetylcluytene F (10). Crystal data for **4**: $C_{20}H_{20}O_8$; MW 388.38, orthorhombic, space group $P2_12_12_1(D_2^4)$ No. 19 from the Laue symmetry and systematic absences $h00$ when $h \neq 2n$, $0k0$ when $k \neq 2n$, 00l when l ≠ 2*n*, *a* = 9.205(2) Å, *b* = 27.985(4) Å, *c* = 6.919(1) Å, *V* = 1782.3(9) $Å^3$, *Z* = 4, D_c = 1.447 g cm^{-3}, μ(Cu Kα radiation, λ = 1.5418 Å) = 9.1 cm^{-1}; crystal dimensions: 0.04 × 0.14 × 0.60 mm.

Crystal data for **6**: $C_{22}H_{24}O_8$; MW 416.43, monoclinic, space group $P2_1(C_2^2)$ No. 4 from the Laue symmetry, systematic absences $0k0$ when $k \neq 2n$, and **6** is chiral, *a* = 16.492(3) Å, *b* = 10.962(2) Å, *c* = 11.150(2) Å, β = 103.16(2)°, *V* = 1963(1) $Å^3$, *Z* = 4, D_c = 1.409 g cm^{-3}, μ(Cu Kα radiation) = 8.6 cm^{-1}; crystal dimensions: 0.04 × 0.14 × 0.60 mm.

Crystal data for **7**: $C_{20}H_{24}O_8$; MW 416.43, orthorhombic, space group $P2_12_12_1(D_2^4)$ No. 19 as for **4** above, *a* = 8.126(1) Å, *b* = 34.780(5) Å, *c* = 7.084(1) Å, *V* = 2002.1-(8) $Å^3$, *Z* = 4, D_c = 1.381 g cm^{-3}, μ(Cu Kα radiation) = 8.4 cm^{-1}; crystal dimensions: 0.14 × 0.18 × 0.60 mm.

Crystal data for **10**: $C_{24}H_{28}O_9$; MW 460.49, orthorhombic, space group $P2_12_12_1(D_2^4)$ No. 19 as for **4** above, *a* = 14.066(2) Å, *b* = 15.009(2) Å, *c* = 10.777(1) Å, *V* = 2275.2(8) $Å^3$, *Z* = 4, D_c = 1.344 g cm^{-3}, μ(Cu Kα radiation) = 8.2 cm^{-1}; crystal dimensions: 0.08 × 0.36 × 0.50 mm.

Preliminary unit-cell dimensions and space group information were derived in each case from oscillation and Weissenberg photographs. Intensity data (4246 nonequivalent ± *h*, +*k*, +*l* reflections for **6**; 2140, 2398, and 2648 +*h*, +*k*, +*l* reflections for **4**, **7**, and **10**, respectively) were recorded on an Enraf-Nonius CAD-4 diffractometer [Cu Kα radiation, graphite monochromator; $\omega - 2\theta$ scans, θ_{max} = 75°; scanwidths (0.90 + 0.14 tan θ)° for **4** (0.80 + 0.14 tan θ)° for **6**, **7**, and **10**]. The intensities of four reference reflections from each crystal, monitored every 2 h during data collection, showed no significant variation (<1% overall). Refined unit-cell parameters were computed from the diffractometer setting angles for 25 reflections (36° < θ < 40°) widely separated in reciprocal space. The usual Lorentz and polarization corrections were applied to the intensity data. Empirical absorption corrections, based on the ϕ-dependency of the intensities of several reflections with χ ca. 90°, were also made to the data for **4**, **6**, and **10**. Those 1702, 3183, 2172, and 2266 reflections for **4**, **6**, **7**, and **10**, respectively, with $I > 3.0\sigma(I)$ were retained for the structure analyses.

The crystal structures were solved by direct methods (MULTAN11/82). Initial coordinates for all non-hydrogen atoms of **4**, **7**, and **10** were obtained from *E*-maps. For **6**, the asymmetric unit consists of two crystallographically independent molecules for which approximate coordinates were obtained in part from an *E*-map and from a series of weighted F_o Fourier syntheses phased successively by an increasing number of atoms. Non-hydrogen atom positional and thermal parameters (at first isotropic and then anisotropic) were adjusted by means of several rounds of full-matrix least-squares calculations. In the later iterations, hydrogen atoms in **4** and **6** were incorporated at their calculated positions, whereas for **7** and **10** hydrogen atom positional and isotropic thermal parameters were included as variables; an extinction correction *g* was also refined during the final cycles for **7** and **10**. The parameter refinements converged (max. shift: esd = 0.03) at *R* = 0.047 (R_w = 0.064, GOF = 1.53) for **4**, *R* = 0.053 (R_w = 0.072, GOF = 1.58) for **6**, *R* = 0.043 [R_w = 0.058, GOF = 1.57, $g = 2.7(3) \times 10^{-6}$] for **7**, and *R* = 0.034 (R_w = 0.047, GOF = 1.30, $g = 1.3(2) \times 10^{-6}$] for **10**, where $R = \sum||F_o| - |F_c||/\sum|F_o|$; $R_w = [\sum w(|F_o| - |F_c|)^2/\sum|F_o|^2]^{1/2}$, GOF = $[\sum w(|F_o| - |F_c|)^2/(N_{observns} - N_{param})]^{1/2}$. Final difference Fourier syntheses contained no unusual features. Atomic parameters, bond lengths, bond angles, and torsion angles for **4**, **6**, **7**, and **10** have been deposited at the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, U.K.

Crystallographic calculations were performed on PDP11/44 and Micro VAX computers by use of the Enraf-Nonius Structure Determination Package (SDP). For all structure-factor calculations, neutral atom scattering factors and their anomalous dispersion corrections were taken from the literature.[8] In the least-squares iterations, $\sum w\delta^2$ [$w = 1/\sigma^2(|F_o|)$, $\Delta = (|F_o| - |F_c|)$] was minimized.

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