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SESQUITERPENE ARYL ESTERS FROM *FERULAGO ANTIOCHIA*

MAHMUT MISKI, HANI A. MOUBASHER* and TOM J. MABRY*

College of Pharmacy;* Department of Botany, The University of Texas at Austin, Austin, TX 78713, U.S.A.

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Key Word Index—*Ferulago antiochia*; Apiaceae; roots; sesquiterpene esters; alloaromadendrane; germacranes.

Abstract—In addition to the known phenylpropanoid myristicin, the petrol extract of the roots of *Ferulago antiochia* yielded six new germacrane esters and a new alloaromadendrane ester. The structures were elucidated by spectral and chemical methods.

INTRODUCTION

Ferulago antiochia Saya & Miski (Sect. Anisotaenia Boiss.) is a recently described species from the Flora of Turkey [1]. Despite close relationship of the genera *Ferulago* and *Ferula*, characteristic sesquiterpene aryl esters of the latter genus are not known from the former. Only various coumarin derivatives are reported from *Ferulago* species [2–7]. As a part of our continuing chemical investigation of the genus *Ferula* and related taxa of the Apiaceae family, we report here the isolation and structural elucidation of seven new sesquiterpene aryl esters and a known phenylpropanoid from the petrol extract of the roots of *F. antiochia*.

RESULTS AND DISCUSSION

The known phenylpropanoid myristicin was easily identified by direct comparison of its spectral and physical properties with those of an authentic sample. The ^{1}H NMR (Table 1), ^{13}C NMR (Table 2) and 2D homonuclear COSY spectra of **1**, $C_{22}H_{28}O_3$ (EIMS), indicated that **1** is a benzoyloxylated spathulenol derivative. The position of benzoyloxy group is deduced from the 2D homonuclear COSY spectrum of **1** as well as comparison of its ^{13}C NMR spectrum with that of spathulenol [8] as C-8. The coupling constants of H-8 (Table 1) in the ^{1}H NMR spectrum of **1** suggested an α stereochemistry for the C-8-benzoyloxy group. Comparison of the spectral data of **1** with those of acetylated 8α-hydroxyspathulenol [9], 8α-*p*-anisoyloxyspathulenol and 8α-*t*-cinnamoyloxyspathulenol [10] indicated that **1** must be 8α-benzoyloxyspathulenol. Furthermore, an X-ray crystallographic examination of **1** confirmed the structure [11].

The structures of **2** ($C_{24}H_{32}O_5$) and **3** ($C_{24}H_{32}O_5$) are easily assigned as diesters of tovarol [12] and shiromodiol [12, 13], respectively, by comparison of their spectral data with those of similar esters. In addition to the proton signals indicating a germacrane skeleton, the ^{1}H NMR spectra of both **2** and **3** displayed characteristic signals for acetyl and a benzoyl ester groups (Table 1). In order to establish the position of attachment of each ester group, **2** was subjected to partial hydrolysis. The absence of an acetyl group signal and upfield shift of the H-6 signal (*ca* 1 ppm) in the ^{1}H NMR spectrum of the partial hydrolysis product **2a** (Table 1) confirmed that the place of acetoxy group in **2** is at C-6. Consequently, the benzoyl group of **2** must be esterified to the C-8 hydroxyl group. A similar esterification pattern (i.e. 6-acetyl and 8-benzoyl) for **3** was corroborated by the chemical transformation of **2** to **3** by selective epoxidation.

Except for the presence of an additional *dd* signal at δ4.34, the ^{1}H NMR spectrum of 6-acetyl-8-benzoylantakyatriol (**4**) (Table 1), $C_{24}H_{32}O_5$ (EIMS), was very similar to the one recorded for **2**. This additional signal shifted *ca* 1 ppm downfield in the ^{1}H NMR spectrum of the acetylation product of **4** (**4a**) (Table 1) indicating the presence of a secondary hydroxyl group in **4** in addition to the acetyl and benzoyl ester groups. The assignment of the hydroxyl group to C-3 easily followed from the 2D homonuclear COSY spectrum of **4**. Relative positions of the acetoxy and benzoyloxy groups were deduced from the ^{1}H NMR spectra of partial (**4b**) and total (**4c**) hydrolysis products of **4** (Table 1). The upfield shift of the H-6 signal (*ca* 1.1 ppm) and the lack of an acetyl methyl signal in the ^{1}H NMR spectrum of **4b** confirmed the acetoxy group to be at C-6 in **4**, as found for **2**. In contrast to the upfield position of the chemical shift of the acetyl methyl group in **4**, none of the acetyl methyl group's signals appeared in an upfield position similar to that of **4** in the ^{1}H NMR spectrum of the peracetylation product of **4c**, that is, **4d** (Table 1). The acetoxy group of **4** must be under the paramagnetic shielding influence of the C-8 benzoyloxy group as observed in **2**. Thus, **4** is assigned the same conformation (i.e. $_{14}D^{1}{}_{15}D^{5}$ [14]) as tovarol [12] and shiromodiol [12, 13]. In order to establish the total stereochemistry and conformation of **4**, a series of NOE differences spectroscopy experiments were carried out. As on the basis of biogenetic grounds the stereochemistry of H-7 is accepted as α [15], the relative stereochemistries of the other asymmetric centres should establish the total stereochemistry and conformation of **4**. Irradiation of the H-7 signal enhanced the H-6 signal but not the H-8 signal confirming the β stereochemistry of the C-6 acetoxy moiety and the α stereochemistry of the C-8 benzoyloxy group. Irradiation of the H-14 methyl signal also enhanced the H-6 signal indicating the α orientation of this methyl

Table 1. ^{1}H NMR spectra of compounds **1**, **2**, **2a**, **3**, **4**, **4a–d**, **5–7**, **8a** and **8b**

H	1	2	2a	3	4	4a	4b
1		5.21 *m**	5.10 *br d* (11)	5.43 *br dd* (8.5)	5.15 *m*	5.17 *br d* (11.5)	5.03 *m*
2a					2.46 *m*	2.49 *m*	2.41 *m*
2b	1.50–2.20 *m*	1.70–2.50 *m*	1.65–2.50 *m*	1.55–2.40 *m*			
3a							
3b					4.34 *dd* (6.5; 8.5)	5.28 *dd* (6.5; 11)	4.32 *dd* (6.5; 8.5)
5	1.33 *dd* (11; 11)	5.21 *br d** (6.5)	5.30 *br d* (6)	2.94 *br d* (6.5)	5.28 *br d* (6.5)	5.38 *br d* (6.5)	5.39 *br d* (6.5)
6	0.71 *dd* (10.5; 11)	5.64 *br d* (6.5)	4.55 *br d* (6)	4.98 *br d* (6.5)	5.66 *br d* (6.5)	5.68 *br d* (6.5)	4.54 *br d* (6.5)
7	1.08 *dd* (9; 10.5)	1.46 *br d* (10.5)	1.40 *br d* (10.5)		1.43 *br d* (10.5)		1.39 *br d* (10.5)
8	4.82 *ddd* (2.5; 9; 10.5)	5.70 *dd* (5; 13)	5.36 *dd* (5; 7)	5.68 *br dd* (6; 12.5)	5.58 *dd* (6; 11.5)	5.56 *dd* (5.5; 11.5)	5.28 *br dd* (5.5; 12)
9a	2.54 *br dd* (10.5; 12.5)	2.80 *dd* (5; 13)	2.72 *br dd* (5; 13)	2.78 *br m*	2.78 *br dd* (6; 12)	2.78 *br dd* (5.5; 12.5)	2.71 *br dd* (5.5; 12)
9b	2.68 *dd* (2.5; 12.5)	1.98 *dd* (13; 13)	2.20 *dd* (7; 13)		2.00 *dd* (11.5; 12)	1.98 *br dd* (11.5; 12.5)	2.21 *br dd* (12; 12)
12	1.17 *s*	1.28 *d* (6.5)	1.15 *d* (6.5)	1.28 *d* (6.5)	1.28 *d* (6.5)	1.28 *d* (6.5)	1.19 *d* (6.5)
13	1.12 *s*	1.04 *d* (6.5)	1.03 *d* (6.5)	1.02 *d* (6.5)	1.03 *d* (6.5)	1.04 *d* (6.5)	1.03 *d* (6.5)
14	4.92 *br s*	1.72 *br s*	1.71 *br s*	1.83 *br s*	1.73 *br s*	1.73 *br s*	1.72 *br s*
15	1.32 *s*	1.55 *br s*	1.50 *br s*	1.24 *s*	1.59 *br s*	1.56 *br s*	1.52 *br s*
OAc		180 *s*		180 *s*	1.81 *s*	2.07; 1.78 *s*	
OR	8.08 *dd* (2; 8) 7.49 *m*	8.05 *dd* (2; 8) 7.50 *m*	8.05 *dd* (2; 8) 7.50 *m*	8.05 *dd* (2; 8) 7.50 *m*	8.06 *dd* (2; 8) 7.51 *m*	8.03 *dd* (2; 8) 7.49 *m*	8.04 *dd* (2; 8) 7.48 *m*

*Overlapping signals.

group. Irradiation of the H-3 signal enhanced both the H-5 and the H-2β signals corroborating the α stereochemistry of the C-3 hydroxyl group. Irradiation of the H-8 signal only affected the H-9β, but not the H-14 methyl signal indicating an α orientation for this methyl group. All other spectral data (see Table 2 and Experimental) were in accord with the structure of 6-acetyl-8-benzoylantakyatriol (**4**) as 6β-acetoxy-8α-benzoyloxygermacra-1(10)*E*,4*E*-diene-3α-ol.

The ^{1}H NMR spectrum of 6-acetyl-8-*t*-cinnamylantakyatriol (**5**), $C_{26}H_{34}O_5$ (EIMS), clearly indicated that **5** had the same germacrane skeleton as **4**, differing only in the type of aromatic side chain. The aromatic side chain of **5** was readily identified from characteristic ^{1}H NMR signals (see Table 1) and an EIMS fragment ([*t*-cinnamate acylium]$^+$ at *m/z* 131) as a *t*-cinnamate. The position of the *t*-cinnamate ester group at C-8 is based on spectral data differences between the ^{1}H NMR spectrum of **5** and that of its partial hydrolysis product (**5a**) (Table 1).

The last two germacrane esters, 4β,5α-epoxy-6-acetyl-8-*t*-cinnamylantakyatriol (**6**) ($C_{26}H_{34}O_6$) and 1α,10β-epoxy-6-acetyl-8-*t*-cinnamylantakyatriol (**7**) ($C_{26}H_{34}O_6$), are closely related to **5**. The ^{1}H NMR spectral data of **6** and **7** (Table 1) clearly indicated that the Δ^4 double bond of **5** in **6** and the $\Delta^{1(10)}$ double bond of **5** in **7** are replaced by an epoxy group. The stereochemistries of these epoxides were assumed to be *trans* (4β, 5α in **6** and 1α, 10β in **7**) as both compounds are probably biogenetically derived from **5** by enzymatic exo-epoxidation of its *trans* 1,10 or 4,5 double bonds. In order to prove these stereochemistries, a series of NOE differences spectroscopy experiments were conducted with **6** and **7**. While irradiation of the H-8 signal of **6** only affected the H-5 signal, irradiation of the H-5 signal enhanced both the H-3 and the H-8 signals, and to some extent the H-1 signal. On the other hand, irradiation of the H-6 signal of **6** markedly enhanced the H-15 methyl signal. These experiments confirmed the stereochemistry for **6**. Similar results were obtained from the NOE difference experiments of **7**. In particular, irradiation of the H-1 signal strongly enhanced the H-3 signal but not the H-14 methyl signal indicating that **7** must be a 10β,1α-epoxy derivative of **5**. Moreover, the structures of **6** and **7** were further confirmed by comparison of the spectral data of **6** and the epoxidation product of **7** with those of the partial and total epoxidation product of **5** [i.e. 4β,5α-epoxy-6-acetyl-8-*t*-cinnamylantakyatriol (**6**) and 1α,10β,4β,5α-diepoxy-6-acetyl-8-*t*-cinnamylantakyatriol (**8a**)] (see Table 1 and Experimental), respectively. It is of interest to note that the total epoxidation of **5** has yielded both **8a** and **8b** (i.e.

(200 MHz, $CDCl_3$, TMS as int. standard, J in Hz in parentheses)

4c	4d	5	6 (55°)	7	8a (400 MHz)	8b (400 MHz)
4.88 *m*	5.07 *br d* (12.5)	5.12 *br dd* (5; 10.5)	5.33 *br dd* (5; 10.5)	2.93 *dd* (1; 10.5)	3.08 *d* (11)	2.99 *d* (6.5; 10)
2.38 *m*	2.46 *m*	2.42 *m*				
2.03 *m*						
4.21 *dd* (6.5; 8.5)	5.38 *m**	4.33 *dd* (6.5; 8.5)	3.38 *dd* (6.5; 10.5)	4.50 *dd* (5.5; 11)	3.48 *dd* (5; 11.5)	3.36 *dd* (8.5; 12)
5.22 *br d* (6.5)	5.38 *m**	5.27 *br d* (6.5)	2.89 *d* (6.5)	5.57 *br d* (6)	3.22 *d* (6.5)	3.09 *d* (8)
4.70 *br d* (6.5)	5.63 *br d* (6.5)	5.63 *br d* (6.5)	4.99 *br d* (6.5)	5.67 *br d* (6)	5.01 *d* (6.5)	5.06 *d* (8)
	1.28 *br d* (9)	1.38 *br d* (10.5)				
4.12 *br dd* (5.5; 12)	5.38 *m**	5.46 *dd* (6; 11.5)	5.47 *dd* (4.5; 11)	5.53 *dd* (6; 10.5)	5.62 *dd* (5.5; 12)	5.58 *br d* (11.5)
2.58 *br dd* (5.5; 12.5)	2.62 *br dd* (5.5; 12.5)	2.71 *br dd* (6; 13)	2.63 *br dd* (4.5; 12.5)	2.33 *br dd* (6; 13)	2.35 *br dd* (5.5; 14)	2.29 *d* (13)
1.88 *br dd* (12; 12.5)	1.76 *dd* (12; 12.5)	1.99 *m**	2.08 *dd* (12; 12.5)	2.23 *dd* (12; 13)	2.30 *br dd* (12; 14)	2.26 *dd* (11.5; 14)
1.11 *d* (6.5)	1.11 *d* (6.5)	1.22 *d* (6.5)	1.22 *d* (6.5)	1.23 *d* (6.5)	1.25 *d* (6.5)	1.16 *d* (6.5)
1.08 *d* (6.5)	0.99 *d* (6.5)	1.02 *d* (6.5)	0.99 *d* (6.5)	1.05 *d* (6.5)	1.03 *d* (6.5)	0.99 *d* (6.5)
1.67 *br s*	1.69 *br s*	1.72 *br s*	1.72 *br s*	1.38 *s*	1.35 *s*	1.47 *s*
1.46 *br s*	1.54 *br s*	1.58 *br s*	1.27 *s*	1.71 *s*	1.53 *s*	1.53 *s*
	2.07 (×2); 1.98 *s*	1.93 *s**	1.95 *s*	1.94 *s*	1.94 *s*	1.99 *s*
		7.69 *d* (16)	7.69 *d* (16)	7.66 *d* (16)	7.67 *d* (16)	7.70 *d* (16)
		7.55 *m*	7.53 *m*	7.53 *m*	7.54 *m*	7.54 *m*
		7.41 *m*	7.41 *m*	7.40 *m*	7.41 *m*	7.41 *m*
		6.46 *d* (16)	6.43 *d* (16)	6.42 *d* (16)	6.42 *d* (16)	6.43 *d* (16)

1α,10β-epoxy analogue of **8a**) in *ca* 2:1 ratio. This must be due to the high conformational flexibility of **6**, which is the first step epoxidation product of **5**, in its chloroform solution at room temperature as indicated by the broad signal pattern of its ^1H NMR spectrum at ambient temperatures.

EXPERIMENTAL

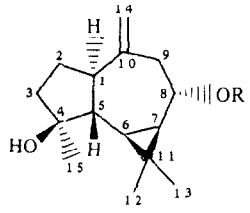
Plant material. The roots of *F. antochia* were collected from the NW slopes of Ziyaret Mountain, *ca* 15 km south of Antakya, Turkey, in May 1982. A voucher specimen is deposited in the Herbarium of Dicle University (DUF 3431-B).

Extraction and isolation of the compounds. Air-dried and coarsely powdered roots (830 g) were extracted with petrol in a Soxhlet. Concentration of the petrol extract *in vacuo* provided 106 g of viscous oil. Some of this oil (35 g) was chromatographed on a silica gel column (7.5 × 75 cm) packed in hexane and eluted with a hexane–EtOAc gradient. A Sephadex LH-20 column packed in cyclohexane–CH_2Cl_2–EtOH (7:4:1) and/or prep. TLC (1–2 mm thickness, silica gel developed with cyclohexane–EtOAc mixtures, 8:2, 7:3 or 3:2) were used for further purification.

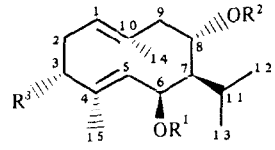
8-α-*Benzoyloxyspathulenol* (**1**). Hexagonal plates from hexane–Et_2O (22 mg), mp 109–110°; IR ν_{max}^{NaCl} cm^{-1}: 3500 (OH), 1720 (C=O), 1645, 1610, 1590, 1270, 1110, 710, 690; EIMS (probe, 70 eV) *m/z* (rel. int.): 340 $[M]^+$ (1.5), 323 $[M-H_2O-H]^+$ (2.2), 218 [M – benzoic acid]$^+$ (25.1), 200 $[218-H_2O]^+$ (24.9), 185 (19.2), 175 (11.7), 160 (24.7), 145 (31.8), 122 [benzoic acid]$^+$ (5.8), 105 [benzoate acylium]$^+$ (100), 77 (45.1).

6-*Acetyl-8-benzoyltovarol* (**2**). Gum (34 mg); IR ν_{max}^{NaCl} cm^{-1}: 1720 (*br*) (C=O), 1610, 1590, 1450, 1270, 1235, 710, 690; EIMS (probe, 70 eV) *m/z* (rel. int.): 218 [M – HOAc – benzoate acylium + H]$^+$ (12.5), 202 [M – HOAc – benzoic acid]$^+$ (77.4), 187 (41.7), 159 (90.3), 145 (51.8), 122 [benzoic acid]$^+$ (28.9), 105 [benzoate acylium]$^+$ (100.0), 77 (71.0) 43 [acetate acylium]$^+$ (87.9); CIMS (CH_4, 0.5 torr, direct probe) *m/z* (rel. int.): 383 [M – H]$^+$ (4.5), 341 [M – acetate acylium]$^+$ (11.0), 279 [M – benzoate acylium]$^+$ (34.3), 237 [M – benzoate acylium – acetate acylium + H]$^+$ (35.1), 219 [M – HOAc – benzoate acylium]$^+$ (100.0), 201 [M – benzoic acid – HOAc – H]$^+$ (86.1), 123 [benzoic acid + H]$^+$ (58.6), 105 [benzoate acylium]$^+$ (58.0).

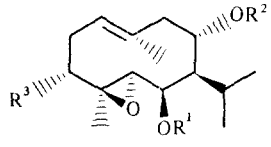
Partial hydrolysis of **2**. Compound **2** (20 mg was) dissolved in an ice-cold 1% ethanolic NaOH soln (3 ml) and kept in a refrigerator for 2 hr. The mixture was poured into 20 ml of an ice-H_2O mixture and extracted with Et_2O (2 × 20 ml). The combined Et_2O extract was dried with $MgSO_4$ and evapd to dryness *in vacuo*. The crude product was purified with prep. TLC to yield 9 mg of 8-benzoyltovarol (**2a**). IR ν_{max}^{NaCl} cm^{-1}: 3500 (OH), 1720 (C=O), 1610, 1590, 1450, 1270, 1100, 710, 690; EIMS (probe,



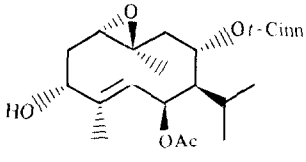
1 R = Benzoate (Bz)



	R^1	R^2	R^3
2	Ac	Bz	H
2a	H	Bz	H
4	Ac	Bz	OH
4a	Ac	Bz	OAc
4b	H	Bz	OH
4c	H	H	OH
4d	Ac	Ac	OAc
5	Ac	*t*-cinn	OH
5a	H	*t*-cinn	OH



	R^1	R^2	R^3
3	Ac	Bz	H
6	Ac	*t*-cinn	OH



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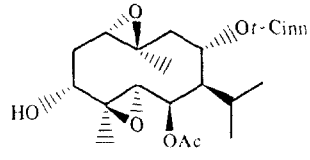
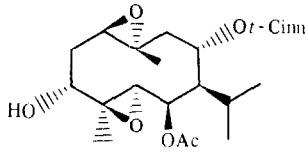


8a



8b

70 eV) *m/z* (rel. int.): 342 $[M]^+$ (0.9), 238 [M – benzoate acylium]$^+$ (13.4), 220 [M – benzoic acid]$^+$ (48.3), 202 $[220-H_2O]^+$ (74.5), 187 (39.6), 159 (84.2), 122 [benzoic acid]$^+$ (23.7), 105 [benzoate acylium]$^+$ (100), 77 (64.5).

6-*Acetyl*-8-*benzoylshiromodiol* (**3**). Gum (17 mg); IR ν_{max}^{NaCl} cm^{-1}: 1720 (*br*) (C=O), 1610, 1590, 1450, 1270, 1240, 730, 710, 690; EIMS (probe, 70 eV) *m/z* (rel. int.): 400 $[M]^+$ (0.2), 236 [M – HOAc – benzoate acylium + H]$^+$ (6.5), 218 [M – HOAc – benzoic acid]$^+$ (23.0), 200 $[218-H_2O]^+$ (23.4), 175 $[218-C_3H_7]^+$ (63.3), 122 [benzoic acid]$^+$ (41.3), 105 [benzoate acylium]$^+$ (100), 77 (65.6), 43 [acetate acylium]$^+$ (92.5); CIMS (CH_4, 0.5 torr, direct probe) *m/z* (rel. int.): 399 $[M-H]^+$ (14.9), 357 [M – acetate acylium]$^+$ (13.4), 295 [M – benzoate acylium]$^+$ (28.3), 277 [M – benzoic acid – H]$^+$ (13.2), 235 [M – HOAc – benzoate acylium]$^+$ (42.2), 219 [M – HOAc – benzoic acid + H]$^+$ (62.9), 201 (100), 123 [benzoic acid + H]$^+$ (9.8), 105 [benzoate acylium]$^+$ (49.7).

Selective epoxidation of **2**. Compound **2** (8 mg) was reacted with *m*-CPBA (8 mg) in the presence of NaOAc (5 mg) in 1 ml $CHCl_3$. After 1 hr the reaction mixture was diluted with 5 ml $CHCl_3$, transferred to a separatory funnel and washed with 5% $NaHCO_3$ (3 × 5 ml). The $CHCl_3$ soln was dried with $MgSO_4$ and the solvent removed under red. pres. The crude product was purified with prep. TLC to yield 4β,5α-epoxy derivative of **2** (5 mg) which was identical in physical and spectral properties to **3**.

6-*Acetyl*-8-*benzoylantakyatriol* (**4**). Gum (5.85 g); IR ν_{max}^{NaCl} cm^{-1}: 3480 (OH), 1745 (C=O), 1720 (C=O), 1610, 1590, 1450, 1275, 1240, 1110, 710, 690; EIMS (probe, 70 eV) *m/z* (rel. int.): 340 [M – HOAc]$^+$ (1.4), 252 [M – benzoate acylium – acetate acylium]$^+$ (0.8), 236 [M – benzoate acylium – HOAc]$^+$ (2.6), 218 [M – benzoic acid – HOAc]$^+$ (18.2), 200 $[218-H_2O]^+$ (6), 189 (8.5), 175 $[218-C_3H_7]^+$ (48.7), 136 (28.5), 122 [benzoic acid]$^+$ (12.2), 105 [benzoate acylium]$^+$ (100), 43 [acetate acylium]$^+$ (68.7);

Table 2. ^{13}CNMR spectra of compounds **1**, **2** and **4a** (22.6 MHz, $CDCl_3$, TMS as int. standard)

C	1	2	4a
1	52.1 *d*	129.8 *d*	127.5 *d*
2	26.7 *t*	24.8 *t*	30.6 *t*
3	41.6 *t*	39.0 *t*	78.1 *d*
4	80.7 *s*	129.5 *s*	131.8 *s*
5	54.6 *d*	132.1 *d*	130.2 *d*
6	28.9 *d*	71.4 *d*	70.4 *d*
7	31.9 *d*	52.4 *d*	51.9 *d*
8	73.2 *d*	74.3 *d*	74.0 *d*
9	46.1 *t*	41.4 *t*	41.4 *t*
10	147.6 *s*	135.5 *s*	134.2 *s*
11	20.9 *s*	26.5 *d*	26.5 *d*
12	28.2 *q*	21.5 *q*	21.5 *q*
13	16.2 *q*	20.9 *q*	20.7 *q*
14	110.3 *t*	23.3 *q*	23.2 *q*
15	25.7 *q*	16.7 *q*	11.8 *q*
OAc		170.6 *s*	170.3; 169.9 *s*
		20.9 *q*	21.1 (×2) *q*
OR	165.4 *s*	165.7 *s*	165.6 *s*
	130.9 *s*	131.0 *s*	130.9 *s*
	129.7 (×2) *d*	129.5 (×2) *d*	129.5 (×2) *d*
	128.3 (×2) *d*	128.6 (×2) *d*	128.6 (×2) *d*
	132.8 *d*	132.9 *d*	133.0 *d*

CIMS (CH_4, 0.5 torr, direct probe) *m/z* (rel. int.): 399 $[M-H]^+$ (3.0), 383 $[M-H_2O+H]^+$ (7.7), 341 $[M-HOAc+H]^+$ (10.1), 323 $[341-H_2O]^+$ (2.8), 277 [M − benzoic acid − H]$^+$ (2.8), 261 [M − benzoic acid − H_2O + H]$^+$ (7.8), 235 [M − benzoate acylium − HOAc]$^+$ (9.6), 219 [M − benzoic acid − HOAc + H]$^+$ (100), 201 $[219-H_2O]^+$ (81.2), 191 (9.3), 175 (16.3), 161 (9.6), 149 (9.8), 123 [benzoic acid + H]$^+$ (5.7), 105 [benzoate acylium]$^+$ (27.3).

Acetylation of **4**. Compound **4** (1 g) was acetylated with Ac_2O–pyridine in the usual manner. The work-up yielded 1.06 g of pure **4a**.

Compound **4a**. Prisms from hexane–Et_2O, mp. 133–134°. IR ν_{max}^{NaCl} cm^{-1}: 1740 (C=O), 1720 (C=O), 1600, 1585, 1450, 1370, 1275, 1240, 1110, 1028, 860, 712; EIMS (probe, 70 eV) *m/z* (rel. int.): 442 $[M]^+$ (0.3), 400 [M − acetate acylium]$^+$ (0.2), 383 [M − HOAc + H]$^+$ (1.8), 340 [M − HOAc − acetate acylium + H]$^+$ (1.1), 260 [M − benzoic acid − HOAc]$^+$ (7.7), 218 [260 − acetate acylium + H]$^+$ (22.2), 200 [260 − HOAc]$^+$ (57.1), 185 (21.3), 175 $[218-C_3H_7]^+$ (25.2), 157 (89.5), 105 [benzoate acylium]$^+$ (100), 77 (56.1), 43 [acetate acylium]$^+$ (62.9).

Alkaline hydrolysis of **4**. Compound **4** (200 mg) was treated with 1% NaOH in EtOH at room temp. After 6 hr, the reaction mixture was worked-up in the usual manner. Two hydrolysis products, **4b** and **4c**, were obtained after purification by prep. TLC.

Compound **4b**. Gum (95 mg); IR ν_{max}^{NaCl} cm^{-1}: 3470 (OH), 1710 (C=O), 1610, 1590, 1450, 1270, 1110, 710, 690; EIMS (probe, 70 eV) *m/z* (rel. int.): 358 $[M]^+$ (0.5), 253 [M − benzoate acylium]$^+$ (0.6), 236 [M − benzoic acid]$^+$ (1.0), 218 $[236-H_2O]^+$ (1.5), 201 $[236-2\times H_2O+H]^+$ (3.1), 175 $[218-C_3H_7]^+$ (8.1), 137 (17.8), 122 [benzoic acid]$^+$ (16.3), 105 [benzoate acylium]$^+$ (100).

Antakyatriol (**4c**). Amorphous (34 mg); IR ν_{max}^{NaCl} cm^{-1}: 3400, 1450, 1375, 1130, 1080, 1040, 1020. 855; EIMS (probe, 70 eV) *m/z* (rel. int.): 254 $[M]^+$ (0.4), 236 $[M-H_2O]^+$ (1.4), 219 $[M-2\times H_2O+H]^+$ (3.3), 201 $[M-3\times H_2O+H]^+$ (2.2), 193 $[236-C_3H_7]^+$ (8.4), 175 (10.5), 139 (39.6), 100 (87.5), 81 (70.0), 71 (100).

Acetylation of antakyatriol (**4c**). Antakyatriol (15 mg) was acetylated as described for **4**. The product was **4d** (20 mg).

Compound **4d**. Gum; IR ν_{max}^{NaCl} cm^{-1}: 1720 (*br*) (C=O), 1420, 1355, 1235 (*br*), 1010, 900, 720, 690; EIMS (probe, 70 eV) *m/z* (rel. int.): 380 $[M]^+$ (0.1), 320 [M − HOAc]$^+$ (1.4), 278 [M − HOAc − acetate acylium + H]$^+$ (26.4), 260 [M − 2 × HOAc]$^+$ (36.8), 218 [260 − acetate acylium + H]$^+$ (42.5), 200 [M − 3 × HOAc]$^+$ (57.3), 175 $[218-C_3H_7]^+$ (26.8), 139 (42.4), 77 (48.3), 43 [acetate acylium]$^+$ (100).

6-*Acetyl*-8-*t*-*cinnamylantakyatriol* (**5**). Gum (285 mg); IR ν_{max}^{NaCl} cm^{-1}: 3450 (OH), 1740 (C=O), 1710 (C=O), 1640, 1580, 1450, 1370, 1270, 1260, 1245, 1170, 770, 700, 680; EIMS (probe, 70 eV) *m/z* (rel. int.): 366 [M − HOAc]$^+$ (0.8), 251 [M − acetate acylium − *t*-cinnamate acylium − H]$^+$ (1.7), 234 [M − HOAc − *t*-cinnamate acylium − H]$^+$ (3.5), 218 [M − HOAc − *t*-cinnamic acid]$^+$ (9.4), 200 $[218-H_2O]^+$ (4.8), 175 $[218-C_3H_7]^+$ (23.0), 157 $[175-H_2O]^+$ (18.0), 148 [*t*-cinnamic acid]$^+$ (30.8), 131 [*t*-cinnamate acylium]$^+$ (100), 103 (65.4), 91 (45.2), 77 (52.8), 43 [acetate acylium]$^+$ (83.9); CIMS (CH_4, 0.5 torr, direct probe) *m/z* (rel. int.): 425 $[M-H]^+$ (3.5), 409 $[M-H_2O+H]^+$ (3.9), 367 [M − HOAc + H]$^+$ (3.3), 277 [M − *t*-cinnamic acid − H]$^+$ (4.7), 235 [M − HOAc − *t*-cinnamate acylium]$^+$ (21.8), 219 [M − HOAc − *t*-cinnamic acid + H]$^+$ (22.5), 201 $[219-H_2O]^+$ (12.3), 191 (7.1), 175 (8.6), 149 [*t*-cinnamic acid + H]$^+$ (31.6), 131 [*t*-cinnamate acylium]$^+$ (42.7).

Partial hydrolysis of **5**. Compound **5** (30 mg) as partially hydrolysed as described for **2** to yield 14 mg of **5a**. IR ν_{max}^{NaCl} cm^{-1}: 3450 (OH), 1710 (C=O), 1640, 1580, 1450, 1370, 1270, 1170, 770, 735, 710, 700, 680; EIMS (probe, 70 eV) *m/z* (rel. int.): 384 $[M]^+$ (0.2), 252 [M − *t*-cinnamate acylium − H]$^+$ (1.3), 236 [M − *t*-cinnamic acid]$^+$ (5.2), 218 $[236-H_2O]^+$ (11.2), 200 $[218-H_2O]^+$ (14.4), 175 $[218-C_3H_7]^+$ (28.6), 148 [*t*-cinnamic acid]$^+$ (36.6), 131 [*t*-cinnamate acylium]$^+$ (100), 77 (47.5).

6-*Acetyl*-8-*t*-*cinnamyl*-4β,5α-*epoxyantakyatriol* (**6**). Gum (22 mg); IR ν_{max}^{NaCl} cm^{-1}: 3450, 1740, 1710, 1640, 1580, 1450, 1370, 1275, 1230, 1170, 770, 735, 710, 685; EIMS (probe, 70 eV) *m/z* (rel. int.): 252 [M − *t*-cinnamate acylium − HOAc + H]$^+$ (1.1), 234 [M − *t*-cinnamic acid]$^+$ (3.5), 216 $[234-H_2O]^+$ (5.6), 201 (3.7), 191 $[234-C_3H_7]^+$ (14.2), 173 (13.1), 161 (15.9), 148 [*t*-cinnamic acid]$^+$ (26.4), 131 [*t*-cinnamate acylium]$^+$ (100), 119 (27.9), 103 (67.6), 91 (41.4), 77 (44.9), 43 [acetate acylium]$^+$ (70.6); CIMS (CH_4, 0.5 torr, direct probe) *m/z* (rel. int.): 441 $[M-H]^+$ (9.4), 425 $[M-H_2O+H]^+$ (42.0), 383 [M − HOAc + H]$^+$ (9.1), 295 [M − *t*-cinnamic acid + H]$^+$ (29.1), 277 $[295-H_2O]^+$ (10.2), 235 [M − *t*-cinnamic acid − HOAc + H]$^+$ (100), 217 $[235-H_2O]^+$ (95.6), 205 (35.9), 173 (29.4), 149 [*t*-cinnamic acid]$^+$ (23.7), 131 [*t*-cinnamate acylium]$^+$ (69.3), 123 (46.5), 107 (62.2), 105 (22.8).

Selective epoxidation of **5**. Compound **5** (15 mg) was selectively epoxidized with *m*-CPBA as described for **2** to yield 13 mg of **6**, identical by physical and chemical properties with the natural **6**.

6-*Acetyl*-8-*t*-*cinnamyl*-1α,10β-*epoxyantakyatriol* (**7**). Gum (18 mg); IR ν_{max}^{NaCl} cm^{-1}: 3450, 1740 (C=O), 1710 (C=O), 1640, 1580, 1450, 1270, 1260, 1240, 1170, 770, 735, 710, 700, 680; EIMS (probe, 70 eV) *m/z* (rel. int.): 251 [M − *t*-cinnamate acylium − HOAc]$^+$ (3.9), 234 [M − *t*-cinnamic acid − HOAc]$^+$ (10.5), 216 $[234-H_2O]^+$ (20.3), 201 (11.7), 173 $[216-C_3H_7]^+$ (35.7), 161 (17.7), 159 (18.7), 148 [*t*-cinnamic acid]$^+$ (35.2), 131 [*t*-cinnamate acylium]$^+$ (100), 119 (43.0), 103 (80.9), 77 (50.6), 43 [acetate acylium]$^+$ (85.7); CIMS (CH_4, 0.5 torr, direct probe) *m/z* (rel. int.): 443 $[M+H]^+$ (5.1), 425 $[M-H_2O+H]^+$ (3.4), 383 [M − HOAc + H]$^+$ (8.0), 313 [M − *t*-cinnamate acylium + 2H]$^+$ (7.6), 295 [M − *t*-cinnamic acid + H]$^+$ (45.7), 277 $[295-H_2O]^+$

(10.5), 235 [M − *t*-cinnamic acid − HOAc + H]$^+$ (100), 217 [235 − H_2O]$^+$ (39.9), 205 (29.4), 173 (27.2), 149 [*t*-cinnamic acid + H]$^+$ (34.8), 131 [*t*-cinnamate acylium]$^+$ (55.2), 123 (29.1), 107 (66.2), 105 (95.1).

Epoxidation of compound **7**. Compound **7** (5 mg) was dissolved in 2 ml $CHCl_3$; 7 mg *m*-CPBA were added gradually while stirring of the soln. After 2 hr the reaction mixture was diluted with 5 ml $CHCl_3$ and worked-up as previously specified to yield **8a** (4.5 mg). IR ν_{max}^{NaCl} cm^{-1}: 3450 (OH), 1740 (C=O), 1710 (C=O), 1640, 1580, 1450, 1270, 1235, 1165, 770, 735, 710; EIMS (probe, 70 eV) *m/z* (rel. int.): 458 [M]$^+$ (0.3), 399 [M − HOAc + H]$^+$ (0.1), 327 [M − *t*-cinnamate acylium]$^+$ (0.8), 311 [M − *t*-cinnamic acid + H]$^+$ (2.9), 266 [M − *t*-cinnamic acid − acetate acylium − H]$^+$ (3.4), 229 (2.0), 227 (1.6), 207 [M − *t*-cinnamic acid − HOAc − C_3H_7]$^+$ (3.5), 167 (5.5), 131 [*t*-cinnamate acylium]$^+$ (100), 103 (37).

Total epoxidation of compound **5**. Compound **5** (50 mg) was treated with *m*-CPBA for 24 hr. After usual work-up and purification by prep. TLC, compounds **8a** (30 mg) and **8b** (14 mg) were obtained. Spectral and physical properties of **8a** were identical with those of epoxidation product of **7**. Compound **8b**: IR ν_{max}^{NaCl} cm^{-1}: 3460 (OH), 1740 (C=O), 1710 (C=O), 1450, 1275, 1240, 1170, 770, 735, 710; EIMS (probe, 70 eV) *m/z* (rel. int.): 458 [M]$^+$ (0.1), 399 [M − HOAc + H]$^+$ (0.2), 327 [M − *t*-cinnamate acylium]$^+$ (0.8), 311 [M − *t*-cinnamic acid + H]$^+$ (6.8), 266 [M − *t*-cinnamic acid-acetate acylium − H]$^+$ (1.4), 227 (2.4), 207 [M − *t*-cinnamic acid − HOAc − C_3H_7]$^+$ (4.8), 167 (5.8), 131 [*t*-cinnamate acylium]$^+$ (100), 103 (36.0).

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