Phytochemistry, Vol. 26, No. 3, pp. 803–807, 1987.
Printed in Great Britain.

0031-9422/87 $3.00 + 0.00
Pergamon Journals Ltd.

OBLIQUIN DERIVATIVES AND OTHER CONSTITUENTS FROM AUSTRALIAN *HELICHRYSUM* SPECIES

J. JAKUPOVIC, V. P. PATHAK, F. BOHLMANN, R. M. KING* and H. ROBINSON*

Institute for Organic Chemistry, Technical University of Berlin, D-1000 Berlin 12, F.R.G.; *Smithsonian Institution, Department of Botany, Washington D.C. 20560, U.S.A.

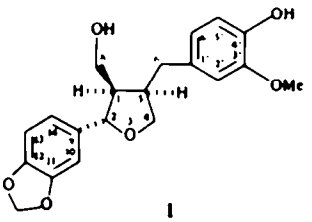
(*Received* 12 *June* 1986)

Key Word Index—*Helichrysum acuminatum*; *H. diosmifolium*; *H. stirlingii*; Compositae; coumarins; obliquin derivatives; cinnamic acid derivatives; lignans; sesquiterpenes; caryophyllene derivatives; azulene derivative; flavanones; styrene derivative; tremetone derivative.

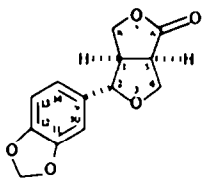
Abstract—The investigation of three Australian *Helichrysum* species afforded in addition to known compounds three new obliquin derivatives, eight cinnamic acid derivatives, a tremetone derivative, a styrene derivative, two lignans, two caryophyllene derivatives and an azulene. The structures were elucidated by highfield ^{1}H NMR.

INTRODUCTION

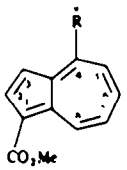
From the large genus *Helichrysum* (Compositae, tribe Inuleae, subtribe Gnaphaliinae) many species have been studied chemically [1]. However, so far little is known on the chemistry of Australian species. We therefore now have studied three species from this group. The results are discussed in this paper.



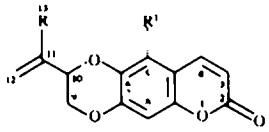
1



2



3 R = Me
4 R = CHO



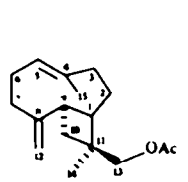
	5	6	7	8	9	10
R	Me	Me	Me	CH_2OH	CH_2OH	CHO
R'	H	OH	OMe	H	OMe	OMe

RESULTS AND DISCUSSION

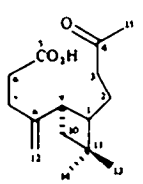
The aerial parts of *H. acuminatum* DC afforded in addition to known compounds (see Experimental) the lignan derivatives **1** and **2** and the azulene **3**.

The ^{1}H NMR spectrum of **1** (see Experimental) was in part close to those of pinoresinol and the corresponding mono dioxymethylene derivative which also were isolated. A pair of double doublets at δ2.89 and 2.53 indicated the presence of a seco-derivative. Spin decoupling allowed the assignment of several sequences which clearly led to the proposed substitution pattern of the tetrahydrofuran ring. The configurations of the chiral centres were determined by NOE difference spectroscopy (NOEs between H-1 and H-5 as well as between H-2, H-6 and H-8). The relative position of the different aromatic residues followed from the fragmentation pattern in the mass spectrum. Base peak is the fragment formed by fission of the 5–6 bond (m/z 137). The lignan **1**, which we have named acuminatin, is closely related to lariciresinol [2] which has the same stereochemistry.

The second lignan **2** also showed in the ^{1}H NMR spectrum (see Experimental) two pairs of lowfield double doublets which were coupled with protons which gave rise to signals at δ3.44 and 3.08, respectively. Furthermore, the typical signals of dioxymethylene benzene were visible. Together with the molecular formula therefore only structure **2**, which we have named acuminatolide, agreed with all data. The stereochemistry followed from the



11



12

couplings and from the NOEs which clearly showed the *cis*-relationship between H-1 and H-5, the *trans*-orientation between H-1 and H-2 as well as *cis*-hydrogens at C-2 and C-8.

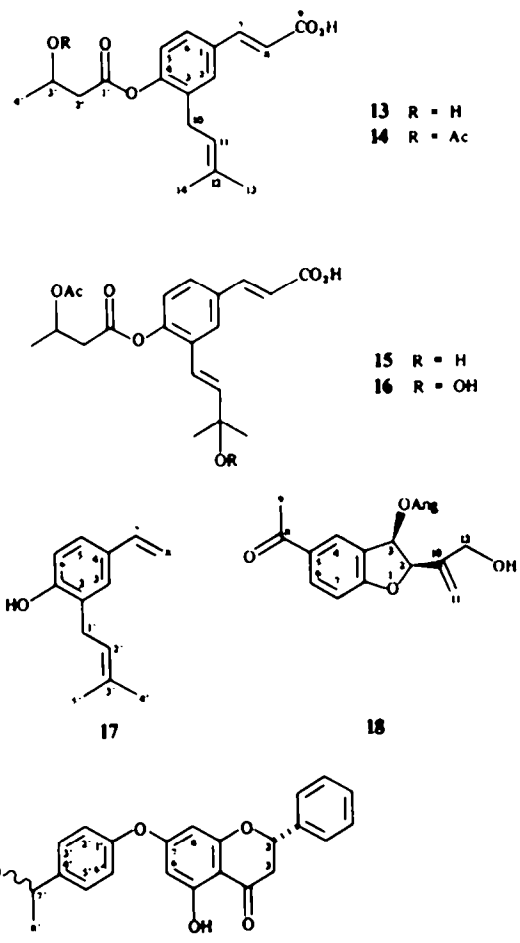
The structure of the violet coloured azulene **3** also followed from the ^{1}H NMR data (see Experimental) which were in part close to the corresponding aldehyde **4** which was reported from *H. bracteatum* [3]. The position of the oxygen function was established by clear NOEs between 4-methyl, H-3 and H-5. The assignment of these protons was achieved by spin decoupling.

The aerial parts of *H. diosmifolium* (Vent.) Sweet. gave the obliquin derivatives **7** [4] and **9** while the roots also gave **5** [5], **6** [4] and **10** together with *ent*-kaurenic acid and the seco-compound **12**. The aerial parts also gave **12** as well as **11**, the prenylated coumaric acid derivatives **13**–**16** together with the known derivative with a free hydroxy group [6] and the acetate [7]. Furthermore the styrene derivative **17**, 8-epi-inuviscolide [8], spathulenol, ent-kaurenic acid, 8β-hydroxy-11α,12β-diacetoxypimar-16-ene [9] and cinnamic acid were present.

The structures of **9** and **10** clearly followed from the ^{1}H NMR spectra (see Experimental) which were similar to those of **5**–**7**. In the case of **9** the methyl signal was replaced by that of a methylol group (δ4.31 *br s*) and in the case of **10** by that of an aldehyde proton (δ9.66 *s*).

The structure of **11** followed from the ^{1}H NMR spectrum which was close to that of caryophyllene. Only one methyl singlet was replaced by the signal of an acetoxy methylene group (δ4.12 and 4.03 *d*, 2.07 *s*). The chemical shifts of the neighbouring protons favoured a 13-*O*-acetate. This was confirmed by NOE difference spectroscopy with the corresponding senecioate (unpublished data). A glucoside of the corresponding alcohol was isolated previously [10]. Also the structure of **12**, which was purified as its methyl ester, followed from the ^{1}H NMR spectrum which was close to that of the corresponding aldehyde [11]. All signals could be assigned by spin decoupling. The changed oxygen function caused a small shift of the H-6 and the signal of the aldehyde proton was replaced by that of a methoxy singlet.

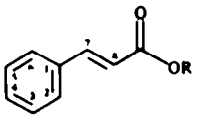
The structures of **13**–**16**, which were transformed to the methyl esters, could be deduced easily from the ^{1}H NMR spectra as that of **13a** was close to those of the free phenol [6]. The nature of the ester groups in **14a** followed from the corresponding ^{1}H NMR signals (δ2.90 and 2.78 *dd*, 5.39 *ddq*, 1.40 *d*, 2.05 *s*). In the spectrum of **13a** these signals were shifted in the expected way and the acetoxy singlet was missing. The data of **15a** indicated that this compound only differed from **14a** by a variation of the prenyl group. A pair of lowfield doublets at δ6.66 and 6.38 and a singlet at δ1.41 (6H) indicated the nature of the side chain. In the spectrum of **16a** an additional broadened singlet at δ8.44 and small shift differences of the signal of the prenyl side chain showed that the corresponding hydroperoxide was present. This was supported by triphenylphosphine reduction which led to **15a**. The ^{1}H NMR of **17** indicated the presence of a trisubstituted benzene derivative, one substituent being a vinyl group (δ6.63 *dd*, 5.59 *d* and 5.10 *d*), one hydroxy and one a prenyl group [δ3.15 *br d* (2H), 5.31 *br t*, 1.79 and 1.78 *br s* (each 3H)]. The relative position of the substituents was deduced from the chemical shifts of the aromatic protons. Most likely **17** is derived from the corresponding acetophenone derivative [11].



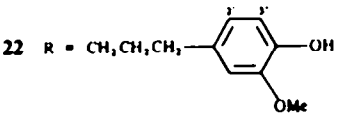
12a–**16a** are the methyl esters

The roots of *H. stirlingii* F. Muell. also gave **5**, **7**, **9** and **10** as well as **8**, the hydroxy derivative of **5**. The structure directly followed from the spectral data. Furthermore naringin, betulinic acid and the tremetone derivative **18** were isolated. The structure of the latter followed from the ^{1}H NMR spectrum which was very close to that of the tremetone [12], only the olefinic methyl signal being replaced by a pair of doublets at δ4.29 and 4.22. The *cis*-configuration at C-2 and C-3 followed from the observed coupling. The aerial parts gave the flavanones pinocembrin, the corresponding 3β-hydroxy and acetoxy derivatives and the 7-substituted compound **19**, 2,3-dihydroxycinnamic acid and the cinnamates **20**–**23**. The structures of these compounds followed from the ^{1}H NMR spectra. The relative position of the oxygen function in **22** and **23** followed from the chemical shifts of the aromatic protons which agreed with those of other phenyl ethyl alcohol derivatives. The structure of **19** followed from the ^{1}H NMR spectrum which was in part close to that of pinocembrin. The substituent at C-7 displayed additional signals at δ7.27 and 6.83 *br d* (each 2H), 4.76 *br dq*, 1.62 and 1.61 *d* and 5.52 *br s*. In agreement with the molecular formula these data led to the proposed structure **19** epimeric at C-7′. The fragmentation pattern also supported this structure. After loss of methyl (*m/z* 361, base peak) RDA led to *m/z* 257 (69%, 361 – $C_6H_5CH{=}CH_2$).

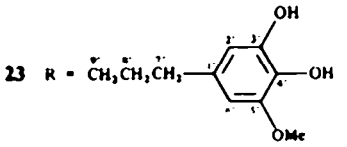
If the chemistry of the three Australian *Helichrysum*



20 R = Geranyl
21 R = CH_2CH_2Ph



22 R = $CH_2CH_2CH_2$



23 R = $CH_2CH_2CH_2$

species is compared with that of the South African species, relationships to a few species are visible. Obliquin derivatives have been reported not only from *H. serpyllifolium* [4] and *H. vestitum* [4] but also from *Phaenocoma* [13], *Stoebe* [14] and *Anaxeton* species [14] while an azulene closely related to **3** as well as lignans have been isolated from *H. bracteatum* [3, 15]. The unusual high accummulation of pinocembrin and also the presence of cinnamates in *H. stirlingii* is remarkable. The common occurrence of obliquin derivatives in the latter species and in *H. diosmifolium* indicated a relationship of these two taxa while the constitutents of *H. acuminatum* resembles more those of *H. bracteatum*.

EXPERIMENTAL

Air dried plant material, collected near Canberra, Australia, was extracted with MeOH–Et_2O–petrol (1:1:1) and the extracts obtained were worked-up and separated as reported previously [16].

The extract of aerial parts of *H. acuminatum* (510 g, voucher Robinson 86-0002) was separated by CC into four fractions [1: Et_2O–petrol (1:4), 2: Et_2O–petrol, (1:1), 3: Et_2O and 4: Et_2O–MeOH (9:1)]. Prep. TLC silica gel, PF 254, C_6H_6–CH_2Cl_2 (1:1) of fraction 1 gave 5 mg **3**. Prep. TLC of fraction 2 in Et_2O–petrol (7:3) gave 10 mg pinoresinol and of fraction 3 in Et_2O afforded 15 mg naringenin. Prep. TLC of fraction 4 in $CHCl_3$ MeOH (17:3) gave three bands (4/1–4/3). HPLC of 4/1 on RP 8 eluting with MeOH H_2O (3:2) at *ca* 100 bar gave 26 mg **2** (R_t 4.6 min) and 60 mg piperitol [15]. HPLC of 4/2 (same conditions) gave 5 mg scopoletin (R_t 3.9 min), 22 mg pinoresinol (R_t 4.4 min) and 22 mg **1** (R_t 6.4 min). Prep. TLC of 4/3 in $CHCl_3$–MeOH (19:1) gave 15 mg eriodictyol. Roots of *H. diosmifolium* (100 g, voucher Robinson 86-0019) gave by CC three fractions. Fraction 1 afforded by prep. TLC in CH_2Cl_2–C_6H_6 (1:1) 20 mg *ent*-kaurenic acid and 15 mg **12**. Prep. TLC of fraction 2 in CH_2Cl_2–C_6H_6–Et_2O (3:3:1) gave 7 mg **5**, 7 mg **7** and 3 mg **6** while that of fraction 3 in Et_2O petrol (7:3) afforded 7 mg **10** (R_f 0.7) and 3 mg **9** (R_f 0.56). The extract of the aerial parts (580 g) was separated into five CC fractions. Prep. TLC of fraction 1 in CH_2Cl_2–C_6H_6 (1:1), gave 5 mg 8β-hydroxy-11α,12β-diacetoxypimar-16-ene, 8 mg **11** (R_f 0.55) and 8 mg **17** (R_f 0.51). Fraction 2 was a mixture of acids (IR and ^{1}H NMR). After addition of CH_2N_2, prep. TLC in CH_2Cl_2 C_6H_6 Et_2O (7:7:1) gave 15 mg methyl-3-prenyl-4-acetoxycinnamate, 25 mg spathulenol and 120 mg **12a** (R_f 0.45). Fraction 3 also was a mixture of acids. After addition of CH_2N_2 prep. TLC in Et_2O petrol (4:1) gave three bands (3/1–3/3). Prep. TLC of 3/1 in CH_2Cl_2–C_6H_6 Et_2O (7:7:1), three developments, gave 17 mg **15a** (R_f 0.71), 7 mg of the corresponding acetate (R_f 0.65), 15 mg of free phenol (R_f 0.43) and 35 mg methyl cinnamoate. Prep. TLC of 3/2 in CH_2Cl_2 C_6H_6–Et_2O (5:5:1) gave 12 mg **7** and 5 mg **16a** (R_f 0.5). Prep. TLC of 3/3 in CH_2Cl_2 C_6H_6 Et_2O (1:1:1) gave 9 mg **9** (R_f 0.41) and 8 mg **17**. Prep. TLC of fraction 4 in Et_2O–petrol (4:1) gave three bands (4/1–4/3). Prep. TLC of 4/1, after addition of CH_2N_2, in CH_2Cl_2–C_6H_6 Et_2O (7:7:1) gave 6 mg **14a**. 4/2 contained 250 mg cinnamic acid and fraction 4/3 gave after addition of CH_2N_2 and repeated prep. TLC 7 mg **13a**. Fraction 5 after addition of CH_2N_2 gave after prep. PTLC in CH_2Cl_2–C_6H_6–Et_2O (3:3:1) 9 mg **15a** (R_f 0.35).

The extract of the aerial parts of *H. stirlingii* (550 g, voucher Robinson 86-0067) gave five CC fractions after elution with Et_2O petrol (1:9), (1:1), (3:1), Et_2O and Et_2O MeOH (9:1). Prep. TLC of one tenth of fraction 1 in CH_2Cl_2–C_6H_6 (1:1) gave 12 mg **20** (R_f 0.72) and 21 mg **21** (R_f 0.61). Fraction 2 contained 17 g pinocembrin. Prep. TLC of one tenth of fraction 3 in CH_2Cl_2 C_6H_6–Et_2O (3:3:1) gave 11 mg **22** (R_f 0.68) and 9 mg **23** (R_f 0.44). Prep. TLC of one tenth of fraction 4 in CH_2Cl_2–C_6H_6 Et_2O (3:3:1) gave 5 mg 3-acetoxypinocembrin and 15 mg 3-hydroxypinocembrin. Fraction 5 contained 1.5 g 2,3-dihydroxycinnamic acid. CC of the extract of the roots (95 g) gave three fractions. Prep. TLC of fraction 1 in CH_2Cl_2 C_6H_6 Et_2O (3:3:1) gave 5 mg **5** and 5 mg **7**. Prep. TLC of fraction 2 (same solvent) gave 9 mg betulonic acid and 7 mg **18** (R_f 0.47). Prep. TLC of fraction 3 in Et_2O petrol (7:3) gave 5 mg **10** and a mixture which gave by HPLC using MeOH H_2O (7:3) 10 mg **8** (R_t 4.1 min) and 7 mg **9** (R_t 4.5 min).

Known compounds were identified by comparing the 400 MHz ^{1}H NMR spectra with those of authentic material and by comparison with lit. data.

Acuminatin (**1**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3600 (OH), 1605, 1517 (aromatic); MS *m/z* (rel. int.): 358.142 [M]$^+$ (62) (calc. for $C_{20}H_{22}O_6$: 358.142), 340 [M − H_2O]$^+$ (6), 327 [M − CH_2OH]$^+$ (3), 192 [$C_{11}H_{12}O_3$]$^+$ (37), 137 [$C_8H_9O_2$]$^+$ (100). ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.37 (*dddd*, H-1), 4.78 (*d*, H-2), 4.04 and 3.74 (*dd*, H-4), 2.71 (*ddddd*, H-5), 2.89 and 2.53 (*dd*, H-6), 3.91 and 3.76 (*dd*, H-8), 6.85 *br s*, 6.84 *d*, 6.77 *br s* (2H), 6.69 *br d*, 6.68 *br s* (aromatic H), 3.87 (*s*, OMe), 5.94 (*s*, OCH_2O); *J* (Hz): 1, 2 = 1, 5 = 1, 8 = 7; 4, 4′ = 8; 4, 5 = 6.5; 5, 6 = 5; 5, 6′ = 10.5; 6, 6′ = 13; 8, 8′ = 11.

Acuminatolide (**2**). Colourless crystals, mp 118°; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1775 (γ-lactone), 1610, 1515, 1500 (aromatic); MS *m/z* (rel. int.): 248.068 [M]$^+$ (100) (calc. for $C_{13}H_{12}O_4$: 248.068), 218 [M − CH_2O]$^+$ (6), 163 (21), 150 (43), 149 (42), 135 (34), 134 (19); ^{1}H NMR ($CDCl_3$): δ 3.08 (*dddd*, H-1), 4.61 (*d*, H-2), 4.36 and 4.19 (*dd*, H-4), 3.44 (*ddd*, H-5), 4.50 and 4.32 (*dd*, H-8), 6.84 and 6.79 (*br s*, aromatic H), 5.97 (*s*, OCH_2O); *J* (Hz): 1, 2 = 7; 1, 5 = 9; 1, 8 = 7; 1, 8′ = 2; 4, 4′ = 9.5; 4, 5 = 9; 4′, 5 = 3.5; 8, 8′ = 10; $[\alpha]_D^{24°}$ − 37 ($CHCl_3$; *c* 0.11).

4-Methyl-1-carbomethoxyazulene (**3**). Amorphous violet powder; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1700 (CO_2R); CIMS *m/z* (rel. int.): 201 [M + 1]$^+$ (100) ($C_{13}H_{12}O_2$ + 1), 169 [201 − MeOH]$^+$ (15); ^{1}H NMR ($CDCl_3$): δ 8.32 (*d*, H-2), 7.32 (*d*, H-3), 7.45 (*d*, H-5), 7.72 (*t*, H-6), 7.50 (*t*, H-7), 9.71 (*d*, H-8), 2.98 (*s*, H-9), 3.95 (*s*, OMe) [*J* (Hz): 2, 3 = 4; 5, 6 = 6, 7 = 7, 8 = 10].

13-Hydroxyobliquin (**8**). Colourless crystals, mp 183°; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3620 (OH), 1730 (coumarin); MS *m/z* (rel. int.): 260.068 [M]$^+$ (100) (calc. for $C_{14}H_{12}O_5$: 260.068), 229 [M − CH_2OH]$^+$ (6), 189 (24), 178 (30), 148 (31), 120 (30); ^{1}H NMR ($CDCl_3$): δ 6.29 (*d*, H-3), 7.57 (*d*, H-4), 7.00 (*s*, H-5), 6.88 (*s*, H-8), 4.46 and 4.14 (*dd*, H-9), 4.75 (*br d*, H-10), 5.43 and 5.38 (*br s*, H-12), 4.29 (*br s*, H-13); *J* (Hz): 3, 4 = 9.5; 9, 9′ = 11.5; 9, 10 = 2; 9′, 10 = 8.

5-Methoxy-13-hydroxyobliquin (**9**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3520 (OH), 1730 (coumarin); MS *m/z* (rel. int.): 290.079 [M]$^+$ (70) (calc. for $C_{15}H_{14}O_6$: 290.079), 262 [M − CO]$^+$ (15), 232 [262 − CH_2O]$^+$ (30), 178 (90), 149 (100); ^{1}H NMR ($CDCl_3$): δ6.24 (*d*, H-3), 7.93 (*d*, H-4), 6.64 (*s*, H-8), 4.49 and 4.14 (*dd*, H-9), 4.76 (*br d*, H-10), 5.44 and 5.40 (*br s*, H-12), 4.31 (*br s*, H-13); *J* (Hz): same as in compound **8**. $[\alpha]_D^{24}$ − 31 ($CHCl_3$; *c* 0.19).

5-Methoxy-13-oxo-obliquin (**10**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1735 (coumarin), 1700 (CHO); MS *m/z* (rel. int.): 288.063 [M]$^+$ (100) (calc. for $C_{15}H_{12}O_6$: 288.063), 260 [M − CO]$^+$ (7), 178 (66), 163 (48), 149 (56); ^{1}H NMR ($CDCl_3$): δ6.26 (*d*, H-3), 7.93 (*d*, H-4), 6.66 (*s*, H-8), 4.52 and 3.98 (*dd*, H-9), 5.10 (*br d*, H-10), 6.71 and 6.40 (*br s*, H-12), 9.66 (*s*, H-13); *J* (Hz): 3, 4 = 9.5; 9, 9′ = 11; 9, 10 = 2.5; 9′, 10 = 7.

13-Acetoxycaryophyllene (**11**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1735, 1250 (OAc); MS *m/z* (rel. int.): 262.193 [M]$^+$ (5) (calc. for $C_{17}H_{26}O_2$: 262.193), 202 [M − AcOH]$^+$ (16), 187 [202 − Me]$^+$ (22), 133 (58), 119 (68), 105 (58), 93 (100); ^{1}H NMR ($CDCl_3$): δ5.29 (*br dd*, H-5), 2.34 (*br ddd*, H-9), 1.11 (*s*, H-12), 4.12 and 4.03 (*d*, H-13), 4.98 and 4.86 (*br s*, H-14), 1.61 (*br s*, H-15); *J* (Hz): 1, 9 = 9.5; 13, 13′ = 11; 5, 6 = 12, 5, 6′ = 4; 9, 10 = 9, 10′ = 9.

Methyl-4-oxo-seco-caryophyllene-5-oate (**12a**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1715 (CO, CO_2R); MS *m/z* (rel. int.): 266.188 [M]$^+$ (2.5) (calc. for $C_{16}H_{26}O_3$: 266.188), 235 [M − OMe]$^+$ (1.5), 208 (10), 167 (14), 135 (44), 126 (56), 108 (100), 93 (95); ^{1}H NMR ($CDCl_3$): δ1.87 (*dt*, H-1), 1.63 (*dt*, H-2), 2.32 (*t*, H-3), 2.44 (*t*, H-6), 2.28 (*br t*, H-7), 2.36 (*br ddd*, H-9), 1.44 and 1.80 (*dd*, H-10), 4.75 and 4.68 (*br s*, H-12), 1.04 and 1.03 (*s*, H-13, H-14), 2.11 (*s*, H-15), 3.67 (*s*, OMe); *J* (Hz): 1, 9 = 9, 10′ = 10, 10′ = 10; 9, 10 = 9; 1, 2 = 2, 3 = 6, 7 = 7. $[\alpha]_D^{24}$ + 14 ($CHCl_3$; *c* 0.28).

Methyl-3-prenyl-4-O-[β-hydroxybutyryl]-coumarate (**13a**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3610 (OH), 1720 (CO_2R), 1640, 1600 (C=C); MS *m/z* (rel. int.): 332.162 [M]$^+$ (3) (calc. for $C_{19}H_{24}O_5$: 332.162), 301 [M − OMe]$^+$ (2), 246 [301 − C_4H_7]$^+$ (100), 191 (70); ^{1}H NMR ($CDCl_3$): δ7.38 (*br s*, H-2), 7.05 (*d*, H-5), 7.39 (*br d*, H-6), 7.65 (*d*, H-7), 6.38 (*d*, H-8), 3.23 (*br d*, H-10), 5.20 (*br t*, H-11), 1.76 (*br s*, H-13), 1.70 (*br s*, H-14), 2.78 and 2.71 (*dd*, H-2′), 4.33 (*ddq*, H-3′), 1.33 (*d*, H-4′), 3.81 (*s*, OMe); *J* (Hz): 5, 6 = 8; 7, 8 = 16; 10, 11 = 7; 2′, 2′ = 16; 2′, 3′ = 3.5; 2′, 3′ = 8.5; 3′, 4′ = 6.5.

Methyl-3-prenyl-4-O-[β-acetoxybutyryl]-coumarate (**14a**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1730 (CO_2R), 1640, 1600 (C=C); MS *m/z* (rel. int.): 374.173 [M]$^+$ (3) (calc. for $C_{21}H_{26}O_6$: 374.173), 343 [M − OMe]$^+$ (4), 314 [M − AcOH]$^+$ (2.5), 246 (41), 191 (30), 69 [C_3H_5CO]$^+$ (100); ^{1}H NMR ($CDCl_3$): δ7.36 (*br s*, H-2), 7.03 (*d*, H-5), 7.38 (*br d*, H-6), 7.65 (*d*, H-7), 6.37 (*d*, H-8), 3.22 (*br d*, H-10), 5.21 (*br t*, H-11), 1.76 (*br s*, H-13), 1.69 (*br s*, H-14), 2.90 and 2.78 (*dd*, H-2′), 5.39 (*ddq*, H-3′), 1.40 (*d*, H-4′), 2.05 (*s*, OAc), 3.81 (*s*, OMe); *J* (Hz) as **13a**, except 2′, 3′ = 7.5; 2′, 3′ = 5.

Methyl-3-[3-hydroxy-3,3-dimethylprop-1-enyl]-4-O-[β-acetoxybutyryl]-coumarate (**15a**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3540 (OH), 1735 (CO_2R), 1640, 1600 (C=C); MS *m/z* (rel. int.): 390.168 [M]$^+$ (0.2) (calc. for $C_{21}H_{26}O_7$: 390.168), 372 [M − H_2O]$^+$ (1), 359 [M − OMe]$^+$ (1), 330 [M − AcOH]$^+$ (0.5), 244 [372 − $C_6H_8O_3$]$^+$ (14), 229 [244 − Me]$^+$ (100), 69 [C_3H_5CO]$^+$ (68); ^{1}H NMR ($CDCl_3$): δ7.66 (*d*, H-2), 7.08 (*d*, H-5), 7.41 (*dd*, H-6), 7.67 (*d*, H-7), 6.43 (*d*, H-8), 6.66 (*d*, H-10), 6.38 (*d*, H-11), 1.42 (*s*, H-13, H-14), 2.90 and 2.81 (*dd*, H-2′), 5.43 (*ddq*, H-3′), 1.41 (*d*, H-4′), 2.06 (*s*, OAc), 3.81 (*s*, OMe); *J* (Hz): 2, 6 = 1.5; 5, 6 = 8; 7, 8 = 10, 11 = 16; 2′, 2′ = 15; 2′, 3′ = 7; 2′, 3′ = 5; 3′, 4′ = 7.

Methyl-3-[3-peroxy-3,3-dimethylprop-1-enyl]-4-O-[β-acetoxybutyryl]-coumarate (**16a**). Colourless oil; CIMS *m/z* (rel. int.): 391 [M − Me]$^+$ (7), 373 [M + 1 − H_2O_2]$^+$ (4), 269 (100); ^{1}H NMR ($CDCl_3$) as compound **15a**, except 6.64 (*d*, H-10), 6.31 (*d*, H-11), 1.44 (*s*, H-13, H-14), 8.44 (*s*, OOH). 5 mg **16a** in 0.5 ml $CDCl_3$ gave, after addition of triphenylphosphine, **15a**, identical with the Me ester of the natural compound.

2-Prenyl-4-vinylphenol (**17**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3600 (OH), 1610 (C=C); CIMS *m/z* (rel. int.): 189 [M + 1]$^+$ (100) ($C_{13}H_{16}O$ + 1), 161 [189 − CO]$^+$ (45); ^{1}H NMR ($CDCl_3$): δ7.16 (*d*, H-3), 7.18 (*dd*, H-5), 6.76 (*d*, H-6), 6.63 (*dd*, H-7), 5.59 (*d*, H-8t), 5.10 (*d*, H-8c), 3.15 (*br d*, H-1′), 5.31 (*br t*, H-2′), 1.79 (*br s*, H-4′), 1.77 (*br s*, H-5′); *J* (Hz): 3, 5 = 2; 5, 6 = 8; 7, 8t = 17; 7, 8c = 11; 1′, 2′ = 7.

3-Angeloyloxy-12-hydroxytremetone (**18**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3600 (OH), 1720 (C=CCO_2R), 1690, 1620 (PhCO); MS *m/z* (rel. int.): 316.131 [M]$^+$ (3.5) (calc. for $C_{18}H_{20}O_5$: 316.131), 216 [M − RCO_2H]$^+$ (64), 201 [216 − Me]$^+$ (32), 83 [C_4H_7CO]$^+$ (100), 55 [83 − CO]$^+$ (73); ^{1}H NMR ($CDCl_3$): δ5.37 (*d*, H-2), 6.38 (*d*, H-3), 8.07 (*d*, H-4), 8.01 (*dd*, H-6), 7.00 (*d*, H-7), 2.57 (*s*, H-9), 5.41 and 5.40 (*br s*, H-11), 4.29 and 4.22 (*d*, H-12), OCOR: 6.11 (*qq*, H-3′), 1.93 (*dq*, H-4′), 1.79 (*dq*, H-5′); *J* (Hz): 2, 3 = 5.5; 4, 6 = 2; 6, 7 = 8.5; 12, 12′ = 13; 3′, 4′ = 7.5; 3′, 5′ = 4′, 5′ = 1.5. $[\alpha]_D^{24}$ + 70 ($CHCl_3$; *c* 0.09).

Pinocembrin-7-O-[4-(1-hydroxyethyl)]-phenylether (**19**). Colourless crystals, mp 107°; MS *m/z* (rel. int.): 376.131 [M]$^+$ (69) (calc. for $C_{23}H_{20}O_5$: 376.131), 361 [M − Me]$^+$ (100), 257 [361 − C_8H_8, RDA]$^+$ (72), 179 (28), 147 (26); ^{1}H NMR ($CDCl_3$): δ5.42 (5.41) (*dd*, H-2), 3.11 (3.10) (*dd*, $H-3_1$), 2.85 (2.84) (*dd*, $H-3_2$), 5.93 (*s*, H-6, H-8), 6.83 (*br d*, H-2′, H-6′), 7.27 (*br d*, H-3′, H-5′), 4.76 (*dq*, H-7′), 1.61 (1.62) (*d*, H-8′), 7.43 (*m*, phenyl), 5.52 (*br s*, OH), 12.5 (12.58) (*s*, 5-OH); *J* (Hz): 2, 3_1 = 13; 2, 3_1 = 2.5; 3_1, 3_2 = 17; 2′, 3′ = 8; 7′, 8′ = 7′, OH = 7.

Geranyl cinnamate (**20**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1720, 1635 (C=CCO_2R); CIMS *m/z* (rel. int.): 285 [M + 1]$^+$ (12), 153 [$C_{10}H_{17}O$]$^+$ (42), 137 [$C_{10}H_{17}$]$^+$ (100); ^{1}H NMR ($CDCl_3$): δ7.53 and 7.39 (*m*, phenyl), 7.70 (*d*, H-7), 6.44 (*d*, H-8), 4.70 (*d*, H-1′), 5.35 (*br t*, H-2′), 2.14 and 2.05 (*m*, H-4′, H-5′), 5.12 (*br t*, H-6′), 1.69 (*br s*, H-8′), 1.52 (*br s*, H-9′), 1.80 (*br s*, H-10′); *J* (Hz): 7, 8 = 16; 1′, 2′ = 5′, 6′ = 7.

2-Phenylethyl cinnamate (**21**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1730, 1650, 1610 (C=CCO_2R); MS *m/z* (rel. int.): 252.115 [M]$^+$ (0.5) (calc. for $C_{17}H_{16}O_2$: 252.115), 131 [RCO]$^+$ (48), 104 [C_8H_8]$^+$ (100), 77 [C_6H_5]$^+$ (30); ^{1}H NMR ($CDCl_3$): δ7.53 and 7.39 (*m* H-2 H-6), 7.68 (*d*, H-7), 6.43 (*d*, H-8), 4.43 (*t*, H-8′), 3.03 (*t*, H-7′), 7.33 and 7.27 (*m*, H-3′, H-7′); *J* (Hz): 7, 8 = 16; 1′, 2′ = 7.

Dihydroconiferyl cinnamate (**22**). Colourless oil; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3550 (OH), 1720, 1645 (C=CCO_2R); MS *m/z* (rel. int.): 312.136 [M]$^+$ (27) (calc. for $C_{19}H_{20}O_4$: 312.136), 164 [M − RCO_2H]$^+$ (100), 149 [164 − Me]$^+$ (48), 131 [RCO]$^+$ (28), 103 [131 − CO]$^+$ (28); ^{1}H NMR ($CDCl_3$): δ7.54 and 7.40 (*m*, H-2-H-6), 7.69 (*d*, H-7), 6.47 (*d*, H-8), 4.23 (*t*, H-9′), 2.01 (*tt*, H-8′), 2.68 (*t*, H-7′), 6.71 (*br s*, H-6′), 6.85 (*d*, H-2′), 6.72 (*d*, H-3′), 3.89 (*s*, OMe); *J* (Hz): 7, 8 = 16; 8′, 9′ = 6.5; 7′, 8′ = 7.5; 2′, 3′ = 8.5.

3′-Hydroxydihydroconiferyl cinnamate (**23**). Colourless oil, IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3460 (OH), 1720, 1640 (C=CCO_2R); MS *m/z* (rel. int.): 328.131 [M]$^+$ (5) (calc. for $C_{19}H_{20}O_5$: 328.131), 180 [M − RCO_2H]$^+$ (15), 131 [RCO]$^+$ (100); ^{1}H NMR ($CDCl_3$): δ7.53 and 7.39 (*m*, H-2 H-6), 7.68 (*d*, H-7), 6.46 (*d*, H-8), 4.23 (*t*, H-9′), 2.01 (*tt*, H-8′), 2.64 (*t*, H-7′), 6.47 (*d*, H-2′), 6.32 (*d*, H-6′), 3.86 (*s*, OMe); *J* (Hz): see compound **22**, except 2′, 6′ = 1.5.

Acknowledgements We thank the Fonds der Chemischen Industrie, Frankfurt, for financial support. V. P. Pathak also thanks the Alexander von Humboldt Foundation for a fellowship.

REFERENCES

1. Jakupovic, J., Kuhnke, J., Schuster, A., Metwally, M. A. and Bohlmann, F. (1986) *Phytochemistry* **25**, 1133 and references cited therein.

2. Hearon, W. M. and MacGregor, W. S. (1955) *Chem. Rev.* **55**, 957.
3. Bohlmann, F. and Zdero, C. (1973) *Chem. Ber.* **106**, 1337.
4. Bohlmann, F. and Zdero, C. (1980) *Phytochemistry* **19**, 331.
5. Dean, F. M. and Parton, B. (1969) *J. Chem. Soc.* 526.
6. Bohlmann, F. and Jakupovic, J. (1979) *Phytochemistry* **18**, 1189.
7. Zdero, C., Bohlmann, F., King, R. M. and Robinson, H. (1987) *Phytochemistry* (in press).
8. Bohlmann, F., Mahanta, P. K., Jakupovic, J., Rastogi, R. C. and Natu, A. A. (1978) *Phytochemistry* **17**, 1165.
9. Bohlmann, F. and Zdero, C. (1975) *Chem. Ber.* **108**, 362.
10. Bohlmann, F., Wallmeyer, M., Jakupovic, J. and Ziesche, J. (1983) *Phytochemistry* **22**, 1645.
11. Bohlmann, F., Zdero, C., King, R. M. and Robinson, H. (1984) *Liebigs Ann. Chem.* 503.
12. Bohlmann, F. and Grenz, M. (1970) *Chem. Ber.* **103**, 90.
13. Bohlmann, F. and Franke, H. (1973) *Phytochemistry* **12**, 726.
14. Bohlmann, F. and Suwita, A. (1978) *Phytochemistry* **17**, 1929.
15. Kisiel, W. (1980) *Planta Med.* **38**, 285.
16. Bohlmann, F., Zdero, C., King, R. M. and Robinson, H. (1984) *Phytochemistry* **23**, 1979.