Pergamon

Tetrahedron 54 (1998) 6065–6078

TETRAHEDRON

Peracid Induced Oxidative Rearrangements of Triterpenoids: Products of New Skeleton from Bauerenyl Acetate

Ajit Kumar Chakravarty* and Binayak Das

Indian Institute of Chemical Biology, Calcutta-700032, India

Kazuo Masuda, Yoko Arai and Kenji Shiojima

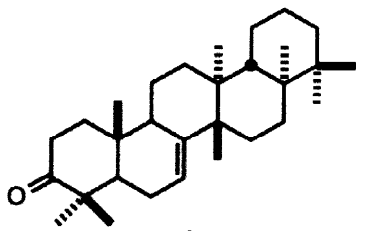
Showa College of Pharmaceutical Sciences, Machida, Tokyo 194-8543, Japan

Received 31 December 1997; accepted 2 April 1998

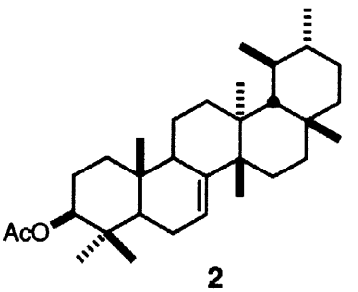
Abstract: Treatment of bauerenyl acetate (**2**) with *m*-chloroperbenzoic acid at 4 °C yielded the migrated products, *viz.* 7α-hydroxy-14,27-cycloisoursan-3β-yl acetate (**9**) and its 15α-hydroxy derivative (**12**) belonging to a new skeleton, 7α-hydroxyisours-14-en-3β-yl acetate (**10**) and 14α,15α-epoxy-7α-hydroxyisoursan-3β-yl acetate (**11**), besides 7α,8α-epoxybaueran-3β-yl acetate (**3**), bauera-7,9(11)-dien-3β-yl acetate (**4**), bauera-6,8-dien-3β-yl acetate (**5**), 7α,8α-epoxybauer-9(11)-en-3β-yl acetate (**6**), 7α,8α,9α,11α-diepoxybaueran-3β-yl acetate (**7**) and 8α,9α-epoxy-7α-hydroxybaueran-3β-yl acetate (**8**). The structures of all the products were elucidated mainly on the basis of 2D NMR spectral analyses. The ^{1}H and ^{13}C chemical shifts of bauerenyl acetate (**2**) and its reaction products (**3–12**) were assigned unambiguously.

Recently we reported[1] a number of products obtained by treatment of swertanone (**1**), a migrated gammacerane triterpenoid, with *m*-chloroperbenzoic acid as well as with mineral acids and Lewis acids. In the main rearranged product, the Δ^{7} double bond of **1** shifted to Δ^{14} position with simultaneous migration of C-14 methyl to C-8 through the carbonium ion at C-8 produced *via* opening of the 7α,8α-epoxide ring initially formed. In the reaction with the same peracid under identical conditions, bauerenyl acetate (**2**), a migrated ursane triterpenoid, gave a mixture of a large number of products having very close *Rf* values on TLC, and not a single compound could be obtained pure by repeated column chromatography over either neutral alumina or silica gel. ^{1}H NMR spectra of some of the chromatographic fractions showed very up-field signals at ~δ 0.2 ppm assignable to cyclopropane methylene protons. This prompted us to undertake separation of the reaction products by prep. HPLC, since no ursane or migrated ursane derivatives with a cyclopropane ring was so far known in the literature. Though the separation of the individual compounds from the mixture of reaction products was found to be very tough even in HPLC, we ultimately were able to isolate as many as ten new compounds (**3–12**) by repeated prep. HPLC. Among them, two compounds **9** and **12** were found to possess new 14,27-cycloisoursane skeleton, and compounds **10** and **11** were proved to be the members of isoursane skeleton. For comparison, compounds **2** and **13** (deshydroxy derivative of **9**) were also subjected to mineral acid rearrangement to get urs-13(18)-en-3β-yl acetate (70%) and α-amyrin acetate (20 %), and α-amyrin acetate (80 %) respectively. The structures of the reaction products were established by detailed analyses of their 2D NMR spectra which also resulted in the unambiguous assignment of ^{1}H and ^{13}C chemical shifts of all the compounds. The results as well as the plausible mechanism of formation of the products have been discussed herein.

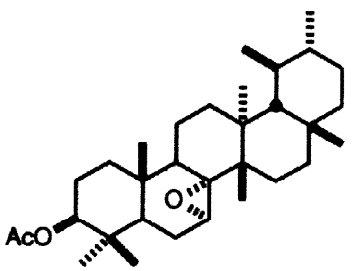
0040-4020/98/$19.00
PII: S0040-4020(98)00300-7



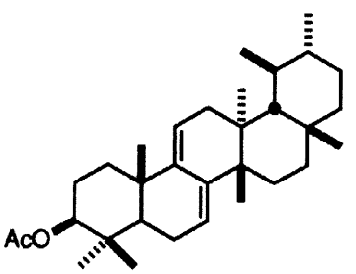
1



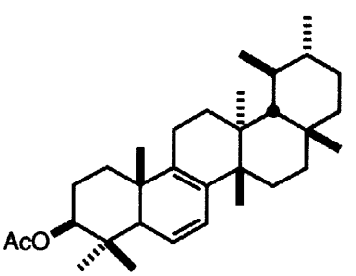
2



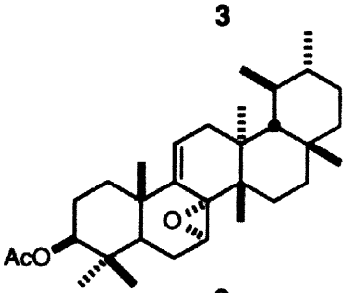
3



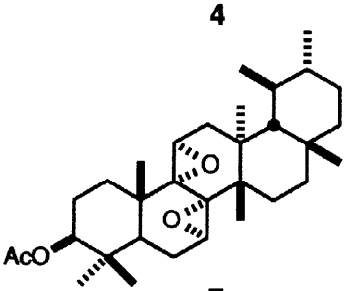
4



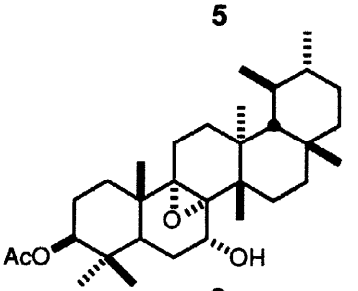
5



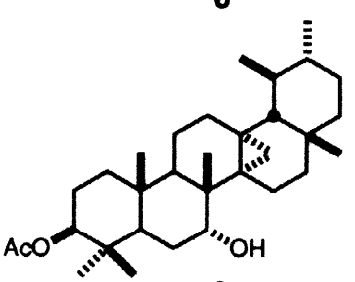
6



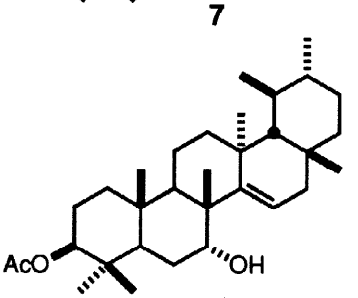
7



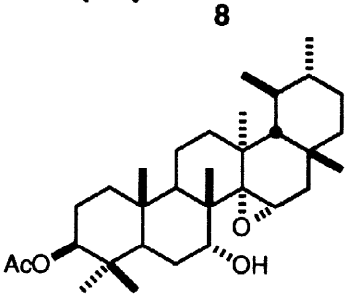
8



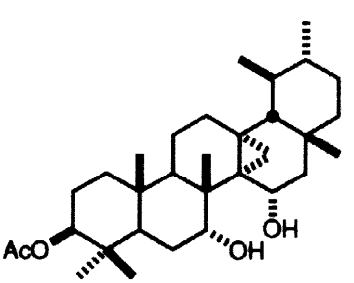
9



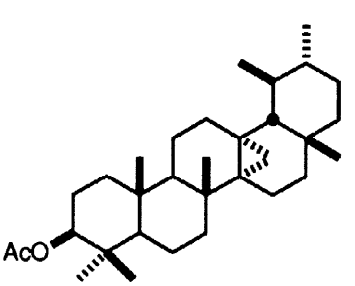
10



11



12



13

Characterization of the products.

For characterization of the products, mainly 1D and 2D NMR spectroscopy were extensively used. The multiplicity of each of the ^{13}C NMR signals of the compounds were deduced from the DEPT experiments. The chemical shifts of the directly bonded ^{1}H and ^{13}C were determined from ^{1}H–^{13}C COSY or HSQC spectra. The two- and three-bond correlation peaks observed for the methyl protons and some methine and methylene protons with the neighbouring carbons in the HMBC spectra of the compounds established their part structures as shown by heavy lines in structures **3a–13a** in Fig. 1. The remaining carbon-carbon connectivities shown by broken lines could be determined from the ^{1}H–^{1}H COSY spectra. Thus the chemical shifts of ^{1}H and ^{13}C of all the compounds summarized in Tables 1 and 2 could be assigned unambiguously.

Table 1. ^{1}H chemical shifts*(δ ppm, $CDCl_3$, 500 MHz) of bauerenyl acetate (**2**) and its reaction products (**3–13**)

Compd.	H_3-23	H_3-24	H_3-25	H_3-26	H_3-27/ H_2-27	H_3-28	H_3-29	H_3-30	H-3α	H-7	H-6/ H-11/ H-15	OAc
2	0.929	0.847	0.766	0.994	0.943	1.037	1.047d (7.0)	0.905d (5.8)	4.516ddd (11.3,4.3)	5.412ddd (4.0,3.0,3.0)		2.054
3	0.858	0.932	0.854	1.004	1.067	1.026	1.040d (6.7)	0.916d (5.8)	4.441dd (11.9,4.0)	3.133dd (1.8,1.8)		2.039
4	0.862	0.956	0.931	0.896	0.713	1.064	1.036d (6.7)	0.904d (6.7)	4.511dd (11.0,4.3)	5.433m	5.217m	2.061
5	0.932	0.993	0.760	1.025	0.894	1.067	0.995d (6.4)	0.908d (6.1)	4.550dd (11.6,4.4)	6.088dd (10.0,2.9)	5.690dd (10.0,2.7)	2.062
6	0.874	0.909	0.981	0.960	1.032	1.053	1.031d (6.7)	0.915d (6.7)	4.487dd (11.7,4.1)	3.292dd (1.5,1.5)	5.705dd (4.9,2.8)	2.043
7	0.874	0.915	1.054	1.028	1.133	1.035	1.027d (5.0)	0.911d (5.8)	4.439dd (11.7,3.8)	3.327dd (1.8,1.8)	3.189dd (1.8,1.8)	2.029
8	0.843	0.843	1.050	1.071	1.130	1.041	0.965br.s	0.891d (5.8)	4.482dd (11.6,4.3)	4.069d (7.0)		2.043
9	0.829	0.821	0.865	1.118	0.227d (5.2) 0.860d (5.2)	0.880	0.923d (5.8)	0.851d (5.5)	4.495dd (11.6,4.9)	3.781dd (2.6,2.6)		2.012
10	0.874	0.871	0.923	1.112	0.988	0.966	1.029d (6.7)	0.974d (6.5)	4.531dd (11.3,4.3)	3.962dd (2.8,2.8)	5.630dd (7.3,2.8)	2.042
11	0.847	0.861	0.921	1.022	1.073	1.022	1.019d (7.0)	0.891d (5.5)	4.555dd (11.4, 4.7)	3.522dd (3.0,3.0)	3.420dd (2.0,2.0)	2.035
12	0.846	0.859	0.902	1.160	0.465d (6.4) 1.060d (6.4)	0.910	0.967d (6.1)	0.880d (5.5)	4.526dd (11.6,4.6)	3.831dd (2.9,2.9)	4.497dd (8.7,8.7)	2.035
13	0.840	0.840	0.881	1.139	0.013d (5.5) 0.650d (5.5)	0.893	0.938d (6.1)	0.870d (5.8)	4.467dd (10.8, 4.7)			2.053

*Figures in the parentheses are the coupling constants in Hz. Assignments were done on the basis of 2D NMR spectral analyses.

Table 2. ^{13}C Chemical shifts†(δ, $CDCl_3$, 125 MHz) of bauerenyl acetate (**2**) and its reaction products (**3**—**13**).

Carbon	2††	3	4	5	6	7	8	9	10	11	12	13
1	36.54	37.14	35.12	32.66	35.75	27.48	31.57	37.65	37.16	37.04	37.48	38.06
2	23.98	23.81	24.20	24.13	24.13	22.88	23.40	23.44	23.59	23.42	23.44	23.53
3	81.16	80.78	80.94	80.76	80.48	79.98	80.22	80.86	80.92	80.83	80.83	81.00
4	37.77	37.16	37.85	37.26	37.02	37.25	37.02	37.21	37.19	37.04	37.21	37.78
5	50.57	44.92	48.02	51.07	39.93	39.57	38.00	46.59	46.34	45.42	46.74	55.79
6	24.21	22.80	23.62	124.42	22.46	22.69	28.19	24.26	23.48	24.89	25.01	18.01
7	116.26	53.72	117.30	124.79	51.99	53.00	63.81	72.88	71.59	71.84	73.18	38.35
8	145.47	64.04	141.19	134.73	62.24	62.57	73.08	41.02	45.43	42.16	41.97	36.97
9	48.16	49.01	144.61	138.31	142.94	62.88	70.67	43.53	41.75	41.85	43.35	50.04
10	35.08	34.96	36.16	37.97	36.52	35.53	36.79	37.55	38.21	38.29	38.04	37.20
11	16.83	16.04	114.30	20.10	124.81	55.52	21.13	16.95	16.73	16.82	17.22	17.60
12	32.39	31.47	36.82	28.75	37.53	33.43	28.36	33.17	32.34	32.67	32.33	35.07
13	37.75	38.78	38.45	37.97	38.76	38.42	39.37	23.73	39.74	37.80	28.44	26.52
14	41.27	39.83	39.86	39.53	39.10	39.19	39.63	27.27	155.27	71.97	32.25	32.15
15	28.89	23.20	27.21	26.09	22.02	21.83	24.31	20.46	118.19	59.08	66.61	21.26
16	37.71	36.63	37.44	37.91	36.90	36.74	37.38	27.05	40.26	39.28	38.44	27.24
17	32.06	32.24	32.23	31.86	32.33	32.00	31.86	31.60	33.58	31.73	33.96	31.89
18	54.92	55.00	52.56	52.23	53.15	54.18	54.03	52.49	60.05	57.06	51.62	53.97
19	35.35	34.87	35.30	35.98	34.92	34.93	35.32	40.92	35.83	35.54	40.36	38.41
20	32.06 (38.0)	31.95	31.92	31.92	31.85	31.87	31.80	38.29	35.93	31.75	38.20	40.75
21	29.22	29.05	29.17	29.63	29.07	29.06	29.19	30.93	28.63	28.50	30.90	31.07
22	31.53 (37.8)	30.92	31.32	33.24	31.20	31.98	32.66	41.87	37.95	30.45	41.74	42.05
23	27.52	27.67	27.52	27.59	27.80	27.17	28.36	27.60	27.65	27.74	27.59	27.86
24	15.80	16.94	16.35	17.69	17.22	16.84	16.62	16.62	16.70	16.92	16.53	16.43
25	13.04	14.43	20.61	13.84	23.76	19.42	17.13	15.68	15.28	15.58	15.52	16.11
26	23.67	19.17	20.30	22.74	17.90	25.24	19.96	18.39	26.96	23.59	19.70	17.96
27	22.67	21.30	17.03	15.69	25.15	19.05	15.69	13.00	19.32	18.81	12.12	13.28
28	38.01 (32.1)	37.62	37.71	38.27	37.59	37.99	37.90	28.11	36.73	36.51	28.35	28.22
29	25.65	25.55	25.09	25.19	17.81	18.80	25.47	17.81	26.68	25.11	17.64	17.91
30	22.55	22.48	22.44	22.43	22.42	22.38	22.46	20.66	22.37	22.37	20.61	20.71
$CO\underline{C}H_3$	21.34	21.30	21.30	21.30	21.30	21.26	21.27	21.28	21.31	21.30	21.30	21.32
$\underline{C}OCH_3$	171.03	170.85	170.99	171.07	170.82	170.62	170.81	170.90	170.93	170.87	170.88	171.00

† Chemical shifts were assigned to specific carbons on the basis of detailed analyses of 2D NMR *viz.* ^1H–^1H COSY, ^1H–^{13}C COSY, HSQC, HMBC and NOESY spectra.

†† Correct assignments on the basis of 2D NMR spectral analyses. Values in the parentheses are the previous assignments[1] on the basis of correlation with the reported data of other triterpenoids.

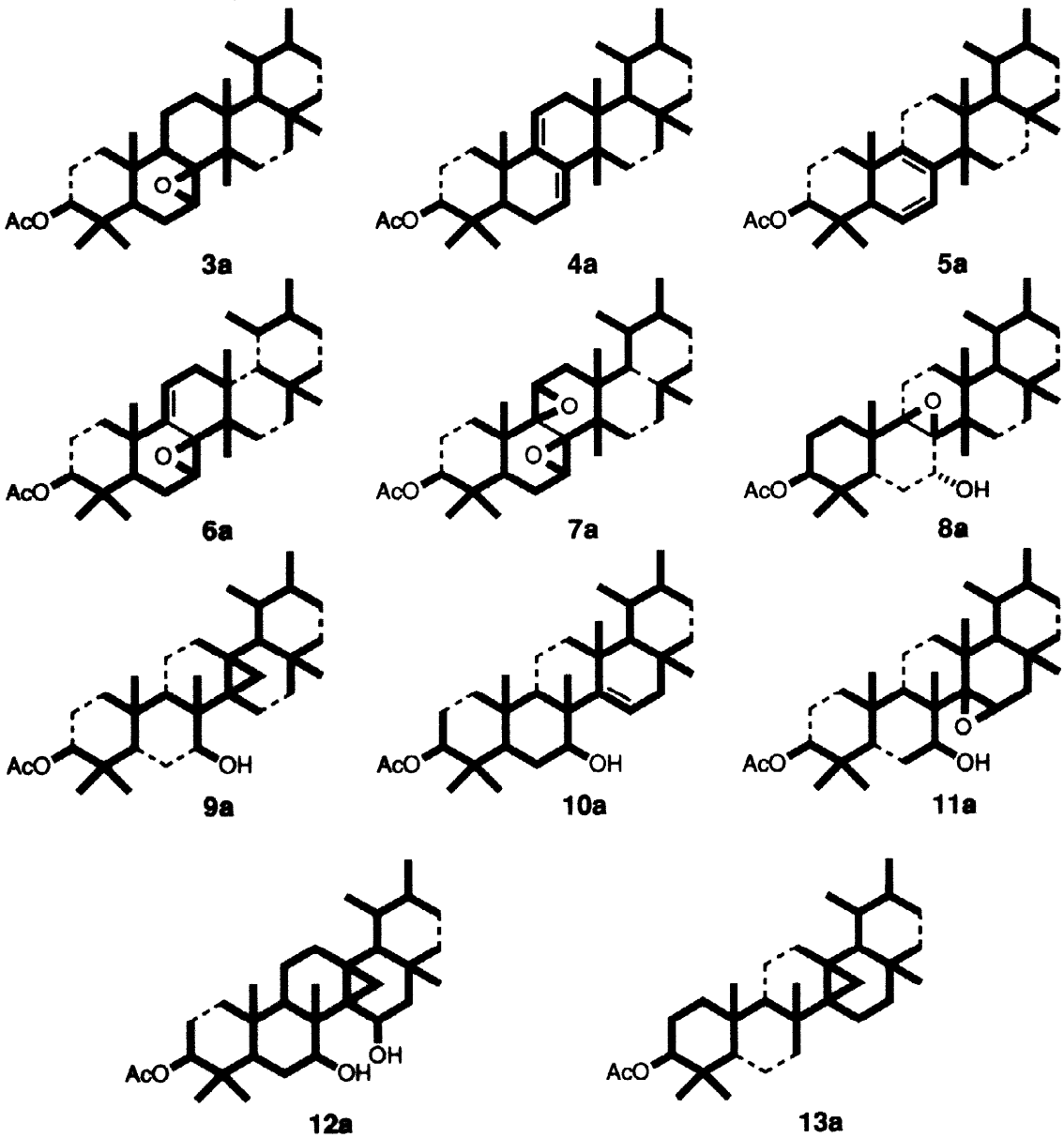


Fig. 1. Part structures (shown by heavy lines) derived from HMBC spectra

7α,8α-Epoxybaueran-3β-yl acetate (3). The high-resolution EIMS of the compound showed its molecular formula to be $C_{32}H_{52}O_3$ (M^+ *m/z* 484.3904) which is 16 mass units higher than that of bauerenyl acetate (**2**). A triplet-like one-proton signal at δ 3.133 ppm (dd, *J*=1.8, 1.8 Hz) in its ^1H NMR spectrum (Table 1) and the signals at 53.72 (d) and 64.04 (s) ppm in its ^{13}C NMR spectrum (Table 2) indicated the presence of a trisubstituted epoxide ring in the molecule. The HMBC correlations of H-9 proton signal (δ 1.77 ppm) with, amongst others, the epoxide carbons C-8 (δ 64.04 ppm) and C-7 (δ 53.72 ppm), and those of the epoxide proton signal (δ 3.133 ppm) with C-6 (δ 22.80 ppm) and C-5 (δ 44.92 ppm) clearly suggested that the epoxide ring must be located at C-7 and C-8 positions. Moreover, the up-field shift of the C-5 and C-15 signals of **3** by ~5 and ~6 ppm respectively compared to those of **2** (Table 2) indicated that the oxygen of the 7,8-epoxide is α-oriented.

Bauera-7,9(11)-dien-3β-yl acetate (4). The EIMS of the compound showed M^+ at *m/z* 466 which is 2 mass units less than that of **2**. While the ^1H NMR spectrum (Table 1) of the compound displayed two one-proton multiplets at δ 5.217 and 5.433 ppm for two olefinic protons, the two singlets at δ 141.19 and 144.61 ppm, and two doublets at δ 114.30 and 117.30 ppm in its ^{13}C NMR spectrum (Table 2) indicated that the compound contains two trisubstituted double bonds. That the two double bonds are conjugated and heteroannular in nature was revealed by the UV absorption maximum at 238 nm. The location of the diene system at $\Delta^{7,9(11)}$ was established by the HMBC spectrum of the compound which showed correlations of the vinyl protons, *viz.* H-7 with C-5, C-6, C-9 and C-14, and H-11 with C-8, C-10 and C-13 (*cf.* **4a** in Fig. 1).

Bauera-6,8-dien-3β-yl acetate (5). The EIMS of the compound exhibited the M^+ at *m/z* 466 as in **4**. Its ^1H NMR spectrum (Table 1) showed a pair of one-proton mutually coupled vinylic proton signals at δ 5.690 (dd, *J*=10.0, 2.7 Hz) and 6.088 (dd, *J*=10.0, 2.9 Hz) ppm both of which were further coupled to a CH proton resonating at δ 2.01 ppm (^1H–^1H COSY) demonstrating the presence of a >CH–CH=CH– moiety in the molecule. Its ^{13}C NMR spectrum (Table 2) exhibited, besides the signals for two vinylic CH carbons at δ 124.42 and 124.79 ppm, two quaternary carbon signals at δ 134.73 and 138.31 ppm indicating the presence of a tetrasubstituted double bond also in the molecule. That the two double bonds are conjugated and homoannular in nature was evident from the UV absorption maximum at 274 nm. Finally the location of the conjugated diene system at $\Delta^{6,8}$ was determined from the HMBC data of H_3-25 and the vinyl protons H-6 and H-7. Thus, H_3-25 showed correlations with C-1, C-5, C-9 (δ 138.31 s) and C-10, H-6 with C-8 (δ 134.73 s), and H-7 with C-5 and C-9.

7α,8α-Epoxybauer-9(11)-en-3β-yl acetate (6). The high resolution EIMS of the compound showed its molecular formula to be $C_{32}H_{50}O_3$ (M^+ *m/z* 482.3786). Its ^1H NMR spectrum displayed the signal for a vinylic proton of a trisubstituted double bond at δ 5.705 ppm (dd, *J*=4.9, 2.8 Hz) and an one-proton signal at δ 3.292 ppm ascribed to the proton of a trisubstituted epoxide ring, besides the signals for eight methyl groups and a carbinyl proton (Table 1). The ^{13}C NMR data (Table 2) also substantiated the presence of a trisubstituted double bond (δ 124.81 d and 142.94 s ppm) and a trisubstitued epoxide ring (δ 51.99 d and 64.24 s ppm). While the three-bond correlation of H_3-25 (δ 0.981 ppm) with C-9 (δ 142.94 ppm) observed in the HMBC spectrum clearly demonstrated the location of the trisubstituted double bond at $\Delta^{9(11)}$ position, the two- and three-bond correlations of the epoxide proton with C-6 (δ 22.46 ppm) and C-5 (δ 39.93 ppm) located the epoxide ring at 7,8-position. On the other hand, the up-field shift of C-5 and C-15 resonance frequencies of **6** by ~8 and ~5 ppm respectively compared to those of the diene **4** (Table 2) indicated that the oxygen of the epoxide ring is α-oriented.

7α,8α,9α,11α-Diepoxybaueran-3β-yl acetate (7). The high resolution EIMS showed the compound to have a molecular formula $C_{32}H_{50}O_4$ (M^+, *m/z* 498.3694). Neither ^1H nor ^{13}C NMR spectrum showed the presence of a double bond in the molecule. On the contrary, the presence of two trisubstituted epoxide rings were indicated [δ_H 3.198 ppm (dd, *J*=1.8, 1.8 Hz) and 3.327 ppm (dd, J=1.8, 1.8 Hz); δ_C 53.00 d, 55.52 d, 62.57 s and 62.88 s ppm]. The three-bond ^1H–^{13}C correlations of H_3-25 (δ 1.054 ppm) and H_3-26 (δ 1.028 ppm) with C-9 (δ 62.88 ppm) and C-8 (δ 62.57 ppm) respectively in its HMBC spectrum suggested that these two carbons (C-8 and C-9) form part of two epoxide rings. Moreover, the correlations of the two

epoxide protons, *viz.* H-7 (δ 3.327 ppm) with C-5 (δ 39.57 ppm), C-6 (δ 22.69 ppm) and C-8 (δ 62.57 ppm), and H-11 (δ 3.189 ppm) with C-9 (δ 62.88 ppm), C-12 (δ 33.43 ppm) and C-13 (δ 38.42 ppm) demonstrated the location of the epoxide rings at 7,8 and 9,11 positions. Since C-5 and C-15 of **7** resonated very close to those of **6** and C-1 (δ 27.48 ppm) of **7** suffered strong up-field shift by ~8 ppm compared to that of **6**, the oxygens of both the epoxide rings must be α-oriented.

8α,9α-Epoxy-7α-hydroxybaueran-3β-yl acetate (8). The high resolution EIMS of the compound showed its molecular formula to be $C_{32}H_{52}O_4$ (M^+ *m/z* 500.3895). Its ^1H NMR spectrum (Table 1) indicated the presence of an axial secondary hydroxyl (δ 4.069 d ppm) and an equatorial secondary acetoxyl (δ 4.482 dd ppm) groups. Its ^{13}C NMR spectrum revealed the presence of a tetrasubstituted epoxide ring (δ 70.67 s and 73.08 s ppm). However, the presence of any double bond in the molecule was not indicated. Examination of the ^1H–^1H COSY spectrum of the compound revealed that the carbinyl proton at δ 4.069 ppm was correlated with H_2-6 protons (δ 1.38 and 1.50 ppm). The axial hydroxyl group was, therefore, located at C-7. Its HMBC spectrum showed three-bond correlations, amongst others, between H_3-25 and C-9 (δ 70.67 s ppm), and between H_3-26 and C-10 (δ 73.08 s ppm) clearly demonstrating the location of the epoxide ring at 8,9 positions. That the epoxide oxygen is α-oriented was indicated by the up-field shift of the resonance frequency of C-1 by ~5 ppm as against that of **2** (Table 2).

7α-Hydroxy-14,27-cycloisoursan-3β-yl acetate (9). The high resolution EIMS of the compound showed its molecular formula to be $C_{32}H_{52}O_3$ (M^+, *m/z* 484.3950). Its ^1H NMR spectrum (Table 1) indicated the presence of a cyclopropane ring and seven methyl groups of which five are tertiary and two secondary. It was, therefore, evident that one of the tertiary methyl groups of bauerenyl acetate (**2**) is involved in the formation of the cyclopropane ring in **9**. The spectrum also indicated the presence of an axial secondary hydroxyl group and an equatorial secondary acetoxyl group in the molecule. Although the ^{13}C NMR spectrum of the compound (Table 2) fully corroborated the above observations, no clear idea was obtained regarding the location of the cyclopropane ring in the molecule. However, the structure of the compound could be established from its HMBC spectral analyses. Thus, two- and three-bond ^1H-^{13}C correlation data summarized in Table 3 revealed the presence of the part structure as shown by heavy lines in **9a** (Fig. 1). The correlations observed for the cyclopropane methylene protons (H_2-27) with C-8, C-12, C-13, C-14, C-15 and C-18 clearly demonstrated the attachment of the cyclopropane methylene group to C-13 and C-14. Again, the three-bond correlations of the hydroxymethine proton (H-7) with C-5 and C-9 indicated that the axial hydroxyl group must be located at C-7. This contention was further supported by the up-field shift of C-5 and C-9 (γ carbons) resonance frequencies compared to those[2] of α- or β-amyrins.

7α-Hydroxyisours-14-en-3β-yl acetate (10). The high resolution EIMS of the compound showed its molecular formula to be $C_{32}H_{52}O_3$ (M^+, *m/z* 484.3930). The presence of a trisubstituted double bond, an axial secondary hydroxyl group and an equatorial secondary acetoxyl group besides six tertiary methyl and two secondary methyl groups were indicated from its ^1H and ^{13}C NMR spectra (Tables 1 and 2). The characteristic splitting pattern of the vinylic proton signal as double doublet with J=7.3 and 2.8 Hz (*cf.* ^1H NMR spectrum of taraxerene[3]) led us to presume that the compound contains a Δ^{14} double bond. This was, in fact, confirmed by the HMBC spectral data of the compound summarized in Table 4. It can be seen therein that H_3-

Table 3. One-bond (^1H–^{13}C COSY) and multiple bond (HMBC) ^1H–^{13}C correlation data of **9**.

δ_H ppm	One-bond correlation δ_C ppm	Multiple-bond correlation δ_C ppm			
0.829 (H_3-23)	27.60 (C-23)	16.62 (C-24)	37.21 (C-4)	46.59 (C-5)	80.86 (C-3)
0.821 (H_3-24)	16.62 (C-24)	27.60 (C-23)	37.21 (C-4)	46.59 (C-5)	80.86 (C-3)
0.865 (H_3-25)	15.68 (C-25)	37.55 (C-10)	37.65 (C-1)	43.53 (C-9)	46.59 (C-5)
1.118 (H_3-26)	18.39 (C-26)	27.27 (C-14)	41.02 (C-8)	43.53 (C-9)	72.88 (C-7)
0.227d (H-27)	13.00 (C-27)	20.46 (C-15) 41.02 (C-8)	23.73 (C-13) 52.49 (C-18)	27.27 (C-14)	33.17 (C-12)
0.880 (H_3-28)	28.11 (C-28)	27.05 (C-16)	31.60 (C-17)	41.87 (C-22)	52.49 (C-18)
0.923d (H_3-29)	17.81 (C-29)	38.29 (C-20)	40.92 (C-19)	52.49 (C-18)	
0.851d (H_3-30)	20.66 (C-30)	30.93 (C-21)	38.29 (C-20)	40.92 (C-19)	
4.495dd (H-3)	80.86 (C-3)	16.62 (C-24)	27.60 (C-23)	37.21 (C-4)	170.90 (OAc)
3.781dd (H-7)	72.88 (C-7)	43.53 (C-9)	46.59 (C-5)		
1.53 (H-15)	20.46 (C-15)	13.00 (C-27)	23.73 (C-13)	31.60 (C-17)	
1.96 (H-15)	20.46 (C-15)	13.00 (C-27)	27.05 (C-16)		

Table 4. One-bond (^1H–^{13}C COSY) and multiple bond (HMBC) ^1H–^{13}C correlation data of **10**.

δ_H ppm	One-bond correlation δ_C ppm	Multiple-bond correlation δ_C ppm			
0.874 (H_3-23)	27.65 (C-23)	16.70 (C-24)	37.19 (C-4)	46.34 (C-5)	80.92 (C-3)
0.871 (H_3-24)	16.70 (C-24)	27.65 (C-23)	37.19 (C-4)	46.34 (C-5)	80.92 (C-3)
0.923 (H_3-25)	15.28 (C-25)	37.16 (C-1)	38.21 (C-10)	41.75 (C-9)	46.34 (C-5)
1.112 (H_3-26)	26.96 (C-26)	41.75 (C-9)	45.43 (C-8)	71.95 (C-7)	155.27 (C-14)
0.988 (H_3-27)	19.32 (C-27)	32.34 (C-12)	39.74 (C-13)	60.05 (C-18)	155.27 (C-14)
0.966 (H_3-28)	36.73 (C-28)	33.58 (C-17)	37.95 (C-22)	40.26 (C-16)	60.05 (C-18)
1.029d (H_3-29)	26.68 (C-29)	35.93 (C-20)	60.05 (C-18)		
0.974d (H_3-30)	22.37 (C-30)	28.63 (C-21)	35.83 (C-19)		
3.962dd (H-7)	71.59 (C-7)	26.96 (C-26)	41.75 (C-9)	46.34 (C-5)	
4.531dd (H-3)	80.92 (C-3)	16.70 (C-24) 170.93 (OAc)	23.59 (C-2)	27.65 (C-23)	37.19 (C-4)
5.630dd (H-15)	118.19 (C-15)	19.32 (C-27) 45.43 (C-8)	26.96 (C-26)	33.58 (C-17)	39.74 (C-13)
1.80, 2.13 (H_2-16)	40.26 (C-16)	33.58 (C-17)	36.73 (C-28)	37.95 (C-22)	60.05 (C-18)
		118.19 (C-15)	155.27 (C-14)		

26 proton signal exhibited correlations with C-7, C-8, C-9 and C-14 (δ 155.27 ppm) and H_3-27 proton signal with C-12, C-13, C-14 and C-18, while H_2-16 methylene proton signals showed correlations with C-14, C-15 (δ 118.19 ppm), C-17, C-18, C-22 and C-28 thereby unambiguously locating the trisubstituted double bond at

Δ^{14} position. Furthermore, the correlations of H_3-26 protons with C-7 (δ 71.59 ppm) and those of H-7 proton with C-5 and C-9 confirmed the location of the axial hydroxyl group at C-7.

14α,15α-Epoxy-7α-hydroxyisoursan-3β-yl acetate (11). The high resolution EIMS of the compound showed its molecular formula to be $C_{32}H_{52}O_4$ (M^+ *m/z* 500.3680). The presence of an axial hydroxyl, an equatorial acetoxyl and a trisubstituted epoxide ring was evident from its ^1H and ^{13}C NMR spectra (Tables 1 and 2). Its HMBC spectrum clearly demonstrated the location of the epoxide ring at 14,15 positions and that of the axial hydroxyl group at C-7 (*cf.* part structure shown by heavy lines in **11a** in Fig. 1). The orientation of the epoxide oxygen as α could be established from its NOESY spectrum which showed NOE interactions: H-15β (epoxide proton) ↔H-16β↔H_3-28β↔H-18β.

7α,15α-Dihydroxy-14,27-cycloisoursan-3β-yl acetate (12). The high resolution EIMS of the compound showed its molecular formula to be $C_{32}H_{52}O_4$ (M^+, *m/z* 500.3844) which is 32 mass units higher than the starting compound **2**. Its ^1H NMR spectrum (Table 1) exhibited, besides two one-proton signals at δ 4.526 (dd, *J*=11.6, 4.6 Hz) and 3.831 (dd, *J*=2.9, 2.9 Hz) ppm attributable to two carbinyl protons of 3β-acetoxy-7α-hydroxy triterpenoids (*vide supra*), an one-proton triplet-like double doublet at δ 4.497 (*J*=8.7, 8.7 Hz) ppm indicating the presence of one more hydroxyl group in the molecule. The appearance of two mutually coupled doublets at δ 0.465 and 1.060 (*J*=6.4 Hz) ppm and signals for five tertiary and two secondary methyl groups in the spectrum led us to assume that the compound is a hydroxy derivative of **9**. A comparison of the ^{13}C NMR spectrum of the compound with that of **9** (Table 2) revealed that the compounds differ only with respect to the substitution pattern in C/D ring system. The location of the additional hydroxyl group could, however, be ascertained from the HMBC spectrum of **12**. The ^1H-^{13}C multiple-bond correlations obtained from the HMBC spectrum of **12**, summarized in Table 5 revealed that the double doublet at δ 4.497 ppm is correlated with the cyclopropane methylene carbon (C-27) and a cylcopropane quaternary carbon (C-14), besides another methylene carbon (C-16) and a quaternary carbon (C-8) clearly demonstrating that the additional hydroxyl group must be located at C-15. The cyclopropane methylene protons (H_2-27) also showed, amongst others, a three-bond correlation with C-15 (δ 66.61 ppm) corroborating the assigned location of the additional hydroxyl group. Finally, the stereochemistry at most of the chiral centres including C-15 could be deduced from the NOE interactions observed in the NOESY spectrum of **12** as depicted in Fig. 2.

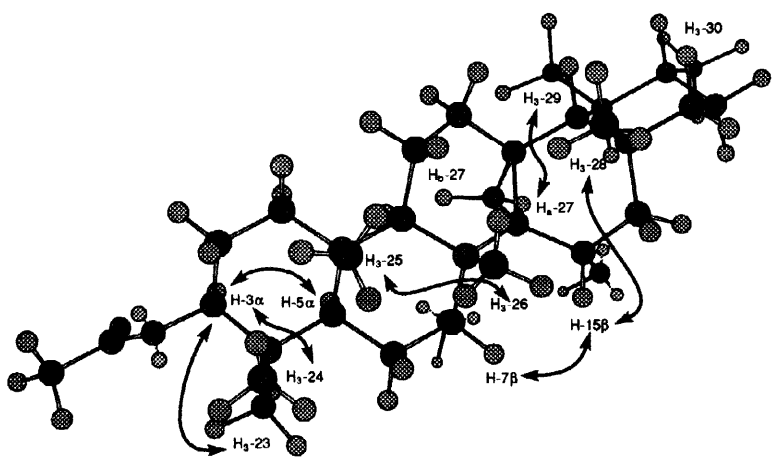


Fig. 2 Chem3D Pro[4] Drawing of **12** and NOEs (↔)

Table 5. One-bond (^1H–^{13}C COSY) and multiple bond (HMBC) ^1H–^{13}C correlation data of **12**.

δ_H ppm	One-bond correlation δ_C ppm	Multiple-bond correlation δ_C ppm			
0.859 (H_3-23)	27.59 (C-23)	16.53 (C-24)	37.21 (C-4)	46.74 (C-5)	80.83 (C-3)
0.846 (H_3-24)	16.53 (C-24)	27.59 (C-23)	37.21 (C-4)	46.74 (C-5)	80.83 (C-3)
0.902 (H_3-25)	15.53 (C-25)	37.48 (C-1)	38.04 (C-10)	43.35 (C-9)	46.74 (C-5)
1.160 (H_3-26)	19.70 (C-27)	32.25 (C-14)	41.97 (C-8)	43.35 (C-9)	73.18 (C-7)
0.465d, 1.06d (H_2-27)	12.12 (C-27)	28.44 (C-13) 66.61 (C-15)	32.25 (C-14)	41.97 (C-8)	51.62 (C-18)
0.910 (H_3-28)	28.35 (C-28)	33.96 (C-17)	41.74 (C-22)	51.62 (C-18)	
0.967d (H_3-29)	17.64 (C-29)	38.20 (C-20)	40.36 (C-19)	51.62 (C-18)	
0.880d (H_3-30)	20.61 (C-30)	30.90 (C-21)	38.20 (C-20)		
4.526dd (H-3)	80.83 (C-3)	16.53 (C-24) 170.88 (OAc)	23.44 (C-2)	27.59 (C-23)	37.21 (C-4)
3.831dd (H-7)	73.18 (C-7)	19.70 (C-26) 46.74 (C-5)	25.01 (C-6)	41.97 (C-8)	43.35 (C-9)
4.497dd (H-15)	66.61 (C-15)	12.12 (C-27)	32.25 (C-14)	38.44 (C-16)	41.97 (C-8)
0.728d (H-18)	51.62 (C-18)	28.44 (C-13)	32.25 (C-14)	33.96 (C-17)	38.44 (C-16)
0.96, 1.24 (H_2-16)	38.44 (C-16)	28.35 (C-28) 51.62 (C-18)	32.25 (C-14)	33.96 (C-17)	41.74 (C-22)
1.60, 1.86 (H_2-12)	32.33 (C-12)	12.12 (C-27) 43.35 (C-9)	17.22 (C-11) 51.62 (C-18)	28.44 (C-13)	32.25 (C-14)

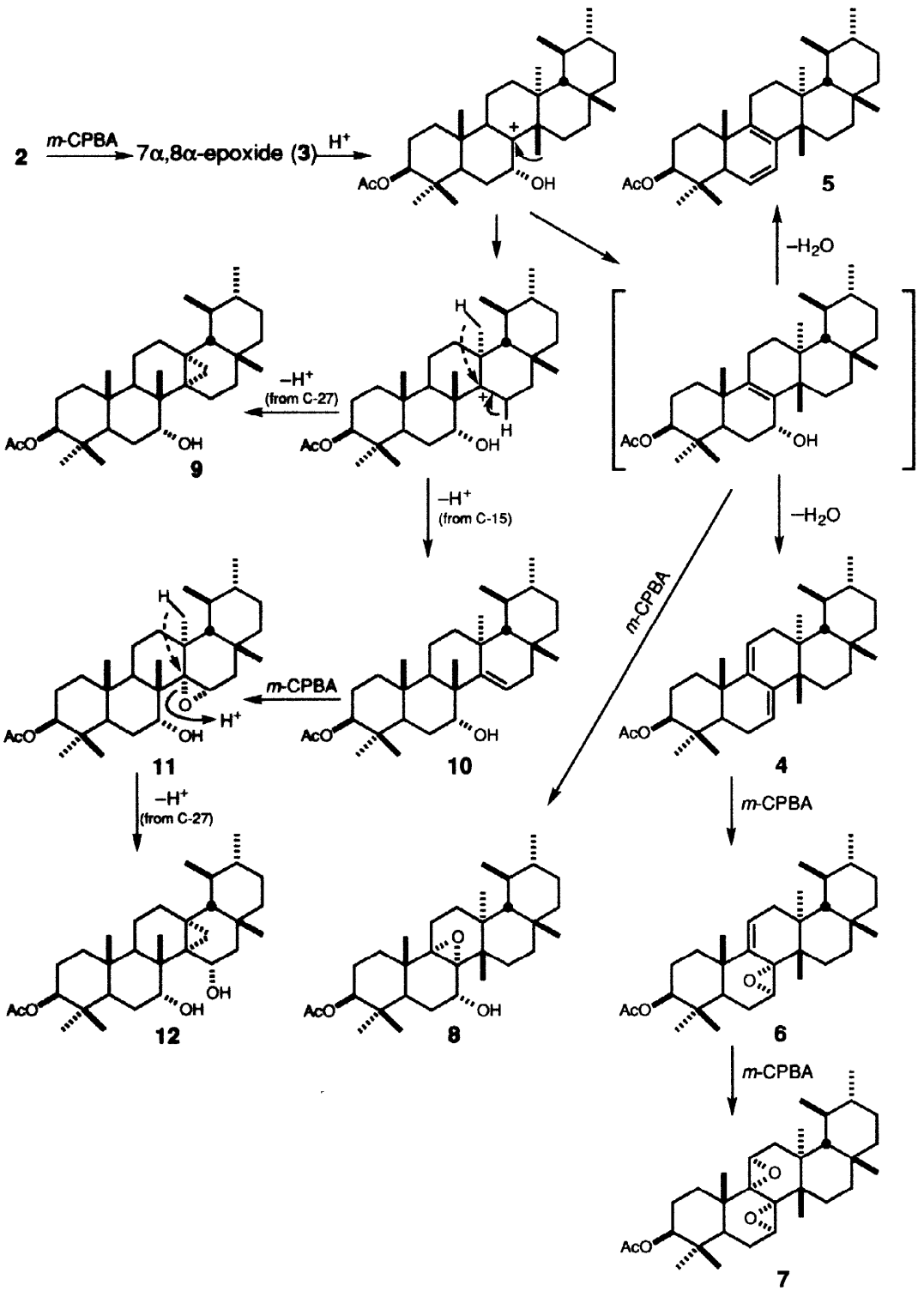
Mechanism of formation of products.

A plausible mechanism for the formation of the products has been suggested as shown in scheme 1 which is self explanatory. However, it deserves special mention that in the formation of the 14,27-cyclo derivatives (**9** and **12**), the elimination of a proton from the C-13 methyl group seems to be favoured over the migration of the methyl group from C-13 to C-14 and subsequent elimination of a proton from C-12 in spite of the fact that urs-12-ene skeleton is very stable and derivatives of this skeleton are abundantly available in nature. Though the reason for this behaviour is not immediately clear, a possible factor that may play a very important role is the weak acidity of the non-aqueous reaction medium containing organic acids. This was substantiated (Scheme 2) by the following facts:

(i) Bauerenyl acetate (**2**) on treatment with dil. H_2SO_4 (2N) did not yield any cyclopropane derivative. On the contrary, it yielded only urs-13(18)-en-3β-yl acetate and α-amyrin acetate in a ratio 3.5 to 1.

(ii) 7α,8α-Epoxybauerenyl acetate (**3**) on treatment with 5% BF_3-etherate in ether at 20 °C for one hour gave **9** (40%) and **10** (20%).

(iii) On treatment of **13** with dil. H_2SO_4 (2N), the cyclopropane ring opens up resulting in the formation of only α-amyrin acetate (80%).

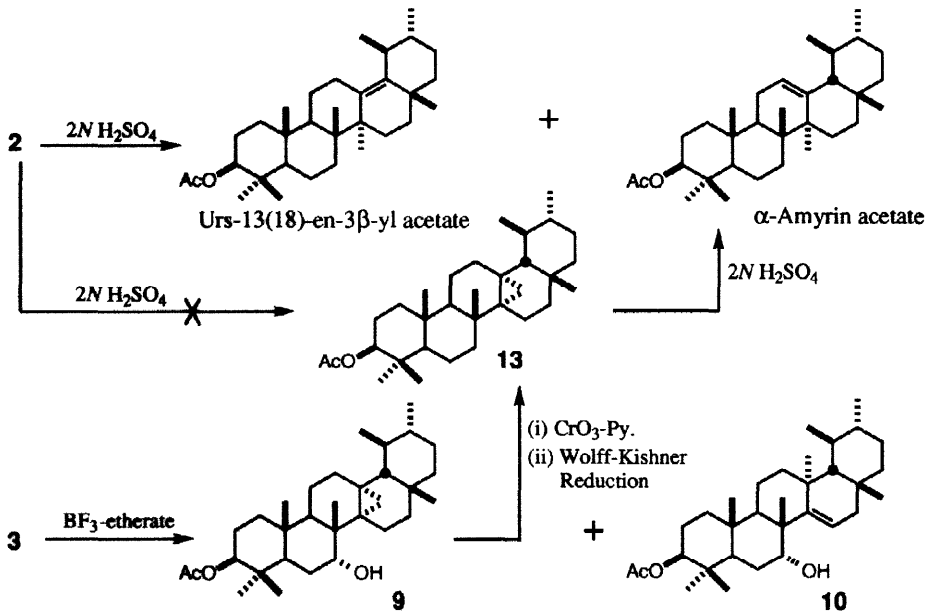


Scheme 1

To the best of our knowledge, deprotonation of a methyl group to form a cyclopropane ring seems to be unprecedented in a weak acid-induced chemical reaction, though similar deprotonation of a methyl group is well-known under physiological conditions, *e.g.* in the biosynthesis of cycloartane derivatives in plant.[5] Since this

type of cyclopropane derivatives were not encountered in the *m*-chloroperbenzoic acid reaction of swertanone (**1**), a migrated gammacerane triterpenoid possessing B/C/D ring system identical with that of bauerenyl acetate (**2**), the *cis* configuration of the D/E ring juncture of **2** may also have some role to play in the formation of the cyclopropane derivatives (**9** and **12**).

It is, therefore, likely that this type of migrated ursanes with cyclopropane ring will be isolated from natural sources in future.



Scheme 2

Experimental

Melting points are uncorrected. UV spectra were recorded on JASCO Ubest-55 spectrophotometer. Low resolution EIMS (JEOL JMS HX-110) and high resolution EIMS (JEOL JMS D-300) were obtained by a direct inlet system at 30 eV. ^{1}H, ^{13}C and 2D NMR spectra were taken on a 500 MHz instrument (JEOL ALPHA 500) in $CDCl_3$ solution. HPLC was performed on a JASCO PU-980 instrument equipped with a JASCO RI-930 detector. The following column and solvents were used for elution: Senshu PAK, ODS-3251-D (C_{18} reverse-phase, 5 μ, 8 mm x 250 mm), CH_3CN-$CHCl_3$ (9 : 1); flow rate 2.2 ml/min.

Reaction of bauerenyl acetate (2) with *m*-chloroperbenzoic acid.

To an ice-cooled solution of **2** (0.3 g) in methylene chloride (25 ml), *m*-chloroperbenzoic acid (55%, 0.6 g) was added and the reaction mixture was kept in the refrigerator (4°C) for 48 hr. After evaporation of the solvent under reduced pressure, the residue was directly subjected to chromatography over neutral alumina. On elution with petroleum ether-chloroform (9 : 1), two fractions, *viz.* A (0.115 g) and B (0.180 g) were obtained. Repeated prep. HPLC of each fraction yielded compounds **3–12** whose physical data are given below. ^{1}H and ^{13}C chemical shifts of the compounds are given in Table 1 and 2 respectively.

7α,8α-Epoxybaueran-3β-yl acetate (3): 62.0 mg (20.7 %); mp. 266–268 °C (acetone); HR-MS (EI) calcd for $C_{32}H_{52}O_3$ (M^+) 484.3916, found 484.3904; LR EI-MS *m/z* (intensity %): 484 (M^+, 100), 469 (M^+-CH_3, 21), 466 (M^+-H_20, 30), 453 (M^+-CH_3-H_2O, 4), 391 (14), 360 (11), 314 (10), 278 (6), 257 (10), 218 (11), 199 (10).

Bauera-7,9(11)-dien-3β-yl acetate (4): Retention time (Rt) 59.0; 6.7 mg (2.2 %); mp. 265–268 °C (acetone); λ_{max} (nm): 238; HR-MS (EI) calcd for $C_{32}H_{50}O_2$ (M^+) 466.3811, found 466.3809; LR EI-MS *m/z* : 466 (M^+, 100), 451 (M^+-CH_3, 7), 406 (M^+-AcOH, 6), 391 (30), 337 (10), 313 (14), 288 (6), 253 (20), 242 (14), 227 (19), 199 (16).

Bauera-6,8-dien-3β-yl acetate (5): Rt 46.4; 1.6 mg (0.5 %); mp. 237–238 °C (acetone); λ_{max}(nm): 274; HR-MS (EI) calcd for $C_{32}H_{50}O_2$ (M^+) 466.3811, found 466.3810; LR EI-MS *m/z* : 466 (M^+, 57), 451 (M^+-CH_3, 3), 406 (M^+-AcOH, 7), 391 (M^+-AcOH-CH_3, 99), 337 (48), 311 (21), 285 (39), 274 (21), 227 (33), 225 (36), 218 (26).

7α,8α-Epoxybauer-9(11)-en-3β-yl acetate (6): 11.1 mg (3.7 %); mp. 249–251 °C (acetone); HR-MS (EI) calcd for $C_{32}H_{50}O_3$ (M^+) 484.3916, found 482.3786; LR EI-MS *m/z*: 482 (M^+, 100), 467 (M^+-CH_3, 23), 422 (M^+-AcOH, 88), 407 (M^+-AcOH-CH_3, 70), 379 (19), 353 (8), 329 (18), 303 (25), 278 (72), 271 (22), 243 (18), 191 (28).

7α,8α,9α,11α-Diepoxybaueran-3β-yl acetate (7): Rt 21.2; 8.6 mg (2.9 %); mp. >300 °C (acetone); HR-MS (EI) calcd for $C_{32}H_{50}O_4$ (M^+) 498.3709, found 498.3694; LR EI-MS *m/z*: 498 (M^+, 39), 483 (M^+-CH_3, 29), 480 (M^+-H_2O, 67), 465 (M^+-H_2O-CH_3, 32), 438 (M^+- AcOH, 22), 423 (M^+-AcOH-CH_3, 16), 420 (M^+-AcOH-H_2O, 54), 405 (M^+-AcOH-H_2O-CH_3, 89), 387 (35), 375 (52), 368 (22), 319 (21), 296 (45), 255 (42), 215 (36), 202 (54), 173 (66), 123 (100).

8α,9α-Epoxy-7α-hydroxybaueran-3β-yl acetate (8): Rt 25.2; 3.8 mg (1.3 %); mp. 289–291 °C (acetone); HR-MS (EI) calcd for $C_{32}H_{52}O_4$ (M^+) 500.3865, found 500.3895; LR EI-MS *m/z*: 500 (M^+, 11), 482 (M^+-H_2O, 100), 467 (M^+-H_2O-CH_3, 29), 440 (M^+- AcOH, 13), 422 (M^+-AcOH-H_2O, 13), 407 (M^+-AcOH-H_2O-CH_3, 17), 368 (29), 358 (14), 329 (23), 327 (23), 305 (28), 274 (45), 255 (25), 236 (19).

7α-Hydroxy-14,27-cycloisoursan-3β-yl acetate (9): Rt 35.4; 13.3 mg (4.4 %); mp. 288–289 °C (acetone); HR-MS (EI) calcd for $C_{32}H_{52}O_3$ (M^+) 484.3916, found 484.3950; LR EI-MS *m/z*: 484 (M^+, 52), 469 (M^+-CH_3, 7), 466 (M^+-H_2O, 14), 453 (57), 451 (M^+-H_2O-CH_3, 13), 391 (M^+-AcOH-H_2O, 14), 360 (9), 314 (10), 284 (9), 257 (100), 255 (23), 203 (12), 187 (26).

7α-Hydroxyisours-14-en-3β-yl acetate (10): Rt 33.1; 3.0 mg (1.0 %); mp. 229–231 °C (acetone); HR-MS (EI) calcd for $C_{32}H_{52}O_3$ (M^+) 484.3916, found 484.3930; LR EI-MS *m/z*: 484 (M^+,13), 469 (M^+-CH_3, 3), 466 (M^+-H_2O, 9), 453 (13), 451(M^+-H_2O-CH_3, 5), 424 (M^+- AcOH,2), 391 (M^+-AcOH-H_2O,4), 360 (100), 314 (74), 278 (43), 257 (29), 255 (10), 203 (7), 187 (12), 173 (19).

14α,15α-Epoxy-7α-hydroxyisouran-3β-yl acetate (11): Rt 27.4; 1.9 mg (0.6 %); mp. 234–237 °C (acetone); HR-MS (EI) calcd for $C_{32}H_{52}O_4$ (M^+) 500.3865, found 500.3680; *m/z*: 500 (M^+,2), 482 (M^+-H_2O,

100), 467 (M^+-H_2O-CH_3,15), 422 (M^+-AcOH-H_2O, 5), 407 (M^+-AcOH-H_2O-CH_3,6), 389 (4), 357 (8), 315 (5), 301 (16), 275 (20), 257 (26), 236 (15), 229 (9).

7α,15α-Dihydroxy-14,27-cycloisoursan-3β-yl acetate (12): Rt 22.3; 3.6 mg (1.2 %); mp. 292–293 °C (acetone); HR-MS (EI) calcd for $C_{32}H_{52}O_4$ (M^+) 500.3865, found 500.3844; LR EI-MS *m/z* 500 (M^+, 6), 482 (M^+-H_2O, 100), 467 (M^+-H_2O-CH_3, 11), 422 (M^+-AcOH-H_2O, 5), 389 (M^+-AcOH-CH_3-H_2O x 2, 6), 368 (11), 357 (14), 301 (6), 285 (14), 257 (25), 233 (20), 207 (9), 189 (21).

14,27-Cycloisoursan-3β-yl acetate (13).

Compound **9** (20 mg) was oxidized with CrO_3-pyridine complex and the product, 7-oxo-compound was subjected to Wolff-Kishner reduction followed by acetylation to give compound **13** (7 mg). Mp. 266-268 °C (acetone); HR-MS (EI) calcd for $C_{32}H_{52}O_2$ (M^+) 468.3967, found 468.3967; LR EI-MS m/z: 468 (M^+, 100), 453 (M^+-CH_3, 24), 408 (M^+-AcOH, 11), 393 (M^+-AcOH-H_2O, 17), 344 (54), 329 (29), 289 (67), 269 (27), 255 (23), 229 (45), 205 (42), 204 (42), 199 (50), 189 (29).

Treatment of 7α,8α-epoxybauerenyl acetate (3) with 5% BF_3-etherate in ether.

To a solution of compound **3** (30 mg) in ether (19 ml), BF_3-etherate (1 ml) was added. The solution was kept at 20 °C for one hour in nitrogen atmosphere. Ice water was added into the reaction mixture and it was extracted with ether to afford the crystalline products which were separated on silica gel CC to give compound **4** (4 mg, 13 %), **9** (12 mg, 40 %) and **10** (6.0 mg, 20 %). All the compounds were identical with those of the *m*-chloroperbenzoic acid reaction products of **2** (^{1}H-NMR).

Acid induced rearrangement of 2.

To a solution of compound **2** (5 mg) in benzene (2.47 ml), AcOH (7.00 ml) and H_2SO_4 (0.53 ml) were added carefully. The solution was kept under N_2 gas for 20 h at 20 °C. After ice water was added, the reaction products were extracted with ether, washed with sat. $NaHCO_3$ solution and water. The product was recrystallised from acetone to afford a crystalline product which showed broad single peak (Rt_R 3.90, cholestane as an internal reference whose retention time was set at 3.0 min.) on GC. The product was found to be a mixture of α-amyrin acetate and urs-13(18)-en-3β-yl acetate (^{1}H-NMR).

Acid induced rearrangement of 13.

Reaction of **13** (few mg) was carried out under the same condition as that of **2**. Starting compound and α-amyrin acetate were detected in the product by ^{1}H-NMR.

References

1. Chakravarty A. K., Das B., Mukhopadhyay S., *Tetrahedron*, **1991**, *47*, 2337.
2. Knight S.A., *Org. Magn. Resonance*, **1974**, *6*, 603. Seo S., Tomita Y., Tori K., *Tetrahedron Lett.*, **1975**, 7.
3. Ageta H., Arai Y., Suzuki H., Kiyotani T., Kitabayashi M., *Chem. Pharm. Bull.*, **1995**, *43 (2)*, 198.
4. *Chem3D Pro* v. 3.1 and N. L. Allinger, MM2 Params., Cambridge Scientific Computing Inc.
5. Abe I., Rohmer M., Prestwich G. D., *Chem. Rev.*, **1993**, *93*, 2189-2206.