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EUDESMANOLIDES, GUAIANOLIDES, GERMACRANOLIDES AND ELEMANOLIDES FROM *ZINNIA* SPECIES*

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Key Word Index—*Zinnia angustifolia; Z. elegans; Z. haageana; Z. linearis; Z. tenuiflora; Z. verticillata;* Compositae; sesquiterpene lactones; eudesmanolides; guaianolides; germacranolides; elemanolides; geranylgeraniol derivative.

Abstract—The investigation of six *Zinnia* species afforded in addition to already known compounds two eudesmanolides, five guaianolides, three germacranolides, five elemanolides and a dihydroxygeranylgeraniol. The structures were elucidated by spectroscopic methods and some chemical transformations. The chemotaxonomic situation is discussed briefly.

INTRODUCTION

So far five *Zinnia* species have been investigated chemically. All contained sesquiterpene lactones [1–4], mainly elemanolides [1, 3, 4], but some also guaianolides [1, 4] and the germacranolide haageanolide [2]. We have now investigated again *Z. haageana* Regel and five further species, which so far were not investigated, to see whether new informations on the relationships of this genus can be obtained from the chemical constituents. Again all species afforded several sesquiterpene lactones, fifteen not being isolated before, while two species contained a geranylgeraniol derivative.

RESULTS AND DISCUSSION

The roots of *Z. angustifolia* HBK afforded the widespread pentaynene **1**, germacrene D, the sesquiterpene lactones **7** [5], **8** [6] and **9** [4] as well as three further ones, which are the eudesmanolides **3** and **4** and the germacranolide **22**. The ^{1}H NMR data of **3** and **4** (Table 1) showed that they differed in the ester residue only. The

Table 1. ^{1}H NMR spectral data of compounds **3**–**6** (270 MHz, $CDCL_3$, TMS as internal standard)

	3	**4**	**5**	**6a**	**6b**
3-H	5.35 *br dd*	5.30 *br dd*	4.03 *br dd*	5.34 *br dd*	5.30 *br dd*
6-H	2.80 *dd*	2.79 *dd*	2.34 *dd*	2.37 *dd*	
6′-H	2.0 *m*	2.0 *m*	2.15 *dd*	2.18 *dd*	
7-H	3.08 *ddddd*	3.07 *ddddd*	1.87 *m*		
8-H	4.52 *dd*	4.51 *dd*	4.07 *m*	4.08 *br s*	
9-H	1.80 *m*	1.80 *m*			
12-H	—	—	3.65 *dd* 3.52 *dd*	3.65 *dd* 3.57 *dd*	
13-H	6.26 *d*	6.26 *d*	0.99 *d*	0.99 *d*	
13′-H	5.64 *d*	5.63 *d*			
14-H	1.19 *s*	1.18 *s*	1.32 *s*	1.35 *s*	
15-H	1.68 *br s*	1.66 *br s*	1.74 *br s*	1.63 *br s*	1.61 *br s*
OCOR	6.06 *qq*	5.70 *qq*	—	6.03 *qq*	5.65 *br s*
	1.98 *dq*	2.19 *d*	—	1.98 *dq*	2.18 *d*
	1.89 *dq*	1.90 *d*	—	1.89 *dq*	1.89 *d*

J (Hz): Compounds **3**/**4**: 2,3 = 7; 6,6′ = 13.5; 6,7 = 7.5; 6′,7 = 10; 7,8 = 7.5; 7,13 = 2.5; 7,13′ = 2; 8,9 = 7.5; compounds **5**/**6**: 2,3 = 7; 6,6′ = 13.5; 6,7 = 3; 6′,7 = 13; 11,13 = 7, 11,12 = 7.5; 11′,12 = 4; 12,12′ = 10.

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* Part 321 in the series "Naturally Occurring Terpene Derivatives". For Part 320 see Bohlmann, F., Gupta, R. K., Jakupovic, J., Robinson, H. and King, R. M. (1981) *Phytochemistry* **20**, 1609.

other signals were close to those of ivangustin and the chemical shift of the proton at the ester group bearing carbon indicated an allylic position, most probably at C-3 since from spin decoupling the signals of 6-H easily could be deduced. The observed 3-H couplings further showed that the ester groups were β-orientated. Partial reduction with $LiAlH_4$ gave the diol **6**, while prolonged reaction led to the triol **5**. The chemical shifts of the proton at the hydroxyl bearing carbon in the spectra of **5** and **6** supported the proposed position at C-3 as the signal of the corresponding proton in ivangustin is at higher fields [7].

The diol **22** could be transformed to the monoacetate **23** and by addition of 4-pyrrolidinopyridine to the diacetate **24**. Partial oxidation afforded the aldehyde **25** and sodium borohydride reduction gave the 11,13-dihydro compound **26** only. Careful investigations of the ^1H NMR spectra of **22** and those of **23**–**26** allowed the assignment of most signals. The presence of an 8,12-lactone was deduced by the chemical shifts of 6- and 8-H, which were assigned by spin decoupling in the usual way, while the α-orientation of 6- to 9-H followed from the corresponding couplings observed. The stereochemistry at C-4, however, could not be established with certainty as the signals of 4- and 5-H always overlapped. The observed $Eu(fod)_3$-induced shifts would agree better with a β-orientation of the CH_2OH group as the 4-H signal obviously is shifted very little, which could be explained only if all the oxygen functions and therefore the shift reagent were above the plane. Although not all signals could be assigned, structure **22** is the most probable one. The stereochemistry at C-11 in the dihydro compound **26** followed from the couplings $J_{7,11}$. We have named **22** zinangustolide. The aerial parts also contained germacrene D, **22** and two further sesquiterpene lactones, 9α-angeloyloxydehydrocostus lactone (**10**) [4] and the germacranolide **27**, a dihydro derivative of **22**. The ^1H NMR data of the latter (Table 2) showed that **27** was the epimer of **26**, obtained by reduction of **22**.

The roots of *Z. elegans* Jacq. afforded **9** [4] and the aerial parts germacrene D and the elemanolides **28**–**31** [4] and **37**–**40** [4]. The roots of *Z. haageana* Regel gave **1**, **9** and the germacranolide **21**, the angelate of haageanolide (**20**) [2]. The ^1H NMR data were similar to those of **20** (Table 3). The observed couplings $J_{8,9}$ required a β-orientation of the angelate residue. The aerial parts afforded germacrene D, **9**, **20** and **21** and the guaianolide **15**, its ^1H NMR data (Table 4) being very close to those of the senecioate **16** [8], where the configuration was erroneously written as 1β-H. The couplings of 1- and 5-H were those of similar guaianolides with *cis*-fused rings, while those of 8- and 9-H indicated an α-orientation of the angelate residue.

The roots of *Z. linearis* Benth afforded **1**, germacrene D, **2**–**4** and **7**–**9**, while the aerial parts contained germacrene D, the guaianolides **10** [4], **11** [4], **14a** [4] and three further ones, the corresponding methylbutyrate **12** and the isovalerate **13**, which could not be separated, as well as the angelate **19**. The ^1H NMR data of **12** and **13** were very similar to those of **10** and **11** (Table 4) and the nature of the ester residue clearly followed from the typical signals. The structure of **19** was deduced from the ^1H NMR data too (Table 4). The presence of an angelate residue at C-14

Table 2. ^1H NMR spectral data of compounds **22**–**27** (270 MHz, TMS as internal standard)

	22(C_6D_6, 80°)	Δ*	**23**($CDCl_3$)	**24**($CDCl_3$)	**25**(C_6D_6, 80°)	**26**($CDCl_3$)	**27**($CDCl_3$)
1-H	6.14 *br dd*	0.20	6.08 *br dd*	6.03 *m*	5.87 *m*	6.08 *br dd*	6.15 *m*
2-H	2.03 *m*	0.09					
3-H	1.40 *m*						
4-H	1.30 *m*	0.07					
5-H	1.45 *m*						
5′-H	1.6 *m*				1.57 *m*		
6-H	5.98 *ddd*	0.28	5.86 *br d*	5.73 *br d*	5.87 *br dd*	5.96 *br dd*	6.15 *m*
7-H	2.89 *dddd*	0.22	3.10 *dddd*	3.17 *dddd*	2.78 *dddd*		
8-H	4.08 *dd*	0.19	4.57 *dd*	4.67 *dd*	3.99 *dd*	4.47 *br dd*	4.52 *br dd*
9-H	4.43 *br s*	0.22	4.73 *br s*	5.64 *brs*	4.10 *br s*	4.63 *br s*	4.48 *br s*
11-H	—	—	—	—	—	2.74 *dq*	2.91 *dq*
13-H	6.21 *d*	0.15	6.26 *d*	6.22 *s*	6.19 *d*	1.42 *d*	1.18 *d*
13′-H	5.29 *d*	0.15	5.52 *d*	5.51 *d*	5.66 *d*		
14-H	1.32 *br s*	0.12	1.69 *br s*	1.76 *br s*	1.18 *br s*	1.69 *br s*	1.71 *br s*
15-H	3.20 *dd*	0.40	3.92 *dd*			3.46 *dd*	
	3.10 *dd*	0.45	3.85 *dd*	3.82 *m*	9.27 *s*	3.34 *dd*	3.32 *m*
OCOR	2.24 *tq*	0.09	2.26 *tq*	2.28 *tq*	2.22 *tq*	2.28 *tq*	2.28 *m*
	1.67 *ddq*	0.08	1.62 *ddq*	1.67 *ddq*	1.5 *m*	1.65 *dq*	1.6 *m*
	1.4 *ddq*	0.08	1.42 *ddq*	1.44 *ddq*	1.3 *m*	1.45 *ddq*	1.45 *m*
	0.86 *t*	0.08	0.88 *t*	0.91 *t*	0.88 *t*	0.90 *t*	0.94 *t*
	1.10 *d*	0.05	1.08 *d*	1.11 *d*	1.08 *d*	1.10 *d*	1.16 *d*
OAc	—	—	2.07 *s*	2.08 *s*		—	—
				2.07 *s*			

* Δ-values after addition of $Eu(fod)_3$.

J (Hz): 1,2 = 10; 1,2′ = 5; 4,15 = 6.5; 4,15′ = 8; 5,6 = 10; 5′,6 = 3.5; 6,7 = 3.5; 7,8 = 6.5; 7,13 = 2; 8,9 = 3.5: 15,15′ = 10; 2′,3′ = 3′,4′ = 2′,5′ = 7; $3_1',3_2'$ = 14; compound **26**: 7,11 = 7; 11,13 = 7; compound **27**: 7,11 = 10.5; 11,13 = 7.

Table 3. ^{1}H NMR spectral data of compound **21** ($CDCl_3$)

1-H	5.24 *br dd*
2-H	2.4–2.2 *m*
3-H	
5-H	4.71 *br d*
6-H	4.59 *dd*
7-H	2.77 *dddd*
8-H	2.23 *br d*, 2.08 *m*
9-H	5.31 *dd*
13-H	6.31 *d*
13'-H	5.56 *d*
14-H	1.50 *br s*
15-H	1.73 *br s*
OCOR	6.09 *qq*
	1.99 *dq*
	1.89 *dq*

J (Hz): 1,2 = 10; 1,2' = 5; 5,6 = 10.5; 6,7 = 9; 7,8 = 10; 7,8' ~ 1; 7,13 = 3.5; 7,13' = 3; 8,9 = 11; 8',9 = 2.5.

was indicated by the downfield shift of 9-H, which was assigned by spin decoupling and the typical signals for 15-H. Although some signals overlapped, the similarity with those of dehydrocostus lactone clearly showed that the stereochemistry was the same in both lactones.

The roots of *Z. tenuiflora* Jacq. again afforded **1** and **9** as well as the guaianolides **14a**, **14b** [2] and **14c** [9] and sitosterol, while the aerial parts contained germacrene D, **9**, the guaianolide **18**, the 11,13-dihydro derivative of **14a**, the elemanolides **28–31** and **37–40** as well as five further ones, the diesters **32–36**, and the geranylgeraniol derivative **41**. The structure of **18** followed from the ^{1}H NMR data (Table 4), which were similar to those of **14a**. The α-orientation of the 11-methyl group was deduced from the observed coupling $J_{7,11}$. The ^{1}H NMR data of **32–36** (Table 5), which could be separated by HPLC only, showed that the stereochemistry must be the same in all compounds. All signals could be assigned by spin decoupling. The couplings of 8- and 9-H were different from those of **28–31**. Inspection of models clearly indicated that the protons at C-8 and C-9 must be in the α-position. The relative position of the different ester groups was deduced by comparing the observed chemical shifts of the signals of 6- and 9-H. In the diangelate **32** these signals were shifted the farthest downfield, while in those lactones which had a saturated ester group (**33–35**) the 9-H signal appeared at higher fields, while the chemical shift of 6-H was nearly the same. In the diester **36** the relative position

Table 4. ^{1}H NMR spectral data of compounds **12**, **13**, **15**, **18** and **19** ($CDCl_3$)

<table>
<tr><th></th><th>12</th><th>13</th><th>15</th><th>18*</th><th>19</th></tr>
<tr><td>1-H</td><td colspan="2">3.24 <i>ddd</i></td><td>3.02 <i>ddd</i></td><td>2.92 <i>ddd</i></td><td>2.7 <i>m</i></td></tr>
<tr><td>2-H</td><td colspan="2">1.88 <i>m</i></td><td>1.85 <i>m</i></td><td>1.83 <i>ddd</i></td><td>1.62 <i>dddd</i></td></tr>
<tr><td>2'-H</td><td colspan="2">2.02 <i>m</i></td><td></td><td>2.56 <i>dd</i></td><td>2.22 <i>m</i></td></tr>
<tr><td>3-H</td><td colspan="2">2.55 <i>br t</i></td><td>2.55 <i>m</i></td><td>5.63 <i>dddd</i></td><td>2.40 <i>dddd</i></td></tr>
<tr><td>3'-H</td><td colspan="2"></td><td>2.47 <i>m</i></td><td>—</td><td>2.54 <i>m</i></td></tr>
<tr><td>5-H</td><td colspan="2">2.93 <i>br t</i></td><td>2.84 <i>br dd</i></td><td>2.85 <i>br dd</i></td><td>2.7 <i>m</i></td></tr>
<tr><td>6-H</td><td colspan="2">3.95 <i>dd</i></td><td>4.05 <i>dd</i></td><td>4.02 <i>dd</i></td><td>3.98 <i>dd</i></td></tr>
<tr><td>7-H</td><td colspan="2">3.11 <i>ddddd</i></td><td>3.21 <i>ddddd</i></td><td>—</td><td>2.7 <i>m</i></td></tr>
<tr><td>8-H</td><td colspan="2">2.38 <i>ddd</i>
1.69 <i>ddd</i></td><td>5.08 <i>ddd</i></td><td>—</td><td>2.1 <i>m</i></td></tr>
<tr><td>9-H</td><td colspan="2">5.55 <i>dd</i></td><td>2.37 <i>dd</i></td><td></td><td>5.93 <i>br d</i></td></tr>
<tr><td>9'-H</td><td colspan="2"></td><td>2.74 <i>dd</i></td><td></td><td></td></tr>
<tr><td>13-H</td><td colspan="2">6.25 <i>d</i></td><td>6.23 <i>d</i></td><td>1.25 <i>d</i></td><td>6.22 <i>d</i></td></tr>
<tr><td>13'-H</td><td colspan="2">5.48 <i>d</i></td><td>5.64 <i>d</i></td><td></td><td>5.49 <i>d</i></td></tr>
<tr><td>14-H</td><td colspan="2">5.16 <i>s</i></td><td>5.31 <i>br s</i></td><td>4.93 <i>br s</i></td><td>4.66 <i>br d</i></td></tr>
<tr><td>14'-H</td><td colspan="2">4.96 <i>s</i></td><td>5.11 <i>br s</i></td><td></td><td>4.55 <i>br d</i></td></tr>
<tr><td>15-H</td><td colspan="2">5.28 <i>br s</i></td><td>5.07 <i>br s</i></td><td>5.41 <i>dd</i></td><td>5.23 <i>br s</i></td></tr>
<tr><td>15'-H</td><td colspan="2">5.09 <i>br s</i></td><td>4.95 <i>br s</i></td><td>5.31 <i>dd</i></td><td>5.05 <i>br s</i></td></tr>
<tr><td>OCOR</td><td>2.40 <i>tq</i>
1.65 <i>m</i>
1.50 <i>m</i>
0.92 <i>t</i>
1.17 <i>d</i></td><td>2.24 <i>d</i>
2.15 <i>m</i>
0.97 <i>d</i></td><td>6.20 <i>qq</i>
2.04 <i>dq</i>
1.94 <i>dq</i></td><td>6.11 <i>qq</i>
2.02 <i>dq</i>
1.91 <i>dq</i></td><td>6.10 <i>qq</i>
2.00 <i>dq</i>
1.92 <i>dq</i></td></tr>
</table>

* 11-H 2.24 *dq*.

J(Hz): Compounds **12/13**: 1,2 = 8; 1,2' = 5; 1,5 = 8; 5,6 = 6,7 = 9; 7,8 = 3.5; 7,8' = 10; 8,9 = 3.5; 7,13 = 3.5; 7,13 = 3.5; 7,13' = 3; compound **15**: 1,2 = 7; 1,5 = 7; 5,6 = 10; 6,7 = 9; 7,8 = 9; 7,13 = 3.5; 7,13' = 3; 8,9 = 5; 9,9' = 14; compound **18**: 1,2 = 7; 1,5 = 7; 2,3 = 7; 2,2' = 14; 3,15 = 1.5; 5,6 = 6.7 = 10; 7,11 = 11; 11,13 = 7; compound **19**: 1,2 = 10; 2,2' = 13; 2,3 = 9; 2,3' = 10; 3,3' = 17; 3,15 = 2; 5,6 = 10.5; 6,7 = 9.5; 7,13 = 3.5; 7,13' = 3; 8,9 = 8; 14,14' = 13.

Table 5. ^{1}H NMR spectral data of compounds **32**–**36** (CDCl$_3$)

	32	**33**	**34**	**35**	**36**
1-H	5.62 *dd*	5.61 *dd*	5.58 *dd*	5.56 *dd*	5.60 *dd*
2*t*-H	4.98 *d*	4.97 *d*	4.98 *d*	4.96 *d*	4.97 *d*
2*c*-H	5.04 *d*	5.03 *d*	5.05 *d*	5.02 *d*	5.03 *d*
3-H	6.55 *s*	6.54 *s*	6.5 *s*	6.55 *s*	6.55 *s*
3′-H	6.18 *s*	6.19 *s*	6.19 *s*	6.18 *s*	6.17 *s*
5-H	3.81 *d*	3.77 *d*	3.74 *d*	3.79 *d*	3.81 *s*
6-H	5.44 *dd*	5.42 *dd*	5.48 *dd*	5.45 *dd*	5.41 *dd*
7-H	3.44 *dddd*	3.44 *dddd*	3.42 *dddd*	3.42 *dddd*	3.44 *dddd*
8-H	5.04 *dd*	4.97 *dd*	4.99 *dd*	5.00 *dd*	5.04 *dd*
9-H	5.36 *d*	5.26 *d*	5.23 *d*	5.25 *d*	5.36 *d*
13-H	6.34 *d*	6.35 *d*	6.37 *d*	6.36 *d*	6.34 *d*
13′-H	5.81 *d*	5.81 *d*	5.81 *d*	5.82 *d*	5.79 *d*
14-H	1.41 *s*	1.37 *s*	1.42 *s*	1.39 *s*	1.42 *s*
15-H	9.40 *s*	9.40 *s*	9.39 *s*	9.39 *s*	9.38 *s*
OAng	6.19 *qq*	6.19 *qq*	6.18 *qq*	6.19 *qq*	6.16 *qq*
	2.02 *dq*	2.01 *dq*	2.01 *dq*	2.01 *dq*	2.01 *dq*
	1.95 *dq*	1.93 *dq*	1.94 *dq*	1.94 *dq*	1.87 *dq*
9-OCOR	6.16 *qq*	2.35 *tq*	2.04 *s*	1.18 *d*	6.13 *q*
	2.02 *dq*	0.91 *t*		1.15 *d*	5.69 *q*
	1.88 *dq*	1.15 *d*			1.98 *dd*

J(Hz): 1,2*t* = 17; 1,2*c* = 11; 5,6 = 3.5; 6,7 = 3; 7,8 = 8,9 = 4; 7,13 = 3.5; 7,13′ = 3.

was assigned by biogenetic considerations only. Therefore the relative position of the esters was uncertain.

The structure of the diterpene triol **41** caused some difficulties. We therefore prepared the mono-, di- and triacetates **42**–**44** as well as the keto diacetate **45**. Careful investigation of the ^{1}H NMR data of **41**–**45** including spin decoupling (Table 6) allowed the assignment of the positions of the hydroxyl groups. The data of **45** clearly showed that the keto group was at C-12. The observed downfield shift of the 10-H signal and irradiation of this signal further showed that one of the acetates was at C-18, while the position of the second was directly assigned from the ^{1}H NMR data by the coupling of 1-H. The stereochemistry of the 10,11-double bond followed from the downfield shift of 10-H in the spectrum of **45**, while the configuration of the 2,3-double bond was deduced by comparing the chemical shifts with those of geraniol and related compounds. The only remaining problem was the stereochemistry of the 6,7-double bond. Although the ^{13}C NMR signals could not be assigned with certainty the observed values for the methyl carbons require one double bond with the Z-configuration. Therefore the stereochemistry seems to be established, except that at C-12 which was not determined. The roots of *Z. verticillata* Andr. afforded **1** and **9**, while the aerial parts again contained germacrene D, **18**, **28**–**40** and **41**.

If the compounds isolated from *Zinnia* species are compared, it is obvious that for one group elemanolides are characteristic, mostly with some guaianolides, but no germacranolides were detected in these species. These are present, again together with guaianolides, in three species only. Of these the lactones **22** and **27** are closely related to the typical elemanolides only. However, since the 4,5-double bond is missing, the transformation to the latter is blocked. So far the typical elemanolides of *Zinnia* have never been found in any taxonomically related genera.

EXPERIMENTAL

The air-dried plant material was extracted with Et$_2$O–petrol (1:2) and the extracts were separated first by column chromatography (Si gel) and further by repeated TLC (Si gel). Some of the sesquiterpene lactones could be separated by HPLC only (reversed phase, RP 18, MeOH–H$_2$O, 7:3). Known compounds were identified by comparing the IR and ^{1}H NMR spectra with those of authentic material. Optical rotation: CHCl$_3$, ^{1}H NMR, 270 MHz, TMS as int. standard.

Zinnia angustifolia (voucher RMK 8182). The roots (30 g) afforded 1 mg **1**, 3 mg germacrene D, 30 mg **3** (Et$_2$O–petrol, 1:3), 6 mg **4** (Et$_2$O–petrol, 1:3), 0.5 mg **7**, 5 mg **8**, 5 mg **9** and 5 mg **22** (Et$_2$O), while the aerial parts (1 kg) gave 50 mg germacrene D, 80 mg **10** and 5 mg **27** (Et$_2$O).

Zinnia elegans (grown from seeds, Bot. Garden Cologne, voucher 70/1340). The roots (150 g) afforded 50 mg **9** and the aerial parts (400 g) 5 mg germacrene D, 10 mg **28**–**31** (nearly equal parts) and 10 mg **37**–**40** (nearly equal parts).

Zinnia haageana (grown from seeds, Bot. Garden Dijon, voucher 70/1342). The roots (100 g) afforded traces of **1**, 20 mg **9** and 5 mg **21** (Et$_2$O–petrol, 1:3), while the aerial parts (80 g) gave 10 mg germacrene D, 3 mg **1**, 3 mg **15** (CH$_2$Cl$_2$–C$_6$H$_6$, 1:1), 40 mg **20** and 15 mg **21**.

Zinnia linearis (grown from seeds, Bot. Garden Padua, voucher 70/1411). The roots (50 g) afforded 1 mg germacrene D, 1 mg **1**, 5 mg **2**, 22 mg **3**, 3 mg **4**, 3 mg **7**, 5 mg **8** and 2 mg **9**, while the aerial parts (600 g) yielded 20 mg germacrene D, 5 mg **10**, 0.5 mg **11**, 3 mg **12** and **13** (HPLC, MeCN–H$_2$O, 3:2), 3 mg **14a** and 10 mg **19** (CH$_2$Cl$_2$–C$_6$H$_6$, 1:1).

Zinnia verticillata (grown from seeds, Bot. Garden Dijon, voucher 79/1382). The roots (30 g) afforded traces of **1** and 8 mg **9**, while the aerial parts (75 g) yielded 2 mg germacrene D, 2 mg phytol, 1 mg **18** (Et$_2$O–petrol, 1:1), 2 mg **28** and **29**, 30 mg **30** and **31**, 5 mg **37** and **38**, 25 mg **39** and **40** (nearly equal parts of these four pairs), a mixture of lactones (Et$_2$O–petrol, 7:3) (separated

Table 6. ^{1}H NMR spectral data of compounds **41**–**45*** ($CDCl_3$)

	41 (C_6D_6)	**42**	**43**	**44**	**45**	**41** (^{13}C NMR)	
1-H	4.02 *br d*	4.56 *br d*	4.56 *br d*	4.56 *br d*	4.56 *br d*	C-1	59.1
2-H	5.42 *tq*	5.36 *tq*	5.37 *tq*	5.36 *tq*	5.37 *tq*	C-2	124.4†
4,5-H	2.00 *m*	2.12 *m*	2.13 *m*	2.11 *m*	2.12 *m*	C-3	139.6‡
6-H	5.15 *tq*	5.11 *tq*	5.12 *tq*	5.12 *tq*	5.17 *tq*	C-4	39.5
8-H	2.00 *m*	2.12 *m*		2.11 *m*	2.16 *br t*	C-5	26.3
9-H	2.19 *dddd* 2.13 *dddd*	2.26 *m*		2.24 *m*	2.47 *br tq*	C-6	124.7†
10-H	5.44 *br t*	5.52 *br t*	5.72 *br t*	5.73 *br t*	6.85 *br t*	C-7	135.2§
12-H	4.16 *br dd*	4.17 *br dd*	4.12 *br dd*	5.21 *br t*	—	C-8	35.1
13-H	2.50 *ddd* 2.35 *ddd*	2.44 *ddd* 2.26 *m*		2.36 *m*	3.38 *br d*	C-9	25.9
14-H	5.22 *tq*	5.13 *tq*	5.13 *tq*	5.02 *tq*	5.31 *tq*	C-10	130.4
16-H	1.54 *br s*	1.61 *br s*	1.62 *br s*	1.61 *br s*	1.64 *br s*	C-11	139.4‡
17-H	1.69 *br s*	1.73 *br s*	1.74 *br s*	1.70 *br s*	1.76 *br s*	C-12	79.9
18-H	4.26 *br s*	4.27 *br s*	4.70 *br d* 4.65 *br d*	4.64 *br s*	4.84 *br s*	C-13	31.9
19-H	1.51 *br s*	1.66 *br s*	1.65 *br s*	1.70 *br s*	1.65 *br s*	C-14	120.2
20-H	1.62 *br s*	1.77 *br s*	1.78 *br s*	1.78 *br s*	1.77 *br s*	C-15	134.9§
OAC	—	2.05 *s*	2.07 *s*	2.07 *s*	2.05 *s*	C-16	25.9
			2.06 *s*	2.06 *s*	2.03 *s*	C-17	18.1
				2.03 *s*		C-18	76.8
						C-19	23.3
						C-20	16.1

* The assignments of 16-, 17- and 19-H may be interchangeable in the spectra of **42**–**44**.

†, ‡, § May be interchangeable.

J(Hz): 1,2 = 7; 2,4 = 2,20 ~ 1.5; 5,6 = 7; 6,8 = 6,19 ~ 1.5; 8,9 = 9,10 = 7; 12,13 = 7; 13,14 = 7; 13,13′ = 15; 14,16 = 14,17 ~ 1.5.

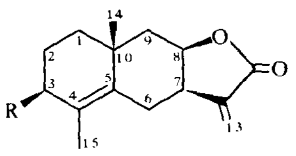
by HPLC yielding 2 mg **32**, 0.5 mg **33**, 2 mg **34** and 2 mg **36**) and 3 mg **41** (Et_2O).

Zinnia tenuiflora (grown from seeds, Bot. Garden Marburg, voucher 79/1339). The roots (50 g) afforded traces of **1**, 2 mg sitosterol, 25 mg **9** and 6 mg **14a**–**14c** (1:3:2), while the aerial parts (100 g) yielded 5 mg germacrene D, 5 mg **9**, 2 mg **18**, 3 mg **28** and **29** (1:1), 35 mg **30** and **31** (1:1), a mixture of **32**–**36** (Et_2O–petrol, 7:3) separated by HPLC: 3 mg **32**, 1 mg **33**, 2 mg **34**, 0.5 mg **35**, 2 mg **36**, 3 mg **37** and **38** (1:1), 30 mg **39** and **40** (1:1) and 20 mg **41**.

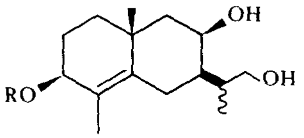
3β-Angeloyloxydesoxyinvangustin (**3**). Colourless crystals, mp 134° (Et_2O–petrol); IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1770 (γ-lactone), 1710, 1650 ($C{=}CCO_2R$); MS *m/z* (rel. int.): 330, 183 $[M]^+$ (7) ($C_{20}H_{26}O_4$), 230 $[M - AngOH]^+$ (43), 215 $[230 - Me]^+$ (33), 83 $[C_4H_7CO]^+$ (100), 55 $[83 - CO]^+$ (87).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{\begin{array}{cccc}589 & 578 & 546 & 436\,\text{nm}\end{array}}{\begin{array}{cccc}-26.0 & -27.8 & -35.2 & -96.8\end{array}} \quad (c = 2.16).$$

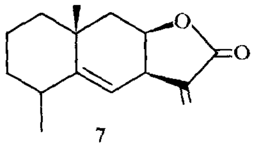
$Me[C{\equiv}C]_5CH{=}CH_2$ **1**



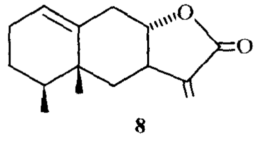
2 R = H
3 R = OAng
4 R = OSen



5 R = H
6a R = Ang
6b R = Sen



7



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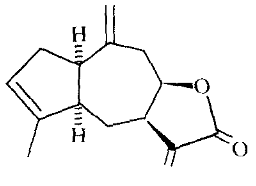

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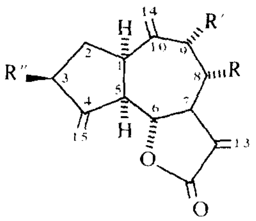
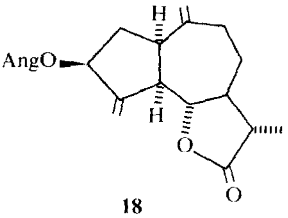


	R	R′	R″
10	H	OAng	H
11	H	OSen	H
12	H	MeBu	H
13	H	*i*-Val	H
14a	H	H	OAng
14b	H	H	OSen
14c	H	H	*i*-Val
15	OAng	H	H
16	OSen	H	H
17	O-*i*-Val	H	H



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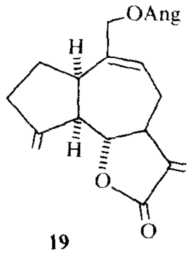
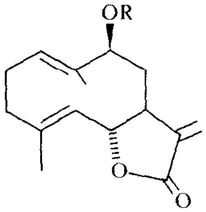
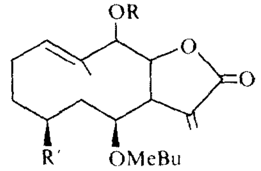


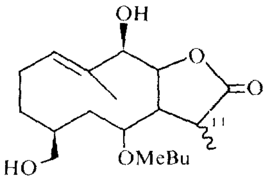
19



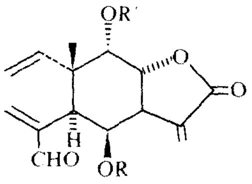
20 R = H
21 R = Ang



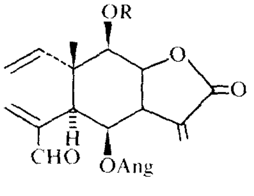
	R	R′
22	H	CH_2OH
23	H	CH_2OAc
24	Ac	CH_2OAc
25	H	CHO



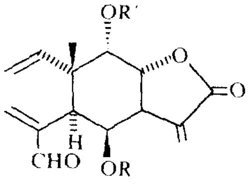
26 11α-H **27** 11β-H



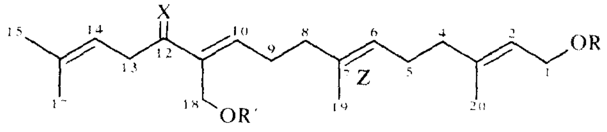
	28	**29**	**30**	**31**
R	H	H	Ang	Meacr
R′	Ang	Meacr	H	H



	32	**33**	**34**	**35**	**36**
R	Ang	MeBu	Ac	*i*-Bu	Meacr



	37	**38**	**39**	**40**
R	H	H	Ang	Meacr
R′	Ang	Meacr	H	H



	41	**42**	**43**	**44**	**45**
R	H	Ac	Ac	Ac	Ac
R′	H	H	Ac	Ac	Ac
X	OH, H	OH, H	OH, H	OAc, H	=O

To 10 mg **3** and **4** (5:1) in 2 ml Et_2O was added 10 mg $LiAlH_4$. After 2 min dil. H_2SO_4 was added. TLC (Et_2O) afforded 6 mg **6a** and **6b**, colourless gum. For ^1H NMR see Table 1. 6 mg **6a** and **6b** was reduced with excess $LiAlH_4$ in Et_2O for 15 min. TLC (Et_2O) afforded 3 mg **5**, colourless gum; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3620 (OH), 1620 (C=C); MS m/z (rel. int.): 254 $[M]^+$ (11), 239 $[M - Me]^+$ (12), 221 $[239 - H_2O]^+$ (18), 203 $[221 - H_2O]^+$ (10), 236 $[M - H_2O]^+$ (10), 177 $[236 - MeCHOH_2]^+$ (100).

3β-Senecioyloxydesoxyivangustin (**4**). Colourless crystals, mp 144° (Et_2O); IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1760 (γ-lactone), 1700, 1650 ($C{=}CCO_2R$); MS m/z (rel. int.): 330.183 $[M]^+$ (4), 230 $[M - SenOH]^+$ (28), 215 $[230 - Me]^+$ (14), 83 $[C_4H_7CO]^+$ (100), 55 $[83 - CO]^+$ (44).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546 \quad 436\,\text{nm}}{-31.0 \quad -32.4 \quad -41.0 \quad -109.5}\ (c = 0.21).$$

9α-Isovaleryloxy- and [2-methylbutyryloxy]-dehydrocostus lactone (**12** *and* **13**). Colourless gum, which was not separated; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1780 (γ-lactone), 1735 (CO_2R); MS m/z (rel. int.): 330.183 $[M]^+$ (7) ($C_{20}H_{26}O_4$), 228 $[M - RCO_2H]^+$ (32), 85 $[RCO]^+$ (39), 57 $[85 - CO]^+$ (100).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546 \quad 436\,\text{nm}}{-21.2 \quad -21.6 \quad -25.6 \quad -50.4}\ (c = 0.25).$$

8α-Angeloyloxydehydrocostus lactone (**15**). Colourless gum; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1780 (γ-lactone), 1720, 1650 ($C{=}CCO_2R$); MS m/z (rel. int.): 328.168 $[M]^+$ (2) ($C_{20}H_{24}O_4$), 228 $[M - RCO_2H]^+$ (31), 83 $[C_4H_7CO]^+$ (100), 55 $[83 - CO]^+$ (71).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546 \quad 436\,\text{nm}}{+69.9 \quad +72.6 \quad +83.1 \quad +144.4}\ (c = 0.8).$$

11β,13-Dihydrozaluzanin C-angelate (**18**). Colourless gum; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1785 (γ-lactone), 1720, 1650 ($C{=}CCO_2R$); MS m/z (rel. int.): 330.183 $[M]^+$ (1) ($C_{20}H_{24}O_4$), 231 $[M - OCOR]^+$ (12), 83 $[C_4H_7CO]^+$ (100), 55 $[83 - CO]^+$ (49).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546 \quad 436\,\text{nm}}{+77.0 \quad +79.0 \quad +89.0 \quad +155.0}\ (c = 0.1).$$

14-Angeloyloxydehydrocostus lactone (**19**). Colourless gum; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1775 (γ-lactone), 1720, 1650 ($C{=}CCO_2R$); MS m/z (rel. int.): 328.158 $[M]^+$ (4) ($C_{20}H_{24}O_4$), 228 $[M - AngOH]^+$ (28), 83 $[C_4H_7CO]^+$ (100), 55 $[83 - CO]^+$ (43).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546 \quad 436\,\text{nm}}{-53.8 \quad -56.7 \quad -65.6 \quad -119.3}\ (c = 0.45).$$

Haageanolide angelate (**21**). Colourless gum; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1770 (γ-lactone), 1710, 1650 ($C{=}CCO_2R$); MS m/z (rel. int.): 330.183 $[M]^+$ (3) ($C_{20}H_{26}O_4$), 230 $[M - RCO_2H]^+$ (11), 83 $[C_4H_7CO]^+$ (55), 55 $[83 - CO]^+$ (100).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546\,\text{nm}}{+96.9 \quad +101.2 \quad +117.6}\ (c = 1.6).$$

Zinangustolide (**22**). Colourless gum; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3620 (OH), 1775 (γ-lactone), 1720 (CO_2R); MS m/z (rel. int.): 366.204 $[M]^+$ (1) ($C_{20}H_{30}O_6$), 264 $[M - RCO_2H]^+$ (16), 246 $[264 - H_2O]^+$ (16), 228 $[246 - H_2O]^+$ (4), 218 $[246 - CO]^+$ (11), 85 $[C_4H_9CO]^+$ (30), 57 $[85 - CO]^+$ (100).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546 \quad 436\,\text{nm}}{+21.3 \quad +22.4 \quad +26.0 \quad +46.6}\ (c = 8.3).$$

9 mg **22** in 0.1 ml Ac_2O was heated for 3 hr at 70°. TLC (Et_2O–petrol, 4:1) afforded 8 mg **23**, colourless gum; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3600 (OH), 1780 (γ-lactone), 1740 (OAc, CO_2R); MS m/z (rel. int.): 408 $[M]^+$ (3), 348 $[M - HOAc]^+$ (0.5), 306 $[M - RCO_2H]^+$ (6), 288 $[306 - H_2O]^+$ (5), 246 $[306 - HOAc]^+$ (10), 228 $[246 - H_2O]^+$ (10), 85 $[C_4H_9CO]^+$ (38), 57 $[85 - CO]^+$ (100). 4 mg **23** in 1 ml $CHCl_3$ was heated with 10 mg 4-pyrrolidinopyridine and 50 mg Ac_2O for 2 hr at 60°. TLC (Et_2O–petrol, 1:1) afforded 3 mg **24**, colourless gum; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1785 (γ-lactone), 1760 (OAc), 1740 (OAc, CO_2R); MS m/z (rel. int.): 450 $[M]^+$ (1), 390 $[M - HOAc]^+$ (1), 288 $[390 - RCO_2H]^+$ (5), 228 $[288 - HOAc]^+$ (8), 85 $[C_4H_9CO]^+$ (46), 57 $[85 - CO]^+$ (100).

10 mg **23** in 1 ml CH_2Cl_2 was stirred for 2 hr with 10 mg pyridine dichromate. TLC (Et_2O – petrol, 1:1) afforded 1 mg **25**, colourless gum; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1780 (γ-lactone), 1725 (CHO, CO_2R). For ^1H NMR see Table 1.

To 5 mg **22** in 1 ml MeOH was added 10 mg $NaBH_4$. TLC (Et_2O) afforded 3 mg **26**, colourless gum; IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3610 (OH), 1780 (γ-lactone), 1725 (CO_2R); MS m/z (rel. int.): 368 $[M]^+$ (3), 266 $[M - RCO_2H]^+$ (10), 248 $[266 - H_2O]^+$ (8), 220 $[248 - CO]^+$ (7), 85 $[C_4H_9CO]^+$ (28), 57 $[85 - CO]^+$ (100).

11β,13-Dihydrozinangustolide (**27**). Colourless gum; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 3640 (OH), 1780 (γ-lactone), 1730 (CO_2R); MS m/z (rel. int.): 368.220 $[M]^+$ (1) ($C_{20}H_{32}O_6$), 266 $[M - RCO_2H]^+$ (8), 248 $[266 - H_2O]^+$ (9), 85 $[C_4H_9CO]^+$ (28), 57 $[85 - CO]^+$ (100).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546 \quad 436\,\text{nm}}{-19.8 \quad -20.7 \quad -23.8 \quad -44.5}\ (c = 0.42).$$

6β,9β-Diangeloyloxy-8-epizinamultifloride (**32**). Colourless gum; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1780 (γ-lactone), 1730, 1650 ($C{=}CCO_2R$), 1700 (CHO); MS m/z (rel. int.): 442.199 $[M]^+$ (10) ($C_{25}H_{30}O_7$) 343 $[M - AngO]^+$ (4), 342 $[M - AngOH]^+$ (3), 243 $[343 - AngOH]^+$ (4), 83 $[C_4H_7CO]^+$ (100), 55 $[83 - CO]^+$ (50).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546 \quad 436\,\text{nm}}{+32.3 \quad +33.9 \quad +40.0 \quad +70.0}\ (c = 0.13).$$

6β-Angeloyloxy-9β-[2-methylbutyryloxy]-8-epizinamultifloride (**33**). Colourless gum; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1785 (γ-lactone), 1730 ($C{=}CCO_2R$, CO_2R), 1700 (CHO); MS m/z (rel. int.): 444.215 $[M]^+$ (5) ($C_{25}H_{32}O_7$), 85 $[C_4H_9CO]^+$ (37), 83 $[C_4H_7CO]^+$ (74), 57 $[85 - CO]^+$ (100), 55 $[83 - CO]^+$ (87).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546 \quad 436\,\text{nm}}{+41.3 \quad +43.8 \quad +50.0 \quad +86.3}\ (c = 0.08).$$

6β-Angeloyloxy-9β-acetoxy-8-epizinamultifluoride (**34**). Colourless gum; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1770 (γ-lactone), 1760 (OAc), 1720, 1650 ($C{=}CCO_2R$), 1695 (CHO); MS m/z (rel. int.): 402.168 $[M]^+$ (10) ($C_{22}H_{26}O_7$), 303 $[M - OAng]^+$ (2), 302 $[M - AngOH]^+$ (1), 242 $[302 - HOAc]^+$ (6), 227 $[242 - Me]^+$ (6), 83 $[C_4H_7CO]^+$ (100).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546 \quad 436\,\text{nm}}{+80.7 \quad +84.0 \quad +96.7 \quad +172.0}\ (c = 0.3).$$

6β-Angeloyloxy-9β-isobutyryloxy-8-epizinamultiflioride (**35**). Colourless gum; IR $\nu_{max}^{CCl_4}$ cm^{-1}: 1785 (γ-lactone), 1730 (CO_2R), 1700 (CHO); MS m/z (rel. int.) 430.199 $[M]^+$ (11) ($C_{24}H_{30}O_7$), 342 $[M - RCO_2H]$ (15), 242 $[342 - AngOH]^+$ (8), 83 $[C_4H_7CO]^+$ (100), 71 $[C_3H_7CO]^+$ (47).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546 \quad 436\,\text{nm}}{+28 \quad +30 \quad +36 \quad +62}\ (c = 0.05).$$

6β-Angeloyloxy-9β-methacryloyloxy-8-epizinamultifloride (**36**). Colourless gum; IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 1780 (γ-lactone), 1720, 1650 ($C{=}CCO_2R$), 1695 (CHO); MS *m/z* (rel. int.): 428.184 $[M]^+$ (11), 399 $[M - CHO]^+$ (7), 342 $[M - RCO_2H]^+$ (2), 329 $[M - OAng]^+$ (4), 243 $[342 - OAng]^+$ (8), 83 $[C_4H_7CO]^+$ (100).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546 \quad 436\,\text{nm}}{+59.7 \quad +62.7 \quad +72.7 \quad +129.3} \; (c = 0.3).$$

12,18-*Dihydroxy-6,7Z-geranylgeraniol* (**41**). Colourless gum; IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 3510 (OH), 1660 ($C{=}C$); MS *m/z* (rel. int.): 286.230 $[M^+ - 2H_2O]^+$ (1), 256 $[286 - CH_2O]^+$ (2), 253 $[M - Me_2C{=}CHCH_2]^+$ (1), 235 $[253 - H_2O]^+$ (8), 217 $[235 - H_2O]^+$ (28), 199 $[217 - H_2O]^+$ (32), 81 $[C_6H_9]^+$ (100), 69 $[C_5H_9]^+$ (91).

$$[\alpha]^{\lambda}_{24^\circ} = \frac{589 \quad 578 \quad 546 \quad 436\,\text{nm}}{+35.9 \quad +37.6 \quad +42.8 \quad +77.6} \; (c = 0.29).$$

To 19 mg **14** in 1 ml C_6H_6 and 0.1 ml pyridine was added 10 mg AcCl. After 2 hr, TLC (Et_2O–petrol, 1:1) afforded 4 mg **42**, 6 mg **43** and 4 mg **44**. **42**: Colourless gum; IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 3640 (OH), 1740, 1240 (OAc); MS (CI, *i*-butane) *m/z* (rel. int.): 287 $[M + 1 - HOAc, H_2O]^+$ (55), 269 $[287 - H_2O]^+$ (100).

43: Colourless gum; IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 3600 (OH), 1740, 1240 (OAc); MS (CI, *i*-butane) *m/z* (rel. int.): 329 $[M + 1 - HOAc, H_2O]^+$ (4), 287 [329 − ketene] (6), 269 $[329 - HOAc]^+$ (35), 217 $[287 - \text{isoprene}]^+$ (100).

44: Colourless gum; IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 1740, 1240 (OAc); MS (CI, *i*-butane) *m/z* (rel. int.): 217 $[M + 1 - 2HOAc, \text{ketene}, \text{isoprene}]^+$ (100), 159 $[217 - C_5H_8]^+$ (48), 141 $[159 - H_2O]^+$ (32). 6 mg **43** in 1 ml CH_2Cl_2 was stirred 1 hr with 10 mg pyridine dichromate. TLC (Et_2O–petrol, 1:1) afforded 4 mg **45**, colourless gum; IR $\nu_{\max}^{CCl_4}$ cm^{-1}: 1740, 1235 (OAc), 1680 ($C{=}CCO$); MS (CI, *i*-butane) *m/z* (rel. int.): 405 $[M]^+$ (0.5), 345 $[405 - HOAc]^+$ (9), 285 $[345 - HOAc]^+$ (78), 267 $[285 - H_2O]^+$ (30), 239 $[267 - CO]^+$ (100).

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