Tetrahedron Vol. 36, pp. 3551 to 3558
Pergamon Press Ltd., 1980. Printed in Great Britain

NEW UNSYMMETRICALLY SUBSTITUTED TETRAHYDROFUROFURAN LIGNANS FROM *ARTEMISIA ABSINTHIUM*

ASSIGNMENT OF THE RELATIVE STEREOCHEMISTRY BY LANTHANIDE INDUCED CHEMICAL SHIFTS

H. GREGER*

Institute of Botany, University of Vienna, A-1030, Vienna, Austria

and

O. HOFER*

Institute of Organic Chemistry, University of Vienna, A-1090 Vienna, Austria

(*Received in Germany* 14 *March* 1980)

Abstract—The isolation of thirteen tetrahydrofurofuran lignans from the roots of *A. absinthium* and six closely related species is reported. A new group of four lignans, all stereoisomers of 1-[(3,4-methylenedioxy-5-methoxy)phenyl]-4-(3,4,5-trimethoxyphenyl)-tetrahydro-1H,3H-furo[3,4-c]furan, was found. The compounds, named sesartemin, episesartemin A, episesartemin B, and diasesartemin, were characterized by ^{1}H NMR (including lanthanide induced shifts), UV, IR and MS. A fifth new lignan of the sesamin type (the eq/eq isomer of fargesin) could be identified as a minor constituent. The relative configurations of two further products (fargesin and epiashantin) could be confirmed by the lanthanide induced shift technique.

In connection with current comparative studies on *Artemisia* polyacetylenes an additional accumulation of lignans of the tetrahydrofurofuran series has been proved to be of considerable systematic significance for the *A. absinthium* group. The light petrol/ether extracts of the roots of five different species afforded three groups of lignans with different arylic substituents which were presented without details on their stereochemistry.[1] In a previous communication the isolation of a fourth group from the chloroform extract of *A. absinthium* was reported.[2]

Since tetrahydrofurofuran lignans have been shown to possess some insecticidal[3] as well as medicinal[4] properties, many naturally occurring derivatives have already been investigated.[5] However, in the *A. absinthium* group four hitherto unknown lignans could be isolated from the Pe/Et_2O extracts as major components. The new lignans were designated as (+)-sesartemin (**10**), (+)-episesartemin A (**11**), (+)-episesartemin B (**12**), and (+)-diasesartemin (**13**). In order to prevent epimerization during the isolation procedure,[6] the lignans were carefully extracted at room temperature and separated by chromatography on silica gel. An extensive examination of seven closely related species (*A. absinthium* L., *A. arborescens* L., *A. canariensis* Less., *A. gorgonum* Webb, *A. siversiana* Willd., *A. macrocephala* Jacquem. ex Bess., *A. jacutica* Drob.) reveals that the roots contain at least thirteen different lignans[2,7] (Table 1). The chemosystematic significance of these compounds will be reported in detail elsewhere.[7]

A. absinthium itself is characterized by a preponderance of epi- and diasesartemin. From the equatorial/axial configurated episesartemin two different crystalline products were separated by fractional crystallization which exhibit almost identical properties: no separation by tlc (which is very well suited for the separation of all other lignans listed in Table 1) and nearly identical spectral behaviour. Consequently, a pair of stereoisomers was to be expected with the two different aromatic moieties standing either ax/eq or *vice versa* (**11**, **12**). This could be confirmed by means of the lanthanide induced shift (LIS) method.[8]

Recently the first ax/eq- eq/ax pair of a lignan glucoside (epipinoresinol-β-D-glucoside) has been reported[9] employing comparative ^{13}C NMR analysis in DMSO-d_6. In case of the unsymmetrically substituted ax/eq pluviatilol[10] the phenolic OH was used to produce shifts of the associated benzylic proton upon formation of the phenolate ion. Furthermore, fargesin[11] (either **4**, Ar^2/Ar^1 ax/eq or the corresponding isomer eq/ax) and epiashantin (**9**)[12] were mentioned, however no further comment on the detailed stereochemistry of the compounds were given. In the *A. absinthium* group both structures could now be assigned unambiguously by the LIS technique as well.

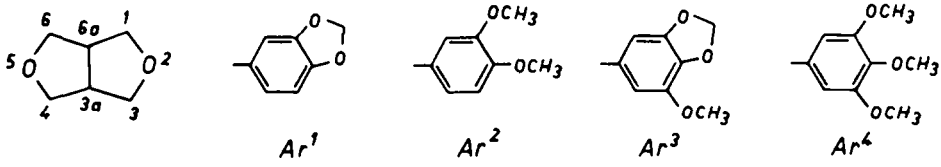
All compounds **1**-**13** show a positive optical rotation with comparable values for the eq/eq, eq/ax and ax/ax type. Following Freudenberg and Sidhu[13] all (+)-sesamin type lignans belong to the same series with the absolute configuration R at the bridge carbons C-3a and C-6a (Table 1). Independant evidence for the absolute configurations of **7** and **13** based on the measurement of the circular dichroism will be published separately.[14]

In the following sections the spectral properties of **1**-**13** are summarized. This representative set of tetrahydrofurofuran lignans allows to point out systematic changes in NMR, UV, IR and MS spectra caused by the nature of the different substituents

Table 1. Some properties of sesamin type lignans (optical rotations in $CHCl_3$, 20 C, c = 0.4–0.5)

No.	Abs.Config. at C- 1	3a	4	6a	Subst.[a] at C-1/C-4	Relat. Config. at C- 1/4	M.P. /°C	$[\alpha]_D$ /°	Trivial Names	Ref.
1	S	R	S	R	Ar^1/Ar^1	eq/eq	120–121	+ 69	Sesamin	3,13,22–24
2	S	R	R	R	Ar^2/Ar^2	eq/ax	124–125	+117	Epieudesmin[b]	15,22
3	S	R	S	R	Ar^1/Ar^2	eq/eq	–[c]	+ 59	–	–
4	S	R	R	R	Ar^1/Ar^2	eq/ax	133–134	+121	Fargesin ?[d]	11[d]
5	S	R	S	R	Ar^4/Ar^4	eq/eq	120–122	+ 48	Yangambin[e]	6,21,25
6	S	R	R	R	Ar^4/Ar^4	eq/ax	118–120	+120	Epiyangambin[e]	2,6,21
7	R	R	R	R	Ar^4/Ar^4	ax/ax	158–159	+287	Diayangambin[e]	2,6,21,26
8	S	R	S	R	Ar^1/Ar^4	eq/eq	–[c]	+ 62	Ashantin	24
9	S	R	R	R	Ar^1/Ar^4	eq/ax	122–123	+119	Epiashantin	12[f]
10	S	R	S	R	Ar^3/Ar^4	eq/eq	112–113	+ 52	Sesartemin	–
11	R	R	S	R	Ar^3/Ar^4	ax/eq	112–114	+115	Episesartemin A	–
12	S	R	R	R	Ar^3/Ar^4	eq/ax	115–116	+127	Episesartemin B	–
13	R	R	R	R	Ar^3/Ar^4	ax/ax	102–104	+315	Diasesartemin	–

[a] Ar^1–Ar^4 are substituents of tetrahydro-1H,3H-furo[3,4-c]furan (numbering see below): Ar^1= [(3,4-methylenedioxy)phenyl], Ar^2= (3,4-dimethoxyphenyl), Ar^3= [(3,4-methylenedioxy-5-methoxy)phenyl], Ar^4= (3,4,5-trimethoxyphenyl) e.g. the IUPAC name for 11: (1R,3aR,4S,6aR)-1-[(3,4-methylenedioxy-5-methoxy)phenyl]-4-(3,4,5-trimethoxyphenyl)-tetrahydro-1H,3H-furo[3,4-c]furan



[b] also: epipinoresinol dimethylether [c] quantity too small for recrystallization [d] relative configuration (eq/ax or ax/eq) not determined in Ref.[11] [e] alternative names for yangambin, epi-, and diayangambin: lirioresinol B, A, and C dimethylether [f] no details are given

(Ar^1–Ar^4) and/or their relative configurations (eq, ax). However, special attention is drawn to the unsymmetrically substituted derivatives of the eq/ax type (**4**, **9**, **11** and **12**), where the interpretation of the ^{1}H NMR LIS data is presented in detail.

NMR and lanthanide induced shifts

The ^{1}H NMR data are listed in Table 2. The pattern of the resonances of the protons due to the tetrahydrofurofuran ring system is very characteristic for the stereochemistry of the compounds: eq/eq, ax/ax or ax/eq; this is already well known.[6,15,16] One characteristic feature should be mentioned additionally. In 3,4,5-trisubstituted aromatic substituents (Ar^3, Ar^4) the resonances of the remaining aromatic protons are found between 6.53–6.61 ppm, in case of 3,4-disubstituted aryl (Ar^1, Ar^2) the three remaining protons show resonance in the region of 6.80–6.94 ppm (Table 2).

Sesamin type lignans with two different aromatic rests standing either axial or equatorial (**11**, **12**) exhibit almost identical ^{1}H NMR spectra. However, an excellent tool to discriminate between them is furnished by the lanthanide induced shift technique. In compounds **4**, **9**, **11** and **12** one of the two aromatic rings carries at least two OMe groups in *ortho* arrangement (Ar^2 and Ar^4), the other one only methylenedioxy (Ar^1) or just one OMe in addition (Ar^3). Shift reagents actually exhibit only very weak coordination to OMe or other ether-like O atoms (e.g. methylenedioxy). In contrary, an *ortho*-dimethoxy arrangement acts very differently since a strong bidentate complex is formed.[17] In case of three OMe (in Ar^4; 3,4,5-trimethoxy) two different bidentate complexes will be present in solution, the C-4 OMe group will be an active coordination center in both complex molecules and should therefore show the highest lanthanide induced shift (LIS) value. Indeed, one OMe exhibits LIS values 3 to 3.5 times higher than the other ones; the OMe of the second ring shows very small LIS values indicating that no (or very weak) coordination takes place at an isolated methoxyl (*ortho* only to methylenedioxy).

Three points of interest should be emphasized in the discussion of the LIS data (Table 3):

(i) In comparison of the complete series of isomers **10**–**13** it turns out that the relative LIS (Table 3, data in brackets) for the protons close to the coordination site are indicative for the stereochemistry of the compounds.

Table 2. ^{1}H NMR data [δ/ppm, $CDCl_3$(TMS)]

No.	C-1,C-4	C-3a,C-6a	C-3,C-6	O-CH_2-O	OCH_3	$H_{aromat.}$
1	4.73(d,2H)[b]	3.06(m,2H)	4.25(dd,2H)[c] 3.88(dd,2H)[d]	5.95(s,2H)	–	6.86 6.80(m,6H)
2	4.88(d,1H)[e] 4.47(d,1H)[f]	3.34(m,1H) 2.92(m,1H)	4.15(m,1H) 3.90(m,2H)[a] 3.34(m,1H)	–	3.93(1Me) 3.92(1Me) 3.90(1Me) 3.89(1Me)	6.94 6.86(m,6H)
3	4.75(d,2H)[b]	3.08(m,2H)	4.26(dd,2H)[c] 3.90(dd,2H)[a]	5.95(s,2H)	3.92(1Me) 3.90(1Me)	6.80– 6.94(m,6H)
4	4.88(d,1H)[e] 4.44(d,1H)[f]	3.33(m,1H) 2.87(m,1H)	4.11(m,1H) 3.87(m,2H)[a] 3.33(m,1H)	5.96(s,2H)	3.92(1Me) 3.90(1Me)	6.80– 6.94(m,6H)
5	4.76(d,2H)[b]	3.12(m,2H)	4.32(dd,2H)[c] 3.95(dd,2H)[g]	–	3.89(4Me) 3.85(2Me)	6.58(s,4H)
6	4.87(d,1H)[e] 4.46(d,1H)[f]	3.37(m,1H) 2.94(m,1H)	4.18(m,1H) 3.90(m,2H)[a] 3.37(m,1H)	–	3.92(4Me) 3.90(1Me) 3.88(1Me)	6.60(s,4H)
7	4.93(d,2H)[h]	3.22(m,2H)	3.76(dd,2H)[i] 3.61(dd,2H)[j]	–	3.90(4Me) 3.87(2Me)	6.61(s,4H)
8	4.76(d,2H)[b]	3.10(m,2H)	4.30(dd,2H)[c] 3.94(dd,2H)[g]	5.98(s,2H)	3.91(2Me) 3.87(1Me)	6.80– 6.86(m,3H) 6.58(s,2H)
9	4.85(d,1H)[e] 4.44(d,1H)[f]	3.34(m,1H) 2.88(m,1H)	4.14(m,1H) 3.87(m,2H)[a] 3.34(m,1H)	5.95(s,2H)	3.90(2Me) 3.87(1Me)	6.80– 6.86(m,3H) 6.58(s,2H)
10	4.74(d,2H)[b]	3.08(m,2H)	4.28(dd,2H)[c] 3.92(dd,2H)[a]	5.96(s,2H)	3.92(1Me) 3.88(2Me) 3.85(1Me)	6.57(s,3H) 6.53(s,1H)
11	4.85(d,1H)[e] 4.44(d,1H)[f]	3.36(m,1H) 2.92(m,1H)	4.16(m,1H) 3.90(m,2H)[a] 3.36(m,1H)	5.98(s,2H)	3.95(1Me) 3.90(2Me) 3.86(1Me)	6.60(s,3H) 6.53(s,1H)
12	4.86(d,1H)[e] 4.44(d,1H)[f]	3.36(m,1H) 2.90(m,1H)	4.14(m,1H) 3.90(m,2H)[a] 3.36(m,1H)	5.97(s,2H)	3.94(1Me) 3.90(2Me) 3.87(1Me)	6.58(s,3H) 6.56(s,1H)
13	4.89(d,2H)[h]	3.18(m,2H)	3.68(dd,2H)[i] 3.59(dd,2H)[j]	5.96(s,2H)	3.93(1Me) 3.89(2Me) 3.86(1Me)	6.57(s,3H) 6.55(s,1H)

[a] covered by OCH_3 resonances; coupling constants: [b] 4 Hz, [c] 9 Hz gem./ 7 Hz vic., [d] 9 Hz gem./ 3.5 Hz vic., [e] 5.5 Hz (equatorial H), [f] 7 Hz (axial H), [g] 9.5 Hz gem./ 3.5 Hz vic. (partially covered by OCH_3), [h] 4.5 Hz, [i] 9.5 Hz gem./ 2.5 Hz vic., [j] 9.5 Hz gem./ 8.5 Hz vic.

Table 3. ^{1}H NMR LIS data of **4** and **9–13** [in ppm for the 1:1 complex, $CDCl_3$, $Eu(fod)_3$; the data in brackets are scaled using an internal reference signal common to **9–13** (1.00 for the 2Me signal of the C-4 aryl)]

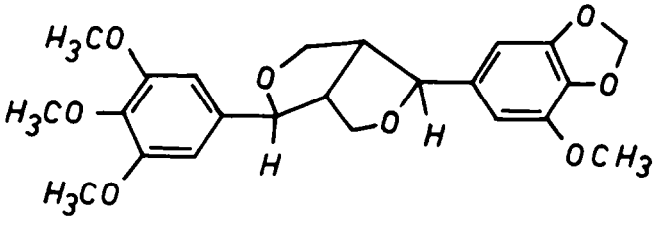
No.	Aryl at C-4			Benzylic H at		Aryl at C-1		
	Ar	OCH_3	$H_{arom.}$	C-1	C-4	Ar	CH_2	OCH_3
4	Ar^2_{ax} 7.24(1Me)	6.46(1Me)	8.48/7.96/3.83	Hax1.40	Heq2.84	Ar^1_{eq} 0.16		–
9	Ar^4_{ax} 9.23(1Me) (3.15)	2.93(2Me) (1.00)	5.20(2H) (1.77)	Hax1.44 (0.49)	Heq2.47 (0.84)	Ar^1_{eq} 0.15 (0.05)		–
10	Ar^4_{eq} 10.07(1Me) (3.47)	2.90(2Me) (1.00)	5.80(2H) (2.00)	Hax2.00 (0.69)	Hax3.05 (1.05)	Ar^3_{eq} 0.25 (0.09)	0.35 (0.12)	
11	Ar^4_{eq} 10.90(1Me) (3.46)	3.15(2Me) (1.00)	5.97(2H) (1.90)	Heq0.73 (0.23)	Hax3.00 (0.95)	Ar^3_{ax} 0.40 (0.13)	0.57 (0.18)	
12	Ar^4_{ax} 8.31(1Me) (3.08)	2.70(2Me) (1.00)	4.90(2H) (1.81)	Hax1.40 (0.52)	Heq2.30 (0.85)	Ar^3_{eq} 0.35 (0.13)	0.45 (0.17)	
13	Ar^4_{ax} 8.60(1Me) (3.16)	2.72(2Me) (1.00)	5.02(2H) (1.85)	Heq1.01 (0.37)	Heq2.56 (0.94)	Ar^3_{ax} 0.37 (0.14)	0.53 (0.19)	

The values for **10** (eq/eq, therefore Ar^4 and complexation site necessarily equatorial) are 3.47/1.00/2.00 for MeO/2MeO/H_{arom}. The comparable data for **13** (necessarily axial trimethoxyphenyl) are 3.16/1.00/1.85. For **11** 3.46/1.00/1.9 and for **12** 3.08/1.00/1.81 is found. The relative LIS data for **11** indicate therefore an equatorial position for the complexation site, for **12** an axial one. The corresponding values for **9** are 3.15/1.00/1.77 indicating an axial trimethoxyphenyl rest.

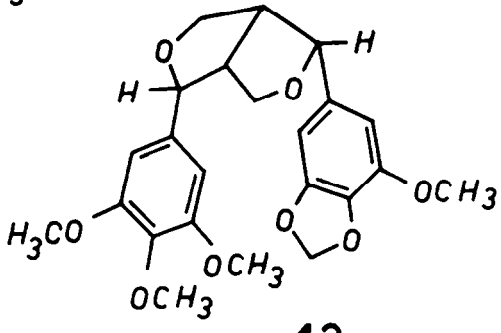
(ii) Comparing the relative values of the benzylic protons (at C-1 and C-4, resp.) of compounds **11**, **12**, **9** and **4**, one observes that only in **11** the benzylic proton at 4.44 ppm which is known to be an axial one[6,15,16] is shifted more than the other one at 4.85 ppm which is equatorial. This shows up in the spectra by an impressive change in the positions of the corresponding resonances: with increasing amounts of reagent the downfield benzylic proton becomes the upfield one and *vice versa* (Fig. 1). Since the more shifted benzylic proton is axial, the associated aromatic system containing the complexation center must be equatorial in **11**. In all other cases the equatorial benzylic proton at 4.85 4.88 ppm is shifted more by the europium reagent than the axial one at 4.44 ppm. Therefore, in **4**, **9** and **12** the aromatic system carrying the coordination site (Ar^2 or Ar^4) is in an axial position.

(iii) A complete quantitative treatment of the LIS includes the calculation of the dipolar magnetic fields for the average axially symmetric complex in solution.[8] In bidentate complexes (**4**, with *ortho*-dimethoxyl) the superposition of two dipolar fields has to be taken into account for a rigorous quantitative treatment.[18] Two different bidentate complex types (for **9**, **11** and **12**) complicate matters again. Nevertheless, some conclusive semiquantitative considerations based on the McConnell-Robertson equation[19] are possible.

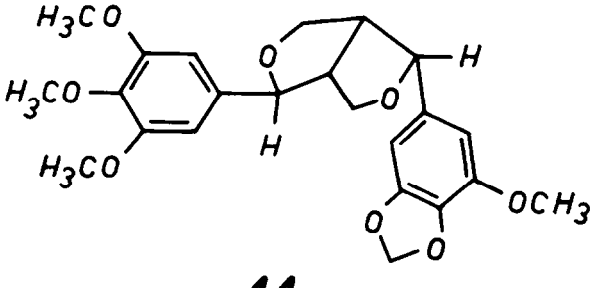
If the complexed aromatic moiety is equatorial, the LIS values of the two benzylic protons must differ substantially: the distances from the average complexation site to the close axial benzylic proton and to the far equatorial one are 6 Å and 9.7 ± 0.2 Å, resp. The coordination site and the two protons of interest are almost on a straight line and the angular component of the McConnell Robertson equation may be neglected.[8] Therefore, following a simple distance relationship (LIS = prop. r^{-3}), the LIS ratio of the two protons should be $r_1^{-3}/r_2^{-3} = 4.2 \pm 0.3 : 4.13$ is found for **11** (Ar^4_{eq}). In case the complexation site is axially positioned, the opposite axial (far) proton is only 7 ± 1 Å in distance from the expected complexation site; this is a rather crude estimate since the perhydrofuran ring systems may be distorted to avoid sterical interactions with the axial aryl system. The other (close) proton is again 6 Å in distance and the estimated ratio of high LIS value/small LIS value (for the benzylic protons) is 1.8 ± 0.5. This is the case for **12** (1.63), **9** (1.71) and **4** (2.04).



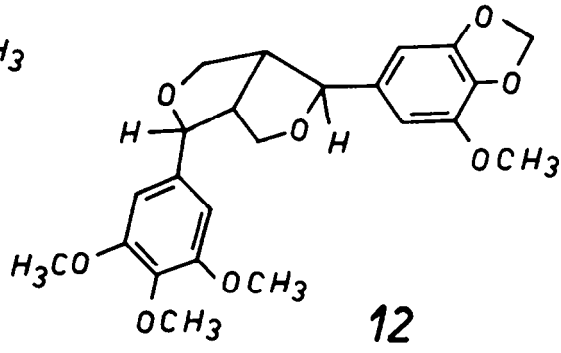
10



13



11



12

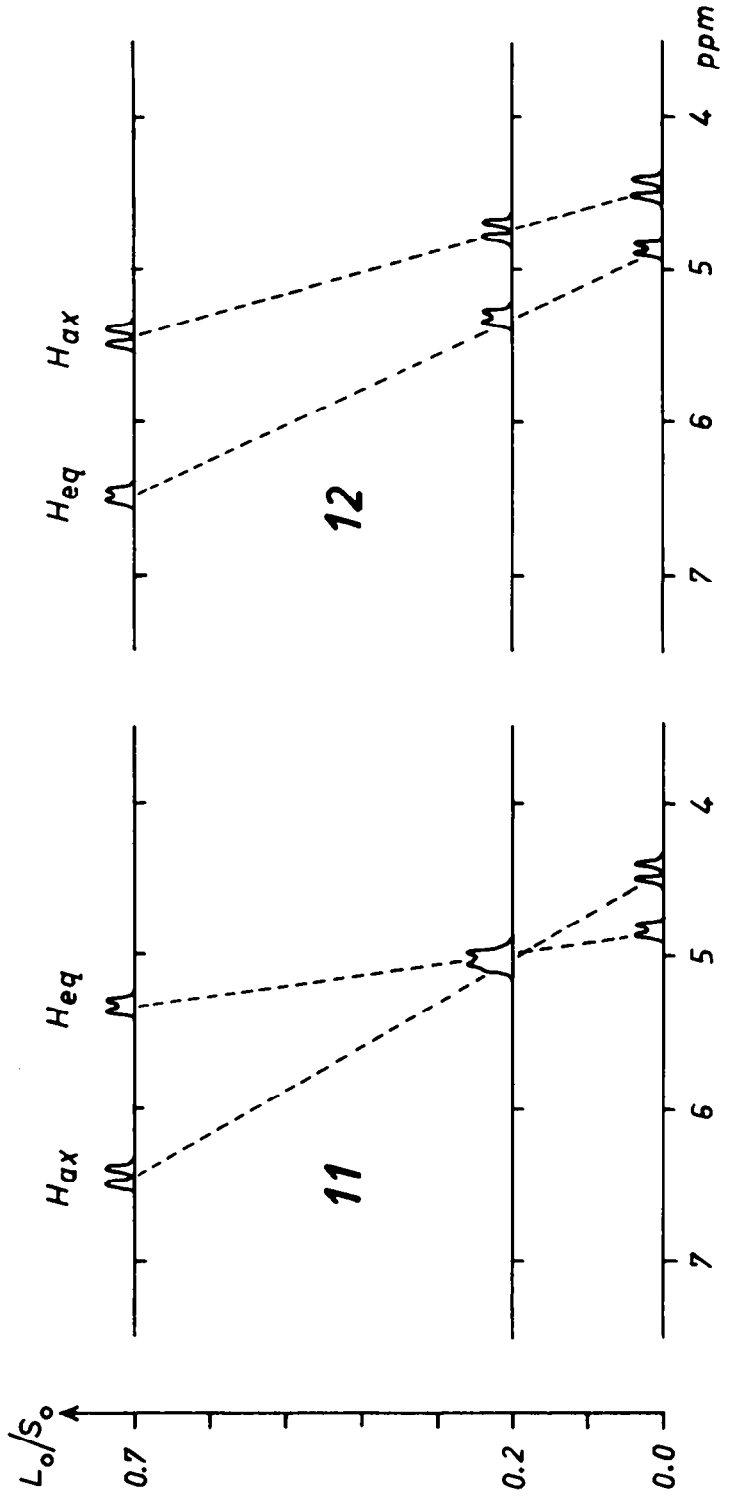


Fig. 1. Shifts of the benzylic protons in the NMR spectra of **11** and **12** at different reagent substrate concentration ratios.

Table 4. UV maxima and shoulders (EtOH)

No.	λ_{max} /nm (ε /1000)		
1	287(10.1)	238(12.7)	204(103.0)
2	279(6.7)	232(19.7)	204(102.3)
3	283(6.9)	232(15.3)	203(94.7)
4	282(8.0)	232(15.0)	203(98.0)
5	270(1.2)	232 sh(10.8)	207(85.4)
6	270(1.9)	232 sh(16.6)	207(101.0)
7	270(1.4)	231 sh(14.5)	207(92.5)
8	283(5.4)	230 [a](14.8)	204(100.5)
9	283(5.3)	231 [a](14.3)	205(94.3)
10	273(2.5)	236 sh(14.0)	207(97.5)
11	273(2.2)	236 sh(13.2)	209(104.5)
12	273(2.3)	235 sh(13.3)	208(98.8)
13	273(2.2)	235 sh(13.5)	207(96.5)

[a] maximum not very distinct, almost shoulder

All evidence presented in (i) (iii) agrees with the relative configurations indicted in Table 1 for the compounds **4**, **9**, **11** and **12**.

UV spectra. In general the UV data (Table 4) are characteristic for the nature of the aromatic substituents of the furofuran system and not for their relative stereochemistry (configuration). For instance all four stereoisomers **10**–**13** show practically identical UV spectra. An increasing number of substituents, especially OMe, shifts the long wave absorption to a lower wavelength with ε decreasing [Table 4: **1** (287 nm, ε = 10 100), **5**-**7** (270 nm, ε ~ 1 500)]. The absorption at ~235 nm changes neither position (230–238 nm) nor strength (ε = 10 – 20 000) very much, but this maximum is converted into a shoulder upon increasing substitution of the aromatic moiety. This is caused mainly by broadening of bands and to a less extent by shifts of the ~235 nm band to lower and the ~205 nm band to higher wavelength upon substitution. The very strong absorption at 204–209 nm is almost unaffected by substituents; neither λ nor ε changes drastically in the series investigated.

IR spectra. The IR data are summarized in Table 5. The absorptions are characteristic for the substitution of the aromatic ring and in some cases for the stereochemistry (relative configuration) of the particular isomers as well. The band at 1633–34 cm^{-1} is for instance characteristic for the aromatic rest Ar^3 (**10**–**13**). A strong broad band at 1245–1250 cm^{-1} is typical for O CH_2 O (Ar^1) and the band at 1265–1270 cm^{-1} for *ortho*-dimethoxyl (Ar^2). In all other compounds with OMe a strong line at 1232–1238 cm^{-1} is observed. The presence of different ether functions within a molecule results in a very broad band in the region of 1230–1270 cm^{-1} (**3**: max 1236, second lower max 1245, sh 1265; **4**: max 1245, lower max 1237, sh 1265; **8**: max 1236, sh 1245; **9**: max 1238, sh 1245). The band at ~1080 cm^{-1} (1075–1090) is absent in all diequatorial isomers.[15] An interesting stereochemical dependence can be observed for the relatively weak bands at ~1326 (1323–1330) and ~1342 cm^{-1} (1340–1345): The former band is stronger in compounds containing an equatorial trimethoxyphenyl rest Ar^4 (**5**, **8**, **10**, **11**) the latter is stronger if Ar^4 is axial (**7**, **9**, **12**, **13**). Consequently, in **6**, with Ar^4 ax and eq both bands are of comparable strength. This of interest especially for the ax/eq-eq/ax pair **11**–**12**.

Mass spectra. The mass spectra of some sesamine derivatives have already been discussed.[20] The stereochemistry of the compounds could not be evaluated from the mass spectra since all stereoisomers

Table 5. IR absorptions in the region 1600–1000 cm^{-1} (CCl_4); bands at 2820–3020 cm^{-1} are almost identical for all compounds

No.	ν /cm^{-1}														
1			1504	1490	1445					1245[a]			1040		
2	1595 w	1515			1465	1455	1417	1370 vw	1340 vw	1270	– – – [b]		1080	1034	
3	1593 w	1515	1504	1491	1465	1443	1420 vw	1370 vw	1344 vw	1236[a]	1135		1042		
4	1590 w	1520	1506	1494	1465 vw	1447	1415	1365 w	1340 vw	1245[a]	1160	1080	1040	1032	
5	1593		1508		1465	1452 vw	1417	1373 w	1344 vw	1330 w	1235	1134			1012
6	1591		1503		1462	1452 w	1415	1367	1342 w	1326 w	1233	1132	1080		1010
7	1592		1506		1461	1450	1417	1366	1345	1330 vw	1232	1132	1085		1011
8	1593		1504	1490	1463	1444	1415 w	1372 w	1342 w	1330 w	1236[a]	1132		1042	1011
9	1590		1505	1493	1465	1447	1417	1363	1342 w	1330 vw	1238[a]	1132	1080	1042	1010
10	1634	1590	1504		1463	1452	1425	1370	1340 vw	1326	1232	1132		1048	1010
11	1634	1592	1506		1462	1451	1425	1370	1340 vw	1325	1232	1132	1075	1050	1010
12	1633	1590	1505		1463	1451	1420	1362	1341	1324 vw	1232	1132	1080	1046	1010
13	1633	1592	1506		1463	1451	1423	1363	1343 w	1323 vw	1232	1132	1083	1050	1010

—— dominant bands, ---- strong, w weak, vw very weak

[a] very broad [b] strong bands at 1237, 1163, and 1140 in this region

Table 6. Typical fragments for the different arylic substituents in the mass spectra of **1–13** [m/e (relative intensity), 70 eV, 80 °]

No.	Ar	$M^{\cdot+}$	$ArCH_2^+$	$ArCHO^{\cdot+}$	$ArC{\equiv}O^+$	$ArCH{=}CH{-}CH_2^+$	$ArCH{=}OH^+$	ArH_2^+	$ArH^{\cdot+}$	Ar^+
1	Ar^1eq	354	135(52)	150(42)	149(100)	161(42)	151(8)	123(4)	122(27)	121(14)
	Ar^1eq	(42)								
2	Ar^2eq	386	151(68)	166(43)	165(100)	177(64)	167(8)	139(8)	138(20)	137(7)
	Ar^2ax	(64)								
3	Ar^1eq	370	135(68)	150(40)	149(100)	161(39)	151(a)	123(8)	122(24)	121(18)
	Ar^2eq	(70)	151(40)	166(30)	165(48)	177(45)	167(9)	139(8)	138(17)	137(6)
4	Ar^1eq	370	135(58)	150(30)	149(100)	161(26)	151(a)	123(5)	122(23)	121(13)
	Ar^2ax	(84)	151(33)	166(31)	165(41)	177(50)	167(8)	139(14)	138(14)	137(5)
5	Ar^4eq	446	181(73)	196(25)	195(48)	207(55)	197(21)	169(21)	168(15)	167(7)
	Ar^4eq	(100)								
6	Ar^4eq	446	181(75)	196(21)	195(47)	207(38)	197(30)	169(31)	168(12)	167(7)
	Ar^4ax	(100)								
7	Ar^4ax	446	181(98)	196(24)	195(33)	207(27)	197(54)	169(43)	168(14)	167(7)
	Ar^4ax	(100)								
8	Ar^1eq	400	135(49)	150(22)	149(57)	161(32)	151(10)	123(3)	122(14)	121(10)
	Ar^4eq	(100)	181(37)	196(23)	195(28)	207(30)	197(23)	169(22)	168(13)	167(4)
9	Ar^1eq	400	135(56)	150(22)	149(73)	161(23)	151(11)	123(4)	122(13)	121(11)
	Ar^4ax	(100)	181(38)	196(23)	195(17)	207(30)	197(50)	169(50)	168(14)	167(6)
10	Ar^3eq	430	165(59)	180(38)	179(65)	191(22)	181(a)	153(15)	152(23)	151(16)
	Ar^4eq	(100)	181(57)	196(24)	195(32)	207(34)	197(18)	169(20)	168(15)	167(6)
11	Ar^3ax	430	165(50)	180(24)	179(32)	191(19)	181(a)	153(15)	152(14)	151(10)
	Ar^4eq	(100)	181(55)	196(16)	195(37)	207(17)	197(13)	169(9)	168(8)	167(5)
12	Ar^3eq	430	165(47)	180(26)	179(62)	191(17)	181(a)	153(9)	152(16)	151(13)
	Ar^4ax	(100)	181(43)	196(18)	195(15)	207(26)	197(37)	169(37)	168(9)	167(6)
13	Ar^3ax	430	165(75)	180(45)	179(59)	191(18)	181(a)	153(20)	152(22)	151(17)
	Ar^4ax	(100)	181(79)	196(25)	195(26)	207(18)	197(44)	169(40)	168(12)	167(7)

[a] peak at this mass coinciding with another prominent fragment of the molecule

showed almost identical fragmentation. We observed in general the same with one exception. High peaks for fragments of type $Ar{-}CH{=}OH^+$ and ArH_2^+ ($Ar{-}CH{=}OH^+ - CO$) could only be observed in compounds with an axial Ar^4 (**6**, **7**, **9**, **12**, **13**). In all other cases, even for equatorial Ar^4 (**5**, **8**, **10**, **11**) this fragmentation path is less important. The remaining fragmentations can be assigned in analogy to Ref. 20; typical fragments for the different arylic substituents (Ar^1–Ar^4) are listed in Table 6.

Acknowledgements—We are grateful to Dr. A. Nikiforov and Mr. H. Bieler for recording the mass spectra and to Dr. W. Silhan for recording the 100 MHz NMR spectra. The generous support of the "Jubiläumsfonds der Oesterreichischen Nationalbank" (project 969) is gratefully acknowledged.

EXPERIMENTAL

Plant material was cultivated under field conditions in the Botanical Garden of the University of Vienna. Voucher specimens are deposited at the herbarium of the Institute of Botany, University of Vienna (WU).

Isolation. Fresh roots (100–300 g) of seven different species belonging to the *A. absinthium* group were separately cut into small pieces and extracted with petrol (b.p. 60 80°)/Et_2O (2:1) for 48 hr at room temp. Et_2O was removed under reduced pressure and the concentrated petrol extract yielded a brown resinous deposit which has been proved to consist mainly of lignans. This resin was dissolved in Et_2O and directly separated by TLC on 1 mm thick layers of silica gel GF254 (Merck) using Et_2O/Pe (4:1) as solvent. The products remaining in the petrol soln were roughly fractionated on a silica gel column eluting with Pe/Et_2O mixtures, with Et_2O increasing from 0 to 100%, and finally with 3–10% MeOH in Et_2O. The lignan containing fractions (50% Et_2O–10% MeOH, Et_2O) were also subjected to preparative tlc. Identical products from both branches of the isolation procedure were combined. Depending on the quantity of roots, 20–120 mg of the major components (**1**, **5**–**13**) could be obtained. **2**, **3** and **4** were isolated only as minor constituents.

According to increasing polarity the following sequence was observed (R_f; silica gel 60 F254, Merck; Et_2O/Pe = 9:1): **1** (0.82), **4** (0.62), **9** (0.60), **3** (0.57), **8** (0.55), **11** and **12** (0.49), **10** (0.45), **13** (0.40), **2** (0.35), **6** (0.31), **5** (0.28), **7** (0.23).

Mps (uncorr., Table 1) were determined using a Kofler micro-hotstage. For the determination of the optical rotations (Table 1) a Perkin Elmer 141 polarimeter was used. NMR spectra were recorded on a Varian XL-100 (chemical shifts, Table 2) or a Varian EM-360 spectrometer (lanthanide induced shifts, Table 3). UV spectra (Table 4) were obtained using a Cary-15 spectrometer. For IR spectra (Table 5), a Perkin Elmer 273 spectrometer was used. The mass spectra (Table 6) were recorded on a Varian MAT CH-7 instrument.

The lanthanide induced shifts were determined by adding increasing amounts of Tris[1,1,1,2,2,3,3-heptafluoro-7,7-dimethyloctanedionato-(4,6)]-europium (Merck) to a solution of 10–15 mg of substrate in 0.5 ml $CDCl_3$. The spectra were recorded at 5–7 different reagent concentrations up to a molar concentration ratio of reagent: substrate = 0.7; the LIS for the 1:1 complex were obtained by extrapolation.

REFERENCES

[1]H. Greger, *Planta Med.* **35,** 84 (1979).
[2]M. Djermanović, S. Mladenović and M. Stefanović, *Bull. Soc. Chim. Beograd.* **41,** 287 (1976).
[3]W. A. Jones, M. Beroza and E. D. Becker, *J. Org. Chem.* **27,** 3232 (1962).
[4]S. Ghosal, S. Banerjee and R. S. Srivastava, *Phytochemistry* **18,** 503 (1979); S. Ghosal, S. Banerjee and D. K. Jaiswal, *Ibid.* **19,** 332 (1980).
[5]T. K. Devon and A. I. Scott, *Handbook of Naturally Occurring Compounds,* Vol. 1. Academic Press, New York San Francisco and London (1975).
[6]L. H. Briggs, R. C. Cambie and R. A. F. Couch, *J. Chem. Soc.* (C), 3042 (1968).
[7]H. Greger, *Biochem. Syst. Ecol.,* submitted.
[8]J. D. Roberts, G. E. Hawkes, J. Husar, A. W. Roberts and D. W. Roberts, *Tetrahedron* **30,** 1833 (1974); O. Hofer, *Topics in Stereochemistry* (Edited by N. L. Allinger and E. L. Eliel, Vol. 9, p. 111. Wiley-Interscience, New York (1976).
[9]M. Chiba, S. Hisada, S. Nishibe and H. Thieme, *Phytochemistry* **19,** 335 (1980).
[10]J. E. T. Corrie, G. H. Green, E. Ritchie and W. C. Taylor, *Aust. J. Chem.* **23,** 133 (1970).
[11]H. Kakisawa, T. Kusumi, H.-Y. Hsü and Y. P. Chen, *Bull. Chem. Soc. Japan* **43,** 3631 (1970); H. Kakisawa, Y. P. Chen and H.-Y. Hsü, *Phytochemistry* **11,** 2289 (1972).
[12]F. Bohlmann, C. Zdero and U. Faass, *Chem. Ber.* **106,** 2904 (1973).
[13]K. Freudenberg and G. S. Sidhu, *Ibid.* **94,** 851 (1962).
[14]O. Hofer and R. Schölm, *Tetrahedron,* in press.
[15]C. K. Atal, K. L. Dhar and A. Pelter, *J. Chem. Soc.* (C), 2228 (1967).
[16]A. J. Birch, P. L. Macdonald and A. Pelter, *Ibid.* (C), 1968 (1967).
[17]G. E. Wright and T. Y. Tang Wei, *Tetrahedron* **29,** 3775 (1973).
[18]O. Hofer, H. Griengl and P. Nowak, *Monatsh. Chem.* **109,** 21 (1978).
[19]H. M. McConnell and R. E. Robertson, *J. Chem. Phys.* **29,** 1361 (1958).
[20]A. Pelter, *J. Chem. Soc.* (C), 1376 (1967).
[21]E. E. Dickey, *J. Org. Chem.* **23,** 179 (1958).
[22]K. Weinges, *Chem. Ber.* **94,** 2522 (1962).
[23]E. D. Becker and M. Beroza, *Tetrahedron Letters* 157 (1962).
[24]R. Hänsel and D. Zander, *Arch. Pharm.* **294,** 699 (1961).
[25]R. Hänsel, Ch. Leuckert and G. Schulz, *Z. Naturforschg.* **21b,** 530 (1966).
[26]G. B. Russel and P. G. Fenemore, *Phytochemistry* **12,** 1799 (1973).
[27]Note added in proof: Another new lignan (Ar^2/Ar^4 = eq/ax; (+)-epimagnolin;[11] s. Tab. 1) could be isolated as a minor constituent; the structure was derived from NMR, ^1H LIS, UV, IR and MS data.