# An Efficient Synthesis of Enantiopure 1-Alkoxy-1,2-propadienes from Propargyl Bromide

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A number of enantiopure functionalized alcohols have been *O*-allenylated by reaction of their corresponding sodium alcoholates with propargyl bromide followed by *t*-BuOK catalyzed isomerization of the resulting propargyl ethers, in good overall yields.

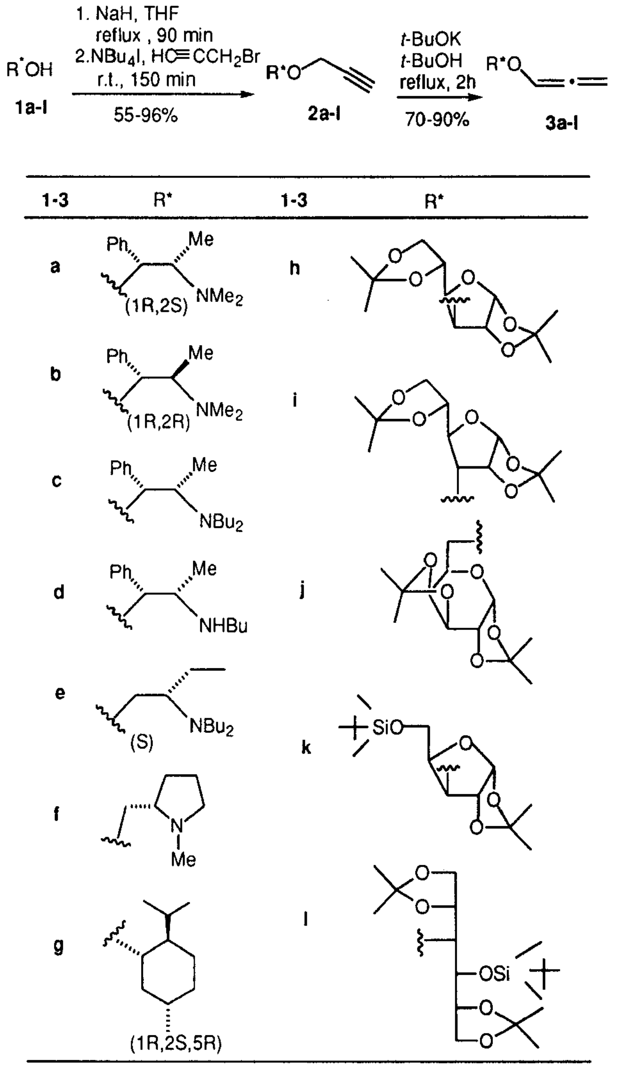
In the two past decades, alkoxyallenes have emerged as versatile building blocks in organic synthesis.[1] The lithium salts of alkoxyallenes, which can serve as synthetic equivalents of $\alpha,\beta$-unsaturated acyl anions[2] and $d^3$, $a^1$-synthons,[3] have been widely used as key intermediates in the synthesis of natural products, e.g. lacrimin A[4] or pyrenophorin.[2] Alkoxyallenes are also good dienophiles which react smoothly in hetero Diels–Alder reactions with a variety of electron-deficient dienes.[5] Moreover, intramolecular Diels–Alder reactions utilizing alkoxyallenic dienophiles have proved to be a useful synthetic tool for the construction of complex ring systems because of the unique geometry of allene molecules which allows a high degree of stereochemical control.[6] Lastly, allenic ethers were shown to be good precursors of $\alpha$-methylene-$\gamma$-butyrolactones[7] and have been used in the preparation of diversely functionalized allylstannanes by palladium(0) catalyzed hydro- or silylstannylation.[8] Although, alkoxyallenes have found many applications in organic synthesis, they have been used sparingly in asymmetric synthesis.[5b,9,10]

As part of a program aimed at developing new alkoxyallene transformations, we were interested in the general preparative synthesis of optically active allenic ethers. Few methods exist to prepare alkoxyallenes;[11] the most popular one, developed by Brandsma et al[12] based on simple alkyl ethers and extended by Tius et al,[13] consists of a two-step reaction starting from propargyl alcohol.

In our case, because we chose enantiopure functionalized alcohols as chiral auxiliaries, the first step of the Brandsma's allenic ethers synthesis,[12] the propargyl ether formation, was accomplished by a Williamson reaction from propargyl bromide. Substitution was first realized in DMF solution, in the presence of an equimolar amount of NaH and propargyl ethers were obtained only in low yields (ca. 30%). Later on, we found that optically active propargyl ethers could be efficiently prepared, at room temperature, by using a catalytic amount of tetrabutylammonium iodide[12] (2 mol%) and THF as solvent (55–96% yield, Table 1). The known enhanced nucleophilic reactivity of tetraalkylammonium alcoholates,[15] the supposed reacting species, allowed the substitution to occur readily (ca. 150 min).

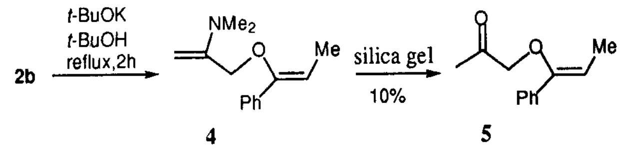
The monopropargylation of 1,2:5,6-di-*O*-isopropylidene-D-mannitol **11** was realized via the reaction of its dibutylstannylene acetal[16] with propargyl bromide in DMF (70% yield).

The prototropic rearrangement of propargyl ethers, which lead to alkoxyallenes (Scheme 1) in good yields (70–90%, Table 1) was achieved, using the Brandsma's procedure,[12] with an equimolar amount of potassium *tert*-butoxide in refluxing *tert*-butyl alcohol for 2 h, except in the case of compound **2k** (24 h).



**Scheme 1**

During the isomerization of the acetylenic ether **2b**, a byproduct (compound **5**), was obtained in 10% yield. $^1H$ and $^{13}C$ NMR spectra of **5** revealed the presence of only one geometrical isomer. Formation of the enol ether **5** must proceed by stereospecific base-induced elimination of potassium dimethylamide followed by addition of dimethylamine to the triple bond or allenic moiety to afford the enamine **4**. The enamine is then hydrolysed to the



Scheme 2

Table 1. Physical Data of Compounds **2** and **3** Prepared

| Product[a] | Yield (%) | mp (°C) (pentane) or bp (°C/mmHg)[b] | $[\alpha]_D^{20}$ ($c$, CHCl$_3$) |
|---|---|---|---|
| **2a** | 84 | 68.5–68.9 | + 166 (1.9) |
| **2b** | 85 | 90/0.01 | + 202 (2.08) |
| **2c** | 70 | oil | − 81 (2.2) |
| **2d** | 55 | 100/0.01 | − 132.8 (2.1) |
| **2e** | 67 | 90/0.01 | + 65.6 (2.1) |
| **2f** | 70 | 90/12 | + 55.6 (1.0) |
| **2g** | 55 | 60/0.01 | − 120 (2.0) |
| **2h** | 98 | 150/0.01 | − 10.6 (1.9) |
| **2i** | 96 | 113–115 | + 112 (2.2) |
| **2j** | 82 | 57–59 | − 77 (2.1) |
| **2k** | 65 | oil | − 37.6 (1.9) |
| **2l** | 70 | oil | + 27.6 (2.5) |
| **3a** | 90 | 90/0.01 | + 102 (2.8) |
| **3b** | 65 | 90/0.01 | + 212 (2.0) |
| **3c** | 80 | oil | − 67.8 (2.6) |
| **3d** | 70 | oil | − 80 (2.0) |
| **3e** | 90 | oil | + 64.5 (2.0) |
| **3f** | 75 | 90/12 | + 66.4 (1.6) |
| **3g** | 70 | 70/0.01 | − 90.9 (2.0) |
| **3h** | 88 | 52–53 | − 18.6 (1.7) |
| **3i** | 70 | 90–91 | + 139 (2.0) |
| **3j** | 83 | oil | − 73.3 (2.1) |
| **3k** | 40 | oil | − 28.0 (2.0) |
| **3l** | 60 | oil | + 33.6 (2.1) |

[a] Satisfactory microanalyses obtained: C ± 0.3, H ± 0.5 %; **2l**, **3g**, **3k** were not analyzed.

[b] Temperature of the oven Kugelrohr apparatus.

methyl ketone **5** during purification on silica gel (Scheme 2). Such a compound **5** was not observed during the isomerization of other *O*-propargyl ephedrine derivatives **2a,c,d**.

Few enantiopure propargyl or allenyl ethers are crystalline solids (Table 1), the majority being syrups obtained in pure form by silica (or alumina) gel chromatography. They can be kept at − 20 °C for a few months without any visible degradation.

In conclusion, we report a convenient and general method for the synthesis of optically active alkoxyallenes. This two-step reaction is amenable to preparative scale synthesis and is accomplished with good overall yield (> 60 %).

Starting materials **1a,b**, **f**, **g–j** were obtained from Aldrich Chemical Co. Compounds **1c–e** were prepared according to the literature procedure.[17] Compound **1k** was obtained by monosilylation of 1,2-*O*-isopropylidene-D-xylofuranose, purchased from Aldrich Chemical Co., using the method of Hernandez et al.[18] Melting points were determined on a Büchi apparatus and are uncorrected. IR spectra were recorded as thin film between NaCl plates or as solids in KBr pellets on a Perkin-Elmer 298 spectrophotometer and were calibrated with the 1601 cm$^{-1}$ absorption of polystyrene. NMR spectra were measured on a Bruker AC 200 Fourier transform spectrophotometer with proton observation at 200 MHz and carbon observation at 50 MHz. Unless otherwise stated, spectra were recorded in CDCl$_3$ and chemical shifts are reported in ppm downfield from TMS ($\delta$). GC/MS analyses were carried out on a Nermag R10-10s quadrupole mass spectrophotometer coupled to a Delsi – DI 700 gas chromatograph fitted with a OV1 capillary column (25 m × 0.32 mm i.d). Optical rotations were obtained on a Perkin-Elmer model 141 polarimeter. Combustion analyses were performed by the Service Central de Microanalyse, CNRS, Solaise. Column chromatography were run on neutral alumina, activity grade 3 (ICN Biomedicals). Analytical TLC were performed on 0.2 mm precoated neutral aluminium oxide containing a fluorescent indicator. Unless otherwise stated, all reactions were carried out under an inert atmosphere.

**Preparation of Propargyl Ethers 2a–l: General Procedure:**
To the solution of the optically active alcohol (10 mmol) in THF (15 mL) cooled at 0 °C was added NaH (60 % dispersion in mineral oil) (0.44 g, 1.1 equiv). The suspension was refluxed for 90 min and cooled at 0 °C. To the suspension were successively added tetrabutylammonium iodide (0.071 g, 0.19 mmol, 0.02 equiv) and propargyl bromide (80 wt.% solution in toluene) (1.2 mL, 10.9 mmol, 1.09 equiv). After stirring for 150 min at r.t., cold water (4 mL) was added dropwise.

*Workup for Amino Alcohol Derived Propargyl Ethers 2a–f:*

Propargyl ethers were extracted with 1 N HCl (2 × 15 mL). The aqueous solution was washed once with Et$_2$O and basified with 1 N NaOH to pH > 10. Propargyl ethers were extracted three times with EtOAc (3 × 10 mL) and the combined organic phases were dried (Na$_2$SO$_4$) and evaporated to dryness. The residue was purified by column chromatography (alumina, 10 g; petroleum ether/Et$_2$O, 90: 10 then 50: 50) to afford pure **2a–b** (Tables 1 and 2).

*Workup for Menthol- and Sugar-Derived Propargyl Ethers 2g–l:*

The aqueous phase was extracted with Et$_2$O (3 × 10 mL). The combined ethereal extracts were dried (Na$_2$SO$_4$), and purified by flash column chromatography (silica gel, 10 g; petroleum ether, then petroleum ether/Et$_2$O, 50: 50) to give pure propargyl ethers **2g–l** (Tables 1 and 2).

**Isomerization of Compounds 2a–l into Alkoxyallenes 3a–l:**
To the solution of propargyl ether (10 mmol) in *t*-BuOH (20 mL) was added *t*-BuOK (1.12 g, 10 mmol). The solution was refluxed for 2 h (TLC monitoring), cooled at r.t., and water (30 mL) and Et$_2$O (50 mL) were added. The aqueous phase was extracted with Et$_2$O (2 × 50 mL). The combined etheral extracts were dried (Na$_2$SO$_4$) and evaporated, and the residue was purified by column chromatography (neutral alumina, 50 g) (see Tables 1 and 2). Compound **3b** was separated from compound **5** by chromatography (silica gel, 30 g; petroleum ether/Et$_2$O, 60: 40).

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(5) (a) Zimmer, R.; Reissig, H.U. *Angew. Chem., Int. Ed. Engl.* **1988**, *27*, 1518.
(b) Arnold, Th.; Orschel, B.; Reissig, H.U. *Angew. Chem., Int. Ed. Engl.* **1992**, *31*, 1033.
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Nagashima, S.; Kanematsu, K. *Tetrahedron Asymmetry* **1990**, *1*, 743.

**Table 2.** Spectroscopic Data of Compounds **2**, **3** and **6** Prepared

| Compound | IR $\nu$ ($cm^{-1}$) | $^1H$ NMR $\delta$, $J$ (Hz) | $^{13}C$ NMR $\delta$ | MS (70 eV) $m/z$ (%) |
|---|---|---|---|---|
| **2a** | 3300, 2100, 1450 | 7.45–7.3 (m, $5H_{arom}$), 5.1 (d, 1H, $J = 4$, H-1), 4.2 (dd, 1H, $J = 17$, 2.8, $CH_2O$), 3.95 (dd, 1H, $J = 17$, 2.8, $CH_2O$), 3 (qd, 1H, $J = 5.7$, 4, H-2), 2.6 [s, 6H, $N(CH_3)_2$], 2.45 (dd, 1H, $J = 2.8$, $HC\equiv C$), 1.2 (d, 3H, $J = 5.7$, 3H-3) | 140.4, 128.2, 127.4, 127.0 ($C_{arom}$), 81.2 (C-1), 80.0 ($HC\equiv\underline{C}$), 74.2 ($H\underline{C}\equiv C$), 65.3 (C-2), 55.6 ($\underline{C}H_2O$), 41.6 [$N(\underline{C}H_3)_2$], 8.3 (C-3) | 217 ($M^+$, 1), 105 (1), 91 (2), 72 (100) |
| **2b** | 3300, 2100, 1450, 1090 | 7.4–7.2 (m, $5H_{arom}$), 4.5 (d, 1H, $J = 9.2$, H-1), 4.2 (dd, 1H, $J = 16$, 2.4, $CH_2O$), 3.7 (dd, 1H, $J = 16$, 2.8, $CH_2O$), 3.0 (qd, 1H, $J = 6.7$, 9.2, H-2), 2.4 [s, 6H, $N(CH_3)_2$], 2.3 (d, 1H, $J = 2.4$, $HC\equiv C$), 0.9 (d, 3H, $J = 6.7$, 3H-3) | 141.6, 127.9, 127.6, 126.9 ($C_{arom}$), 81.3 (C-1), 79.4 ($HC\equiv\underline{C}$), 74.3 ($H\underline{C}\equiv C$), 65.4 (C-2), 54.5 ($\underline{C}H_2O$), 39.3 [$N(\underline{C}H_3)_2$], 9.1 (C-3) | 217 ($M^+$, 0.2), 117 (10), 72 (100), 42 (10) |
| **2c** | 3300, 2100, 1450 | 7.45–7.3 (m, 5H, $H_{arom}$), 4.4 (d, 1H, $J = 6.6$, H-1), 4.1 (dd, 1H, $J = 15.6$, 2.4, $CH_2O$), 3.8 (dd, 1H, $J = 15.6$, 2.4, $CH_2O$), 2.9 (m, 1H, H-2), 2.35 (m, 5H, $2NCH_2$, $HC\equiv C$), 1.3–1 (m, 11H), 0.9–0.7 (m, 6H, $2CH_3$) | 140.9, 127.5, 127.4, 127.1 ($C_{arom}$), 83.1 (C-1), 80.1 ($HC\equiv\underline{C}$), 73.8 ($H\underline{C}\equiv C$), 60.1 (C-2), 55.7 ($\underline{C}H_2O$), 50.2 ($N\underline{C}H_2$), 31.1 ($CH_2$), 20.4 ($\underline{C}H_2CH_3$), 14.1 ($CH_3$), 9.6 (C-3) | 258 (6), 157 (12), 156 (100), 44 (18), 41 (16), 39 (10) |
| **2d** | 3500–3300, 2100, 1450 | 7.4–7.2 (m, 5H, $H_{arom}$), 4.5 (d, 1H, $J = 4.3$, H-1), 4.2 (dd, 1H, $J = 15.7$, 2.4, $CH_2O$), 3.9 (dd, 1H, $J = 15.7$, 2.4, $CH_2O$), 2.8 (m, 1H, H-2), 2.6–2.5 (m, 2H, $NCH_2$), 2.4 (t, 1H, $J = 2.4$, $HC\equiv C$), 1.5–1.4 [m, 5H, $NCH_2(C\underline{H}_2)_2$, NH], 1.2–0.9 (m, 6H, $2CH_3$) | 139.4, 127.4 ($C_{arom}$), 82.9 (C-1), 80.0 ($HC\equiv\underline{C}$), 74.1 ($H\underline{C}\equiv C$), 58.1 (C-2), 56.0 ($\underline{C}H_2O$), 46.8 ($N\underline{C}H_2$), 32.3 ($NCH_2\underline{C}H_2$), 20.4 ($\underline{C}H_2CH_3$), 15.5 ($CH_3$), 13.9 ($CH_3$) | 245 ($M^+$, 0.2), 118 (100), 117 (45), 91 (25) |
| **2e** | 3300, 2100, 1460, 1200 | 4.15 (d, 1H, $J = 6.6$, H-1), 4.1 (dd, 1H, $J = 15.6$, 2.4, $CH_2O$), 3.8 (dd, 1H, $J = 15.6$, 2.4, $CH_2O$), 2.9 (m, 1H, H-2), 2.35 (m, 5H, $HC\equiv C$, 2H-4), 1.3–1.0 (m, 10H), 0.9–0.7 (m, 9H) | 80.0 ($HC\equiv\underline{C}$), 73.9 ($H\underline{C}\equiv C$), 70.5 (C-1), 61.1 (C-2), 58.1 ($\underline{C}H_2O$), 50.3 ($CH_2$), 31.6 ($CH_2$), 22.2 ($CH_2$), 20.4 ($CH_2$), 14.0 ($CH_3$), 11.6 (C-4) | 239 ($M^+$, 1.3), 171 (13), 170 (100), 41 (15), 39 (10), 29 (11) |
| **2f** | 3300, 2150, 1450, 1100 | 4.2 (d, 2H, $J = 2.4$, $CH_2C\equiv C$), 3.5 (dd, 1H, $J = 10.5$, 5, $CH_2O$), 3.6 (dd, 1H, $J = 10.5$, 5, $CH_2O$), 3.05 (m, 1H), 2.4 (m, 5H), 2.2 (m, 1H, $NCH_3$, H-5, $HC\equiv C$), 2.0–1.5 (m, 4H) | 79.8 ($HC\equiv\underline{C}$), 74.3 ($H\underline{C}\equiv C$), 72.6 ($\underline{C}H_2O$), 64.7 (C-2), 58.4 (C-5), 57.7 ($\underline{C}H_2O$), 41.4 ($N\underline{C}H_3$), 28.5 (C-4), 22.8 (C-3) | 153 ($M^+$, 1), 84 (100), 42 (39), 39 (12) |
| **2g** | 3300, 2100, 1450, 1100 | 4.25 (dd, 1H, $J = 16$, 2.3, $C\underline{H}_2O$), 4.1 (dd, 1H, $J = 16$, 2.3, $C\underline{H}_2O$), 3.25 (td, 1H, $J = 10$, 6.2, H-1), 2.4 (t, 1H, $J = 2.3$, $HC\equiv C$), 2.3–2.0 (m, 2H), 1.7–1.5 (m, 2H), 1.4–1.2 (m, 2H), 1.2–0.8 (m, 12H) | 80.7 ($HC\equiv\underline{C}$), 78.0 (C-1), 73.5 ($H\underline{C}\equiv C$), 55.2 ($CH_2O$), 48.2 (C-2), 39.8 (C-6), 34.5 (C-4), 31.5 (C-5), 25.4 [$\underline{C}H(CH_3)_2$], 23.3 (C-3), 22.3 ($CH_3$), 21.0 ($CH_3$), 16.2 ($CH_3$) | 194 ($M^+$, 0.4), 138 (40), 41 (100) |
| **2h** | 3300, 2100, 1380, 1210, 1180 | 5.9 (d, 1H, $J = 3.7$, H-1), 4.6 (d, 1H, $J = 3.7$, H-2), 4.3 (d, 2H, $J = 2.4$, $C\underline{H}_2O$), 4.2–4.0 (m, 5H, H-3, H-4, H-5, 2H-6), 2.5 (t, 1H, $J = 2.4$, $\underline{H}C\equiv C$), 1.6–1.3 (4s, 12H) | 111.8, 108.9 [$2\underline{C}(CH_3)_2$], 105.2 (C-1), 82.8, 81.4, 81.0 ($HC\equiv\underline{C}$), 79.3, 75.2 ($H\underline{C}\equiv C$), 72.5 (C-5), 67.2 (C-6), 58.1, 26.6, 26.3, 25.1 ($4CH_3$) | 283 ($M^+ - 15$, 2.5), 101 (23), 43 (100) |
| **2i** | 3300, 2100, 1380, 1200, 1050 | 5.8 (d, 1H, $J = 3.8$, H-1), 4.8 (d, 1H, $J = 3.8$, H-2), 4.5–4.4 (m, 3H), 4.2–4.0 (m, 4H), 2.5 (t, 1H, $J = 2.3$, $HC\equiv C$), 1.55–1.4 (4s, 12H, $4CH_3$) | 113.0, 109.8 [$2\underline{C}(CH_3)_2$], 103.8 (C-1), 79.2 ($HC\equiv\underline{C}$), 77.9 (C-3), 77.0, 75.7 (C-2, C-4), 74.9 ($H\underline{C}\equiv C$), 65.1 (C-6), 57.4 ($C\equiv C\underline{C}H_2$), 26.8, 26.6, 26.4, 25.3 ($4CH_3$) | 283 ($M^+ - 15$, 5), 101 (60), 43 (100) |
| **2j** | 3300, 2100, 1380, 1200, 1050 | 5.54 (d, 1H, $J = 5$, H-1), 4.6 (dd, 1H, $J = 2.2$, 8, $C\equiv CCH_2$), 4.3 (dd, 1H, $J = 8$, 2.2, $C\equiv CCH_2$), 4.25–4.20 (m, 3H), 4 (m, 1H), 3.7 (m, 2H), 2.4 (t, 1H, $J = 2.2$, $HC\equiv C$), 1.55–1.3 (4s, 12H) | 109.2, 108.4 [$\underline{C}(CH_3)_2$], 96.2 (C-1), 79.6 ($HC\equiv\underline{C}$), 74.5 ($H\underline{C}\equiv C$), 71.1, 70.6, 70.4 (C-2, C-3, C-4), 68.6, 66.7 (C-6), 58.4, 25.9, 25.8, 24.8, 24.4 ($4CH_3$) | 283 ($M^+ - 15$, 6), 100 (14), 43 (100) |
| **2k** | 3300, 2100, 1380, 1200, 1100 | 5.9 (d, 1H, $J = 3.8$, H-1), 4.6 (d, 1H, $J = 3.8$, H-2), 4.2 (m, 3H), 4.1 (d, 1H, $J = 3.2$, H-3), 3.82 (d, 2H, $J = 6.7$), 2.45 (t, 1H, $J = 2.4$, $\underline{H}C\equiv C$), 1.3 (s, 3H), 0.9 (s, 9H), 0.1 (s, 6H) | 111.5 [$\underline{C}(CH_3)_2$], 104.9 (C-1), 82.4 (C-3), 80.9 ($HC\equiv\underline{C}$), 80.5, 79.1 (C-2, C-4), 74.9 ($H\underline{C}\equiv C$), 59.7 (C-5), 57.6 ($C\equiv C\underline{C}H_2$), 26.7 ($CH_3$), 26.2 ($CH_3$), 25.8 [$CH(\underline{C}H_3)_3$], 18.1 [$\underline{C}(CH_3)_3$], $-5.2$, $-5.3$ [$Si(CH_3)_2$] | 327 ($M^+ - 15$, 3), 285 (18), 43 (100) |
| **2l**[a] | 3450, 3280, 2120, 1450, 1380 | 4.3 (d, 2H, $J = 2.4$, $C\equiv CCH_2$), 4.2–4.1 (m, 4H), 4.1–3.9 (m, 4H), 2.4 (t, 1H, $J = 2.4$, $HC\equiv C$), 2.1 (m, 1H), 1.3–1.2 (4s, 12H, $4CH_3$) | 109.3, 108.9 [$\underline{C}(CH_3)_2$], 79.8 ($HC\equiv\underline{C}$), 79.4, 77.8, 75.5, 75.0 (C-2, C-3, C-4, C-5), 72.2 ($H\underline{C}\equiv C$), 67.3, 66.0 (C-1, C-6), 59.8 ($C\equiv C\underline{C}H_2$), 26.8, 26.5, 25.3 ($4CH_3$) | 285 ($M^+ - 15$, 6), 111 (12), 43 (100) |
| **3a** | 1950, 1450, 1200 | 7.45–7.2 (m, 5H, $H_{arom}$), 6.6 (t, 1H, $J = 5.7$, $C{=}CHOR$), 5.3 (dd, 1H, $J = 11$, 5.7, $H_2C{=}C$), 5.1 (dd, 1H, $J = 11.5$, 7.0, $H_2C{=}C$), 4.9 (d, 1H, $J = 3.4$, H-1), 2.7 (qd, 1H, $J = 6.8$, 3.4, H-2), 2.35 (s, 6H), 1.0 (d, 3H, $J = 6.8$, 3H-3) | 202.1 ($C{=}\underline{C}{=}C$), 141.1, 128.1, 126.9, 126.4, 126.3 ($C_{arom}$), 120.3 ($H_2C{=}C{=}\underline{C}$), 90.3 ($H_2\underline{C}{=}C$), 80.7 (C-1), 64.9 (C-2), 41.7 [$N(CH_3)_2$], 8.4 ($CH_3$) | 217 ($M^+$, < 1), 72 (100), 42 (11) |
| **3b** | 1950, 1450, 1200 | 7.4–7.3 (m, 5H, $H_{arom}$), 6.6 (t, 1H, $J = 6$, $C{=}CHOR$), 5.4 (dd, 1H, $J = 8$, 6, $H_2C{=}C$), 5.1 (dd, 1H, $J = 8$, 6, $H_2C{=}C$), 4.5 (d, 1H, $J = 9$, H-1), 3 (qd, 1H, $J = 7$, 9, H-2), 2.4 [s, 6H, $N(CH_3)_2$], 0.65 (d, 3H, $J = 7$, 3H-3) | 202.2 ($C{=}\underline{C}{=}C$), 140.6, 128.1, 127.8, 127.7 ($C_{arom}$), 120.4 ($H_2C{=}C{=}\underline{C}$), 90.3 ($H_2\underline{C}{=}C$), 82.2 (C-1), 63.2 (C-2), 40.7 [$N(CH_3)_2$], 9.6 ($CH_3$) | 217 ($M^+$, < 1), 162 (2), 72 (100), 42 (6) |

**Table 2.** (continued)

| Compound | IR $\nu$ (cm$^{-1}$) | $^1$H NMR $\delta$, $J$ (Hz) | $^{13}$C NMR $\delta$ | MS (70 eV) $m/z$ (%) |
|---|---|---|---|---|
| **3c** | 1950, 1450, 1200 | 7.2 (m, 5H, $H_{arom}$), 6.6 (t, 1H, $J = 6$, C=CHOR), 5.3 (dd, 1H, $J = 8.2, 6$, $H_2C=C$), 5.2 (dd, 1H, $J = 8.2, 6$, $H_2C=C$), 4.6 (d, 1H, $J = 5.5$, H-1), 3 (m, 1H, H-2), 2.4 (m, 4H, 2$NCH_2$), 1.4–0.9 (m, 11H, H-3, 5$CH_2$), 0.9–0.8 (m, 6H, 2$CH_3$) | 202.3 ($C=\underline{C}=C$), 141.7, 127.8, 127.0, 126.9 ($C_{arom}$), 120.5 ($H_2C=C=\underline{C}$), 90.0 ($H_2\underline{C}\equiv C$), 82.6 (C-1), 60.6 (C-2), 50.3 ($NCH_2$), 31.2, 20.4 (4$CH_2$), 14.1 (2$CH_3$), 9.5 ($CH_3$) | 246 ($M^+ - 15$, 4), 157 (12), 156 (100) |
| **3d** | 3500–3300, 1950, 1450, 1200 | 7.3 (m, 5H, $H_{arom}$), 6.6 (t, 1H, $J = 6$, C=CHOR), 5.3 (dd, 1H, $J = 8, 6$, $H_2C=C$), 5.2 (dd, 1H, $J = 8, 6$, $H_2C=C$), 4.6 (d, 1H, $J = 4.8$, H-1), 2.8 (m, 1H), 2.5 (m, 2H, N–$CH_2$), 1.5–1.2 (m, 5H, NH, 2$CH_2$), 1.2–1.0 (m, 3H), 1.0–0.8 (3H, 3H-3) | 202.0 ($C=\underline{C}=C$), 139.7, 128.1, 127.4, 126.9 ($C_{arom}$), 120.8 ($H_2C=C=\underline{C}$), 90.3 ($H_2\underline{C}=C$), 82.7 (C-1), 58.0 (C-2), 46.8 ($N\underline{C}H_2$), 32.4, 20.4 (2$CH_2$), 15.3 ($CH_3$), 13.9 (C-3) | 245 ($M^+$, < 1), 139 (11), 100 (100) |
| **3e** | 1950, 1450, 1200, 1050 | 6.7 (t, 1H, $J = 5.9$, C=CHOR), 5.4 (d, 2H, $J = 5.9$, $H_2C=C$), 3.7 (dd, 1H, $J = 10.2, 5.9$, H-1), 3.4 (dd, 1H, $J = 10.2, 5.9$, H-1), 2.7 (m, 1H, H-2), 2.5 (m, 4H, $NCH_2$), 1.4–0.9 (m, 10H, 5$CH_2$), 0.9–0.8 (m, 9H) | 201.4 ($C=\underline{C}=C$), 121.8 ($H_2C=C=\underline{C}$), 90.4 ($H_2\underline{C}=C$), 69.1 (C-1), 60.5 (C-2), 50.3 (2$N\underline{C}H_2$), 31.7 ($CH_2$), 22.1 (C-3), 20.5 ($CH_2$), 14.1 (2$CH_3$), 11.7 (C-4) | 239 ($M^+$, 1), 171 (13), 70 (100) |
| **3f** | 1950, 1450, 1200, 1050 | 6.8 (t, 1H, $J = 6$, C=CHOR), 5.4 (d, 2H, $J = 6$, $H_2C=C$), 3.6 (dd, 1H, $J = 10, 5$, $CH_2O$), 3.5 (dd, 1H, $J = 10, 5$, $CH_2O$), 3.05 (m, 1H, H-2), 2.4 (m, 4H, H-5, $NCH_3$), 2.3 (m, 1H), 2.0–1.5 (m, 4H, 2H-3, 2H-4) | 201.3 ($C=\underline{C}=C$), 121.9 ($H_2C=C=\underline{C}$), 90.7 ($H_2\underline{C}=C$), 70.9 ($\underline{C}H_2O$), 64.2 (C-2), 57.7 (C-5), 41.4 ($NCH_3$), 28.4 (C-4), 22.8 (C-3) | 153 ($M^+$, < 1), 84 (100), 42 (41), 39 (10) |
| **3g** | 1950, 1450, 1200 | 6.65 (t, 1H, $J = 6$, C=CHOR), 5.45 (dd, 1H, $J = 7.5, 6$, $H_2C=C$), 5.35 (dd, 1H, $J = 7.5, 6$, $H_2C=C$), 3.5 (td, 1H, $J = 10.6, 4.3$, H-1), 2.3–2 (2H), 1.7–1.5 (2H), 1.4–1.2 (2H), 1.2–0.8 (12H) | 201.6 ($C=\underline{C}=C$), 120.6 ($H_2C=C=\underline{C}$), 89.5 ($H_2\underline{C}=C$), 78.5 (C-1), 48.2 (C-2), 40.6 (C-6), 34.4 (C-4), 31.3 (C-5), 25.9 [$\underline{C}H(CH_3)_2$], 23.5, 21.1 ($CH_3$), 20.7 ($CH_3$), 16.4 ($CH_3$) | 194 ($M^+$, 4), 139 (12), 135 (25), 83 (100) |
| **3h** | 1950, 1450, 1200 | 6.7 (t, 1H, $J = 6$, C=CHOR), 5.8 (d, 1H, $J = 3.8$, H-1), 5.65 (dd, 1H, $J = 8.5, 6$, $H_2C=C$), 5.5 (dd, 1H, $J = 8.5, 6$, $H_2C=C$), 4.6 (d, 1H, $J = 3.8$, H-2), 4.35 (m, 1H, H-5), 4.25 (d, 1H, $J = 3$, H-3), 4.2 (dd, 1H, $J = 7.5, 3$, H-4), 4.1 (dd, 1H, $J = 8.6, 5.6$, H-6), 4 (dd, 1H, $J = 8.6, 5.6$, H-6), 1.5–1.3 (4s, 12H, 4$CH_3$) | 200.5 ($C=\underline{C}=C$), 120.1 ($H_2C=C=\underline{C}$), 111.8, 109.2 [$\underline{C}(CH_3)_2$], 105.1 (C-1), 92.0 ($H_2\underline{C}=C$), 82.1 (C-2), 80.3 (C-3), 79.9 (C-4), 72.3 (C-5), 67.0 (C-6), 26.8, 26.7, 26.2, 25.3 (4$CH_3$) | 298 ($M^+$, 0.1), 283 (2), 43 (100) |
| **3i** | 1950, 1380, 1200, 1020 | 6.8 (t, 1H, $J = 6$, C=CHOR), 5.8 (d, 1H, $J = 3.8$, H-1), 5.6 (dd, 1H, $J = 8.4, 6$, $H_2C=C$), 5.5 (dd, 1H, $J = 8.4, 6$, $H_2C=C$), 4.7 (m, 1H, H-2), 4.4 (m, 1H, H-4), 4.2 (m, 2H, H-3, H-5), 4.1 (m, 2H, 2H-6), 1.55–1.40 (4s, 12H) | 200.7 ($C=\underline{C}=C$), 120.8 ($H_2C=C=\underline{C}$), 112.9, 109.7 [$\underline{C}(CH_3)_2$], 103.8 (C-1), 91.9 ($H_2\underline{C}=C$), 77.2 (C-3), 76.3, 75.7 (C-2, C-4, C-5), 64.8 (C-6), 26.6, 26.4, 25.9, 25.2 (4$CH_3$) | 283 ($M^+ - 15$, 11), 101 (69), 43 (100) |
| **3j** | 1950, 1380, 1200, 1020 | 6.75 (t, 1H, $J = 5.9$, C=CHOR), 5.6 (d, 1H, $J = 5$, H-1), 5.5 (t, 2H, $J = 5.9$, $H_2C=C$), 4.6 (dd, 1H, $J = 7.9, 2.2$, H-3), 4.40 (m, 1H, H-2), 4.3 (m, 1H, H-4), 4.0 (m, 1H, H-5), 3.7 (d, 2H, $J = 6.2$, 2-$H_6$), 1.55–1.3 (4s, 12H, 4$CH_3$) | 200.9 ($C=\underline{C}=C$), 121.7 ($H_2C=C=\underline{C}$), 109.4, 108.6 [$\underline{C}(CH_3)_2$], 96.3 (C-1), 91.3 ($H_2C=C$), 71.0, 70.7, 70.5 (C-2, C-3, C-4), 67.2 (C-6), 65.9 (C-5), 26.0, 25.9, 24.9, 24.5 (4$CH_3$) | 283 ($M^+ - 15$, 2), 81 (10), 43 (100) |
| **3k** | 1950, 1380, 1200, 1020 | 6.65 (t, 1H, $J = 6$, C=CHOR), 5.9 (d, 1H, $J = 3.8$, H-1), 5.6 (dd, 1H, $J = 8, 6$, $H_2C=C$), 5.4 (dd, 1H, $J = 8, 6$, $H_2C=C$), 4.6 (d, 1H, $J = 3.8$, H-2), 4.3 (m, 1H, H-4), 4.2 (d, 1H, $J = 3.1$, H-3), 3.8 (m, 2H, 2H-5), 1.6–1.3 [2s, 6H, $C(CH_3)_2$], 0.9 [s, 9H, $C(CH_3)_3$], 0.1 [s, 6H, $Si(CH_3)_2$] | 200.6 ($C=\underline{C}=C$), 120.4 ($H_2C=C=\underline{C}$), 111.8 [$\underline{C}(CH_3)_2$], 105.1 (C-1), 92.1 ($H_2\underline{C}=C$), 82.2 (C-3), 80.2, 79.7, (C-2, C-4), 60.0 (C-5), 26.9, 26.5, 26.0 (5$CH_3$), 18.4 [$\underline{C}(CH_3)_3$], − 5.2, − 5.3 [$Si(CH_3)_2$] | 327 ($M^+ - 15$, 3), 197 (13), 97 (100) |
| **3l** | 1950, 1450, 1360, 1380, 1200, 1050 | 6.7 (t, 1H, $J = 6$, C=CHOR), 5.4 (d, 2H, $J = 6$, $H_2C=C$), 4.3–4.1 (m, 4H), 4.1–3.9 (m, 3H), 3.8 (dd, 1H, $J = 8.4, 1.1$), 1.4–1.35 [4s, 12H, 2$C(CH_3)_2$], 0.90 [s, 9H, $C(CH_3)_3$], 0.11 [2s, 6H, $Si(CH_3)_2$] | 200.8 ($C=\underline{C}=C$), 122.4 ($H_2C=C=\underline{C}$), 109.2, 108.2 [$\underline{C}(CH_3)_2$], 91.3 ($H_2\underline{C}=C$), 79.7, 76.3, 73.4, 71.9 (C-2, C-3, C-4, C-5), 67.0, 66.0 (C-1, C-6), 26.7, 26.5, 26.0, 25.3, 25.0 (7$CH_3$), 18.3 [$\underline{C}(CH_3)_3$], − 4.1, − 4.2 [$Si(CH_3)_2$] | 399 ($M^+ - 15$, 2), 143 (13), 43 (100) |
| **5** | 1725, 1650, 1600, 1100–1080 | 7.4–7.2 (m, 5H, $H_{arom}$), 5.38 (q, 1H, $J = 7.1$, C=CH), 4.2 (s, 2H, $CH_2O$), 2.2 (s, 3H, $CH_3CO$), 1.83 (d, 3H, $J = 7.1$, $CH_3$) | 205.2 (CO), 153.6 [$C=\underline{C}(OR)CH_3$], 128.5, 128.0, 125.8 ($C_{arom}$), 109.8, 75.0 ($\underline{C}H_2O$), 26.5 ($\underline{C}H_3CO$), 11.2 ($\underline{C}H_3$) | 190 ($M^+$, 11), 133 (61), 133 (61), 117 (65), 115 (62), 43 (100) |

[a] Spectroscopic data of the corresponding 4-OH derivative of **2l**.

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