Odorless regioselective ring opening of epoxides with S-alkylisothiouuronium salts as masked thiols in water

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Abstract
Opening of epoxides with various S-alkylisothiouuronium salts as thiol equivalent in water has been carried out in excellent yield following an environmentally benign odorless reaction condition. Yields were excellent in every case.

Keywords: Epoxides, thiolysis, alkylisothiouuronium salts, β-Hydroxy sulfides, water

Introduction

β-Hydroxy sulfides serve as important intermediates for the synthesis of several bioactive and medicinally important natural products. Most often, they can be synthesized by the ring opening of epoxides with thiols in the presence of a base or a homogeneous and heterogeneous acidic catalysts in organic solvents. A number of special reaction conditions have also been reported in the literature. These conditions include microwave irradiation and use of complex Lewis acids for the enantioselective ring opening. Opening of epoxides with thiols have also been reported in water in the presence of some catalysts. Despite their synthetic utilities most of the reaction conditions suffer from a number of drawbacks, which include the use of obnoxious thiols, strong and non-selective acidic catalysts, expensive and toxic reagents, organic solvents, low yield and long reaction time. Recently, we required a diverse range of β-hydroxy sulfides for their use in the synthesis of several medicinally active molecules. For this purpose, we were looking for a method through which the above-mentioned drawbacks could be avoided and large quantities of β-hydroxy sulfides could be obtained in an environmentally benign way. Recently we noted a report on the thia-Michael reaction in water using S-alkylisothiouuronium salts as thiol equivalent. Prompted by this, we envisioned that S-alkylisothiouuronium salts could be used as masked thiols for the regioselective opening of epoxides in water following a green chemistry approach, avoiding the use of malodorous thiols and organic solvents. Earlier, a series of reports appeared in the literature for the epoxide ring opening with amines and aza, thia-Michael
reactions using water as reaction media. We herein report a simple and practical method for the synthesis of β-hydroxy sulfides by opening of oxiranes with in situ generated thiolate ions using S-alkylisothiouronium salts catalyzed by sodium hydroxide in water (Scheme 1). To the best of our knowledge, there is no report of the thiolysis of epoxides using S-alkylisothiouronium salts in water.

![Scheme 1. Regioselective thiolysis of epoxide in water using S-alkylisothiouronium salts.](image)

### Table 1. Opening of epoxides with S-alkylisothiouronium salts in the presence of NaOH in water

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<th>Yield (%)</th>
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Table 1. Continued

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<td>22: R = Benzyl</td>
<td>23: R = C\textsubscript{14}H\textsubscript{29}</td>
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<td>24: R = allyl</td>
<td>25: R = methyl</td>
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<tr>
<td></td>
<td>26: R = 4-methoxybenzyl</td>
<td>27: R = 3,4-dimethylbenzyl</td>
<td>30</td>
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</tr>
</tbody>
</table>

| 7     | ![6](image) | ![6](image) | 30         | 90        |
|       | 28: R = Benzyl      | 29: R = C\textsubscript{14}H\textsubscript{29} | 40         | 85        |
|       | 30: R = allyl       | 31: R = methyl      | 30         | 92        |
|       | 32: R = 4-methoxybenzyl | 33: R = 3,4-dimethylbenzyl | 30         | 85        |

Results and Discussion

In order to study the thiolysis of epoxide derivatives a series of oxirane derivatives were prepared from carbohydrate and phenolic precursors. For this purpose, a series of hydroxy group containing carbohydrate derivatives, phenols and benzyl alcohol were treated with epichlorohydrine in the presence of a base to furnish oxirane derivatives in excellent yield. After considerable experimentation, we found that treatment of epoxides with 1.5 equiv of S-alkylisothiouronium salts in the presence of NaOH (2.5 equiv.) in water at room temperature resulted in formation of \( \beta \)-hydroxy sulfides (Table 1). The synthesis of a series of \( \beta \)-hydroxy sulfides was achieved using a variety of epoxides and S-alkylisothiouronium salts by stirring the reaction mixture in water at room temperature in the presence of NaOH. It was observed that the quantity of water does not have a significant role in the rate of reaction. However, stirring has an important role in the reaction rate, which was confirmed from a comparative study. Only \( \sim50\% \) conversion took place by keeping a mixture of epoxide, S-alkylisothiouronium salts and NaOH in water at room temperature without stirring even after 24 h. S-alkylisothiouronium salts can easily be prepared from the corresponding alkyl halide on treatment with thiourea and used without purification. The reaction can be carried out in a large scale without the requirement of
organic solvent and obnoxious thiols. Most of the reactions are highly regioselective. All products were characterized by their NMR and mass spectral data.

Conclusions

In summary, we have demonstrated an economical and practical environmentally benign methodology for the synthesis of a wide range of β-hydroxy sulfides in water using S-alkylisothiouronium salts as masked thiols, avoiding the use of obnoxious thiols. Operational simplicity, high yields, high regioselectivity makes this protocol superior to the existing methods.

Experimental Section

General Procedures. All reactions were monitored by thin layer chromatography over silica gel coated TLC plates. The spots on TLC were visualized by warming ceric sulphate (2% Ce(SO₄)₂ in 2N H₂SO₄) sprayed plates on a hot plate. Silica gel 230-400 mesh was used for column chromatography. ¹H and ¹³C NMR spectra were recorded on Brucker Advance DPX 300 MHz using CDCl₃ as solvents and TMS as internal reference unless stated otherwise. Chemical shift values are expressed in δ ppm. ESI-MS were recorded on a MICROMASS QUTTRO II triple quadrupole mass spectrometer. Elementary analysis was carried out on Carlo ERBA-1108 analyzer. Commercially available grades of organic solvents of adequate purity are used in many reactions.

Preparation of oxirane substrates
To a solution of sugar alcohol or phenol (2 mmol) in THF (5 mL) was added epichlorohydrine (2.5 mmol) at 0 °C and the reaction mixture was allowed to stir at room temperature for 3 h. The reaction mixture was poured into water and extracted with CH₂Cl₂ (50 mL). The organic layer was washed with aq. NaHCO₃, water, dried (Na₂SO₄) and concentrated under reduced pressure. The crude product was purified over SiO₂ using hexane-EtOAc (10:1) as eluant to give pure oxirane derivatives.

**Compound 1.** Yellow oil; ¹H NMR (CDCl₃, 300 MHz): δ 5.87-5.83 (m, 1 H), 4.55 (dd, J = 14.7, 3.7 Hz, 1 H), 4.30-4.25 (m, 1 H), 4.11-4.03 (m, 2 H), 4.00-3.86 (m, 3 H), 3.67-3.43 (m, 1 H), 3.16-3.10 (m, 1 H), 2.82-2.76 (m, 1 H), 2.65-2.60 (m, 1 H), 1.72, 1.49, 1.42, 1.30 (4 s, 12 H); ¹³C (CDCl₃, 75 MHz): δ 111.7, 108.9, 105.1, 82.8, 81.0, 72.2, 70.5, 67.3, 67.0, 50.5, 44.2, 26.1 (2 C), 25.4, 25.3; ESI-MS (C₁₅H₂₄O₇): 339.1 [M+Na]^⁺; Anal. Calcd. for C₁₅H₂₄O₇: C, 56.95; H, 7.65; found: C, 56.80; H, 7.92.

**Compound 2.** Yellow oil; ¹H NMR (CDCl₃, 300 MHz): δ 5.54 (d, J = 5.0 Hz, 1 H), 4.63 (dd, J = 8.0, 2.5 Hz, 1 H), 4.30 (dd, J = 8.0, 2.4 Hz, 1 H), 4.27 (dd, J = 5.2, 2.5 Hz, 1 H), 4.25 (dd, J = 11.6, 4.8 Hz, 1 H), 4.20 (dd, J = 11.6, 7.6 Hz, 1 H), 4.04-4.00 (m, 1 H), 3.48-3.30 (m, 2 H), 3.16-3.10 (m, 1 H), 2.78-2.60 (m, 2 H), 1.52, 1.45, 1.34, 1.33 (4 s, 12 H); ¹³C (CDCl₃, 75 MHz): δ
109.5, 108.6, 96.2, 71.0, 70.6, 70.3, 69.0, 63.9, 63.3, 50.0, 44.2, 26.0 (2 C), 24.8, 24.6; ESI-MS (C_{13}H_{24}O_{7}): 339.1 [M+Na]^+; Anal. Calcd. for C_{13}H_{24}O_{7}: C, 56.95; H, 7.65; found: C, 56.77; H, 7.90.

**Compound 3.** Yellow oil; \(^1H\) NMR (CDCl\(_3\), 300 MHz): \(\delta\) 4.59-4.56 (m, 1 H), 4.38-4.36 (m, 1 H), 4.22-4.19 (m, 1 H), 3.91-3.65 (m, 3 H), 3.61-3.56 (m, 2 H), 3.46-3.40 (m, 1 H), 3.15-3.11 (m, 1 H), 2.78-2.75 (m, 1 H), 2.63-2.57 (m, 1 H), 1.52, 1.45, 1.42, 1.33 (4 s, 12 H); \(^{13}C\) NMR (CDCl\(_3\), 75 MHz): \(\delta\) 109.3, 108.9, 102.9, 73.2, 72.7, 71.4, 70.6, 70.4, 61.4, 50.9, 44.5, 26.9, 26.3, 25.7, 24.5; ESI-MS (C\(_{15}\)H\(_{24}\)O\(_7\)): 339.0 [M+Na]^+; Anal. Calcd. for C\(_{15}\)H\(_{24}\)O\(_7\): C, 56.95; H, 7.65; found: C, 56.77; H, 7.90.

**Compound 4.** Yellow oil; \(^1H\) NMR (CDCl\(_3\), 300 MHz): \(\delta\) 6.85-6.78 (m, 4 H), 4.14-4.10 (m, 1 H), 3.94-3.88 (m, 1 H), 3.75 (s, 3 H), 3.31-3.28 (m, 1 H), 2.88-2.85 (m, 1 H), 2.72-2.70 (m, 1 H); \(^{13}C\) NMR (CDCl\(_3\), 75 MHz): \(\delta\) 154.0, 152.5, 115.5 (2 C), 114.5 (2 C), 69.4, 55.4, 50.0, 44.5; ESI-MS (C\(_{10}\)H\(_{12}\)O\(_3\)): 181.1 [M+1]^+; Anal. Calcd. for C\(_{10}\)H\(_{12}\)O\(_3\): C, 66.65; H, 6.71; found: C, 66.53; H, 6.85.

**Compound 5.** Yellow oil; \(^1H\) NMR (CDCl\(_3\), 300 MHz): \(\delta\) 7.42-7.10 (m, 5 H), 4.26-3.98 (m, 2 H), 3.11-3.0 (m, 1 H), 2.77-2.43 (m, 2 H); \(^{13}C\) NMR (CDCl\(_3\), 75 MHz): \(\delta\) 155.7, 127.3 (2 C), 126.1, 117.2 (2 C), 70.3, 51.0, 44.0; ESI-MS (C\(_9\)H\(_{10}\)O\(_2\)): 151.1 [M+1]^+; Anal. Calcd. for C\(_9\)H\(_{10}\)O\(_2\): C, 71.98; H, 6.71; found: C, 71.84; H, 6.87.

**Compound 6.** Yellow oil; \(^1H\) NMR (CDCl\(_3\), 300 MHz): \(\delta\) 7.56-7.40 (m, 5 H), 4.72 (br s, 2 H), 3.71-3.42 (m, 2 H), 2.90-2.82 (m, 1 H), 2.70-2.42 (m, 2 H); \(^{13}C\) NMR (CDCl\(_3\), 75 MHz): \(\delta\) 139.9, 127.1 (2 C), 127.0, 126.8 (2 C), 71.9, 70.8, 50.1, 44.8; ESI-MS (C\(_{10}\)H\(_{12}\)O\(_2\)): 165.1 [M+1]^+; Anal. Calcd. for C\(_{10}\)H\(_{12}\)O\(_2\): C, 73.15; H, 7.37; found: C, 73.0; H, 7.50.

**Typical experimental procedure for the opening of epoxide**

To a suspension of epoxide (1.0 mmol) in water (3 mL) was added appropriate S-alkylisothiouronium salts (1.5 mmol) and NaOH (2.5 mmol) and the reaction mixture was allowed to stir briskly at room temperature for appropriate time (Table 1). After completion of the reaction (TLC), the reaction mixture was extracted with ethyl acetate. The organic layer was dried (Na\(_2\)SO\(_4\)) and concentrated under reduced pressure. The pure product was obtained by passing the crude product through a short pad of SiO\(_2\).

**Spectral data of β-hydroxy sulfides**

**Compound 7.** Yellow oil; \(^1H\) NMR (CDCl\(_3\), 200 MHz): \(\delta\) 7.32-7.24 (m, 5 H, Ar-H), 5.88 (d, \(J\) = 3.5 Hz, 1 H), 4.52-4.51 (m, 1 H), 4.31-4.28 (m, 1 H), 4.16-4.04 (m, 2 H), 4.01-3.96 (m, 2 H), 3.86-3.82 (m, 1 H), 3.76-3.72 (m, 3 H), 3.59-3.56 (m, 1 H), 2.58-2.50 (m, 2 H), 1.50, 1.44, 1.34, 1.33 (4 s, 12 H); \(^{13}C\) NMR (CDCl\(_3\), 50 MHz): \(\delta\) 138.6-127.5 (Ar-C), 112.2, 109.6, 105.9, 84.6, 82.9, 81.6, 73.2, 72.8, 69.2, 68.2, 37.2, 34.5, 27.3 (2 C), 26.7 (2 C); ESI-MS (C\(_{22}\)H\(_{32}\)O\(_7\)S): m/z 463.2 [M+Na]^+; Anal. Calcd. for C\(_{22}\)H\(_{32}\)O\(_7\)S: C, 59.98; H, 7.32; found: C, 59.80; H, 7.48.

**Compound 8.** Yellow oil; \(^1H\) NMR (CDCl\(_3\), 200 MHz): \(\delta\) 5.88 (d, \(J\) = 3.4 Hz, 1 H), 4.54-4.53 (m, 1 H), 4.31-4.28 (m, 1 H), 4.26-3.99 (m, 3 H), 3.77-3.65 (m, 2 H), 3.60-3.57 (m, 1 H), 2.62-
2.49 (m, 3 H), 1.60-1.53 (m, 2 H), 1.48, 1.41, 1.36, 1.31 (4 s, 12 H), 1.30-1.24 (m, 22 H), 0.88 (t, J = 6.9 Hz, 3 H); $^{13}$C NMR (CDCl$_3$, 50 MHz): δ 112.2, 109.7, 105.9, 84.7, 82.9, 81.7, 73.2, 69.3, 68.2, 35.5, 32.3, 30.0-23.0 (16 C), 14.5; ESI-MS (C$_{29}$H$_{54}$O$_7$S): m/z 569.3 [M+Na]$^+$. Anal. Calcd. for C$_{29}$H$_{54}$O$_7$S: C, 63.70; H, 9.95; found: C, 63.50; H, 10.10.

**Compound 9.** Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): δ 5.89 (d, J = 3.5 Hz, 1 H), 4.55 (d, J = 3.6 Hz, 1 H), 4.34-4.28 (m, 1 H), 4.17-3.97 (m, 3 H), 3.94-3.79 (m, 2 H), 3.63-3.58 (m, 2 H), 2.62-2.57 (m, 2 H), 2.16 (s, 3 H), 1.50, 1.44, 1.37, 1.32 (4 s, 12 H); $^{13}$C NMR (CDCl$_3$, 50 MHz): δ 112.2, 109.7, 105.9, 84.6, 82.9, 81.7, 73.1, 72.7, 68.9, 68.2, 37.3, 27.3 (2 C), 26.6 (2 C), 16.6; ESI-MS (C$_{16}$H$_{32}$O$_8$S): m/z 387.2 [M+Na]$^+$. Anal. Calcd. for C$_{16}$H$_{32}$O$_8$S: C, 52.73; H, 7.74; found: C, 52.57; H, 7.90.

**Compound 10.** Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): δ 7.74 (d, J = 8.6 Hz, 2 H), 6.84 (d, J = 8.6 Hz, 2 H), 5.88 (d, J = 3.8 Hz, 1 H), 4.53 (d, J = 3.5 Hz, 1 H), 4.33-4.23 (m, 1 H), 4.16-4.04 (m, 2 H), 4.01-3.97 (m, 2 H), 3.89-3.82 (m, 1 H), 3.81 (s, 3 H), 3.77-3.68 (m, 3 H), 3.59-3.54 (m, 1 H), 2.57-2.46 (m, 2 H), 1.50, 1.43, 1.34, 1.32 (4 s, 12 H); $^{13}$C NMR (CDCl$_3$, 50 MHz): δ 159.1-114.3 (Ar-C), 112.3, 109.7, 105.9, 84.7, 83.0, 81.7, 73.2, 72.7, 69.2, 68.2, 55.5, 36.6, 34.0, 27.3 (2 C), 26.6 (2 C); ESI-MS (C$_{23}$H$_{34}$O$_8$S): m/z 493.2 [M+Na]$^+$. Anal. Calcd. for C$_{23}$H$_{34}$O$_8$S: C, 58.70; H, 7.28; found: C, 58.52; H, 7.50.

**Compound 11.** Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): δ 7.05-6.98 (m, 3 H), 5.85 (d, J = 3.4 Hz, 1 H), 4.49-4.48 (m, 1 H), 4.32-4.18 (m, 1 H), 4.11-3.98 (m, 2 H), 3.96-3.93 (m, 2 H), 3.84-3.65 (m, 4 H), 3.54-3.53 (m, 2 H), 2.54-2.49 (m, 2 H), 2.22 (s, 3 H), 1.47, 1.41, 1.31, 1.30 (4 s, 12 H); $^{13}$C NMR (CDCl$_3$, 50 MHz): δ 130.1-125.9 (Ar-C), 112.3, 109.8, 106.0, 84.7, 83.0, 81.7, 73.2, 72.8, 69.1, 68.2, 36.9, 34.5, 27.3 (2 C), 26.7 (2 C), 21.0, 19.8; ESI-MS (C$_{24}$H$_{36}$O$_7$S): m/z 491.0 [M+Na]$^+$. Anal. Calcd. for C$_{24}$H$_{36}$O$_7$S: C, 61.51; H, 7.74; found: C, 61.30; H, 7.90.

**Compound 12.** Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): δ 7.32-7.23 (m, 5 H, Ar-H), 5.53 (d, J = 1.2 Hz, 1 H), 4.62-4.58 (m, 1 H), 4.32-4.30 (m, 1 H), 4.24-4.21 (m, 1 H), 3.98-3.93 (m, 1 H), 3.88-3.85 (m, 1 H), 3.75 (brs, 2 H), 3.67-3.59 (m, 3 H), 3.55-3.53 (m, 1 H), 2.55-2.53 (m, 2 H), 1.54, 1.45, 1.34 (3 s, 12 H); $^{13}$C NMR (CDCl$_3$, 50 MHz): δ 138.6-127.4 (Ar-C), 109.7, 108.9, 96.6, 74.8, 71.5, 70.8, 70.7, 70.1, 69.5, 66.9, 37.0, 30.1, 26.5 (2 C), 25.3, 24.9; ESI-MS (C$_{24}$H$_{32}$O$_7$S): m/z 463.2 [M+Na]$^+$. Anal. Calcd. for C$_{24}$H$_{32}$O$_7$S: C, 59.98; H, 7.32; found: C, 59.80; H, 7.46.

**Compound 13.** Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): δ 5.90-5.75 (m, 1 H), 5.53 (d, J = 4.9 Hz, 1 H), 5.15-5.09 (m, 2 H), 4.62-4.59 (m, 1 H), 4.33-4.22 (m, 2 H), 3.99-3.75 (m, 2 H), 3.69-3.47 (m, 4 H), 3.35-3.15 (m, 2 H), 2.60-2.56 (m, 2 H), 1.54, 1.45, 1.34 (3 s, 12 H); $^{13}$C NMR (CDCl$_3$, 50 MHz): δ 134.5, 117.7, 109.7, 108.9, 96.6, 74.5, 71.5, 70.8, 70.7, 70.2, 69.6, 67.2, 35.6, 34.2, 26.5 (2 C), 25.3, 24.9; ESI-MS (C$_{18}$H$_{30}$O$_7$S): m/z 413.2 [M+Na]$^+$. Anal. Calcd. for C$_{18}$H$_{30}$O$_7$S: C, 55.36; H, 7.74; found: C, 55.20; H, 7.86.

**Compound 14.** Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): δ 5.53 (d, J = 4.9 Hz, 1 H), 4.62-4.59 (m, 1 H), 4.32-4.22 (m, 2 H), 3.99-3.90 (m, 2 H), 3.71-3.65 (m, 3 H), 3.62-3.48 (m, 2 H), 2.66-2.59 (m, 2 H), 2.15 (s, 3 H), 1.54, 1.45, 1.34 (3 s, 12 H); $^{13}$C NMR (CDCl$_3$, 50 MHz): δ 109.9, 108.9, 96.6, 74.7, 71.0, 70.8, 70.6, 70.2, 69.4, 67.0, 37.9, 26.3 (2 C), 25.3, 24.9, 16.5; ESI-MS
(C_{16}H_{28}O_{2}S): m/z 387.1 [M+Na]^{+}; Anal. Calcd. for C_{16}H_{28}O_{2}: C, 52.73; H, 7.74; found: C, 52.57; H, 7.90.

**Compound 15.** Yellow oil; ^1^H NMR (CDCl$_3$, 200 MHz): δ 7.22 (d, J = 8.6 Hz, 2 H), 6.83 (d, J = 8.5 Hz, 2 H), 5.52-5.50 (m, 1 H), 4.61-4.57 (m, 1 H), 4.31-4.21 (m, 2 H), 3.97-3.93 (m, 1 H), 3.87-3.84 (m, 1 H), 3.79 (s, 3 H), 3.70 (brs, 2 H), 3.66-3.53 (m, 2 H), 3.48-3.44 (m, 1 H), 2.54-2.51 (m, 2 H), 1.54, 1.44, 1.34 (3 s, 12 H); ^13^C NMR (CDCl$_3$, 50 MHz): δ 159.1-114.3 (Ar-C), 109.7, 108.9, 96.6, 74.5, 74.1, 71.5, 70.5, 69.7, 66.9, 67.2, 55.5, 36.5, 34.7, 26.5 (2 C), 25.3, 24.9; ESI-MS (C_{23}H_{34}O_{8}S): m/z 493.2 [M+Na]^{+}; Anal. Calcd. for C_{23}H_{34}O_{8}S: C, 58.70; H, 7.28; found: C, 58.54; H, 7.50.

**Compound 16.** Yellow oil; ^1^H NMR (CDCl$_3$, 200 MHz): δ 7.08-7.03 (m, 3 H), 5.52 (d, J = 4.8 Hz, 1 H), 4.61-4.58 (m, 1 H), 4.32-4.22 (m, 2 H), 3.98-3.87 (m, 2 H), 3.78-3.48 (m, 6 H), 2.61-2.53 (m, 2 H), 2.30, 2.26 (2 s, 6 H), 1.54, 1.41, 1.34 (3 s, 12 H); ^13^C NMR (CDCl$_3$, 50 MHz): δ 136.9-125.6 (Ar-C), 109.7, 108.9, 96.6, 74.5, 74.1, 71.5, 70.5, 70.0, 69.6, 69.3, 67.2, 36.8, 34.9, 26.5 (2 C), 25.3, 24.9, 20.1, 19.8; ESI-MS (C_{24}H_{36}O_{7}S): m/z 491.2 [M+Na]^{+}; Anal. Calcd. for C_{24}H_{36}O_{7}S: C, 61.51; H, 7.74; found: C, 61.35; H, 7.52.

**Compound 17.** Yellow oil; ^1^H NMR (CDCl$_3$, 200 MHz): δ 5.92-5.70 (m, 1 H), 5.22-5.09 (m, 2 H), 4.60-4.57 (m, 1 H), 4.36-4.34 (m, 1 H), 4.24-4.21 (m, 1 H), 3.92-3.76 (m, 2 H), 3.75-3.52 (m, 6 H), 3.18-3.15 (m, 1 H), 2.87-2.80 (m, 1 H), 2.62-2.55 (m, 2 H), 1.54, 1.48, 1.41, 1.35 (4 s, 12 H); ^13^C NMR (CDCl$_3$, 50 MHz): δ 134.5, 117.7, 109.3, 108.7, 102.8, 75.5, 73.3, 71.3, 71.2, 70.5, 69.5, 61.4, 35.6, 34.5, 26.9, 26.3, 25.7, 24.4; ESI-MS (C_{18}H_{30}O_{7}S): m/z 413.2 [M+Na]^{+}; Anal. Calcd. for C_{18}H_{30}O_{7}S: C, 55.36; H, 7.74; found: C, 55.20; H, 7.88.

**Compound 18.** Yellow oil; ^1^H NMR (CDCl$_3$, 200 MHz): δ 4.59-4.56 (m, 1 H), 4.35-4.33 (m, 1 H), 4.22-4.19 (m, 1 H), 3.91-3.85 (m, 2 H), 3.75-3.48 (m, 5 H), 2.71-2.50 (m, 4 H), 1.62-1.54 (m, 2 H), 1.53, 1.47, 1.40, 1.34 (4 s, 12 H), 1.28-1.24 (m, 22 H), 0.88 (t, J = 6.8 Hz, 3 H); ^13^C NMR (CDCl$_3$, 50 MHz): δ 109.3, 108.8, 102.9, 75.5, 73.4, 71.3, 70.8, 70.6, 69.5, 61.4, 36.2, 33.1, 30.1-29.6 (12 C), 26.9, 26.3, 25.8, 24.4, 14.5; ESI-MS (C_{20}H_{34}O_{7}S): m/z 569.3 [M+Na]^{+}; Anal. Calcd. for C_{20}H_{34}O_{7}S: C, 63.70; H, 9.95; found: C, 63.52; H, 10.14.

**Compound 19.** Yellow oil; ^1^H NMR (CDCl$_3$, 200 MHz): δ 6.87-6.80 (m, 4 H), 5.88-5.74 (m, 1 H), 5.17-5.11 (m, 2 H), 4.07-3.99 (m, 1 H), 3.98-3.94 (m, 2 H), 3.78 (s, 3 H), 3.20-3.18 (m, 2 H), 2.83-2.64 (m, 3 H); ^13^C NMR (CDCl$_3$, 50 MHz): δ 154.6-115.0 (Ar-C and CH=CH$_2$), 71.6, 69.1, 55.9, 35.5, 34.5; ESI-MS (C_{13}H_{18}O_{2}S): m/z 255.1 [M+1]^{+}; Anal. Calcd. for C_{13}H_{18}O_{2}S: C, 61.39; H, 7.13; found: C, 61.22; H, 7.30.

**Compound 20.** Yellow oil; ^1^H NMR (CDCl$_3$, 200 MHz): δ 6.87-6.80 (m, 4 H), 4.17-4.05 (m, 1 H), 4.03-3.95 (m, 2 H), 3.77 (s, 3 H), 2.88 (brs, 1 H), 2.84-2.66 (m, 2 H), 2.16 (s, 3 H); ^13^C NMR (CDCl$_3$, 50 MHz): δ 154.6-115.0 (Ar-C), 71.5, 68.7, 55.9, 38.3, 16.4; ESI-MS (C$_{11}$H$_{16}$O$_{3}$S): m/z 229.1 [M+1]^{+}; Anal. Calcd. for C$_{11}$H$_{16}$O$_{3}$S: C, 57.87; H, 7.06; found: C, 57.72; H, 7.25.

**Compound 21.** Yellow oil; ^1^H NMR (CDCl$_3$, 200 MHz): δ 7.28-6.82 (m, 8 H), 4.06-3.99 (m, 1 H), 3.94-3.92 (m, 2 H), 3.81 (s, 3 H), 3.78 (s, 3 H), 3.72 (s, 2 H), 2.76-2.58 (m, 3 H); ^13^C NMR (CDCl$_3$, 50 MHz): δ 159.2-130.2 (Ar-C), 71.5, 69.2, 55.9, 55.6, 36.4, 35.0; ESI-MS
Compound 22. Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): $\delta$ 7.33-6.90 (m, 10 H), 4.11-4.0 (m, 1 H), 4.01-3.99 (m, 2 H), 3.78 (br s, 2 H), 2.80-2.62 (m, 3 H); $^{13}$C NMR (CDCl$_3$, 50 MHz): $\delta$ 158.8-115.0 (Ar-C), 70.8, 69.2, 37.0, 35.2; ESI-MS (C$_{16}$H$_{18}$O$_2$S): $m/z$ 275.1 [M+1]$^+$; Anal. Calcd. for C$_{16}$H$_{16}$O$_2$S: C, 70.04; H, 6.61; found: C, 69.90; H, 6.77.

Compound 23. Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): $\delta$ 7.32-6.91 (m, 5 H), 4.15-4.09 (m, 1 H), 4.06-4.05 (m, 2 H), 2.90-2.69 (m, 3 H), 2.60-2.55 (m, 2 H), 1.67-1.57 (m, 2 H), 1.42-1.26 (m, 22 H), 0.91 (t, $J$ = 6.5 Hz, 3 H); $^{13}$C NMR (CDCl$_3$, 50 MHz): $\delta$ 158.2-114.9 (Ar-C), 70.4, 69.0, 36.3, 33.1, 32.3-23.1 (12 C), 14.6; ESI-MS (C$_{23}$H$_{46}$O$_2$S): $m/z$ 381.3 [M+1]$^+$; Anal. Calcd. for C$_{23}$H$_{44}$O$_2$S: C, 72.58; H, 10.59; found: C, 72.45; H, 10.74.

Compound 24. Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): $\delta$ 7.32-6.90 (m, 5 H), 5.88-5.74 (m, 1 H), 5.17-5.11 (m, 2 H), 4.13-4.07 (m, 1 H), 4.05-4.03 (m, 2 H), 3.20-3.18 (m, 2 H), 2.85-2.65 (m, 3 H); $^{13}$C NMR (CDCl$_3$, 50 MHz): $\delta$ 158.8-121.6 (Ar-C), 118.1, 114.9, 70.5, 69.3, 35.5, 34.6; ESI-MS (C$_{13}$H$_{16}$O$_2$S): $m/z$ 225.1 [M+1]$^+$; Anal. Calcd. for C$_{13}$H$_{14}$O$_2$S: C, 64.25; H, 7.19; found: C, 64.10; H, 7.37.

Compound 25. Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): $\delta$ 7.32-6.91 (m, 5 H), 4.19-4.08 (m, 1 H), 4.06-4.04 (m, 2 H), 2.97 (br s, 1 H), 2.86-2.68 (m, 2 H), 2.17 (s, 3 H); $^{13}$C NMR (CDCl$_3$, 50 MHz): $\delta$ 158.8-114.9 (Ar-C), 70.7, 68.7, 38.3, 16.4; ESI-MS (C$_{10}$H$_{14}$O$_2$S): $m/z$ 199.1 [M+1]$^+$; Anal. Calcd. for C$_{10}$H$_{14}$O$_2$S: C, 60.57; H, 7.12; found: C, 60.44; H, 7.27.

Compound 26. Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): $\delta$ 7.25-6.80 (m, 9 H), 4.07-3.98 (m, 1 H), 3.96-3.95 (m, 2 H), 3.78 (s, 3 H), 3.70 (br s, 2 H), 2.74-2.56 (m, 3 H); $^{13}$C NMR (CDCl$_3$, 50 MHz): $\delta$ 159.2-114.4 (Ar-C), 70.7, 69.0, 55.5, 36.4, 35.0; ESI-MS (C$_{13}$H$_{20}$O$_2$S): $m/z$ 305.1 [M+1]$^+$; Anal. Calcd. for C$_{17}$H$_{20}$O$_2$S: C, 67.08; H, 6.62; found: C, 67.0; H, 6.75.

Compound 27. Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): $\delta$ 7.30-6.89 (m, 8 H), 4.19-4.07 (m, 1 H), 4.02-3.99 (m, 2 H), 3.82-3.72 (m, 2 H), 2.85-2.62 (m, 3 H), 2.33, 2.28 (2 s, 6 H); $^{13}$C NMR (CDCl$_3$, 50 MHz): $\delta$ 158.8-114.9 (Ar-C), 70.7, 69.2, 36.7, 35.2, 20.2, 19.8; ESI-MS (C$_{13}$H$_{20}$O$_2$S): $m/z$ 303.2 [M+1]$^+$; Anal. Calcd. for C$_{18}$H$_{22}$O$_2$S: C, 71.48; H, 7.33; found: C, 71.32; H, 7.48.

Compound 28. Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): $\delta$ 7.39-7.22 (m, 5 H, Ar-H), 4.55 (brs, 2 H, PhCH$_2$), 3.96-3.86 (m, 1 H, CH), 3.75 (brs, 2 H, SCH$_2$Ph), 3.56-3.46 (m, 2 H, OCH$_2$), 2.66-2.51 (m, 3 H, OH and SCH$_2$); $^{13}$C NMR (CDCl$_3$, 50 MHz): $\delta$ 138.6-127.5 (Ar-C), 73.8 (PhCH$_2$), 73.3 (OCH$_2$), 69.7 (CH), 37.0 (SCH$_2$), 35.2 (SCH$_2$); ESI-MS (C$_{13}$H$_{20}$O$_2$S): $m/z$ 289.1 [M+1]$^+$; Anal. Calcd. for C$_{17}$H$_{20}$O$_2$S: C, 70.80; H, 6.99; found: C, 70.67; H, 7.16.

Compound 29. Yellow oil; $^1$H NMR (CDCl$_3$, 200 MHz): $\delta$ 7.40-7.29 (m, 5 H, Ar-H), 4.58 (brs, 2 H, PhCH$_2$), 3.95-3.88 (m, 1 H, CH), 3.60-3.50 (m, 2 H, OCH$_2$), 2.76-2.60 (m, 2 H, SCH$_2$), 2.58-2.51 (m, 3 H, OH and SCH$_2$), 1.64-1.54 (m, 2 H, CH$_2$), 1.38-1.25 (m, 22 H, (CH$_2$)$_{11}$), 0.91 (t, $J$ = 6.3 Hz, 3 H, CH$_3$); $^{13}$C NMR (CDCl$_3$, 50 MHz): $\delta$ 138.3-128.1 (Ar-C), 73.8 (PhCH$_2$), 73.3 (OCH$_2$), 69.6 (CH), 36.4 (SCH$_2$), 33.0 (SCH$_2$), 32.3-23.1 (CH$_2$)$_{12}$, 14.6 (CH$_3$); ESI-MS
(C₂₄H₄₂O₂S): m/z 395.3 [M+1]; Anal. Calcd. for C₂₄H₄₂O₂S: C, 73.04; H, 10.73; found: C, 72.90; H, 10.86.

**Compound 30.** Yellow oil; ¹H NMR (CDCl₃, 200 MHz): δ 7.39-7.28 (m, 5 H, Ar-H), 7.08-7.01 (m, 5 H, Ar-H), 4.57 (brs, 2 H, PhCH₂), 3.95-3.86 (m, 1 H, CH), 3.78-3.69 (m, 2 H, OCH₂), 3.58 (m, 2 H, SCH₂), 2.72-2.52 (m, 3 H, OH and SCH₂), 2.32, 2.27 (2 s, 6 H, 2 CH₃); ¹³C NMR (CDCl₃, 50 MHz): δ 138.3-125.7 (Ar-C), 73.8 (PhCH₂), 73.3 (OCH₂), 69.2 (CH), 51.9 (SCH₂), 42.2, 23.9, 22.8 (2 s, 6 H, 2 CH₃); ESI-MS (C₁₉H₂₄O₂S): m/z 317.1 [M+1]; Anal. Calcd. for C₁₉H₂₄O₂S: H, 7.64; found: H, 7.78.

**Compound 31.** Yellow oil; ¹H NMR (CDCl₃, 200 MHz): δ 7.35-7.28 (m, 5 H, Ar-H), 7.22 (d, J = 8.6 Hz, 2 H), 6.82 (d, J = 8.6 Hz, 2 H), 4.55 (brs, 2 H, PhCH₂), 3.95-3.86 (m, 1 H, CH), 3.78-3.69 (m, 2 H, OCH₂), 3.58 (m, 2 H, SCH₂), 2.72-2.52 (m, 3 H, OH and SCH₂), 2.32, 2.27 (2 s, 6 H, 2 CH₃); ¹³C NMR (CDCl₃, 50 MHz): δ 138.3-125.7 (Ar-C), 73.8 (PhCH₂), 73.3 (OCH₂), 69.2 (CH), 51.9 (SCH₂), 42.2, 23.9, 22.8 (2 s, 6 H, 2 CH₃); ESI-MS (C₁₉H₂₄O₂S): m/z 317.1 [M+1]; Anal. Calcd. for C₁₉H₂₄O₂S: C, 72.11; H, 7.64; found: C, 72.0; H, 7.78.

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**References**


