"One-pot" Access to α-D-Mannopyranosides from Glycals Employing Ruthenium Catalysis

Sravanthi Chittela, Thurpu Raghavender Reddy, Palakodety Radha Krishna and Sudhir Kashyap*

D-207, Discovery Laboratory, Organic and Biomolecular Chemistry Division, CSIR-Indian Institute of Chemical Technology, Hyderabad-500 007, INDIA
*Corresponding author. Tel.: +91-402-716-1649; fax: +91-402-716-0387; e-mail: skashyap@iict.res.in

Supporting Information

Index

General synthesis information S2
General procedure for chemical synthesis S3
$^1$H, $^{13}$C NMR, IR and MS/HRMS Spectra S4-S47
Optical Rotation data S48-S50
**Experimental**

**General Synthesis Information.** Reactions were run in screw capped glass vials (4 mL) stirred with Teflon®-coated magnetic stir bars. Moisture and air-sensitive reactions were performed in flame-dried round bottom flasks, fitted with rubber septa or glass gas adapters, under a positive pressure of nitrogen. Moisture and air-sensitive liquids or solutions were transferred via nitrogen-flushed syringe. Concentration of solvents was accomplished by rotary evaporation using a Büchi rotary evaporator at temperatures between 35 °C and 50 °C. Experiments were monitored by thin layer chromatography (TLC).

**Materials.** Unless otherwise noted, materials were obtained from commercial suppliers and used without purification. Removal of solvent under reduced pressure refers to distillation with a Büchi rotary evaporator attached to a vacuum pump (~3 mmHg). Products obtained as solids or high boiling oils were dried under vacuum (~1 mmHg).

**Chromatography.** Analytical TLC was performed using Whatman 250 micron aluminum backed UV F254 precoated silica gel flexible plates. Subsequent to elution, ultraviolet illumination at 254 nm allowed for visualization of UV active materials. Staining with p-anisaldehyde, basic potassium permanganate solution, or Molisch's reagents allowed for further visualization. The retardation factor (Rf) is the ratio of the distance traveled by the compound to the distance traveled by the eluent.

**Physical Data.** Proton nuclear magnetic resonance spectra (1H NMR) were recorded on Avance 300 or Avance 500 MHz nuclear magnetic resonance spectrometers. Chemical shifts for 1H NMR spectra are reported as δ in units of parts per million (ppm) relative to tetramethylsilane (δ 0.0) using the residual solvent signal as an internal standard or tetramethylsilane itself: chloroform-d (δ 7.26, singlet). The number of protons (n) for a given resonance is indicated by nH. IR spectra were recorded on Bruker Alpha spectrometer and mass analyses (ESI) were performed on Finnegan MAT 1020 mass spectrometer operating at 70 eV.
General experimental procedure for Ru-catalyzed one-pot glycosylation/dihydroxylation method: (1) To a stirred solution of 3,4,6-tri-O-acetyl-D-glucal 1 (1 equiv) and acceptor (1.2 equiv) in anhydrous acetonitrile (2 mL/mmol) under an atmosphere of argon was added RuCl₃ (5 mol%) at room temperature. The reaction mixture was stirred until the complete consumption of the starting material (glycal), adjudged by TLC. (2) The reaction mixture was cooled at 0 °C and diluted with EtOAc (2 mL). An aqueous solution of NaIO₄ (1.5 equiv) and CeCl₃·7H₂O (5 mol%) in 1 mL H₂O was added to above mentioned reaction and stirred vigrously. The reaction deemed complete by TLC in utmost 10 min to obtain corresponding diols. The reaction was quenched with saturated NaHCO₃ (10 mL), diluted with EtOAc (10 mL), and extracted with EtOAC (3 X 30 mL). The combined organic layers were washed with brine solution, dried over anhydrous Na₂SO₄, concentrated in vacuo and purified by silica gel column chromatography (Hexanes-EtOAc 2:1). Following acetylation of diol in CH₂Cl₂ (5 mL), pyridine (0.5 mL), and acetic anhydride (5 equiv) in the presence of catalytic amount of DMAP gave corresponding per-acetylated glycoside. Following usual work-up and purification by chromatography (silica gel, hexanes-EtOAc) afforded desired α-D-mannopyranosides (3a-s) as major product in good yields. All the compounds were confirmed by ¹H NMR, ¹³C NMR and MS/HRMS spectroscopy and overall data were in complete agreement with the assigned structures.
\[^1\]H NMR Spectrum of compound 3a in CDCl\(_3\) (500 MHz)

\[^{13}\]C NMR Spectrum of compound 3a in CDCl\(_3\) (75 MHz)
$^1$H NMR Spectrum of compound 3a (Pure) in CDCl$_3$ (500 MHz)

$^{13}$C NMR Spectrum of compound 3a (Pure) in CDCl$_3$ (75 MHz)
IR Spectrum of compound 3a in CHCl₃

HRMS Spectrum of compound 3a

HRMS (ESI) m/z [M + NH₄]⁺ calcd. for C₂₁H₃₀NO₁₀⁺: 456.18642; found: 456.18803.
IR Spectrum of compound 3b in CHCl₃

HRMS Spectrum of compound 3b

PRK-CH-2-37#8-30 RT: 0.03-0.10 AV: 23
T: FTMS (1,1) + p ESI Full ms [100.00-2000.00]

<table>
<thead>
<tr>
<th>m/z</th>
<th>Intensity</th>
<th>Relative</th>
<th>Theo. Mass</th>
<th>Delta (ppm)</th>
<th>RDB equiv.</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>504.28187</td>
<td>63658160.0</td>
<td>100.00</td>
<td>504.28032</td>
<td>3.07</td>
<td>4.5</td>
<td>C₂₄H₄₂O₁₀N</td>
</tr>
</tbody>
</table>

HRMS (ESI) m/z [M + NH₄]⁺ calcd. for C₂₄H₄₂NO₁₀⁺: 504.28195; found: 504.28032.
IR Spectrum of compound 3c in CHCl₃

HRMS Spectrum of compound 3c

HRMS (ESI) m/z [M + NH₄]⁺ calcd. for C₁₈H₃₀NO₁₀⁺: 420.18642; found: 420.18789.
$^1$H NMR Spectrum of compound 3d in CDCl$_3$ (500 MHz)

$^{13}$C NMR Spectrum of compound 3d in CDCl$_3$ (75 MHz)
IR Spectrum of compound 3d in CHCl₃

HRMS Spectrum of compound 3d

T: FTMS [1,1] + p ESI Full ms [100.00-2000.00]

HRMS (ESI) m/z [M + NH₄]⁺ calcd. for C₂₁H₃₆NO₁₀⁺: 462.23337; found: 462.23470.
\[^1^H\text{NMR Spectrum of compound 3e in CDCl}_3 (500 MHz)\]

\[^{13}\text{C NMR Spectrum of compound 3e in CDCl}_3 (75 MHz)\]
IR Spectrum of compound 3e in CHCl₃

HRMS Spectrum of compound 3e

HRMS (ESI) m/z [M + NH₄]^⁺ calcd. for C₁₈H₃₂NO₁₁⁺: 438.19699; found: 438.19841.
\(^1\)H NMR Spectrum of compound 3f in CDCl\(_3\) (500 MHz)

\(^13\)C NMR Spectrum of compound 3f in CDCl\(_3\) (75 MHz)
IR Spectrum of compound 3f in CHCl₃

HRMS Spectrum of compound 3f

<table>
<thead>
<tr>
<th>m/z</th>
<th>Intensity</th>
<th>Relative Theo. Mass</th>
<th>Delta (ppm)</th>
<th>RDB equiv.</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>549.17334</td>
<td>17918168.0</td>
<td>100.00</td>
<td>2.22</td>
<td>13.5</td>
<td>C₂₈H₃₀O₁₀Na⁺</td>
</tr>
</tbody>
</table>

HRMS (ESI) m/z [M + Na]⁺ calcd. for C₂₈H₃₀O₁₀Na⁺: 549.17312; found: 549.17555.
$^1$H NMR Spectrum of compound 3g in CDCl$_3$ (300 MHz)

$^{13}$C NMR Spectrum of compound 3g in CDCl$_3$ (75 MHz)
IR Spectrum of compound 3g in CHCl₃

HRMS Spectrum of compound 3g

HRMS (ESI) m/z [M + NH₄]⁺ calcd. for C₁₉H₂₇N₂O₁₂⁺: 463.15585; found: 463.15871.
$^{1}$H NMR Spectrum of compound $3h$ in CDCl$_3$ (300 MHz)

$^{13}$C NMR Spectrum of compound $3h$ in CDCl$_3$ (125 MHz)
IR Spectrum of compound 3h in CHCl₃

FTIR Analysis Report

HRMS Spectrum of compound 3h

HRMS (ESI) m/z [M + NH₄]⁺ calcd. for C₂₂H₂₇N₂O₁₂⁺: 511.15585; found: 511.15926.
$^1$H NMR Spectrum of compound 3i in CDCl$_3$ (500 MHz)

$^{13}$C NMR Spectrum of compound 3i in CDCl$_3$ (75 MHz)
IR Spectrum of compound 3i in CHCl₃

HRMS Spectrum of compound 3i

T: FTMS {1,1} + p ESI Full ms [100.00-2000.00]

HRMS (ESI) m/z [M + NH₄]⁺ calcd. for C₁₆H₂₇ClNO₁₀⁺: 428.13180; found: 428.13350.
H NMR Spectrum of compound 3j in CDCl$_3$ (500 MHz)

13C NMR Spectrum of compound 3j in CDCl$_3$ (75 MHz)
IR Spectrum of compound 3j in CHCl₃

HRMS Spectrum of compound 3j

HRMS (ESI) m/z [M + Na]⁺ calcd. for C₂₄H₂₁NO₁₂Na⁺: 548.17385; found: 548.17422.
$^1$H NMR Spectrum of compound 3k in CDCl$_3$ (300 MHz)

$^{13}$C NMR Spectrum of compound 3k in CDCl$_3$ (125 MHz)
HRMS Spectrum of compound 3k

HRMS (ESI) m/z [M + NH₄]⁺ calcd. for C₄₂H₅₄NO₁₅⁺: 812.34880; found: 812.34842.
**1H NMR Spectrum of compound 3I in CDCl₃ (300 MHz)**

**13C NMR Spectrum of compound 3I in CDCl₃ (75 MHz)**
IR Spectrum of compound 31 in CHCl₃

HRMS Spectrum of compound 31

HRMS (ESI) m/z [M + NH₄]⁺ calcd. for C₄₂H₄₈NO₁₈⁺: 854.28659; found: 854.28402.
$^1$H NMR Spectrum of compound 3m in CDCl$_3$ (300 MHz)

$^{13}$C NMR Spectrum of compound 3m in CDCl$_3$ (125 MHz)
IR Spectrum of compound 3m in CHCl₃

HRMS Spectrum of compound 3m

HRMS (ESI) m/z [M + NH₄]⁺ calcd. for C₄₂H₅₄NO₁₅⁺: 812.34880; found: 812.34827.
IR Spectrum of compound 3n in CHCl$_3$

HRMS Spectrum of compound 3n

HRMS (ESI) $m/z$ [M + NH$_4$]$^+$ calcd. for C$_{42}$H$_{48}$NO$_{18}$: 854.28659; found: 854.28660.
\(^{1}\text{H NMR Spectrum of compound 3o in CDCl}_3\) (300 MHz)

\(^{13}\text{C NMR Spectrum of compound 3o in CDCl}_3\) (125 MHz)
IR Spectrum of compound 3o in CHCl₃

HRMS Spectrum of compound 3o

HRMS (ESI) m/z [M + NH₄]⁺ calcd. for C₂₆H₄₂NO₁₅⁺: 608.25490; found: 608.25378.
$^1$H NMR Spectrum of compound 3p in CDCl$_3$ (300 MHz)

$^{13}$C NMR Spectrum of compound 3p in CDCl$_3$ (75 MHz)
IR Spectrum of compound 3p in CHCl₃

HRMS Spectrum of compound 3p

HRMS (ESI) m/z [M + NH₄]⁺ calcd. for C₂₃H₃₈NO₅⁺: 552.22868; found: 552.22884.
$^1$H NMR Spectrum of compound 3q in CDCl$_3$ (300 MHz)

$^{13}$C NMR Spectrum of compound 3q in CDCl$_3$ (125 MHz)
IR Spectrum of compound 3q in CHCl$_3$

HRMS Spectrum of compound 3q

HRMS (ESI) $m/z$ [M + Na]$^+$ calcd. for C$_{33}$H$_{37}$NO$_{14}$Na$^+$: 694.21063; found: 694.21162.
\[ \text{\^1H NMR Spectrum of compound 3r in CDCl\textsubscript{3} (500 MHz)} \]

\[ \text{\^13C NMR Spectrum of compound 3r in CDCl\textsubscript{3} (125 MHz)} \]
IR Spectrum of compound 3r in CHCl₃

HRMS Spectrum of compound 3r

HRMS (ESI) m/z [M + Na]⁺ calcd. for C₃₄H₃₉NO₁₄Na⁺: 708.22628; found: 708.22732.
\(^{1}\)H NMR Spectrum of compound 3s in CDCl\(_3\) (300 MHz)

\(^{13}\)C NMR Spectrum of compound 3s in CDCl\(_3\) (75 MHz)
**IR Spectrum of compound 3s in CHCl₃**

**HRMS Spectrum of compound 3s**

**HRMS (ESI) m/z [M + Na]⁺ calcd. for C₃₅H₃₉NO₁₄Na⁺: 720.22628; found: 720.22724.**
$^1$H NMR Spectrum of compound 3a' in CDCl$_3$ (500 MHz)

$^{13}$C NMR Spectrum of compound 3a' in CDCl$_3$ (75 MHz)
$^1$H NMR Spectrum of compound 3a$'$ (Pure) in CDCl$_3$ (500 MHz)

$^{13}$C NMR Spectrum of compound 3a$'$ (Pure) in CDCl$_3$ (75 MHz)
IR Spectrum of compound 3a' in CHCl₃

HRMS Spectrum of compound 3a'

HRMS (ESI) m/z [M + NH₄]^+ calcd. for C₁₇H₂₆NO₈^+: 372.16529; found: 372.16804.
IR Spectrum of compound 3b' in CHCl₃

ESI Spectrum of compound 3b'

ESI m/z [M + Na]⁺ calcd. for C₂₀H₃₄O₈Na⁺: 425.21459; found: 425.
## Optical Rotation data sheet:

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Compound</th>
<th>Conc. (c, CHCl₃)</th>
<th>Optical Rotation, [α]₀³₀⁰⁰</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image" alt="3a" /></td>
<td>(c 3.8, CHCl₃)</td>
<td>+32.609</td>
</tr>
<tr>
<td>2</td>
<td><img src="image" alt="3b" /></td>
<td>(c 3.9, CHCl₃)</td>
<td>+103.780</td>
</tr>
<tr>
<td>3</td>
<td><img src="image" alt="3c" /></td>
<td>(c 4.8, CHCl₃)</td>
<td>+49.720</td>
</tr>
<tr>
<td>4</td>
<td><img src="image" alt="3d" /></td>
<td>(c 2.6, CHCl₃)</td>
<td>+52.329</td>
</tr>
<tr>
<td>5</td>
<td><img src="image" alt="3e" /></td>
<td>(c 5.2, CHCl₃)</td>
<td>+27.192</td>
</tr>
<tr>
<td>6</td>
<td><img src="image" alt="3f" /></td>
<td>(c 4.1, CHCl₃)</td>
<td>+41.951</td>
</tr>
<tr>
<td>7</td>
<td><img src="image" alt="3g" /></td>
<td>(c 4.5, CHCl₃)</td>
<td>+84.578</td>
</tr>
<tr>
<td></td>
<td>Structure</td>
<td>Molecular Formula</td>
<td>Log P (c, CHCl₃)</td>
</tr>
<tr>
<td>-----</td>
<td>-----------</td>
<td>-------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>8</td>
<td><img src="image" alt="Structure 3h" /></td>
<td>AcO₃O₂Ac₂O₂Ac₂O₂</td>
<td>(c 3.3, CHCl₃)</td>
</tr>
<tr>
<td>9</td>
<td><img src="image" alt="Structure 3i" /></td>
<td>AcO₃O₂Ac₂O₂Ac₂O₂</td>
<td>(c 3.5, CHCl₃)</td>
</tr>
<tr>
<td>10</td>
<td><img src="image" alt="Structure 3j" /></td>
<td>AcO₃O₂Ac₂O₂Ac₂O₂</td>
<td>(c 1.5, CHCl₃)</td>
</tr>
<tr>
<td>11</td>
<td><img src="image" alt="Structure 3k" /></td>
<td>AcO₃O₂Ac₂O₂Ac₂O₂</td>
<td>(c 3.9, CHCl₃)</td>
</tr>
<tr>
<td>12</td>
<td><img src="image" alt="Structure 3l" /></td>
<td>AcO₃O₂Ac₂O₂Ac₂O₂</td>
<td>(c 4.4, CHCl₃)</td>
</tr>
<tr>
<td>13</td>
<td><img src="image" alt="Structure 3m" /></td>
<td>AcO₃O₂Ac₂O₂Ac₂O₂</td>
<td>(c 0.7, CHCl₃)</td>
</tr>
<tr>
<td>14</td>
<td><img src="image" alt="Structure 3n" /></td>
<td>AcO₃O₂Ac₂O₂Ac₂O₂</td>
<td>(c 2.1, CHCl₃)</td>
</tr>
<tr>
<td></td>
<td>Structure</td>
<td>Observed (c, solvent)</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-----------</td>
<td>----------------------</td>
<td></td>
</tr>
</tbody>
</table>
| 15 | ![Structure 3o](image) | (c 1.8, CHCl₃) | +37.889  
| 16 | ![Structure 3p](image) | (c 4.9, CHCl₃) | +4.122  
| 17 | ![Structure 3q](image) | (c 4.7, CHCl₃) | +61.310  
| 18 | ![Structure 3r](image) | (c 1.7, CHCl₃) | +12.920  
| 19 | ![Structure 3s](image) | (c 2.2, CHCl₃) | -36.364  
| 20 | ![Structure 3a’](image) | (c 2.1, CHCl₃) | +23.810  
| 21 | ![Structure 3b’](image) | (c 1.4, CHCl₃) | +63.571  