Palladium catalysed carbonylation of 2-iodoglycals for the synthesis of C-2 carboxylic acids and aldehydes taking formic acid as carbonyl Source

Ajaz Ahmed\textsuperscript{a,b} Nazar Hussain\textsuperscript{a,b} Monika Bhardwaj\textsuperscript{b} Anuj Kumar Chhalodia\textsuperscript{b} Amit Kumar\textsuperscript{b} and Debaraj Mukherjee\textsuperscript{a,b,*}

\textsuperscript{a}Natural Product Chemistry Division, Indian Institute of Integrative Medicine (IIIM), Jammu, India.

\textsuperscript{b}Academy of Scientific and Innovative Research (AcSIR-IIIM), Jammu-180001, India.

Email: dmukherjee@iiim.ac.in
# Table of Contents

| Chapter                                                                 | Page no. |
|------------------------------------------------------------------------|----------|
| 1 General Consideration                                                | S3       |
| 2 Optimization tables                                                 | S3-S4    |
| 3 General procedures                                                  | S5-S9    |
| 4 Characterization data: products                                      | S10-S22  |
| 5 NMR spectra                                                         | S23-S45  |
1 General Consideration:

$^1$H and $^{13}$C NMR spectra were recorded using 400, 101 and 126 MHz spectrometers with TMS as internal standard. Chemical shifts are expressed in parts per million (δ ppm). Silica gel coated aluminium plates were used for TLC. The products were purified by column chromatography on silica gel (60-120 mesh) using petroleum ether–ethyl acetate as the eluent to obtain the pure products. Exact masses of all products were derived by using HRMS having QTOF analyzer. Reagents used were mostly purchased from Sigma Aldrich.

2. Optimization Tables:

Table 2.1. Effect of solvent on reaction for synthesis of 3a:

| entry | Pd source | ligand | temp (°C) | time (h) | solvent   | yield (%) |
|-------|-----------|--------|-----------|----------|-----------|-----------|
| 1     | Pd(OAc)$_2$ | L2 (10) | 90        | 2        | DMSO      | 27        |
| 2     | Pd(OAc)$_2$ | L2 (10) | 90        | 2        | THF       | 53        |
| 3     | Pd(OAc)$_2$ | L2 (10) | 90        | 2        | DMF       | 82        |
| 4     | Pd(OAc)$_2$ | L2 (10) | 90        | 2        | ACN       | 13        |
| 5     | Pd(OAc)$_2$ | L2 (10) | 90        | 2        | MeOH      | traces    |

In all cases reactions were carried out using 1a (1 equiv) and 2a (2 equiv) triethylamine (2 equiv) at 90 °C in a sealed tube.
### Table 2.2. Optimization of equivalent of DCC used for the synthesis of 3a:

| entry | Pd source  | ligand  | temp | time | DCC    | yield |
|-------|------------|---------|------|------|--------|-------|
|       | (mol %)    | ((°C))  | (h)  | (equiv) | (%) b |
| 1     | Pd(OAc)₂   | L2 (10) | 90   | 2     | 2.5    | 46    |
| 2     | Pd(OAc)₂   | L2 (10) | 90   | 2     | 2.0    | 53    |
| 3     | Pd(OAc)₂   | L2 (10) | 90   | 2     | 1.5    | 58    |
| 4     | Pd(OAc)₂   | L2 (10) | 90   | 2     | 0.4    | 64    |
| 5     | Pd(OAc)₂   | L2 (10) | 90   | 2     | 1.0    | 82    |
| 6     | Pd(OAc)₂   | L2 (10) | 90   | 2     | 0.6    | 52    |
| 7     | Pd(OAc)₂   | L2 (10) | 90   | 2     | 1.1    | 78    |

In all cases reactions were carried out in DMF using 1a (1 equiv) and 2a (2 equiv) triethylamine (2 equiv) at 90 °C in a sealed tube.

### Table 2.3. Optimization of different bases for the synthesis of 3a:

| entry | Pd source  | ligand  | temp | time | bases     | yield |
|-------|------------|---------|------|------|-----------|-------|
|       | (mol %)    | ((°C))  | (h)  | (2 equiv)) | (%) b |
| 1     | Pd(OAc)₂   | L2 (10) | 90   | 2     | Et₃N      | 82    |
| 2     | Pd(OAc)₂   | L2 (10) | 90   | 2     | DBU       | 58    |
| 3     | Pd(OAc)₂   | L2 (10) | 90   | 2     | K₂CO₃     | 42    |
| 4     | Pd(OAc)₂   | L2 (10) | 90   | 2     | Na₂CO₃    | 45    |
| 5     | Pd(OAc)₂   | L2 (10) | 90   | 2     | KOtBu     | 32    |
| 6     | Pd(OAc)₂   | L2 (10) | 90   | 2     | NaOtBu    | 37    |

In all cases reactions were carried out in DMF using 1a (1 equiv) and 2a (2 equiv) DCC (1 equiv) at 90 °C in a sealed tube.
3 General procedures

3.1 General procedure for the Synthesis of 2-iodo glycals

\[ \text{PO} \overset{\text{NIS, (4.4 mmol, 1.2 equiv)}}{\rightarrow} \text{PO} \overset{\text{AgNO}_3, (0.73 mmol, 0.2 equiv)}}{\rightarrow} \text{I} \]

\[ \text{MeCN} \]

By taking tri-O-acetyl-D-glucal as an example, to a stirred solution of tri-O-acetyl-D-glucal (1g) in dry CH\textsubscript{3}CN (10 mL) at 80 °C under N\textsubscript{2} atmosphere were added successively NIS (991 mg, 4.4 mmol) and AgNO\textsubscript{3} (124 mg, 0.73 mmol) and stirred for 4 h. On consumption of starting material (TLC monitoring), the reaction mixture was filtered through sintered funnel and the filtrate was evaporated to give a crude product which was purified by silica gel column chromatography (30% of EtOAc/hexane) to obtain 1a-1h.

3.2 General Procedure for the synthesis of C-2 Sugar Carboxylic acids:

To a solution of 2-iodo glycals (1.0 equiv) in DMF in an oven dried screw capped sealed tube were added Pd(OAc)\textsubscript{2} (0.05 equiv), 1,1'-Bis(diphenylphosphino)ferrocene(DPPF) (0.10 equiv) N,N'-Dicyclohexylcarbodiimide(DCC) (1 equiv), formic Acid (2 equiv), and triethylamine (2 equiv). Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 °C for 2 h. Upon reaction completion, the resulting mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO\textsubscript{4} and concentrated. The residue left was purified by column chromatography on silica gel (60-120 mesh) hexanes/ethyl acetate as eluent to obtained 3 as desired product.

3.3 General Procedure for the Synthesis of 2-Formyl Glycals:

\[ \text{RO} \overset{\text{HCOOH, (2.0 equiv)}}{\rightarrow} \text{RO} \overset{\text{Pd(OAc)}_2, (5 \text{ mol \%})}}{\rightarrow} \text{RO} \overset{\text{DPPF, (10 \text{ mol \%})}}{\rightarrow} \text{H} \]

To a solution of 2-iodo glycals (1.0 equiv) in DMF in an oven dried screw capped sealed tube were added Pd(OAc)\textsubscript{2} (0.05 equiv), 1,1'-Bis(diphenylphosphino)ferrocene (DPPF) (0.10
equiv) N,N'-Dicyclohexylcarbodiimide (DCC) (1 equiv), formic Acid (2 equiv), triethylamine (2 equiv) and triethylsilane. Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 °C for 2 h. Upon reaction completion, the resulting mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO₄ and concentrated. The residue left was purified by column chromatography on silica gel (60-120 mesh) hexanes/ ethyl acetate as eluent to obtained 3aa-3ab as desired products.

3.4 Procedure for synthesis of 5a

In an oven dried round bottom flask stirred mixture of anisaldehyde (0.15 mmol, 0.7 equiv) and aniline (0.15 mmol, 0.7 equiv) in methanol for 2 h at rt. Then, glycal based acid 3a (0.22 mmol, 1 equiv) and cyclohexylisocyanide (0.18 mmol, 0.8 equiv) were added and resulting reaction mixture was stirred at rt for 48 h. After completion the reaction mixture was diluted with ethyl acetate and washed with brine. The organic layer was dried over sodium sulphate and evaporated in vacuo. The residue left was purified by column chromatography on silica gel (60-120 mesh) and pet ether/ ethyl acetate ( 82/18) as eluent to obtained desired product 5a as colorless oil (93 mg, 55 %).

3.5 Procedure for Synthesis of 5b

To a solution of glycal based acid 3a (0.22 mmol, 1 equiv) in 3 mL of anhydrous THF in an oven dried round bottom flask under N₂ atmosphere. Thionyl chloride (0.33 mmol, 1.5 equiv)
was also added and resulting reaction mixture was stirred at 50 °C in preheated oil bath under N\textsubscript{2} atmosphere for 1 h. then cooled the reaction mixture to 0 °C and add this reaction mixture to already prepared 37% ammonium hydroxide solution at 0 °C on continue stirring. After 5 minute the reaction mixture was diluted with chloroform and worked up with water. The organic layer was dried over sodium sulphate and evaporated in vacuo. The residue left was purified by column chromatography using silica gel (60-120 mesh) and pet ether/ ethyl acetate (65/35) as eluent to obtained 5b as colorless semi solid product (74 mg, 74 %).

3.6 Procedure for Synthesis of 5c

To a solution of glycal based acid 3a (0.22 mmol, 1 equiv) in 3 mL of DCM in an oven dried round bottom flask. Phosphorous pentachloride (0.26 mmol, 1.2 equiv) was also added and resulting reaction mixture was allowed to stirr at 45 °C on reflux in preheated oil bath under N\textsubscript{2} atmosphere for 1 h. then cooled the reaction mixture to 0 °C and then added 8-aminoquinoline (0.24 mmol, 1.1 equiv), after 5 minutes pyridine (1.3 mmol, 6 equiv) was added, and resulting reaction mixture was stirred at rt for 2 h. After completion the reaction mixture was diluted with ethyl acetate and washed with brine. The organic layer was dried over sodium sulphate and evaporated in vacuo. The residue left was purified by column chromatography on silica gel (60-120 mesh) and pet ether/ ethyl acetate (90/10) as eluent to obtained desired product 5c as colorless oil (86 mg, 67 %).

3.7 Procedure for synthesis of 7
To a solution of glycal based acid $3a$ (0.22 mmol, 1 equiv) in 3 mL of anhydrous DMSO in an oven dried round bottom flask under $N_2$ atmosphere. 1,2,3,4,6-penta-$O$-acetyl-(α,β)-D-galactopyranosyl Bromide (0.22 mmol, 1 equiv) and triethylamine (0.24 mmol, 1.1 equiv) were also added and resulting reaction mixture was stirred at 40 °C in preheated oil bath under $N_2$ atmosphere until complete consumption of starting material (about 5 h) was observed by TLC analysis. After completion the reaction mixture was diluted with 25 mL of ethyl acetate and washed with 20 mL of brine. The organic layer was dried over sodium sulphate and evaporated in vacuo. The residue left was purified by column chromatography using silica gel (60-120 mesh) and pet ether/ethyl acetate (85/15) as eluent to obtained $5e$ as colourless gummy product (117 mg, 68 %).

### 3.8 Procedure for Synthesis of $9$

![Reaction Scheme]

To a solution of glycal based acid $3a$ (0.22 mmol, 1 equiv) in 1 mL of anhydrous MeCN in an oven dried round bottom flask under $N_2$ atmosphere. 2-(trimethylsilyl) phenyl trifluoromethanesulfonate (0.43 mmol, 2 equiv) and cesium fluoride (0.65 mmol, 3 equiv) were also added and resulting reaction mixture was stirred at rt under $N_2$ atmosphere until complete consumption of starting material (about 4 h) was observed by TLC analysis. After completion the reaction mixture was diluted with ethyl acetate and washed with brine. The organic layer was dried over sodium sulphate and evaporated in vacuo. The residue left was purified by column chromatography using silica gel (60-120 mesh) and pet ether/ethyl acetate (93/7) as eluent to obtained $9$ as colourless gummy product (95 mg, 82 %).
3.9 Procedure for Synthesis of 11

To a solution of glycal based acid 3a (0.22 mmol, 1 equiv) in 3 mL of DCM in an oven dried round bottom flask. Phosphorous pentachloride (0.26 mmol, 1.2 equiv) was also added and resulting reaction mixture was allowed to stirr at 45 °C on reflux in preheated oil bath under N₂ atmosphere for 1 h. then cooled the reaction mixture to 0 °C and then added Thiophenol (0.24 mmol, 1.1 equiv), after 5 minutes pyridine (1.3 mmol, 6 equiv) was added, and resulting reaction mixture was stirred at rt for 2 h. After completion the reaction mixture was diluted with ethyl acetate and washed with brine. The organic layer was dried over sodium sulphate and evaporated in vacuo. The residue left was purified by column chromatography on silica gel (60-120 mesh) and pet ether/ ethyl acetate (92/8) as eluent to obtained desired product 11 as colorless gummy (87 mg, 67 %).
Characterization of the products:

To a stirred solution of di-\(\text{-O-benzyl-L-rhamnal}\) (0.5 g, 1.61 mmol) in dry CH\(_3\)CN (10 mL) at 80 °C under N\(_2\) atmosphere were added successively NIS (435 mg, 1.93 mmol) and AgNO\(_3\) (55 mg, 0.32 mmol) and stirred for 1.5 h. On consumption of starting material (TLC monitoring), the reaction mixture was filtered through sintered funnel and the filtrate was evaporated to give a crude product which was purified by silica gel column chromatography (3% of EtOAc/hexane) to obtain \(1c\) as amorphous solid (456 mg, 65%).

\(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.49-7.45 (m, 2H), 7.43 – 7.35 (m, 8H), 6.74 (s, 1H), 4.80 (t, \(J = 10.6\) Hz, 2H), 4.68 (t, \(J = 11.3\) Hz, 2H), 4.25 – 4.20 (m, 1H), 4.17 (d, \(J = 5.2\) Hz, 1H), 3.67 (dd, \(J = 7.2, 5.6\) Hz, 1H), 1.41 (d, \(J = 6.6\) Hz, 3H).

\(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \(\delta\) 148.9, 138.0, 137.8, 128.7, 128.5, 128.3, 128.1, 128.0, 128.0, 79.8, 79.1, 74.3, 73.7, 72.5, 71.3, 17.0.

HRMS calcd for C\(_{20}\)H\(_{22}\)IO\(_3\) [M+H]\(^+\) 437.0614, found 437.0619;

[\(\alpha\)]\(_D\) -29.7 (c 1, CHCl\(_3\)).

To a stirred solution of 4-((benzyloxy)methyl)-2,2-dimethyl-dihydro-4H-galactal (0.5 g, 1.81 mmol) in dry CH\(_3\)CN (10 mL) at 80 °C under N\(_2\) atmosphere were added successively NIS (489 mg, 2.17 mmol) and AgNO\(_3\) (62 mg, 0.36 mmol) and stirred for 20 minutes. On consumption of starting material (TLC monitoring), the reaction mixture was filtered through sintered funnel and the filtrate was evaporated to give a crude product which was purified by silica gel column chromatography (3% of EtOAc/hexane) to obtain \(1d\) as oil (436 mg, 60%).

\(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.39-7.35 (m, 2H), 7.33 – 7.29 (m, 1H), 6.71 (s, 1H), 4.65 (d, \(J = 12.0\) Hz, 2H), 4.61 – 4.55 (m, 1H), 4.38 (d, \(J = 5.8\) Hz, 1H), 4.23 (t, \(J = 6.3\) Hz, 1H), 3.83 – 3.79 (m, 1H), 3.75 – 3.71 (m, 1H), 1.48 (s, 3H), 1.39 (s, 3H).

\(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) 148.4, 137.8, 128.5, 127.9, 127.8, 111.1, 74.8, 74.2, 74.1, 73.9, 73.65, 69.4, 27.8, 27.0.
HRMS calcd for C\textsubscript{16}H\textsubscript{20}IO\textsubscript{4} [M+H]\textsuperscript{+} 403.0406, found 403.0409; 
[\alpha]_D ^0 -38.6 (c 1, CHCl\textsubscript{3}).

To a stirred solution of tri-\textit{O}-ethyl-\textit{D}-glucal (0.5 g, 2.17 mmol) in dry CH\textsubscript{3}CN (10 mL) at 80 °C under N\textsubscript{2} atmosphere were added successively NIS (587 mg, 2.61 mmol) and AgNO\textsubscript{3} (74 mg, 0.43 mmol) and stirred for 1.5 h. On consumption of starting material (TLC monitoring), the reaction mixture was filtered through sintered funnel and the filtrate was evaporated to give a crude product which was purified by silica gel column chromatography (3% of EtOAc/hexane) to obtain 1\textsubscript{e} as liquid (472 mg, 61%).

\textbf{1\textsuperscript{H} NMR (400 MHz, CDCl\textsubscript{3})} \delta 6.59 (s, 1H), 4.04 (dd, \textit{J} = 7.3, 3.9 Hz, 1H), 3.79 (d, \textit{J} = 5.5 Hz, 1H), 3.73 – 3.66 (m, 3H), 3.64 – 3.58 (m, 4H), 3.50 – 3.43 (m, 2H), 1.23-1.19 (m, 4H), 1.18 – 1.14 (m, 5H).

\textbf{1\textsuperscript{3}C NMR (126 MHz, CDCl\textsubscript{3})} \delta 148.2, 79.8, 77.2, 74.9, 71.7, 68.3, 67.1, 66.9, 66.0, 15.6, 15.1.

HRMS calcd for C\textsubscript{12}H\textsubscript{22}IO\textsubscript{4} [M+H]\textsuperscript{+} 357.0563, found 357.0565. 
[\alpha]_D ^0 +48.9 (c 1, CHCl\textsubscript{3}).

To a stirred solution of tri-\textit{O}-tertbutyldimethylsilyl-\textit{D}-glucal (0.5 g, 1.02 mmol) in dry CH\textsubscript{3}CN (10 mL) at 80 °C under N\textsubscript{2} atmosphere were added successively NIS (276 mg, 1.23 mmol) and AgNO\textsubscript{3} (35 mg, 0.20 mmol) and stirred for 1.5 h. On consumption of starting material (TLC monitoring), the reaction mixture was filtered through sintered funnel and the filtrate was evaporated to give a crude product which was purified by silica gel column chromatography (3% of EtOAc/hexane) to obtain 1\textsubscript{h} as liquid (424 mg, 67%).

\textbf{1\textsuperscript{H} NMR (400 MHz, CDCl\textsubscript{3})} \delta 6.64 (s, 1H), 4.17 (dd, \textit{J} = 6.6, 5.7 Hz, 1H), 3.98 (s, 1H), 3.95 – 3.89 (m, 1H), 3.85 (d, \textit{J} = 1.6 Hz, 1H), 3.77 (dd, \textit{J} = 11.4, 4.9 Hz, 1H), 0.93 (s, 9H), 0.90 (d, \textit{J} = 2.0 Hz, 18H), 0.24 (s, 3H), 0.14 (s, 3H), 0.10 (s, 6H), 0.05 (d, \textit{J} = 5.1 Hz, 6H).
\textbf{\textsuperscript{13}C NMR (126 MHz, CDCl\textsubscript{3})} \(\delta\) 146.0, 79.5, 73.2, 70.5, 70.2, 61.2, 26.0, 25.8, 25.7, 18.4, 18.0, 18.0, -4.1, -4.3, -4.6, -4.7, -5.2, -5.3.

HRMS calcd for \(C_{24}H_{52}IO_4Si_3\left[M+H\right]^+\) 615.2218, found 615.2229.

\([\alpha]_D^0 +24.0\) (c 1, CHCl\textsubscript{3}).

To a solution of \textit{1a} (0.18 mmol, 1.0 equiv) in DMF in an oven dried screw capped sealed tube were added \(\text{Pd(OAc)}_2\) (0.009 mmol, 0.05 equiv), \((\text{DPPF}) (0.018\) mmol, 0.10 equiv), \((\text{DCC}) (0.18\) mmol, 1 equiv), formic Acid (0.36 mmol, 2 equiv), and triethylamine (0.36 mmol, 2 equiv). Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 \(^\circ\text{C}\) for 1.5 h. Upon reaction completion, the resulting mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO\textsubscript{4} and concentrated. The residue left was purified by column chromatography on silica gel (60-120 mesh) hexanes/ethyl acetate (85/15) as eluent to obtained \textit{3a} as colourless gummy product (68 mg, 80%).

\textbf{\textit{1H NMR (400 MHz, CDCl\textsubscript{3})}} \(\delta\) 7.76 (s, 1H), 7.33 – 7.27 (m, 6H), 7.26-7.23 (m, 9H), 4.64 (d, \(J = 11.1\) Hz, 2H), 4.54-4.52 (m, 3H), 4.44 (d, \(J = 17.1\) Hz, 2H), 4.32 (s, 1H), 3.82 – 3.73 (m, 2H), 3.64 – 3.59 (m, 1H).

\textbf{\textit{13C NMR (126 MHz, CDCl\textsubscript{3})}} \(\delta\) 172.9, 157.5, 138.2, 137.8, 137.4, 128.6, 128.4, 128.4, 128.0, 127.8, 127.8, 127.7, 104.7, 77.4, 73.4, 72.3, 71.5, 71.3, 68.3, 67.7.

HRMS (ESI) calculated \(C_{28}H_{27}O_6\left[M-H\right]^-\) : 459.1808, Found: 459.1827;

\([\alpha]_D^0 +43.2\) (c 1, CHCl\textsubscript{3}).

To a solution of \textit{1b} (0.23 mmol, 1.0 equiv) in DMF in an oven dried screw capped sealed tube were added \(\text{Pd(OAc)}_2\) (0.001 mmol, 0.05 equiv), \((\text{DPPF}) (0.002\) mmol, 0.10 equiv), \((\text{DCC}) (0.23\) mmol, 1 equiv), formic Acid (0.46 mmol, 2 equiv), and triethylamine (0.46 mmol, 2 equiv). Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 \(^\circ\text{C}\) for 1.5 h. Upon reaction completion, the resulting
mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO$_4$ and concentrated. The residue left was purified by column chromatography on silica gel (60-120 mesh) hexanes/ethyl acetate (85/15) as eluent to obtained 3b as colourless gummy product (69 mg, 85%).

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.73 (s, 1H), 7.36 – 7.28 (m, 7H), 7.27-7.23 (m, 3H), 4.72 (d, $J = 11.5$ Hz, 1H), 4.60 – 4.52 (m, 3H), 4.45 (d, $J = 12.1$ Hz, 1H), 4.36 (s, 1H), 3.59 (s, 1H), 1.38 (d, $J = 7.1$ Hz, 3H).

$^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 173.4, 157.5, 138.5, 137.6, 128.6, 128.4, 128.0, 127.9, 127.7, 127.7, 104.2, 74.8, 74.8, 72.5, 71.6, 68.5, 16.6.

HRMS (ESI) calculated C$_{21}$H$_{21}$O$_5$ [M-H$^-$]: 353.1389, Found: 353.1408;

$[\alpha]_D$ -32.5 (c 1, CHCl$_3$).

To a solution of 1c (0.18 mmol, 1.0 equiv) in DMF in an oven dried screw capped sealed tube were added Pd(OAc)$_2$ (0.009 mmol, 0.05 equiv), (DPPF) (0.018 mmol, 0.10 equiv), (DCC) (0.18 mmol, 1 equiv), formic Acid (0.36 mmol, 2 equiv), and triethylamine (0.36 mmol, 2 equiv). Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 °C for 1.5 h. Upon reaction completion, the resulting mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO$_4$ and concentrated. The residue left was purified by column chromatography on silica gel (60-120 mesh) hexanes/ethyl acetate (85/15) as eluent to obtained 3c as colourless gummy product (65 mg, 76%).

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.62 (s, 1H), 7.32-7.28 (m, 7H), 7.28-7.24 (m, 8H), 4.80 – 4.71 (m, 2H), 4.65 (dd, $J = 17.6$, 8.3 Hz, 2H), 4.58 (d, $J = 7.0$ Hz, 1H), 4.55 – 4.51 (m, 2H), 4.45 (d, $J = 11.9$ Hz, 1H), 4.00 – 3.95 (m, 2H), 3.89 – 3.85 (m, 1H).

$^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 172.3, 157.5, 138.9, 138.0, 137.5, 128.6, 128.4, 128.2, 128.0, 127.9, 127.7, 127.6, 127.4, 106.2, 77.2, 74.1, 73.8, 73.5, 71.7, 68.3, 67.3.

HRMS (ESI) calculated C$_{28}$H$_{27}$O$_6$ [M-H$^-$]: 459.1808, Found: 459.1825;

$[\alpha]_D$ -25.7 (c 1, CHCl$_3$).
To a solution of 1d (0.25 mmol, 1.0 equiv) in DMF in an oven dried screw capped sealed tube were added Pd(OAc)$_2$ (0.012 mmol, 0.05 equiv), (DPPF) (0.025 mmol, 0.10 equiv), (DCC) (0.25 mmol, 1 equiv), formic Acid (0.49 mmol, 2 equiv), and triethylamine (0.49 mmol, 2 equiv). Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 °C for 1.5 h. Upon reaction completion, the resulting mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO$_4$ and concentrated. The residue left was purified by column chromatography on silica gel (60-120 mesh) hexanes/ ethyl acetate (82/18) as eluent to obtained 3d as colourless gummy product (60 mg, 75%).

$^1$H NMR (400 MHz, CDCl$_3$) δ 7.61 (s, 1H), 7.34 – 7.23 (m, 5H), 4.94 (d, $J = 6.3$ Hz, 1H), 4.65 – 4.52 (m, 2H), 4.38 (d, $J = 6.2$ Hz, 1H), 4.16 – 4.09 (m, 1H), 3.88 – 3.82 (m, 1H), 3.79 – 3.74 (m, 1H), 1.36 (s, 3H), 1.33 (s, 3H).

$^{13}$C NMR (126 MHz, CDCl$_3$) δ 171.7, 157.6, 137.6, 128.5, 127.9, 127.8, 111.0, 107.9, 75.8, 73.7, 72.0, 69.2, 67.6, 27.8, 26.5.

HRMS (ESI) calculated C$_{17}$H$_{19}$O$_6$ [M-H]$: 319.1182, Found: 319.1196;

$[\alpha]_D$ -29.0 (c 1, CHCl$_3$).

To a solution of 1e (0.28 mmol, 1.0 equiv) in DMF in an oven dried screw capped sealed tube were added Pd(OAc)$_2$ (0.014 mmol, 0.05 equiv), (DPPF) (0.028 mmol, 0.10 equiv), (DCC) (0.28 mmol, 1 equiv), formic Acid (0.56 mmol, 2 equiv), and triethylamine (0.56 mmol, 2 equiv). Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 °C for 2 h. Upon reaction completion, the resulting mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO$_4$ and concentrated. The residue left was purified by column chromatography on
silica gel (60-120 mesh) hexanes/ ethyl acetate (90/10) as eluent to obtained 3e as colorless gummy product (59 mg, 76 %).

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.66 (s, 1H), 4.56 – 4.48 (m, 1H), 4.09 (d, $J = 2.2$ Hz, 1H), 3.71 – 3.66 (m, 2H), 3.65 – 3.60 (m, 2H), 3.59 – 3.53 (m, 3H), 3.51 – 3.43 (m, 2H), 1.19 – 1.15 (m, 4H), 1.15 – 1.12 (m, 5H).

$^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 172.7, 157.2, 104.7, 77.6, 72.0, 68.6, 67.8, 66.8, 65.4, 65.1, 15.5, 15.4, 15.1.

HRMS (ESI) calculated C$_{13}$H$_{21}$O$_6$ [M-H] $^{-}$ : 273.1338, Found: 273.1351; $\lbrack \alpha \rbrack_D +58.0$ (c 1, CHCl$_3$).

To a solution of 1f (0.25 mmol, 1.0 equiv) in DMF in an oven dried screw capped sealed tube were added Pd(OAc)$_2$ (0.012 mmol, 0.05 equiv), (DPPF) (0.025 mmol, 0.10 equiv), (DCC) (0.25 mmol, 1 equiv), formic Acid (0.5 mmol, 2 equiv), and triethylamine (0.5 mmol, 2 equiv). Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 °C for 2.5 h. Upon reaction completion, the resulting mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO$_4$ and concentrated. The residue left was purified by column chromatography on silica gel (60-120 mesh) hexanes/ ethyl acetate (68/32) as eluent to obtained 3f as colourless gummy product (58 mg, 73 %).

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.81 (s, 1H), 5.66 (dd, $J = 2.8$, 1.6 Hz, 1H), 5.19 (t, $J = 3.0$ Hz, 1H), 4.66 – 4.56 (m, 1H), 4.46 (dd, $J = 12.1$, 7.9 Hz, 1H), 4.19 (dd, $J = 12.1$, 4.4 Hz, 1H), 2.12 (s, 3H), 2.10 (s, 3H), 2.07 (s, 3H).

$^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 170.4, 170.3, 169.5, 169.3, 158.0, 103.3, 74.9, 65.9, 62.1, 60.9, 20.7, 20.7, 20.6.

HRMS (ESI) calculated C$_{13}$H$_{15}$O$_9$ [M-H] $^{-}$ : 315.0716, Found: 315.0728; $\lbrack \alpha \rbrack_D +46.8$ (c 1, CHCl$_3$).
To a solution of 1g (0.31 mmol, 1.0 equiv) in DMF in an oven dried screw capped sealed tube were added Pd(OAc)$_2$ (0.015 mmol, 0.05 equiv), (DPPF) (0.031 mmol, 0.10 equiv), (DCC) (0.31 mmol, 1 equiv), formic Acid (0.62 mmol, 2 equiv), and triethylamine (0.62 mmol, 2 equiv). Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 °C for 2.5 h. Upon reaction completion, the resulting mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO$_4$ and concentrated. The residue left was purified by column chromatography on silica gel (60-120 mesh) hexanes/ ethyl acetate (70/30) as eluent to obtained 3g as colourless gummy product (56 mg, 75 %).

$1^H$ NMR (400 MHz, CDCl$_3$) $\delta$ 7.91 (s, 1H), 5.61 (t, J = 2.0 Hz, 1H), 5.02 (d, J = 1.9 Hz, 1H), 4.51 – 4.43 (m, 1H), 4.06 (d, J = 12.6 Hz, 1H), 2.11 (s, 3H), 2.10 (s, 3H).

$13^C$ NMR (101 MHz, CDCl$_3$) $\delta$ 171.2, 169.5, 169.2, 160.3, 102.9, 65.3, 64.6, 61.0, 20.9, 20.8.

HRMS (ESI) calculated C$_{10}$H$_{11}$O$_7$ [M-H]$^-$ : 243.0505, Found: 243.0516;

$[\alpha]_D^0$ +63.9 (c 1, CHCl$_3$).

To a solution of 1h (0.16 mmol, 1.0 equiv) in DMF in an oven dried screw capped sealed tube were added Pd(OAc)$_2$ (0.008 mmol, 0.05 equiv), (DPPF) (0.016 mmol, 0.10 equiv), (DCC) (0.16 mmol, 1 equiv), formic Acid (0.32 mmol, 2 equiv), and triethylamine (0.32 mmol, 2 equiv). Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 °C for 2 h. Upon reaction completion, the resulting mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO$_4$ and concentrated. The residue left was purified by column
chromatography on silica gel (60-120 mesh) hexanes/ethyl acetate (90/10) as eluent to 

obtained 3f as colourless gummy product (66 mg, 76%).

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.74 (s, 1H), 4.27-4.24 (m, 2H), 3.90 – 3.83 (m, 2H), 3.72 

(dd, $J = 12.7$, 4.5 Hz, 1H), 0.85-0.77 (m, 27H), 0.18 – -0.01 (m, 18H).

$^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 172.7, 158.1, 105.0, 80.8, 69.8, 63.6, 62.2, 25.7, 25.6, 18.0, 17.9, -4.6, -4.8, -4.8, -4.9.

HRMS (ESI) calculated C$_{25}$H$_{51}$O$_6$Si$_3$ [M-H]$: 531.2993, Found: 531.3003;

$[\alpha]_D$ +24.0 (c 1, CHCl$_3$).

To a solution of 1a (0.18 mmol, 1.0 equiv) in DMF in an oven dried screw capped sealed 
tube were added Pd(OAc)$_2$ (0.009 mmol, 0.05 equiv), (DPPF) (0.018 mmol, 0.10 equiv), 
(DCC) (0.18 mmol, 1 equiv), formic Acid (0.36 mmol, 2 equiv), triethylamine (0.36 mmol, 2 
equiv) and TMSH (0.22 mmol, 1.2 equiv). Closed sealed tube tightly with screw cork and the 
resulting mixtures was stirred at preheated oil bath at 90 °C for 2 h. Upon reaction 
completion, the resulting mixture was extracted with ethyl acetate and the combined organic 
extracts were washed with brine, dried over MgSO$_4$ and concentrated. The residue left was 
purified by column chromatography on silica gel (60-120 mesh) hexanes/ethyl acetate (92/8) 
as eluent to obtained 3aa as colourless gummy product (59 mg, 72%).

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 9.44 (s, 1H), 7.43 (s, 1H), 7.40 – 7.37 (m, 2H), 7.36 – 7.34 

(m, 3H), 7.34 – 7.31 (m, 5H), 7.30 – 7.26 (m, 5H), 4.80 – 4.68 (m, 2H), 4.64 – 4.50 (m, 5H), 4.46 
(t, $J = 2.2$ Hz, 1H), 3.88 (t, $J = 2.2$ Hz, 1H), 3.86 – 3.81 (m, 1H), 3.70 – 3.66 (m, 1H).

$^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 190.5, 164.4, 138.1, 137.6, 137.2, 128.8, 128.6, 128.5, 128.4, 128.1, 127.9, 127.9, 127.8, 127.7, 117.7, 79.4, 73.4, 72.5, 71.7, 71.3, 68.4, 65.2.

HRMS (ESI) calculated C$_{28}$H$_{28}$O$_5$ [M+H]$^+$: 445.2015, Found: 445.2029;

$[\alpha]_D$ +47.9 (c 1, CHCl$_3$).
To a solution of 1b (0.23 mmol, 1.0 equiv) in DMF in an oven dried screw capped sealed tube were added Pd(OAc)$_2$ (0.011 mmol, 0.05 equiv), (DPPF) (0.023 mmol, 0.10 equiv), (DCC) (0.23 mmol, 1 equiv), formic Acid (0.46 mmol, 2 equiv), triethylamine (0.46 mmol, 2 equiv) and TMSH (0.27 mmol, 1.2 equiv). Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 °C for 2 h. Upon reaction completion, the resulting mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO$_4$ and concentrated. The residue left was purified by column chromatography on silica gel (60-120 mesh) hexanes/ ethyl acetate (92/8) as eluent to obtained 3ab as colourless gummy product (61 mg, 78%).

$^1$H NMR (400 MHz, CDCl$_3$) δ 9.36 (s, 1H), 7.34 – 7.27 (m, 7H), 7.23-7.19 (m, 3H), 4.72 (d, $J = 11.5$ Hz, 1H), 4.60 (dd, $J = 9.3, 4.3$ Hz, 2H), 4.52 (d, $J = 12.0$ Hz, 1H), 4.41 (d, $J = 12.1$ Hz, 2H), 3.61 (s, 1H), 1.41 (d, $J = 7.1$ Hz, 3H).

$^{13}$C NMR (126 MHz, CDCl$_3$) δ 190.6, 164.6, 138.5, 137.5, 128.6, 128.4, 128.0, 127.9, 127.7, 127.7, 117.5, 76.9, 74.8, 72.7, 71.7, 66.2, 16.9.

HRMS (ESI) calculated C$_{21}$H$_{23}$O$_4$ [M+H]$^+$: 339.1596, Found: 339.1591;

[$\alpha$]$_D$ -36.0 (c 1, CHCl$_3$).

To a solution of 1c (0.18 mmol, 1.0 equiv) in DMF in an oven dried screw capped sealed tube were added Pd(OAc)$_2$ (0.009 mmol, 0.05 equiv), (DPPF) (0.018 mmol, 0.10 equiv), (DCC) (0.18 mmol, 1 equiv), formic Acid (0.36 mmol, 2 equiv), triethylamine (0.36 mmol, 2 equiv) and TMSH (0.22 mmol, 1.2 equiv). Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 °C for 2 h. Upon reaction completion, the resulting mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO$_4$ and concentrated. The residue left was purified by column chromatography on silica gel (60-120 mesh) hexanes/ ethyl acetate (92/8) as eluent to obtained 3ac as colourless gummy product (65 mg, 79%).

$^1$H NMR (400 MHz, CDCl$_3$) δ 9.32 (s, 1H), 7.38-7.31 (m, 9H), 7.30-7.27 (m, 5H), 7.22 (s, 1H), 4.76 (s, 2H), 4.73 – 4.66 (m, 2H), 4.61 (d, $J = 2.3$ Hz, 1H), 4.57-4.53 (m, 4H), 4.03 – 3.98 (m, 2H), 3.84 – 3.80 (m, 1H).
$^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 189.5, 164.5, 138.1, 137.5, 128.6, 128.5, 128.3, 128.1, 128.0, 127.8, 127.7, 127.5, 119.3, 78.8, 73.8, 73.5, 73.2, 71.6, 68.5, 64.8.

**HRMS (ESI)** calculated C$_{28}$H$_{29}$O$_5$ [M+H]$^+$: 445.2015, Found: 445.2026; [$\alpha$]$_D$ -29.4 (c 1, CHCl$_3$).

\[ \text{O} \]
\[ \text{EtO} \]
\[ \text{EtO} \]
\[ \text{CHO} \]
\[ 3\text{ad} \]

To a solution of 1e (0.28 mmol, 1.0 equiv) in DMF in an oven dried screw capped sealed tube were added Pd(OAc)$_2$ (0.014 mmol, 0.05 equiv), (DPPF) (0.028 mmol, 0.10 equiv), (DCC) (0.28 mmol, 1 equiv), formic Acid (0.56 mmol, 2 equiv), triethylamine (0.56 mmol, 2 equiv) and TMSH (0.337 mmol, 1.2 equiv). Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 °C for 2 h. Upon reaction completion, the resulting mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO$_4$ and concentrated. The residue left was purified by column chromatography on silica gel (60-120 mesh) hexanes/ ethyl acetate (91/9) as eluent to obtained 3ad as colourless gummy product (50 mg, 69%).

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 9.28 (s, 1H), 7.27 (s, 1H), 4.62 – 4.50 (m, 1H), 4.13 (s, 1H), 3.69 – 3.63 (m, 2H), 3.60 – 3.56 (m, 2H), 3.57-3.51 (m, 3H), 3.46 – 3.42 (m, 2H), 1.19-1.13 (m, 4H), 1.13 – 1.08 (m, 5H).

$^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 190.4, 164.3, 117.8, 79.6, 72.0, 68.8, 66.7, 65.5, 65.4, 15.5, 15.4, 15.1.

**HRMS (ESI)** calculated C$_{13}$H$_{22}$O$_5$ [M+H]$^+$: 259.1545, Found: 259.1556; [$\alpha$]$_D$ +41.0 (c 1, CHCl$_3$).

\[ \text{TBSO}^- \]
\[ \text{TBSO}^- \]
\[ \text{O} \]
\[ \text{CHO} \]
\[ 3\text{ae} \]

To a solution of 1h (0.16 mmol, 1.0 equiv) in DMF in an oven dried screw capped sealed tube were added Pd(OAc)$_2$ (0.008 mmol, 0.05 equiv), (DPPF) (0.016 mmol, 0.10 equiv), (DCC) (0.16 mmol, 1 equiv), formic Acid (0.32 mmol, 2 equiv), triethylamine (0.32 mmol, 2 equiv) and TMSH (0.192 mmol, 1.2 equiv). Closed sealed tube tightly with screw cork and the resulting mixtures was stirred at preheated oil bath at 90 °C for 2 h. Upon reaction completion, the resulting mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over MgSO$_4$ and concentrated. The residue left was purified by column chromatography on silica gel (60-120 mesh) hexanes/ ethyl acetate (91/9) as eluent to obtained 3ae as colourless gummy product (50 mg, 69%).
extracts were washed with brine, dried over MgSO₄ and concentrated. The residue left was purified by column chromatography on silica gel (60-120 mesh) hexanes/ethyl acetate (91/9) as eluent to obtained 3ae as colourless gummy product (59 mg, 70%).

**1H NMR (400 MHz, CDCl₃)** δ 9.30 (s, 1H), 7.42 (s, 1H), 4.37 (d, J = 1.7 Hz, 2H), 3.95 – 3.89 (m, 2H), 3.83 (dd, J = 12.8, 4.5 Hz, 1H), 0.87 (s, 1H), 0.84 (s, 1H), 0.30-0.22 (m, 4H), 0.20 -0.16 (m, 5H), 0.13-0.06 (m, 9H).

**13C NMR (126 MHz, CDCl₃)** δ 190.0, 165.3, 118.1, 82.3, 69.9, 62.3, 61.2, 25.7, 25.5, -4.7, -4.9, -5.1.

**HRMS (ESI)** calculated C₂₅H₅₃O₅Si₃ [M+H]⁺: 517.3201, Found: 517.3208; [α]₀ +26.3 (c 1, CHCl₃).

![Image of compound 5a](image)

Synthesized according to general procedure 3.4

**1H NMR (400 MHz, CDCl₃)** δ 7.37 – 7.32 (m, 5H), 7.32 – 7.30 (m, 5H), 7.25 – 7.21 (m, 6H), 7.18 – 7.11 (m, 5H), 6.73 (d, J = 8.7 Hz, 2H), 6.60 (s, 1H), 6.29 (d, J = 8.0 Hz, 1H), 6.15 (s, 1H), 4.71 (d, J = 11.5 Hz, 1H), 4.64 – 4.56 (m, 2H), 4.48 – 4.36 (m, 3H), 4.33 – 4.24 (m, 2H), 3.90 – 3.84 (m, 1H), 3.76 (s, 3H), 3.73 (t, J = 4.1 Hz, 1H), 3.50-4.46 (m, 2H), 2.00 – 1.88 (m, 2H), 1.74 – 1.63 (m, 8H).

**13C NMR (126 MHz, CDCl₃)** δ 169.6, 169.2, 159.1, 151.2, 142.7, 138.5, 137.8, 137.6, 130.7, 129.4, 128.9, 128.8, 128.5, 128.4, 128.3, 127.9, 127.8, 127.7, 127.6, 127.5, 127.0, 127.0, 113.7, 110.0, 76.7, 73.5, 72.5, 72.5, 72.1, 71.6, 68.0, 66.8, 55.2, 48.6, 32.9, 32.9, 25.5, 24.8, 24.8.

**HRMS (ESI)** calculated C₄₉H₅₃N₂O₇ [M+H]⁺: 781.3853, Found: 781.3867; [α]₀ +138.0 (c 1, CHCl₃).

![Image of compound 5b](image)

Synthesized according to general procedure 3.5
1H NMR (400 MHz, CDCl3) δ 7.61 (s, 1H), 7.41 – 7.37 (m, 3H), 7.36-7.34 (m, 5H), 7.33-7.31 (m, 4H), 7.30-7.28 (m, 1H), 7.27 – 7.23 (m, 2H), 5.59 (s, 2H), 4.70 (s, 2H), 4.61 – 4.54 (m, 2H), 4.52 – 4.47 (m, 2H), 4.38 (d, J = 3.3 Hz, 1H), 4.10 (t, J = 4.1 Hz, 1H), 3.85 – 3.81 (m, 1H), 3.76 – 3.72 (m, 1H), 3.45 (s, 1H).

13C NMR (126 MHz ) δ 168.8, 154.2, 137.6, 137.4, 137.1, 128.7, 128.6, 128.5, 128.2, 128.1, 128.0, 127.9, 127.8, 106.9, 76.6, 73.5, 72.2, 71.3, 70.3, 69.8, 67.5.

HRMS (ESI) calculated C28H30NO5 [M+H]+: 460.2124, Found: 460.2139; [α]D +89.6 (c 1, CHCl3).

O

BnO

BnO

BnO

O

H

N

5c

Synthesized according to general procedure 3.6

1H NMR (400 MHz, CDCl3) δ 10.57 (s, 1H), 8.86 (d, J = 7.5 Hz, 1H), 8.41 (d, J = 3.2 Hz, 1H), 8.15 (d, J = 7.3 Hz, 1H), 7.81 (s, 1H), 7.59-7.50 (m, 3H), 7.41 – 7.37 (m, 5H), 7.36-7.34 (m, 2H), 7.33-7.31 (m, 3H), 7.29 – 7.27 (m, 4H), 7.26-7.24 (m, 1H), 5.11 (d, J = 11.2 Hz, 1H), 4.72 – 4.67 (m, 3H), 4.58 (s, 1H), 4.53-4.50 (m, 1H), 4.46 – 4.41 (m, 2H), 4.10 (s, 1H), 3.87 – 3.80 (m, 1H), 3.71 – 3.66 (m, 1H).

13C NMR (126 MHz, CDCl3) δ 165.5, 153.4, 149.4, 147.9, 138.7, 137.9, 137.7, 137.4, 136.3, 135.1, 128.6, 128.4, 128.3, 128.1, 128.0, 127.9, 127.8, 127.6, 127.5, 127.5, 121.1, 116.8, 108.2, 76.2, 73.4, 71.8, 70.9, 70.5, 70.5, 67.5.

HRMS (ESI) calculated C37H34N2O5 [M+H]+: 587.2546, Found: 587.2555; [α]D +76.9 (c 1, CHCl3).

O

AcO

O

AcO

AcO

O

AcO

7, 63%

O

Bn

O

Bn

BnO

Synthesized according to general procedure 3.7

1H NMR (400 MHz, CDCl3) δ 7.81 (s, 1H), 7.76 (s, 1H), 7.40-7.36 (m, 4H), 7.35 – 7.33 (m, 5H), 7.32-7.30 (m, 5H), 7.30-7.29 (m, 6H), 7.29 – 7.27 (m, 6H), 7.27-7.25 (m, 2H), 5.82 (d, J = 8.4 Hz, 1H), 5.74 (d, J = 8.3 Hz, 1H), 5.49 – 5.35 (m, 3H), 5.16 – 5.11 (m, 1H), 4.72 – 4.64
(m, 3H), 4.61 – 4.42 (m, 9H), 4.40 – 4.36 (m, 2H), 4.22 – 4.08 (m, 6H), 3.87 – 3.75 (m, 3H),
3.66-3.62 (m, 2H), 2.21 (s, 2H), 2.20 (s, 3H), 2.15 (s, 2H), 2.08 (d, J = 1.9 Hz, 6H), 2.05 (s,
2H), 2.03 (s, 3H), 1.96 (s, 2H).

**13C NMR (101 MHz, CDCl3)** δ 172.3, 170.3, 170.2, 170.1, 170.0, 169.9, 169.5, 169.4, 169.0, 165.2, 157.2, 157.3, 138.2, 138.2, 137.8, 137.8, 137.5, 137.4, 128.6, 128.4, 128.3, 128.1, 128.0, 127.8, 127.7, 127.7, 104.7, 104.1, 92.2, 92.1, 77.3, 73.4, 73.4, 72.3, 72.2, 71.7, 71.6, 71.5, 71.4, 71.3, 71.3, 70.9, 70.9, 68.3, 68.2, 67.9, 67.8, 67.8, 67.6, 66.9, 66.9, 61.1, 61.0, 60.4, 22.7, 21.0, 20.8, 20.6, 20.6, 20.5.

**HRMS (ESI)** calculated C_{42}H_{47}O_{15} [M+H]^+ : 791.2915, Found: 791.2929;
[α]_D^+123.7 (c 1, CHCl_3).

![Image 9]

Synthesized according to general procedure 3.8

**1H NMR (400 MHz, CDCl3)** δ 7.95 (s, 1H), 7.46 – 7.40 (m, 4H), 7.39 – 7.37 (m, 3H), 7.35-7.34 (m, 3H), 7.33 – 7.30 (m, 6H), 7.30 – 7.24 (m, 2H), 7.20-7.16 (m, 2H), 4.76-4.72 (m, 2H), 4.67 – 4.58 (m, 4H), 4.54-4.52 (m, 1H), 4.48 (t, J = 2.1 Hz, 1H), 3.93 (t, J = 2.0 Hz, 1H), 3.90 – 3.85 (m, 1H), 3.77 – 3.73 (m, 1H).

**13C NMR (126 MHz, CDCl3)** δ 165.8, 156.9, 150.8, 138.1, 137.8, 137.4, 129.4, 128.6, 128.5, 128.4, 128.1, 127.9, 127.8, 127.7, 125.6, 121.9, 105.0, 77.3, 73.4, 72.7, 71.6, 71.4, 68.2, 68.0.

**HRMS (ESI)** calculated C_{34}H_{32}O_{6} [M+H]^+ : 537.2277, Found: 537.2282;
[α]_D^+74.0 (c 1, CHCl_3).

![Image 11]

**1H NMR (400 MHz, CDCl3)** δ 7.94 (s, 1H), 7.62 – 7.56 (m, 1H), 7.54 – 7.51 (m, 2H), 7.48 –7.45 (m, 3H), 7.43 – 7.39 (m, 3H), 7.38 – 7.35 (m, 3H), 7.34-7.32 (m, 2H), 7.31-7.29 (m, 3H), 7.28 – 7.25 (m, 3H), 4.76 – 4.67 (m, 2H), 4.62 – 4.55 (m, 3H), 4.54 – 4.48 (m, 3H), 3.90 – 3.82 (m, 2H), 3.71 – 3.66 (m, 1H).
$^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 188.1, 155.4, 138.0, 137.7, 137.3, 135.4, 129.4, 129.2, 128.6, 128.49, 128.4, 128.1, 127.9, 127.9, 127.8, 127.8, 127.3, 77.8, 73.4, 72.64, 71.6, 71.3, 68.1, 67.8.

HRMS (ESI) calculated C$_{34}$H$_{32}$O$_5$S [M+H]$^+$ : 553.2049, Found: 553.2062; $[\alpha]_D$ +57.3 (c 1, CHCl$_3$).

$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 1c

![ spectra ]
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 1d
\( \text{H NMR (400 MHz) and } \text{C NMR (126 MHz) of compound 1e} \)

\[
\begin{align*}
\text{1e} \quad \text{EtO} & \quad \text{EtO} \\
\text{BnO} & \quad \text{I}
\end{align*}
\]
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 1h
1H NMR (400 MHz) and 13C NMR (101 MHz) of compound 3a
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 3b
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 3c
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 3d
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 3e
\(^1\)H NMR (400 MHz) and \(^{13}\)C NMR (101 MHz) of compound 3f
$^{1}$H NMR (400 MHz) and $^{13}$C NMR (101 MHz) of compound 3g
$^1$H NMR (400 MHz) and $^{13}$C NMR (101 MHz) of compound 3h
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 3aa
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 3ab
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 3ac
$^{1}$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 3ad
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 3ae
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 5a
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 5b
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 5c
$^1$H NMR (400 MHz) and $^{13}$C NMR (101 MHz) of compound 7
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 9
$^1$H NMR (400 MHz) and $^{13}$C NMR (126 MHz) of compound 11
