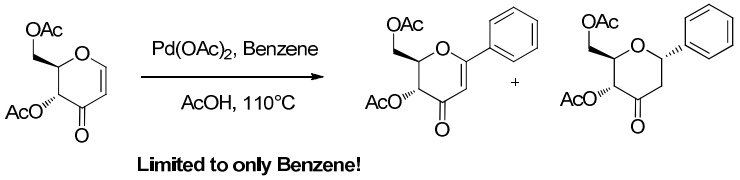
4.1 Introduction

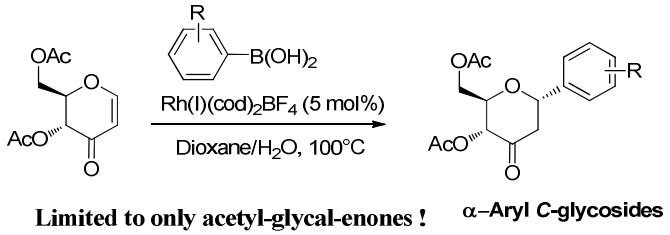
As discussed in the Chapters 1-3, aryl *C*-glycosides are important classes of compounds that received significant attention over the decades due their potential bioactivities [1]. In particular, several natural products including angucyclines, urdamycinones A–D, marmycin A–B, kidamycin, etc. are embedded with 2-deoxy-aryl-*C*-glycoside units [2]. In this perspective, numerous synthetic methodologies have been developed for the preparation of 2-deoxy aryl-*C*-glycosides [1a-c]. Among the developed routes, glycal mediated synthesis of aryl-*C*-glycosides very attractive and promising in terms of reaction conditions and yield. In this context, we have developed glycal and aryl diazonium salts mediated synthesis of derivatives of 2-deoxy aryl-*C*-glycosides in good to excellent yields (as discussed in the chapter 2 and 3) [3]. However, considering the potential explosive nature of aryl diazonium salts as well as difficulties in isolation and storage issues, [4] we have searched for the new aryl donors that are green and commercially available. *In this context, the following chapter will describe the stereoselective preparation of 2-deoxy aryl-α-C-glycosides from arylboronic acids and enones derived from glycals.*

Stereoselective 1,4-conjugate addition reactions has become a powerful tool in synthetic organic chemistry for the assembly of various chiral organic molecules [5]. In this context, in 1991, Guy Ville reported palladium catalyzed 1,4-conjucate addition reaction of benzene with enones derived from glycals (**here after it will be called as "glycal-enones**") (**Scheme 4.1**) [6]. There are two issues with this reaction protocol. First of all, this method provided a mixture of oxidative addition product and 1,4-conjucate addition product. Secondly, this method is limited to simple benzene.

Alternatively, Maddaford *et al.* reported a rhodium(I)-catalyzed 1,4-addition of arylboronic acids to glycal-enones (**Scheme 4.2**) [7]. This approach provides stereoselective aryl C-glycosides in good yields. However, this method limited to acetylated enones (other protecting groups were not tested) and also required expensive rhodium catalyst. Therefore identifying a new method for the stereoselective 1,4-conjugate addition protocol for the aryl-c-glycosides preparation, is of great interest.



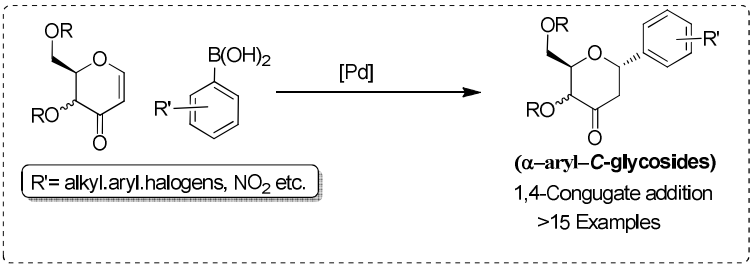
Scheme 4.1 Palladium catalyzed Formation of aryl *C*-glycosides.



Scheme 4.2 Rhodium catalyzed stereoselective 1,4-addition of arylboronic acids: Formation of α-Selective aryl *C*-glycosides

A combination of palladium and arylboronic acid in asymmetric 1,4-conjugate addition reactions is well-known in the literature [8]. However, such combination was not investigated in coupling reaction with glycal-enones. Palladium catalysts are relatively cheaper, moisture friendly and easy to handle. Due to these reasons we have aimed to develop palladium mediated 1,4-conjucate addition of arylboronic acids to glycal-enones under mild reaction conditions. *In this context, as a part of our previous chapters 2&3, herein we have developed a mild procedure for the stereo-selective*

conjugate addition reaction of glycal-enones with arylboronic acid in the presence of palladium acetate and 1,10-phenanthroline ligand (**Scheme 4.3**).

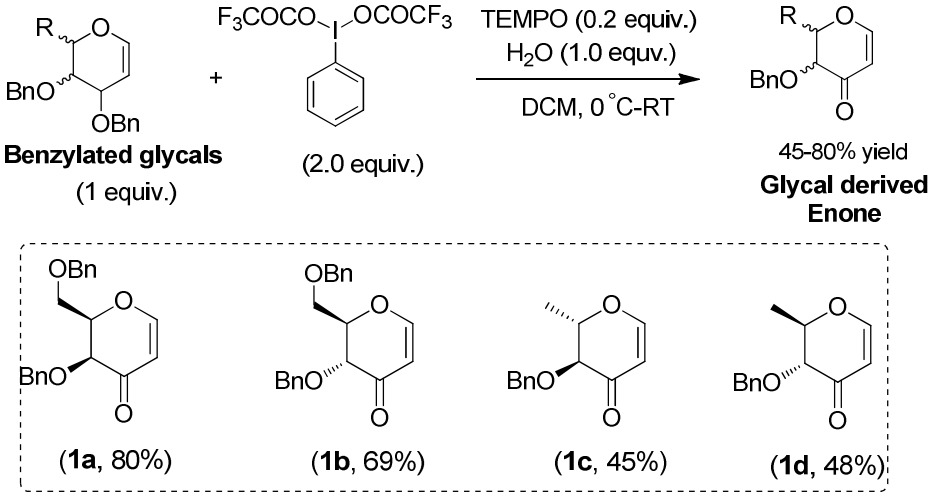


Scheme 4.3 Palladium catalyzed reaction of glycal enones with arylboronic acids.

4.2 Results and Discussion

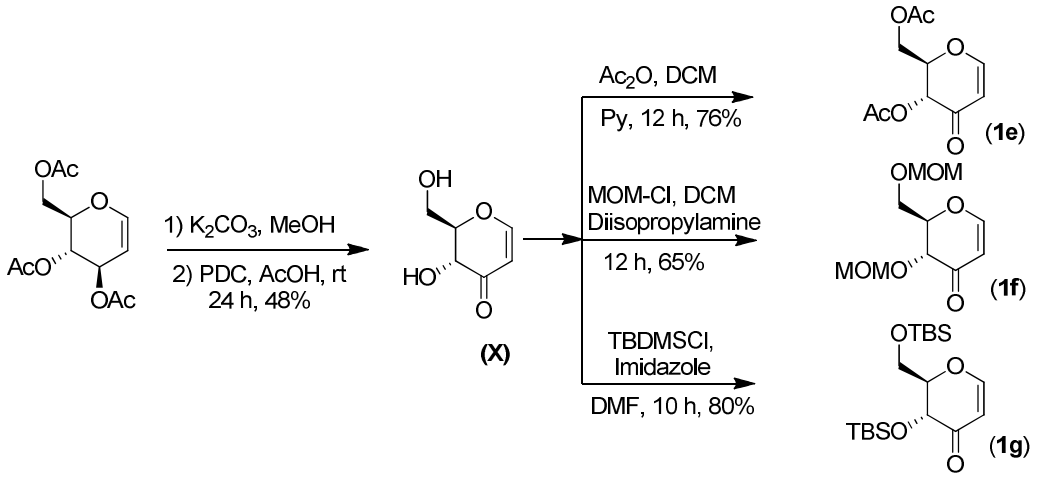
4.2.1. Synthesis of enones derived from glycal

At the beginning, we have synthesized different benzyl protected glycal-enones (**1a-1d**) from corresponding glycals including D-glucal, D-galactal, L-rhamnal and D-rhamnal via selective oxidation of *C*-3 position using $PhI(OCOCF_3)_2$ and TEMPO (**Scheme 4.4**) [9]. The enones **1a-1d** was obtained in 45-80% yields.



Scheme 4.4 Synthesis of glycal derived enones from benzyl protected glycals.

Further, glycal-enones bearing different protecting groups including acetate (**1e**), MOM (**1f**) and TBS (**1g**) were prepared from unprotected glycal (**X**) as shown in **Scheme 4.5**. These enones were obtained in 65-80%.

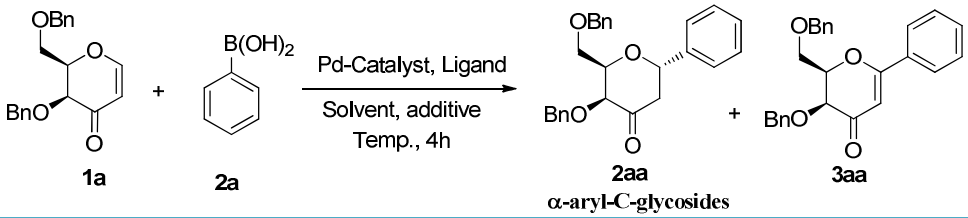


Scheme 4.5 Synthesis of different protected glycal-enones.

Having synthesized a wide range of glycal-enones, we performed the optimization study for 1,4-conjucate addition reaction using galactal-enone **1a** and phenylboronic acid **2a** as model substrates (**Table-4.1**). Initially, the reaction was investigated in presence of palladium acetate (10 mol%) and acetic acid (2 equiv.) in DMF solvent. This reaction provided only a trace amount of 2-deoxy 3-keto α-aryl glycoside **2aa,** however with complete stereoselectivity (i.e. α-anomer). Having realized the importance of ligands in palladium catalyzed 1,4-conjugate addition reactions, [5, 8] we have attempted the coupling reaction in the presence of 2,2-bipridine, a widely used ligand in palladium catalysis. To our delight, this reaction provided the desired product in 20% yield. Under this condition, we have also observed the formation of oxidative coupling product **3aa** in a trace amount. To understand the importance of acid additive,

we performed the reaction in the absence of acetic acid. Interestingly, this reaction provided **3aa** in 15% yield while the desired product **2aa** was obtained only in a trace amount (**Table-4.1,** entries 1-3). Further, the addition reaction was performed in different solvents including dioxane, THF and acetonitrile in the presence of palladium acetate and acetic acid. However, among all the DMF was remained the best (**Table-4.1,** entries 4-6). Hence, a further optimization was performed with different ligands including DMAP, pyridine, TMEDA, DABCO and 1,10-phenanthroline. Among the tested ligands, 1,10-phenanthroline was found to efficient by providing the desired product **2aa** in 32% yield, however along with 10% of **3aa** (**Table-4.1,** entries 7-11). Further, to identify the optimum temperature, the reaction was performed at 80°C, 100 °C and 120°C. The reaction proceeds efficiently at 100°C by providing the desired product **2aa** in 49% yield (**Table-4.1,** entries 12-14).

Table 4.1 Optimization of the reaction condition.[a,b]



SN.	Solvents	Ligand (0.2 equiv.)	Additive (2.0 equiv.)	Temp °C	Yield (%)[b]	
					2aa	3aa
1	DMF	---	AcOH	60	<10	--
2	DMF	2,2-Bipy	AcOH	60	20	<5
3	DMF	2,2-Bipy	----	60	<5	15
4	dioxane	2,2-Bipy	AcOH	60	10	7
5	THF	2,2-Bipy	AcOH	60	15	<5
6	CH_3CN	2,2-Bipy	AcOH	60	16	<5

7	DMF	DMAP	AcOH	60	<10	--
8	DMF	Pyridine	AcOH	60	<10	--
9	DMF	TMEDA	AcOH	60	<10	--
10	DMF	DABCO	AcOH	60	<10	--
11	DMF	1,10-Phen	AcOH	60	32	10
12	DMF	1,10-Phen	AcOH	80	41	12
13	DMF	1,10-Phen	AcOH	100	49	14
14	DMF	1,10-Phen	AcOH	120	43	10
15	DMF	1,10-Phen	PTSA	100	<10	<5
16	DMF	1,10-Phen	TfOH	100	35	10
17	**DMF**	**1,10-Phen**	**TFA**	**100**	**66**	**<5**
18[c]	DMF	1,10-Phen	TFA	100	20	<5
19[d]	DMF	1,10-Phen	TFA	100	25	<5
20[e]	DMF	1,10-Phen	TFA	100	25	<5
21[f]	DMF	1,10-Phen	TFA	100	<10	**<5**

[a]**Reaction condition:** Galactcal enone **1a** (81 mg, 0.25 mmol) and phenylboronic acid **2a** (61 mg, 0.5 mmol, 2 equiv.), $Pd(OAc)_2$ (10 mol%) and ligand (0.2 equiv.), additive (2 equiv.) were stirred in appropriate solvent (3 mL), under O_2 atmosphere. [b]Isolated yield. [c]$PdCl_2$ was used as the catalyst. [d]$Pd(dba)_2$ was used as the catalyst. [e]$PdCl_2(CH_3CN)_2$was used as the catalyst. [f]$Pd(PPh)_4$ was used as the catalyst.

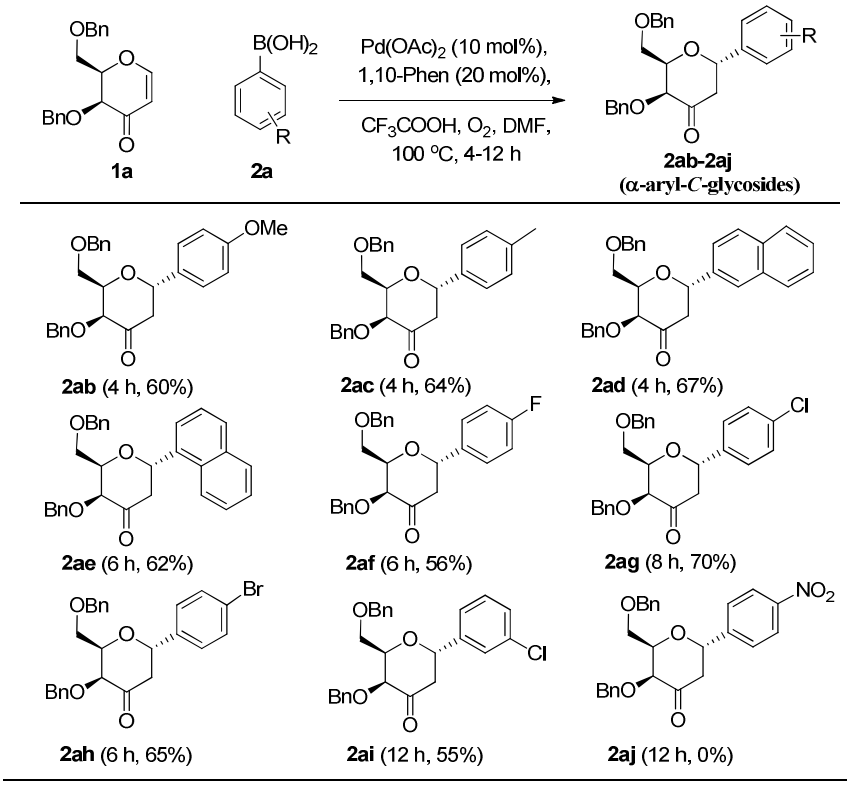
In continuation of optimization study, different organic acid additives including PTSA, TfOH and TFA were screened. In this context, trifluoroacetic acid (TFA) has provided the desired product in 66% yield while **3aa** was observed only in negligible amount (<5%). Moreover, it is also important to note that a significant amount of unidentified products (mostly decomposed) were observed during the coupling reactions (**Table-4.1,** entries 15-17). Finally, we have tested the efficiency of different palladium catalysts including $PdCl_2$, $Pd(dba)_2$, $PdCl_2(CH_3CN)_2$ and $Pd(PPh)_4$ in the conjugate addition

reaction. The palladium acetate was found to be superior among all, which is also a cost effective (**Table-4.1,** entries 18-21).

4.3 Substrates Scope

Having optimized the reaction condition in hand, the scope of different arylboronic acids was investigated (**Table 4.2**). Initially, the reaction was carried out with arylboronic acids bearing electron donating groups. To our delight, these reactions were provided the desired products **2ab and 2ac** in 60-64% yields**.**

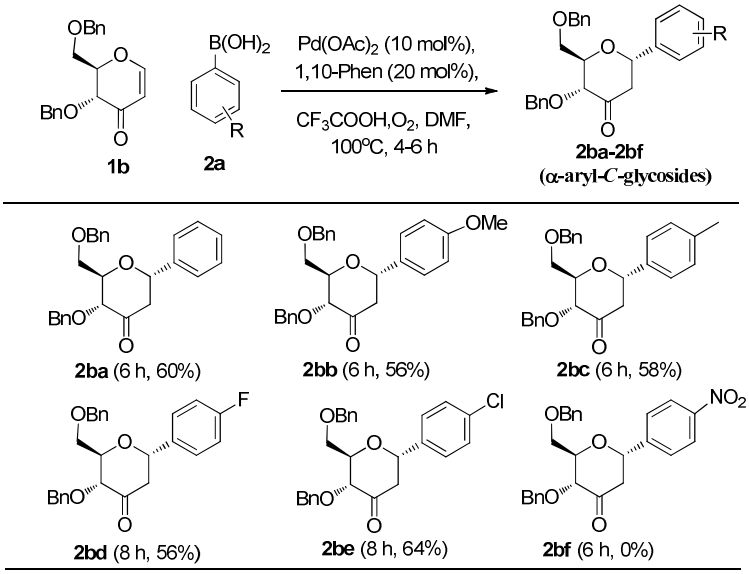
Table 4.2 Synthesis of 2-deoxy-*α*-aryl-*C*-glycosides from D-galactal enone.[a,b]



[a]**Reaction condition**: Enone **1a** (0.25 mmol) and arylboronic acid (0.5 mmol, 2 equiv.), $Pd(OAc)_2$ (10 mol%) and 1,10-Phen (0.2 equiv.), CF_3COOH (2.0 equiv.) were stirred in DMF solvent (3 mL). [b]Isolated yield.

To expand the scope of the developed methodology, we further attempted 1,4-conjugated addition reaction between glucal-enone **1b** and different arylboronic acids under optimized conditions (**Table 4.3**). Similar to galactal-enone, glucal-enone also gave the desired stereoselective coupling products **2ba-2be** in good yields.

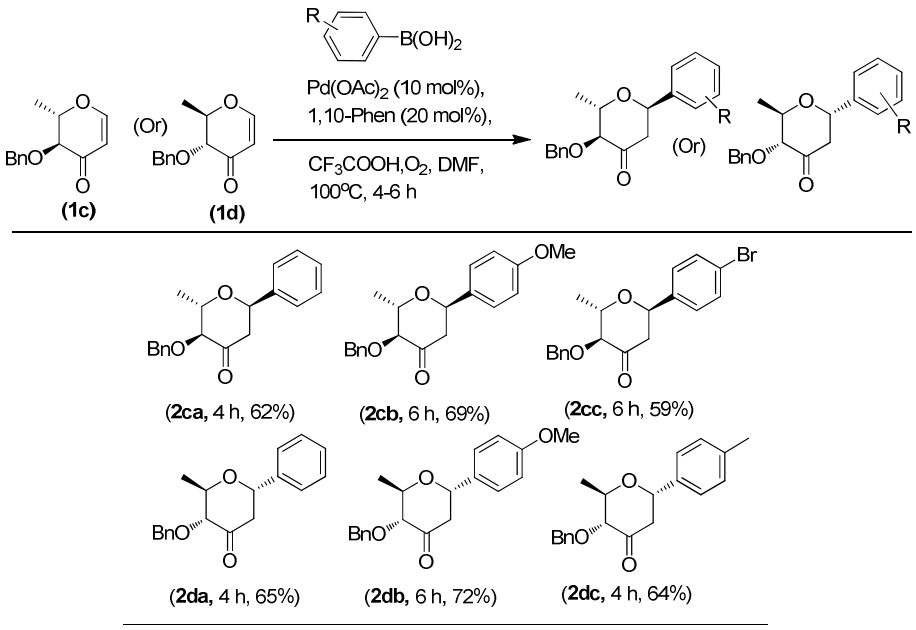
Table 4.3 Synthesis of 2-deoxy-*α*-aryl-*C*-glycoside with arylboronic acids and di-*O*-benzyl-D-glucal enone.



Reaction condition: Enone (0.25 mmol) and arylboronic acid (0.5 mmol, 2 equiv.), $Pd(OAc)_2$ (10 mol%) and 1,10-Phen (0.2 equiv.), CF_3COOH (2.0 equiv.) were stirred in DMF solvent (3 mL). [a] Time and Isolated yield.

Further, we have investigated the coupling reaction of 6-deoxy sugar based gycal-enones with different arylboronic acids (**Table 4.4**). In this context, electron donating as well as withdrawing groups functionalized arylboronic acids underwent coupling reaction with L-rhamnal enone and gave the conjugate addition products **2ca-2cc** in good yields. Similarly, D-rhamnal enone also participated in the coupling reaction to provide the desired products **2da-2dc** in excellent yields.

Table 4.4 Synthesis of 2-deoxy-*α*-aryl-*C*-glycoside from L-rhamnal-enone (**1c**) and D-rhamnal enone (**1d**).[a,b]



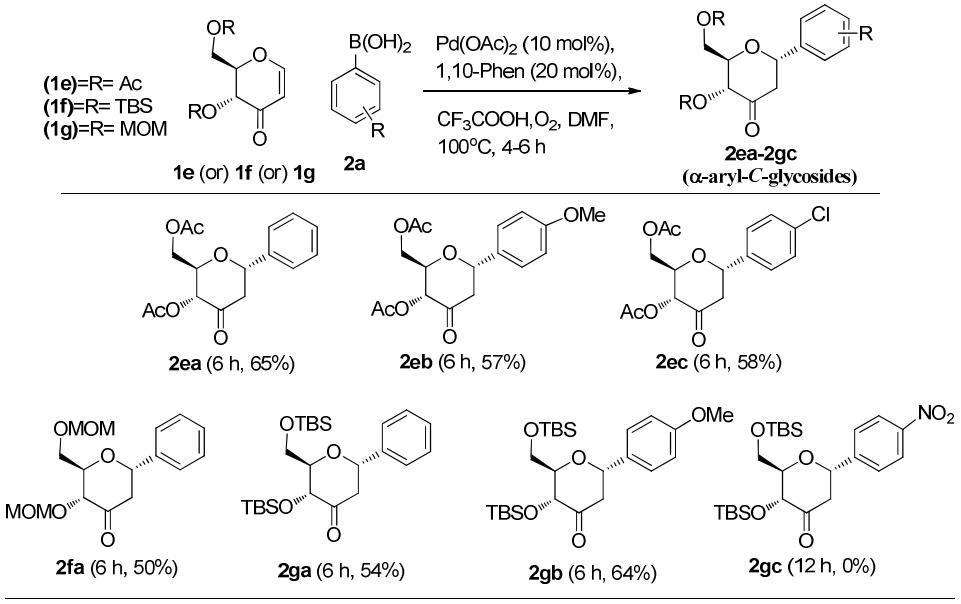
[a]**Reaction condition**: Enone (0.25 mmol) and arylboronic acid (0.5 mmol, 2 equiv.), $Pd(OAc)_2$ (10 mol%) and 1,10-Phen (0.2 equiv.), CF_3COOH (2.0 equiv.) were stirred in DMF solvent (3 mL). [b]Isolated yield.

4.3.1 Protecting group compatibility

Finally we have attempted the coupling reaction with glucal enones with different protecting groups to check their compatibility under the optimized conditions (**Table 4.5**). To our delight acetyl protected glucal-enone **1e** reacted with phenylboronic acids bearing different substitutions to provide the product **2ea-2ec** in 57-65% yields. Moreover, the reactions of other commonly used protecting groups such as MOM and TBS protected glycal-enones were also proceeded smoothly to furnish the corresponding 1,4-conjugate addition products **2fa-2gb** in good yields. However 4-

nitrophenylboronic acid with TBS protected glycal enone was failed to give the desired product.

Table 4.5 Synthesis of 2-deoxy-*α*-aryl-*C*-glycoside from different protected glucal-enone with arylboronic acids.[a,b]

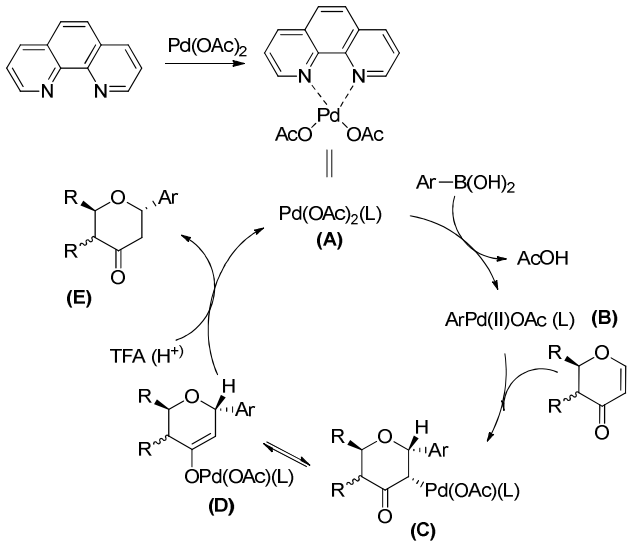


[a]**Reaction condition**: Enone (0.25 mmol) and arylboronic acid (0.5 mmol, 2 equiv.), $Pd(OAc)_2$ (10 mol%) and 1,10-Phen (0.2 equiv.), CF_3COOH (2.0 equiv.) were stirred in DMF solvent (3 mL). [b]Isolated yield.

4.4 Plausible Reaction Mechanism

A plausible mechanism for the palladium catalyzed 1,4-conjucate addition reaction is shown in the **scheme 10**.[8b, 8d] Palladium acetate coordinates with 1,10-phenanthroline to form an electron rich palladium (II) complex **A** which undergoes transmetalation with arylboronic acid to form the complex **B**. Subsequently, the intermediate **B** is added to the enone from α-face to form intermediate **C**. This intermediate undergoes for palladotropic shift to form enolate **D** which is hydrolyzed to

product (3-keto, 2-deoxy α-aryl-*C*-glycosides) and catalyst (Pd) in the presence of trifluoroacetic acid.



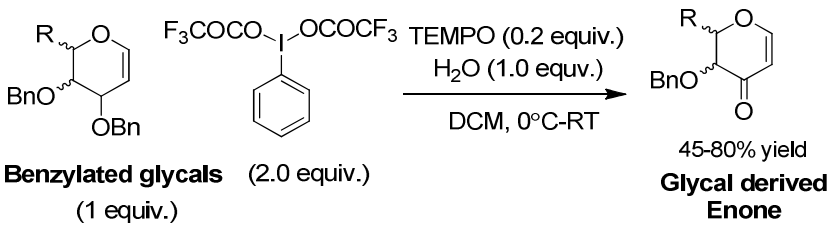
Scheme 4.6 Plausible mechanism of the reaction.

4.5 Summary and Conclusion

In conclusion, we have successfully developed an efficient method for 1,4-conjugate addition reaction of arylboronic acids with enone derived from glycals. The reaction was accomplished in the presence of palladium acetate, 1,10-phenanthroline ligand and trifluoroacetic acid. A wide range of benzyl protected enones derived from D-glucal, D-galactal, L-rhamnal and D-rhamnal were C-glycosylated smoothly. Compatibility of different protecting groups including acetyl, MOM and TBS were also investigated. Overall, the developed methodology provided 2-deoxy-α-aryl-*C*-glycosides in good yields.

4.6 Experimental Section

4.6.1. General procedure for oxidation of C-3 of glycals to glycal derived enones 1a-1d



The benzyl protected glycals (5.0 mmol) was dissolve in CH_2Cl_2 (40 ml) and stirred at 0°C. To this solution $PhI(OCOCF_3)_2$ (10.0 mmol), 2,2,6,6-Tetramethylpiperidine 1-oxyl (TEMPO) (1.0 mmol) and water (5.0 mmol) were added respectively under nitrogen atmosphere. The resulting reaction mixture was stirred for required time at the same temperature. After completion (monitored by TLC), the reaction mixture was quenched with saturated solution of $NaHCO_3$ and extracted with CH_2Cl_2 (twice). The combined organic layers were washed with brine and dried over anhydrous Na_2SO_4. The organic layer was evaporated and residue was purified by column chromatography (SiO_2, EtOAc/petroleum ether) to give 3-keto glycals as a product (45%-80%) yield.

4.6.2. (2R,3S)-3-(benzyloxy)-2-((benzyloxy)methyl)-2H-pyran-4(3H)-one (1a)

Compound **1a** was prepared from 3,4,6-tri-*O*-benzyl-D-galactal using the general above procedure and purified by column chromatography on silica gel EtOAc/petroleum ether (15:85) to afford as a colourless oil (1.31 g, 80% yield);R*f* = 0.4 (EtOAc/petroleum ether (20:80)); $[\alpha]_D^{23}$ = -30.5 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.27–7.18 (m, 11H), 5.34 (dd, *J* = 6.1, 1.6 Hz, 1H), 4.62 (d, *J* = 11.9 Hz, 1H), 4.47 (d, *J* = 11.9 Hz, 1H), 4.41–4.37 (m, 3H), 3.82 (dd, *J* = 10.2, 7.1 Hz, 1H), 3.66 (dd, *J* = 10.2, 5.3

Hz, 1H), 3.60 (dd, *J* = 2.4, 1.6 Hz, 1H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 189.3, 162.6, 137.3, 136.9, 128.3, 128.3, 128.1, 127.9, 127.8, 127.6, 105.0, 80.5, 74.0, 73.5, 71.9, 67.5. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{20}H_{21}O_4$: 325.1440; found: 325.1445.

4.6.3 (2R,3R)-3-(benzyloxy)-2-((benzyloxy)methyl)-2H-pyran-4(3H)-one (1b)

Compound **1b** was prepared from 3,4,6-tri-*O*-benzyl-D-glucal using the above general procedure and purified by column chromatography on silica gel EtOAc/petroleum ether (15:85) to afford as a colourless oil (1.13 g, 69% yield); Rf = 0.40 (EtOAc/petroleum ether (20:80)); $[\alpha]_D^{23}$ = +242 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.35–7.27 (m, 11H), 5.37 (d, *J* = 5.9 Hz, 1H), 5.06 (d, *J* = 11.1 Hz, 1H), 4.61–4.55 (m, 2H), 4.52 (d, *J* = 12.0 Hz, 1H),4.44–4.40 (m, 1H), 4.22 (d, *J* = 11.6 Hz, 1H), 3.79 (d, *J* = 3.3 Hz, 2H).**^{13}C NMR** (125 MHz, $CDCl_3$) δ 193.4, 162.2, 137.4, 137.3, 128.4, 128.3, 128.3, 128.3, 127.9, 127.8, 127.7, 105.1, 80.9, 74.5, 74.0, 73.5, 67.8. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{20}H_{21}O_4$: 325.1440; found: 325.1443.

4.6.4 Synthesis of (2S,3S)-3-(benzyloxy)-2-methyl-2H-pyran-4(3H)-one (1c)

Compound **1c** was prepared from 3,4-di-*O*-benzyl-L-rhamnal using the above general procedure and purified by column chromatography on silica gel, EtOAc/petroleum ether (10:90) to afford as a colourless oil (493 mg, 45% yield); R*f* = 0.4 (EtOAc/petroleum ether (10:90)); $[\alpha]_D^{23}$ = -305 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.39–7.28 (m, 5H), 7.25–7.24 (m, 1H), 5.37 (d, *J* = 5.9 Hz, 1H), 5.02 (d, *J* = 11.5 Hz, 1H), 4.65 (d, *J* = 11.5 Hz, 1H), 4.50–4.44 (m, 1H), 3.71 (d, *J* = 9.8 Hz, 1H), 1.42 (d, *J* = 6.5 Hz, 3H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 193.0, 162.1, 137.2, 128.4,

128.3, 128.3, 127.9, 104.9, 78.5, 78.5, 73.8, 17.0. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{13}H_{14}NaO_3$: 241.0841; found: 241.0850.

4.6.5. Synthesis of (2R,3R)-3-(benzyloxy)-2-methyl-2H-pyran-4(3H)-one (1d)

Compound **1d** was prepared from 3,4-di-*O*-benzyl-D-rhamnal using the above general procedure and purified by column chromatography on silica gel, EtOAc/petroleum ether (10:80) to afford as a colourless oil 526 mg (48% yield); R*f* = 0.40 (EtOAc/petroleum ether (10:80)); $[\alpha]_D^{24}$ = +276 (c = 0.1, $CHCl_3$);**^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.38–7.27 (m, 5H), 7.24 (d, *J* = 6.0 Hz, 1H), 5.36 (d, *J* = 5.9 Hz, 1H), 5.01 (d, *J* = 11.5 Hz, 1H), 4.64 (d, *J* = 11.5 Hz, 1H), 4.48–4.43 (m, 1H), 3.71 (d, *J* = 9.9 Hz, 1H), 1.41 (d, *J* = 6.5 Hz, 3H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 193.0, 162.2, 137.1, 128.3, 128.2, 127.9, 104.8, 78.4, 78.4, 73.7, 17.0.HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{13}H_{15}O_3$: 219.1021; found: 219.1019.

4.6.6. Synthesis of unprotected glycal enone, (2R,3R)-3-hydroxy-2-(hydroxymethyl)-2H-pyran-4(3H)-one (X)

The synthesis of enones **1e-1g** was prepared from (2R,3R)-3-hydroxy-2-(hydroxymethyl)-2H-pyran-4(3H)-one as described below *(see the **scheme** 4.5 in the text)*: To a solution of tri-O-acetyl-D-glucal (10.0 g, 36.7 mmol, 1.0 equiv) in MeOH (60 mL) was added K_2CO_3 (0.5 g, 3.6 mmol, 0.1 equiv) and stirred at room temperature. After the completion of reaction (TLC monitoring) filtered it through a pad of celite, the filtrate was concentrated in vacuo to give D-glucal (5.3 g) in quantitative yield and used in the next step without further purification. To a solution of D-Glucal (5.3 g, 36.27 mmol) in ethyl acetate (150 mL) were added acetic acid (2.5

mL) and PDC (Pyridinium Dichromate) (17.75 g, 47.15 mmol) at room temperature. The reaction mixture was stirred for 24 hours, and then filtered through a pad of Celite. The filtrate evaporated in vacuo and residue was purified by column chromatography (SiO_2, EtOAc/petroleum ether (80:20) to give (2R,3R)-3-hydroxy-2-(hydroxymethyl)-2H-pyran-4(3H)-one **(X)** as a white solid 2.51 g (48% yield). R*f* =0.7 (ethyl acetate); $[\alpha]_D^{23}$ = +284 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.43 (d, *J* = 5.7 Hz, 1H), 5.47 (d, *J* = 5.7 Hz, 1H), 4.40 (d, *J* = 13.3 Hz, 1H), 4.20 (d, *J* = 13.3 Hz, 1H), 4.09 (dd, *J* = 12.7, 1.8 Hz, 1H), 4.02 (dd, *J* = 12.6, 3.9 Hz, 1H), 2.91 (s, 1H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 194.4, 164.1, 103.5, 83.0, 67.7, 61.3. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_6H_9O_4$: 145.0501; found: 145.0507.

4.6.7. Synthesis of 4,6-di-O-acetyl-1,5-anhydro-2-deoxy-D-erythro-hex-1-en-3-ulose (1e)

To a stirred solution of **X** (432 mg, 3 mmol) in CH_2Cl_2 (10 mL) were added acetic anhydride (2.83 mL, 30 mmol) followed by pyridine (1 mL) at room temperature. The solution was stirred for the 12 hours, and upon completion of the reaction (TLC monitoring), it was quenched with saturated aqueous $NaHCO_3$ and extracted with ethyl acetate. The organic layer was washed with brine, dried over Na_2SO_4. The combined organic layer evaporated and residue was purified by column chromatography SiO_2, EtOAc/petroleum ether (15:85) to gave the pure **1e** as colorless viscous oil 520 mg (76% yield).; R*f* =0.3 (EtOAc/petroleum ether (20:80)); $[\alpha]_D^{23}$ = +246 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.37 (d, *J* = 5.9 Hz, 1H), 5.55 (d, *J* = 13.2 Hz, 1H), 5.50 (d, *J* = 5.9 Hz, 1H), 4.63–4.59 (m, 1H), 4.44 (dd, *J* = 12.7, 4.2 Hz, 1H), 4.38 (dd, *J* = 12.8, 2.2 Hz, 1H), 2.19 (s, 3H), 2.12 (s, 3H).**^{13}C NMR** (125 MHz, $CDCl_3$) δ 187.7,

170.3, 169.1, 162.3, 105.3, 78.2, 67.9, 61.3, 20.5, 20.3. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{10}H_{13}O_6$: 229.0712; found: 229.0715.

4.6.8. Synthesis of 4,6-di-O- methoxymethyl -1,5-anhydro-2-deoxy-D-erythro-hex-1-en-3-ulose (1f)

To a stirred solution of **X** (432 mg, 3 mmol) in anhydrous CH_2Cl_2 (10 mL) and cooled to 0°C after which diisopropylethyl amine (2.54 mL, 18 mmol) was added followed by the drop wise addition of chloromethyl methyl ether (0.91 mL, 12 mmol). The solution was stirred for the 12 hours, and after completion of the reaction (TLC monitoring), and diluted with CH_2Cl_2. The organic layer was washed with a 1M HCl solution and brine, dried over Na_2SO_4. The combined organic layer evaporated and residue was purified by column chromatography SiO_2, EtOAc/petroleum ether (15:85) to gave the pure **1f** as colorless oil 452 mg (65% yield). R*f* =0.6 (EtOAc/petroleum ether (20:80)).; $[\alpha]_D^{23}$ = +223 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.34 (d, *J* = 5.9 Hz, 1H), 5.40 (d, *J* = 5.9 Hz, 1H), 4.98 (d, *J* = 6.7 Hz, 1H), 4.81 (d, *J* = 6.7 Hz, 1H), 4.72–4.69 (m, 2H), 4.47–4.43 (m, 1H), 4.40 (d, *J* = 11.9 Hz, 1H), 3.97 (dd, *J* = 11.5, 2.3 Hz, 1H), 3.89 (dd, *J* = 11.5, 4.3 Hz, 1H), 3.46 (s, 3H), 3.40 (s, 3H).**^{13}C NMR** (125 MHz, $CDCl_3$) δ 192.5, 162.1, 105.1, 97.3, 96.7, 80.7, 71.5, 65.4, 56.3, 55.4. HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{10}H_{17}O_6$: 233.1025; found: 233.1035.

4.6.9. Synthesis of 4,6-di-O-tert-butyldimethylsilyl-l,5-anhydro-2-deoxy-D-erythro-hex-l-en-3-ulose (1g)

To a stirred solution of **X** (432 mg, 3 mmol) in DMF (10 mL) were added tert-butyl(chloro)dimethylsilane (1.13 g, 7.5 mmol) followed by imidazole (612.1 mg, 9 mmol) at room temperature. The resulting solution was stirred for the 10 hours, and

after completion of the reaction (TLC monitoring), it was quenched with water and extracted with ethyl acetate. The organic layer was washed with brine, dried over Na_2SO_4. The combined organic layer evaporated and residue was purified by column chromatography (SiO_2, EtOAc/petroleum ether (10:90)) to afford the pure **1g** as colourless oil 894mg (80% yield). R*f* =0.4 (EtOAc/petroleum ether (10:90)).; $[\alpha]_{D}^{24}$= +181.5 (c = 0.1, $CHCl_3$);**^{1}H NMR** (500 MHz, $CDCl_3$): δ 7.28 (d, J = 5.6 Hz, 1H),5.30 (d, J = 5.6 Hz, 1H),4.41 (d, J = 12.4 Hz, 1H),4.17 (td, J = 2.4, 12.4 Hz, 1H),3.9—4.0 (m, 2H),0.9—1.0 (m, 18H), 0.23 (s, 3H),δ 0.09 (s, 9H),**^{13}C NMR** (125 MHz, $CDCl_3$): δ 194.0,162.0,104.5,83.7,69.5,61.5,25.90,25.88,18.5,18.4,-4.0,-5.2,-5.3,-5.6,; HRMS (ESI): m/z $[M + H]^+$ calcd for $C_{18}H_{37}O_4Si_2$: 373.2230; found: 373.2233.

4.6.10. General procedure for 1,4-conjugate addition reactions

To a stirred solution of glycals derived enone **(1a-1g)** (0.25 mmol) in DMF (3 mL) at room temperature were added CF_3COOH (2 equiv.), $Pd(OAc)_2$ (10 mol%) and 1,10-phenanthroline (20 mol%) respectively. After stirring for 10 minutes the reaction mixture was heated at 90°C to which arylboronic acid (0.50 mmol (2 equiv.)) was added and stirred further for appropriate time. After completion of reaction (TLC monitoring), it was cool to room temperature, diluted with ethyl acetate (30 mL) and filtered through pad of celite. The filtrate was evaporated in vacuo and the residue was purified by column chromatography (SiO_2, EtOAc/petroleum ether as eluent) to gave the respective conjugate addition product.

4.7 Analytical Data of the Synthesized Aryl-*C*-Glycoside Products

4.7.1. (*2R,3S,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-phenyldihydro-2H-pyran-4(3H)-one (2aa)

The compound **2aa** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (10:90) as eluent to afford as white foam (66 mg, 66%); R*f* = 0.6 (EtOAc/petroleum ether (20:80)); $[a]_D^{22}$ = +110 (c = 0.1, $CHCl_3$);**^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.28–7.19 (m, 15H), 5.25 (dd, *J* = 9.8, 3.6 Hz, 1H), 4.86 (d, *J* = 12.1 Hz, 1H), 4.51 (d, *J* = 4.5 Hz, 1H), 4.48 (d, *J* = 4.8 Hz, 1H), 4.42 (d, *J* = 12.3 Hz, 1H), 4.38-4.34 (m, 1H), 4.09 (dd, *J* = 6.5, 1.1 Hz, 1H), 3.78–3.71 (m, 2H), 2.74 (dd, *J* = 14.5, 3.7 Hz, 1H), 2.59–2.54 (m, 1H).**^{13}C NMR** (125 MHz, $CDCl_3$) δ 204.1, 140.5, 137.9, 137.4, 128.5, 128.4, 128.3, 128.0, 127.9, 127.8, 127.6, 127.5, 125.9, 79.2, 76.4, 74.7, 73.5, 72.6, 68.4, 47.8.

4.7.2. (*2R,3S,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-(4-methoxyphenyl) dihydro-2H-pyran-4(3H)-one (2ab)

The compound **2ab** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (15:85) as eluent to afford as yellowish viscous oil (65 mg, 60%); R*f* = 0.5 (EtOAc/petroleum ether (20:80)); $[a]_D^{22}$ = +125 (c = 0.1, $CHCl_3$);**^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.30–7.18 (m, 12H), 6.80–6.79 (m, 2H), 5.20 (dd, *J* = 9.5, 3.7 Hz, 1H), 4.85 (d, *J* = 12.1 Hz, 1H), 4.49 (dd, *J* = 12.2, 1.9 Hz, 2H), 4.42 (d, *J* = 12.3 Hz, 1H), 4.34–4.30 (m, 1H), 4.07 (dd, *J* = 6.3, 1.1 Hz, 1H), 3.77–3.70 (m, 5H), 2.72 (dd, *J* = 14.4, 3.8 Hz, 1H), 2.61–2.56 (m, 1H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 204.4, 159.3, 137.9, 137.4, 132.5, 128.4, 128.3, 127.9, 127.8, 127.6, 127.6, 127.4, 113.9, 79.2, 76.2, 74.5, 73.5, 72.6, 68.4, 55.2,

47.7.

4.7.3. (*2R,3S,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-(p-tolyl)dihydro-2H-pyran-4(3H)-one (2ac)

The compound **2ac** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (08:92) as eluent to afford as yellowish oil (67 mg, 64%); R*f* = 0.7 (EtOAc/petroleum ether (20:80)); $[\alpha]_D^{22}$ = +92 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.28–7.20 (m, 10H), 7.14 (d, *J* = 8.1 Hz, 2H), 7.07 (d, *J* = 7.9 Hz, 2H), 5.22 (dd, *J* = 9.6, 3.7 Hz, 1H), 4.85 (d, *J* = 12.1 Hz, 1H), 4.49 (dd, *J* = 12.2, 2.9 Hz, 2H), 4.42 (d, *J* = 12.3 Hz, 1H), 4.39–4.32 (m, 1H), 4.07 (dd, *J* = 6.4, 0.9 Hz, 1H), 3.77–3.70 (m, 2H), 2.72 (dd, *J* = 14.4, 3.7 Hz, 1H), 2.60–2.59 (m), 2.25 (s, 3H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 204.3, 137.9, 137.8, 137.4, 137.4, 129.2, 128.4, 128.3, 127.9, 127.8, 127.6, 127.5, 126.0, 79.3, 76.3, 74.7, 73.5, 72.6, 68.4, 47.7, 21.0.

4.7.4. (*2R,3S,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-(naphthalen-2-yl)dihydro-2H-pyran-4(3H)-one (2ad)

The compound **2ad** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (15:85) as eluent to afford as yellowish viscous oil (76 mg, 67%); R*f* = 0.6 (EtOAc/petroleum ether (20:80)); $[\alpha]_D^{26}$ = -72.3 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.87–7.81 (m, 4H), 7.53–7.41 (m, 3H), 7.41–7.32 (m, 10H), 5.53 (dd, *J* = 9.6, 3.7 Hz, 1H), 4.99 (d, *J* = 12.1 Hz, 1H), 4.65–4.63 (m, 1H), 4.62 (d, *J* = 5.2 Hz, 1H), 4.57–4.54 (m, 1H), 4.52–4.49 (m, 1H), 4.23 (dd, *J* = 6.4, 1.1 Hz, 1H), 3.93–3.85 (m, 2H), 2.96–2.93 (m, 1H), 2.81–2.76 (m, 1H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 204.1, 137.9, 137.8, 137.4,

133.1, 133.0, 128.5, 128.4, 128.4, 128.3, 128.0, 128.0, 128.0, 127.8, 127.6, 127.6, 127.6, 126.2, 126.1, 124.9, 123.9, 79.3, 76.47, 74.9, 73.6, 72.7, 68.5, 47.7.

4.7.5. (*2R,3S,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-(naphthalen-1-yl)dihydro-2H-pyran-4(3H)-one (2ae)

The compound **2ae** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (10:90) as eluent to afford as yellowish viscous oil (70 mg, 62%); R*f* = 0.7 (EtOAc/petroleum ether (20:80)); $[\alpha]_D^{26}$ = -63.8 (c = 0.1, $CHCl_3$);**^{1}H NMR** (500 MHz, $CDCl_3$) δ 8.00 (d, *J* = 8.4 Hz, 1H), 7.84 (d, *J* = 7.9 Hz, 1H), 7.79 (d, *J* = 8.2 Hz, 1H), 7.59 (d, *J* = 7.1 Hz, 1H), 7.48–7.42 (m, 3H), 7.37–7.26 (m, 10H), 6.14 (dd, *J* = 9.2, 3.8 Hz, 1H), 4.95 (d, *J* = 12.1 Hz, 1H), 4.60–4.56 (m, 2H), 4.48 (d, *J* = 12.1 Hz, 1H), 4.44–4.42 (m, 1H), 4.20 (d, *J* = 6.1 Hz, 1H), 3.92–3.86 (m, 2H), 3.04 (dd, *J* = 14.5, 3.8 Hz, 1H), 2.81 (dd, *J* = 14.4, 9.3 Hz, 1H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 204.6, 137.8, 137.4, 135.7, 133.7, 130.5, 128.7, 128.4, 128.4, 128.3, 127.9, 127.8, 127.6, 127.5, 126.3, 125.6, 125.2, 123.3, 79.3, 76.1, 73.5, 72.6, 71.8, 68.5, 46.6.

4.7.6. (*2R,3S,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-(4-fluorophenyl)dihydro-2H-pyran-4(3H)-one (2af)

The compound **2af** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (15:85) as eluent to afford as yellowish viscous oil (59 mg, 56%); R*f* = 0.6 (EtOAc/petroleum ether (20:80)); $[\alpha]_D^{25}$ = -69.9 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.36–7.27 (m, 11H), 7.04–7.01 (m, 2H), 5.30 (dd, *J* = 9.8, 3.6 Hz, 1H), 4.94 (d, *J* = 12.1 Hz, 1H), 4.58–4.55 (m, 2H), 4.49 (d, *J* = 12.3 Hz, 1H), 4.43–4.40 (m, 1H), 4.15 (dd, *J* = 6.5,

1.1 Hz, 1H), 3.85–3.78 (m, 2H), 2.79 (dd, *J* = 14.5, 3.6 Hz, 1H), 2.62–2.57 (m, 1H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 203.9, 163.3, 161.4, 137.8, 137.4, 136.3, 128.5, 128.3, 128.0, 127.8, 127.7, 127.7, 127.6, 127.6, 115.5, 115.3, 79.1, 76.4, 74.2, 73.6, 72.7, 68.4, 47.9.

4.7.7. (*2R,3S,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-(4-chlorophenyl)dihydro-2H-pyran-4(3H)-one (2ag)

The compound **2ag** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (08:92) as eluent to afford as yellowish viscous oil (76 mg, 70%); R*f* = 0.6 (EtOAc/petroleum ether (20:80)); $[\alpha]_D^{22}$ = +95.5 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.29–7.18 (m, 14H), 5.23 (dd, *J* = 9.9, 3.6 Hz, 1H), 4.87 (d, *J* = 12.1 Hz, 1H), 4.50 (dd, *J* = 12.2, 7.7 Hz, 2H), 4.42 (d, *J* = 12.3 Hz, 1H), 4.36–4.33 (m, 1H), 4.08 (dd, *J* = 6.5, 1.1 Hz, 1H), 3.78–3.71 (m, 2H), 2.71 (dd, *J* = 14.5, 3.6 Hz, 1H), 2.52–2.47 (m, 1H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 203.7, 139.1, 137.8, 137.3, 133.7, 128.7, 128.5, 128.3, 128.0, 127.8, 127.6, 127.3, 79.1, 76.5, 74.1, 73.6, 72.7, 68.5, 47.8.

4.7.8. (*2R,3S,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-(4-bromophenyl)dihydro-2H-pyran-4(3H)-one (2ah)

The compound **2ah** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (15:85) as eluent to afford as yellowish viscous oil (78 mg, 65%); R*f* = 0.6 (EtOAc/petroleum ether (20:80)); $[\alpha]_D^{25}$ = -76.0 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.46–7.45 (m, 2H), 7.35–7.26 (m, 10H), 7.19 (d, *J* = 8.4 Hz, 2H), 5.28 (dd, *J* = 9.9, 3.4 Hz, 1H), 4.93 (d, *J* = 12.1 Hz, 1H), 4.58–4.54 (m, 2H), 4.48 (d, *J* = 12.3 Hz, 1H), 4.43–4.40

(m, 1H), 4.15–4.14 (m, 1H), 3.85–3.78 (m, 2H), 2.79–2.76 (m, 1H), 2.58–2.53 (m, 1H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 203.9, 139.6, 137.7, 137.3, 132.2, 131.6, 128.4, 128.3, 128.0, 127.8, 127.6, 127.6, 121.8, 117.2, 79.0, 76.5, 74.1, 73.6, 72.7, 68.5, 47.8.

4.7.9. (*2R,3S,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-(3-chlorophenyl)dihydro-2H-pyran-4(3H)-one (2ai)

The compound **2ai** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (15:85) as eluent to afford as yellowish viscous oil (60 mg, 55%); R*f* = 0.5 (EtOAc/petroleum ether (20:80)); $[\alpha]_D^{25}$ = +72.7 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.36–7.26 (m, 13H), 7.18–7.16 (m, 1H), 5.30 (dd, *J* = 10.0, 3.5 Hz, 1H), 4.95 (d, *J* = 12.1 Hz, 1H), 4.59–4.55 (m, 2H), 4.49 (d, *J* = 12.3 Hz, 1H), 4.45–4.42 (m, 1H), 4.15 (d, *J* = 6.6 Hz, 1H), 3.85–3.78 (m, 2H), 2.78 (dd, *J* = 14.5, 3.5 Hz, 1H), 2.59–2.54 (m, 1H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 203.5, 142.7, 137.8, 137.4, 134.5, 129.8, 128.5, 128.3, 128.1, 128.0, 127.8, 127.6, 126.1, 123.9, 79.0, 76.6, 74.1, 73.6, 72.7, 68.5, 47.9.

4.7.10. (*2R,3R,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-phenyldihydro-2H-pyran-4(3H)-one (2ba)

The compound **2ba** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (10:90) as eluent to afford as yellowish viscous oil (60 mg, 60%); R*f* = 0.6 (EtOAc/petroleum ether (20:80)); $[\alpha]_D^{22}$ = +140 (c = 0.1, $CHCl_3$);**^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.31 (d, *J* = 7.4 Hz, 2H), 7.28–7.17 (m, 12H), 5.40 (dd, *J* = 6.6, 2.9 Hz, 1H), 4.76 (d, *J* = 11.1 Hz, 1H), 4.52 (d, *J* = 12.1 Hz, 1H), 4.40 (d, *J* = 12.0 Hz, 1H), 4.35 (d, *J* = 11.0 Hz, 1H), 4.17 (d, *J* = 8.7 Hz, 1H), 3.73–3.53 (m, 3H), 3.04 (dd, *J* = 14.7, 3.0 Hz, 1H), 2.97-2.93

(m, 1H).**^{13}C NMR** (125 MHz, $CDCl_3$) δ 206.3, 138.5, 137.8, 137.3, 128.6, 128.3, 128.3, 128.1, 128.1, 127.8, 127.7, 127.6, 127.3, 79.5, 75.1, 74.6, 73.4, 73.3, 69.0, 43.9.

4.7.11. (*2R,3R,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-(4-methoxyphenyl) dihydro-2H-pyran-4(3H)-one (2bb)

The compound **2bb** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (20:80) as eluent to afford as yellowish viscous oil (60 mg, 56%); R*f* = 0.4 (EtOAc/petroleum ether (20:80)); $[a]_D^{22}$ = +125.1 (c = 0.1, $CHCl_3$);**^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.27–7.18 (m, 12H), 6.79–6.77 (m, 2H), 5.37 (dd, *J* = 6.7, 2.8 Hz, 1H), 4.78 (d, *J* = 11.1 Hz, 1H), 4.52 (d, *J* = 12.1 Hz, 1H), 4.40 (d, *J* = 12.1 Hz, 1H), 4.35 (d, *J* = 11.1 Hz, 1H), 4.16 (d, *J* = 8.3 Hz, 1H), 3.70 (s, 3H), 3.63– 3.58 (m, 3H), 3.01 (dd, *J* = 14.6, 2.9 Hz, 1H), 2.98–2.94 (m, 1H).**^{13}C NMR** (125 MHz, $CDCl_3$) δ 206.6, 159.3, 137.8, 137.3, 130.5, 128.8, 128.3, 128.3, 128.1, 127.8, 127.7, 127.6, 113.9, 79.6, 74.8, 74.1, 73.4, 73.4, 69.0, 55.2, 44.0.

4.7.12. (*2R,3R,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-(p-tolyl)dihydro-2H-pyran-4(3H)-one (2bc)

The compound **2bc** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (15:85) as eluent to afford as white foam (60 mg, 58%); R*f* = 0.6 (EtOAc/petroleum ether (20:80)); $[a]_D^{22}$ = +70.1 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.27–7.18 (m, 12H), 7.06 (d, *J* = 8.0 Hz, 2H), 5.38 (dd, *J* = 6.7, 2.7 Hz, 1H), 4.77 (d, *J* = 11.1 Hz, 1H), 4.51 (d, *J* = 12.1 Hz, 1H), 4.40 (d, *J* = 12.1 Hz, 1H), 4.35 (d, *J* = 11.1 Hz, 1H), 4.16 (d, *J* = 8.4 Hz, 1H), 3.69–3.55 (m, 3H), 3.02 (dd, *J* = 14.6, 2.9 Hz, 1H), 2.97-2.92 (m, 1H),

2.24 (s, 3H).**^{13}C NMR** (125 MHz, $CDCl_3$) δ 206.6, 137.9, 137.8, 137.4, 135.5, 129.3, 128.3, 128.3, 128.1, 127.8, 127.8, 127.7, 127.4, 79.6, 75.0, 74.3, 73.5, 73.4, 69.1, 44.0, 21.0.

4.7.13. (*2R,3R,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-(4-fluorophenyl) dihydro-2H-pyran-4(3H)-one (2bd)

The compound **2bd** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (15:85) as eluent to afford as white foam (59 mg, 56%); R*f* = 0.5 (EtOAc/petroleum ether (20:80)); $[a]_D^{22}$ = +143 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.29–7.17 (m, 12H), 6.99–6.92 (m, 2H), 5.37 (dd, *J* = 6.2, 3.4 Hz, 1H), 4.76 (d, *J* = 11.1 Hz, 1H), 4.50 (d, *J* = 12.1 Hz, 1H), 4.40 (d, *J* = 12.1 Hz, 1H), 4.35 (d, *J* = 11.1 Hz, 1H), 4.15 (d, *J* = 8.9 Hz, 1H), 3.6 –3.58 (m, 3H), 3.02–2.92 (m, 2H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 206.1, 163.4, 161.4, 137.7, 137.2, 134.4, 129.2, 129.1, 128.3, 128.3, 128.1, 127.9, 127.8, 127.7, 115.6, 115.4, 79.5, 74.7, 74.6, 73.5, 73.3, 69.0, 44.0.

4.7.14. (*2R,3R,6S*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-(4-chlorophenyl) dihydro-2H-pyran-4(3H)-one (2be)

The compound **2be** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (10:90) as eluent to afford as yellowish viscous oil (70 mg, 64); R*f* = 0.6 (EtOAc/petroleum ether (20:80)); $[?]_D^{26}$ = +112 (c = 0.1, $CHCl_3$);**^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.34–7.25 (m, 14H), 5.43 (dd, *J* = 6.3, 3.6 Hz, 1H), 4.82 (d, *J* = 11.2 Hz, 1H), 4.57 (d, *J* = 12.1 Hz, 1H), 4.47 (d, *J* = 12.1 Hz, 1H), 4.41 (d, *J* = 11.2 Hz, 1H), 4.21 (d, *J* = 8.1 Hz, 1H), 3.72–3.63 (m, 3H), 3.08–2.99 (m, 2H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 206.0, 137.7,

137.2, 137.1, 134.1, 128.8, 128.7, 128.4, 128.3, 128.1, 127.9, 127.8, 127.7, 79.4, 74.9, 74.6, 73.5, 73.3, 69.1, 43.9.

4.7.15. (*2S,3S,6R*)-3-(benzyloxy)-2-methyl-6-phenyldihydro-2H-pyran-4(3H)-one (2ca)

The compound **2ca** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (10:90) as eluent to afford as white foam (46 mg, 62%); R*f* = 0.3 (EtOAc/petroleum ether (20:80)); $[\square]_D^{25}$ = -71.4 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.32–7.18 (m, 10H), 5.23–5.21 (m, 1H), 4.78 (d, *J* = 11.5 Hz, 1H), 4.42 (d, *J* = 11.5 Hz, 1H), 3.78–3.72 (m, 1H), 3.60 (d, *J* = 7.8 Hz, 1H), 3.08 (dd, *J* = 14.2, 3.5 Hz, 1H), 2.86 (dd, *J* = 14.2, 6.5 Hz, 1H), 1.22 (d, *J* = 6.3 Hz, 4H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 206.4, 139.0, 137.2, 128.6, 128.3, 128.1, 128.0, 127.9, 127.1, 84.7, 74.6, 73.0, 71.9, 44.4, 18.0.

4.7.16. (*2S,3S,6R*)-3-(benzyloxy)-6-(4-methoxyphenyl)-2-methyldihydro-2H-pyran-4(3H)-one (2cb)

The compound **2cb** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (15:85) as eluent to afford as white foam (56 mg, 69%); R*f* = 0.3 (EtOAc/petroleum ether (20:80)); $[\square]_D^{25}$ = -84.6 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.36–7.29 (m, 7H), 6.87 (d, *J* = 8.7 Hz, 2H), 5.28 (dd, *J* = 6.7, 3.1 Hz, 1H), 4.88 (d, *J* = 11.5 Hz, 1H), 4.50 (d, *J* = 11.5 Hz, 1H), 3.83–3.74 (m, 4H), 3.67 (d, *J* = 8.1 Hz, 1H), 3.12 (dd, *J* = 14.2, 3.2 Hz, 1H), 2.96– 2.92 (m, 1H), 1.28 (d, *J* = 6.2 Hz, 3H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 206.6, 159.2, 137.2, 131.0, 128.6, 128.3, 128.2, 127.9, 113.9, 84.8, 74.3, 73.0, 71.4, 55.2, 44.5, 18.2.

4.7.17. (*2S,3S,6R*)-3-(benzyloxy)-6-(4-bromophenyl)-2-methyldihydro-2H-pyran-4(3H)-one (2cc)

The compound **2cc** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (10:90) as eluent to afford as white foam (55 mg, 50%); R*f* = 0.3 (EtOAc/petroleum ether (20:80)); $[a]_D^{25}$ = -96.4 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, CDCl3) δ 7.47 (d, J = 8.5 Hz, 2H), 7.36–7.24 (m, 7H), 5.23 (dd, *J* = 6.2, 4.0 Hz, 1H), 4.84 (d, *J* = 11.5 Hz, 1H), 4.48 (d, *J* = 11.5 Hz, 1H), 3.84–3.76 (m, 1H), 3.66 (d, *J* = 7.6 Hz, 1H), 3.09 (dd, *J* = 14.2, 3.9 Hz, 1H), 2.92 (dd, *J* = 14.1, 6.4 Hz, 1H), 1.28 (d, *J* = 6.4 Hz, 3H); **^{13}C NMR** (125 MHz, CDCl3) δ 206.2, 138.2, 137.3, 131.9, 129.0, 128.5, 128.3, 128.1, 122.3, 84.6, 74.2, 73.1, 72.4, 44.5, 18.1

4.7.18. (*2R,3R,6S*)-3-(benzyloxy)-2-methyl-6-phenyldihydro-2H-pyran-4(3H)-onev (2da)

The compound **2da** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (10:90) as eluent to afford as white foam (48 mg, 65%); R*f* = 0.5 (EtOAc/petroleum ether (10:90)); $[a]_D^{25}$ = +150 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.39–7.24 (m, 10H), 5.29 (dd, *J* = 6.3, 3.7 Hz, 1H), 4.85 (d, *J* = 11.5 Hz, 1H), 4.49 (d, *J* = 11.5 Hz, 1H), 3.84–3.80 (m, 1H), 3.67 (d, *J* = 7.8 Hz, 1H), 3.15 (dd, *J* = 14.2, 3.7 Hz, 1H), 2.94–2.90 (m, 1H), 1.29 (d, *J* = 6.3 Hz, 3H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 206.3, 139.0, 137.2, 128.6, 128.3, 128.1, 128.0, 127.9, 127.0, 84.6, 74.5, 72.9, 71.8, 44.4, 18.0.

4.7.19. (2R,3R,6S)-3-(benzyloxy)-6-(4-methoxyphenyl)-2-methyldihydro-2H-pyran-4(3H)-one (2db)

The compound **2db** was prepared using the general procedure **4.6.10.** and column

chromatography was performed on silica gel using EtOAc/petroleum ether (15:85) as eluent to afford as white foam (59 mg, 72%); R*f* = 0.25 (EtOAc/petroleum ether (20:80)); $[\square]_D^{25}$ = +151 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.36–7.29 (m, 7H), 6.88–6.86 (m, 2H), 5.28 (dd, *J* = 6.7, 3.1 Hz, 1H), 4.88 (d, *J* = 11.5 Hz, 1H), 4.50 (d, *J* = 11.5 Hz, 1H), 3.83–3.74 (m, 4H), 3.67 (d, *J* = 8.1 Hz, 1H), 3.12 (dd, *J* = 14.2, 3.1 Hz, 1H), 2.95 (dd, *J* = 14.0, 6.5 Hz, 1H), 1.29 (d, *J* = 6.2 Hz, 3H).**^{13}C NMR** (125 MHz, $CDCl_3$) δ 206.6, 159.2, 137.2, 131.0, 128.6, 128.3, 128.2, 127.9, 113.9, 84.8, 74.3, 73.0, 71.4, 55.2, 44.5, 18.2.

4.7.20. (*2R,3R,6S*)-3-(benzyloxy)-2-methyl-6-(p-tolyl)dihydro-2H-pyran-4(3H)-one (2dc)

The compound **2dc** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (10:90) as eluent to afford as white foam (50 mg, 64%); R*f* = 0.5 (EtOAc/petroleum ether (20:80)); $[a]_D^{25}$ = +122 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.27–7.14 (m, 7H), 7.06 (d, *J* = 7.6 Hz, 2H), 5.20 (s, 1H), 4.79 (d, *J* = 11.5 Hz, 1H), 4.42 (d, *J* = 11.5 Hz, 1H), 3.75–3.70 (m, 1H), 3.59 (d, *J* = 7.9 Hz, 1H), 3.06 (d, *J* = 14.2 Hz, 1H), 2.85 (dd, *J* = 14.2, 6.6 Hz, 1H), 2.25 (s, 3H), 1.21 (t, *J* = 7.4 Hz, 3H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 206.5, 137.8, 137.3, 136.0, 129.3, 128.3, 128.1, 127.9, 127.1, 84.7, 74.5, 73.0, 71.6, 44.4, 21.0, 18.1.

4.7.21. ((*2R,3R,6S*)-3-acetoxy-4-oxo-6-phenyltetrahydro-2H-pyran-2-yl)methyl acetate (2ea)

The compound **2ea** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (20:80) as

eluent to afford as colourless viscous oil (50 mg, 65%); R*f* = 0.5 (EtOAc/petroleum ether (25:75)); $[a]_D^{25}$ = +84.2 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.36–7.33 (m, 5H), 5.52 (t, *J* = 10.0 Hz, 1H)5.30–5.25 (m, 1H), 4.30–4.29 (m, 2H), 3.79–3.71 (m, 1H), 3.15–3.14 (m, 2H), 2.09 (s, 6H);**^{13}C NMR** (125 MHz, $CDCl_3$) δ 200.1, 170.5, 169.2, 137.5, 128.9, 128.5, 127.5, 75.1, 73.5, 71.4, 62.8, 42.8, 20.7, 20.3.

4.7.22. ((*2R,3R,6S*)-3-acetoxy-6-(4-methoxyphenyl)-4-oxotetrahydro-2H-pyran-2-yl)methyl acetate (2eb)

The compound **2eb** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (30:70) as eluent to afford as colourless viscous oil (48 mg, 57%); R*f* = 0.3 (EtOAc/petroleum ether (25:75)); $[a]_D^{25}$ = +123 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.30–7.26 (m, 2H), 6.91–6.86 (m, 2H) 5.51 (t, *J* = 11.0 Hz, 1H) 5.30–5.25 (m, 1H), 4.32–4.24 (m, 1H), 4.16–4.09 (m, 1H), 3.80–3.72 (m, 4H), 3.17–3.14 (m, 2H), 2.12–2.11 (m, 6H);**^{13}C NMR** (125 MHz, $CDCl_3$) δ 200.4, 170.5, 169.3, 159.7, 129.5, 129.0, 74.9, 73.6, 71.0, 62.8, 55.2, 43.0, 20.7, 20.3.

4.7.23. ((*2R,3R,6S*)-3-acetoxy-6-(4-chlorophenyl)-4-oxotetrahydro-2H-pyran-2-yl)methyl acetate (2ec)

The compound **2ec** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (15:85) as eluent to afford as colourless viscous oil (49 mg, 58%); R*f* = 0.5 (EtOAc/petroleum ether (25:75)); $[\alpha]_D^{25}$ = +89.4 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.39–7.32 (m, 4H), 5.53–5.52 (m, 1H) 5.31–5.29 (m, 1H), 4.29–4.28 (m, 1H), 4.19–4.16 (m, 1H), 3.81–3.89 (m, 1H), 3.20–3.18 (m, 2H), 2.15–2.14 (m, 6H); **^{13}C NMR** (125 MHz,

$CDCl_3$) δ 200.0, 170.5, 169.3, 136.0, 134.7, 129.2, 129.0, 74.6, 73.5, 71.6, 62.8, 42.8, 20.7, 20.4.

4.7.24. (*2R,3R,6S*)-3-(methoxymethoxy)-2-((methoxymethoxy)methyl)-6-(p-tolyl)dihydro-2H-pyran-4(3H)-one (2fa)

The compound **2fa** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (30:70) as eluent to afford as colourless viscous oil (41 mg, 50%); R*f* = 0.5 (EtOAc/petroleum ether (20:80)); $[a]_D^{25}$ = +145 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.20–7.18 (m, 2H), 7.08 (d, *J* = 8.0 Hz, 2H), 5.38 (d, *J* = 6.0 Hz, 1H), 4.71 (d, *J* = 6.5 Hz, 2H), 4.64–4.61 (m, 3H), 4.29 (d, *J* = 8.0 Hz, 1H), 3.70–3.65 (m, 2H), 3.61 (d, *J* = 9.0 Hz, 1H), 3.35 (s, 3H), 3.31 (s, 3H), 3.04 (d, *J* = 9.5 Hz, 21H), 2.98–2.94 (m, 2H), 2.25 (s, 3H).**^{13}C NMR** (125 MHz, $CDCl_3$) δ 205.8, 138.0, 135.3, 129.3, 127.3, 96.9, 96.7, 76.7, 75.0, 74.2, 66.7, 56.3, 55.5, 43.9, 21.0.

4.7.25. (*2R,3R,6S*)-3-((tert-butyldimethylsilyl)oxy)-2-(((tert-butyldimethylsilyl) oxy)methyl)-6-phenyldihydro-2H-pyran-4(3H)-one (2ga)

The compound **2ga** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (5:95) as eluent to afford as colorless oil (61 mg, 54%); R*f* = 0.5 (EtOAc/petroleum ether (10:90)); $[a]_D^{25}$ = +76.6 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.39–7.33 (m, 4H), 7.29–7.27 (m, 1H), 5.43 (dd, *J* = 7.0, 3.5 Hz, 1H), 4.32 (dd, *J* = 9.0, 1.0 Hz, 1H), 3.87–3.81 (m, 2H), 3.52–3.49 (m, 1H), 3.08 (dd, 1H, *J* = 15.0, 3.5 Hz), 2.95–2.90 (m, 1H), 0.91 (s, 9H), 0.88 (s, 9H), 0.14 (s, 3H), 0.081 (s, 3H), 0.07 (s, 3H), 0.03 (s, 3H); **^{13}C NMR** (125 MHz, $CDCl_3$) δ 206.4, 139.1, 128.6, 127.9, 127.2, 77.6, 74.8, 74.8,

63.2, 43.5, 25.9, 25.7, 18.3, -4.3, -5.1, -5.3, -5.5.

4.7.26. (*2R,3R,6S*)-3-((tert-butyldimethylsilyl)oxy)-2-(((tertbutyldimethylsilyl)oxy) methyl) -6-(4-methoxyphenyl)dihydro-2H-pyran-4(3H)-one (2gb)

The compound **2gb** was prepared using the general procedure **4.6.10.** and column chromatography was performed on silica gel using EtOAc/petroleum ether (15:85) as eluent to afford as colourless oil (77 mg, 64%); R*f* = 0.3 (EtOAc/petroleum ether (10:90)); $[a]_D^{25}$ = +69.4 (c = 0.1, $CHCl_3$); **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.28–7.25 (m, 2H), 6.86–6.83 (m, 2H), 5.38 (dd, *J* = 7.0 ,3.0 Hz, 1H), 4.29 (dd, *J* = 9.0, 1.0 Hz, 1H), 3.85–3.78 (m, 2H), 3.78 (s, 3H), 3.48-3.45 (m, 1H), 3.04 (dd, J = 15.0, 3.0 Hz, 1H), 2.92–2.91 (m, 1H), 0.90 (s, 9H), 0.87 (s, 9H), 0.13 (s, 3H), 0.072 (s, 3H), 0.065 (s, 3H), 0.023 (s, 3H); **^{13}C NMR** (125 MHz, $CDCl_3$) δ 206.6, 159.1, 131.1, 128.6, 113.9, 77.3, 74.9, 74.4, 63.1, 55.2, 43.6, 25.9, 25.7, 18.4, -4.2, -5.0, -5.3, -5.5.

4.8 Spectral Data for Few Products

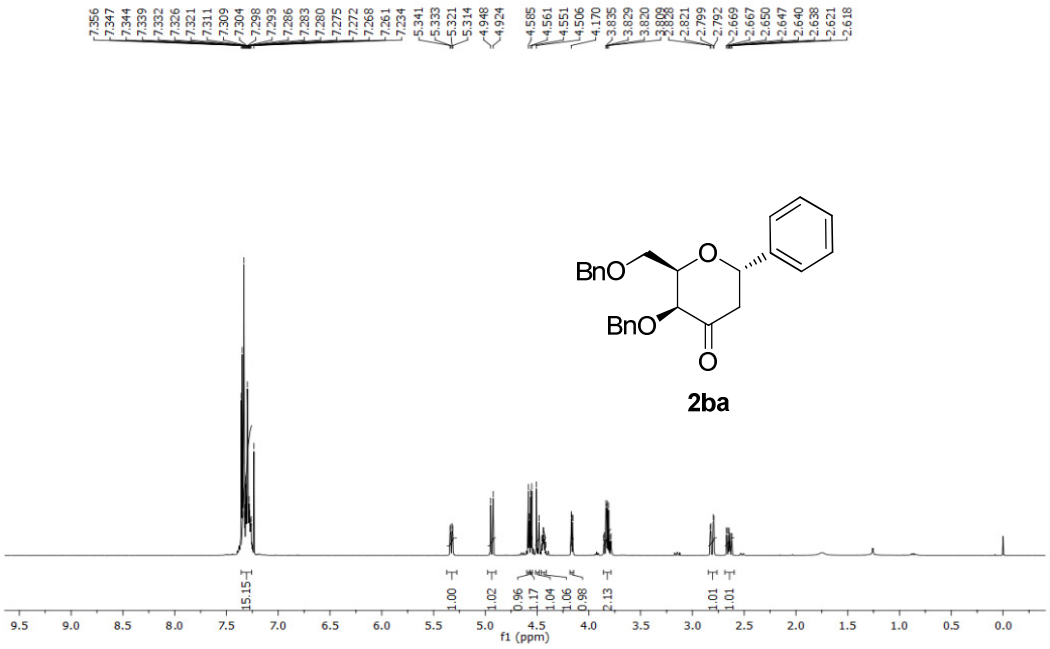


Figure 4.1 ^{1}**H-NMR** spectrum of compound **2aa** in $CDCl_3$

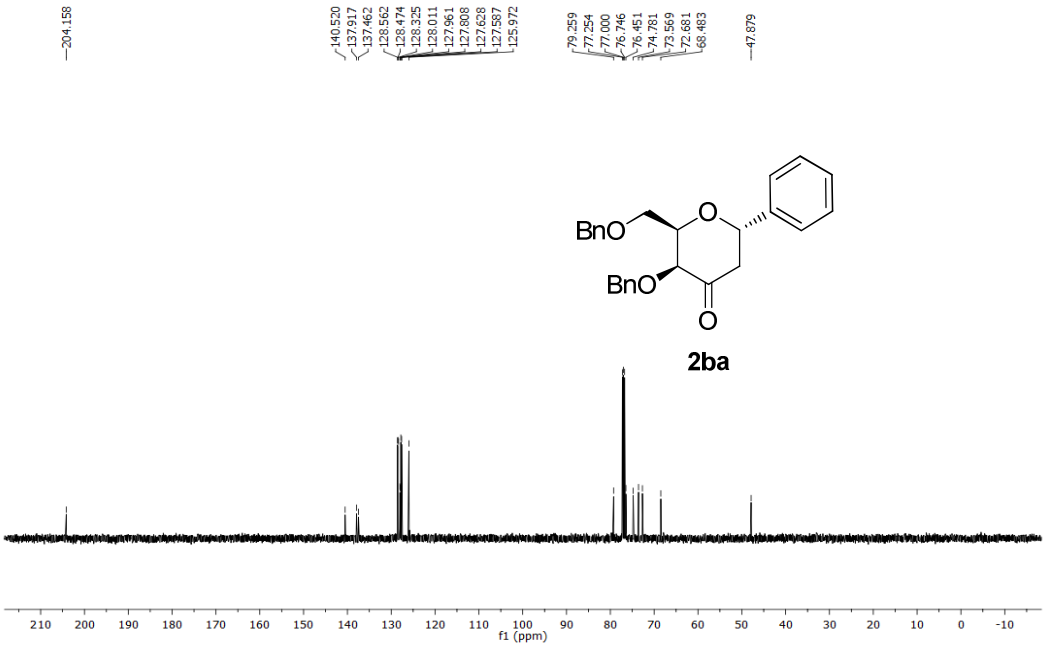


Figure 4.2 ^{13}**C-NMR** spectrum of compound **2aa** in $CDCl_3$

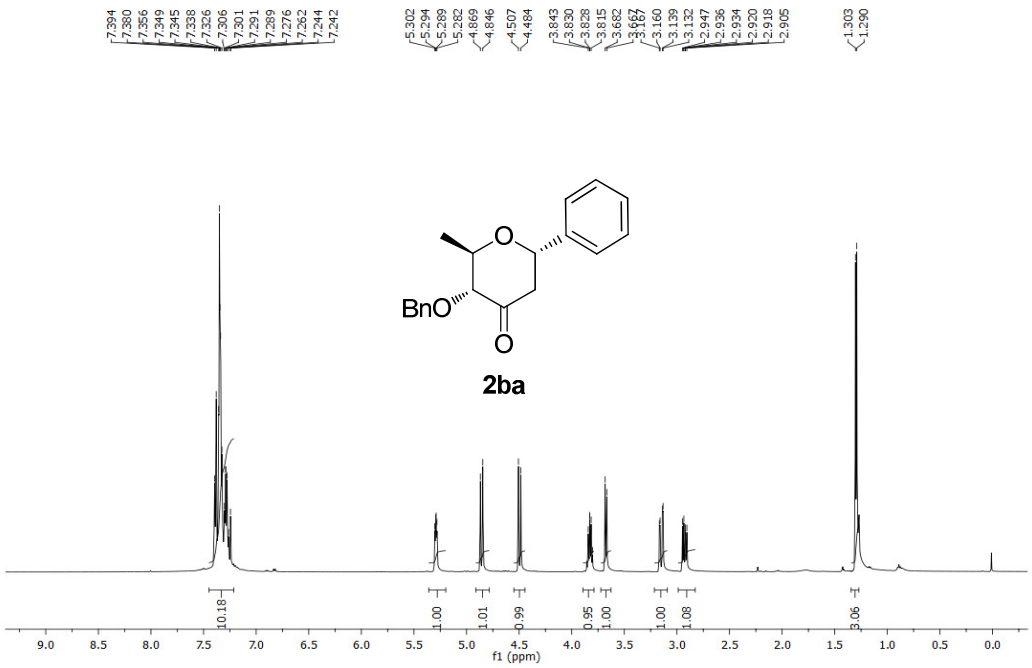


Figure 4.3 ^{1}H-NMR spectrum of compound **2da** in **$CDCl_3$**

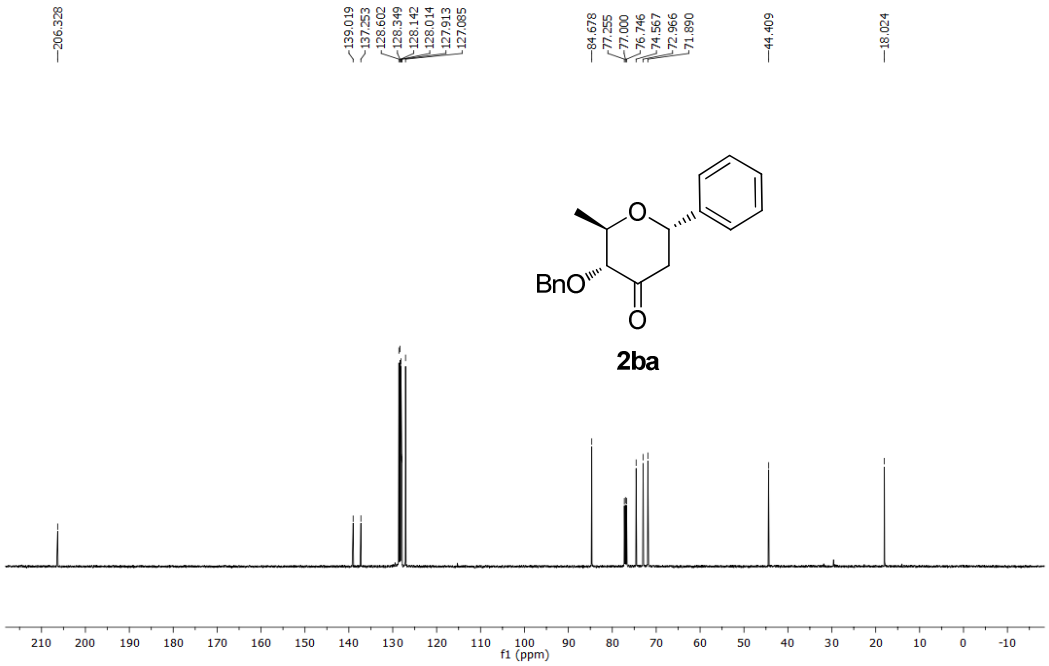


Figure 4.4 ^{13}C-NMR spectrum of compound **2da** in **$CDCl_3$**

4.9 References

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