Pergamon

SCIENCE DIRECT®

Tetrahedron 59 (2003) 2309–2316

TETRAHEDRON

Asymmetric synthesis of azetidin-2-ones by [2+2] cycloaddition using chiral imines derived from D-(+)-glucose

M. Arun,[a] S. N. Joshi,[a] V. G. Puranik,[b] B. M. Bhawal[c] and A. R. A. S. Deshmukh[a,*]

[a]*Division of Organic Chemistry (Synthesis), National Chemical Laboratory, Pune 411 008, India*
[b]*Division of Physical Chemistry, National Chemical Laboratory, Pune 411 008, India*
[c]*Emcure Pharmaceuticals Ltd., Emcure House, T-184, M.I.D.C. Bhosari, Pune 411 026, India*

Received 31 October 2002; revised 13 January 2003; accepted 6 February 2003

Abstract—Asymmetric synthesis of β-lactams by the [2+2] cycloaddition of ketenes with chiral imines derived from D-(+)-glucose was carried out; predominantly *cis*-β-lactams were formed with very high diastereoselectivity. The stereochemistry at C-3 and C-4 was established as 3*S* and 4*R* from the known absolute configuration of the sugar moiety.

1. Introduction

The β-lactam skeleton is the key structural unit of the most widely employed class of antibacterial agents, the β-lactam antibiotics.[1] The constant need for new drugs displaying broader antibacterial activity and the necessity for new β-lactam antibiotics to combat the microorganisms that have built up resistance against the most traditional drugs,[2] have maintained the interest of organic chemists in β-lactams for decades. As a consequence, a plethora of methods for the production of β-lactams are now available, and the topic has been reviewed on more than one occasion.[3] A convenient procedure for the synthesis of the β-lactam ring skeleton is the [2+2] cyclocondensation of ketenes to the imines, known as the Staudinger reaction.[4] In particular this method has provided useful and economic entries to β-lactams, mainly due to the ready availability of both Schiff's bases and ketenes. In this context, in spite of the high level of achievement reached in the Staudinger reaction, the subject still continues to be an active area of research.[5] Over the past few years this reaction has been extensively developed using a combination of either chiral ketenes and achiral imines or achiral ketenes and chiral imines, generally providing good diastereoselectivity.[6]

In the diastereoselective synthesis of β-lactams chiral starting materials such as aldehydes, acids/acid halides and amines have been widely used. High levels of stereoselections were achieved when the β-carbon of the chiral aldehyde is attached to a heteroatom.[7] In recent years several researchers have studied different approaches to optically pure β-lactams of predictable absolute stereochemistry.[8] Independent work from Hoffmann–La Roche laboratories and Bose et al.[9] has extensively utilized the Staudinger reaction for asymmetric β-lactam synthesis. It has been shown that the reaction of an acid chloride (or equivalent) with a Schiff base in the presence of triethylamine leads to a single, optically pure, *cis* stereoisomer of a β-lactam if the Schiff's base is derived from an optically active aldehyde and an achiral amine.

A substituted β-lactam constitutes a densely functionalized molecule that can undergo various types of reactions including molecular rearrangements.[10] Additionally the strained four membered heterocyclic ring can be cleaved to several types of compounds such as β-hydroxyacids, β-aminoacids, etc.[11]

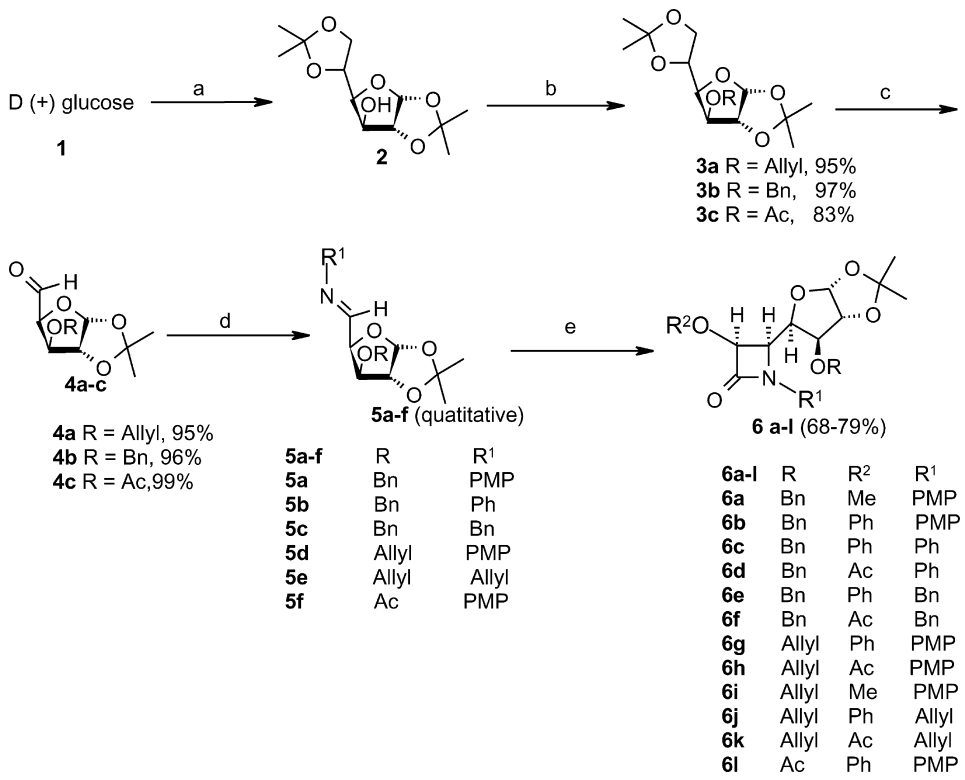
2. Results and discussion

We have been studying the Staudinger reaction for the diastereoselective construction of the β-lactam ring for several years.[12] In this publication we wish to report our work on the application of D-(+)-glucose derived optically pure 3-*O*-alkyl-1,2-isopropylidene α-D-xylopentodialdo **1**–**4** furanose (**4a**–**c**) (Scheme 1) for the synthesis of variously substituted chiral *cis* β-lactams via the Staudinger reaction.

Treatment of D-(+)-glucose with zinc chloride in the presence of anhydrous acetone using the known procedure[13a,b] provided diacetonide **2**, which was then alkylated with allyl bromide/benzyl bromide using NaH.[13c] Acylation of the glucose diacetonide using Ac_2O and DMAP provided the acetate **3c**.[13d] Heating the diacetonides **3a**–**c** in 70% aqueous acetic acid for 3 h selectively deprotected the acetonide at C-5, C-6, providing the diol in quantative yield. Oxidative cleavage of the diol

Keywords: asymmetric synthesis; ketenes; imines; Staudinger reaction.
* Corresponding author. Fax: +91-20-5893153/5893355;
e-mail: arasd@dalton.ncl.res.in

0040–4020/03/$ - see front matter
doi:10.1016/S0040-4020(03)00239-4



Scheme 1. *Reagents and conditions*: (a) $ZnCl_2$, H_3PO_4, acetone, rt, 30 h, (b) (i) allyl bromide, 50% aq. NaOH, CH_2Cl_2, TBAB, rt, 24 h; (ii) NaH, DMF, benzyl chloride, rt, 2.5 h; (iii) Ac_2O, Et_3N, DMAP, CH_2Cl_2, rt, 3 h, (c) (i) 70% HOAc, 70°C, 3 h; (ii) silica gel supported $NaIO_4$, (d) $ArNH_2$, CH_2Cl_2, $MgSO_4$; 6–8 h, (e) R^2OCH_2COCl, Et_3N, CH_2Cl_2, 0°C to rt, 15 h.

using $NaIO_4$ yielded the aldehydes **4a–c**.[13e] The optically active imines **5a–f** can be obtained by treatment of aldehydes **4a–c** with various amines in quantitative yields. These imines were unstable and used as such without purification for the next step. The cycloaddition reaction of the imines **5a–f** with acid chlorides (phenoxyacetyl chloride, acetoxy acetyl chloride and methoxy acetyl chloride) in the presence of excess triethylamine (0 °C to rt, 15 h) provided *cis*-β-lactams (**6a–l**) in very good yields (Table 1, Scheme 1). In all cases, a single diastereomer was obtained as no trace of the other diastereomer could be detected in the 200 MHz ^{1}H NMR spectral analysis of the crude reaction mixture.

Table 1. Synthesis of β-lactams **6a–l** from the imines **5a–f** via the Staudinger reaction

β-Lactams **6a–l**	R	R^2	R^1	Yield (%)[a]
6a	Bn	Me	PMP[b]	75
6b	Bn	Ph	PMP	75
6c	Bn	Ph	Ph	71
6d	Bn	Ac	Ph	72
6e	Bn	Ph	Bn	74
6f	Bn	Ac	Bn	70[c]
6g	Allyl	Ph	PMP	79
6h	Allyl	Ac	PMP	70
6i	Allyl	Me	PMP	72
6j	Allyl	Ph	Allyl	69
6k	Allyl	Ac	Allyl	68
6l	Ac	Ph	PMP	75

[a] Isolated yield.
[b] PMP=*p*-Methoxyphenyl.
[c] Addition of acid chloride was carried out at 0°C.

The relative configuration of the β-lactam **6b** was established from single crystal X-ray diffraction analysis (Fig. 1).[14] The configuration at C-3 and C-4 of the β-lactam **6b** was ascertained as 3*R*,4*S*. It is interesting to note that the chiral imines derived from D-(+)-glucose undergo the cycloaddition reaction stereospecifically providing a single isomer in optically pure form. Some of these pure β-lactams were transformed into useful synthetic intermediates.

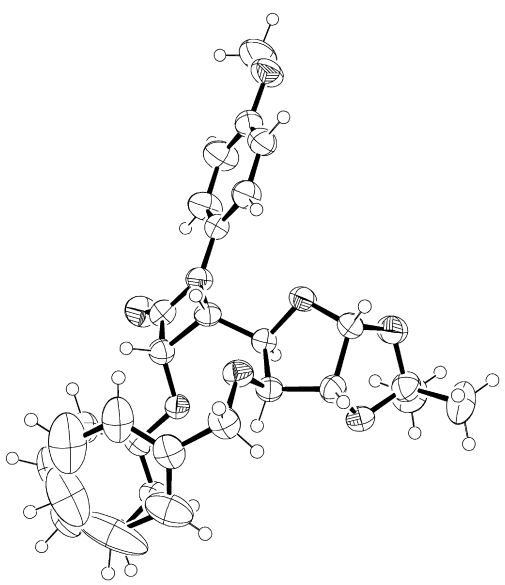
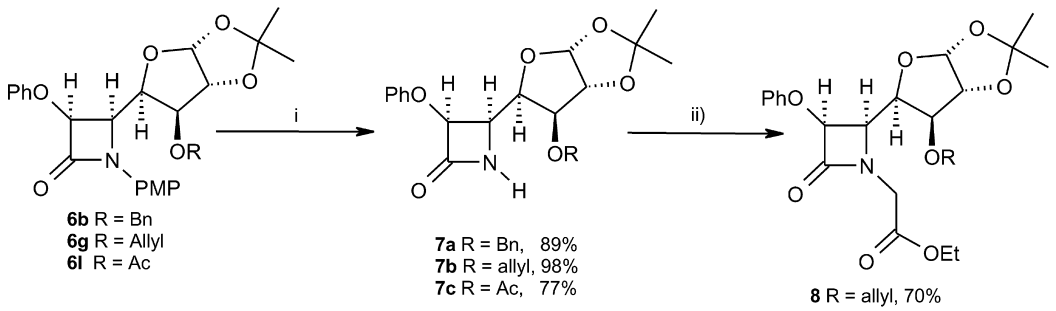


Figure 1. ORTEP diagram for compound **6b**.



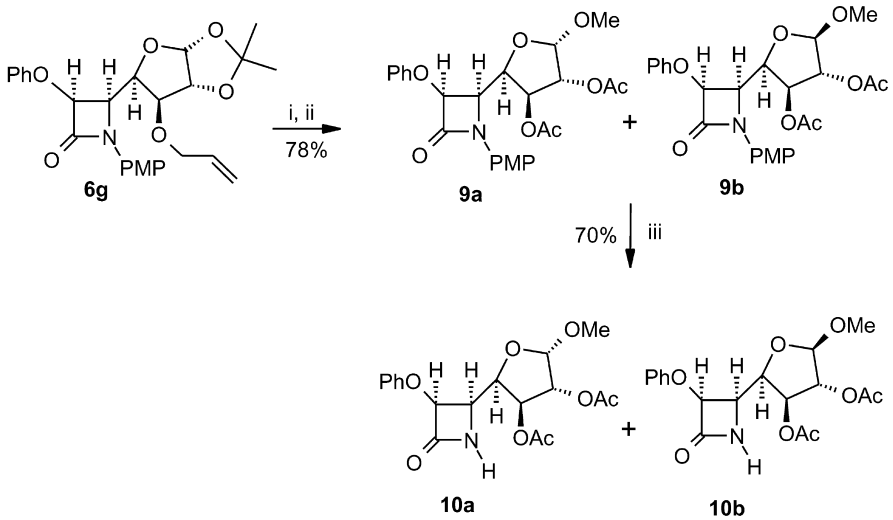
Scheme 2. *Reagents and conditions*: (i) CAN, CH_3CN, H_2O; (ii) NaH, THF, $BrCH_2COOEt$.

The oxidative cleavage of the *p*-anisyl moiety in **6b**–**6g** and **6l** was achieved using CAN[15] to provide the *N*-unsubstituted β-lactams **7a**–**c** in high yields (Scheme 2). One of the *N*-unsubstituted β-lactams **6b** was alkylated using ethyl bromoacetate in the presence of sodium hydride in THF to give *N*-alkylated β-lactam **8** in very good yield.

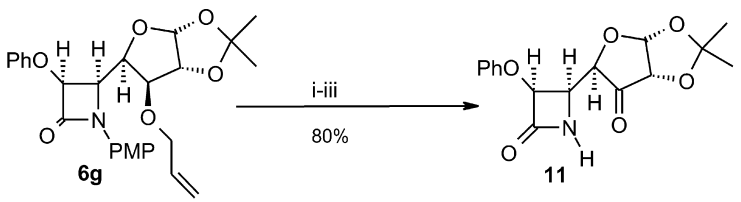
Following a reported procedure[16] compound **6g** was heated under reflux with iodine in methanol to remove the acetonide protection. But this reaction did not provide good yields of the glycosides. Deprotection of both the allyl group and the acetonide of compound **6g** was achieved by refluxing with methanol in the presence of Pd/C and PTSA providing an inseparable mixture of anomers. Acylation using standard conditions of Ac_2O, DMAP and triethylamine, provided the diacetate **9a**,**b** in very good yield. The reaction was complete in 4 h and no starting material was observed on TLC. The PMP group of the diacetate was removed by oxidative cleavage using CAN to provide the *N*-unsubstituted β-lactams **10a**,**b** in good yields (Scheme 3). The *O*-allyl group of β-lactam **6g** was also easily removed by a known procedure[17] using Pd/C, mCPBA and the corresponding hydroxy β-lactam was oxidized to keto β-lactam (**11**) (Scheme 4). Further work to use this β-lactam for the synthesis of carbapenam derivatives is in progress.

3. Conclusion

In conclusion we have shown that the optically pure aldehydes derived from cheaply available D-(+)-glucose provided optically pure *cis*-β-lactams in good yield. Only a single diastereomer was obtained in all the cases. The X-ray analysis of one of the compounds (**6b**) allowed assignment of the relative configuration at the two newly formed chiral centers as 3*R* and 4*S*.



Scheme 3. *Reagents and conditions*: (i) Pd/C, PTSA, MeOH, reflux, 24 h; (ii) Ac_2O, DMAP, Et_3N, CH_2Cl_2, 4 h; (iii) CAN, CH_3CN, 0°C to rt, 1 h.



Scheme 4. *Reagents and conditions*: (i) Pd/C, MeOH, reflux, then mCPBA, Et_3N; (ii) Dess Martin Oxdn., CH_2Cl_2, (iii) CAN, CH_3CN, 0°C to rt, 1 h.

4. Experimental

4.1. General

^1H and ^{13}C NMR Spectra were recorded in $CDCl_3$ solution on a Bruker AC 200 or Bruker MSL 300 spectrometers and chemical shifts are reported in ppm downfield from tetramethylsilane for ^1H NMR. Infrared spectra were recorded on Perkin–Elmer Infrared Spectrophotometer, Model 599-B or Shimadzu FTIR-8400 using sodium chloride optics. Melting points were determined on a Thermonik Campbell melting point apparatus and were uncorrected. The microanalyses were performed on a Carlo-Erba, CHNS-O EA 1108 Elemental analyzer. Optical rotations were recorded on a JASCO-181 digital Polarimeter under standard conditions.

4.2. General procedure for the preparation of β-lactams (6a–l)

A solution of the acid chloride (phenoxyacetyl chloride, acetoxyacetyl chloride and methoxyacetyl chloride) (1.5 mmol) in methylene chloride was added to a solution of the imine **5a–f** (1 mmol) and triethylamine (4.5 mmol) in CH_2Cl_2 (20 mL) at 0 °C. After the addition was complete the reaction mixture was allowed to warm up to room temperature and stirred for 15 h. The reaction mixture was then washed with water (10 mL), saturated sodium bicarbonate solution (10 mL) and saturated brine solution (10 mL). The organic layer was then dried over anhydrous Na_2SO_4, and concentrated to give the crude β-lactams (**6a–l**), which were then purified by silica gel column chromatography.

4.2.1. (3*S*,4*R*,3a′*R*,5′*R*,6′*S*,6a′*R*)-4-(6′-Benzyloxy-2′,2′-dimethyl-tetrahydrofuro [2′,3′,d], [1′,3′] dioxol-5yl)-3-methoxy-1- (4-methoxyphenyl)-azetidin-2-one (6a). Oil; yield 75%; [found: C, 66.02; H, 6.57; N, 3.19; $C_{25}H_{29}NO_7$ requires C, 65.92, H, 6.41; N, 3.07]; $[\alpha]_D^{25}=-217.2$ (*c* 1, $CHCl_3$); ν_{max} ($CHCl_3$) 1743 cm^1; δ_H (200 MHz, $CDCl_3$) 1.32 (3H, s, *CH*$_3$), 1.46 (3H, s, *CH*$_3$), 3.47 (3H, s, O*CH*$_3$), 3.78 (3H, s, ArO*CH*$_3$), 4.28 (1H, d, *J*=3.5 Hz, C*H*–CH–OBz), 4.35–4.48 (2H, m, OC*Ha*HbPh and BzO–CHC*H*), 4.50 (1H, d, *J*=3.5 Hz, BzO–C*H*–CH), 4.64 (1H, dd, *J*=4.9, 3.9 Hz, CH_3OCHC*H*), 4.75 (1H d, *J*=4.9 Hz, CH_3OC*H*), 4.78 (1H, d, *J*=11.7 Hz, OCHaHbPh), 6.05 (1H, d, *J*=3.9 Hz, anomeric C*H*), 7.28 (9H, m, Ar); δ_C (50.3 MHz) 26.1, 26.6, 55.2, 58.4, 58.7, 71.7, 81.2, 81.9, 82.1, 82.6, 104.7, 111.5, 113.8, 119.5, 127.7, 127.9, 128.0, 128.3, 131.2, 137.3, 156.3, 164.9; MS (*m*/*z*): 455 (M^+).

4.2.2. (3*S*,4*R*,3a′*R*,5′*R*,6′*S*,6a′*R*)-4-(6′Benzyloxy-2′,2′dimethyl-tetrahydrofuro [2′,3′,d], dioxol-5′yl)-1-(4-methoxyphenyl)-3-phenoxy-azetidin-2-one (6b). White solid; yield 75%; mp 148 °C; [found: C, 69.85; H, 6.01; N, 2.51; $C_{30}H_{31}NO_7$ requires C, 69.60; H, 6.04; N, 2.70], $[\alpha]_D^{24}=-245.0$ (*c* 1.85, CH_2Cl_2); ν_{max} ($CHCl_3$) 1749 cm^1; δ_H (200 MHz, $CDCl_3$) 1.34 (3H, s, *CH*$_3$), 1.54 (3H, s, *CH*$_3$), 3.78 (3H, s, O*CH*$_3$), 4.3 (1H, d, *J*=3.7 Hz, C*H*CHOBz), 4.45 (1H, d, *J*=3.7 Hz, BzOCHC*H*), 4.5–4.8 (2H, m, OC*Ha*HbPh and PhOCHC*H*), 5.31 (1H, d, *J*=5.4 Hz, PhOC*H*), 6.08 (1H, d, *J*=3.9 Hz, anomeric C*H*), 6.87 (1H, d, *J*=8 Hz, PhCHa*Hb*), 6.9–7.77 (15H, m, Ar); δ_C (50.3 MHz) 26.3, 26.8, 55.4, 58.5, 71.9, 79.1, 81.4, 81.9, 83.1, 104.9, 111.8, 113.9, 115.6, 119.8, 122.4, 127.5, 128.0, 128.5, 129.6, 131.2, 137.1, 156.55, 157.4, 163.4; MS (*m*/*z*): 517 (M^+).

4.2.3. (3*S*,4*R*,3a′*R*,5′*R*,6′*S*,6a′*R*,)-4-(6′-Benzyloxy-2′, 2′-dimethyl-tetrahydrofuro [2′,3′,d][1′-3′] dioxol-5′yl)-3-phenoxy-1-phenyl azetidin-2-one (6c). White solid; yield 71%; mp 112 °C; [found: C, 71.40, H, 6.09, N, 2.77; $C_{29}H_{29}NO_6$ requires C, 71.42; H, 5.99; N, 2.87]; $[\alpha]_D^{24}=-285.0$ (*c* 1, $CHCl_3$); ν_{max} (nujol) 1751 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.33 (3H s, *CH*$_3$), 1.48 (3H, s, *CH*$_3$), 4.26 (1H, d, *J*= 11.2 Hz, PhC*Ha*Hb), 4.41 (1H, d, *J*=3 Hz, C*HCHOBz*), 4.60 (1H, d, *J*=3.9 Hz, BzOCHC*H*), 4.67 (1H, d, *J*=3 Hz, BzOC*HCH*), 4.70–4.74 (1H, m, PhCHa*Hb*), 4.74 (1H, dd, *J*=5.4, 3.4 Hz, PhOCHC*H*), 5.29 (1H, d, *J*=5.4 Hz, PhOC*H*), 6.05 (1H, d, *J*=3.9 Hz, anomeric C*H*), 6.98–7.76 (15H, m, Ar); δ_C (50.3 MHz) 26.1, 26.8, 57.7, 67.4, 71.0, 78.9, 81.1, 81.3, 82.4, 104.6, 111.0, 115.5, 118.0, 120.0, 121.4, 122.5, 123.9, 124.5, 127.7, 128.4, 128.9, 129.8, 137.52, 137.4, 133.5, 157.2, 158.0, 164.5; MS (*m*/*z*): 487 (M^+).

4.2.4. (2*R*,3*S*,3a′*R*,5′*R*,6′*S*,6a′*R*)-3-Acetic acid-2-(6′-benzyloxy-2′,2′-dimethyl-tetrahydrofuro [2′,3′,d], [1′,3′dioxol-5′yl]-4-oxo-1-phenyl azetidin-2-one (6d). Gummy substance; yield 72%, [found: C, 66.33; H, 6.17; N, 3.19; $C_{25}H_{27}NO_7$ requires C, 66.19; H, 6.00, N, 3.09]; $[\alpha]_D^{27}=-244.1$ (*c* 1, $CHCl_3$); ν_{max} ($CHCl_3$) 1766 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.32 (3H, s, *CH*$_3$), 1.46 (3H, s, *CH*$_3$), 2.05 (3H, s, OCO*CH*$_3$), 3.99 (1H, d, *J*=3.6 Hz, BzOCHC*H*), 4.38 (1H, d, *J*=11.2 Hz, PhC*Ha*Hb), 4.47 (1H, dd, *J*=3.0, 3.9 Hz, C*H*CHOBz), 4.63 (1H, d, *J*=3.9 Hz, BzOC*H*CH), 4.63 (1H, d, *J*=11.2 Hz, PhCHa*Hb*), 4.75 (1H, dd, *J*=5.9, 3.9 Hz, AcOCHC*H*), 6.04 (1H, d, *J*=3.9 Hz, anomeric C*H*), 6.06 (1H, d, *J*=5.9 Hz, AcOC*H*), 7.07–7.68 (10H m, Ar); δ_C (50.3 MHz, $CDCl_3$) 20.0, 25.9, 26.4, 57.2, 71.4, 72.8, 80.6, 81.1, 81.8, 104.5, 111.4, 117.9, 124.3, 127.8, 128.0, 128.3, 136.5, 137.2, 162.3, 168.3; MS (*m*/*z*): 453 (M^+).

4.2.5. (3*S*,4*R*,3a′*R*,5′*R*,6′*S*,6a′*R*)-1-Benzyl-4-(6′-benzyloxy-2′,2′-dimethyl-tetrahydrofuro [2′,3′,d], [1′,3′ dioxol-5′yl)-3-phenoxy azetidin-2-one (6e). Oil; yield 74%; [found: C, 71.95; H, 6.40; N, 2.95; $C_{30}H_{31}NO_6$ requires C, 71.82; H, 6.23; N, 2.79]; $[\alpha]_D^{25}=-206.4$ (*c* 1, $CHCl_3$); ν_{max} ($CHCl_3$) 1758 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.32 (3H, s, *CH*$_3$), 1.50 (3H, s, *CH*$_3$), 4.11 (1H, dd, *J*=4.0, 6.0 Hz, C*H*CHOBz), 4.22 (1H, d, *J*=14.0 Hz, PhC*Ha*HbN), 4.24 (1H, d, *J*=12.0 Hz, PhC*Ha*Hb*O*), 4.30, (1H, d, *J*=14.0 Hz, PhCHa*HbN*), 4.53 (2H, m, PhOCHC*H* and BzOCHC*H*), 4.63 (1H, d, *J*=4.0 Hz, BzOC*H*CH), 4.79 (1H, d, *J*= 12.0 Hz, PhCHa*Hb*O), 5.16 (1H, d, *J*=4.9 Hz, PhOC*H*CH), 6.03 (1H, d, *J*=4 Hz, anomeric C*H*), 7.3 (15H, m, Ar); δ_C (50.3 MHz, $CDCl_3$) 25.9, 26.4, 44.9, 56.0, 71.2, 79.8, 81.0, 81.6, 82.0, 104.6, 111.3, 114.3, 115.2, 121.7, 127.0, 127.9, 128.1, 128.9, 135.6, 136.7, 157.0, 164.9; MS (*m*/*z*): 501 (M^+).

4.2.6. (2*R*,3*S*,3a′*R*,5′*R*,6′*S*,6a′*R*)-3-Acetic acid-2-(6′-benzyloxy-2′,2′-dimethyl-tetrahydrofuro [2′,3′,d], [1′,3′dioxol-5′yl]-1-benzyl-4-oxo-azetidin-3yl ester (6f). Oil; yield

70%; [found: C, 66.92; H, 6.37; N, 3.13; $C_{26}H_{29}NO_7$ requires C: 66.78, H: 6.25, N: 2.99]; $[\alpha]_D^{25}=-216.1$ (*c* 1, $CHCl_3$); ν_{max} ($CHCl_3$) 1751 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.36 (3H, s, *CH*$_3$), 1.51 (3H, s, *CH*$_3$), 1.97 (3H, s, OCO*CH*$_3$), 4.02 (1H, dd, *J*=4.9, 3.4 Hz, AcOCHC*H*), 4.21 (1H, d, *J*=14.6 Hz, NC*Ha*HbPh), 4.30 (1H, d, *J*=11.8 Hz, OC*Ha*HbPh), 4.31 (1H, d, *J*=3.5 Hz, BzOCHC*H*), 4.53 (1H, d, *J*=11.8 Hz, NCHa*Hb*), 4.56 (1H, dd, *J*=3.4, 3.5 Hz, C*H*CHOBz), 4.62 (1H, d, *J*=3.9 Hz, BzOC*H*CH), 4.74 (1H, d, *J*=14.6 Hz, OCHa*Hb*Ph), 5.85 (1H, d, *J*=4.9 Hz, AcOC*H*), 5.98 (1H, d, *J*=3.9 Hz, anomeric C*H*), 7.19 (10H, m, Ar); δ_C (50.3 MHz, $CDCl_3$) 20.2, 26.0, 26.6, 45.2, 55.3, 71.3, 74.0, 80.6, 81.2, 81.5, 104.8, 111.7, 127.4, 127.8, 128.0, 128.3, 135.4, 136.4, 164.1, 168.5; MS (*m*/*z*):467 ($M^{+\cdot}$).

4.2.7. (3*S*,4*R*,3a′*R*,5′*R*,6′*S*,6a′*R*)-4-(6′-Allyloxy-2′, 2′-dimethyl-tetrahydrofuro[2′,3′-d][1′,3′] dioxol-5′yl)-1-(-4-methoxyphenyl)-3-phenoxy azetidin-2-one (6g). White solid; yield 79%; mp 144–145 °C; [found: C, 66.89; H, 6.39; N, 3.15; $C_{26}H_{29}NO_7$ requires C, 66.78; H, 6.25; N, 2.99]; $[\alpha]_D^{29}=-242.0$ (*c* 1, $CHCl_3$); ν_{max} ($CHCl_3$) 1751 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.30 (3H, s, CH_3), 1.50 (3H, s, *CH*$_3$), 3.80 (3H, s, O*CH*$_3$), 3.90 (2H, m, O*CH*$_2$), 4.10 (1H, dd, *J*=3, 3.4 Hz, C*H*CHO–allyl), 4.32 (1H, d, *J*=3 Hz, allyl–OCHC*H*), 4.58 (1H, d, *J*=3.4 Hz, allyl–OC*H*CH), 4.69 (1H, dd, *J*=5.4, 3.4 Hz, PhOCHC*H*), 5.10 (2H, m, CH=C*H*$_2$), 5.46 (1H, d, *J*=5.4 Hz, PhOC*H*), 5.75 (1H, m, C*H*=CH$_2$), 6.06 (1H, d, *J*=3.9 Hz, anomeric C*H*), 6.80–7.8 (9H, m, Ar); δ_C (50.3 MHz, $CDCl_3$) 26.2, 26.7, 55.3, 58.6, 70.7, 79.2, 81.3, 81.8, 82.8, 104.8, 111.6, 113.9, 115.6, 117.4, 119.7, 122.4, 129.5, 131.1, 133.7, 156.5, 157.4, 163.3; MS (*m*/*z*): 467 ($M^{+\cdot}$).

4.2.8. (2*R*,3*S*,3a′*R*,5′*R*,6′*S*,6a′*R*)-Acetic acid-2-(6′-allyloxy-2, 2-dimethyl-tetrahydrofuro [2′,3′-d][1′,3′] dioxol-5′yl)-1-(4-methoxyphenyl)-4-oxo-azetidin-3yl ester (6h). Oil; yield 70%; [Found: C, 67.12; H, 6.47; N, 3.35; $C_{22}H_{27}NO_8$ requires C, 60.94; H, 6.28; N, 3.23]; $[\alpha]_D^{25}=-225.9$ (*c* 1, $CHCl_3$); ν_{max} ($CHCl_3$) 1751 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.32 (3H, s, *CH*$_3$), 1.47 (3H, s, *CH*$_3$), 2.21 (3H, s, OCO*CH*$_3$), 3.78 (3H, s, O*CH*$_3$), 3.80–3.89 (2H, m, OC*H*$_2$CH=CH$_2$), 3.92 (1H, d, *J*=3.4 Hz, allyl–OCHC*H*), 4.41 (1H, dd, *J*=3.4, 3.8 Hz, C*H*CHO–allyl), 4.59 (1H, d, *J*=3.8 Hz, allyl–OC*H*CH), 4.63 (1H, dd, *J*=5.6, 3.4 Hz, AcOCHC*H*), 5.10 (2H, m, CH=C*H*$_2$), 5.77 (1H, m, C*H*=CH$_2$), 6.01 (1H, d, *J*=3.9 Hz, anomeric C*H*), 6.15 (1H, d, *J*=5.6 Hz, AcOC*H*), 6.83–7.63 (4H, m, Ar); δ_C (50.3 MHz, $CDCl_3$) 20.6, 26.1, 26.6, 55.3, 57.9, 70.8, 72.9, 80.7, 81.5, 81.8, 82.2, 104.7, 111.7, 113.8, 118.2, 119.7, 130.9, 133.4, 156.5, 162.0, 168.5; MS (*m*/*z*): 433 (M^{+}).

4.2.9. (2*R*,3*S*,3a′*R*,5′*R*,6′*S*,6a′*R*)-4-(6′-Allyloxy-2′,2′-dimethyltetrahydrofuro [2′,3′-d][1′,3′] dioxol-5′yl)-3-methoxy-1-(4-methoxyphenyl) azetidin-2-one (6i). Oil; yield 72%; [found: C, 62.32; H, 6.87; N, 3.62; $C_{21}H_{27}NO_7$ requires C, 62.19; H, 6.71; N, 3.45]; $[\alpha]_D^{29}=-209.1$ (*c* 1, $CHCl_3$); ν_{max} ($CHCl_3$) 1747 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.31 (3H, s, *CH*$_3$), 1.44 (3H, s, *CH*$_3$), 3.66 (3H, s, O*CH*$_3$), 3.78 (3H, s, ArO*CH*$_3$), 3.92 (1H, dd, *J*=5.8, 3.4 Hz, MeOCHC*H*), 4.11 (2H, m, OC*H*$_2$CH=CH$_2$), 4.36 (2H, m, allyl–OC*H*CH and MeOC*H*), 4.52 (2H, m, allyl–OCHC*H* and C*H*CHO–allyl), 5.21 (2H, m, CH=C*H*$_2$), 5.81 (1H, m, C*H*=CH$_2$), 6.02 (1H d, *J*=3.9 Hz, anomeric C*H*), 7.25 (2H, d, *J*=9 Hz, Ar), 7.45 (2H, d, *J*=9 Hz, Ar); δ_C (50.3 MHz, $CDCl_3$) 26.1, 26.7, 55.3, 58.6, 59.0, 70.8, 8.3, 82.0, 82.2, 82.7, 104.8, 111.5, 113.9, 117.2, 119.5, 131.3, 133.9, 156.3, 164.9; MS (*m*/*z*): 405 (M^{+}).

4.2.10. (3*S*,4*R*,3a′*R*,5′*R*,6′*S*,6a′*R*)-1-Allyl-4-(6′-allyloxy-2′,2′-dimethyltetrahydrofuro [2′,3′-d][1′,3′] dioxol-5′yl)-3-phenoxy azetidin-2-one (6j). Oil; yield 69%; [found: C, 66.02; H, 6.57; N, 3.19; $C_{22}H_{27}NO_6$ requires C, 65.90; H, 6.42; N, 3.07]; $[\alpha]_D^{27}=-206.8$ (*c* 1, $CHCl_3$); ν_{max} ($CHCl_3$) 1759 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.29 (3H, s, *CH*$_3$), 1.50 (3H, s, *CH*$_3$), 3.70 (2H, m, NC*H*$_2$CH=CH$_2$), 4.00 (2H, m, OC*H*$_2$CH=CH$_2$), 4.11 (1H, d, *J*=3.4 Hz, allyl–OCHC*H*), 4.47 (1H, dd, *J*=3.4, 3.9 Hz, C*H*CHO–allyl), 4.57 (1H, d, *J*=3.9 Hz, allyl–OC*H*CH), 4.80 (1H, dd, *J*=4.8, 3.9 Hz, PhOCHC*H*) 5.05 (4H, m, N–CH$_2$CH=C*H*$_2$ and O–CH$_2$-CH=C*H*$_2$), 5.32 (1H, d, *J*=4.9 Hz, PhOC*H*), 5.65 (2H, m, N–CH$_2$C*H*=CH$_2$ and O–CH$_2$C*H*=CH$_2$), 5.96 (1H, d, *J*=3.9 Hz, anomeric C*H*), 6.80–7.35 (5H, m, Ar); δ_C (50.3 MHz, $CDCl_3$) 26.1, 26.7, 43.9, 56.6, 70.6, 79.9, 81.3, 82.2, 104.8, 111.6, 115.5, 117.3, 118.3, 122.2, 129.4, 131.3, 133.7, 157.4, 165.4; MS (*m*/*z*): 401 ($M^{+\cdot}$).

4.2.11. (2*R*,3*S*,3a′*R*,5′*R*,6′S,6a′R)-Acetic acid, 1-allyl-4-(6′-allyloxy-2′,2′-dimethyltetrahydrofuro[2′,3′-d][1′,3′] dioxol-5′yl) azetidin-2-one (6k). Oil; yield 68%; [found: C, 66.02; H, 6.57; N, 3.19; $C_{22}H_{27}NO_6$ requires C, 65.90; H, 6.42; N, 3.07]; $[\alpha]_D^{24}=-238.9$ (*c* 1, $CHCl_3$); ν_{max} ($CHCl_3$) 1758 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.32 (3H, s, *CH*$_3$), 1.50 (3H, s, *CH*$_3$), 2.10 (3H, s, OCO*CH*$_3$), 3.75 (4H, m, NC*H*$_2$ and OC*H*$_2$), 4.00 (1H, dd, *J*=3.5, 3.7 Hz, C*H*CHO–allyl), 4.27 (1H, dd, *J*=4.8, 3.5 Hz, AcOCHC*H*), 4.33 (1H, d, *J*=3.7 Hz, allyl–OCHC*H*), 4.53 (1H, d, *J*=4.0 Hz, allyl–OC*H*CH), 5.15–5.30 (4H m, NCH$_2$CH=C*H*$_2$ and OCH$_2$CH=C*H*$_2$), 5.69–5.90 (2H, m, NCH$_2$C*H*=CH$_2$ and OCH$_2$C*H*=CH$_2$), 5.29 (1H, d, *J*=4.0 Hz, AcOC*H*), 5.99 (1H, d, *J*=4.8 Hz, anomeric C*H*); δ_C (50.3 MHz, $CDCl_3$) 19.8, 25.5, 26.1, 43.3, 55.4, 59.3, 70.0, 73.2, 79.9, 81.0, 81.2, 104.3, 110.9, 117.3, 130.9, 133.1, 163.4, 168.0; MS (*m*/*z*): 368 ($M^{+\cdot}$).

4.2.12. (3*S*,4*R*,3a′*R*,5′*R*,6′*S*,6a′*R*)-Acetic acid 5′-{1-(4-methoxyphenyl)-4-oxo-3-phenoxy azetidin-2yl}-2′,2′-dimethyl tetrahydrofuro[2′,3′-d][1′,3′]dioxol-6′-yl-ester (6l). White solid; yield 75%; mp 171 °C; [found: C, 64.06; H, 5.97; N, 3.12; $C_{25}H_{27}NO_8$ requires C, 63.94; H, 5.80; N, 2.98]; $[\alpha]_D^{25}=-235.6$ (*c* 1, $CHCl_3$); ν_{max} ($CHCl_3$) 1747 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.35 (3H, s, *CH*$_3$), 1.50 (3H, s, *CH*$_3$), 2.05 (3H, s, OCO*CH*$_3$) 3.80 (3H, s, O*CH*$_3$), 4.57 (1H, d, *J*=3.9 Hz, AcOCHC*H*), 4.62 (1H, dd, *J*=3.0, 3.5 Hz, C*H*CHOAc), 4.68 (1H, dd, *J*=4.9, 3.5 Hz, PhOCHC*H*), 5.33 (1H, d, *J*=4.9 Hz, PhOC*H*), 5.64 (1H, d, *J*=3.0 Hz, AcOC*H*CH), 6.02 (1H d, *J*=3.9 Hz, anomeric C*H*), 6.89–7.25 (9H, m, Ar); δ_C (50.3 MHz, $CDCl_3$) 20.0, 25.7, 26.1, 54.8, 57.9, 77, 79.1, 79.6, 82.9, 104.0, 111.6, 113.5, 115.7, 119.2, 122.3, 129.1, 130.5, 156.2, 157.0, 162.9, 168.8; MS (*m*/*z*): 469 ($M^{+\cdot}$).

4.3. General procedure for the preparation of *N*-unsubstituted β-lactams (7a–c)

To a solution of the β-lactam (**6b, g, l**) (0.38 mmol) in

acetonitrile, was added a solution of CAN (0.63 g, 1.16 mmol) in water (3 mL) at 0 °C and the reaction mixture was stirred at that temperature for 1 h. After the completion of the reaction (TLC) cold water (20 mL) was added to the reaction mixture and extracted with EtOAc (3×30 mL). The combined organic layers were washed with 5% sodium bicarbonate solution (10 mL), 10% sodium sulphite solution (10 mL), followed by 10% sodium bicarbonate solution (10 mL), dried over Na_2SO_4 and filtered. The filtrate was concentrated and column chromatography of the crude provided the *N*-unsubstituted β-lactams in good yields.

4.3.1. (3*S*,4*R*,3a′*R*,5*R*,6*S*,6a′*R*)-4-(6′-Benzyloxy-2′,2′-dimethyltetrahydrofuro-[2,3-d][1,3],dioxol-5yl)-3-phenoxyazetidin-2-one (7a). White solid; yield 89%; mp 137 °C; [found: C, 67.40; H, 2.35, N, 3.59; $C_{23}H_{25}NO_6$ requires C, 67.14, H, 6.12; N, 3.40]; $[\alpha]_D^{25}=-190.7$ (*c* 1, $CHCl_3$); ν_{max} [$CHCl_3$] 3405, 3285, 3020, 1749 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.39 (3H, s, *CH*$_3$), 1.56 (3H, s, *CH*$_3$), 4.17 (1H, d, *J*=3.3 Hz, BzOCHC*H*), 4.30 (1H, dd, *J*=3.3, 3.7 Hz, C*H*CHOBz), 4.33 (1H, d, *J*=11.8 Hz, PhC*Ha*Hb), 4.50 (1H, d, *J*=3.7 Hz, BzOC*H*CH), 4.63 (1H, d, *J*=11.8 Hz, PhCHa*Hb*), 4.70 (1H, dd, *J*=3.3, 5.1 Hz, PhOCHC*H*), 5.29 (1H, d, *J*=5.1 Hz, PhOC*H*), 6.01 (1H, d, *J*=3.7 Hz, anomeric C*H*), 6.40 (1H, s, N*H*), 7.06–7.34 (5H, m, Ar); δ_C (50.3 MHz, $CDCl_3$) 26.2, 26.7, 52.9, 71.6, 80.6, 80.8, 81.9, 82.3, 104.6, 111.9, 115.4, 122.2, 127.3, 127.8, 128.3, 129.4, 137.0, 157.2, 166.3; MS (*m*/*z*): 411 (M^+).

4.3.2. (3*S*,4*R*,3a′*R*,5*R*,6*S*,6a′*R*)-4-(6′-Allyloxy-2′,2′-dimethyl-tetrahydrofuro[2′,3′-d][1′,3′]dioxol-5′yl)-3-phenoxy azetidin-2-one (7b). Gummy substance; yield 98%; [found: C, 63.27; H, 6.59; N, 4.03; $C_{19}H_{23}NO_6$ requires C, 63.13; H, 6.41; N, 3.87]; $[\alpha]_D^{29}=-189.2$ (*c* 0.60, $CHCl_3$); ν_{max} ($CHCl_3$) 3410, 1751 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.34 (3H, s, *CH*$_3$), 1.51 (3H, s, *CH*$_3$), 3.79 (2H, m, OC*H*$_2$), 4.02 (1H, d, *J*=3.4 Hz, allyl–OCHC*H*), 4.25 (1H, dd, *J*=4.9, 3.4 Hz, C*H*CHO–allyl), 4.44 (1H, d, *J*=3.9 Hz, allyl–OC*H*CH), 4.59 (1H, dd, *J*=3.9, 4.9 Hz, PhOCHC*H*), 5.12 (2H, m, CH=C*H*$_2$), 5.28 (1H, m, C*H*=CH$_2$), 5.35 (1H, d, *J*=4.9 Hz, PhOC*H*), 5.94 (1H, d, *J*=3.9 Hz, anomeric C*H*), 6.35 (1H, s, N*H*), 7.01–7.36 (5H, m, Ar); δ_C (50.3 MHz, $CDCl_3$) 26.2, 26.7, 52.3, 70.0, 79.3, 80.6, 80.9, 81.6, 82.0, 104.3, 111.0, 115.4, 115.8, 117.0, 122.2, 129.7, 134.6, 157.4, 166.4; MS (*m*/*z*): 361 ($M^{+\cdot}$).

4.3.3. (3*S*,4*R*,3a′*R*,5*R*,6*S*,6a′*R*)-Acetic acid 2′,2′-dimethyl-5′-(4-oxo-3-phenoxy azetidin-5′-yl) tetrahydrofuro[2′,3′-d]-[1′3′dioxol-6′-yl-ester (7c). Gummy substance; yield 78%; [found: C, 59.69; H, 6.02; N, 3.97; $C_{18}H_{21}NO_7$ requires C, 59.48; H, 5.82; N, 3.85]; $[\alpha]_D^{27}=-205.2$ (*c* 1, $CHCl_3$); ν_{max} ($CHCl_3$) 3415, 3018, 1747 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.33 (3H, s, CH_3), 1.52 (3H, s, CH_3), 2.05 (3H, s, $OCOCH_3$), 4.07–4.22 (2H, m, AcOCHCH and CHCHOAc), 4.56 (1H, d, *J*=3.4 Hz, AcOCHCH), 4.80 (1H, dd, *J*=4.9, 3.9 Hz, PhOCHCH), 5.36 (1H, d, *J*=3.4 Hz, PhOCH), 5.94 (1H, d, *J*=3.4 Hz, anomeric CH), 6.47 (1H, s, NH), 7.01– 7.35 (5H, m, Ar); δ_C (50.3 MHz, $CDCl_3$) 20.4, 26.0, 26.4, 52.3, 76.7, 79.1, 81.1, 83.5, 104.1, 112.2, 115.7, 122.4, 129.4, 157.2, 166.5, 169.2; MS (*m*/*z*): 363 ($M^{+\cdot}$).

4.4. (3*S*,4*R*,3a′*R*,5*R*,6*S*,6a′*R*) [2-(6′-Allyloxy-2′2′-dimethyltetrahydrofuro[2′,3′-d][1′,3′]dioxol-5′yl)-4-oxo-3-phenoxy azetidin-1-yl] acetic acid ethyl ester (8)

A solution of the β-lactam **7b** (0.78 g, 2.16 mmol) in anhydrous THF (10 mL) was added to the 50% suspension of NaH in mineral oil at 0 °C and the reaction mixture was refluxed for 2 h. The reaction was then cooled to 0 °C and a solution of ethyl bromoacetate (1.19 mL, 0.01 mol) in anhydrous THF (10 mL) was added slowly. The reaction mixture was refluxed gently for 8 h. The excess reagent was quenched at 0 °C with MeOH (5 mL), diluted with water (20 mL) and extracted with EtOAc (3×25 mL). The organic layers were washed with water (10 mL), sat. brine soln. (10 mL), dried over Na_2SO_4, filtered and concentrated to get the crude ethyl ester. The crude ester was purified by silica gel column chromatography to get pure compound **8** as oil (0.67 g).

Colourless oil; yield 70%; [found: C, 47.83; H, 9.07; N, 4.40; $C_{23}H_{29}NO_8$ requires C, 47.67; H, 8.93; N, 4.28]; $[\alpha]_D^{25}=-96.0$ (*c* 0.72, $CHCl_3$); ν_{max} ($CHCl_3$) 1730, 1749 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.10–1.40 (9H, m, CH_2CH_3 and two CH_3), 1.50 (2H, s, N*CH*$_2$), 3.68 (1H, dd, *J*=5.3 Hz, 6.9 Hz, PhOCHC*H*), 4.00–4.56 (6H, m, OC*H*$_2$CH=CH$_2$, OC*H*$_2$CH$_3$, C*H*CHO–allyl and allyl–OCHC*H*), 5.10–5.35 (3H, m, OCH$_2$CH=C*H*$_2$ and allyl–OC*H*CH), 5.40 (1H, d, *J*=4.9 Hz, PhOC*H*), 5.60–5.80 (1H, m, OCH$_2$C*H*=CH$_2$), 5.90 (1H, d, *J*=3.9 Hz, anomeric C*H*), 6.90–7.40 (5H, m, Ar); δ_C (50.3 MHz, $CDCl_3$) 13.8, 25.9, 26.4, 42.4, 57.0, 61.0, 70.3, 80.0, 80.6, 81.8, 104.6, 115.2, 115.4, 117.2, 122.0, 129.2, 133.4, 157.1, 165.6, 167.6; MS (*m*/*z*): 447 (M^+).

4.5. (3*R*,4*S*,3′*S*,4′*R*,5*R*)-Acetic acid-4-acetoxy-2-methoxy-5-[1′-(4′-methoxyphenyl)-4′-oxo-3′phenoxy azetidin-5-yl)tetrahydrofuran-3-yl-ester (9a,b)

A solution of the β-lactam **6g** (1.77 g, 3.79 mmol) in 20 mL MeOH was treated with 10%Pd/C (0.177 g), PTSA (0.177 g), and refluxed for 24 h. The catalyst was removed by filtration and the filtrate was passed through a short column of silica gel. Solvent was removed under reduced pressure to get the crude diol (1.24 g, 82%) as an inseparable mixture of diastereomers. A solution of this diol (0.35 g, 0.87 mmol) in methylene chloride was treated with acetic anhydride (0.266 g, 2.61 mmol), triethylamine (0.529 g, 5.23 mmol) in the presence of catalytic amount of DMAP and stirred at rt for 4 h. The reaction was quenched with saturated NH_4Cl solution (15 mL). The organic layer was then separated and washed thoroughly with water (10 mL), sat. brine soln. (10 mL), dried over Na_2SO_4, filtration through a bed of silica followed by removal of the solvent provided the diastereomeric mixture of diacetates (**9a, b**, 0.4 g, 95%).

Gum; $[\alpha]_D^{25}=-76.6$ (*c* 0.89, $CHCl_3$); [found: C, 61.99, H, 5.80, N, 2.97 $C_{25}H_{27}NO_9$ requires C: 61.83, H: 5.60, N: 2.88]; ν_{max} ($CHCl_3$) 1753 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.85 (3H, s, OCO*CH*$_3$), 1.90 (3H, s, OCO*CH*$_3$), 2.15 (3H, s, OCO*CH*$_3$), 2.20 (3H, s, OCO*CH*$_3$), 3.25 (3H, s, O*CH*$_3$), 3.50 (3H, s, O*CH*$_3$), 3.80 (6H, s, ArO*CH*$_3$), 4.67–4.88 (4H, m, C*H*CHOAc and AcOCHC*H*), 5.00 (2H, m, AcOC*H*CH), 5.21 (1H, d, *J*=4.4 Hz, PhOC*H*), 5.30 (2H, m, PhOCHC*H*),

5.26 (1H, d, J=5.4 Hz, PhOC*H*), 5.80–5.90 (2H, m, anomeric C*H*), 6.85–7.75 (18H, m, Ar, for both isomers); δ_C (50.3 MHz, $CDCl_3$) 17.8, 26.9, 26.7, 53.5, 55.8, 57.4, 73.0, 73.7, 74.3, 74.7, 75.0, 76.3, 76.8, 98.0, 105.0, 111.2, 113.2, 117.2, 117.6, 120.1, 126.9, 127.9, 154.1, 154.2, 154.8, 157.0, 160.7, 166.6, 167.4; MS (*m*/*z*): 485 (M^+).

4.6. (3*R*,4*S*,5*R*,3′*S*,4′*R*)-Acetic acid 4-acetoxy-2-methoxy-5-(4′-oxo-3′-phenoxyazetidin-2-yl)tetrahydrofuran-3-yl-ester (10a,b)

To a solution of the diacetate (**9a**,**b**, 0.42 g, 0.86 mmol) in acetonitrile (20 mL), was added a solution of CAN (1.42 g, 2.59 mmol) in water (3 mL) at 0 °C and the reaction mixture was stirred at this temperature for 1 h. After the completion of the reaction (TLC) cold water was added to the reaction mixture and extracted with EtOAc (3×40 mL) and the combined organic layers were washed with 5% sodium bicarbonate solution (20 mL), 10% sodium sulphite (20 mL) solution followed by 10% sodium bicarbonate solution (20 mL), dried over Na_2SO_4 and filtered. The filtrate was concentrated and column chromatography of the crude product provided thick gummy diastereomeric mixture of **10a**,**b** (0.23 g).

Gum; yield 72%; [found: C, 57.12; H, 5.67; N, 3.82; $C_{18}H_{21}NO_8$ requires C, 56.97; H, 5.58; N, 3.69]; $[\alpha]_D^{27}$=−93.3 (*c* 0.60, $CHCl_3$); ν_{max} ($CHCl_3$) 3298, 1753 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.90 (3H, s, $OCOCH_3$), 1.95 (3H, s, $OCOCH_3$), 2.15 (6H, s, $OCOCH_3$), 3.40 (3H, s, OCH_3), 3.45 (3H, s, OCH_3), 4.13 (2H, two dd's merged, J=4.8, 4.9, 4.9, 6.0 Hz, PhOCHCH), 4.92–5.04 (4H, m, CHCHOAc and AcOCHCH), 5.14 (1H, d, J=4.9 Hz, PhOCH), 5.23 (2H, m, AcOCHCH), 5.52 (1H, d, J=6.0 Hz, PhOCH), 5.74 (1H, d, J=4.9 Hz, anomeric CH), 5.78 (1H, d, J=4.9 Hz, anomeric CH), 6.5 (2H, s, NH), 6.95–7.40 (10H, m, Ar); δ_C (50.3 MHz, $CDCl_3$) 17.8, 17.9, 52.7, 53.5, 55.8, 57.4, 73.0, 73.7, 74.3, 74.7, 75.0, 76.3, 79.7, 98.0, 105.0, 111.2, 111.2, 113.2, 113.4, 117.2, 117.6, 120.0, 120.1, 126.9, 127.9, 128.1, 154.0, 154.2, 154.8, 157.0, 160.6, 160.7, 166.5, 166.6, 167.4; MS (*m*/*z*): 379 (M^+).

4.7. (3*S*,4*R*,3a′*R*,5*R*,6a′*R*)-4-(2′,2′-dimethyl-6′-oxo-tetrahydrofuro[2′,3′d][1′,3′]dioxol-5′-yl)-3-phenoxy azetidin-2-one (11)

Gummy substance; yield 93%; [found: C, 60.32; H, 5.43; N, 4.55; $C_{16}H_{17}NO_6$ requires C, 60.16; H, 5.36; N, 4.38]; $[\alpha]_D^{25}$=+32.7 (*c* 1, $CHCl_3$); ν_{max} ($CHCl_3$), 3413, 1758, 1730 cm^{-1}; δ_H (200 MHz, $CDCl_3$) 1.38 (3H, s, *CH*$_3$), 1.48 (3H, s, *CH*$_3$), 4.13 (1H, d, J=4.4 Hz, CHCOC*H*), 4.78 (1H, d, J=4.8 Hz, C*H*COCH), 5.43 (1H, d, J=4.9 Hz, PhOC*H*), 4.85 (1H, dd, J=4.9, 4.8 Hz, PhOCHC*H*), 5.69 (1H, d, J=4.4 Hz, anomeric C*H*), 6.75 (1H, s, N*H*), 7.04 –7.37 (5H, m, Ar); δ_C (50.3 MHz, $CDCl_3$) 27.4, 29.6, 54.9, 75.1, 76.7, 81.4, 103.1, 114.2, 115.5, 115.9, 123.0, 129.7, 157.1, 166.7, 166.9; MS (*m*/*z*): 319 (M^+).

Acknowledgements

The authors (M. A. and S. N. J.) thank CSIR for the financial support.

References

1. For reviews on β-lactam antibiotics, see: (a) Dürkheimer, W.; Blumbach, J.; Lattrell, R.; Scheunemann, K. H. *Angew. Chem., Int. Ed. Engl.* **1985**, *24*, 180. (b) *Chemistry and biology of β-lactam Antibiotics*; Vols. 1–3. Morin, R. B.; Gorman, M., Eds.; Academic: New York, 1982. (c) Coulton, S.; Hunt, E. *Recent Progress in the Chemical Synthesis of Antibiotics and Related Microbial Products*; Lukacs, G., Ed.; Springer: Berlin, 1993; Vol. 2, p 621. (d) Southgate, R. *Contemp. Org. Synth.* **1994**, *1*, 417.
2. *The Chemistry of β-lactams*; Page, M. I., Ed.; Chapman and Hall: London, 1992.
3. For comprehensive general reviews, see: (a) Koppel, G. A. *Small Ring Heterocycles*; Hasner, A., Ed.; Wiley: New York, 1983; Vol. 2, p 219. (b) Backes, J. In *Houben-Weyl, Methoden der Organischem Chemie*; Muller, E., Bayer, O., Eds.; Thieme: Stuttgart, 1991; p 31 Band E16B. (c) DeKimpe, N. *Comprehensive Heterocyclic Chemistry II*; Katritzky, A. R., Rees, C. W., Scriven, E. F. V., Padwa, A., Eds.; Pergamon: Oxford, 1996; Vol. 1B, p 507.
4. Staudinger, H. *Liebigs Ann. Chem.* **1907**, *356*, 51.
5. (a) Alcaide, B.; Almendros, P. *Chem. Soc. Rev.* **2001**, *30*, 226–240. (b) Palomo, C.; Aizpurua, J.; Mielgo, A.; Linden, A. *J. Org. Chem.* **1996**, *26*, 61.
6. For reviews on asymmetric Staudinger reaction, see: (a) Cooper, R. D. G.; Daugherty, B. W.; Boyd, D. B. *Pure Appl. Chem.* **1987**, *59*, 485. (b) Van der Steen, F. H.; Van Koten, G. *Tetrahedron* **1991**, *47*, 5703. (c) Georg, G. I.; Ravikumar, V. T. *The Organic Chemistry of β-lactams*; VCH: New York, 1993; pp 295.
7. (a) Bose, A. K.; Womelsdorf, J. F.; Krishnan, L.; Urbanczyk-Lipkowska, Z.; Shelly, D. C.; Manhas, M. S. *Tetrahedron* **1991**, *47*, 5379. (b) Kawabata, T.; Kimura, Y.; Ito, Y.; Tereshima, S.; Sasaki, A.; Sanagawa, M. *Tetrahedron* **1988**, *44*, 2149.
8. Bose, A. K.; Manhas, M. S.; Van derVeen, J. M.; Bari, S. S.; Wagle, D. R. *Tetrahedron* **1992**, *48*, 4831.
9. (a) Hubschwerlen, C.; Schmid, G. *Helv. Chem. Acta.* **1983**, *66*, 206. (b) Bose, A. K.; Manhas, M. S.; Van derVeen, J. M.; Bari, S. S.; Wagle, D. R. *Tetrahedron Lett.* **1985**, *26*, 33. (c) Palomo, C.; Cossio, F. P.; Cuevas, C. *Tetrahedron Lett.* **1991**, *32*, 3109.
10. Manhas, M. S.; Amin, G. S.; Bose, A. K. *Hetrocycles* **1976**, *5*, 669.
11. (a) Banik, B. K.; Manhas, M. S.; Bose, *J. Org. Chem.* **1993**, *58*, 307. (b) Palomo, C.; Oiarbide, M.; Landa, A.; Esnal, A.; Linden, A. *J. Org. Chem.* **2001**, *66*, 4180–4186.
12. (a) Jayaraman, M.; Deshmukh, A. R. A. S.; Bhawal, B. M. *Synlett* **1992**, 749–750. (b) Jayaraman, M.; Srirajan, V.; Deshmukh, A. R. A. S.; Bhawal, B. M. *Tetrahedron* **1996**, *52*, 3741–3756. (c) Srirajan, V.; Deshmukh, A. R. A. S.; Bhawal, B. M. *Tetrahedron* **1996**, *52*, 5585–5590.
13. (a) Schimidt, O. T. *Methods Carbohydr. Chem.* **1963**, *2*, 318. (b) Stevens, J. D. *Methods Carbohydr. Chem.* **1972**, *6*, 123. (c) Brimacombe, J. S.; Ching, O. A. *Carbohydr. Res.* **1968**, *8*, 82. (d) Tsui, H. C.; Paquette, L. A. *J. Org. Chem.* **1998**, *63*, 9968–9977. (e) Yong, L. Z.; Tony, K. M. S. *J. Org. Chem.* **1997**, *62*(8), 2622–2624.
14. X-Ray data for **6b**: a=9.7300 (10) Å, b=13.598 (3) Å, c=20.599 (3) Å, α=90°C, β=90°C, γ=90°C, V=2725.4 (8) $Å^3$, z=4, ρ_{calcd}=1.261 Mg m^{-3}, $wR2$=0.1235, $R1$=0.0575, T=293 (2) K, GOF=1.233. The data were collected on Enariuf Nonius CAD-4 single crystal X-ray diffractometer using

Cu Kα radiation (λ=1.54060 Å) and $\omega-2\theta$ scan mode to a θ range of 3.89 to 59.82°C. The structure was solved by direct positional and anisotropic thermal parameters for non-hydrogen atom converged to Rw=0.1235, $R1$=0.0575 for 2314 unique observed reflections. Hydrogen atoms were geometrically fixed and confirmed by a difference Fourier that was held fixed during the refinement. The refinements were carried out using SHELEX-97.[18] Crystallographic data (excluding structure factors) for the structure **6b** in this paper has been deposited with the Cambridge Crystallographic data Centre as supplementary publication number CCDC 200446.

15. Kronenthal, D. R.; Han, C. Y.; Taylor, M. K. *J. Org. Chem.* **1982**, *47*, 2765–2768.
16. Szarek, W.; Zamojski, A.; Tiwari, K. N.; Ison, E. R. *Tetrahedron Lett.* **1986**, *27*, 3827.
17. (a) Boss, R.; Scheffold, R. *Angew. Chem., Int. Ed. Engl.* **1976**, *15*, 558. (b) Barili, P. L.; Berti, G.; Bertozzi, D.; Catelani, G.; Colonna, F.; Corsetti, T.; D'Andrea, F. *Tetrahedron* **1990**, *46*, 5365.
18. Sheldrick, G.M. SHELXL-97 Program for crystal structure solution and refinement, University of Göttingen, Germany, 1997.