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Modulating Steric Effects in Diastereoselective Staudinger Reaction : Synthesis of Optically Pure *cis*-β-Lactams

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Abstract: Diastereoselection in the synthesis of β-lactams (**14** and **15**) *via* ketene-imine cycloaddition (Staudinger reaction) using different chiral auxiliaries has been examined. While sterically demanding imines derived from bicyclic aldehyde (**1**) with a β chiral centre provided excellent selectivity, use of imines derived from bicyclic aldehyde (**17**) with a γ chiral centre was not effective. Improvement of stereoselectivity was also sought using imines (**6** and **7**) derived from chiral amines (**2d,e**) and chiral aldehyde (**1**). The bicyclic terpenoid skeleton of the chiral auxiliary in **1** was dismantled by ruthenium tetroxide oxidation to give multiply functionalized β-lactams **23a-d** in good yield.

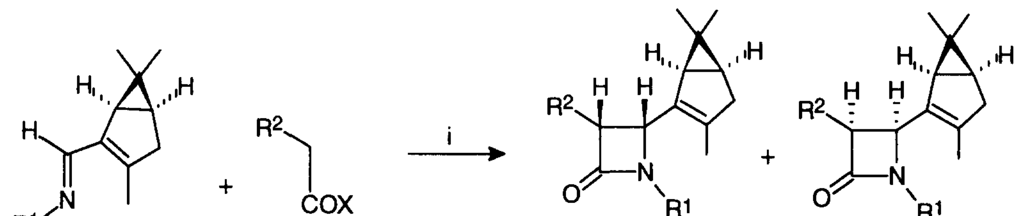
Staudinger reaction has found wide acceptance in stereoselective synthesis of β-lactams.[1,2] The organized transition state of the cycloaddition reaction offers diverse options to design suitable partners of the ketene and the imine so that product stereochemistry can be efficiently controlled. Chiral centres present at adjacent sites of the reacting groups can dictate the preference for a particular diastereoisomer.[2] Ideally, there are three sites where a chirality directing group may be located : a) the aldehyde component of the imine, b) the amine component of the imine, and, c) the ketene precursor.

It has been argued, and even theoretically corroborated, that if the aldehyde component has a chiral α-carbon with a hetero atom attached to it, high diastereoselectivity in the cycloaddition reaction is assured.[3] In the course of our studies, we observed a highly diastereoselective cycloaddition where the selectivity is controlled by a sterically demanding, bicyclic aldehyde component.[4] Significantly, the nearest chiral centre was located at the β-carbon from the aldehydic group. In this paper, we present a detailed account of this study and related results. The emphasis here is the exploitation of a readily available, homochiral precursor (+)-3-carene both as a chirality directing group as well as a latent functional appendage to be unravelled later *en route* to other potentially biological important targets.

In the first phase, the efficacy of a β-chiral centre in controlling selectivity was examined. Since a formal 2+2 cycloaddition requires a close approach of the reacting partners to attain an organized transition state and steric interaction among the substituents should be heightened as a result of proximity, it was surmised that stereoface-discrimination should be possible with a considerably bulky substituent. (+)-3-Carene is an abundantly available, inexpensive natural product with a bicyclic skeleton. The aldehyde **1** derived from (+)-3-carene retains the imposing *gem*-dimethyl group in the fused cyclopropane ring which can effectively shield one face of the molecule from reagent approach. Also, this route would provide a facile entry to a novel class of chemical entity that features a β-lactam moiety attached to a cyclopropane. These are attractive derivatives since they combine the biological activity of β-lactams with the pesticidal properties of cyclopropanes (pyrethroids).

The bicyclic aldehyde, 2-formyl-3,6,6-trimethylbicyclo(3.1.0)hex-2-ene (**1**) was prepared from optically pure (+)-3-carene by a reported procedure.[5] The aldehyde **1** on treatment with various amines (**2a-e**) in the presence of methylene chloride and anhyd $MgSO_4$, offered the imines (**3-7**) in quantitative yield. These imines (**3-7**) on treatment with the acid chlorides (**8-12**) in the presence of triethylamine at -78 °C to room temperature gave diastereomeric mixture of *cis*-β-lactams (**14** & **15**) in very high isolated yield (Scheme 1, Table 1). The

Scheme 1



	R1
3	PMP
4	Bn
5	Furfuryl
6	-CH(Me)Ph (*R*)
7	-CH(Me)Ph (*S*)

	R2	X
8	PhthN	Cl
9	PhO	Cl
10	Bn	Cl
11	MeO	Cl
12	AcO	Cl
13	N_3	O^-K^+

14a-s **15a-s**

Reagents and conditions: i) Et_3N/CH_2Cl_2, -78 °C to rt, 12 h.

azido β-lactams (**14** & **15**) were prepared by Bose's mixed anhydride method using cyanuric chloride at -78 °C.[6] No appreciable change in diasteroselectivity was observed when the reaction was carried out at higher temperatures, though the chemical yields dropped (Table 2). The highest diastereoselectivity was observed in the reaction between phthalimidoacetyl chloride (**8**) and imine **3**, which gave a 90:10 diastereomeric mixture of cis-β-lactams **14a** and **15a** in 98% yield. The ratio of two diastereomers were determined by ^1H NMR spectral data and HPLC analysis.[7] These diastereomers were separated by column chromatography. In most of the cases the major diastereomer (**14**) could also be obtained from the mixture by a single crystallization.

Use of a chiral amine in combination with the chiral aldehyde **1** had marginal effect on the diastereoselective β-lactam ring formation.[8] The imines (**6** & **7**) derived from chiral α-phenylethyl amines (**2d** & **2e**) and bicyclic aldehyde (**1**) afforded a diastereomeric mixture of β-lactams (**14p-s** & **15p-s**) in high yield but the distereoselectivity was largely unaffected. A slight improvement in diaseteroselectivity (96:4) was observed when phthalimidoacetyl chloride (**8**) and imine (**6**) derived from (*R*)-(+)-phenylethyl amine (**2d**) was used (Table 1, entry 16). However, diastereoselectivity was decreased when imines (**7**) derived from (*S*)-(-)-phenylethyl amine (**2e**) was used for β-lactam formation (Table 1, entries 18,19).

Table 1. Synthesis of β-lactams **14** and **15** by cycloaddition of imines (**3-7**) with ketene precursors (**8-13**).

Entry No.	Compds **14** & **15**	R^1	R^2	Yield[a] (%)	Ratio[b] of **14** : **15**
1	**a**	PMP-	PhthN-	98(76)	90:10
2	**b**	PMP-	PhO-	99(69)	77:33
3	**c**	PMP-	BnO-	92	75:25
4	**d**	PMP-	MeO-	80	55:45
5	**e**	PMP-	AcO-	76	85:15
6	**f**	PMP-	N_3-	66(47)	86:14
7	**g**	Bn-	PhthN-	90(72)	88:12
8	**h**	Bn-	PhO-	92	65:35
9	**i**	Bn-	BnO-	99	60:40
10	**j**	Bn-	MeO-	96	89:11
11	**k**	Bn-	AcO-	88	85:15
12	**l**	Bn-	N_3-	70(48)	67:33
13	**m**	Fu-	PhthN-	91(71)	82:18
14	**n**	Fu-	PhO-	87	70:30
15	**o**	Fu-	N_3-	68	80:20
16	**p**	(*R*)-Ph(Me)CH-	PhthN-	92	96:4
17	**q**	(*R*)-Ph(Me)CH-	PhO-	65	63:37
18	**r**	(*S*)-Ph(Me)CH-	PhthN-	86	72:28
19	**s**	(*S*)-Ph(Me)CH-	PhO-	94	55:45

[a] Isolated yields of mixture of diastereomers (**14** & **15**), numbers in parentheses refers to the isolated yields of chemically and optically pure major isomer (**14**) obtained by a single crystallization. [b] The ratio of diastereomers is determined by ^{1}H NMR and HPLC analysis.

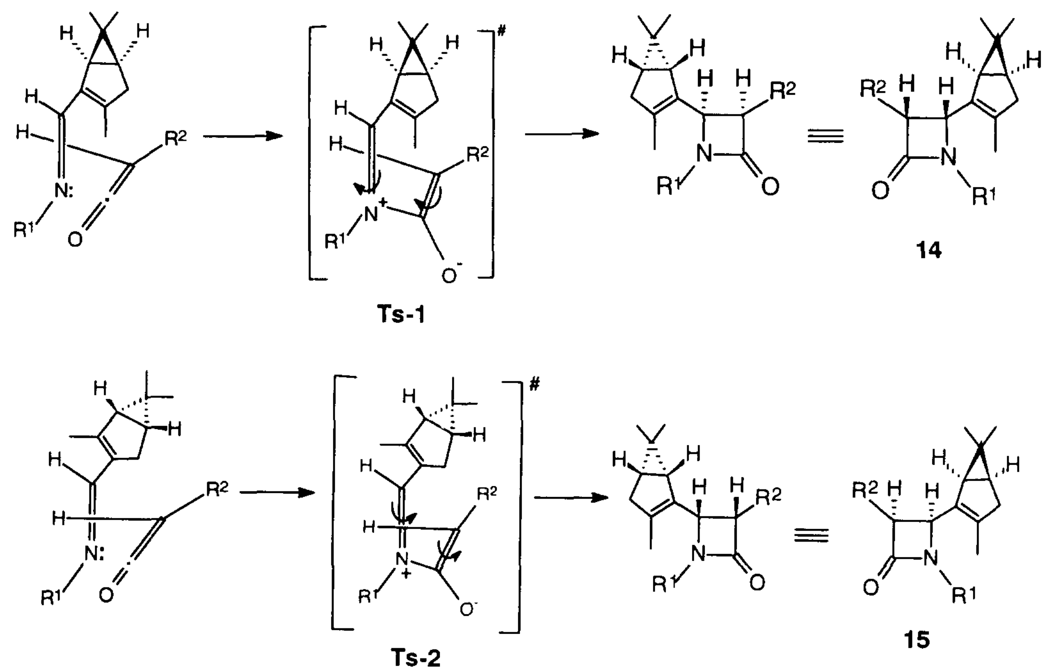
Table 2. Synthesis of β-lactams **14a** and **15a** (R^1 = PMP, R^2 = PhthN) by cycloaddition of imines (**3**) with phthalimidoacetyl chloride (**8**) at various temperature.

Entry No.	Reaction temp. (°C)	Yield[a] (%)	Ratio[b] of **14** : **15**
1	-78	98	90:10
2	-40	89	86:14
3	-15	86	85:15
4	0	69	85:15

[a] Isolated yields of mixture of diastereomers (**14a** & **15a**). [b] The ratio of diastereomers is determined by ^{1}H NMR and HPLC analysis.

We believe that the steric course of the reaction is determined by the steric bulk of the cyclopropyl group containing a *gem*-dimethyl substitution : the ketene approaches the imine from the face opposite to the cyclopropane (Scheme-2). Considering the neighboring double bond, the imine can adopt two possible orientations - *cisoid* and *transoid* with respect to the double bond. Analysis of product stereochemistry indicates that the major product **14** results from the reaction between the *cisoid* imine and the ketene from the less hindered face (TS-1). The minor product **15** results from a similar reaction between the *transoid* imine and the ketene, also approaching from the less hindered direction (Ts-2). Thus, the selectivity is a manifestation of kinetic control.

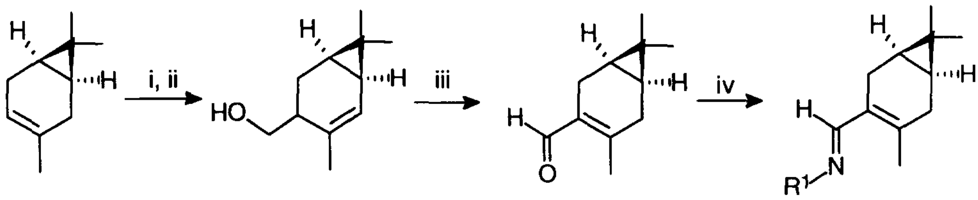
Scheme 2



While the steric bulk of the aldehyde **1** was effective in inducing substantial diastereoselectivity, it should be noted that the nearest chiral centre was at the β carbon from the aldehyde end. We examined the imines (**18** & **19**) derived from (+)-3-carene where the chiral centre is located at the γ-position in a [4.1.0] bicyclic system for possible stereodifferentiation.

The aldehyde, 3-formyl-4,7,7-trimethylbicyclo[4.1.0] hept-3-ene **17**, was obtained by Swern oxidation[9] (Scheme 3) of homochiral 3-hydroxymethyl-4,7,7- trimethylbicyclo[4.1.0]hept-3-ene (**16**), which was prepared from (+)-3-carene by following known procedure.[10] Treatment of the aldehyde **17** with amines (**2a,b**) gave the imines **18** & **19** in almost quantitative yields. These imines (**18** & **19**) on subsequent annulation by the usual ketene-imine cycloaddition procedure with acid chloride (**9** & **10**) gave almost 1:1 diastereomeric mixture of β-lactams **20** & **21** in moderate to poor isolated yields (Scheme 4, Table 3). All attempts to separate these diastereomers by chromatography failed. However, in one case the major diastereomer (**20a**) was obtained in pure form by fractional crystallization from methanol.

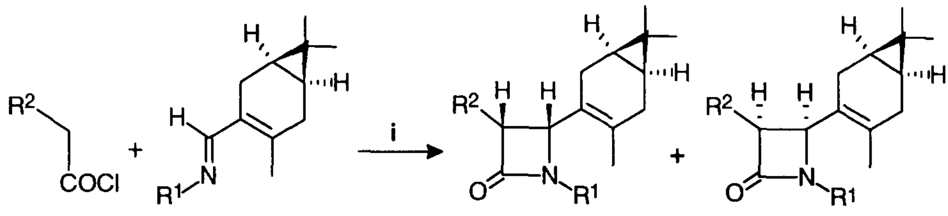
Scheme 3



(+)-3-Carene 16 17 18 R^1 = PMP
19 R^1 = Bn

Reagents and conditions: i) $(CH_2O)_n$/AcOH/reflux, 48h. ii) KOH/MeOH/reflux, 8h. iii) DMSO/$(COCl)_2$/Et_3N/CH_2Cl_2, -60 °C to rt. iv) R^1NH_2 (**2a,b**)/CH_2Cl_2/$MgSO_4$, rt, 4h.

Scheme 4



9, 10 18, 19 20a-d 21a-d

Reagents and conditions: i) Et_3N/CH_2Cl_2, -23 °C to rt, 12h.

Table 3. Synthesis of β-lactams **20** and **21** by cycloaddition of imines (**18**, **19**) with ketene precursors (**9**, **10**).

Entry No.	Compds **20 & 21**	R^1	R^2	Yield[a] (%)	Ratio[b] of **20 & 21**
1	**a**	PMP-	PhO-	46	54:46
2	**b**	Bn-	PhthN-	48	54:46
3	**c**	Bn-	PhO-	32	55:45
4	**d**	Bn-	BnO-	53	56:44

[a] Isolated yields of mixture of diastereomers (**20** & **21**). [b] The ratio of diastereomers is determined by ^1H NMR and HPLC analysis.

The stereochemistry of the major isomer (**14f**) was ascertained by single crystal X-ray diffraction analysis.[4] The absolute configuration at C-3 and C-4 positions of the β-lactam was assigned as 3*R*, 4*S* on the basis of known absolute configuration (1'*R*, 5'*S*) of the bicyclic moiety. The absolute configuration of the other β-lactams was assigned by correlating of ^1H NMR, ^{13}C NMR and HPLC analysis data with that of **14f**. This was further confirmed by shift reagent [(+)-Eu(tfc)$_3$] ^{1}H NMR experiment for some representative examples (Table 4). In all the cases the minor diastereomer showed more shift than the major diastereomer, which clearly indicate the similar trend of diastereoselectivity in β-lactam ring formation.

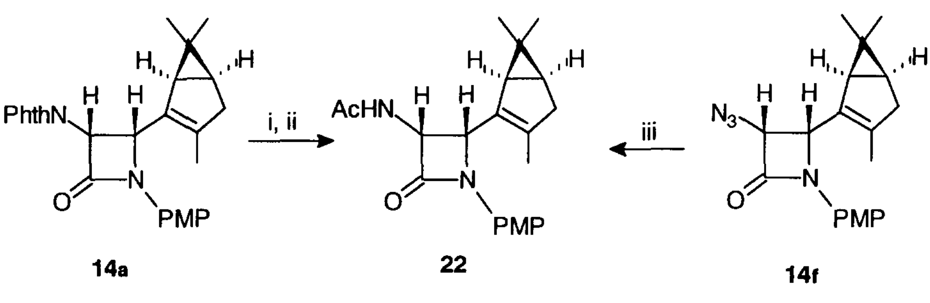
Table 4. ^{1}H NMR chemical shifts of C-3 proton of β-lactam (**14** & **15**) using [(+)-Eu(tfc)$_3$].

Entry No.	Compd.	The chemical shift (δ)					
	14 & **15**	Before the addition of [(+)-Eu(tfc)$_3$] (δ_1)		After the addition of [(+)-Eu(tfc)$_3$][a] (δ_2)		Net Shift (δ_2-δ_1)	
		Major (**14**)	Minor (**15**)	Major (**14**)	Minor (**15**)	Major (**14**)	Minor (**15**)
1	**b**	5.30	5.40	5.45	5.60	0.15	0.20
2	**f**	4.95	5.04	5.05	5.25	0.10	0.21
3	**h**	5.20	5.25	5.60	5.83	0.40	0.58
4	**m**	5.40	5.25	5.58	5.73	0.18	0.48
5	**o**	4.70	4.75	5.00	5.10	0.30	0.35

[a] 1 mole equiv shift reagent was used.

The optical rotation of each pair of diastereomers followed a consistent pattern except for the 3-phthalimido β-lactam **14a** (see experimental). To establish the configuration assignment beyond doubt for this compound, a chemical correlation was undertaken. The conversion of major diastereomer, 3-azidoβ-lactam (**14f**) to 3-acyamino-β-lactam (**22**) was accomplished by reductive acylation[11] with PPh_3 followed by treatment of acetyl chloride in presence of triethylamine (Scheme 5). The deprotection of phthalimido group of the major diastereomer **14a** by N-methylhydrazine[12] followed by acylation offered the same 3-acyamino-β-lactam (**22**). This transformation confirmed the assigned absolute configuration of the diastereomer **14a**.

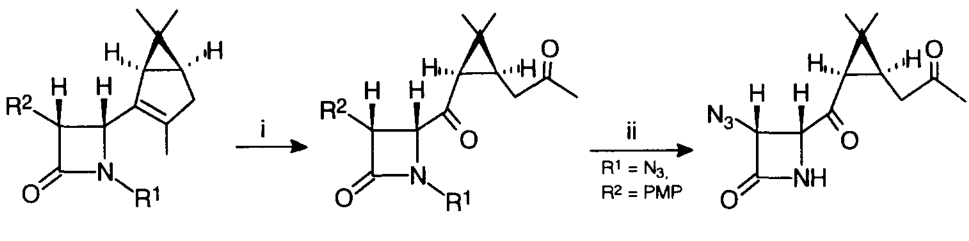
Scheme 5



Reagents and conditions: i) $MeNHNH_2/CH_2Cl_2$, rt, 32 h. ii) $AcCl/Et_3N$, rt, 1h. iii) PPh_3/C_6H_6/reflux, 8h; then $Et_3N/AcCl$, rt, 1h.

The oxidative cleavage of the bicyclic moiety at C-4 of β-lactam (**14b-d,f**) using RuO_4 offered the diketones (**23a-d**) in excellent yield (Scheme 4). The Kronethal's cerium ammonium nitrate (CAN) oxidation[13] of the diketone **23d** offered N-unsubstituted β-lactam (**24**) in 85% yield (Scheme 6). This procedure provided a new class of β-lactams with a cyclopropane substituent. The ketone functionalities can further provide access to diversely functionalized derivatives for biological screening, the results of which will be communicated later.

Scheme 6



Reagents and conditions: i) $RuCl_3/NaIO_4/CH_3CN:CCl_4:H_2O$ (2:2:3), 0 °C, 4h. ii) CAN (3 equiv.)/$CH_3CN:H_2O$, 0 °C, 1h.

To summarize, we have demonstrated that a high diastereofacial selectivity in ketene-imine cycloaddition to β-lactams can be achieved with sterically demanding imines.

Experimental Section

^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ solution on a Bruker AC 200 spectrometer at 200 and 50 MHz, respectively. The ^{1}H chemical shifts are reported in ppm downfield from tetramethylsilane. The ^{13}C chemical shifts are reported in ppm relative to the center line of $CDCl_3$ (77.0 ppm). Infrared spectra were recorded on a Perkin-Elmer Infracord Spectrophotometer Model 599-B using sodium chloride optics. Melting points were determined on a Thermonik Campbell melting point apparatus and are uncorrected. Mass spectra were determined on a Finnigan Mat-1020 spectrometer, and microanalysis were performed on a Carlo-Erba 1100 automatic analyzer. Optical rotations were recorded on a JASCO-181 digital polarimeter under standard conditions. Methylene chloride was distilled over P_2O_5, toluene was freshly distilled over potassium-benzophenone ketyl under argon. Silica gel (SD's, 60-120 mesh) was used for column chromatography.

General procedure for the preparation of imines 3-7. To a solution of amine [**2a-e**, 20 mmol, *p*-anisidine (**2a**), benzylamine (**2b**), furfurylamine (**2c**), (*R*)-phenylethyl amine (**2d**) or (*S*)-phenylethyl amine (**2e**)] in dry CH_2Cl_2 (50 mL), aldehyde **1** (21 mmol) was added in presence of anhyd $MgSO_4$ (10 g) and the resulting mixture was stirred at r.t. for 24 h. The reaction mixture was then filtered and the solid was washed with CH_2Cl_2. The combined filtrates were concentrated to get imine **3-7** in almost quantitative yields. The imines thus obtained were sufficiently pure and were used without further purification.

A general procedure for the synthesis of the β-lactam (14a-s & 15a-s). A solution of the acid chloride (**8-12**, 7.5 mmol) in dry CH_2Cl_2 (20 mL) was slowly added to a solution of imines (**3-7**, 5 mmol) and triethylamine (20 mmol) in CH_2Cl_2 (20 mL) at -78 °C. The reaction mixture was then allowed to warm up to room temperature and stirred further for 12 h. It was then washed with water (30 mL), satd. $NaHCO_3$ (30 mL) and brine. The organic layer was dried (anhyd Na_2SO_4) and concentrated to give a diastereomeric mixture of β-lactams **14a-s** and **15a-s** in 68-99% yield. The diastereomers **14** (major) and **15** (minor) were separated by column chromatography (silica gel, 60-120 mesh, 10% EtOAc in pet. Ether) and in some cases the major diastereomer **14** was isolated by single crystallization using suitable solvents. In few cases the diastereomers could not be separated from mixture by column chromatography.

($3R,4S,1'R,5'S$) and ($3S,4R,1'R,5'S$) 1-(p-Anisyl)-3-phthalimido-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]-azetidin-2-one (14a and 15a). The two diastereomers **14a** (major) and **15a** (minor) were separated by column chromatography.

14a ($3R,4S,1'R,5'S$). M.p. : 143-144 °C (CH_2Cl_2-pet. Ether). $[\alpha]^{25}_D$: -14.6 (c 1, CH_2Cl_2). ^1H NMR: δ 0.60 (s, 3H, CH_3); 0.67 (s, 3H, CH_3); 0.92 - 1.03 (m, 1H, C5 ' H); 1.40 (s, 3H, CH_3); 1.70 - 1.90 (m, 2H, C1' H, C4' H); 2.05 (dd, J = 10 & 20 Hz, 1H, C4' H); 3.80 (s, 3H, OCH_3); 5.10 (d, J = 5 Hz, 1H, C4 H); 5.60 (d, J = 5 Hz, 1H, C3 H); 6.85 (d, J = 9 Hz, 2H, Arm); 7.35 (d, J = 9 Hz, 2H, Arm); 7.60 - 7.85 (m, 4H, Arm); ^{13}C NMR: δ 13.4 (CH_3), 13.5 (CH_3), 20.5 (C6'), 25.7 (CH_3), 26.2 (C5'), 38.3 (C1'), 38.8 (C4'), 56.6 (OCH_3), 56.8 (C4), 57.8 (C3), 114.2, 119.2, 123.6, 129.6, 131.4, 131.8, 134.4, 137.4, 156.7, 160. 8 (β-lactam CO), 166.8 (Phth- CO); IR: 1760, 1730 and 1520 cm^{-1}. Anal. Calcd $C_{27}H_{26}O_4N_2$: C, 73.28; H, 5.92; N, 6.33. Found: C, 73.6; H, 6.2; N, 6.1.

15a ($3S,4R,1'R,5'S$). M.p. :188-190 °C (CH_2Cl_2-pet. Ether). $[\alpha]^{25}_D$: -10.7 (c 1, CH_2Cl_2); ^1H NMR: δ 0.35 (s, 3H, CH_3); 0.75 (s, 3H, CH_3); 1.05 - 1.15 (m, 1H, C5 ' H); 1.60 - 1.70 (m, 1H, C1' H); 1.75 (s, 3H, CH_3); 1.95 (d, J = 20 Hz, 1H, C4' H); 2.40 (dd, J = 10 & 20 Hz, 1H, C4' H); 3.80 (s, 3H, OCH_3); 5.10 (d, J = 5 Hz, 1H, C4 H); 5.50 (d, J = 5Hz, 1H, C3 H); 6.47 (d, J = 9 Hz, 2H, Arm); 6.90 (d, J = 9 Hz, 2H, Arm); 7.70 - 7.95 (m, 4H, Arm); ^{13}C NMR: δ 12.7, 13.3, 20.4, 25.4, 27.3, 37.5, 38.5, 55.3, 56.8, 57.8, 114.2, 118.2, 123.4, 127.3, 131.6, 131.9, 134.2, 143.1, 156.2, 160.4 (β-lactam CO), 166.6 (Phth- CO); IR: 1760, 1730 and 1520 cm^{-1}. Anal. Calcd $C_{27}H_{26}O_4N_2$: C, 73.28; H, 5.92; N, 6.33. Found: C, 73.58; H, 6.06; N, 6.39.

($3R,4S,1'R,5'S$) and ($3S,4R,1'R,5'S$) 1-(p-Anisyl)-3-phenoxy-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]-azetidin-2-one (14b and 15b). The two diastereomers **14b** (major) and **15b** (minor) were separated by column chromatography.

14b ($3R,4S,1'R,5'S$). M.p. 150-151 °C (CH_2Cl_2-pet. Ether). $[\alpha:]^{25}_D$: +20.1 (c 0.5, CH_2Cl_2). ^1H NMR: δ 0.55 (s, 3H, CH_3); 0.90 (s, 3H, CH_3); 1.00 - 1.12 (t, J = 5 Hz, 1H, C5 'H); 1.60 (s, 1H, C1' H); 1.75 (s, 3H, CH_3); 1.98 (d, J = 20 Hz, 1H, C4' H); 2.38 (dd, J = 10 & 20 Hz, 1H, C4' H); 3.70 (s, 3H, OCH_3); 5.05 (d, J = 5 Hz, 1H, C4 H); 5.30 (d, J = 5 Hz, 1H, C3 H); 6.80 (d, J = 9 Hz, 2H, Arm); 6.85 - 7.00 (m, 3H, Arm); 7.15 - 7.35 (m, 4H, Arm); ^{13}C NMR: δ 13.6 (CH_3), 14.2 (CH_3), 21.5 (C6'), 26.4 (CH_3), 27.3 (C5'), 37.8 (C1'), 38.7 (C4'), 55.5 (OCH_3), 57.2 (C4), 82.0 (C3), 114.6, 116.0, 118.7, 122.1, 129.2, 129.5, 131.4, 141.9, 156.6, 158.5, 163.3 (β-lactam CO). IR: 1760 cm^{-1}. Anal. Calcd for $C_{25}H_{27}O_3N$: C, 77.09; H, 6.99; N, 3.59. Found: C, 76.65; H, 7.12; N, 3.42.

15b ($3S,4R,1'R,5'S$). M.p. 83-85 °C (CH_2Cl_2-pet. Ether). $[\alpha:]^{25}_D$: -48.2 (c 1, CH_2Cl_2). ^1H NMR: δ 0.16 (s, 3H, CH_3); 0.72 (s, 3H, CH_3); 1.00 - 1.10 (m, 1H, C5 'H); 1.60 (s, 3H, CH_3); 1.72 - 1.90 (m, 2H, C1' H, C4' H); 2.00 - 2.20 (dd, J = 10 & 20 Hz, 1H, C4' H); 3.70 (s, 3H, OCH_3); 5.00 (d, J = 5 Hz, 1H, C4 H); 5.40 (d, J = 5 Hz, 1H, C3 H); 6.77 (d, J = 9 Hz, 2H, Arm); 6.85 - 7.00 (m, 3H, Arm); 7.10 - 7.30 (m, 4H, Arm); ^{13}C NMR: δ 12.8, 13.1, 20.2, 25.7, 26.2, 37.5, 38.2, 55.1, 55.8, 80.8, 113.8, 115.3, 118.8, 121.7, 128.9, 129.3, 130.5, 140.5, 156.3, 157.1, 162.3 (β-lactam CO); MS: m/z 389 (M^+, 70%), 296 (25), 268 (33), 240 (100); IR: 1760, 1600, 1520 cm^{-1}.

($3R,4S,1'R,5'S$) and ($3S,4R,1'R,5'S$) 1-(p-Anisyl)-3-benzyloxy-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14c and 15c). The two diastereomers **14c** (major) and **15c** (minor) were separated by column chromatography.

14c ($3R,4S,1'R,5'S$). M.p. 90 °C (CH_2Cl_2-pet. Ether). $[\alpha]^{25}_D$: +32.6 (c 1, CH_2Cl_2). ^1H NMR: δ 0.70 (s, 3H, CH_3); 0.90 (s, 3H, CH_3); 1.10 - 1.20 (m, 1H, C5 'H); 1.60 - 1.70 (m, 1H, C1' H); 1.80 (s, 3H, CH_3); 2.10 (d, J = 20 Hz, 1H, C4' H); 2.38 (dd, J = 10 & 20 Hz, 1H, C4' H); 3.80 (s, 3H, OCH_3); 4.80 (d, J = 5 Hz, 1H, C4 H); 4.80 - 4.95 (m, 3H, C3 H, OBn); 6.85 (d, J = 9 Hz, 2H, Arm); 7.30 - 7.50 (m, 7H, Arm); ^{13}C NMR: δ 13.6 (CH_3), 14.0 (CH_3), 21.3 (C6'), 26.3 (CH_3), 27.1 (C5'), 38.2 (C1'), 38.7 (C4'), 55.5 (OCH_3), 56.7 (C4), 73.1 (Bn), 82.6 (C3), 114.4, 118.5, 128.1, 128.5, 129.5, 131.6, 137.3, 140.9, 156.3, 165.3 (β-lactam CO).

15c ($3S,4R,1'R,5'S$). M.p: 92 °C (CH_2Cl_2-pet. Ether). $[\alpha]^{25}_D$: +20.8 (c 1, CH_2Cl_2). ^1H NMR: δ 0.25 (s, 3H, CH_3); 0.80 (s, 3H, CH_3); 1.15 - 1.30 (m, 1H, C5 'H); 1.67 (s, 1H, C1' H); 1.75 (s, 3H, CH_3); 2.05 (d, J = 10 Hz, C4' H); 2.50 (d, J = 10 & 20 Hz, 1H, C4' H); 3.80 (s, 3H, OCH_3); 4.60 (d, J = 11 Hz, 1H, BnO); 4.72 (d, J = 11 Hz, 1H, BnO); 4.85 - 4.95 (m, 2H, C3 H & C4 H); 6.85 (d, J = 9 Hz, 2H, Arm); 7.22 (d, J = 9 Hz, 2H, Arm); 7.30 - 7.45 (m, 5H, Arm); ^{13}C NMR: δ 13.0 (CH_3), 13.4 (CH_3), 20.6 (C6'), 26.0 (CH_3), 26.4 (C5'), 37.8 (C1'), 38.4

(C4'), 55.2 (OCH_3), 55.8 (C4), 72.9 (Bn), 82.7 (C3), 113.9, 118.9, 127.8, 128.0, 128.2, 130.8, 137.0, 139.8, 156.2, 163.9 (β-lactam CO); IR : 1760, 1530 cm^{-1}. Anal. Calcd for $C_{26}H_{29}O_3N$: C, 77.43; H, 7.19; N, 3.47. Found: C, 77.58; H, 7.06; N, 3.39.

(3*R*,4*S*,1'*R*,5'*S*) and (3*S*,4*R*,1'*R*,5'*S*) 1-(p-Anisyl)-3-methoxy-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14d and 15d). The two diastereomers **14d** (major) and **15d** (minor) were separated by column chromatography.

14d (3*R*,4*S*,1'*R*,5'*S*). M.p. 115-118 °C (CH_2Cl_2-pet. Ether). $[\alpha]^{25}_D$: +56.1 (c 1, CH_2Cl_2). ^{1}H NMR: δ 0.85 (s, 3H, CH_3); 1.00 (s, 3H, CH_3); 1.15 - 1.25 (m, 1H, C5 'H); 1.55 - 1.65 (m, 1H, C1' H); 1.77 (s, 3H, CH_3); 2.10 (d, *J* = 20 Hz, 1H, C4' H); 2.50 (dd, *J* = 10 & 20 Hz, 1H, C4' H); 3.55 (s, 3H, OCH_3); 3.80 (s, 3H, OCH_3); 4.65 (d, *J* = 5 Hz, 1H, C4 H); 4.90 (d, *J* = 5 Hz, 1H, C3 H); 6.90 (d, *J* = 9 Hz, 2H, Arm); 7.40 (d, *J* = 9 Hz, 2H, Arm); ^{13}C NMR: δ 13.4 (CH_3), 14.1 (CH_3), 21.4 (C6'), 26.4 (CH_3), 27.1 (C5'), 37.9 (C1'), 38.6 (C4'), 55.4 (OCH_3), 56.7 (OCH_3), 59.2 (C4), 85.1 (C3), 114.3, 118.3, 129.7, 131.6, 140.7, 156.3, 164.7 (β-lactam CO).

15d (3*S*,4*R*,1'*R*,5'*S*). M.p.: 147-148 °C (CH_2Cl_2-pet. Ether). $[\alpha]^{25}_D$: -149.6 (c 1, CH_2Cl_2). ^{1}H NMR: δ 0.25 (s, 3H, CH_3); 0.80 (s, 3H, CH_3); 1.15 - 1.30 (m, 1H, C5 'H); 1.80 (s, 3H, CH_3); 1.90 - 2.10 (m, 2H, C1' H, C4'H); 2.55 (dd, *J* = 10 & 20 Hz, 1H, C4' H); 3.50 (s, 3H, OCH_3); 3.75 (s, 3H, OCH_3); 4.70 (d, *J* = 5 Hz, 1H, C4 H); 4.95 (d, *J* = 5Hz, 1H, C3 H); 6.85 (d, *J* = 9 Hz, 2H, Arm); 7.25 (d, *J* = 9 Hz, 2H, Arm); ^{13}C NMR: δ 13.2, 13.4, 20.7, 26.1, 26.5, 37.8, 38.6, 55.4, 55.6, 58.7, 84.7, 114.0, 119.1, 130.7, 130.9, 140.1, 156.4, 164.2 (β-lactam CO); IR: 1740 and 1520 cm^{-1}. Anal. Calcd for $C_{20}H_{25}O_3N$: C, 73.41; H, 7.64; N, 4.28. Found: C, 73.38; H, 7.86; N, 4.33.

(3*R*,4*S*,1'*R*,5'*S*) and (3*S*,4*R*,1'*R*,5'*S*) 3-Acetoxy-1-(p-anisyl)-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14e and 15e). The mixture of diastereomers **14e** and **15e** was obtained in 76% yield as an oil, which could not be separated by column chromatography. $[\alpha]^{25}_D$ (*Mixture*): -60.66 (c 1, CH_2Cl_2). ^{1}H NMR (*Mixture*): δ 0.32 and 0.82 (s, total 3H, CH_3); 0.75 and 1.00 (s, total 3H, CH_3); 1.15 - 1.27 (m, 1H, C5' H); 1.60 - 1.70 (m, 1H, C1' H); 1.70 (s, 3H, CH_3); 1.97 (d, *J* = 20 Hz, 1H, C4' H); 2.10 and 2.15 (s, total 3H, Ac); 2.45 (dd, *J* = 10 & 20 Hz, 1H, C4' H); 3.80 (s, 3H, CH_3); 5.00 and 5.07 (d, *J* = 5 Hz, total 1H, C4 H); 5.85 and 5.95 (d, *J* = 5 Hz, total 1H, C3 H); 6.85 (d, *J* = 9 Hz, 2H, Arm); 7.32 (d, *J* = 9 Hz, 2H, Arm); ^{13}C NMR (*Mixture*): δ 12.9, 13.1, 13.3, 13.8, 20.1, 20.6, 20.8, 25.8, 26.1, 27.0, 27.9, 37.3, 37.6, 38.5, 55.2, 55.7, 56.6, 75.7, 76.2, 113.9, 114.2, 118.2, 118.9, 127.6, 128.9, 130.3, 130.8, 141.4, 142.2, 156.3, 161.5, 161.9, 169.1, 169.5 ; IR: 1750 and 1740 cm^{-1}.

(3*R*,4*S*,1'*R*,5'*S*) and (3*S*,4*R*,1'*R*,5'*S*) 1-(p-Anisyl)-3-azido-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14f and 15f). The two diastereomers **14f** (major) and **15f** (minor) were separated by column chromatography.

14f (3*R*,4*S*,1'*R*,5'*S*). M.p. 105 °C (MeOH). $[\alpha]^{25}_D$: +108.4 (c 0.5, $CHCl_3$). ^{1}H NMR: δ 0.90 (s, 3H, CH_3); 1.05 (s, 3H, CH_3); 1.20 - 1.30 (m, 1H, C5 'H); 1.55 - 1.70 (m, 1H, C1' H); 1.78 (s, 3H, CH_3); 2.15 (d, *J* = 20 Hz, 1H, C4' H); 2.50 (dd, *J* = 10 & 20 Hz, 1H, C4' H); 3.80 (s, 3H, OCH_3); 4.85 (d, *J* = 5 Hz, 1H, C4 H); 4.95 (d, *J* = 5 Hz, 1H, C3 H); 6.87 (d, *J* = 9 Hz, 2H, Arm); 7.35 (d, *J* = 9 Hz, 2H, Arm); ^{13}C NMR: δ 13.6 (CH_3), 13.9 (CH_3), 21.7 (C6'), 26.4 (CH_3), 27.5 (C5'), 37.4 (C1'), 38.7 (C4'), 55.5 (OCH_3), 56.3 (C4), 67.2 (C3), 114.5, 118.5, 128.6, 131.1, 142.8, 156.6, 161.2 (β-lactam CO). IR (Neat): 2120 and 1760 cm^{-1}. Anal. Calcd for $C_{19}H_{22}O_2N_4$: C, 67.43; H, 6.55; N, 16.55. Found: C, 67.38; H, 6.78; N, 16.42.

15f (3*S*,4*R*,1'*R*,5'*S*). $[\alpha]^{25}_D$: -154.8 (c 2, CH_2Cl_2). ^{1}H NMR: δ 0.35 (s, 3H, CH_3); 0.80 (s, 3H, CH_3); 1.25 - 1.30 (m, 1H, C5' H); 1.80 (bs, 4H, CH_3, C1' H); 2.07 (d, *J* = 20 Hz, 1H, C4' H); 2.57 (dd, *J* = 10 & 20 Hz, 1H, C4' H); 3.80 (s, 3H, OCH_3); 4.95 (d, *J* = 5 Hz, 1H, C4 H); 5.04 (d, *J* = 5 Hz, 1H, C3 H); 6.85 (d, *J* = 9 Hz, 2H, Arm); 7.20 (d, *J* = 9 Hz, 2H, Arm); ^{13}C NMR: δ 13.4 (CH_3), 20.9 (C6'), 26.0 (CH_3), 26.7 (C5'), 37.9 (C1'), 38.7 (C4'), 55.3 (OCH_3), 55.5 (C4), 66.9 (C3), 114.2, 119.3, 129.3, 130.4, 141.8, 156.8, 161.2 (β-lactam CO) MASS: 338 (M+, 7%), 310 (10), 255 (25), 160 (50), 146 (100) IR: 2120 and 1760 cm^{-1}. Anal. Calcd for $C_{19}H_{22}O_2N_4$: C, 67.43; H, 6.55; N, 16.55. Found: C, 67.0; H, 6.1; N, 16.8.

(3*R*,4*S*,1'*R*,5'*S*) 1-Benzyl-3-phthalimido-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14g). The major diastereomer **14g (3*R*,4*S*,1'*R*,5'*S*)** was obtained in pure form by a single crystallization in 72% yield from diastereomeric mixture. M.p. 149-150 °C (CH_2Cl_2-pet. Ether). $[\alpha]^{25}_D$: -28 (c 1, CH_2Cl_2). ^1H NMR: δ 0.77 (s, 3H, CH_3); 1.05 (s, 3H, CH_3); 1.07 - 1.15 (m, 1H, C5 ' H); 1.30 (s, 3H, CH_3); 1.85 (d, *J* = 20 Hz, 1H, C4' H); 2.00 - 2.25 (m, 2H, C1' H, C4' H); 4.07 (d, *J* = 15.2 Hz, 1H, Bn); 4.55 (d, *J* = 5.2 Hz, 1H, C4 H); 5.15 (d, *J* = 15 .2 Hz, 1H, Bn); 5.47 (d, *J* = 5.2 Hz, 1H, C3 H); 7.20 - 7.45 (m, 5H, Arm); 7.72 - 7.95 (m, 4H, Arm); ^{13}C NMR: δ 13.0 (CH_3), 13.6 (CH_3), 20.4 (C6'), 25.9 (CH_3), 26.3 (C5'), 37.8 (C1'), 37.9 (C4'), 45.4 ($PhCH_2$), 55.5 (C4), 58.3 (C3), 123.4, 127.7, 128.1, 128.8, 129.4, 131.5, 134.3, 135.3, 137.8, 164.0 (β-lactam CO), 166.6 (Phth- CO); MS: *m/z* 426 (M^+, 58%), 411 (50), 383 (20), 335 (25), 275 (50), 91 (100); IR: 1770, 1720 and 1460 cm^{-1}. Anal. Calcd $C_{27}H_{26}O_3N_2$: C, 76.03; H, 6.14; N, 6.57. Found: C, 75.73; H, 6.12; N, 6.42.

(3*R*,4*S*,1'*R*,5'*S*) and (3*S*,4*R*,1'*R*,5'*S*) 1-Benzyl-3-phenoxy-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14h and 15h). The two diastereomers **1.6h** (major) and **1.7h** (minor) were separated by column chromatography.

14h (3*R*,4*S*,1'*R*,5'*S*). Isolated as an oil. $[\alpha]^{25}_D$: -21.6 (c 1, CH_2Cl_2). ^1H NMR: δ 0.40 (s, 3H, CH_3); 1.00 (s, 3H, CH_3); 1.10 - 1.20 (m, 1H, C5 ' H); 1.52 (s, 3H, CH_3); 1.65 - 1.75 (m, 1H, C1' H); 2.00 (d, *J* = 20 Hz, 1H, C4' H); 2.42 (dd, *J* = 10 & 20 Hz, 1H, C4' H); 4.00 (d, *J* = 15 Hz, 1H, Bn); 4.57 (d, *J* = 4.5 Hz, 1H, C4 H); 4.77 (d, *J* = 15 Hz, 1H, Bn); 5.30 (d, *J* = 4.5 Hz, 1H, C3 H); 6.90 - 7.10 (m, 3H, Arm); 7.20 - 7.45 (m, 7H, Arm); ^{13}C NMR: δ 13.2, 13.4, 20.9, 26.4, 27.0, 37.7, 38.4, 44.4, 55.6, 82.3, 115.5, 121.8, 127.8, 128.4, 128.7, 128.9, 129.2, 129.4, 135.2, 142.6, 158.3, 166.2 (β-lactam CO); MS: *m/z* 373 (M^+, 20%), 318 (12), 237 (10), 147 (12) and 91 (100); IR: 1770 and 1600 cm^{-1}.

15h (3*S*,4*R*,1'*R*,5'*S*). M.p. 111-112 °C (CH_2Cl_2-pet. Ether). $[\alpha]^{25}_D$: -35.7 (c 1, CH_2Cl_2); ^1H NMR: δ 0.90 (s, 3H, CH_3); 1.10 (s, 3H, CH_3); 1.10 - 1.20 (m, 1H, C5 ' H); 1.47 (s, 3H, CH_3); 1.90 - 2.10 (m, 2H, C1' H, C4' H); 2.25 (dd, *J* = 10 & 20 Hz, 1H, C4' H); 3.80 (d, *J* = 15 Hz, 1H, Bn); 4.53 (d, *J* = 4.5 Hz, 1H, C4 H); 5.00 (d, *J* = 15 Hz, 1H, Bn); 5.35 (d, *J* = 4.5 Hz, 1H, C3 H); 6.90 - 7.05 (m, 4H, Arm); 7.20 - 7.55 (m, 6H, Arm); ^{13}C NMR: δ 12.7, 13.9, 20.1, 26.0, 37.5, 38.1, 44.2, 55.0, 81.7, 115.2, 121.5, 127.6, 128.0, 128.4, 128.6, 128.9, 129.1, 134.9, 140.7, 157.0, 165.3; MS: *m/z* 373 (M^+, 20%), 318 (12), 237 (10), 147 (12) and 91 (100); IR: 1770 and 1600 cm^{-1}. Anal. Calcd $C_{25}H_{27}O_2N$: C, 80.39; H, 7.29; N, 3.75. Found: C, 80.37; H, 7.61; N, 4.00.

(3*R*,4*S*,1'*R*,5'*S*) and (3*S*,4*R*,1'*R*,5'*S*) 1-Benzyl-3-benzyloxy-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14i and 15i). The mixture of two diastereomers **14i** and **15i** was isolated as an oil in 99% yield, which could not be separated by column chromatography. $[\alpha]^{25}_D$: (*Mixture*) -12.6 (c 1, CH_2Cl_2). ^1H NMR (*Mixture*): δ 0.62 and 0.92 (s, total 3H, CH_3); 0.85 and 1.10 (s, total 3H, CH_3); 1.25 - 1.35 (m, 1H, C5' H); 1.52 (s, 3H, CH_3); 2.00 2.20 (m, 2H, C4' H, C1' H); 2.32 - 2.57 (m, 1H, C4' H); 3.72 (d, *J* = 15 Hz, 1H, $PhCH_2$); 3.90 (d, *J* = 15 Hz, 1H, $PhCH_2$); 4.20 - 5.00 (m, 4H); 7.12 - 7.40 (m, 10H, Arm); ^{13}C NMR: (*Mixture*): δ 12.8, 13.0, 13.5, 14.2, 20.4, 20.6, 26.0, 26.3, 26.4, 26.7, 38.0, 38.4, 44.0, 44.2, 54.9, 55.1, 72.6, 72.7, 73.0, 83.2, 83.6, 127.1, 127.5, 127.6, 127.7, 127.8, 127.9, 128.1, 128.2, 128.5, 128.7, 129.0, 130.8, 135.3, 137.0, 137.1, 137.4, 139.7, 141.4, 166.8, 167.9; IR: 1750 cm^{-1}.

(3*R*,4*S*,1'*R*,5'*S*) and (3*S*,4*R*,1'*R*,5'*S*) 1-Benzyl-3-methoxy-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14j and 15j). The two diastereomers **14j** and **15j** could not be separated by column chromatography, which is isolated as an oily mixture in 96% yield. $[\alpha]^{25}_D$ ***(Mixture)***: -26.2 (c 1, CH_2Cl_2). ^1H NMR: ***(Mixture)***: δ 0.75 and 0.90 (s, total 3H, CH_3); 1.00 and 1.10 (s, total 3H, CH_3); 1.15 - 1.30 (m, 1H, C5' H); 1.50 and 1.52 (s, total 3H, CH_3); 1.60 - 1.80 (m, 1H, C1' H); 1.95 - 2.15 (m, C4' H); 2.35 - 2.65 (m, 1H, C4' H); 3.42 and 3.45 (s, total 3H, OCH_3); 3.12 and 3.90 (d, *J* = 15 Hz, total 1H, Bn); 4.25 - 4.35 (m, 1H, C4 H); 4.50 - 4.60 (m, 1H, C3 H); 4.72 and 4.90 (d, *J* = 15 Hz, total 1H, Bn); 7.12 - 7.45 (m, 5H, Arm); ^{13}C NMR: ***(Mixture)***: δ 12.4, 12.6, 13.4, 13.7, 19.9, 20.4, 25.9, 26.4, 37.4, 37.9, 43.7, 54.4, 54.7, 57.9, 58.4, 85.3, 127.2, 127.7, 128.3, 128.8, 130.1, 134.9, 139.3, 140.8, 166.5, 167.1; IR: 1750 cm^{-1}.

(3*R*,4*S*,1'*R*,5'*S*) and (3*S*,4*R*,1'*R*,5'*S*) 3-Acetoxy-1-benzyl-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14k and 15k). The diastereomeric mixture of **14k** and **15k** was isolated as an oil in 88% and could not be separated by column chromatography. $[\alpha]^{25}_D$ *(Mixture)*: -25.43 (c 1, CH_2Cl_2). ^{1}H NMR: *(Mixture)*: δ 0.72 and 0.87 (s, total 3H, CH_3); 1.02 and 1.07 (s, total 3H, CH_3); 1.13 - 1.27 (m, 1H, C5' H); 1.50 (s, 3H, CH_3); 1.65 1.80 (m, 2H, C4' H, C1' H); 2.07 and 2.15 (s, total 3H, Ac); 2.30 - 2.47 (m, 1H, C4' H); 3.77 and 3.95 (d, J = 15 Hz, total 1H, $PhCH_2$); 4.47 (d, J = 5 Hz, 1H, C4 H); 4.70 and 4.92 (d, J = 15 Hz, total 1H, $PhCH_2$); 5.70 and 5.82 (d, J = 5 Hz, total 1H, C3 H); 7.15 - 7.45 (m, 5H, Arm) ^{13}C NMR: *(Mixture)*: δ 12.7, 13.0, 13.4, 13.7, 14.0, 20.0, 20.4, 20.7, 26.2, 27.0, 37.7, 38.3, 44.5, 55.1, 76.6, 78.1, 127.7, 128.0, 128.4, 128.6, 128.7, 129.0, 135.0, 141.5, 143.0, 164.5, 165.0, 169.2, 169.5; IR: 1750 cm^{-1}.

(3*R*,4*S*,1'*R*,5'*S*) 3-Azido-1-benzyl-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14l). The diastereomeric mixture of **14l** and **15l** was obtained in 70% yield from which the major diastereomer **14l** was obtained in pure form (48%) by a single crystallization (MeOH). M.p. 105 - 107 °C. $[\alpha]^{25}_D$: +62.0 (c 1, CH_2Cl_2). ^{1}H NMR: δ 0.80 (s, 3H, CH_3); 1.10 (s, 3H, CH_3); 1.20 - 1.30 (m, 1H, C5 'H); 1.50 (s, 3H, CH_3); 1.60 - 1.70 (m, 1H, C1' H); 2.10 (d, J = 20 Hz, 1H, C4' H); 2.45 (dd, J = 10 & 20 Hz, 1H, C4' H); 3.95 (d, J = 14.5 Hz, 1H, $PhCH_2$); 4.35 (d, J = 5 Hz, 1H, C4 H); 4.65 - 4.80 (m, 2H, $PhCH_2$, C3 H); 7.10 - 7.50 (m, 5H, Arm); ^{13}C NMR: δ 13.2, 13.7, 21.5, 26.5, 27.5, 37.3, 38.5, 45.0, 54.8, 67.7, 128.0, 128.2, 128.8, 134.8, 143.6, 164.2; MS: *m/z* 322 (M+, 2%), 294 (15), 224 (15), 176 (18), 146 (30) and 91 (100); IR: 2100, 1760 and 1650 cm^{-1}. Anal. Calcd $C_{19}H_{22}ON_4$: C, 70.78; H, 6.88; N, 17.38. Found C, 70.68; H, 6.63; N, 17.45.

(3*R*,4*S*,1'*R*,5'*S*) and (3*S*,4*R*,1'*R*,5'*S*) 1-Furfuryl-3-phthalimido-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14m and 15m). The two diastereomers **14m** and **15m** were separated by column chromatography. The major diastereomer **14m** was also obtained in 72% yield by single crystallization from another run.

14m (3*R*,4*S*,1'*R*,5'*S*). M.p. 151 - 153 °C (CH_2Cl_2-pet. Ether). $[\alpha]^{25}_D$: -38 (c 1, CH_2Cl_2). ^{1}H NMR: δ 0.75 (s, 3H, CH_3); 1.05 (s, 3H, CH_3); 1.05 - 1.15 (m, 1H, C5 ' H); 1.30 (s, 3H, CH_3); 1.82 (d, J = 20 Hz, 1H, C4' H); 1.95 - 2.05 (m, 1H, C1' H); 2.20 (dd, J = 10 & 20 Hz, 1H, C4' H); 4.07 (d, J = 15 Hz, 1H, Bn); 4.55 (d, J = 5 Hz, 1H, C4 H); 5.05 (d, J = 15 Hz, 1H, Bn); 5.45 (d, J = 5 Hz, 1H, C3 H); 6.25 - 6.40 (m, 2H, Arm); 7.40 (d, J = 2 Hz, Arm); 7.70 - 7.95 (m, 4H, Arm); ^{13}C NMR: δ 13.2, 13.4, 20.4, 26.0, 26.3, 37.8, 37.9, 56.1, 58.3, 108.5, 110.4, 123.4, 129.3, 131.5, 134.3, 137.9, 142.6, 148.7, 163.6, 166.5; MS: *m/z* 416 (M^+, 50%), 401 (50), 335 (50), 269 (60), 188 (50), 81 (100); IR: 1770 and 1730 cm^{-1}. Anal. Calcd $C_{25}H_{24}O_4N_2$: C, 72.09; H, 5.81; N, 6.73. Found C, 71.90; H, 5.50; N, 6.78.

15m (3*S*,4*R*,1'*R*,5'*S*). Isolated as an oil. $[\alpha]^{25}_D$: +41.2 (c 1, CH_2Cl_2). ^{1}H NMR: δ 0.15 (s, 3H, CH_3); 0.65 (s, 3H, CH_3); 1.00 - 1.15 (m, 1H, C5 ' H); 1.25 - 1.40 (m, 1H, C1' H); 1.60 (s, 3H, CH_3); 1.90 (d, J = 20 Hz, 1H, C4' H); 2.35 (dd, J = 10 & 20 Hz, 1H, C4' H); 4.20 (d, J = 15 Hz, 1H, Bn); 4.65 (d, J = 5 Hz, 1H, C4 H); 5.80 (d, J = 15 Hz, 1H, Bn); 5.35 (d, J = 5 Hz, 1H, C3 H); 6.25 - 6.40 (m, 2H, Arm); 7.40 (d, J = 2 Hz, Arm); 7.70 - 7.95 (m, 4H, Arm); IR: 1770 and 1730 cm^{-1}.

(3*R*,4*S*,1'*R*,5'*S*) and (3*S*,4*R*,1'*R*,5'*S*) 1-Furfuryl-3-phenoxy-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14n and 15n). Isolated as a diastereomeric mixture in 87% yield as an oil. The two diastereomers **14n** and **15n** could not be separated by column chromatography. $[\alpha]^{25}_D$: *(Mixture)*: +3.8 (c 1, CH_2Cl_2). ^{1}H NMR: *(Mixture)*: δ 0.45 and 0.85 (s, total 3H, CH_3); 0.95 and 1.05 (s, total 3H, CH_3); 1.10 - 1.20 (m, 1H, C5' H); 1.60 and 1.63 (s, total 3H, CH_3); 1.70 - 1.80 (m, 1H, C1' H); 1.90 - 2.50 (m, 2H, C4' H); 3.85 and 4.07 (d, J = 15 Hz, total 1H, $PhCH_2$); 4.55 - 5.00 (m, 2H, C4 H, $PhCH_2$); 5.30 and 5.35 (d, J = 5 Hz, total 1H, C3 H); 6.20 - 6.40 (m, 2H, Arm); 6.90 - 7.50 (m, 6H, Arm); ^{13}C NMR: *(Mixture)*: δ 12.6, 12.8, 13.0, 13.6, 19.9, 20.4, 25.9, 26.6, 36.3, 36.8, 37.2, 37.4, 37.9, 55.5, 55.6, 81.6, 81.9, 108.3, 110.2, 115.0, 121.4, 127.9, 128.8, 129.0, 140.6, 142.3, 148.4, 156.9, 157.8, 164.8, 165.4; IR: 1760 and 1600 cm^{-1}.

(3*R*,4*S*,1'*R*,5'*S*) 3-Azido-1-furfuryl-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14o). The major diastereomer **14o** was obtained in pure form by column chromatography as an oil from the diasetereomeric mixture. $[\alpha]^{25}_D$: +80.9 (c 1, CH_2Cl_2). ^1H NMR: δ 0.80 (s, 3H, CH_3); 1.07 (s, 3H, CH_3); 1.20 - 1.30 (m, 1H, C5 'H); 1.60 (s, 3H, CH_3); 1.60 - 1.70 (m, 1H, C1' H); 2.05 (d, *J* = 20 Hz, 1H, C4' H); 2.45 (dd, *J* = 10 & 20 Hz, 1H, C4' H); 4.05 (d, *J* = 15 Hz, 1H, $PhCh_2$); 4.45 (d, *J* = 5 Hz, 1H, C4 H); 4.62 (d, *J* = 15 Hz, 1H, $PhCH_2$); 4.70 (d, *J* = 5 Hz, 1H, C3 H); 6.15 - 6.35 (m, 2H, Arm); 7.37 (d, *J* = 2 Hz, 1H, Arm); ^{13}C NMR: δ 13.0, 13.4, 21.2, 26.2, 27.2, 36.9, 37.1, 38.3, 55.2, 67.4, 108.7, 110.3, 127.8, 142.6, 143.4, 148.2, 163.8 IR: 2100 and 1760 cm^{-1}. Anal. Calcd $C_{17}H_{20}O_2N_4$: C, 65.36; H, 6.45; N, 17.93. Found C, 65.68; H, 6.63; N, 17.64.

(3*R*,4*S*,1'*R*,5'*S*,1''*R*) 1-[1''-phenylethyl)]- 3-phthalimido-4-[3',6',6'-trimethylbicyclo(3.1.0)-hex-2'-en-2'-yl] azetidin-2-one (14p). The diastereomer **14p** (major) was isolated in 84% yield by crystallization from pet.-ether/acetone. M.p. 147-148°C. $[\alpha]^{25}_D$: -26.12 (c 1, CH_2Cl_2). ^1H NMR: δ 0.75 (s, 3H, CH_3); 0.8 (s, 3H, CH_3); 0.9-1.0 (m, 1H, C5'H); 1.35 (s, 3H, CH_3); 1.70 (d, 3H, J = 7.0 Hz, CH_3); 1.9 (m, 1H, C1'H); 1.95-2.10 (m, 2H, C4'H); 4.6 (d, 1H, J = 5.0 Hz, C4H); 5.0 (q, 1H, J = 7.0 Hz); 5.35 (d, 1H, J = 5.0 Hz, C3H); 7.30-7.50 (m, 5H, Arm); 7.70-7.80 (dd, 4H, J = 10 and 20 Hz, Arm); ^{13}C NMR: δ 13.2, 13.3, 19.7, 20.5, 25.6, 26.1, 38.4, 38.8, 53.6, 57.0, 57.7, 123.5, 127.1, 127.6, 128.8, 130.1, 131.7, 134.4, 137.8, 140.6, 164.7, 166.8; IR: 3040, 1760, 1730, 1400 cm^{-1}. Anal. Calcd $C_{28}H_{28}N_2O_3$: C, 76.36; H, 6.36; N, 6.36; Found C, 76.1; H, 6.8; N, 6.5.

(3*R*,4*S*,1'*R*,5'*S*,1''*R*) and (3*S*,4*R*,1'*R*,5'*S*,1''*R*) 3-phenoxy-1-[1''-phenylethyl)]-4-[3',6',6'-trimethylbicyclo (3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14q and 15q). The two diastereomers **14q** (major) and **15q** (minor) were separated by column chromatography.

14q (3*R*,4*S*,1'*R*,5'*S*,1''*R*). Isolated as an oil. $[\alpha]^{25}_D$: -3.10 (c 1, CH_2Cl_2). ^1H NMR: δ 0.4 (s, 3H, CH_3); 0.95 (s, 3H, CH_3); 1.0 - 1.1 (m, 1H, C5'H); 1.5 (s, 3H, CH_3); 1.15 (m, 1H, C'H); 1.8 (d, 3H, J = 10 Hz, CH_3); 2.2 - 2.3 (dd, 2H, J = 10 and 20 Hz, C4'H); 4.6 (q, 1H, J = 10 Hz, CH); 5.2 (d, 1H, J = 5.0 Hz, C3H); 6.9 - 7.0 (m, 3H, Arm); 7.2 - 7.4 (m, 7H, Arm). ^{13}C NMR: δ 13.5, 14.0, 19.5, 21.0, 26.5, 27.0, 38.0, 38.5, 53.5, 55.0, 82.0, 115.5, 122.0, 127.5, 128.0, 128.5, 129.0, 129.5, 141.0, 142.0, 159.2, 166.5; IR : 1740 cm^{-1}.

15q (3*S*,4*R*,1'*R*,5'*S*,1''*R*). Isolated as an oil. $[\alpha]^{25}_D$: +4.80 (c 1, CH_2Cl_2). ^1H NMR: δ 0.70 (s, 3H, CH_3); 0.9 (s, 3H, CH_3); 1.30 - 1.40 (m, 1H, C5'H); 1.45 - 1.50 (m, 1H, C1'H); 1.5 (s, 3H, CH_3); 1.6 (d, 3H, J = 14.0 Hz, CH_3); 1.9 - 2.05 (dd, 2H, J = 10 and 20 Hz, C4'H); 4.6 (d, 1H, J = 5.0 Hz, C4H); 4.80 (q, 1H, J = 10 Hz, CH); 5.75 (d, 1H, J = 5.0 Hz, C3H); 6.85 - 7.00 (m, 3H, Arm); 7.15 - 7.35 (m, 7H, Arm); ^{13}C NMR: δ 13.2, 13.3, 19.6, 20.2, 25.9, 26.0, 38.4, 52.9, 56.3, 80.6, 115.3, 121.6, 127.0, 127.6, 128.6, 129.0, 129.3, 129.7, 139.9, 140.0, 157.1, 165.6; IR : 3010, 1740 cm^{-1}.

(3*R*,4*S*,1'*R*,5'*S*,1''*S*) and (3*S*,4*R*,1'*R*,5'*S*,1''*S*) 1-[1''-phenylethyl)]-3-phthalimido-4-[3',6',6'-trimethyl bicyclo(3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14r and 15r). The two diastereomers **14r** (major) and **15r** (minor) were separated by column chromatography.

14r (3*R*,4*S*,1'*R*,5'*S*,1''*S*). Isolated as an oil. $[\alpha]^{25}_D$: -16.89 (c 1, CH_2Cl_2). ^1H NMR: δ 0.75 (s, 3H, CH_3); 1.0 (s, 3H, CH_3); 1.05 (m, 1H, C5'H); 1.25 (s, 3H, CH_3); 1.75 - 1.85 (m, 1H, C1'H); 2.0 (d, 3H, J = 10 Hz, CH_3); 2.05 - 2.20 (dd, 2H, J = 15.0 Hz, C4'H); 4.35 (q, 1H, J = 12 Hz); 4.4 (d, 1H, J = 5.0 Hz, C4H); 5.3 (d, 1H, J = 5.0 Hz, C3H); 7.25 - 7.40 (m, 5H, Arm); 7.65 - 7.8 (dd, 4H, J = 10 and 20 Hz, Arm); ^{13}C NMR: δ 12.7, 13.4, 20.1, 20.3, 25.7, 26.0, 37.8, 55.5, 56.3, 57.3, 123.1, 126.2, 127.4, 128.6, 129.5, 131.3, 134.1, 137.6, 141.6, 163.7 (β-lactam CO-), 166.4 (Phthalimido CO-); IR: 3020, 1730, 1220 cm^{-1}. Anal. Calcd for $C_{28}H_{28}N_2O_3$: C, 76.36; H, 6.36; N, 6.36; Found C, 75.8; H, 6.1; N, 5.9.

15r (3*S*,4*R*,1'*R*,5'*S*,1''*S*). M.p. 115-117 °C. $[\alpha]^{25}_D$: +51.73 (c 1, CH_2Cl_2). ^1H NMR: δ 0.1 (s, 3H, CH_3); 0.60 (s, 3H, CH_3); 0.8 - 0.9 (m, 1H, C5'H); 1.75 (s, 3H, CH_3); 1.65 (d, 3H, J = 14.0 Hz, CH_3); 1.75 - 1.80 (m, 1H, C1'H); 2.3 (dd, 2H, J = 15 and 20 Hz, C4'H); 4.45 (d, 1H, J = 5.0 Hz, C4H); 5.15 (d, 1H, J = 5.0 Hz, C3H); 5.20 (q, 1H, J = 10.0 Hz, CH); 7.25 - 7.45 (m, 5H, Arm); 7.70 - 7.90 (dd, 4H, J = 10 and 20 Hz, Arm); ^{13}C NMR: δ 12.7, 13.0, 18.0, 20.2, 25.5, 27.45, 38.0, 51.7, 54.3, 57.7, 123.4, 127.3, 127.8, 128.6, 128.9, 132.3, 134.3, 139.0, 143.4, 163.4, 166.1; IR: 1730 cm^{-1}.

(3*R*,4*S*,1'*R*,5'*S*,1''*S*) and (3*S*,4*R*,1'*R*,5'*S*,1''*S*) 3-phenoxy-1-[1''-phenylethyl)]-4-[3',6',6'-trimethylbicyclo (3.1.0)-hex-2'-en-2'-yl]azetidin-2-one (14s and 15s). The diastereomeric mixture of **14s** and **15s** was obtained in 94% yield, from which pure major isomer **14s** was isolated by column chromatography as an oil.

14s (3*R*,4*S*,1'*R*,5'*S*,1''*S*). $[\alpha]^{25}_D$: -27.77 (c 3, CH_2Cl_2). ^1H NMR: δ 0.9 (s, 3H, CH_3); 1.10 (s, 3H, CH_3); 1.20 (m, 1H, C5'H); 1.30 (m, 1H, C1'H); 1.45 (s, 3H, CH_3); 1.95 (d, 3H, J = 14.0 Hz, CH_3); 2.10 (d, 1H, J = 14.0 Hz, C4'H); 2.25 (dd, 1H, C4'H); 4.15 (q, 1H, J = 10.0 Hz, CH); 4.45 (d, 1H, J = 5.0 Hz, C4H); 5.25 (d, 1H, J = 5.0 Hz, C3H); 6.90 - 7.35 (m, 10H, Arm); ^{13}C NMR: δ 11.9, 13.2, 13.5, 14.11, 20.4, 20.8, 26.4, 29.8, 38.1, 38.6, 55.8, 56.1, 81.1, 115.6, 116.0, 121.9, 126.7, 129.0, 129.3, 129.5, 129.7, 141.4, 141.9, 157.5, 165.7; IR : 3000, 1750, 1730, 1220 cm^{-1}.

Preparation of aldehyde (17). A solution of dimethyl sulfoxide (24 mmol) in CH_2Cl_2 (5 mL) was added to a stirred solution of oxalyl chloride (12 mmol) in CH_2Cl_2 (25 mL) over 30 minutes at -60°C under nitrogen atmosphere and it was stirred at this temp. for another 30 minutes. A solution of alcohol **16** (1.8 g, 11 mmol) in CH_2Cl_2 (10 mL) was added drop wise over 10 minutes at -60°C. The reaction mixture was stirred for 15 minutes and then warmed to -50°C. Triethyl amine (55 mmol), was added over 5 minutes and the reaction mixture was slowely allowed to warm to r.t. and water (30 mL) was added. The aqueous phase was extraced with CH_2Cl_2 (15 mL) twice and the combined organic layer was washed with brine, dried over Na_2SO_4, concentrated to give an oil and it was used as such for imine the formation.

General procedure for the preparation of imines 18 and 19. To a solution of amine [**2a-b**, 12 mmol, *p*-anisidine (**2a**), benzylamine (**2b**)] in dry CH_2Cl_2 (20 mL), aldehyde **17** (15 mmol) was added in presence of anhyd $MgSO_4$ (10 g) and the resulting mixture was stirred at r.t. for 12 h. The reaction mixture was then filtered and the solid was washed with CH_2Cl_2. The combined filtrates were concentrated to get imine in almost quantitative yields. The imines **18** and **19** thus obtained were sufficiently pure and were used without further purification.

General Procedure for the Preparation of β-lactams 20 and 21.

A solution of the acid chloride (**9** or **10**, 7.5 mmol) in anhydrous CH_2Cl_2 (20 mL) was slowly added to a solution of imine (**18** or **19**, 5 mmol) and triethylamine (20 mmol) in CH_2Cl_2 (20 mL) at -23 °C. After the completion of addition, the reaction mixture was allowed to warm up to room temperature and stirred further for 12 h. The reaction mixture was then washed with water (30 mL), satd. $NaHCO_3$ (30 mL), brine (15 mL) and dried (anhyd Na_2SO_4). The removal of solvent at reduced pressure gave diastereomeric mixture of β-lactams **20a-d** and **21a-d** in 32-53% yield. The attempts to separate diastereomers by column cromatography were failed in all the cases. However, the crystallization of the diastereomeric mixture of **20a** and **21a** (R^2 = OPh) from methanol gave the major β-lactam **20a** in pure form.

(3*R*,4*S*,1'*S*,6'*R*) 1-(p-Anisyl)-3-phenoxy-4-[3',7',7'-trimethylbicyclo(4.1.0)-hept-3'-en-4'-yl]azetidin-2-one (20a). M.p. 179 - 181°C ; ^1H NMR: δ 1.0 (s, 3H, CH_3); 1.2 (s, 3H, CH_3); 1.4 (t, 1H, J = 10.0 Hz, CH); 1.65 (m, 2H, CH_2); 2.0 (s, 3H, CH_3); 2.5 (m, 2H, CH_2); 2.85 (m, 1H, CH); 3.8 (s, 3H, CH_3); 5.3 (d, 1H, J = 5.0 Hz, C4H); 5.55 (d, 1H, J = 5.0 Hz, C3H); 7.0 (dd, 4H, J = 10.0 and 20.0 Hz, Arm); 7.05 - 7.35 (m, 5H, Arm); IR: 3020, 1750, 1230 cm^{-1}; $\alpha]^{25}_D$: +96.1 (c 1, CH_2Cl_2) Anal. Calcd for $C_{20}H_{25}O_5N$: C, 66.87; H, 6.96; N, 3.89. Found C, 66.90; H, 6.83; N, 3.78.

(3*R*,4*S*,1'*S*,6'*R*) and (3*S*,4*R*,1'*S*,6'*R*) 1-(Benzyl)-3-phthalimido-4-[3',7',7'-trimethylbicyclo(4.1.0)-hept-3'-en-4'-yl]-azetidin-2-one (20b and 21b). Isolated as a diastereomeric mixture in 48% yield as a yellow solid. The two diastereomers **20b** and **21b** could not be separated by column chromatography. M.p. 73 - 75°C. $[\alpha]^{25}_D$ (*Mixture*) : +83.57 (c 0.9, CH_2Cl_2). ^1H NMR (*Mixture*) : δ 0.5 and 0.95 (s, total 3H,CH_3); 1.05 and 1.15 (s, total 3H, CH_3); 1.45 and 1.55 (s, total 3H, CH_3); 1.4 - 1.6 (m, 3H, CH_2 and CH); 2.4 (m, 2H, CH_2); 3.0 (m, 1H, CH); 4.15 - 4.3 (dd, 1H, C_3'H, *J* = 5.0 Hz.); 4.6 (dd, 2H, Benzylic CH_2); 5.10 (dd, 2H, Benzylic CH_2, *J* = 15 and 25 Hz.); 5.5 - 5.65 (dd, 1H, C_4'H, *J* = 5.0 Hz.); 7.25 - 7.5 (m, total 5H, Arm.); 7.6 - 7.95 (m, total 4H, Arm). ^{13}C NMR (*Mixture*) : δ 10.4, 10.8, 14.4, 14.9, 21.87, 22.0, 23.2, 23.4, 25.0, 25.7, 32.4, 32.6, 47.5, 57.9, 58.3, 59.3, 60.3, 123.7, 123.9, 128.6, 129.1, 129.2, 131.2, 132.9, 134.0, 134.4, 134.7, 147.4, 147.9, 164.4, 164.8, 166.8, 194.9, 195.1. IR: 3020, 1760, 1730, 1600 cm^{-1}.

(3*R*,4*S*,1′*S*,6′*R*) and (3*S*,4*R*,1′*S*,6′*R*) 1-(Benzyl)-3-phenoxy-4-[3′,7′,7′-trimethylbicyclo(4.1.0)-hept-3′-en-4′-yl]-azetidin-2-one (20c and 21c). Isolated as a diastereomeric mixture in 32% yield as an oil. The two diastereomers **20c** and **21c** could not be separated by column chromatography. $[\alpha]^{25}_D$ (*Mixture*) : +105.7 (c 1, CH_2Cl_2). ^1H NMR (*Mixture*) : δ 0.9 and 1.05 (s, total 3H, CH_3); 1.15 and 1.2 (s, total 3H, CH_3); 1.45 (m, 2H, CH_2); 1.6 and 1.7 (s, total 3H, CH_3); 2.3 (m, 1H, CH); 2.55 (m, 2H, CH_2); 3.0 (m, 1H, CH); 4.0 and 5.0 (dd, total 2H, J = 15.0 and 25.0 Hz, benzylic CH_2); 4.65 (dd, total 1H, J = 5.0 Hz, C3H); 5.4 (dd, total 1H, J = 5.0 Hz, C4H); 6.9 - 7.4 (m, total 10H, Arm); ^{13}C NMR (*Mixture*) : δ 10.5, 10.6, 14.7,14.8, 22.2, 22.6, 23.7, 24.9, 25.8, 28.3, 28.4, 33.2, 46.3, 58.3, 59.1, 82.3, 82.4, 115.5, 115.8, 122.6, 122.8, 128.4, 128.6, 128.7, 128.9, 129.1, 129.2, 129.6, 134.1, 134.2, 134.9, 146.8, 157.1, 157.3, 165.7, 195.3, 195.6; IR: 3040, 1770, 1230 cm^{-1}. Anal. Calcd for $C_{20}H_{25}O_5N$: C, 66.87; H, 6.96; N, 3.89. Found C, 66.90; H, 6.83; N, 3.78.

(3*R*,4*S*,1′*S*,6′*R*) and (3*S*,4*R*,1′*S*,6′*R*) 1-(Benzyl)-3-benzyloxy-4-[3′,7′,7′-trimethylbicyclo(4.1.0)-hept-3′-en-4′-yl]-azetidin-2-one (20d and 21d). Isolated as a diastereomeric mixture in 53% yield as an oil. The two diastereomers **20d** and **21d** could not be separated by column chromatography. $[\alpha]^{25}_D$ (*Mixture*) : +82.88 (c 1, CH_2Cl_2). ^1H NMR (*Mixture*) : δ 0.9 and 1.05 (s, total 3H, CH_3); 1.1 and 1.2 (s, total 3H, CH_3); 1.45 (dd, 2H, J = 7.0 and 14.0 Hz, CH_2); 1.6 and 1.65 ((s, total 3H, CH_3); 2.4 (m, 2H, CH_2); 2.75 (m, 1H, CH); 3.0 (m, 1H, CH); 3.9 and 4.6 (dd, total 2H, J = 15.0 and 25.0 Hz, N-benzylic CH_2); 4.45 (dd, total 1H, J = 5.0 Hz, C3H); 4.55 and 4.85 (dd, total 2H, J = 10.0 and 15.0 Hz, o-benzylic CH_2); 4.8 (dd, total 1H, J = 5.0 Hz, C3H); 7.1 - 7.4 (m, total 10H, Arm); ^{13}C NMR (*Mixture*) : δ 10.2, 10.3, 14.6, 22.9, 23.0, 24.0, 24.1, 25.0, 26.0, 28.1,28.3, 33.0, 45.9, 58.4, 59.0, 73.3, 83.1, 83.6, 127.9, 128.1, 128.3, 128.3, 128.5, 128.7, 128.8, 129.2, 129.2, 136.3, 148.1, 148.2, 167.0, 167.5, 195.0, 195.5. IR: 3010, 1770, 1730 cm^{-1}. Anal. Calcd for $C_{20}H_{25}O_5N$: C, 66.87; H, 6.96; N, 3.89. Found C, 66.90; H, 6.83; N, 3.78.

Synthesis of 3-Acylamino-1-(p-Anisyl)-4-[3′,6′,6′-trimethylbicyclo(3.1.0)-hex-2′-en-2′-yl]azetidin-2-one (22) from 14a. To a solution of the 3-phthalimido β-lactam (**14a**, 0.442 g, 1 mmol) in CH_2Cl_2 (10 mL) methyl hydrazine (0.050 g, 1.1 mmol) was added and the reaction mixture was stirred at room temperature for 32 h. After the completion of the reaction (TLC) the solvent was evaporated and the product was purified by column chromatography. The resulting product was treated with acetyl chloride (0.12 g, 1.5 mmol) in the presence of triethylamine (3 mL) and stirred for 1h. The usual work up gave crude product, which was purified by column chromatography to obtain 0.318 g (90%) of pure 3-acyl β-lactam (**22**) as a white solid. M.p. 131-132 °C (MeOH). $[\alpha]^{25}_D$: -79.2 (c 1, CH_2Cl_2). ^1H NMR: δ 0.50 (s, 3H, CH_3); 0.75 (s, 3H, CH_3); 1.20 - 1.35 (m, 1H); 1.57 - 1.65 (m, 1H); 1.70 (s, 3H, CH_3); 2.03 (s, 3H, $COCH_3$); 2.10 (bs, 1H); 2.55 (dd, *J* = 8 & 16 Hz, 1H); 3.80 (s, 3H, OCH_3); 5.05 (d, *J* = 6 Hz, 1H, C4 H); 5.55 (d, *J* = 6 & 10 Hz, 1H, C3 H); 6.80 - 6.95 (m, 3H, NH, Arm); 7.23 (d, *J* = 9 Hz, 2H, Arm); IR: 3400, 1740, and 1680 cm^{-1}. Anal. Calcd $C_{21}H_{26}O_3N_2$: C, 71.18; H, 7.34; N, 7.90. Found C, 71.09; H, 7.43; N, 7.76.

Synthesis of 3-acylamino β-lactam 22 from 14f. To a solution of the 3-azido β-lactam **14f** (0.338 g, 1 mmol) in benzene (30 mL), PPh_3 (0.314 g, 1.2 mmol) was added and the reaction mixture was refluxed for 8 h. After the completion of the reaction (TLC) the reaction mixture was cooled and triethylamine (2 mL) followed by acetyl chloride (0.12 g, 1.5 mmol) was added and the reaction mixture was stirred at room temperature for 1h. After the completion of the reaction (TLC), the reaction mixture was washed with water (2 X 30 mL) and then dried. The removal of solvent offered the crude product, which was purified by column chromatography (silica gel, 60-120 mesh, 10% AcoEt in pet. Ether) to give the 3-acylβ-lactam **22** (0.884 g, 81%) as a white solid. This compound was found to be identical with 3-acylβ-lactam **22** obtained from β-lactam **14a** by comparing its m.p. and other spectral data.

General Procedure for the Preparation of Diketones 23a-d. To a solution of β-lactam **14 (b-d,f)** (2 mmol) $CH_3CN:CCl_4:H_2O$ (2:2:3, 7 mL), powdered $NaIO_4$ (6 mmol) was added followed by a catalytic amount of $RuCl_3$ (4 mg) at 0 °C and the reaction mixture was stirred for 4 h at 0 °C. After completion of the reaction (TLC), the reaction mixture was diluted with water and extracted with $CHCl_3$ (2X20 mL). The combined organic extracts were dried and concentrated to give crude product, which on column purification (silica gel, 60-120 mesh, $CHCl_3$/EtOAc mixtures) furnished the diketones **23a-d** in 90 - 95%.

(3*R*,4*R*,1'*R*,3'*S*)-1-(p-Anisyl)-4-{[2',2'-dimethyl-3'-(2'-oxoprop-1'-yl)cyclopropyl]carbonyl}-3-phenoxy-azetidin-2-one (23a). Isolated as an yellow oil in 93% yield. $[\alpha]^{25}_D$: +72.3 (c 1, CH_2Cl_2). ^{1}H NMR: δ 1.00 (s, 3H, CH_3); 1.25 (s, 3H, CH_3); 1.65 (dd, J = 8 & 16 Hz, 1H); 2.12 (s, 3H, CH_3); 2.17 (d, J = 8 Hz, 1H); 2.85 (d, J = 8 Hz, 2H); 3.80 (s, 3H, OCH_3); 4.77 (d, J = 5 Hz, 1H, C4 H); 5.50 (d, J = 5Hz, 1H, C3 H); 6.92 (d, J = 9 Hz, 2H, Arm); 7.00 - 7.40 (m, 7H, Arm); ^{13}C NMR: δ 13.8, 28.9, 30.0, 32.5, 33.4, 34.0, 37.1, 55.5, 64.1, 66.0, 81.4, 114.4, 114.7, 115.4, 115.8, 118.4, 118.6, 122.8, 129.7, 130.4, 157.0, 157.4, 161.9, 203.5, 207.6; IR: 1770, 1750 and 1710 cm^{-1}.

(3*R*,4*R*,1'*R*,3'*S*)-1-(p-Anisyl)-3-benzyloxy-4-{[2',2'-dimethyl-3'-(2'-oxoprop-1'-yl)cyclopropyl]carbonyl}-azetidin-2-one (23b). Yield 90%. M.p. 115-116 °C (CH_2Cl_2-pet. Ether). $[\alpha]^{25}_D$: +52.9 (c 1, CH_2Cl_2). ^{1}H NMR : δ 1.05 (s, 3H, CH_3); 1.20 (s, 3H, CH_3); 1.60 (dd, J = 8 & 16 Hz, 1H); 2.05 (d, J = 8 Hz, 1H); 2.07 (s, 3H, CH_3); 2.80 (dd, J = 8 Hz, 2H); 3.80 (s, 3H, OCH_3); 4.60 (d, J = 5.2 Hz, 1H, C4 H); 4.70 (d, J = 11 Hz, 1H, Bn); 4.82 (d, J = 11 Hz, 1H, Bn); 5.00 (d, J = 5.2 Hz, 1H, C3 H); 6.90 (d, J = 9 Hz, 2H, Arm); 7.25 7.45 (m, 7H, Arm); 13C NMR: δ 13.7, 28.7, 29.8, 31.6, 32.9, 33.7, 37.2, 55.4, 65.7, 73.2, 82.2, 114.4, 118.4, 128.1, 128.4, 130.6, 136.5, 156.6, 163.4, 203.8, 207.5; IR: 1760, 1720 and 1710 cm-1. Anal. Calcd $C_{26}H_{29}O_5N$: C, 71.72; H, 6.66; N, 3.22. Found C, 71.64; H, 6.89; N, 3.33.

(3*R*,4*R*,1'*R*,3'*S*)-1-(p-Anisyl)-4-{[2',2'-dimethyl-3'-(2'-oxoprop-1'-yl)cyclopropyl]carbonyl}-3-methoxy-azetidin-2-one (23c). Yield 95%. M.p. 88-89 °C (MeOH). $[\alpha]^{25}_D$: +90.4 (c 1, CH_2Cl_2). ^{1}H NMR: δ 1.15 (s, 3H, CH_3); 1.27 (s, 3H, CH_3); 1.60 - 1.75 (m, 1H); 2.07 (d, J = 8 Hz, 1H); 2.15 (s, 3H, CH_3); 2.80 (dd, J = 8 & 16 Hz, 1H); 3.00 (dd, J = 8 & 16 Hz, 1H); 3.53 (s, 3H, OCH_3); 3.80 (s, 3H, OCH_3); 4.60 (d, J = 5 Hz, 1H, C4 H); 4.82 (d, J = 5Hz, 1H, C3 H); 6.90 (d, J = 9 Hz, 2H, Arm); 7.30 (d, J = 9 Hz, 2H, Arm); ^{13}C NMR: δ 14.0, 28.9, 30.0, 31.9, 33.0, 33.8, 37.3, 55.5, 59.4, 65.9, 84.8, 114.5, 118.4, 130.5, 156.7, 163.2, 204.2, 207.7 IR: 1760, 1740 and 1720 cm-1. Anal. Calcd $C_{20}H_{25}O_5N$: C, 66.87; H, 6.96; N, 3.89. Found C, 66.90; H, 6.83; N, 3.78.

(3R,4R,1'R,3'S)-1-(p-Anisyl)-3-azido-4-{[2',2'-dimethyl-3'-(2'-oxoprop-1'-yl)cyclopropyl]carbonyl}-azetidin-2-one (23d). Yield 95%. M.p. 107-108°C (MeOH). $[\alpha]^{25}_D$: +121.9 (c 1, CH_2Cl_2). ^{1}H NMR: δ 1.20 (s, 3H, CH_3); 2.15 (s, 3H, CH_3); 1.70 (dd, J = 8 & 16 Hz, 1H); 2.05 (d, J = 8 Hz, 1H); 2.15 (s, 3H, CH_3); 2.85 (dd, J = 8 & 16 Hz, 1H); 3.00 (dd, J = 8 & 16 Hz, 1H); 3.80 (s, 3H, OCH_3); 4.65 (d, J = 5 Hz, 1H, C4 H); 5.05 (d, J = 5Hz, 1H, C3 H); 6.90 (d, J = 9 Hz, 2H, Arm); 7.30 (d, J = 9 Hz, 2H, Arm); ^{13}C NMR: δ 13.8, 28.7, 29.8, 32.4, 33.3, 34.2, 37.1, 55.2, 64.1, 66.0, 114.4, 118.4, 130.0, 156.8, 159.9, 202.6, 207.2; MS: *m/z* 370 (M^+, 10%), 149 (100); IR: 2140, 1750, 1720 and 1700 cm^{-1}. Anal. Calcd $C_{19}H_{22}O_4N_4$: C, 61.60; H, 5.98; N, 15.12. Found C, 61.56; H, 5.99; N, 14.96

N-Unsubstituted β-lactam 24. To a solution of the β-lactam **23d** (0.740 g, 2 mmol) in CH_3CN (10 mL), a solution of CAN (3.290 g, 6 mmol) in water (5 mL) was added dropwise at 0 °C and the reaction mixture was stirred for 1 h. After the completion of the reaction, cold water was added to the reaction mixture and it was extracted with EtOAc (3 X 30 mL). The organic layer was washed with water (3 X 20 mL), $Na_2S_2O_5$ (10%, 20 mL), satd. $NaHCO_3$ (20 mL) and finally with water and dried (Na_2SO_4). The crude product obtained after removal of solvent was purified by column chromatography (silica gel, 60-120, 20% EtOAc in pet. Ether) to get the *N*-unsubstituted product **24** (0.447 g, 85%) as a gum. $[\alpha]^{25}_D$:+131.1 (c 1, $CHCl_3$). ^{1}H NMR: δ 1.15 (s, 3H, CH_3); 1.25 (s, 3H, CH_3); 1.70 - 1.85 (m, 1H); 2.00 (d, J = 8 Hz, 1H); 2.10 (s, 3H, CH_3); 2.90 (d, J = 8 Hz, 2H); 4.40 (d, J = 6 Hz, 1H, C4 H); 5.00 (dd, J = 2 & 6 Hz, 1H, C3 H); 6.95 (bs, 1H, NH) IR: 3300, 2125, 1780, 1760 and 1720 cm-1.

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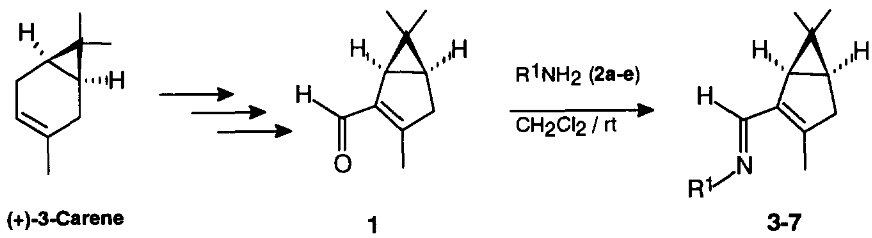

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