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Regio- and π-facial selective Lewis acid interceded Diels–Alder reactions of α-dienyl-β-lactams: an indepth analysis

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ABSTRACT

The regio-, diastereo-, and π-facial selective Lewis acid mediated Diels–Alder reactions of *cis*/*trans*-3-butadienyl-2-azetidinones with unsymmetrical dienophiles viz. methyl acrylate, dimethyl fumarate, and acrolein leading to the synthesis of diastereomerically pure and biologically potent 1,3,4-trisubstituted-2-azetidinones are reported. Theoretical calculations at HF/6-31G** and 6-31G**/DFT levels have been performed to support the observed π-facial selectivity. The formation of diastereomerically pure '*endo*' adducts is supported by the X-ray diffraction studies.

1. Introduction

Diels–Alder cycloaddition is one of the most versatile and synthetically useful reactions in which up to four stereogenic centers can be generated in a single step.[1] The stereochemistry, regiochemistry as well as the topography in DA cycloaddition reactions can be easily predicted.[2] A third stereochemical feature, the π-facial selectivity that arises when the addents possess two distinguishable reactive faces, is the subject of an important discussion in recent years.[3] Frequently the presence of atleast one stereocentre in the vicinity of the diene imparts sufficient perturbation to influence the π-facial selectivity. Mehta and Uma[2f] proposed the following qualitative hierarchy of stereochemical effects: steric>through space electrostatic repulsion or attraction>stabilizing orbital interaction>hyperconugation>ground state orbital distortion. Till date, such studies have been restricted on dissymmetric 1,3-cyclopentadienes, 1,3-cyclohexadienes, conformationally locked 1(*E*)-substituted 1,3-dienes, polycyclic or cage annulated derivatives with minimum conformational ambiguities.[3,4] Recent studies have examined 5-(2-oxazolynyl)-1,2,3,4,5-pentamethylcyclopentadiene,[5] 1,6-annulated cyclohexa-1,3-dienes,[6] 3,5-disubstituted-1-vinyl-cyclopentene,[7] sugar derived cyclic dienes,[8a] 6-alkenyl tetrahydropyridinones,[8b] and the dienes embedded in a cyclic framework. However, much less attention has been paid to the facial selective DA reactions of acyclic unactivated dienes.[9–11] Earlier reports on such selective DA cycloadditions (Fig. 1, A) involving the use of (*E*)-2-hydroxy-3,5-hexadiene[9] with symmetrical dienophiles viz. maleic anhydride, *N*-phenyl maleimide, tetracyanoethylene, and acetylenic ester dienophiles lacked topographic discrimination resulting in mixtures of *endo*- and *exo*-adducts (Fig. 1, B and C). The utility of sulfinyl-substituted 1-hydroxymethyldienes[12a] and hindered silyloxy dienes[12b] in diastereoselective DA cycloaddition reactions has also been reported. Alcaide and co-workers in a series of recent papers reported the multistep synthesis and Diels–Alder cycloaddition reactions of 4-butadienyl-2-azetidinones with few symmetrical dienophiles under refluxing conditions leading to mixtures of corresponding *exo* and *endo* adducts.[17,18] Evidently, synthesis as well as DA

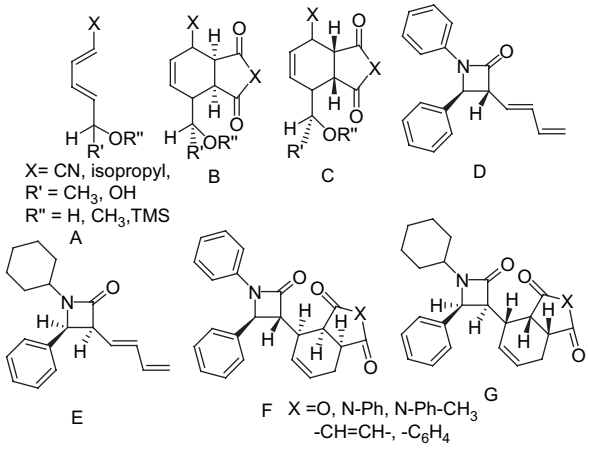

Figure 1.

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Table 1
Lewis acid catalyzed reactions of **1a–c** with different dienophiles **2a–c**

Entry	Lactam	Dienophile	LA	Temperature (°C)	Overall Yield (%)
1	**1a/1b/1c**	**2a**	$AlCl_3$	rt	55/62/59
2	**1a/1b/1c**	**2a**	$AlCl_3$	−78	75/82/81
3	**1a/1b/1c**	**2a**	$TiCl_4$	rt	69/73/87
4	**1a/1b/1c**	**2a**	$TiCl_4$	−78	Quantitative
5	**1a/1b/1c**	**2a**	$SnCl_4$	rt	75/79/73
6	**1a/1b/1c**	**2a**	$SnCl_4$	−78	Quantitative
7	**1a/1b/1c**	**2b**	$AlCl_3$	rt	44/35/39
8	**1a/1b/1c**	**2b**	$AlCl_3$	−78	49/42/45
9	**1a/1b/1c**	**2b**	$TiCl_4$	rt	66/71/73
10	**1a/1b/1c**	**2b**	$TiCl_4$	−78	Quantitative
11	**1a/1b/1c**	**2b**	$SnCl_4$	rt	52/49/43
12	**1a/1b/1c**	**2b**	$SnCl_4$	−78	60/64/52
13	**1a/1b/1c**	**2c**	$AlCl_3$	rt	24/29/25
14	**1a/1b/1c**	**2c**	$AlCl_3$	−78	36/47/41
15	**1a/1b/1c**	**2c**	$TiCl_4$	rt	51/55/54
16	**1a/1b/1c**	**2c**	$TiCl_4$	−78	66/59/64
17	**1a/1b/1c**	**2c**	$SnCl_4$	rt	88/85/94
18	**1a/1b/1c**	**2c**	$SnCl_4$	−78	Quantitative

(i) All the reactions were conducted separately using CH_2Cl_2 as solvent. (ii) The spectrum of the crude adducts show the formation of single isomer. (iii) Yields of adducts were measured prior to crystallization.

cycloaddition reactions of such acyclic functionalized dienes continue to be the topic of intense investigation[13] and there are still unmet challenges associated in achieving high diastereo- and facial selectivity. In continuation of our interest in chemistry of α-functionalized dienes,[14–16,18] we have recently explored the Lewis acid promoted diastereofacial selective DA cycloaddition of *cis*/*trans*-3-butadienyl-2-azetidinones (Fig. 1, D and E) with symmetrical dienophiles.[19] These reactions resulted in the formation of diastereomerically pure 1,3,4-trisubstituted-2-azetidinones (Fig. 1, F and G) as potential antibacterial agents,[20] antielastogenic agents,[21] potent cholesterol absorption inhibitors,[22] human cytomegalovirus protease inhibitors,[23] and thrombin inhibitors.[24]

In the itinerary to develop efficient and highly selective routes for the synthesis of such highly functionalized 2-azetidinones, we report herein Lewis acid catalyzed highly regio-, diastereo- as well as π-facial selective Lewis acid catalyzed Diels–Alder reactions of *cis*/*trans*-3-butadienyl-2-azetidinones having stereocentres at α- and β-positions with relatively less explored unsymmetrical dienophiles.

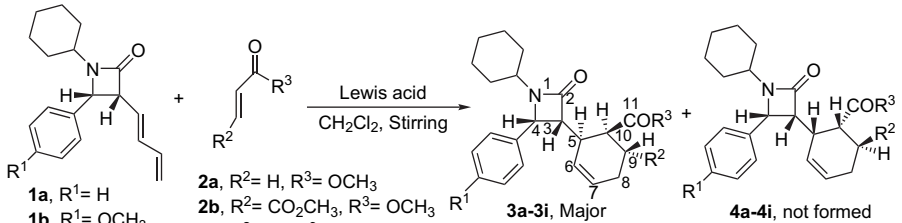
2. Results and discussion

Racemic *cis*/*trans*-3-butadienyl-2-azetidinones were prepared by the earlier reported [2+2] cycloaddition reactions of butadienyl ketene, generated in situ from sorbyl chloride and triethylamine, with *N*-alkyl/*N*-aryl imines.[13] The common Lewis acids viz. $AlCl_3$, $TiCl_4$, $SnCl_4$, $InCl_3$, and $MgBr_2$ were explored for their comparative effects on the desired regio- and diastereoselectivity in their DA cycloaddition reactions with unsymmetrical dienophiles viz. methyl acrylate, dimethyl fumarate, and acrolein.

The DA cycloaddition reactions of *cis*-dienyl-2-azetidinones with the above mentioned unsymmetrical dienophiles in the presence of Lewis acid[25] catalysts (Table 1) resulted in regio-, stereo-, and remarkably high π-facial selective formation of novel 1,3,4-trisubstituted-2-azetidinone derivatives (**3**) in good yields (Scheme 1).

Interestingly, the use of different Lewis acids with methyl acrylate and dimethyl fumarate, as dienophiles, invariably promoted remarkably high diastereofacial selectivity. The reactions of **1a–c** with methyl acrylate **2a** in the presence of titanium(IV) chloride resulted in diastereomerically pure adducts **3a**, **3d**, and **3g**, respectively, in good yields (81%—to nearly quantitative, entries 1–6; Table 1) and the high-resolution ^1H NMR spectra (500 MHz) of the crude reaction mixtures did not show the presence of even traces of any other diastereoisomer. The reactions of **1a–c** with dimethyl fumarate **2b** in the presence of tin(IV) chloride also resulted in reasonable yields of the corresponding adduct (entries 11 and 12, Table 1). The yields of the adducts in the above reactions were found to be lower when aluminium chloride was used as catalyst (entries 1, 2, 7, and 8, Table 1) probably due to the deterioration of the adducts because of the higher acidity of the catalyst.

However, the best results in terms of yields and selectivity were obtained with the use of titanium(IV) chloride as catalyst especially at −78 °C. The diastereomerically pure adducts obtained in the reactions of **1a–c** with **2a–c** were characterized as '*endo*' adducts **3** with the help of analytical data and spectral evidences, the details of which are provided in Section 5 while the salient features are discussed here. Compound **3a**, for example, analyzed for $C_{23}H_{29}NO_3$ showed a molecular ion peak at *m*/*z* 367 in its mass spectrum. Its IR spectrum showed a strong absorption at 1727 cm^{-1} due to the carbonyl group of β-lactam ring. Its high-resolution ^1H NMR (500 MHz) spectrum showed a characteristic doublet at δ 4.81 (*J*=5.5 Hz) assigned to H_4 of the β-lactam ring, a two proton multiplet at δ 1.82 due to H_{8a} and H_{8b}, multiplet at δ 1.97 due to H_9 and another multiplet at δ 2.48 due to H_5. The coupling constant *J*=5.0 Hz between H_5 and H_{10} helped in establishing the cis stereochemistry between these protons while the coupling constant *J*=12.5 Hz confirms the trans stereochemical relationship between H_3 and H_5 protons. Its ^{13}C NMR spectrum showed the presence of two carbonyls at δ 165.4 (C-2) and δ 172.6 (C-11). Since, the α-position of dienyl component of **1** is a stereocentre one may



3a, 4a: R^1= H, R^2= H, R^3= OCH_3
3b, 4b: R^1= H, R^2= CO_2CH_3, R^3= OCH_3
3c, 4c: R^1= H, R^2= H, R^3= H
3d, 4d: R^1= OCH_3, R^2= H, R^3= OCH_3
3e, 4e: R^1= OCH_3, R^2= CO_2CH_3, R^3= OCH_3
3f, 4f: R^1= OCH_3, R^2= H, R^3= H
3g, 4g: R^1= Cl, R^2= H, R^3= OCH_3
3h, 4h: R^1= Cl, R^2=CO_2CH_3, R^3= OCH_3
3i, 4i: R^1= Cl, R^2= H, R^3= H

Scheme 1.

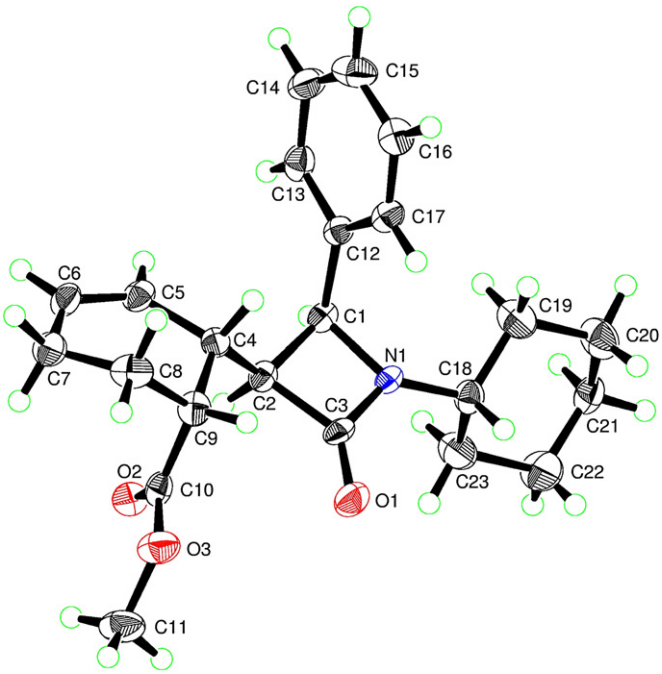


Figure 2. ORTEP diagrams of the compound **3a** in two projections as determined by X-ray crystallography.

expect two possible '*endo*' adducts (**3** and **4**) having *syn* and *anti*-relationship between H_3 of 2-azetidinone ring and H_5 of the cyclohexenyl moiety. These two '*endo*' adducts could not be easily distinguished with the help of high-resolution NMR spectra largely due to complexity of their spectrum and possible free rotation across C_3–C_5 single bond. However, the X-ray crystallographic studies of the DA adduct obtained in the reaction of **1a** with methyl acrylate **2a** has unequivocally established the '*endo*' structure **3a** having *anti* stereochemistry between H_3 of 2-azetidinone and H_5 of the cyclohexyl ring (Fig. 2).[26]

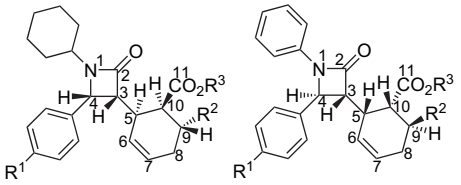


Figure 3. Stereochemistry of '*endo*' adducts.

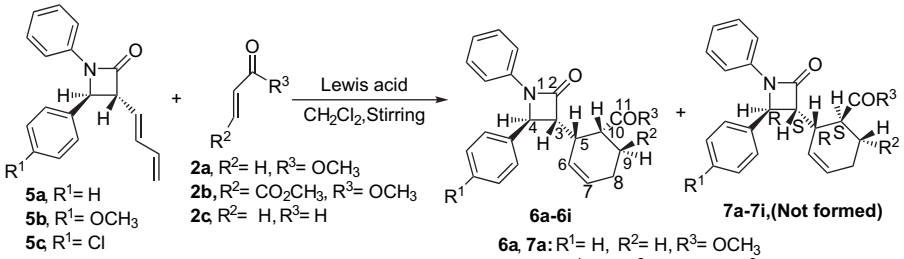
In an attempt to generalize the diastereofacial selectivity observed above, the reactions of **1a–c** were examined using acrolein **2c** as dienophiles. These reactions also resulted in the regio- and diastereofacially specific formation of corresponding adducts in good yields (Scheme 1). The diastereoisomer obtained in the reaction of **1a** with **2c** was characterized as '*endo*' adduct **3c** on the basis of coupling constant values of 12 Hz (H_3–H_5) and 6 Hz (H_5–H_{10}) establishing the *anti* and *syn* relationship between H_3–H_5 and H_5–H_{10}, respectively (Fig. 3).

In continuation of these studies, we have examined the Lewis acid catalyzed DA cycloaddition reactions of *trans*-butadienyl-2-azetidinones **5a–c** with unsymmetrical dienophiles **2a–c** (Scheme 2). As expected, these reactions also resulted in highly regio- and diastereofacial specific formation of the corresponding DA cycloadducts **6a–i** in good yields (Table 2). The high-resolution ^{1}H NMR spectrum of their crude reaction mixture also did not show the presence of even traceable amounts of the likely alternate '*endo*' adducts **7** (Scheme 2). The overall behavior of different Lewis acids in these DA cycloaddition reactions is almost similar to the one observed in DA cycloaddition reactions of *cis*-3-dienyl-2-azetidinones **1a–c**. For example, the use of aluminium(III) chloride and tin(IV) chloride especially in the reaction of **5a–c** with **2b** resulted in the deterioration of adducts and improvement in yields was noticed when the reactions were carried at low temperatures (Table 2, Fig. 3).

Table 2
Lewis acid catalyzed reactions of **5a–c** with different dienophiles **2a–c**

Entry	Lactam	Dienophile	LA	Temperature (°C)	Overall yield (%)
1	**5a/5b/5c**	**2a**	$AlCl_3$	rt	75/83/81
2	**5a/5b/5c**	**2a**	$AlCl_3$	−78	91/86/83
3	**5a/5b/5c**	**2a**	$TiCl_4$	rt	78/86/92
4	**5a/5b/5c**	**2a**	$TiCl_4$	−78	Quantitative
5	**5a/5b/5c**	**2a**	$SnCl_4$	rt	79/81/83
6	**5a/5b/5c**	**2a**	$SnCl_4$	−78	Quantitative
7	**5a/5b/5c**	**2b**	$AlCl_3$	rt	35/38/41
8	**5a/5b/5c**	**2b**	$AlCl_3$	−78	40/40/48
9	**5a/5b/5c**	**2b**	$TiCl_4$	rt	66/71/73
10	**5a/5b/5c**	**2b**	$TiCl_4$	−78	Quantitative
11	**5a/5b/5c**	**2b**	$SnCl_4$	rt	35/32/40
12	**5a/5b/5c**	**2b**	$SnCl_4$	−78	47/44/53
13	**5a/5b/5c**	**2c**	$AlCl_3$	rt	20/27/27
14	**5a/5b/5c**	**2c**	$AlCl_3$	−78	33/46/35
15	**5a/5b/5c**	**2c**	$TiCl_4$	rt	54/57/48
16	**5a/5b/5c**	**2c**	$TiCl_4$	−78	61/52/56
17	**5a/5b/5c**	**2c**	$SnCl_4$	rt	75/76/69
18	**5a/5b/5c**	**2c**	$SnCl_4$	−78	Quantitative

(i) All the reactions were conducted separately using CH_2Cl_2 as solvent. (ii) The spectrum of the crude adducts show the formation of single isomer. (iii) Yields of adducts were measured prior to crystallization.



5a, R^1= H
5b, R^1= OCH_3
5c, R^1= Cl

2a, R^2= H, R^3= OCH_3
2b, R^2= CO_2CH_3, R^3= OCH_3
2c, R^2= H, R^3= H

6a, 7a: R^1= H, R^2= H, R^3= OCH_3
6b, 7b: R^1= H, R^2= CO_2CH_3, R^3= OCH_3
6c, 7c: R^1= H, R^2= H, R^3= H
6d, 7d: R^1= OCH_3, R^2= H, R^3= OCH_3
6e, 7e: R^1= OCH_3, R^2= CO_2CH_3, R^3= OCH_3
6f, 7f: R^1= OCH_3, R^2= H, R^3= H
6g, 7g: R^1= Cl, R^2= H, R^3= OCH_3
6h, 7h: R^1= Cl, R^2=CO_2CH_3, R^3= OCH_3
6i, 7i: R^1= Cl, R^2= H, R^3= H

Scheme 2.

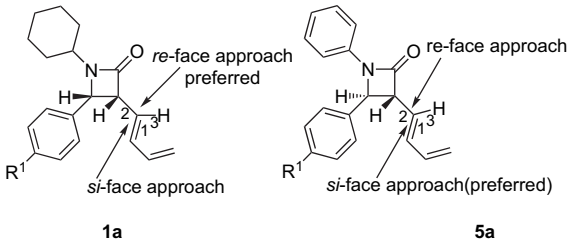


Figure 4. Facial discrimination of the dienyl-2-azetidinones.

The DA cycloadducts thus obtained were characterized as '*endo*' adducts **6a–i** on the basis of analytical and spectral evidences. The compound **6b**, for example, analyzed for $C_{25}H_{25}NO_5$ showed a molecular ion peak at *m*/*z* 419 in its mass spectrum. Its IR spectrum showed a strong absorption peak at 1726 cm^{-1} due to the carbonyl group of the β-lactam ring. Its high-resolution ^1H NMR (500 MHz) spectrum showed in addition to the other peaks, a characteristic doublet at δ 4.81 (J=2.5 Hz) corresponding to H_4 of the β-lactam ring, multiplet at δ 2.22 due to H_{8a}, another multiplet at δ 2.55 corresponding to H_{8b}, multiplet at δ 2.95 assigned to H_9, unresolved doublet of doublet at δ 3.21 (J=6.3, 11.0 Hz) assigned to H_{10} and two singlets at δ 3.29 and δ 3.68 corresponding to the ester groups. The *syn–syn* stereochemical relationship between the two protons H_3–H_5 and H_5–H_{10} is established by the coupling constant values of J=5.0 and 6.3 Hz between these protons. Its ^{13}C NMR spectrum showed the presence of three carbonyls at δ 165.2 (C-2), δ 172.6 and 174.8 (C-11, C-12) (Fig. 2).

Thus, the DA cycloaddition reactions of *trans*-3-butadienyl-2-azetidinones **1a–c**, with unsymmetrical dienophiles **2a–c** in presence of Lewis acid catalysts resulted in formation of diastereomerically pure '*endo*' adducts **3a–i** having cis stereochemistry between H_3 of 2-azetidinones moiety and H_5 of cyclohexyl ring in contrast to the trans-$H_{3,5}$ relationship observed in the adducts formed in DA cycloaddition reactions of **5a–c** with unsymmetrical dienophiles **2a–c**. The formation of the '*endo*' cycloadducts **3** and **6** in reactions of *cis*/*trans*-3-butadienyl-2-azetidinones **1** and **5** with unsymmetrical dienophiles clearly reveals the preferred *re*- and *si*-π-facial approach of the LA–unsymmetrical dienophile complex to the dienyl component of *cis*- and *trans*-3-dienyl-2-azetidinones, respectively (Fig. 4).

3. Theoretical study

In order to gain a deeper insight and to provide a reasonable rationale for the observed π-facial selectivity, ab initio calculations have been performed using 6-31G* basis sets. The reaction pathways for the preferred approach of LA–dienophile complex to the predominant conformation of *cis*/*trans*-3-butadienyl-2-azetidinones have been examined. For the present study, methyl acrylate **2a** and the *s-cisoid* conformers of **1** and **5** have been selected arbitrarily. In a sequential reaction pathway, the LA–methyl acrylate complex is allowed to approach *si*-face (lower face, Fig. 5a) as well as *re*-face (upper face; Fig. 5b) of the most preferred conformation (*s-cisoid*) of diene tethered *trans-N*-phenyl-2-azetidinones **5a**. A comparison of the plot of interaction energy versus intermolecular distance reveals the operation of steric factors at shorter intermolecular distances and at larger intermolecular distance (more than 4.0 Å) the interaction energy is insignificant (Fig. 6). Thus, the plot of interaction energy versus intermolecular distances does not provide useful information for the approach of the Lewis acid–dienophile complex toward diene. The re-examination of this cycloaddition reaction by constructing a model where the steric factors are largely reduced reveals that the lower (*si*-) face approach is much more preferred at large intermolecular distances (3–3.5 Å).

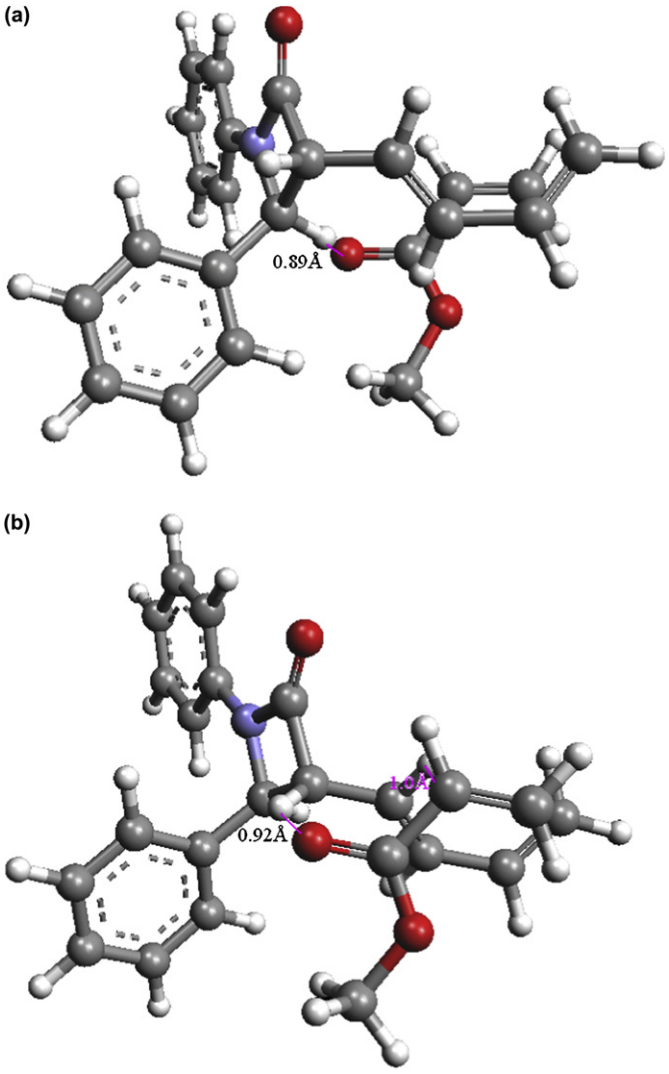


Figure 5.

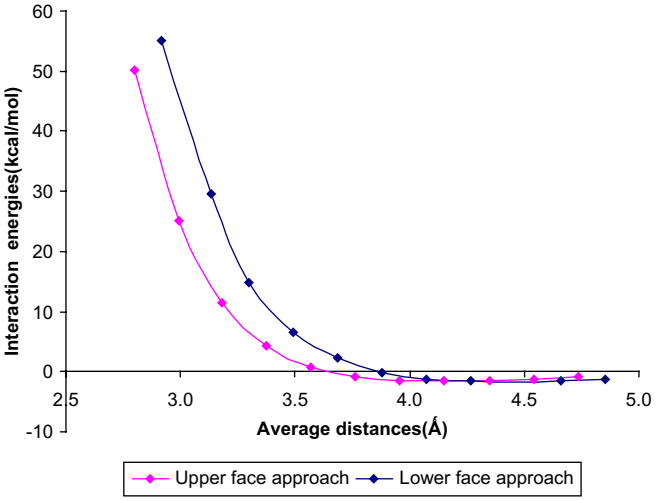


Figure 6. The plots of interaction distances versus interaction energies for lower and upper face interaction of methyl acrylate with *trans-N*-phenyl-3-butadienyl-2-azetidinones.

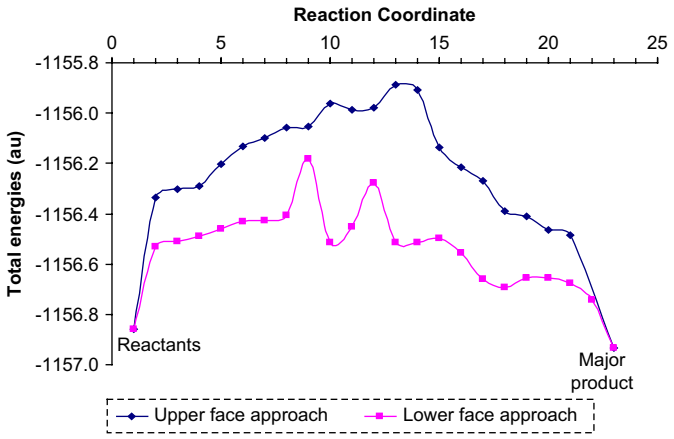


Figure 7.

In order to have a further insight into the rationale operating in this example, we have also analyzed the sequential reaction pathway through the transition state for both upper and lower face approaches of the dienophile toward *N*-phenyl-3-butadienyl-2-azetidinone. It is observed that the approach of the dienophile from the lower face (*si*-face) requires lesser activation energy while passing through the transition state as compared to the upper face approach (Fig. 7).

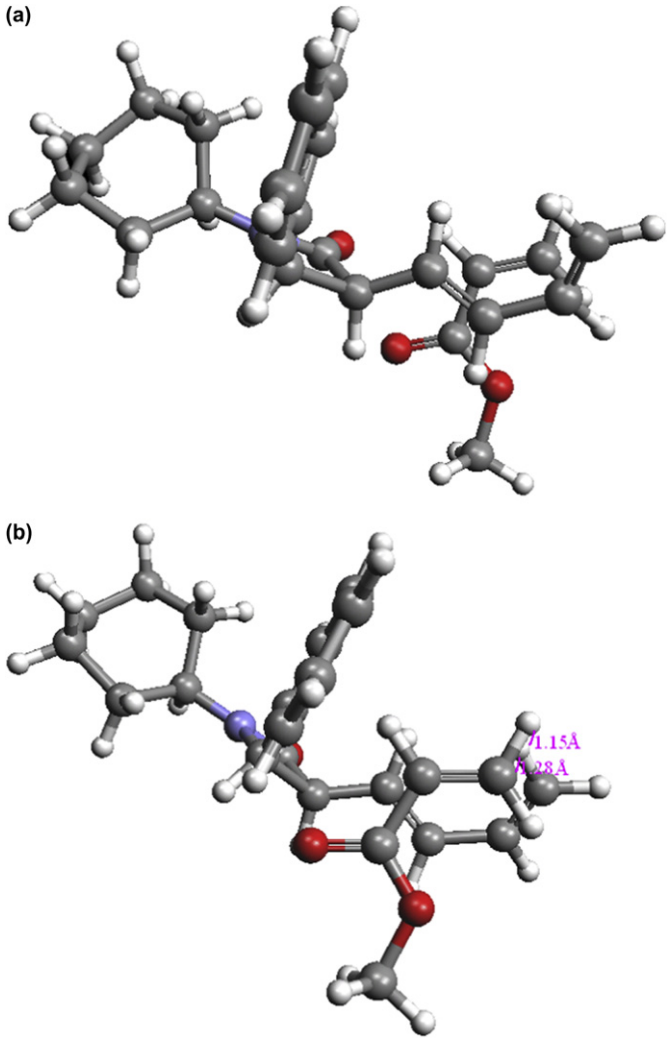


Figure 8.

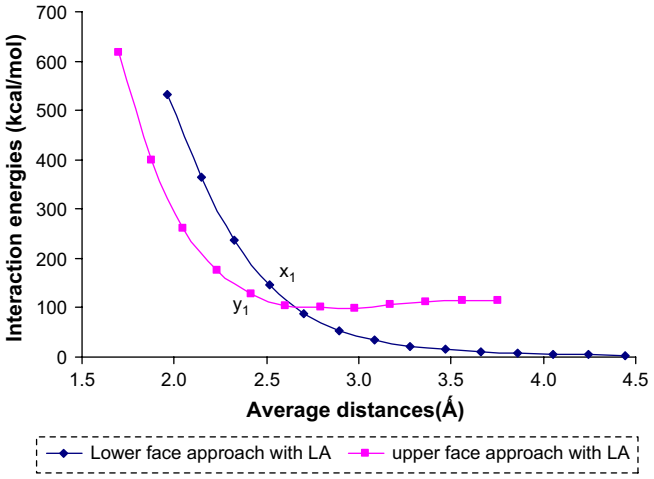


Figure 9. The plot of interaction distances versus interaction energies for lower and upper interaction of methyl acrylate with *cis*-*N*-cyclohexyl 3-butadienyl lactam in the presence of $AlCl_3$.

The sequential approach of the LA–methyl acrylate complex from both *si*-(lower face; Fig. 8a) as well as *re*-face (upper face; Fig. 8b) of least sterically oriented diene tethered *N*-cyclohexyl-2-azetidinones **1a** exhibits the operation of steric factors at distances <2.5 Å (Fig. 9) This factor appears to be less significant beyond 2.5 Å (Figs. 8 and 9). A comparison of the plot of interaction energy versus intermolecular distance during the approach of LA–dienophile complex toward **1a** from *si*- as well as *re*-face of the diene reveals the preferred *re*-face approach leading to the formation of the observed adducts **3a**–**f** (Fig. 8). These plots further reveal that the steric factors operate more significantly in DA cycloaddition reactions of *trans*-*N*-phenyl-3-butadienyl-2-azetidinones with methyl acrylate than in the reaction of *N*-cyclohexyl-3-butadienyl-2-azetidinones.

The experimentally observed preferred *re*-face (upper face) cycloaddition reaction of **1a** and for *si*-face (lower face) cycloaddition reactions in case of **5a** might be explained with the help of respective lower activation energy values. In simple terms, the observed π-facial selectivities may easily be depicted by the approach of the LA–dienophile complex from the side of hydrogen attached (sterically favored) to the C-4 of the *cis*/*trans*-dienyl-β-lactam ring.

4. Conclusion

In conclusion, highly regio-, diastereo-, and π-facially selective Diels–Alder cycloadditions of *cis*/*trans*-3-butadienyl-azetidinones having stereocentres at its α- and β-positions, with unsymmetrical dienophiles leading to the formation of biologically potent 1,3,4-trisubstituted-2-azetidinones derivatives have been developed. The results are well supported by the theoretical calculations.

5. Experimental section

5.1. General

Melting points were determined by open capillary using Veego Precision Digital Melting Point apparatus (MP-D) and are uncorrected. IR spectra were recorded on a Shimadzu D-8001 spectrophotometer. ^{1}H NMR spectra were recorded in deutero-chloroform with Bruker AC-E 200 (200 MHz and 500 MHz) spectrometers using TMS as internal standard. Chemical shift values are

expressed as parts per million downfield from TMS and *J* values are in hertz. Splitting patterns are indicated as s: singlet, d: doublet, t: triplet, m: multiplet, q: quartet, and br: broad peak. ^{13}C NMR spectra were recorded on a Bruker AC-200E (60 MHz) spectrometers in deuterochloroform using TMS as internal standard. Mass spectra were recorded on Shimadzu GCMS-QP-2000 mass spectrometer. Elemental analyses were performed on Heraus CHN-O-Rapid Elemental Analyzer. Column chromatography was performed on a silica gel (60–120 mesh) or Harrison Research Chromatotron using 2 mm plates (Silica gel 60 PF254). *trans*-Dienyl-2-azetidinones were prepared by the reported methods and same procedure was employed for the synthesis of *cis*-dienyl-2-azetidinones using *N*-alkyl imines.

5.2. Procedure

The procedure for Diels–Alder reactions involved the addition of 1.5 mmol of Lewis acid to a well stirred solution of dienophile (1 mmol) in dry dichloromethane (10 ml) at the reaction temperature. The solution was allowed to stir for 5 min followed by the addition of dienyl-2-azetidinones (1 mmol). The progress of the reaction was monitored by TLC taking diene as the limiting reactant.

5.2.1. 2-(1-Cyclohexyl-2-oxo-4-phenyl-azetidin-3-yl)-cyclohex-3-enecarboxylic acid methyl ester, ***3a***

Pale yellow solid, mp 185–186 °C, δ_H ($CDCl_3$, 300 MHz) 1.49 (m, 4H, H, cyclohexyl), 1.65 (m, 3H, H, cyclohexyl), 1.73 (m, 3H, H, cyclohexyl), 1.79 (m, 2H, $H_{8a,8b}$), 1.97 (m, 2H, $H_{9a,9b}$), 2.48 (unresolved dddd, *J*=2.5, 5.0, 8.7, 12.5 Hz, 1H, H_5), 3.09 (ddd, *J*=3.7, 8.7, 10.5 Hz, 1H, H_{10}), 3.32 (m, 1H, cyclohexyl), 3.71 (s, 3H, $-OCH_3$), 3.78 (dd, *J*=5.5, 12.5 Hz, 1H, H_3), 4.81 (d, *J*=5.5 Hz, 1H, H_4), 4.83 (dd, *J*=5.0, 9.0 Hz, 1H, H_6), 5.43 (dddd, *J*=1.1, 3.4, 9.0, 11.2 Hz,1H, H_7), 7.36 (m, 5H, aromatic), δ_C ($CDCl_3$, 75 MHz) 22.6, 24.1, 24.9, 25.1, 25.2, 30.5, 31.3, 33.2, 40.7, 51.4, 52.7, 55.4, 57.0, 126.1, 126.9, 127.8, 128.2, 128.4, 136.8, 168.9, 173.8; *m*/*z* 367 (M^+). ν_{max} (KBr)/cm^{-1} 1740, 1705, 1384, 1230, 1123. Anal. Calcd for $C_{23}H_{29}NO_3$: C, 75.17; H, 7.95; N, 3.81; found: C, 75.32; H, 8.09; N, 3.68.

5.2.2. 3-(1-Cyclohexyl-2-oxo-4-phenyl-azetidin-3-yl)-cyclohex-4-ene-1,2-dicarboxylic acid dimethyl ester, ***3b***

Viscous liquid, δ_H ($CDCl_3$, 300 MHz) 1.49 (m, 4H, H, cyclohexyl), 1.70 (m, 6H, H, cyclohexyl), 2.10 (m, 2H, H_{8a}, H_{8b}), 2.79 (ddd, *J*=2.4, 5.1, 13.9 Hz, 1H, H_5), 2.99 (ddd, *J*=6.6, 11.8, 16.2 Hz, 1H, H_9), 3.12 (dd, *J*=5.1, 11.8 Hz, 1H, H_{10}), 3.30 (m, 1H, H, cyclohexyl), 3.72 (s, 3H, $-OCH_3$), 3.78 (dd, *J*=5.6, 13.9 Hz, 1H, H_3), 3.80 (s, 3H, $-OCH_3$), 4.81 (d, *J*=5.6 Hz, 1H, H_4), 5.47 (m, 1H, H_6), 5.92 (m, 1H, H_7), 7.36 (m, 5H, aromatic), δ_C ($CDCl_3$, 75 MHz) 22.1, 24.9, 26.3, 30.1, 32.4, 35.4, 37.8, 42.3, 52.3, 54.7, 58.9, 62.7, 116.0, 124.2, 128.1, 128.7, 130.7, 137.0, 164.3, 172.5, 175.3; *m*/*z* 425 (M^+). ν_{max} (KBr)/cm^{-1} 1732, 1694, 1531, 1425. Anal. Calcd for $C_{25}H_{31}NO_5$: C, 70.57; H, 7.34; N, 3.29; found: C, 70.73; H, 7.49; N, 3.12.

5.2.3. 2-(1-Cyclohexyl-2-oxo-4-phenyl-azetidin-3-yl)-cyclohex-3-enecarbaldehyde, ***3c***

Viscous liquid, δ_H ($CDCl_3$, 200 MHz) 1.69 (m, 10H, H, cyclohexyl), 2.03 (m, 4H, $H_{8,9}$), 2.58 (ddd, *J*=6.2, 11.9, 1H, H_5), 2.87 (unresolved ddd, *J*=6.2, 10.4 Hz, 1H, H_{10}), 3.34 (m, 1H, cyclohexyl), 3.45 (dd, *J*=5.45, 11.9 Hz, 1H, H_3), 4.91 (d, *J*=5.45 Hz, 1H, H_4), 4.97 (m, 1H, H_6), 5.53 (m, 1H, H_7), 7.30 (m, 5H, aromatic), 9.5 (d, *J*=1.7, 1H, –CHO), δ_C ($CDCl_3$, 75 MHz) 22.5, 23.8, 25.2, 32.4, 33.3, 36.1, 37.5, 42.2, 58.1, 61.2, 117.3, 122.8, 125.6, 128.5, 131.2, 137.5, 165.1, 203.5; *m*/*z* 337 (M^+). ν_{max} (KBr)/cm^{-1} 1746, 1708, 1645, 1582, 1263. Anal. Calcd for $C_{22}H_{27}NO_2$: C, 78.30; H, 8.06; N, 4.15; found: C, 78.46; H, 8.23; N, 3.98.

5.2.4. 2-[1-Cyclohexyl-2-(4-methoxy-phenyl)-4-oxo-azetidin-3-yl]-cyclohex-3-enecarboxylic acid methyl ester, ***3d***

White solid, mp 207–208 °C, δ_H ($CDCl_3$, 200 MHz) 1.53 (m, 10H, $H_{cyclohexyl}$), 2.00 (m, 2H, H_{8a-8b}), 2.23 (m, 2H, $H_{9a,9b}$), 2.52 (dddd, *J*=2.2, 4.6, 5.1, 12.8 Hz, 1H, H_5), 3.14 (ddd, *J*=2.5, 4.6, 9.0 Hz, 1H, H_{10}), 3.35 (m, 1H, cyclohexyl), 3.45 (dd, *J*=5.42, 12.8 Hz, 1H, H_3), 3.76 (s, 3H, $-OCH_3$), 3.88 (s, 3H, $-OCH_3$), 4.84 (d, *J*=5.42 Hz, 1H, H_4), 4.96 (m, 1H, H_6), 5.49 (m, 1H, H_7), 6.99 (d, *J*=8.5 Hz, 2H, aromatic), 7.33 (d, *J*=8.5 Hz, 2H, aromatic), δ_C ($CDCl_3$, 75 MHz) 22.1, 23.7, 27.3, 29.0, 32.1, 37.4, 40.0, 43.5, 52.3, 54.7, 58.2, 61.4, 116.3.0, 120.4, 125.8, 126.1, 128.1, 137.5, 165.8, 174.2; *m*/*z* 397 (M^+). ν_{max} (KBr)/cm^{-1} 1747, 1708, 1527, 1329. Anal. Calcd for $C_{24}H_{31}NO_4$: C, 72.52; H, 7.86; N, 3.52; found: C, 74.71; H, 7.98; N, 3.41.

5.2.5. 3-[1-Cyclohexyl-2-(4-methoxy-phenyl)-4-oxo-azetidin-3-yl]-cyclohex-4-ene-1,2-dicarboxylic acid dimethyl ester, ***3e***

White solid, mp 145–146 °C, δ_H ($CDCl_3$, 200 MHz) 1.62 (m, 10H, H, cyclohexyl), 2.01 (m, 2H, H_8), 2.79 (m, 1H, H_5), 2.83 (ddd, *J*=5.1, 11.2, 15.3 Hz, 1H, H_9), 3.07 (dd, *J*=6.7, 11.2 Hz, 1H, H_{10}), 3.35 (m, 1H, cyclohexyl), 3.52 (s, 3H, $-OCH_3$), 3.69 (s, 3H, $-OCH_3$), 3.80 (dd, *J*=5.5, 12.0 Hz, 1H, H_3), 3.82 (s, 3H, $-OCH_3$), 4.87 (d, *J*=5.5 Hz, 1H, H_4), 4.98 (m, 1H, H_6), 5.45 (m, 1H, H_7), 7.36 (m, 4H, aromatic), δ_C ($CDCl_3$, 75 MHz) 21.7, 24.2, 27.4, 30.5, 32.0, 35.6, 38.7, 43.0, 52.3, 52.5, 55.7, 58.0, 62.7, 118.3, 125.7, 127.0, 128.2, 129.5, 137.6, 165.0, 170.3, 174.9; *m*/*z* 455 (M^+). ν_{max} (KBr)/cm^{-1} 1733, 1705, 1666, 1593, 1421, 1257. Anal. Calcd for $C_{26}H_{33}NO_6$: C, 68.55; H, 7.30; N, 3.07; found: C, 68.67; H, 7.44; N, 2.93.

5.2.6. 2-[1-Cyclohexyl-2-(4-methoxy-phenyl)-4-oxo-azetidin-3-yl]-cyclohex-3-enecarbaldehyde, ***3f***

Oily liquid, δ_H ($CDCl_3$, 200 MHz) 1.50 (m, 10H, cyclohexyl), 1.87 (m, 2H, H_8), 2.10 (m, 2H, H_9), 2.73 (m, 1H, H_5), 3.11 (m, 1H, H_{10}), 3.35 (m, 1H, cyclohexyl), 3.43 (m, 1H, *J*=5.42, 11.4 Hz, H_3), 3.87 (s, 3H, $-OCH_3$), 4.92 (d, *J*=5.42 Hz, 1H, H_4), 4.97 (m, 1H, H_6), 5.48 (m, 1H, H_7), 7.34 (m, 4H, aromatic), δ_C ($CDCl_3$, 75 MHz) 22.4, 23.8, 24.9, 27.4, 27.5, 34.8, 38.0, 42.2, 55.3, 62.1, 63.8, 115.3, 121.3, 126.1, 127.4, 128.0, 138.1, 166.1, 204.2; *m*/*z* 367 (M^+). ν_{max} (KBr)/cm^{-1} 1750, 1715, 1683, 1500, 1461, 1309. Anal. Calcd for $C_{23}H_{29}NO_3$: C, 75.17; H, 7.95; N, 3.81; found: C, 75.34; H, 8.14; N, 3.67.

5.2.7. 2-[2-(4-Chloro-phenyl)-1-cyclohexyl-4-oxo-azetidin-3-yl]-cyclohex-3-enecarboxylic acid methyl ester, ***3g***

White solid, mp 185–186 °C, δ_H ($CDCl_3$, 300 MHz) 1.57 (m, 10H, H, cyclohexyl), 2.08 (m, 4H, $H_{8,9}$), 2.52 (m, 1H, H_5), 3.09 (unresolved ddd, *J*=3.5, 6.2, 9.8 Hz, 1H, H_{10}), 3.28 (m, 1H, cyclohexyl), 3.70 (s, 3H, $-OCH_3$), 3.78 (dd, *J*=5.4, 12.3 Hz, 1H, H_3), 4.81 (d, *J*=5.4 Hz, 1H, H_4), 4.82 (m, 1H, H_6), 5.43 (dddd, *J*=1.1, 3.4, 8.7, 9.9 Hz, 1H, H_7), 7.36 (m, 4H, aromatic), δ_C ($CDCl_3$, 75 MHz) 21.5, 23.8, 26.0, 28.7, 32.3, 37.7, 42.9, 51.3, 54.2, 60.2, 62.7, 116.2, 122.7, 127.4, 128.2, 130.7, 135.9, 164.0, 172.8; *m*/*z* 401 (M^+). ν_{max} (KBr)/cm^{-1} 1734, 1698, 1583, 1507, 1438. Anal. Calcd for $C_{23}H_{28}ClNO_3$: C, 68.73; H, 7.02; N, 3.48; found: C, 68.89; H, 7.24; N, 3.57.

5.2.8. 3-[2-(4-Chloro-phenyl)-1-cyclohexyl-4-oxo-azetidin-3-yl]-cyclohex-4-ene-1,2-dicarboxylic acid dimethyl ester, ***3h***

Viscous liquid, δ_H ($CDCl_3$, 200 MHz) 1.49 (m, 4H, H, cyclohexyl), 1.70 (m, 6H, H, cyclohexyl), 2.10 (m, 2H, H_{8a}, H_{8b}), 2.79 (ddd, *J*=2.4, 5.1, 13.9 Hz, 1H, H_5), 2.99 (ddd, *J*=6.6, 11.8, 16.2 Hz, 1H, H_9), 3.12 (dd, *J*=5.1, 11.8 Hz 1H, H_{10}), 3.30 (m, 1H, cyclohexyl), 3.72 (s, 3H, $-OCH_3$), 3.78 (dd, *J*=5.6, 13.9 Hz, 1H, H_3), 3.80 (s, 3H, $-OCH_3$), 4.81 (d, *J*=5.6 Hz, 1H, H_4), 5.47 (m, 1H, H_6), 5.92 (m, 1H, H_7), 7.36 (m, 5H, aromatic), δ_C ($CDCl_3$, 75 MHz) 21.2, 22.78, 25.4, 27.0, 33.9, 35.4, 37.8, 44.7, 52.5, 55.0, 60.1, 62.7, 118.2, 121.7, 127.2, 128.0, 129.9, 135.3, 163.7, 172.8, 173.9; *m*/*z* 459 (M^+). ν_{max} (KBr)/cm^{-1} 1738, 1712, 1675, 1431, 1128. Anal. Calcd for $C_{25}H_{30}ClNO_5$: C, 65.28; H, 6.57; N, 3.05; found: C, 65.41; H, 6.70; N, 3.15.

5.2.9. 2-[2-(4-Chloro-phenyl)-1-cyclohexyl-4-oxo-azetidin-3-yl]-cyclohex-3-enecarbaldehyde, ***3i***

Viscous Liquid, δ_H ($CDCl_3$, 300 MHz) 1.71 (m, 10H, cyclohexyl), 2.00 (m, 2H, H_8), 2.17 (m, 2H, H_9), 2.67 (unresolved ddd, J=6.7, 12.4 Hz, 1H, H_5), 3.23 (m, 1H, H_{10}), 3.33 (m, 1H, cyclohexyl), 3.38 (dd, J=5.1, 12.4 Hz, 1H, H_3), 4.73 (d, J=5.1 Hz, 1H, H_4), 5.52 (m, 1H, H_6), 6.15 (m, 1H, H_7), 7.39 (m, 4H, aromatic), 9.51 (d, J=2.4 Hz, 1H, H_{11}), δ_C ($CDCl_3$, 75 MHz) 22.1, 23.0, 25.5, 25.9, 27.3, 32.6, 35.2, 37.4, 60.1, 62.9, 116.0, 121.3, 125.5, 128.1, 130.7, 137.9, 165.8, 205.1; m/z 371 (M^+). ν_{max} (KBr)/cm^{-1} 1743, 1718, 1679, 1506, 1471, 1335. Anal. Calcd for $C_{22}H_{26}ClNO_2$: C, 71.05; H, 7.05; N, 3.77; found: C, 71.18; H, 7.14; N, 3.59.

5.2.10. 2-(2-Oxo-1,4-diphenyl-azetidin-3-yl)-cyclohex-3-enecarboxylic acid methyl ester, ***6a***

White solid, mp 174–175 °C, δ_H ($CDCl_3$, 300 MHz) 1.87 (m, 2H, H_{8a-8b}), 2.14 (m, 2H, $H_{9a,9b}$), 2.95 (ddd, J=3.8, 5.3, 6.4 Hz, 1H, H_5), 3.17 (ddd, J=2.7, 6.4, 10.8 Hz, 1H, H_{10}), 3.26 (dd, J=2.4, 5.3 Hz, 1H, H_3), 3.45 (s, 3H, $-OCH_3$), 4.87 (d, J=2.4 Hz, 1H, H_4), 5.84 (m, 1H, H_6), 5.89 (m, 1H, H_7), 7.32 (m, 10H, aromatic), δ_C ($CDCl_3$, 75 MHz) 22.4, 24.7, 36.9, 47.0, 55.3, 59.0, 60.6, 118.2, 124.0, 125.2, 125.5, 126.2, 127.2, 128.9, 129.1, 137.0, 137.5, 165.8, 172.5; m/z 361 (M^+). ν_{max} (KBr)/cm^{-1} 1751, 1706, 1596, 1500, 1458, 1390, 1294. Anal. Calcd for $C_{23}H_{23}NO_3$: C, 76.43; H, 6.41; N, 3.88; found: C, 74.57; H, 6.57; N, 3.75.

5.2.11. 3-(2-Oxo-1,4-diphenyl-azetidin-3-yl)-cyclohex-4-ene-1,2-dicarboxylic acid dimethyl ester, ***6b***

White solid, mp 201–202 °C, δ_H ($CDCl_3$, 500 MHz) 2.23 (m, 1H, H_{8a}), 2.61 (m, 1H, H_{8b}), 2.95 (m, 1H, H_9), 3.12 (dd, J=2.5, 5.0, 1H, H_3), 3.21 (dd, J=6.2, 11.3 Hz, 1H, H_{10}), 3.28 (unresolved ddd, J=5.0, 6.2 Hz, 1H, H_5), 3.40 (s, 3H, $-OCH_3$), 3.68 (s, 3H, $-OCH_3$), 4.81 (d, J=2.5 Hz, 1H, H_4), 5.84 (ddd, J=2.0, 3.0, 8.5, Hz, 1H, H_6), 5.89 (dddd, J=2.0, 3.7, 8.5, 9.9, 1H, H_7), 7.32 (m, 10H, aromatic), δ_C ($CDCl_3$, 75 MHz) 28.0, 34.9, 38.2, 44.28, 51.6, 52.13, 57.9, 61.5, 116.9, 123.9, 124.6, 126.3, 128.1, 128.6, 128.9, 129.10, 137.1, 137.2, 165.7, 172.6, 174.8; m/z 419 (M^+). ν_{max} (KBr)/cm^{-1} 1735, 1702, 1689, 1596, 1492. Anal. Calcd for $C_{25}H_{25}NO_5$: C, 71.58; H, 6.01; N, 3.34; found: C, 71.70; H, 6.17; N, 3.23.

5.2.12. 2-(2-Oxo-1,4-diphenyl-azetidin-3-yl)-cyclohex-3-enecarbaldehyde, ***6c***

White solid, mp 169–170 °C, δ_H ($CDCl_3$, 300 MHz) 1.92 (m, 2H, $H_{8a,8b}$), 2.11 (m, 2H, $H_{9a,9b}$), 2.72 (ddd, J=4.1, 5.7, 8.2, 1H, H_5), 3.12 (dddd, J=1.9, 3.9, 5.7, 9.6 1H, H_{10}), 3.36 (dd, J=2.4, 8.2 Hz, 1H, H_3), 4.78 (d, J=2.4 Hz, 1H, H_4), 5.80 (ddd, J=2.1, 4.2, 8.9 Hz, 1H, H_6), 6.10 (unresolved ddd, J=3.7, 8.9 Hz, 1H, H_7), 7.26 (m, 10H, aromatic), 9.6 (d, J=1.9 Hz, 1H, H_{11}), δ_C ($CDCl_3$, 75 MHz) 21.3, 23.7, 36.7, 48.9, 59.7, 61.1, 116.2, 123.5, 125.6, 126.8, 128.4, 129.5, 129.6, 129.9, 137.0, 137.40, 166.8, 204. m/z 331 (M^+). ν_{max} (KBr)/cm^{-1} 1735, 1720, 1660, 1609, 1496, 1460, 1360. Anal. Calcd for $C_{22}H_{21}NO_2$: C, 79.73; H, 6.39; N, 4.23; found: C, 79.84; H, 6.47; N, 4.11.

5.2.13. 2-[2-(4-Methoxy-phenyl)-4-oxo-1-phenyl-azetidin-3-yl]-cyclohex-3-enecarboxylic acid methyl ester, ***6d***

White solid, mp 163–164 °C, δ_H ($CDCl_3$, 300 MHz) 1.87 (m, 2H, H_{8a-8b}), 2.07 (m, 2H, $H_{9a,9b}$), 3.01 (unresolved ddd, J=5.2, 6.1, 1H, H_5), 3.20 (m, 1H, H_{10}), 3.39 (dd, J=2.2, 5.2 Hz, 1H, H_3), 3.44 (s, 3H, $-OCH_3$), 3.53 (s, 3H, $-OCH_3$), 4.80 (d, J=2.2 Hz, 1H, H_4), 6.01 (m, 1H, H_6), 6.12 (m, 1H, H_7), 7.28 (m, 9H, aromatic), δ_C ($CDCl_3$, 75 MHz) 23.1, 24.3, 37.7, 47.2, 55.2, 55.7, 58.1, 61.5, 116.2, 125.0, 125.8, 126.2, 126.9, 127.9, 128.8, 129.2, 136.8, 137.2, 164.5, 176.3; m/z 391 (M^+). ν_{max} (KBr)/cm^{-1} 1743, 1712, 1529, 1483, 1242. Anal. Calcd for $C_{24}H_{25}NO_4$: C, 73.64; H, 6.44; N, 3.58; found: C, 73.77; H, 6.57; N, 3.43.

5.2.14. 3-[2-(4-Methoxy-phenyl)-4-oxo-1-phenyl-azetidin-3-yl]-cyclohex-4-ene-1,2-dicarboxylic acid dimethyl ester, ***6e***

White solid, mp 187–188 °C, δ_H ($CDCl_3$, 200 MHz) 2.17 (m, 1H, H_{8a}), 2.55 (m, 1H, H_{8b}), 3.01 (m, 1H, H_9), 3.12 (dd, J=2.7, 5.3, 1H, H_3), 3.21 (dd, J=6.2, 11.0 Hz, 1H, H_{10}), 3.28 (unresolved ddd, J=5.3, 6.2 Hz, 1H, H_5), 3.40 (s, 3H, $-OCH_3$), 3.52 (s, 3H, $-OCH_3$), 3.68 (s, 3H, $-OCH_3$), 4.83 (d, J=2.7 Hz, 1H, H_4), 5.92 (m, 1H, H_6), 6.02 (m, 1H, H_7), 7.27 (m, 9H, aromatic), δ_C ($CDCl_3$, 75 MHz) 26.2, 33.6, 37.6, 43.5, 51.1, 52.7, 55.6, 57.5, 60.2, 116.9, 123.9, 124.0, 126.9, 127.6, 128.0, 128.2, 128.5, 136.9, 137.5, 164.7, 171.0, 175.2; m/z 449 (M^+). ν_{max} (KBr)/cm^{-1} 1742, 1727, 1653, 1605, 1492. Anal. Calcd for $C_{26}H_{27}NO_6$: C, 69.47; H, 6.05; N, 3.12; found: C, 69.62; H, 6.15; N, 3.23.

5.2.15. 2-[2-(4-Methoxy-phenyl)-4-oxo-1-phenyl-azetidin-3-yl]-cyclohex-3-enecarbaldehyde, ***6f***

White solid, mp 169–170 °C, δ_H ($CDCl_3$, 300 MHz) 1.97 (m, 1H, H_{8a}), 2.01 (m, 1H, H_{8b}), 2.16 (m, 2H, $H_{9a,9b}$), 2.51 (unresolved ddd, J=5.5, 7.9, 1H, H_5), 3.05 (dddd, J=1.7, 3.0, 5.5, 10.5, 1H, H_{10}), 3.38 (dd, J=2.35, 7.9 Hz, 1H, H_3), 3.63 (s, 3H, $-OCH_3$), 4.77 (d, J=2.35 Hz, 1H, H_4), 5.80 (unresolved ddd, J=4.9, 9.2 Hz, 1H, H_6), 6.10 (unresolved ddd, J=7.6, 9.2 Hz, 1H, H_7), 7.26 (m, 10H, aromatic), 9.67 (d, J=1.7 Hz, 1H, H_{11}), δ_C ($CDCl_3$, 75 MHz) 22.1, 23.5, 35.8, 48.0, 54.7, 58.2, 61.3, 115.5, 124.5, 126.1, 126.3, 127.9, 128.0, 128.4, 130.2, 137.9, 165.8, 205; m/z 361 (M^+). ν_{max} (KBr)/cm^{-1} 1742, 1717, 1664, 1586, 1491. Anal. Calcd for $C_{23}H_{23}NO_3$: C, 76.43; H, 6.41; N, 3.88; found: C, 76.56; H, 6.49; N, 3.76.

5.2.16. 2-[2-(4-Chloro-phenyl)-4-oxo-1-phenyl-azetidin-3-yl]-cyclohex-3-enecarboxylic acid methyl ester, ***6g***

White solid, mp 174–175 °C, δ_H ($CDCl_3$, 200 MHz) 2.07 (m, 2H, H_{8a-8b}), 2.19 (m, 2H, $H_{9a,9b}$), 3.02 (unresolved ddd, J=5.1, 6.5 Hz, 1H, H_5), 3.21 (m, 1H, H_{10}), 3.40 (dd, J=2.1, 5.1 Hz, 1H, H_3), 3.55 (s, 3H, $-OCH_3$), 4.80 (d, J=2.1 Hz, 1H, H_4), 5.68 (m, 1H, H_6), 5.83 (m, 1H, H_7), 7.20 (m, 9H, aromatic), δ_C ($CDCl_3$, 75 MHz) 22.7, 23.9, 37.5, 47.7, 54.3, 60.1, 61.2, 117.5, 122.1, 123.9, 126.3, 127.4, 127.7, 128.50, 128.53, 135.2, 137.5, 164.3, 174.0; m/z 395 (M^+). ν_{max} (KBr)/cm^{-1} 1729, 1715, 1498, 1379. Anal. Calcd for $C_{23}H_{22}ClNO_3$: C, 69.78; H, 5.60; N, 3.54; found: C, 69.86; H, 5.69; N, 3.46.

5.2.17. 3-[2-(4-Chloro-phenyl)-4-oxo-1-phenyl-azetidin-3-yl]-cyclohex-4-ene-1,2-dicarboxylic acid dimethyl ester, ***6h***

White solid, mp 213–214 °C, δ_H ($CDCl_3$, 200 MHz) 2.13 (m, 2H, H_{8a}), 2.63 (m, 1H, H_{8b}), 2.73 (unresolved ddd, J=11.4, 17.8 Hz, 1H, H_9), 2.95 (dd, J=2.3, 5.3, 1H, H_3), 3.17 (unresolved ddd, J=6.7, 11.4, 1H, H_{10}), 3.32 (m, 1H, H_5), 3.40 (s, 3H, $-OCH_3$), 3.51 (s, 3H, $-OCH_3$), 4.88 (d, J=2.3 Hz, 1H, H_4), 5.98 (m, 1H, H_6), 6.17 (m, 1H, H_7), 7.32 (m, 9H, H, aromatic), δ_C ($CDCl_3$, 75 MHz) 26.1, 33.0, 38.1, 45.6, 52.1, 53.1, 59.1, 62.0, 117.2, 121.7, 125.5, 126.2, 127.1, 128.4, 128.7, 129.0, 137.0, 137.5, 164.3, 173.0, 175.1; m/z 453 (M^+). ν_{max} (KBr)/cm^{-1} 1741, 1732, 1558, 1500, 1458, 1352. Anal. Calcd for $C_{25}H_{24}ClNO_5$: C, 66.15; H, 5.33; N, 3.09; found: C, 66.28; H, 5.48; N, 3.18.

5.2.18. 2-[2-(4-Chloro-phenyl)-4-oxo-1-phenyl-azetidin-3-yl]-cyclohex-3-enecarbaldehyde, ***6i***

White solid, mp 169–170 °C, δ_H ($CDCl_3$, 200 MHz) 2.00 (m, 2H, H_{8a-8b}), 2.14 (m, 2H, $H_{9a,9b}$), 2.62 (ddd, J=3.6, 5.5, 7.7 Hz, 1H, H_5), 2.97 (unresolved ddd, J=5.5, 9.4 Hz, 1H, H_{10}), 3.24 (dd, J=2.1, 7.7 Hz, 1H, H_3), 4.90 (d, J=2.1 Hz, 1H, H_4), 5.71 (m, 1H, H_6), 6.12 (m, 1H, H_7), 7.21 (m, 9H, aromatic), 9.30 (d, J=1.8 Hz, 1H, –CHO), δ_C ($CDCl_3$, 75 MHz) 23.7, 24.0, 35.4, 50.1, 58.3, 62.7, 117.1, 122.7, 124.3, 126.4, 128.0, 128.3, 128.7, 129.1, 137.1, 137.3, 164.0, 205.6; m/z 365 (M^+). ν_{max} (KBr)/cm^{-1} 1752, 1727, 1653, 1594. Anal. Calcd for $C_{22}H_{20}ClNO_2$: C, 72.22; H, 5.51; N, 3.83; found: C, 72.36; H, 5.59; N, 3.76.

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25. These reactions were also tried in the presence of $MgBr_2$, $InCl_3$, and $Y(OTf)_3$. In all cases the type of products remained same. However, the reactions took very long time for their completion (2 days in case of $MgBr_2$ with methyl acrylate as dienophile) possibly owing to their weak acidity.
26. Crystal data for **3a** $C_{23}H_{29}NO_3$, M=373.39, triclinic, space group $P\bar{1}$, a 9.322(3), b 12.927(5), c 16.621(6) Å, α 88.528(7), β 80.793(8), γ 88.645(7), V=1976.08 Å^3, Z: 4, Z': 0, CCDC 239793. Diffraction data were measured on a Bruker APEX CCD-Detector X-ray diffractometer. Structure solution and refinement were carried out using Shelx-97.