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[4+2] and [2+2] Cycloaddition Reactions of 1-(4-Methylphenyl) and 1-Benzyl-1,3-Diaza-1,3-Butadienes with Ketenes

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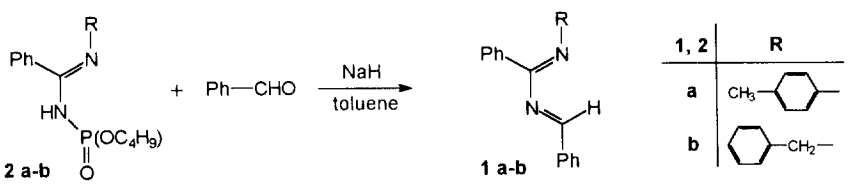
Abstract: [4+2] and [2+2] cycloaddition reactions of 1-(4-methylphenyl) and 1-benzyl-1,3-diaza-1,3-butadienes with monophenyl, diphenyl, monochloro and ethoxycarbonylketenes are described. The mechanism of these reactions is also discussed. © 1997 Elsevier Science Ltd.

Cycloaddition reactions of diazadienes have been extensively studied because of their importance in the synthesis of a wide variety of nitrogen containing heterocycles.[1] Under these, [2+2] and [4+2] cycloaddition reactions of 1,3-diaza-1,3-butadienes with ketenes could represent a versatile route for the synthesis of important β-lactam derivatives as well as of different pyrimidinones. During the last decades, in connection with the development of new synthetic approaches to these derivatives[2], there has been some interest in the reactions, especially the cycloaddition reactions, of 1,3-diaza-1,3-butadienes and several works demonstrated their capability to participate in [2+2] and [4+2] cycloaddition with ketenes.[3] In particular, Mazumdar and co-workers successfully investigated the reactivity of 4-sec.amino, 4-bis-sec.amino, 4-alkylthio-4-sec.amino and 2 or 4-alkylthio-1,3-diaza-1,3-dienes, which undergo [4+2] cycloaddition reactions with mono and disubstituted ketenes giving rise to different pyrimidinones.[3b,f-g] The driving force for the mode of cycloaddition is probably related to the pronounced charge alternation in diene reactants, enhanced by the substituents in position 4, and to the possibility for the primary adducts of the cycloaddition to evolve from dihydropyrimidinones to more stable pyrimidinones through elimination of neutral molecules. On the other hand only [2+2] cycloaddition products were isolated when simple aryl or alkyl substituted as well as 4-sec.amino, 1,3-diaza-1,3-dienes reacted with diphenylketenes and steric factors have been invoked to explain the cycloaddition pathway.[3a-c] Moreover one example of [4+2] cycloaddition with diphenylketene was reported for the reaction with a bulky alkyl substituted diazadiene[3c], whereas no reports have appeared in the literature for the reaction of simple alkyl or aryldiazadienes with monosubstituted ketenes.

In connection with our ongoing interest in the synthesis of heterocyclic compounds starting from amidines and their derivatives[4], recently we described a new synthesis of the 1-(4-methylphenyl)-2,4-diphenyl-1,3-diaza-1,3-butadienes **1a**[4b] starting from dibutylphosphoramidate **2a** and benzaldehyde (Scheme 1).

In this work we extended the same synthetic approach to the 1-benzyl-2,4-diphenyl-1,3-diaza-1,3-butadiene **1b**[5] with the aim to study the behaviour of both compounds **1a-b** in cycloaddition reactions with mono and disubstituted ketenes and to deepen our knowledge of the mechanism(s) involved.

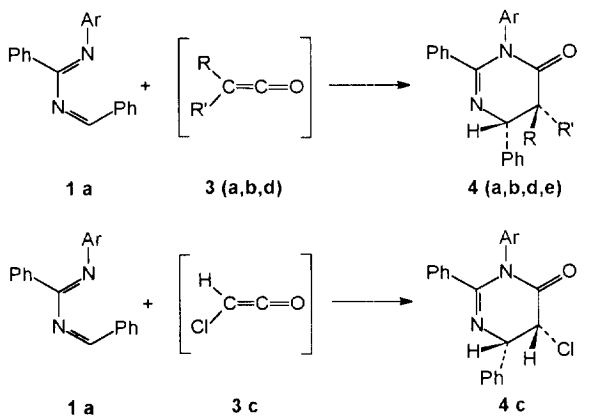


SCHEME 1

RESULTS

The reactions of 1,3-diaza-1,3-butadienes **1a-b** with ketenes **3a-d**, formally derived from phenylacetic, diphenylacetic, chloroacetic and from the monoethylester of malonic acid, were performed by slow dropwise addition of a solution of the appropriate acyl chloride (1.1 mmol) in dry toluene to an ice cooled solution of 1,3-diaza-1,3-diene **1a** or **1b** (1 mmol) and triethylamine (2.3 mmol) in dry toluene. Best results were obtained working in dilute solution (about 0.085 mmolar) to avoid the polymerisation of ketenes. After usual work up, the reaction mixture was purified by crystallisation or by flash chromatography over silica gel.

The 1,3-diaza-1,3-butadiene **1a**, bearing a 4-methylphenyl group on N-1, undergo [4+2] cycloaddition with the *in situ* generated ketenes **3a-d** giving rise to the dihydropyrimidin-6-ones **4a-d** (Scheme 2).



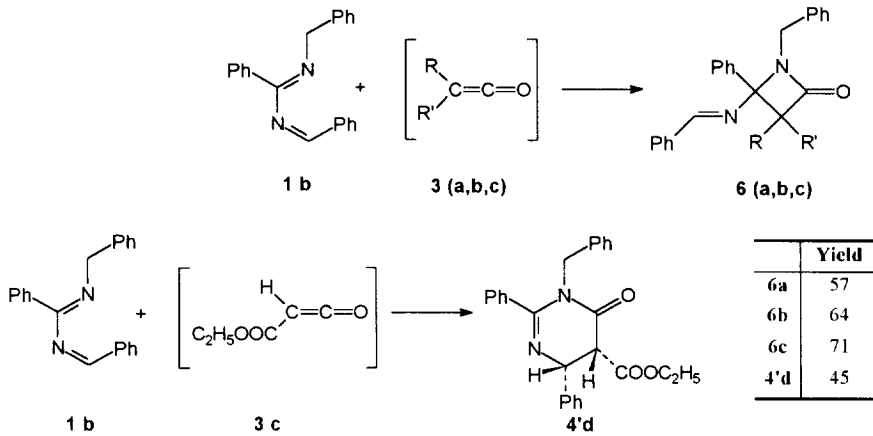
	Yield	R	R'	Ar
4a	66	H	Ph	$CH_3C_6H_4$
4b	75	Ph	Ph	$CH_3C_6H_4$
4c	22	H	Cl	$CH_3C_6H_4$
4d	52	H	$COOC_2H_5$	$CH_3C_6H_4$
4e	17	Ph	H	$CH_3C_6H_4$
5	68	H	-	$CH_3C_6H_4$

SCHEME 2

It is worth to note that the formation of dihydropyrimidinone **4b** represents the first example of a [4+2] cycloaddition reaction between a fully aryl substituted diazadiene (**1a**) and diphenylketene, such mode of cycloaddition being observed only with bulky alkyl substituted diazadienes.[3c] Furthermore, in the reaction of **1a** with chloroketene **3c** it was possible to isolate, beside the 4,5-dihydropyrimidin-6-one **4c** (22%), the pyrimidin-6-one **5** (68%), which originate from **4c** by loss of hydrogen chloride. Treatment of the crude reaction mixture, containing both **4c** and **5**, with an excess of triethylammine in hot toluene resulted in the isolation of **5** in 90% yield. Poorer yields were observed with the ethoxycarbonylketene which probably undergoes partial polymerisation also in dilute solution. Finally in the reaction of **1a** with **3a** a small amount of *trans* isomer **4e** (17 %) was isolated.

The reactions performed with 1,3-diaza-1,3-butadiene **1b**, bearing a benzyl group on N-1, and ketenes **3a-c** resulted in the isolation of the [2+2] cycloaddition reaction products, the azetidinones **6a-c** (Scheme 3).

The novelty in this case is represented by the [2+2] cycloaddition observed with phenyl and chloroketene **3a,c** which react in a [4+2] mode with all diazadienes tested until now by other groups.[3b,d,e,f,g] On the other hand, the reaction between **1b** and ketene **3d** resulted in the isolation of the dihydropyrimidin-6-one **4'd**, the product of the [4+2] cycloaddition. All compounds **4a-d**, **5**, **6a-c** and **4'd** were identified on the basis of analytical and spectral data (IR, ^{1}H-NMR, ^{13}C-NMR) (Table 2) and, in particular, the reported values[3] for the C=O bond stretching are in agreement with the proposed structures, whereas *cis* and *trans* configurations were attributed by the analysis of the ^{1}H-NMR coupling constant values which are in the order of $J_{cis} > J_{trans}$ (calculated by Karplus equation). Moreover, *cis*-dihydropyrimidin-6-one **4a** was quantitatively converted in the more stable *trans* isomer **4e** when heated in hot toluene in the presence of an excess (4 mmol) of 4-(N,N-dimethylamino)-pyridine.



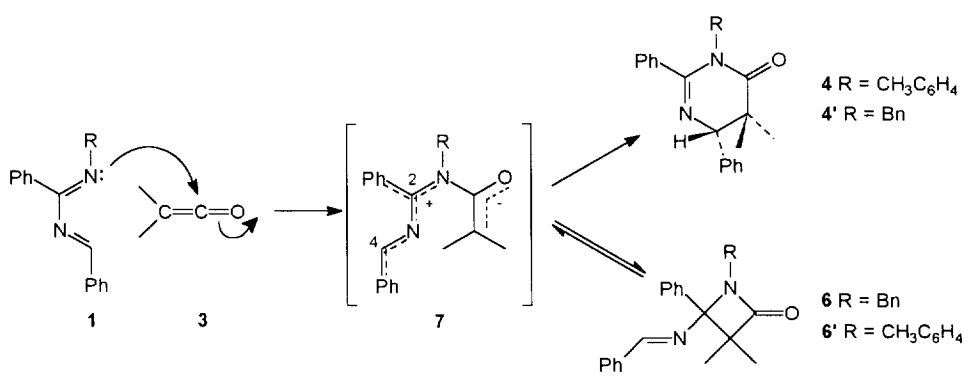
	Yield	R	R'
6a	57	Ph	H
6b	64	Ph	Ph
6c	71	H	Cl
4'd	45	H	$COOC_2H_5$

SCHEME 3

DISCUSSION

By simple application of perturbation theory, 1,3-diaza-1,3-dienes can be described as highly electron deficient dienes and their chemistry characterised by pronounced charge alternation. On the other hand, in cycloaddition reactions, ketenes react preferentially through a [2+2] mechanism, even if inverse-demand Diels-Alder reactions can be observed with electron-deficient dienes. Moreover, in agreement with several reports[3c,f] and owing to the great difference in electronegativity of the reacting atoms, a polar stepwise mechanism can be proposed for both cycloaddition pathways.

On the basis of these simple considerations, the proposed mechanism for the reaction between 1,3-diaza-1,3-dienes **1a-b** and ketenes **3a-d** involves the nucleophilic attack of N-1 upon the C=O carbonyl group of ketene leading to the zwitterionic intermediate 7, subsequent intramolecular attack of the more nucleophilic carbanion on C-4 or C-2 of the diene system results respectively in the formation of dihydropyrimidin-6-ones **4** or β-lactams **6**, Scheme 4.



SCHEME 4

The formation of β-lactams **6** is a kinetically governed process, whereas pyrimidin-6-ones **4** are the thermodynamically controlled products. The reaction pathway is controlled, in our opinion, by the relative

stability of the effectively isolated products (**6**, R = Bn and **4**, R = $CH_3C_6H_4$) with respect to the hypothetical β-lactams **6'**, with R = $CH_3C_6H_4$, and pyrimidin-6-ones **4'**, with R = Bn, and the energies calculated, for the obtained and hypothetical reaction products, using the MM+ method[6] support this hypothesis.

Table 1.

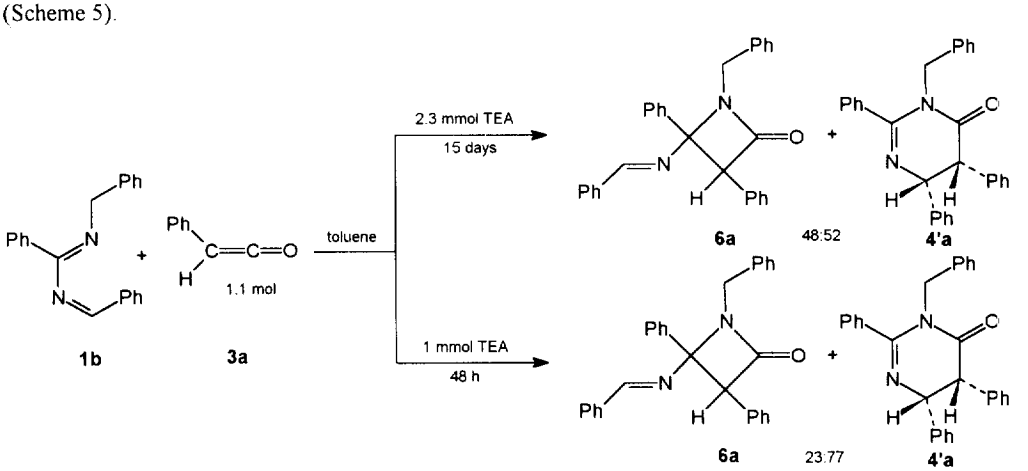
Compound	Potential Energy[a] (kcal/mol)	Compound	Potential Energy[a] (kcal/mol)
6a	13.5	**6'a**	30.8
6b	17.4	**6'b**	34.6
6c	24.9	**6'c**	43.6
6d	13.6	**6'd**	34.0
4a	8.4	**4'a**	-4.6
4b	15.6	**4'b**	1.2
4c	15.4	**4'c**	0.9
4d	8.6	**4'd**	-4.6

[a] Energies of **4** and **4'** are referred to the *cis*-isomers. *Trans* isomers are lower in energy by about 0.7-1.5 kcal/mol.

Both observed and hypothetical dihydropyrimidin-6-ones **4** and **4'** in fact, are lower in energy than the corresponding β-lactams **6** and **6'**. For these latter compounds however, the isolated β-lactams **6** are lower in energy than hypothetical β-lactams **6'** and consequently closer to the [4+2] cycloaddition products. Thus the major energy difference between **4** and **6'** with respect to **6** and **4'** favours in the first case the formation of the thermodynamically controlled product. Whereas in the second case the energy difference involved is smaller and the formation of the kinetically controlled product is allowed.

The energy differences observed can be probably explained by the steric hindrance between the substituents of the azetidinone ring. The [2+2] cycloaddition of **1a** with ketenes give rise to an azetidinone (**6'** in Scheme 4) with two phenyl substituents in vicinal position (N-1 and C-4), suffering from steric hindrance as demonstrated also by the construction of a 3D model. Instead azetidinones **6**, in which the phenyl group on N-1 is moved away from the β-lactam ring by the insertion of the methylenic group, are more stable and easily isolable cycloadducts.

Moreover, in accordance with these assertions, while the formation of pyrimidinones **4** is an irreversible process, the initially formed β-lactams **6** could evolve towards the more stable [4+2] cycloaddition products. In order to confirm these hypothesis we performed some interesting experiments with diazadienes **1a-b** and ketene **3a** (Scheme 5).



SCHEME 5

The first experiment, for **1b**, was performed using the same molar ratio described above and sampling the reaction every 24 h. The ^{1}H-NMR analysis of each sample showed the initial formation of the sole azetidinone **6a** and its subsequent and gradual transformation into the dihydropyrimidin-6-one **4'a**. After 15 days, usual work up of the reaction mixture gave, with an overall yield of 57%, **6a** and **4'a** in 48:52 ratio. The second experiment, performed using equimolecular amounts of diazadiene and triethylamine and a slight excess (1.1 mol) of acyl chloride, resulted in the isolation, after 48 h, of **6a** and **4'a** in 23:77 ratio (overall yield: 56%). The same approach applied to the reaction between diazadiene **1a** and ketene **3a** shows the formation, even during the reagent addition, of dihydropyrimidin-6-one **4a** as the sole reaction product.

In conclusion, in our opinion, cycloaddition reactions of diene **1a** with ketenes proceed directly to [4+2] cycloaddition products, the formation of [2+2] adducts being forbidden for steric reasons. On the contrary, from diene **1b** and ketenes, [2+2]cycloadducts formation is allowed even if these latter compounds evolved towards more stable [4+2] adducts when prolonged reaction times were used or in particular microreversibility conditions.

Finally, the apparently anomalous behaviour of ketene **3d** in the reaction with diazadiene **1b** was initially explained supposing that a fast cycloreversion from **6** to **4** took place, but several reactions, performed in different conditions and monitored by ^{1}H-NMR, always showed the formation of the dihydropyrimidin-6-one **4'd** as the sole reaction product. Probably, in this case, the major stability of the intermediate **7**, related to the presence of an ethoxycarbonyl substituent on the ketene moiety capable of delocalizing the negative charge within the adjacent carbonyl group, increases this tendency to give the thermodynamically controlled cycloadduct.

EXPERIMENTAL

1,3-diaza-1,3-butadiene **1a**[3b] and ketenes **3a-d**[7] are known compounds and were prepared according to described methods. All other chemicals and solvents are commercially available and were used after distillation or treatment with drying agents. Merck silica gel 60 F_{254} thin-layer plates were employed for thin layer chromatography. Merck silica gel (230-400 mesh) was employed for flash column chromatography. Melting points, measured with a Büchi apparatus, are "uncorrected". Infrared spectra were recorded on a FT-IR Perkin Elmer 16 PC spectrophotometer, using KCl disks or KBr tablets. ^{1}H-NMR (200 MHz) and ^{13}C-NMR (50.3 Mhz) spectra were recorded in $CDCl_3$, with a Varian-Gemini 200 spectrometer, using TMS as internal standard.

1-Benzyl-2,4-diphenyl-1,3-diaza-1,3-butadiene (1b). To a stirred slurry of sodium hydride, 55% in mineral oil (1.06 g, 24.4 mmol) in dry toluene (25 ml), a solution of dibutyl-N-(α-phenylmethyl)benzyl phosphoramidate (8.20 g, 20.4 mmol) in dry toluene (20 ml) was added dropwise, at 35-40°C under nitrogen. After hydrogen evolution ceased the mixture was cooled to room temperature and benzaldehyde (4.33g, 40.8 mmol) was added. The reaction mixture was stirred for 18-20 hours and then washed two times with a cold saturated solution of $NaHCO_3$. The organic layer was dried over anhydrous sodium sulphate and freed from solvent under reduced pressure without heating. The crude product was purified by flash chromatography over silica gel column and then recrystallized from petroleum ether. Yield: 3.5g, 57%. White solid, m.p. 89-90 °C. I.R. (KCl disks, cm^{-1}): 1565-1640 (ν C=O and ν C=C). ^{1}H-NMR ($CDCl_3$, δ ppm from TMS): 4.65 (s, 2H, CH_2), 7.20-7.60 (m, 11H, arom.), 7.85-7.95 (m, 4H, arom.), 8.20 (s, 1H, CH=N).

Reactions of 2,4-diphenyl-1,3-diaza-1,3-butadienes 1a-b with ketenes 3a-d. A solution of appropriate acyl chloride (1.1 mmol) in dry toluene (8 ml) was added slowly (over a period of 1h) to a nitrogen flushed, well stirred and ice-water cooled solution of 1,3-diaza-1,3-butadiene **1a** or **1b** (1.0 mmol) and triethylamine (2.3 mmol) in dry toluene (14 ml). After complete addition of acyl chloride, the reaction mixture was stirred for 3-24 hours at 25°C. It was then thoroughly washed first with a cold saturated solution of $NaHCO_3$ and then with cold water. The organic layer was dried over anhydrous sodium sulphate and freed from solvent under reduced pressure at 40°C. The crude product was purified by crystallisation or by flash chromatography over silica gel column. For data see Table 2.

Table 2. Dihydropyrimidin-6-ones **4a-e**, **4'a**, **4'd**, pyrimidin-4-one **5** and 2-azetidinones **6a-c**.

	Time (h)	Eluent	m.p., °C (solvent)	Elemental analysis, %[a] C	H	N	I.R., cm^{-1} (ν C=N, C=O)	^{1}H-NMR (200 Mhz) $CDCl_3$, δ from TMS	^{13}C-NMR (50 Mhz) $CDCl_3$, δ from TMS
4a	24	PE / EtOAc 9:1	185 (dec) (*i*-Pr_2O)	83.55 (83.62)	5.72 (5.81)	6.60 (6.73)	1629, 1709	2.25 (s, 3H, CH_3), 4.15 and 5.48 (AX system, 2H, CH-CH, J=7.9), 6.95 and 7.05 (AA'BB' system, 4H, arom., J=8.0), 7.12-7.38 (m, 13H, arom), 7.45 (dd, 2H, arom).	21.5 (CH_3), 54.3 (Ph-<u>C</u>H-C=O), 62.4 (Ph-<u>C</u>H-N), 127.6, 127.9, 128.4, 128.5, 129.0, 129.1, 129.2, 129.8, 129.9 (CH arom.), 135.5, 135.7, 136.5, 137.8, 140.8 (C arom.), 156.1 (Ph-<u>C</u>=N), 170.6 (C=O).
4b	6	-	234-236 (*i*-Pr_2O)	85.15 (85.33)	5.71 (5.73)	5.44 (5.69)	1635, 1707	2.25 (s, 3H, CH_3), 5.75 (s, 1H, CH), 6.76 and 6.89 (AA'BB' system, 4H, arom., J=7.8), 6.92-7.25 (m, 15H, arom.), 7.42 (m, 3H, arom.), 7.71 (dd, 2H, arom.)	21.5 (CH_3), 60.9 (Ph-<u>C</u>-Ph), 68.2 (Ph-<u>C</u>H-N), 126.8, 127.4, 128.3, 128.4, 128.5, 128.6, 128.7, 129.0, 129.4, 129.5, 129.9, 131.0 (CH arom.), 135.8, 136.0, 137.0, 137.9, 140.4, 141.0, (C arom.), 155.3 (Ph-<u>C</u>=N), 171.7 (C=O)
4c	5	PE / TEA 9:1	154-155 (dec) (PE)	73.43 (73.69)	5.18 (5.11)	7.39 (7.47)	1644, 1718	2.25 (s, 3H, CH_3), 4.76 and 5.39 (AX system, 2H,CH-CH, J=6.7), 6.95 and 7.05 (AA'BB' system, 4H, arom., J=7.8), 7.27 (t, 3H, arom.), 7.32-7.49 (m, 7H, arom.).	24.0 (CH_3), 59.5 (Cl-<u>C</u>H-C=O), 67.5 (Ph-<u>C</u>H-N), 129.9, 130.4, 130.5, 131.0, 131.3, 131.9, 132.2, 132.4 (CH arom.), 137.2, 137.3, 139.8, 140.8 (C arom.) 158.5 (Ph-<u>C</u>=N), 168.2 (C=O).
4d	24	PE / TEA 9:1	158-160 (dec) (*i*-Pr_2O)	75.50 (75.70)	5.78 (5.87)	6.71 (6.79)	1634, 1700	1.22 (t, 3H, CH_2-<u>CH_3</u>), 2.24 (s, 1H, Ph-<u>CH_3</u>), 3.94 and 5.49 (AX system, 2H, CH-CH, J=8.2), 4.2 (m, 2H, <u>CH_2</u>-CH_3), 6.94 and 7.03 (AA'BB' system, 4H, arom., J=8.5),7.15-7.49 (m, 10H, arom.).	14.5 (CH_2-<u>CH_3</u>), 21.5 (Ph-CH_3), 54.8 (O=C-<u>C</u>H-COOEt), 60.9 (Ph-<u>C</u>H-N), 62.4 (<u>CH_2</u>-CH_3), 127.5, 128.4, 128.5, 129.3, 129.9, 130.1 (CH arom.), 134.9, 135.2, 138.0, 139.6 (C arom.), 156.5 (Ph-<u>C</u>=N), 166.6 (O=<u>C</u>-OEt), 168.1 (N-<u>C</u>=O).
4e	17	PE / EtOAc 9:1	147-150 (*i*-Pr_2O)	83.43 (83.62)	5.75 (5.81)	6.68 (6.73)	1640, 1708	2.28 (s, 3H, CH_3), 4.33 and 5.49 (AX system, 2H, CH-CH, J=5.5), 6.85-7.35 (m, 17H, arom.,), 7.50 (dd, 2H, arom).	21.5 (CH_3), 53.3 (Ph-<u>C</u>H-C=O), 63.0 (Ph-<u>C</u>H-N), 127.7, 127.9, 128.2, 128.4, 128.5, 128.7, 128.9, 129.3, 129.8, 129.9, 130.0 (CH arom.), 133.6, 135.5, 135.7, 137.8, 139.2 (C arom.), 156.1 (Ph-<u>C</u>=N), 171.2 (C=O).

4'd	24	PE / EtOAc 9:1	98-99 (i-Pr_2O)	75.53 (75.70)	5.90 (5.87)	6.77 (6.79)	1640, 1692	1.21 (t, 3H, CH_2-CH_3), 3.87 and 5.31 (AX system, 2H, CH-CH, J=8.1), 4.19 (m, 2H, CH_2-CH_3), 4.85 and 4.95 (AB system, 2H, Ph-CH_2-, J=15.3), 6.78 (dd, 2H, arom.), 7.15-7.46 (m, 13H, arom.).	14.5 (CH_2-CH_3), 47.6 (Ph-CH_2-N), 54.3 (O=C-CH-COOEt), 60.6 (Ph-CH-N), 62.3 (CH_2-CH_3), 127.5, 128.0, 128.2, 128.3, 128.6, 128.9, 129.0, 129.1, 130.7 (CH arom.), 134.9, 136.9, 139.2 (C arom.), 157.4 (N-C=N), 167.0 (O=C-OEt), 168.3 (N-C=O)
4'a	48	PE / EtOAc 9:1	169-170 (i-Pr_2O)	83.47 (83.62)	5.74 (5.81)	6.68 (6.73)	1644, 1698	4.02 and 5.17 (AX system, 2H, CH-CH, J=8.3), 4.85 and 4.98 (AB system, 2H, Ph-CH_2-, J=15.5), 6.83 (dd, 2H, arom.), 7.08-7.48 (m, 18H, arom.).	57.8 (CH_2), 63.9 (Ph- CH-C=O), 73.9 (Ph-CH-N), 137.7, 137.8, 137.9, 138.3, 138.6, 138.8, 138.9, 139.0, 139.1, 140.5 (CH arom.), 145.5, 146.8, 147.5, 150.5 (C arom.), 167.0 (Ph-C=N), 181.2 (C=O).
5	24	PE / TEA 9:1	201-203 (i-Pr_2O)	81.28 (81.63)	5.29 (5.36)	8.19 (8.28)	1670 (ν C=O)	2.23 (s, 3H, CH_3), 6.95-7.55 (m, 12H arom. and 1H, CH-C=O), 8.10 (dd, 2H, arom.).	21.7 (CH_3), 108.6 (CH-C=O), 127.9, 128.4, 128.8, 129.2, 129.5, 129.9, 130.1, 131.2 (CH arom.), 135.1, 135.7, 136.7, 139.1 (C arom.), 159.7 (Ph-C-N), 160.5 (N=C-N), 136.7 (C=O).
6a	5	PE / EtOAc 9:1	oil	83.47 (83.62)	5.85 (5.81)	6.67 (6.73)	1645, 1755	4.00 and 5.02 (AX system, 2H, Ph-CH_2-, J=15.5), 4.62 (s, 1H, Ph-CH-C=O), 7.08-7.28 (m, 8H, arom.), 7.32-7.48 (m, 10H, arom.), 7.55-7.64 (dd, 2H, arom.), 8.12 (s, 1H, Ph-CH=N).	45.6 (CH_2), 71.3 (Ph-CH-C=O), 88.4 (N-C-N), 127.5, 128.2, 128.4, 128.5, 128.8, 129.1, 129.2, 129.3, 129.8, 131.9 (CH arom.), 133.4, 136.0, 137.0, 137.7 (C arom.), 158.7 (Ph-CH=N), 168.8 (C=O).
6b	3	PE / EtOAc 9:1	174-176 (PE)	85.15 (85.33)	5.68 (5.73)	5.54 (5.69)	1650, 1750	3.69 and 4.02 (AX system, 2H, Ph-CH_2-, J=15.4), 7.00-7.60 (m, 15H, arom. and 1H Ph-CH=N).	45.6 (CH_2), 80.5 (Ph-C-Ph), 90.8 (N-C-N), 126.7, 127.1, 128.1, 128.4, 128.5, 128.6, 128.7, 128.8, 129.1, 129.4, 129.7, 129.9, 131.3 (CH arom.), 135.9, 137.7, 138.9, 139.2, 139.4 (C arom.), 159.6 (Ph-CH=N), 171.2 (C=O).
6c	5	PE / TEA 9:1	110-111 (i-Pr_2O /PE)	73.56 (73.69)	5.17 (5.11)	7.32 (7.47)	1645, 1765	3.98 and 4.93 (AX system, 2H, Ph-CH_2-, J=15.5), 4.80 (s, 1H, Cl-CH-C=O), 7.22-7.60 (m, 15H, arom.), 7.98 (s, 1H, Ph-CH=N).	46.1 (CH_2), 69.4 (Cl-CH-C=O), 88.6 (N-C-N), 128.5, 128.9, 129.1, 129.2, 129.3, 129.4, 129.7, 129.8, 132.4 (CH arom.), 134.4, 136.8 (C arom.), 160.6 (Ph-CH=N), 164.5 (C=O).

[a] Calculated values in parentheses. PE = petroleum ether, TEA = triethylamine.

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5. Hunter and Sim (see ref. 2a) described the synthesis of **1b** by zinc chloride-catalysed condensation of N-benzylbenzamidine and benzaldehyde, but we were unable to reproduce their results.
6. MM+ runs molecular mechanics calculation. This program is an extension of MM2 developped by Allinger and co-workers (Allinger, N. L. *J. Am. Chem. Soc.* **1977**, 99, 8127-8147) and is designed primarily for small organic molecules.
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