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Regioselective palladium-catalysed cycloaddition reactions of 1-alkyl-2-vinylazetidines with ketenimines and ketenes

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Dedicated to Professor Renato Ugo on the occasion of his 65th birthday. We have learned so much from Professor Ugo, a remarkably creative and humane person

Abstract

1-Alkyl-2-vinylazetidines undergo regioselective cycloaddition reactions with a wide range of ketenimines and ketenes, in the presence of $Pd(OAc)_2$ and PPh_3 under mild conditions (room temperature and pressure), to afford six-membered ring products in moderate to good yields.

Keywords: Regioselectivity; 1-Alkyl-2-vinylazetidines; Ketenimines

Considerable attention has been focussed in recent years to palladium-catalysed ring expansion reactions of heterocyclic compounds [1]. In this field, the reaction of strained rings and carbon electrophiles has been achieved at elevated temperatures, with good regioselectivities [2] and a few examples with stereocontrol [3]. The introduction of a vinyl group at the 2-position of the strained ring affected positively the reaction: at mild temperature and pressure oxiranes [4–8], oxetanes [9], thiiranes [10], and aziridines [11] were successfully applied incorporating a wide range of heterocumulenes.

We previously reported the synthesis of tetrahydropyrimidinone, tetrahydropyrimidinime and thiazinanimine analogs by mild palladium-catalysed cyclisation of 2-vinylazetidines with aryl and alkylisocyanates, diarylcarbodiimides and arylisothiocyanates [12]. The six-membered ring products are obtained in good to high yields and with excellent regioselectivity. These transformations are readily achieved at room temperature and pressure and likely occur by a π-allyl palladium intermediate and featuring a possible equilibrium of kinetic and thermodynamic products via cyclisation in the product-forming step. Other ring opening reactions have been reported with 2-vinylazetidines using Pd(O) catalysts indicating the ring cleavage via π-allyl intermediate [13,14].

We also reported previously the synthesis of substituted pyrrolidine derivatives from 2-alkyl and 2-arylaziridines and ketenimines using Li- or Pd-based catalysts. Lithium-based catalysts were found to work at milder temperatures (room temperature to 50 °C) than palladium-based systems (75 °C) [15].

In an effort to generalise the cycloaddition method using 2-vinylazetidines, we investigated the reaction

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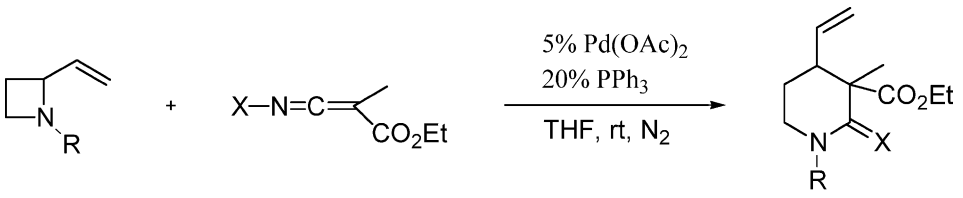
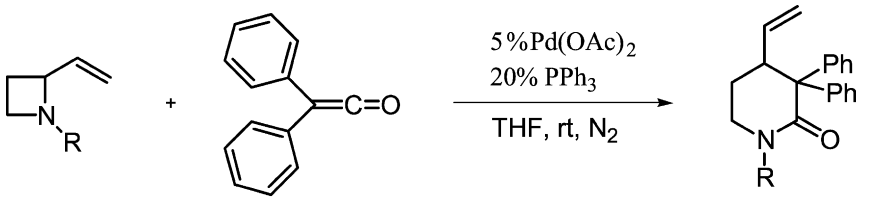


1a, R = Cy
1b, R= *n*Bu

2a, X = C_6H_5
2b, X = nBu
2c, X = C_6H_4Cl*p*
2d, X = C_6H_4Br*p*
2e, X = C6H4OMe*p*

3a-e
4a-e

Scheme 1.



1a,R = Cy
1b, R= *n*Bu

5

6a-b

Scheme 2.

between 1-alkyl-2-azetidines with ketenimines and ketenes (Schemes 1 and 2).

The 1-alkyl-2-vinylazetidines (**1a** and **1b**) [16], ketenimines (**2a**–**2e**) [17] and ketene (**5**) [18] were prepared according to literature procedures.

Treatment of a 5 mol% solution (anhydrous and degassed THF) of $Pd(OAc)_2$ and 20 mol% of triphenylphosphine, with 1-alkyl-2-vinylazetidine (**1a** and **1b**) followed by heterocumulene (**2a**–**2e**) or **5** at room temperature and pressure afforded the corresponding six-membered heterocycles (**3a**–**3e**, **4a**–**4e**, and **6a** and **6b**; see Tables 1–3). Purities were assessed by ^{1}H NMR, ^{13}C NMR, IR and HRMS (EI^+ mode) (see Appendix A).

All ketenimines used in this study are based on less sterically demanding groups, with a carboethoxy substituent to enhance the electrophilic character. Using ketenimines (**2a**–**2e**), palladium-catalysed ring expansion enables one to synthesise only one regioisomer of tetrahydropiperidine-derivated compounds (**3a**–**3e** and **4a**–**4e**; see Tables 1 and 2). Indeed the cycloaddition is totally stereoselective: NOE experiments show the carboethoxy and vinyl groups in *cis*-position. Characteristic features in the NMR spec-

Table 1
Cycloaddition of 1-cyclohexyl-2-vinylazetidine (**1a**) with ketenimines (**2a**–**2e**)[a]

Entry	Ketenimine	Time[b] (h)	Product	Yield[c] (%)
1	**2a**	48	**3a**	61
2	**2b**	48	**3b**	57
3	**2c**	22	**3c**	65
4	**2d**	24	**3d**	51
5	**2e**	48	**3e**	30

[a] $Pd(OAc)_2$ and PPh_3 were premixed for 30 min in 4.0 ml of dry and degassed THF followed by addition of 1.0 mmol of **1a** and **2** with 1.0 ml of dry THF, at room temperature and pressure.

[b] Indicated by consumption of one or both substrates (GC or IR).

[c] Purified by silica gel preparative TLC using a mixture of with ether/*n*-pentane as a developer.

Table 2
Cycloaddition of 1-*n*-butyl-2-vinylazetidine (**1b**) with ketenimines (**2a**–**2e**)[a]

Entry	Ketenimine	Time[b] (h)	Product	Yield[c] (%)
1	**2a**	24	**4a**	52
2	**2b**	24	**4b**	55
3	**2c**	2	**4c**	66
4	**2d**	24	**4d**	69
5	**2e**	48	**4e**	Traces
6[d]	**2c**	24	**4c**	40

[a] $Pd(OAc)_2$ and PPh_3 were premixed for 30 min in 4.0 ml of dry and degassed THF followed by addition of 1.0 mmol of **1b** and **2** with 1.0 ml of dry THF, at room temperature and pressure.
[b] Indicated by consumption of one or both substrates (GC or IR).
[c] Purified by silica gel preparative TLC using a mixture of with ether/*n*-pentane as a developer.
[d] Azetidine/ketenimine = 1/2.

tra of tetrahydropiperidin-2-ylidines were signals between 5 and 6 ppm for the vinyl protons and signals at ∼173 and ∼151 ppm corresponding to the ester and imine carbons. These groups were also identified by the stretching frequency in the IR at ∼1735 cm^{-1} (λC=O) and 1630–1600 cm^{-1} (λC=N).

Changes on the substrate affected the outcome of the reactions. Increasing the size of the *N*-alkyl group on the azetidine increased the reaction times (compare results from both Tables 1 and 2). The bulkier cyclohexyl group, as in **1a**, could obstruct the reaction, favouring the formation of by-products such as dimerised heterocumulene. Regarding the *N*-substituent in the ketenimines, some observations can be made. Use of electron-donating groups (such as *n*-butyl) deactivated the heterocumulene (see entry 2; Tables 1 and 2). Electronic effects were also apparent with mono-substituted aryl groups. The reaction requires an electron-withdrawing group on the aromatic ring: *p*-chloro and *p*-bromo substituents increase the reaction rates and yields indicating greater electrophilic character on the reactive carbon. For instance, 1-*n*-butyl-2-vinylazetidine (**1b**) and *p*-chlorophenylketenimine (**2c**) can be cycloadded in 65% isolated yield after 2 h of reaction (entry 3; Table 2). Additionally, electron-donating groups, such as OMe, deactivated the substrate: lower yields or only traces of desired products were obtained by the reaction of **2e** with **1a** or **1b** (entry 5; Tables 1 and 2). Increasing the amount of heterocumulene does not seem to have a positive effect on the reaction giving low rate and yield (compare entries 3 and 6; Table 2).

Table 3
Cycloaddition of 1-alkyl-2-vinylazetidines (**1a** and **1b**) with diphenylketene (**5**)[a]

Entry	Azetidine	Time[b] (h)	Yield[c] (%)
1	 (**1a**)	22	71
2	 (**1b**)	16	76

[a] $Pd(OAc)_2$ and PPh_3 were premixed for 30 min in 4.0 ml of dry and degassed THF followed by addition of 1.0 mmol of **1** and **3** with 1.0 ml of dry THF, at room temperature and pressure.
[b] Indicated by consumption of one or both substrates (GC or IR).
[c] Purified by silica gel preparative TLC using a mixture of with ether/*n*-pentane as a developer.

Ketenes are known to be more reactive heterocumulenes than ketenimines. The regioselective addition of diphenylketene (**5**) with 1-alkyl-2-vinylazetidines gave tetrahydropiperidinone derivatives (**6a** and **6b**; Scheme 2). The results are shown in Table 3. The tetrahydropiperidinone compounds displayed a signal at ∼171 ppm, which it is indicative of amide carbonyl carbons, verifying that this product was formed and not the alternative, where an exocyclic alkene would be present. The identifying features of the ^1H NMR conclusively supported the structure of **6a** and **6b** with multiplets at ∼5 and ∼5.8 ppm of the vinyl protons, and the broad multiplet at ∼3.6 ppm representing the C_4 hydrogen. As observed with ketenimines, the reaction is faster when 1-*n*-butyl is used as *N*-alkyl chain in the azetidine, giving 76% isolated yield in 16 h. Hindrance by the *N*-alkyl group would be important in the incipient attack on the heterocumulene and subsequent ring closing.

In summary, tetrahydropiperidin-2-ylidenes and tetrahydropiperidones were prepared regioselectively in moderate to good yields, under mild conditions, by palladium(0)-catalysed cycloaddition reactions of *N*-alkylated 2-vinylazetidines with ketenimines and ketenes. The best results are obtained when ketene is used as heterocumulene (up to 76% yield). Work is in progress to study the stereoselectivity of the method using a chiral ligand in the reaction mixture.

Acknowledgements

We are grateful to the Natural Sciences and Engineering Research Council of Canada for support of this research.

Appendix A. Characterisation data for the products

- *N*-(3-Carboethoxy-1-cyclohexyl-3-methyl-4-vinyl-piperidin-2-yildene)-aniline (**3a**): 61% yield; colourless oil. IR (neat) ν (cm^{-1}): 1613 (C=N), 1736 (C=O). ^1H NMR ($CDCl_3$) δ (ppm): 0.9–1.2 (br, 4H, cyclohexyl), 1.1 (t, 3H, $^3J = 7.1$ Hz, CH_3), 1.3 (s, 3H, CH_3), 1.3 (m, 2H, CH_2 ring), 1.5–1.9 (br, 6H, cyclohexyl), 2.9 (m, 1H, NCH), 3.2 (m, 2H, NCH_2 ring), 3.9 (q, 2H, OCH_2), 4.0–4.2 (br, 1H, CH ring), 5.0 (m, 2H, CH_2 vinyl), 5.6 (m, 1H, CH vinyl), 6.6–7.1 (m, 5H, Ph). ^{13}C NMR ($CDCl_3$) δ (ppm): 173.39 (C=O), 153.83 (C=N), 150.22 (phenyl), 136.84 (CH vinyl), 128.12 (phenyl), 121.19 (phenyl), 120.21 (phenyl), 116.60 (CH_2 vinyl), 60.61 (quarternary C), 60.05 (OCH_2), 54.95 (NCH), 45.36 (NCH_2 ring), 40.90 (CH ring), 29.32 (CH_2 ring), 28.93 (cyclohexyl), 25.73 (cyclohexyl), 25.55 (cyclohexyl), 24.39 (cyclohexyl), 19.15 (CH_3), 13.84 (CH_3). MS (*m*/*e*): 368 [M^+]. EIHRMS calculated for $C_{23}H_{32}N_2O_2$ 368.2464, found 368.2447.
- *N*-(3-Carboethoxy-1-cyclohexyl-3-methyl-4-vinyl-piperidin-2-yildene)-butylamine (**3b**): 57% yield; colourless oil. IR (neat) ν (cm^{-1}): 1613 (C=N), 1730 (C=O). ^1H NMR ($CDCl_3$) δ (ppm): 0.9 (t, 3H, CH_3), 1.0–1.9 (br, m, 22H, methylene groups of cyclohexyl, $CH_3CH_2CH_2$ of the *n*-Bu group), 2.7 (m, 1H, CH ring), 2.9–3.3 (br, m, 4H, CH and NCH_2 ring), 4.0–4.3 (br, 2H, OCH_2), 4.4–4.6 (br, 1H, NCH_2), 5.0 (m, 2H, CH_2 vinyl), 5.6 (m, 1H, CH vinyl). ^{13}C NMR ($CDCl_3$) δ (ppm): 173.41 (C=O), 151.57 (C=N), 136.55 (CH vinyl), 116.50 (CH_2 vinyl), 60.14 (quarternary C), 60.85 (OCH_2), 53.75 (NCH), 46.84 (NCH_2 ring), 46.38 (NCH_2), 40.90 (CH ring), 30.29 (CH_2), 30.24 (cyclohexyl), 29.28 (CH_2 ring), 26.10 (CH_2), 25.67 (cyclohexyl), 25.57 (cyclohexyl), 24.29 (cyclohexyl), 19.71 (CH_3), 14.08 (CH_3). MS (*m*/*e*): 348 [M^+]. EIHRMS calculated for $C_{21}H_{36}N_2O_2$ 348.2777, found 348.2777.
- *N*-(3-Carboethoxy-1-cyclohexyl-3-methyl-4-vinyl-piperidin-2-yildene)-*p*-chloroaniline (**3c**): 65% yield; colourless oil. IR (neat) ν (cm^{-1}): 1610 (C=N), 1737 (C=O). ^1H NMR ($CDCl_3$) δ (ppm): 0.9–1.8 (m, 12H, Cy methylenes, CH_2 of piperidine ring), 1.1 (t, 3H, $^3J = 7.1$ Hz, CH_3), 1.1 (s, 3H, CH_3), 2.9 (m, 1H, CH ring), 3.1–3.3 (m, 2H, NCH_2 ring), 3.8 (q, 2H, OCH_2), 4.2 (br, 1H, NCH), 5.0 (m, 2H, CH_2 vinyl), 5.6 (m, 1H, CH vinyl), 6.5–7.0 (m, 4H, *p*-ClC_6H_4). ^{13}C NMR ($CDCl_3$) δ (ppm): 173.43 (C=O), 154.38 (C=N), 148.95 (CH vinyl), 136.75, 128.22, 125.14, 122.53 (*p*-ClC_6H_4 aryl carbons), 116.94 (CH_2 vinyl), 65.83 (quarternary C), 60.72 (OCH_2), 55.16 (NCH), 45.56 (CH ring), 40.98 (NCH_2 ring), 30.07 (CH_2 ring), 29.37 (cyclohexyl), 25.84 (cyclohexyl), 24.43 (cyclohexyl), 19.15 (CH_3), 13.84 (CH_3). MS (*m*/*e*) 402 [M^+], 404 [$M^+ + 2$]. EIHRMS calculated for $C_{23}H_{31}ClN_2O_2$ 402.2074, found 402.2083.
- *N*-(3-Carboethoxy-1-cyclohexyl-3-methyl-4-vinyl-piperidin-2-yildene)-*p*-bromoaniline (**3d**): 51% yield; colourless oil. IR (neat) ν (cm^{-1}): 1625 (C=N), 1740 (C=O). ^1H NMR ($CDCl_3$) δ (ppm): 0.9–1.8 (br, 12H, cyclohexyl methylenes and CH_2 ring), 1.0 (t, 3H, $^3J = 7.1$ Hz, CH_3), 1.1 (s, 3H, CH_3), 2.8 (m, 1H, NCH), 3.2–3.4 (m, 2H, NCH_2 ring), 3.7 (q, 2H, OCH_2), 4.2 (br, 1H, NCH), 4.9–5.2 (m, 2H, CH_2 vinyl), 5.5–5.7 (m, 1H, CH vinyl), 6.5–7.3 (m, 4H, *p*-BrC_6H_4). ^{13}C NMR ($CDCl_3$) δ (ppm): 173.43 (C=O), 154.23 (C=N), 149.51 (CH vinyl), 136.68, 131.22, 122.80, 116.91 (*p*-BrC_6H_4), 112.63 (CH_2 vinyl), 67.12 (quarternary C), 60.62 (OCH_2), 59.20 (NCH), 53.29 (CH ring), 40.98 (NCH_2 ring), 30.06 (CH_2 ring), 29.36 (cyclohexyl), 25.72 (cyclohexyl), 24.43 (cyclohexyl), 19.21 (CH_3), 13.90 (CH_3). MS (*m*/*e*): 446 [M^+], 448 [$M^+ + 2$]. EIHRMS calculated for $C_{23}H_{31}BrN_2O_2$ 446.1569, found 446.1564.
- *N*-(3-Carboethoxy-1-cyclohexyl-3-methyl-4-vinyl-piperidin-2-yildene)-*p*-methoxyaniline (**3e**): 30% yield; colourless oil. IR (neat) ν (cm^{-1}): 1610 (C=N), 1737 (C=O). ^1H NMR ($CDCl_3$) δ (ppm): 0.9–1.9 (br, m, 12H, cyclohexyl methylenes and CH_2 of piperidine), 1.1 (t, 3H, $^3J = 5.9$ Hz, CH_3), 1.3 (s, 3H, CH_3), 2.9 (m, 1H, CH ring), 3.0–3.2 (br, 2H, NCH_2 ring), 3.7 (s, 3H, OMe), 3.8 (q,

2H, OCH_2), 4.0–4.2 (br, 1H, NCH) 5.0 (m, 2H, CH_2 vinyl), 5.6 (m, 1H, CH vinyl), 6.6 (d, 2H, $^2J = 6.0$ Hz, *p*-$MeOC_6H_4$), 6.8 (d, 2H, 6.6 (d, 2H, $^2J = 6.0$ Hz, *p*-$MeOC_6H_4$). ^{13}C NMR ($CDCl_3$) δ (ppm): 173.49 (C=O), 153.95 (C=N), 136.96 (CH vinyl), 122.17, 121.65, 116.65, 114.35, 114.13 (*p*-$MeOC_6H_4$ and vinyl methylene), 65.61 (quarternary C), 60.68 (OCH_2), 55.62 (OCH_3), 54.99 (NCH), 45.62 (CH ring), 41.01 (NCH_2 ring), 29.49 (CH_2 ring), 29.06 (cyclohexyl), 25.89 (cyclohexyl), 24.52 (cyclohexyl), 19.15 (CH_3), 13.92 (CH_3). MS (*m*/*e*): 398 [M^+]. EIHRMS calculated for $C_{24}H_{36}N_2O_3$ 398.2617, found 398.2594.

- *N*-(3-Carboethoxy-1-*n*-butyl-3-methyl-4-vinylpiperidin-2-yildene)-aniline (**4a**): 52% yield; colourless oil. IR (neat) ν (cm^{-1}): 1603 (C=N), 1738 (C=O). ^{1}H NMR ($CDCl_3$) δ (ppm): 0.9 (t, 3H, CH_3), 1.1 (t, 3H, $^3J = 7.1$ Hz, CH_3), 1.3 (m, 2H, CH_2), 1.4 (s, 3H, CH_3), 1.5 (m, 2H, CH_2), 1.8 (m, 2H, CH_2 ring), 2.9 (m, 1H, CH ring), 3.1–3.3 (m, 2H, NCH_2 ring), 3.8 (q, 2H, OCH_2), 4.2 (br, 2H, NCH_2), 5.0 (m, 2H, CH_2 vinyl), 5.6 (m, 1H, CH vinyl), 6.6–7.1 (m, 5H, phenyl). ^{13}C NMR ($CDCl_3$) δ (ppm): 172.19 (C=O), 154.30 (C=N), 137.25 (CH vinyl), 129.58, 128.12, 124.02 (phenyl carbons), 116.90 (CH_2 vinyl), 65.83 (quarternary C), 61.85 (OCH_2), 60.79 (NCH), 52.70 (NCH_2 ring), 45.94 (CH ring), 28.49 (CH_2), 24.11 (CH_2 ring), 20.05 (CH_2), 18.8 (CH_3), 13.98 (CH_3), 13.84 (CH_3). MS (*m*/*e*): 342 [M^+]. EIHRMS calculated for $C_{21}H_{30}N_2O_2$ 342.2307, found 342.2316.
- *N*-(3-Carboethoxy-1-*n*-butyl-3-methyl-4-vinylpiperidin-2-yildene)-*n*-butylamine (**4b**): 55% yield; colourless oil. IR (neat) ν (cm^{-1}): 1599 (C=N), 1736 (C=O). ^{1}H NMR ($CDCl_3$) δ (ppm): 0.9–1.5 (m, 20H, CH_2 and CH_3 groups), 2.0 (m, 2H, CH_2 ring), 2.6 (m, 1H, CH ring), 2.9–3.4 (br, 4H, NCH_2 ring and NCH_2), 4.0–4.4 (br, 2H, NCH_2 and OCH_2), 5.0 (m, 2H, CH_2 vinyl), 5.7 (m, 1H, CH vinyl). ^{13}C NMR ($CDCl_3$) δ (ppm): 174.32 (C=O), 152.56 (C=N), 141.79 (CH vinyl), 115.98 (CH_2 vinyl), 62.43 (quarternary C), 63.42 (OCH_2), 57.23, 48.67, 47.53 (NCH_2 carbons), 44.69 (CH ring), 29.48 (CH_2), 23.94 (CH_2 ring), 22.32 (CH_2), 18.01 (CH_3), 14.02 (CH_3), 13.78 (CH_3). MS (*m*/*e*): 322 [M^+]. EIHRMS calculated for $C_{19}H_{34}N_2O_2$ 311.4855, found 311.4845.
- *N*-(3-Carboethoxy-1-*n*-butyl-3-methyl-4-vinylpiperidin-2-yildene)-*p*-chloroaniline (**4c**): 66% yield; colourless oil. IR (neat) ν (cm^{-1}): 1597 (C=N), 1739 (C=O). ^{1}H NMR ($CDCl_3$) δ (ppm): 0.9–1.8 (m, 15H, CH_2 and CH_3 groups), 2.9 (m, 1H, CH ring), 3.1–3.5 (m, 2H, NCH_2 ring), 3.7 (m, 2H, OCH_2), 4.2 (br, 2H, NCH_2), 5.0 (m, 2H, CH_2 vinyl), 5.5 (m, 1H, CH vinyl), 6.5–7.0 (m, 4H, *p*-ClC_6H_4). ^{13}C NMR ($CDCl_3$) δ (ppm): 173.52 (C=O), 154.12 (C=N), 143.12 (CH vinyl), 137.07, 130.12, 129.31, 125.02 (aryl carbons), 117.21 (CH_2 vinyl), 63.12 (quarternary C), 62.38 (NCH_2), 60.75 (OCH_2), 52.30 (NCH_2 ring), 45.70 (CH ring), 28.38 (CH_2), 24.32 (CH_2 ring), 21.31 (CH_2), 17.89 (CH_3), 13.50 (CH_3), 13.28 (CH_3). MS (*m*/*e*): 376 [M^+], 378 [$M^+ + 2$]. EIHRMS calculated for $C_{21}H_{29}ClN_2O_2$ 376.1910, found 376.1918.
- *N*-(3-Carboethoxy-1-*n*-butyl-3-methyl-4-vinylpiperidin-2-yildene)-*p*-bromoaniline (**4d**): 69% yield; colourless oil. IR (neat) ν (cm^{-1}): 1609 (C=N), 1738 (C=O). ^{1}H NMR ($CDCl_3$) δ (ppm): 0.8 (m, 3H, CH_3), 1.1 (t, 3H, $^3J = 7.1$ Hz, CH_3), 1.2 (m, 2H, CH_2), 1.3 (s, 3H, CH_3), 1.4 (m, 2H, CH_2), 1.8 (m, 2H, CH_2 ring), 2.9 (m, 1H, CH ring), 3.2–3.5 (m, 2H, NCH_2 ring), 3.8 (m, 2H, OCH_2), 4.3 (br, 2H, NCH_2), 5.0 (m, 2H, CH_2 vinyl), 5.6 (m, 1H, CH vinyl), 7.1 (m, 2H, phenyl), 7.3 (m, 2H, phenyl). ^{13}C NMR ($CDCl_3$) δ (ppm): 173.37 (C=O), 153.11 (C=N), 136.19 (CH vinyl), 131.96, 131.03, 123.06, 121.45 (aryl carbons), 117.18 (CH_2 vinyl), 64.52 (quarternary C), 61.97 (NCH_2), 60.95 (OCH_2), 47.30 (NCH_2 ring), 45.99 (CH ring), 28.42 (CH_2), 24.01 (CH_2 ring), 20.04 (CH_2), 18.78 (CH_3), 15.56 (CH_3), 14.04 (CH_3). MS (*m*/*e*): 420 [M^+], 422 [$M^+ + 2$]. EIHRMS calculated for $C_{21}H_{29}BrN_2O_2$ 420.1412, found 420.1417.
- *N*-1-Cyclohexyl-3,3-diphenyl-4-vinylpiperidin-2-one (**6a**): 71% yield; pale yellow oil. IR (neat) ν (cm^{-1}): 1630 (C=O). ^{1}H NMR ($CDCl_3$) δ (ppm): 1.0–2.0 (br, 12H, cyclohexyl and CH_2 ring), 3.2 (q, 2H, $J = 5.1$ Hz, NCH_2 ring), 3.6 (m, 1H, CH ring), 4.5–4.7 (br, 1H, NCH), 5.0 (m, 2H, CH_2 vinyl), 5.8 (m, 1H, CH vinyl), 7.1–7.4 (m, 10H, phenyl). ^{13}C NMR ($CDCl_3$) δ (ppm): 170.88 (C=O), 138.29 (CH vinyl), 142.82, 141.27, 130.50, 129.68, 127.25, 126.85, 126.31 (aryl carbons), 115.77 (CH_2 vinyl), 61.04 (CPh_2 ring), 53.49 (NCH), 43.10 (NCH_2

ring), 40.33 (CH ring), 29.59 (CH_2 ring), 29.40, 25.63, 25.54 (cyclohexyl carbons). MS (*m*/*e*): 359 [M^+]. EIHRMS calculated for $C_{25}H_{29}NO$ 359.2249, found 359.2236.

- *N*-1-Cyclohexyl-3, 3-diphenyl-4-vinylpiperidin-2-one (**6b**): 76% yield; white-off oil. IR (neat) ν (cm^{-1}): 1632 (C=O). ^1H NMR ($CDCl_3$) δ (ppm): 0.8–1.5 (m, 7H, C_3H_7), 2.1 (br, 2H, CH_2 ring), 3.5 (m, 1H, NCH_2 ring), 3.6 (m, 2H, NCH_2 ring and CH ring), 4.8 (m, 2H, NCH_2), 5.0 (m, 2H, CH_2 vinyl), 6.0 (m, 1H, CH vinyl), 7.1–7.4 (m, 10H, phenyl). ^{13}C NMR ($CDCl_3$) δ (ppm): 169.21 (C=O), 140.02 (CH vinyl), 143.23, 132.51, 129.78, 128.68, 127.17, 127.07 (aryl carbons), 116.28 (CH_2 vinyl), 60.32 (CPh_2 ring), 52.49 (NCH_2), 42.33 (NCH_2 ring), 40.33 (CH ring), 29.32 (CH_2 ring), 27.22 (CH_2), 20.16 (CH_2), 13.24 (CH_3). MS (*m*/*e*): 333 [M^+].

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