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Tetrahedron Letters
Tetrahedron Letters 48 (2007) 6034–6038

4-Indolylbutanals from rhodium-catalyzed hydroformylation of allylindoles as precursors of benzofused indolizines

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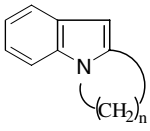
Received 1 February 2007; revised 8 June 2007; accepted 18 June 2007
Available online 21 June 2007

Abstract—New 4-indolylbutanals have been prepared via a rhodium-catalyzed hydroformylation of differently substituted *N*-allylindoles. The aldehydes bearing an electron-donating group on the indole nucleus 3-position can evolve into benzofused indolizines via a one pot intramolecular cyclodehydration.

Benzofused indolizines are present in an astonishing variety of biologically active compounds. In particular, structure **I** has attracted much attention as an analogue of the potent antitumor antibiotics mitomycins.[1]



I

a: n = 3 **b**: n = 4

benzofused indolizines

Amongst the synthetic methods for the construction of ring system **Ib**, intramolecular radical cyclization,[2] classical intramolecular nucleophilic substitution,[3] the Dieckmann ring expansion approach[4] and the recent 1,2-alkyl migration process in indolylborate have been reported.[5] For our part we considered hydroformylation-based pathways, because the succession of a carbonylation and a cyclization step could afford these types of frameworks. During the last few years, the hydroformylation of unsaturated compounds has become a more versatile tool in the synthesis of fine chemicals.[6] As far as indole chemistry is concerned, the hydroformylation reaction has been used in the indole ring building,[7] and indole-based phosphine ligands have been tested in the hydroformylation of simple alkenes.[8] Moreover, very few examples are available regarding the application of the oxo process to indolyl olefins. In particular only the cobalt-catalyzed hydroformylation of *N*-vinylindoles, which forms the branched isomer as the major product,[9] and 3-allylindole have been reported:[10] in the latter case no isolable and identifiable products were obtained.

Our previous studies on the rhodium-catalyzed hydroformylation of *N*-allylpyrroles[11] demonstrated that *oxo* products 4-(pyrrol-1-yl)butanals spontaneously cyclize to indolizine derivatives. In this Letter we report that the analogous 4-(indol-1-yl)butanals can be obtained via hydroformylation of variously substituted *N*-allylindoles. These aldehydes can either be isolated and characterized or, interestingly, undergo an in situ intramolecular cyclization on the indole 2-position to benzofused dihydroindolizines: the crucial requirement is the presence of an electron-donor group on the indole 3-position (Scheme 1).

N-Allylindoles **1a**–**h** were prepared via N-allylation of the proper indoles (yields $\geqslant$65%). This step was accomplished in diethyl ether via a phase-transfer process in which 18-crown-6 was employed as the transfer agent and potassium *tert*-butoxide as the base.[12] For the preparation of **1a**–**d**,**g**,**h**, the starting indoles were commercially available. For the synthesis of **1f**, the functionalized indole was obtained via esterification of the commercial 3-indolyl acetic acid.[13] In contrast, **1e** was

Keywords: Hydroformylation; Rhodium-catalyst; Indolylbutanals; Synthesis; Intramolecular cyclodehydration; Benzofused indolizines.
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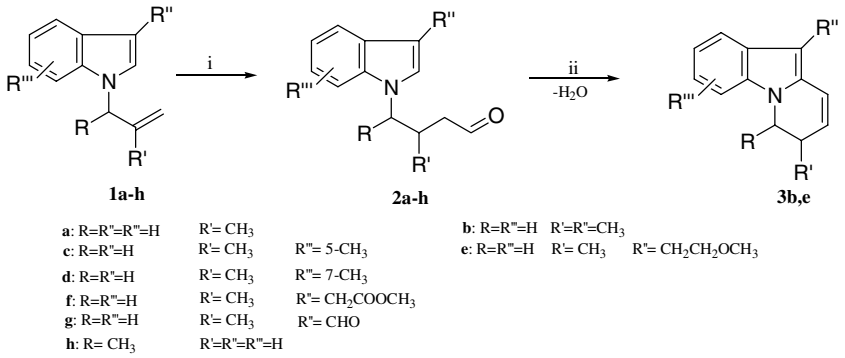
doi:10.1016/j.tetlet.2007.06.076



Scheme 1. Reagents and conditions: (i) $Rh_4(CO)_{12}$, CO/H_2 1:1, 100 atm, 100 °C, benzene, 0.5–3.5 h; (ii) the same conditions as (i), 40 h under CO atmosphere, after CO/H_2 gas mixture removal.

obtained from **1f** via reduction with $LiAlH_4$ in THF and successive methylation of the resulting alcohol with CH_3I in KOH/DMSO.[14a] Compounds **1g** and **1h** are known.[14b,c]

Hydroformylation experiments on 3-(indol-1-yl)alk-1-enes **1a**–**h** were carried out in benzene with $Rh_4(CO)_{12}$ as the catalyst precursor,[15,16] according to a typical procedure.[17]

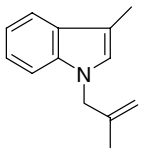
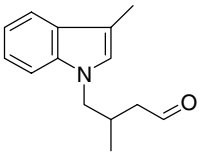
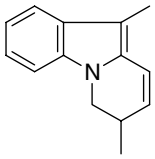
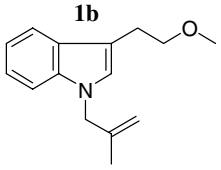
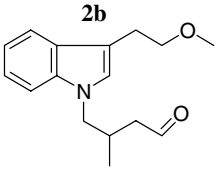
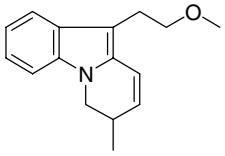
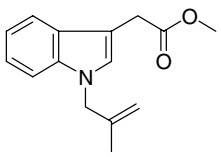
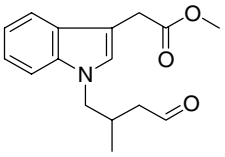
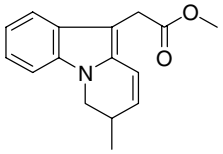
As far as vinylidenic olefins are concerned, the simple *N*-β-methallylindole **1a** forms the linear aldehyde 4-(indol-1-yl)butanal **2a** as the sole product after 3 h. A similar behavior was observed when a methyl group was present on the indole 3-position (vinylidenic olefins **1b**), the linear aldehyde **2b** being exclusively formed (Table 1). No significant differences were found when the methyl group was on the indole 5- and 7-positions, respectively (vinylidenic olefins **1c** and **d**): in fact the corresponding aldehydes **2c** and **d** were obtained as exclusive products. The chemo-selectivity of the reaction was also independent of the nature of the substituent on the indole 3-position: in fact with olefins **1e** and **f** bearing an electron-donor group ($R'' = CH_2CH_2OCH_3$ or CH_2COOCH_3) (Table 1) as well as in the case of olefin **1g** characterized by an electron-withdrawing group ($R'' = CHO$) 4-indolylbutanals **2e**–**g** were chemo-selectively formed (Table 1).

The hydroformylation of vinyl olefin **1h** under the same experimental conditions was faster, the conversion being complete after 0.5–1 h. However, in this case the linear aldehyde 4-(indol-1-yl)pentanal **2h** was not the sole product,[18] the branched 2-methyl-3-(indol-1-yl)butanal **2′h** being formed in a **2′/2** molar ratio = 40/60. In the light of the above findings we can affirm that as far as the regio- and the chemo-selectivity is concerned vinylidenic and vinyl indolyl olefins investigated behave similarly.[19]

When the CO/H_2 mixture was removed from the crude reaction mixture containing **2b** and the reactor was pressurized with CO only, a decrease of **2b** was observed with a simultaneous formation of the benzofused dihydroindolizine **3b** (Table 1). After 40 h, **3b** was the sole product present in the crude reaction mixture. Under the same experimental conditions, olefin **1e** containing the methoxyethyl group on the indole 3-position, gave the corresponding dihydroindolizine **3e** (Table 1). In contrast, cyclodehydration of aldehyde **2f** does not occur. Neither does aldehyde **2a** undergo this transformation and the result is the same independent of the position of the methyl group on the alkyl chain bonded to the nitrogen atom: indeed aldehyde **2h** also remains intact. Olefins **1c** and **d** behave in the same manner: the corresponding aldehydes **2c** and **d** were recovered unchanged after heating for a long time. Aldehyde **2g** also does not cyclize. The above data suggest that the presence of a group activating at least as much as methyl should be present on the indole 3-position in order to promote indolizine formation; in this way the less nucleophilic indole 2-position becomes capable of reacting with the aldehyde carbonyl carbon atom to give a new six-membered ring. Subsequent dehydration gives the highly conjugated benzofused dihydroindolizine system. The cyclization into **2f** was induced by adding a catalytic amount (5%) of pyridinium *para*-toluensulfonate into the diluted (1:3 with benzene) reaction mixture and heating for 2 h (Table 1). The resulting yellow/orange suspension was filtered and the filtrate evaporated under reduced pressure giving the benzofused indolizine **3f** in high yield (Table 1). Analogously, pyridinium *para*-toluensulfonate promotes the cyclodehydration of **2b** to **3b** and **2e** to **3e** in a very short time (Table 1). A similar cyclization attempt on the other aldehydes **2a**,**c**,**d**,**h** was unsuccessful: it was not possible to recover any starting material nor isolate any product. Also in the case of **2g** the cyclization does not occur. Interestingly, in spite of the darkening of the solution, most of the starting aldehyde was recovered by simple filtration on celite. Thus the presence of an electron-withdrawing group on the indole 3-position is crucial for the survival of indolylbutanals under the mild acidic conditions; otherwise intermolecular reactions take place probably on the more favored β-position of the indolyl units.[20]

4-Indolylbutanals **2a**–**h** and the benzofused 5,6-dihydroindolizines **3b**,**e**,**f** are new compounds, and they have been characterized by ^1H and ^{13}C NMR spectroscopy and GC–MS.[21,22] These derivatives are stable enough to be handled at room temperature without decomposition and they can be stored at 0 °C for several weeks.

Table 1. Hydroformylation[a] of the *N*-allylindoles **1b**,**e**,**f** to 4-(indol-1-yl)butanals **2b**,**e**,**f** and further cyclization to benzofused indolizines **3b**,**e**,**f**

Substrate	Yield[b] (%)	Hydroformylation time (h)	Hydroformylation products	Yield[c] (%)	Cyclization products	Yield[d] (%)	
						[e]	[f]
 **1b**	78	3.5	 **2b**	82	 **3b**	80	75
 **1e**	70	3	 **2e**	75	 **3e**	78	80
 **1f**	75	3	 **2f**	80	 **3f**	81	—

[a] $Rh_4(CO)_{12}$ (100/1 = substrate/Rh), 100 atm total pressure ($CO/H_2 = 1/1$), 100 °C, benzene as the solvent.
[b] Yield of pure isolated product (Al_2O_3; hexane).
[c] Yield of pure isolated product (celite).
[d] Yield of pure isolated product (Al_2O_3/hexane for **3b**; Al_2O_3/CH_2Cl_2/hexane (1:1) for **3e**; Al_2O_3/CH_2Cl_2/hexane = 1/1 for **3f**).
[e] Pyridinium *para*-toluensulfonate (5%) catalyzed, 2h, benzene at reflux.
[f] Rhodium-catalyzed, 40 h under N_2 atmosphere, after CO/H_2 gas mixture removal.

To sum up, the synthesis of new indolylbutanals has been described based on the rhodium-catalyzed hydroformylation of readily available *N*-allylindoles. These compounds can undergo an in situ intramolecular cyclodehydration giving benzofused indolizines in good yield: the required condition is the presence of an electron-donor group on the indole 3-position making the 2-position electron-rich enough to undergo the electrophilic attack of the aldehyde carbonyl carbon atom. Due to the pharmacological importance of mytomicins,[1] we believe that the construction of mitomycin-like compounds hydropyrido[1,2-*a*]indoles via annulation of 4-indolylbutanals reported here can be a useful addition to the indole chemistry.

Acknowledgement

Financial support by MIUR—Programma di Ricerca Scientifica di Rilevante Interesse Nazionale—is gratefully acknowledged.

References and notes

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14. (a) Compound **1a**: ^{1}H NMR ($CDCl_3$) δ 7.63 (m, 1H, H_{ind}), 7.38–7.06 (m, 4H, H_{ind}), 6.51 (d, $J = 1.4$ Hz, 1H, H_{ind}), 4.89 (br s, 1H, CH=), 4.71 (br s, 1H, CH=), 4.63 (s, 2H, CH_2–N), 2.04 (s, 3H, CH_3–C=). ^{13}C NMR ($CDCl_3$) δ 20.2, 52.8, 101.6, 109.9, 112.9, 119.6, 121.1, 121.7, 128.5, 128.9, 136.6, 141.4. MS *m/e* 171 (M^+, 100), 156 (85), 130 (53), 89 (14), 77 (14), 39 (16). Compound **1b**: ^{1}H NMR ($CDCl_3$) δ 7.64 (m, 1H, H_{ind}), 7.36–7.13 (m, 3H, H_{ind}), 6.91 (br s, 1H, H_{ind}), 4.94 (br s, 1H, CH=), 4.79 (br s, 1H, CH=), 4.63 (br s, 2H, CH_2–N), 2.40 (d, $J = 1.2$ Hz, 3H, $CH_{3\text{-ind}}$), 1.73 (br s, 3H, CH_3–C=). ^{13}C NMR ($CDCl_3$) δ 9.9, 20.2, 52.6, 109.7, 110.7, 112.6, 118.9, 119.2, 121.7, 126.1, 129.1, 135.9, 141.8. MS *m/e* 185 (M^+, 100), 170 (94), 144 (48), 130 (30), 115 (10), 103 (17), 77 (25), 51 (13), 44 (12), 40 (40). Compound **1c**: ^{1}H NMR ($CDCl_3$) δ 7.56 (br s, 1H, H_{ind}), 7.31 (br s, 1H, H_{ind}), 7.18–7.14 (m, 2H, H_{ind}), 6.56 (d, $J = 2.6$ Hz, 1H, H_{ind}), 5.02 (br s, 1H, CH=), 4.83 (br s, 1H, CH=), 4.71 (s, 2H, CH_2–N), 2.59 (s, 3H, $CH_{3\text{-ind}}$), 1.78 (s, 3H, CH_3–C=). ^{13}C NMR ($CDCl_3$) δ 20.1, 21.7, 52.9, 101.1, 109.7, 112.8, 120.9, 123.4, 128.6, 128.8, 129.2, 135.1, 141.6. MS *m/e* 185 (M^+, 100), 170 (75), 144 (30). Compound **1d**: ^{1}H NMR ($CDCl_3$) δ 7.53 (m, 1H, H_{ind}), 7.08–6.94 (m, 3H, H_{ind}), 6.55 (d, $J = 3.4$ Hz, 1H, H_{ind}), 4.90–4.81 (m, 3H, CH=, CH_2–N), 4.31 (s, 1H, CH=), 2.70 (br s, 3H, $CH_{3\text{-ind}}$), 1.82 (br s, 3H, CH_3–C=). ^{13}C NMR ($CDCl_3$) δ 19.5, 20.2, 54.6, 101.8, 111.2, 119.3, 119.9, 120.3, 124.7, 129.8, 130.3, 135.3, 143.5. MS *m/e* 185 (M^+, 100), 170 (80), 144 (42), 130 (15), 103 (13), 77 (16), 39 (15). Compound **1e**: ^{1}H NMR ($CDCl_3$) δ 7.62 (br s, 1H, H_{ind}), 7.22–7.07 (m, 4H, H_{ind}), 6.60 (s, 1H, H_{ind}), 4.63 (br s, 1H, CH=), 4.54 (br s, 1H, CH=), 4.02 (br s, 2H, CH_2–N), 3.55 (t, 2H, $J = 7.0$ Hz, CH_2–O), 3.15 (s, 3H, OCH_3), 3.05 (t, 2H, $J = 7.0$ Hz, CH_2–C), 1.30 (s, 3H, CH_3–C=). ^{13}C NMR ($CDCl_3$) δ 141.5, 141.3, 137.0, 126.2, 124.5, 121.7, 119.4, 119.2, 112.2, 109.8, 73.3, 58.1, 51.9, 26.0, 19.4. MS *m/e* 189 (M^+–40, 42), 144 (100). Compound **1f**: ^{1}H NMR ($CDCl_3$) δ 7.64 (m, 1H, H_{ind}), 7.34–7.10 (m, 4H, H_{ind}), 4.93 (br s, 1H, CH=), 4.76 (br s, 1H, CH=), 4.63 (s, 2H, CH_2–CO), 3.81 (s, 2H, CH_2–N), 3.73 (s, 3H, OCH_3), 1.70 (s, 3H, CH_3–C=). ^{13}C NMR ($CDCl_3$) δ 19.9, 31.2, 52.1, 52.5, 107.3, 109.8, 112.8, 119.1, 119.4, 121.9, 127.3, 136.7, 141.2, 142.1, 172.7. MS *m/e* 243 (M^+, 39), 184 (100), 168 (9), 142 (10), 55 (14); (b) Thalji, R. K.; Ahrendt, K. A.; Bergman, R. G.; Ellman, J. A. *J. Org. Chem.* **2005**, *70*, 6775–6781; (c) Yi, C. S.; Yun, S. Y. *Org. Lett.* **2005**, *7*, 2181–2183.
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17. Hydroformylation: *General procedure*. To a solution of 5–6 ml of the olefinic substrate in benzene, $Rh_4(CO)_{12}$ in the proper molar ratio is introduced by suction into an evacuated 25 ml stainless steel autoclave, which is then filled with carbon monoxide up to the desired pressure (45 atm) and heated up to 100 °C. After 15 min, hydrogen (H_2) is introduced giving the desired final pressure (CO/H_2 = 1/1). The autoclave is then rocked to the proper conversion (GC and/or ^{1}H NMR control) and allowed to cool down to room temperature. The residual reaction gases are evacuated and the crude reaction mixture is directly taken out of the open autoclave for a further manipulation.
18. Typical MS data for **2h**: MS *m/e* 201 (M^+, 78), 186 (12), 173 (12), 158 (12), 144 (100), 130 (11), 117 (25), 89 (20).
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21. Compound **2a**: ^{1}H NMR ($CDCl_3$) δ 9.64 (s, 1H, CHO), 7.71–7.08 (m, 4H, H_{ind}), 6.56 (d, $J = 3.2$ Hz, 1H, $H_{\alpha\text{-ind}}$), 4.03 (t, $J = 7.6$ Hz, 2H, CH_2–N), 2.69 (m, 1H, C*H*–CH_3), 2.36 (t, $J = 6.0$ Hz, 2H, C*H*$_2$–CHO), 1.02 (d, $J = 6.8$ Hz, 3H, C*H*$_3$–CH). ^{13}C NMR ($CDCl_3$) δ 18.3, 29.7, 30.0, 48.5, 52.1, 101.8, 109.8, 119.8, 121.4, 122.0, 128.5, 128.7, 137.0, 201.3. MS *m/e* 201 (M^+, 64), 183 (75), 173 (25), 168 (41), 130 (100), 103 (12), 77 (14), 39 (11). Compound **2b**: ^{1}H NMR ($CDCl_3$) δ 9.63 (s, 1H, CHO), 7.60–7.08 (m, 4H, H_{ind}), 6.83 (s, 1H, Hα-ind), 3.94 (dd, $J = 3.4$, 7.4 Hz, 2H, CH_2–N), 2.65 (m, 1H, C*H*–CH_3), 2.37–2.29 (m, 5H, C*H*$_2$–CHO, CH_3-ind), 0.99 (d, $J = 6.8$ Hz, 3H, C*H*$_3$–CH). ^{13}C NMR ($CDCl_3$) δ 10.1, 18.4, 29.8, 48.5, 51.8, 109.8, 110.8, 119.2, 119.5, 122.0, 126.3, 129.2, 137.0, 201.8. MS *m/e* 215 (M^+, 15), 197 (100), 182 (78), 167 (33), 144 (17). Compound **2c**: ^{1}H NMR ($CDCl_3$) δ 9.65 (br s, 1H, CHO), 7.65 (d, $J = 7.4$ Hz, 1H, H_{ind}), 7.26–7.07 (m, H, H_{ind}), 6.83 (s, 1H, $H_{\alpha\text{-ind}}$), 3.94 (dd, $J = 3.4$, 7.4 Hz, 2H, CH_2–N), 2.65 (m, 1H, C*H*–CH_3), 2.37–2.29 (m, 5H, C*H*$_2$–CHO, CH_3-ind), 0.99 (d, $J = 6.8$ Hz, 3H, C*H*$_3$–CH). ^{13}C NMR ($CDCl_3$) δ 18.4, 21.9, 29.8, 48.6, 52.2, 101.3, 109.7, 121.1, 123.7, 128.7, 129.0, 129.3, 135.0, 201.7. MS *m/e* 215 (M^+, 45), 197 (100), 182 (70), 167 (22), 144 (50), 39 (9). Compound **2d**: ^{1}H NMR ($CDCl_3$) δ 9.63 (d, $J = 1.2$ Hz, 1H, CHO), 7.65 (d, $J = 7.4$ Hz, 1H, H_{ind}), 7.26–7.07 (m, 3H, H_{ind}), 6.64 (d, $J = 3.2$ Hz, 1H, $H_{\alpha\text{-ind}}$), 4.25 (q, $J = 4.0$ Hz, 2H, CH_2–N), 2.65 (br s, 4H, C*H*–CH_3, $CH_{3\text{-ind}}$), 2.38 (dd, $J = 1.6$, 5.2 Hz, 1H, C*H*–CHO), 2.34 (dd, $J = 2.2$, 8.6 Hz, 1H, C*H*′–CHO), 1.07 (d, $J = 6.6$ Hz, 3H, C*H*$_3$–CH). ^{13}C NMR ($CDCl_3$) δ 17.9, 20.5, 31.9, 48.3, 54.4, 102.1, 119.7, 120.2, 121.0 125.3, 130.2, 130.5, 135.0, 201.5. MS *m/e* 215 (M^+, 60), 197 (100), 182 (73), 167 (25), 144 (62), 77 (12), 39 (13). Compound **2e**: ^{1}H NMR (C_6D_6) δ 8.97 (br s, 1H, CHO), 7.25–7.10 (m, 4H, H_{ind}), 6.6 (s, 1H, $H_{\alpha\text{-ind}}$), 3.60 (t, 2H, $J = 7.0$ Hz, CH_2–O), 3.40–3.12 (m, 5H, CH_2–N + OCH_3), 3.08 (t, 2H, $J = 7.0$ Hz, CH_2–C), 2.12 (m, 1H, CH–), 1.65–1.41 (m, 2H, CH_2–CHO), 0.46 (d, 3H, $J = 7.0$ Hz, CH_3). ^{13}C NMR (C_6D_6) δ 18.2, 25.2, 29.5, 46.7, 52.1, 58.4, 72.9, 109.1, 112.2, 118.9, 119.4, 119.7, 126.2, 131.5, 137.0, 200.5. Compound **2f**: ^{1}H NMR (C_6D_6) δ 8.96 (s, 1H, CHO), 7.72 (d, $J = 6.0$ Hz, 1H, H_{ind}), 7.27–6.99 (m, 3H, H_{ind}), 6.72 (s, 1H, $H_{\alpha\text{-ind}}$), 3.65 (s, 2H, CH_2–CO), 3.31, (s, 3H, CH_3O), 3.26 (m, 2H, CH_2–N), 2.11 (m, 2H, C*H*–CH_3), 1.52 (m, 2H, C*H*$_2$–CHO), 0.48 (d, $J = 7.0$ Hz, 3H, C*H*$_3$–CH). ^{13}C NMR (C_6D_6) δ 17.5, 29.0, 31.0, 47.7, 51.1, 51.2, 109.8, 111.2, 119.5, 119.6, 122.1, 127.1, 131.1, 136.9, 171.8, 199.5. MS *m/e* 273 (M^+, 84), 245 (9), 214 (79), 202 (100), 186 (49), 170 (30), 143 (37), 130 (72), 115 (19), 85 (17). Compound **2g**: ^{1}H NMR (C_6D_6) δ 9.98 (s, 1H, CHO), 9.03 (s, 1H, CHO), 7.22–7.10 (m, 4H, H_{ind}), 6.81 (s, 1H, $H_{\alpha\text{-ind}}$), 3.4 (dd, $J = 6.4$, 14.0 Hz, 1H, CH–N), 3.03 (dd, $J = 8$, 14.2 Hz, 1H, CH′-N), 2.05 (m, 1H, C*H*–CH_3), 1.51 (dq, $J = 1.2$, 3.2 Hz, 2H, C*H*$_2$–CHO), 0.39 (d, $J = 6.6$ Hz, 3H, C*H*$_3$–CH). ^{13}C NMR (C_6D_6) δ 199.6, 184.2, 138.9, 137.6, 125.7, 124.1, 123.1, 122.4, 118.5, 110.6, 51.7, 47.4, 28.4, 17.3.
22. Compound **3b**: As a colorless oil. ^{1}H NMR ($CDCl_3$) δ 7.58 (d, $J = 7.8$ Hz, 1H, H_{ind}), 7.23–7.11 (m, 3H, H_{ind}), 6.42 (dd, $J = 2.2$, 10.0 Hz, 1H, CH=), 5.88 (dd, $J = 3.8$,

10.0 Hz, 1H, CH═), 4.20 (dd, $J = 6.2$, 11.8 Hz, 1H, CH–N) 3.63 (dd, $J = 8.4$, 11.8 Hz, 1H, CH′–N), 2.89 (br s, 1H, C*H*–CH_3), 2.37 (s, 3H, CH_3-ind), 1.26 (d, $J = 7$ Hz, 3H, CH_3–CH). ^{13}C NMR ($CDCl_3$) δ 8.5, 18.9, 30.3, 47.2, 107.7, 108.7, 117.6, 119.2 (2C), 122.3, 129.6, 130.0, 131.7, 137.1. MS *m*/*e* 197 (M^+, 100), 182 (81), 167 (33), 40 (15). Compound **3e**: As a yellow oil. ^{1}H NMR (C_6D_6) δ 7.63 (d, 1H, $J = 7.0$ Hz, H_{ind}), 7.30–7.04 (m, 3H, H_{ind}), 6.52 (dd, $J = 2.1$; 11 Hz, 1H, CH═), 5.48 (dd, $J = 3.6$; 11 Hz, 1H, CH═), 3.63–3.46 (m, 4H, CH_2–N, CH_2–O), 3.16–2.92 (m, 5H, CH_2–C, OCH_3), 2.3 (m, 1H, C*H*–CH_3), 0.75 (d, $J = 7.0$ Hz, 3H, CH_3–CH). ^{13}C NMR (C_6D_6) δ 18.1, 25.0 29.8, 46.6, 58.2, 73.4, 108.7, 109.3, 117.7, 119.3, 119.4, 122.2, 129.3, 129.5, 132.0, 137.3. MS *m*/*e* 241 (M^+, 54), 196 (100), 180 (12). Compound **3f**: As a yellow oil. ^{1}H NMR ($CDCl_3$) δ 7.79 (d, $J = 7.0$ Hz, 1H, H_{ind}), 7.28–7.04 (m, 3H, H_{ind}), 6.55 (dd, $J = 2.2$, 10.0 Hz, 1H, CH═), 5.49 (dd, $J = 3.8$, 10.0 Hz, 1H, CH═), 3.63 (s, 2H, CH_2–CO), 3.51 (dd, $J = 6.4$, 11.8 Hz, 1H, CH–N), 3.22 (s, 3H, CH_3O), 2.94 (dd, $J = 9.2$, 11.8 Hz, 1H, CH′–N), 2.21 (br s, 1H, C*H*–CH_3), 0.69 (d, $J = 7.4$ Hz, 3H, CH_3–CH). ^{13}C NMR ($CDCl_3$) δ 18.0, 29.7, 30.1, 46.4, 51.2, 65.7, 104.7, 108.8, 117.3, 119.5, 119.9, 122.5, 130.5, 132.3, 137.1, 171.3. MS *m*/*e* 255 (M^+, 35), 196 (100), 180 (43), 167 (8).