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Synthesis of Imidazo[1,5-*a*]quinolines and Imidazo[5,1-*a*]isoquinolines *via* the In-Mediated Allylation of Reissert Compounds

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Allylindium reagents have been used extensively for the introduction of allyl group in a Barbier type manner to various electrophiles.[1-3] Although many reactive electrophiles such as aldehydes and imines have been used in the indium-mediated allylations,[1] the reaction of less reactive nitrile has not been reported much except the first successful results of Yamamoto group[2] and our recent papers.[3]

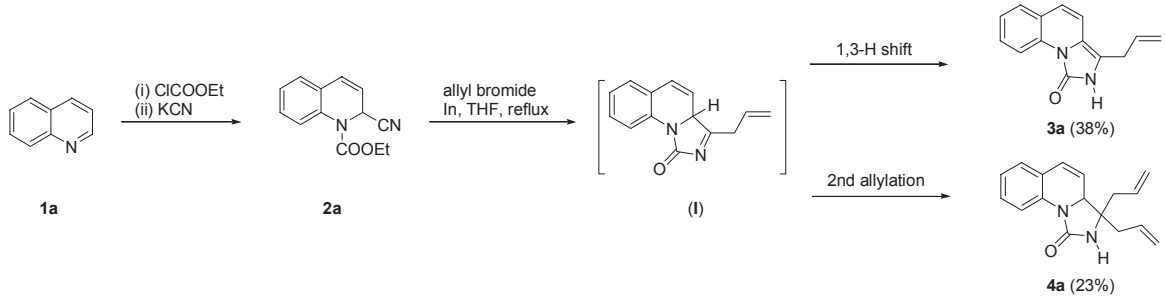
Recently, we reported a series of indium-mediated Barbier type allylations of nitrile groups in γ-cyanoesters,[3a] γ-ketonitriles,[3b] δ-ketonitriles,[3c] *ortho*-cyanobenzoates,[3d] and *N*-(*ortho*-cyanoaryl)amides.[3e] From the recent studies, we found that the intrinsic reactivity of a nitrile group toward allylindium reagents is sufficient to form the corresponding imine or enamine intermediates, and the intermediates can form various cyclic compounds when the molecule has a suitable electrophilic quencher such as ester[3a,d] or sterically hindered ketone group.[3b,c] Very recently, we reported an efficient synthesis of quinazoline derivatives *via* the In-mediated Barbier type allylation and dehydrative cyclization protocol from *N*-(*ortho*-cyanoaryl)amides.[3e] In the paper, a carbamate moiety could also be used as an electrophilic quencher for the imine intermediate.[3e]

Thus we strongly believed that a Reissert compound[4] such as **2a** could form imidazo[1,5-*a*]quinoline derivative **3a** by the reaction with allylindium reagents, as shown in Scheme 1. Reissert compounds (*N*-acyldihydroazaaromatic-α-nitriles) have been widely used for the synthesis of various heterocyclic compounds.[4] In addition, many imidazole-containing fused heterocycles including imidazo[1,5-*a*]quinoline derivatives are important constituents in many biologically active substances.[5,6]

The starting material **2a** was prepared from quinoline (**1a**) according to the reported methods.[4] The reaction of **2a**, allyl bromide (3.0 equiv), and indium powder (1.5 equiv) in refluxing THF for 20 min afforded 3-allyl-2*H*-imidazo[1,5-*a*]quinolin-1-one (**3a**) in moderate yield (38%) along with a diallylation product **4a** in 23%. The reaction mechanism could be suggested as an indium-mediated Barbier type allylation of nitrile to form the imine intermediate and the following cyclization to form (**I**) in Scheme 1. The 1,3-H shift in (**I**) produced **3a** while the second allylation of (**I**) afforded **4a**. The ratio of **3a**/**4a** was not changed by modifying the reaction conditions. Reduction of the amounts of allyl bromide and indium caused an incomplete reaction. Lowering the reaction temperature and longer time did not improve the yields of products nor alter the ratio of **3a**/**4a**.

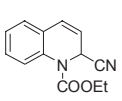
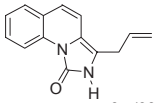
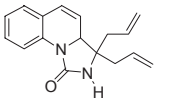
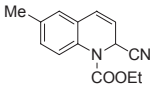
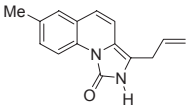
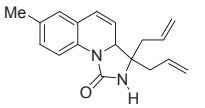
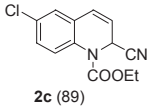
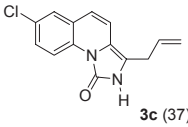
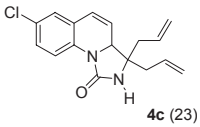
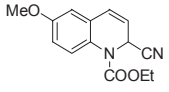
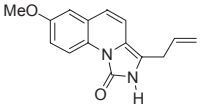
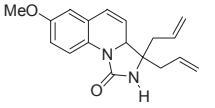
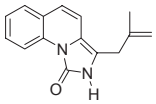
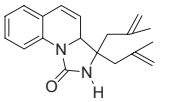
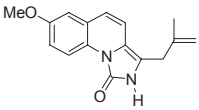
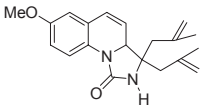
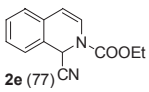
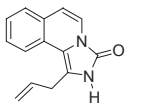
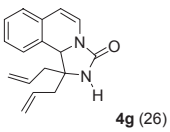
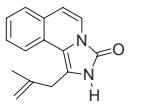
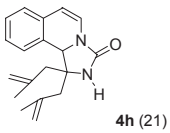
Encouraged by the results we prepared various Reissert compounds **2b-e** from quinoline and isoquinoline derivatives,[4] and the reactions with allylindium (or methallylindium) reagents were examined. The results are summarized in Table 1. The reactions of **2b-d** showed very similar results with those of **2a**. Mono-allyl derivatives **3b-d** were obtained in 37 - 40% and **4b-d** in 23 - 27% (entries 2-4). The reactions with methallylindium reagents (entries 5 and 6), however, produced the corresponding mono-methallyl derivatives (**3e** and **3f**) in increased yields (58 - 63%) while the yields of di-methallyl derivatives (**4e** and **4f**) decreased presumably due to the increased steric crowdedness of a methallyl moiety. The trend was very similar for the Reissert compound of isoquinoline **2e** (entries 7 and 8), and four imidazo[5,1-*a*]isoquinolin-3-one derivatives **3g**, **4g**, **3h** and **4h** were obtained.

As a next examination, the reaction of Reissert compound **5**[7] of benzimidazole was examined under the same conditions. As shown in Scheme 2, diallylation product **6** was isolated as the major product (62%). In the reaction, we could not isolate the corresponding mono-allyl derivative.

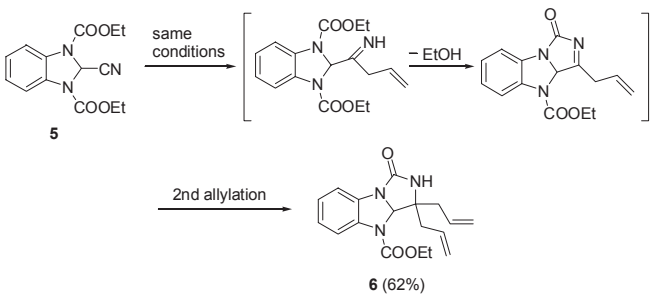


Scheme 1

Table 1. In-mediated allylation of Reissert compounds

Entry	Substrate (%)[a]	Products (%)[b]	
1	 **2a** (85)	 **3a** (38)	 **4a** (23)
2	 **2b** (85)	 **3b** (39)	 **4b** (27)
3	 **2c** (89)	 **3c** (37)	 **4c** (23)
4	 **2d** (83)	 **3d** (40)	 **4d** (26)
5[c]	**2a**	 **3e** (58)	 **4e** (21)
6[c]	**2d**	 **3f** (63)	 **4f** (22)
7	 **2e** (77)	 **3g** (38)	 **4g** (26)
8[c]	**2e**	 **3h** (59)	 **4h** (21)

[a]Prepared by ClCOOEt/KCN/CH_2Cl_2/H_2O or ClCOOEt/TMSCN/CH_2Cl_2 as reported.[4] [b]Conditions: Substrate (1.0 equiv), allyl bromide (3.0 equiv), In (1.5 equiv), THF, reflux, 20 min. [c]Methallyl bromide was used.



Scheme 2

In summary, a facile indium-mediated synthesis of allyl-substituted imidazo[1,5-*a*]quinoline and its derivatives has been disclosed starting from the Reissert compounds of quinoline and related compounds.

Experimental Section

Typical procedure for the synthesis of 2a. A mixture of quinoline (**1a**, 129 mg, 1.0 mmol), ethyl chloroformate (217 mg, 2.0 mmol), and potassium cyanide (195 mg, 3.0 mmol) in CH_2Cl_2/H_2O (3:1, 2 mL) was stirred at room temperature for 2 h. After the usual aqueous workup and column chromatographic purification process (hexanes/CH_2Cl_2/EtOAc, 10:1:1), we obtained **2a** (194 mg, 85%) as a white solid. Other compounds (**2b**, **2d** and **2e**) were synthesized similarly (77 - 85%), and the structures were confirmed by comparison with the reported spectroscopic data (**2a**,[4c] **2b**,[4c] **2d**,[4e] **2e**[4c]).

Typical procedure for the synthesis of 2c. To a stirred solution of 6-chloroquinoline (163 mg, 1.0 mmol) and ethyl chloroformate (217 mg, 2.0 mmol) in CH_2Cl_2 (2 mL) was added trimethylsilyl cyanide (297 mg, 3.0 mmol), and the reaction mixture was stirred at room temperature for 2 h. After the usual aqueous workup and column chromatographic purification process (hexanes/CH_2Cl_2/EtOAc, 10:1:1) compound **2c** was isolated as a white solid (234 mg, 89%). Compound **5**[7] was prepared similarly (59%), and the spectroscopic data of unknown **2c** is as follows.

Compound 2c: 89%; white solid, mp 121 - 122 °C; IR (KBr) 2241, 1719, 1487, 1375, 1319 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 1.35 (t, *J* = 7.2 Hz, 3H), 4.24-4.41 (m, 2H), 6.03 (dd, *J* = 9.0 and 6.6 Hz, 1H), 6.13 (d, *J* = 6.6 Hz, 1H), 6.68 (d, *J* = 9.0 Hz, 1H), 7.18 (d, *J* = 2.4 Hz, 1H), 7.28 (dd, *J* = 9.0 and 2.4 Hz, 1H), 7.62 (d, *J* = 8.4 Hz, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 14.29, 43.01, 63.68, 115.64, 120.35, 125.32, 126.78, 126.87, 128.72, 128.78, 130.62, 131.81, 152.73; ESIMS *m*/*z* 263 (M^++H).

Typical procedure for the synthesis of 3a and 4a. A stirred mixture of **2a** (114 mg, 0.5 mmol), allyl bromide (181 mg, 1.5 mmol), and indium powder (86 mg, 0.75 mmol) in THF (1.5 mL) was heated to reflux for 20 min. After the usual aqueous workup and column chromatographic purification process (hexanes/CH_2Cl_2/EtOAc, 7:2:1), we obtained compound **3a** (43 mg, 38%) and **4a** (31 mg, 23%). Other compounds were synthesized similarly, and the spectroscopic data are as follows.

Compound 3a: 38%; pale yellow solid, mp 168 - 169 °C; IR (KBr) 1682, 1601, 1462, 1379 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 3.40 (dt, *J* = 6.6 and 1.5 Hz, 2H), 5.15-5.30 (m, 2H), 5.88-6.01 (m, 1H), 6.53 (d, *J* = 9.9 Hz, 1H), 6.70 (d, *J* = 9.6 Hz, 1H), 7.16 (td, *J* = 7.5 and 1.2 Hz, 1H), 7.27 (dd, *J* = 8.1 and 1.5 H, 1H), 7.35 (ddd, *J* = 8.4, 7.2 and 1.5 Hz, 1H), 9.00 (dd, *J* = 7.8 and 0.6 Hz, 1H), 11.28 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 28.62, 111.15, 115.68, 116.35, 117.47, 117.70, 120.99, 124.08, 124.53, 126.96, 128.00, 133.72, 134.62, 151.33; ESIMS *m*/*z* 225 (M^++H). Anal. Calcd for $C_{14}H_{12}N_2O$: C, 74.98; H, 5.39; N, 12.49. Found: C, 75.21; H, 5.53; N, 12.24.

Compound 4a: 23%; pale yellow oil; IR (film) 3237, 1709, 1489, 1402, 1383 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.32 (dd, *J* = 13.8 and 7.5 Hz, 1H), 2.42-2.46 (m, 2H), 2.56 (dd, *J* = 13.8 and 7.5 Hz, 1H), 4.87 (t, *J* = 2.1 Hz, 1H), 4.96 (br s, 1H), 5.14-5.23 (m, 4H), 5.75 (dd, *J* = 10.2 and 1.8 Hz, 1H), 5.80-5.95 (m, 2H), 6.43 (dd, *J* = 10.2 and 2.4 Hz, 1H), 6.94 (td, *J* = 7.5 and 0.9 Hz, 1H), 7.01 (dd, *J* = 7.5 and 1.8 Hz, 1H), 7.17-7.23 (m, 1H), 8.10 (d, *J* = 8.4 Hz, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz)

δ 38.92, 42.04, 61.41, 62.14, 117.87, 119.82, 121.00, 121.33, 122.62, 123.68, 127.05, 127.59, 129.04, 131.51, 132.05, 135.29, 157.93; ESIMS *m*/*z* 267 (M^++H). Anal. Calcd for $C_{17}H_{18}N_2O$: C, 76.66; H, 6.81; N, 10.52. Found: C, 76.94; H, 6.87; N, 10.45.

Compound 3b: 39%; pale yellow solid, mp 180 - 182 °C (decomp); IR (KBr) 1688, 1466, 1387 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.35 (s, 3H), 3.40 (d, *J* = 6.6 Hz, 2H), 5.15-5.30 (m, 2H), 5.88-6.01 (m, 1H), 6.50 (d, *J* = 9.6 Hz, 1H), 6.70 (d, *J* = 9.6 Hz, 1H), 7.08 (s, 1H), 7.16 (dd, *J* = 8.4 and 1.8 Hz, 1H), 8.87 (d, *J* = 8.4 Hz, 1H), 11.14 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 20.87, 28.66, 110.82, 115.60, 116.22, 117.50, 117.80, 121.10, 124.42, 127.32, 128.79, 132.39, 133.55, 133.79, 151.15; ESIMS *m*/*z* 239 (M^++H). Anal. Calcd for $C_{15}H_{14}N_2O$: C, 75.61; H, 5.92; N, 11.76. Found: C, 75.58; H, 6.13; N, 11.54.

Compound 4b: 27%; pale yellow oil; IR (film) 3235, 1705, 1497, 1393 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.26 (s, 3H), 2.31 (dd, *J* = 13.8 and 6.9 Hz, 1H), 2.42-2.45 (m, 2H), 2.54 (dd, *J* = 13.8 and 7.8 Hz, 1H), 4.77 (br s, 1H), 4.84 (t, *J* = 2.1 Hz, 1H), 5.13-5.23 (m, 4H), 5.74 (dd, *J* = 10.2 and 2.1 Hz, 1H), 5.77-5.94 (m, 2H), 6.39 (dd, *J* = 10.2 and 2.4 Hz, 1H), 6.83 (d, *J* = 1.8 Hz, 1H), 7.01 (dd, *J* = 8.4 and 1.5 Hz, 1H), 7.97 (d, *J* = 8.4 Hz, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 20.64, 38.91, 42.10, 61.40, 62.25, 117.78, 119.78, 121.01, 121.33, 123.59, 127.60, 127.64, 129.53, 131.54, 132.02, 132.10, 132.79, 157.90; ESIMS *m*/*z* 281 (M^++H). Anal. Calcd for $C_{18}H_{20}N_2O$: C, 77.11; H, 7.19; N, 9.99. Found: C, 77.43; H, 7.22; N, 9.76.

Compound 3c: 37%; pale yellow solid, mp 203 - 205 °C (decomp); IR (KBr) 1688, 1456, 1383 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 3.39 (d, *J* = 6.6 Hz, 2H), 5.19-5.30 (m, 2H), 5.85-5.98 (m, 1H), 6.49 (d, *J* = 9.6 Hz, 1H), 6.76 (d, *J* = 9.6 Hz, 1H), 7.25-7.26 (m, 1H), 7.29 (dd, *J* = 9.0 and 2.4 Hz, 1H), 8.92 (d, *J* = 9.0 Hz, 1H), 9.91 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 28.21, 111.35, 117.03 (2C), 117.12, 117.18, 119.47, 125.95, 126.02, 127.30, 128.69, 133.09, 133.56, 150.41; ESIMS *m*/*z* 259 (M^++H), 261 (M^++2+H).

Compound 4c: 23%; pale yellow oil; IR (film) 3223, 1709, 1485, 1385 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.30 (dd, *J* = 13.8 and 7.5 Hz, 1H), 2.43-2.46 (m, 2H), 2.53 (dd, *J* = 13.8 and 7.5 Hz, 1H), 4.85 (t, *J* = 2.1 Hz, 1H), 5.14-5.24 (m, 5H), 5.76-5.93 (m, 2H), 5.81 (dd, *J* = 10.2 and 1.8 Hz, 1H), 6.36 (dd, *J* = 9.9 and 2.7 Hz, 1H), 6.98 (d, *J* = 2.1 Hz, 1H), 7.14 (dd, *J* = 8.7 and 2.7 Hz, 1H), 8.05 (dd, *J* = 8.7 and 0.3 Hz, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 38.95, 42.00, 61.55, 62.04, 119.08, 120.00, 121.06, 122.75, 125.13, 126.62, 126.65, 127.49, 128.61, 131.32, 131.87, 133.83, 157.72; ESIMS *m*/*z* 301 (M^++H), 303 (M^++2+H).

Compound 3d: 40%; pale yellow solid, mp 170 - 171 °C; IR (KBr) 1678, 1562, 1470, 1391 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 3.40 (d, *J* = 6.3 Hz, 2H), 3.83 (s, 3H), 5.16-5.29 (m, 2H), 5.88-6.01 (m, 1H), 6.50 (d, *J* = 9.6 Hz, 1H), 6.73 (d, *J* = 9.6 Hz, 1H), 6.80 (d, *J* = 3.0 Hz, 1H), 6.92 (dd, *J* = 9.0 and 3.0 Hz, 1H), 8.92 (d, *J* = 9.0 Hz, 1H), 11.04 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 28.67, 55.46, 111.12, 111.23, 113.78, 116.28, 117.45, 117.52, 117.61, 120.79, 125.78, 128.59, 133.79, 150.97, 155.96; ESIMS *m*/*z* 255 (M^++H).

Compound 4d: 26%; pale yellow oil; IR (film) 3221, 1703, 1497, 1396 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.31 (dd, *J* = 13.8 and 7.5 Hz, 1H), 2.41-2.45 (m, 2H), 2.53 (dd, *J* = 13.8 and 7.5 Hz, 1H), 3.76 (s, 3H), 4.81 (t, *J* = 2.1 Hz, 1H), 5.09 (br s, 1H), 5.13-5.21 (m, 4H), 5.79 (dd, *J* = 9.9 and 2.1 Hz, 1H), 5.78-5.94 (m, 2H), 6.39 (dd, *J* = 9.9 and 2.7 Hz, 1H), 6.59 (d, *J* = 3.0 Hz, 1H), 6.76 (dd, *J* = 8.7 and 3.0 Hz, 1H), 7.99 (d, *J* = 8.7 Hz, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 38.99, 42.18, 55.43, 61.33, 62.12, 112.61, 113.70, 119.02, 119.68, 120.78, 122.49, 124.86, 127.36, 128.71, 131.58, 132.10, 155.07, 157.99; ESIMS *m*/*z* 297 (M^++H).

Compound 3e: 58%; pale yellow solid, mp 184 - 185 °C; IR (KBr) 1695, 1601, 1466, 1383 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 1.75 (s, 3H), 3.33 (s, 2H), 4.90 (t, *J* = 1.5 Hz, 1H), 4.95 (d, *J* = 0.6 Hz, 1H), 6.56 (d, *J* = 9.6 Hz, 1H), 6.72 (d, *J* = 9.6 Hz, 1H), 7.17 (td, *J* = 7.5 and 1.2 Hz, 1H), 7.28 (dd, *J* = 7.5 and 1.5 Hz, 1H), 7.36 (ddd, *J* = 8.4, 7.2 and 1.5 Hz, 1H), 9.00 (dd, *J* = 8.4 and 0.3 Hz, 1H), 10.81 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.80, 32.89, 110.88, 113.19, 115.61, 116.34, 118.25, 121.24, 124.11, 124.50, 126.99, 128.09, 134.67, 141.74, 151.13; ESIMS *m*/*z* 239 (M^++H). Anal. Calcd for $C_{15}H_{14}N_2O$: C, 75.61; H, 5.92; N, 11.76. Found: C, 75.67; H, 6.08; N, 11.59.

Compound 4e: 21%; pale yellow oil; IR (film) 3238, 1709, 1489, 1402, 1381 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 1.85 (s, 3H), 1.86 (s, 3H), 2.11 (d, *J* = 13.5 Hz, 1H), 2.34 (d, *J* = 13.5 Hz, 1H), 2.51 (d, *J* = 13.5 Hz, 1H), 2.71 (d, *J* = 13.5 Hz, 1H), 4.77 (s, 1H), 4.80 (s, 2H), 4.98 (s, 1H), 5.05 (s, 1H), 5.07 (s, 1H), 5.71 (dd, *J* = 10.2 and 1.5 Hz, 1H), 6.44 (dd, *J* = 10.2 and 2.4 Hz, 1H), 6.93 (t, *J* = 7.2 Hz, 1H), 7.01 (d, *J* = 6.0 Hz, 1H), 7.17-7.22 (m, 1H), 8.14 (d, *J* = 8.1 Hz, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 24.64, 25.76, 42.43, 43.46, 60.66, 61.87, 116.82, 117.33, 117.59, 120.69, 122.58, 123.62, 127.11, 127.88, 129.15, 135.45, 140.42, 141.01, 157.67. Anal. Calcd for $C_{19}H_{22}N_2O$: C, 77.52; H, 7.53; N, 9.52. Found: C, 77.84; H, 7.66; N, 9.33.

Compound 3f: 63%; pale yellow solid, mp 178 - 179 °C; IR (KBr) 1686, 1612, 1560, 1476, 1391 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 1.74 (t, *J* = 0.6 Hz, 3H), 3.33 (s, 2H), 3.83 (s, 3H), 4.89 (t, *J* = 1.5 Hz, 1H), 4.94 (t, *J* = 0.6 Hz, 1H), 6.51 (d, *J* = 9.6 Hz, 1H), 6.73 (d, *J* = 9.6 Hz, 1H), 6.80 (d, *J* = 2.7 Hz, 1H), 6.92 (dd, *J* = 9.0 and 2.7 Hz, 1H), 8.92 (d, *J* = 9.0 Hz, 1H), 11.06 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.81, 32.91, 55.46, 111.07, 111.25, 113.09, 113.77, 116.22, 117.47, 118.08, 120.89, 125.78, 128.62, 141.82, 150.88, 155.94; ESIMS *m*/*z* 269 (M^++H).

Compound 4f: 22%; pale yellow solid, mp 168 - 169 °C; IR (KBr) 3219, 1703, 1495, 1393 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 1.85 (s, 3H), 1.86 (s, 3H), 2.11 (d, *J* = 13.5 Hz, 1H), 2.34 (d, *J* = 14.1 Hz, 1H), 2.50 (d, *J* = 14.1 Hz, 1H), 2.68 (d, *J* = 13.5 Hz, 1H), 3.77 (s, 3H), 4.66 (br s, 1H), 4.76 (d, *J* = 0.9 Hz, 1H), 4.80 (d, *J* = 0.9 Hz, 1H), 4.97-5.01 (m, 2H), 5.07 (t, *J* = 1.5 Hz, 1H), 5.75 (dd, *J* = 9.9 and 2.1 Hz, 1H), 6.41 (dd, *J* = 9.9 and 2.7 Hz, 1H), 6.59 (d, *J* = 3.0 Hz, 1H), 6.76 (dd, *J* = 9.0 and 3.0 Hz, 1H), 8.03 (d, *J* = 9.0 Hz, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 24.93, 26.05, 42.77, 43.91, 55.82, 61.01, 62.14, 113.13, 114.06, 117.04, 117.57, 119.04, 122.15, 125.13, 128.03, 129.20, 140.76, 141.38, 155.40, 157.94; ESIMS *m*/*z* 325 (M^++H).

Compound 3g:[5a] 38%; pale yellow solid, mp 160 - 163 °C (decomp); IR (KBr) 1701, 1599, 1468, 1414, 1371 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 3.67 (dd, *J* = 4.2 and 1.5 Hz, 2H), 5.17-5.25 (m, 2H), 5.94-6.05 (m, 1H), 6.28 (d, *J* = 7.5 Hz, 1H), 7.21-7.34 (m, 3H), 7.39 (d, *J* = 7.5 Hz, 1H), 7.62 (d, *J* = 7.5 Hz,

1H), 11.26 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 30.40, 110.31, 111.75, 115.38, 117.33, 120.29, 122.50, 125.95, 126.64, 127.02, 127.77, 129.00, 132.72, 148.89; ESIMS *m*/*z* 225 (M^++H).

Compound 4g:[5a] 26%; pale yellow oil; IR (film) 3235, 1717, 1460, 1418, 1383 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 2.34 (dd, *J* = 14.1 and 7.8 Hz, 1H), 2.56-2.64 (m, 2H), 2.78 (ddt, *J* = 14.4, 6.0 and 1.5 Hz, 1H), 4.94-5.08 (m, 2H), 5.18-5.21 (m, 1H), 5.25 (d, *J* = 5.4 Hz, 2H), 5.52 (br s, 1H), 5.61-5.75 (m, 1H), 5.63 (d, *J* = 7.8 Hz, 1H), 5.90-6.04 (m, 1H), 6.76 (d, *J* = 7.5 Hz, 1H), 7.00 (dd, *J* = 7.5 and 1.2 Hz, 1H), 7.08-7.22 (m, 3H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 40.45, 43.00, 60.37, 64.59, 105.78, 119.53, 120.19, 122.84, 124.43, 125.77, 126.32, 127.93, 128.01, 131.10, 132.51, 132.70, 156.63.

Compound 3h: 59%; pale yellow solid, mp 214 - 215 °C; IR (KBr) 1709, 1599, 1464, 1412, 1373 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.84 (s, 3H), 3.60 (s, 2H), 4.86 (s, 1H), 4.90-4.91 (m, 1H), 6.30 (d, *J* = 7.8 Hz, 1H), 7.22-7.34 (m, 3H), 7.40 (d, *J* = 7.8 Hz, 1H), 7.59-7.62 (m, 1H), 10.97 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 22.36, 34.65, 110.29, 111.77, 112.74, 115.83, 120.37, 122.63, 125.97, 126.70, 127.04, 127.76, 129.10, 140.77, 148.81; ESIMS *m*/*z* 239 (M^++H).

Compound 4h: 21%; pale yellow solid, mp 140 - 141 °C; IR (KBr) 3219, 1721, 1634, 1460, 1416 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.76 (s, 3H), 1.88 (s, 3H), 2.30 (d, *J* = 13.5 Hz, 1H), 2.57 (d, *J* = 13.5 Hz, 1H), 2.66 (s, 2H), 4.69 (d, *J* = 0.9 Hz, 1H), 4.86 (d, *J* = 0.9 Hz, 1H), 4.97-5.01 (m, 2H), 5.10 (br s, 1H), 5.34 (s, 1H), 5.63 (d, *J* = 7.5 Hz, 1H), 6.80 (d, *J* = 7.5 Hz, 1H), 6.99-7.02 (m, 1H), 7.12-7.20 (m, 3H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 24.71, 25.34, 43.01, 45.17, 59.66, 64.35, 105.94, 116.57, 117.40, 123.06, 124.69, 125.78, 126.33, 127.95, 128.05, 132.84, 140.13, 141.11, 155.67; ESIMS *m*/*z* 295 (M^++H).

Compound 6: 62%; white solid, mp 145 - 146 °C; IR (KBr) 3242, 1725, 1711, 1492, 1383 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.43 (t, *J* = 7.2 Hz, 3H), 2.31 (d, *J* = 7.2 Hz, 2H), 2.68 (d, *J* = 5.4 Hz, 2H), 4.37 (q, *J* = 7.2 Hz, 2H), 4.97-5.04 (m, 2H), 5.25-5.29 (m, 2H), 5.52-5.66 (m, 1H), 5.85-5.99 (m, 2H), 6.02 (br s, 1H), 7.00-7.03 (m, 2H), 7.38-7.41 (m, 1H), 7.53 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 14.53, 40.33, 41.54, 62.62, 65.30, 81.01, 114.37, 114.53, 120.22, 120.50, 123.65, 123.91, 131.07, 132.41, 133.48, 133.70, 152.87, 159.79; ESIMS *m*/*z* 328 (M^++H). Anal. Calcd for $C_{18}H_{21}N_3O_3$: C, 66.04; H, 6.47; N, 12.84. Found: C, 66.21; H, 6.34; N, 12.69.

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