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Synthesis of Dienamides *via* the Reaction of Nitrile with Allylindium Reagents and Intramolecular Acyl Group Quenching Cascade

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Various dienamide derivatives were synthesized in reasonable yields from benzonitriles having an amide moiety at the *ortho*-position, *via* the sequential (i) In-mediated allylation of nitrile moiety to form an imine intermediate, (ii) intramolecular quenching of an acyl group by the imine intermediate, and (iii) a proton transfer to dienamide.

Key Words: Dienamides, Indium, Nitrile, Allylation, Barbier reaction

Introduction

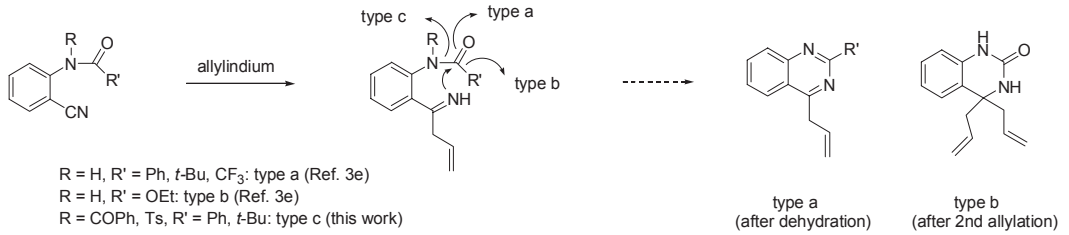
Allylindium reagents have been used extensively for the introduction of allyl group in a Barbier type manner to various electrophiles.[1-3] Although many reactive electrophiles such as aldehydes and imines have been used in the indium-mediated allylations,[1] the reaction of less reactive nitrile has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

Recently, we reported a series of indium-mediated Barbier type allylations of nitrile groups in γ-cyanoesters,[3a] γ-keto-nitriles,[3b] δ-ketonitriles,[3c] and *ortho*-cyanobenzoates.[3d] The intrinsic reactivity of nitrile group toward allylindium reagents was found to be sufficient to form the corresponding imine or enamine intermediates, and the corresponding δ-valerolactams,[3a] pyrroles,[3b] isoquinolines,[3c] and isoindolones[3d] were obtained in good to moderate yields. A nitrile group can be attacked by allylindium reagents when the molecule has a suitable electrophilic quencher, whereas isolated nitrile did not react with allylindium reagents. As an electrophilic quencher, ester[3a,d] and sterically hindered ketone group[3b,c] have been used successfully.

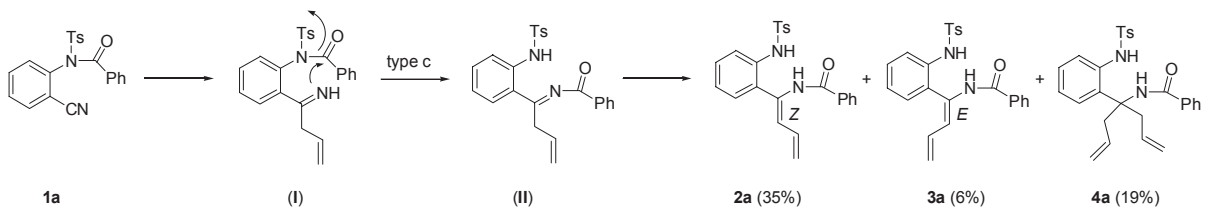
Results and Discussion

Very recently, we found that an amide group can be used as a suitable electrophilic quencher for the imine intermediate during the synthesis of a quinazoline scaffold,[3e] as shown in Scheme 1. Initial allylation of the nitrile group produced an imine intermediate, and the nitrogen atom attacked the carbonyl group of amide and form the corresponding quinazoline after dehydration (type a). For the carbamate derivative (R' = OEt) the reaction produced diallyl quinazolone after the second allylation (type b). During the studies, we thought that a transfer of an acyl group (COR') to the nitrogen atom of an imine intermediate could be possible (type c), as shown in Scheme 1 and Scheme 2 (*vide infra*).

Initially, we examined the reaction of *N*-tosyl-*N*-benzoyl derivative **1a**[4] and allyl bromide (4.0 equiv) in the presence of indium metal (2.0 equiv) in THF (reflux, 30 min), as shown in Scheme 2. The reaction afforded three compounds **2a**, **3a** and **4a**. The reaction was not completed with lesser amounts of allyl bromide and/or indium metal, and the reaction at lower temperature was also less effective.[3] The plausible mechanism for



Scheme 1



Scheme 2

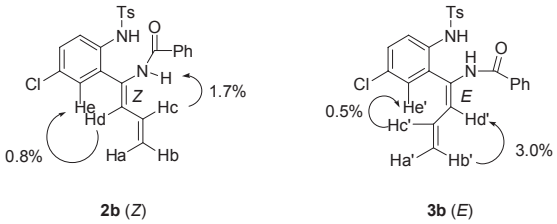
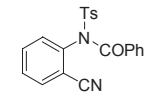
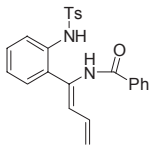
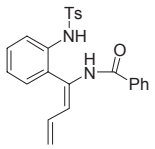
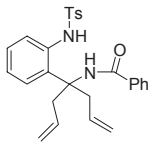
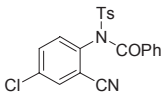
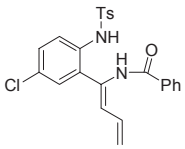
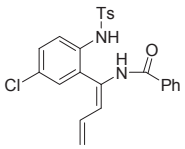
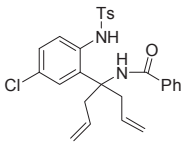
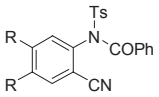
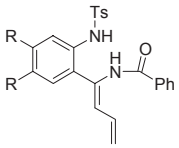
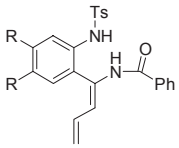
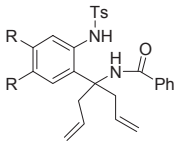
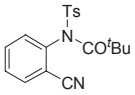
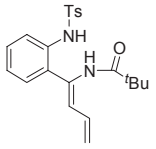
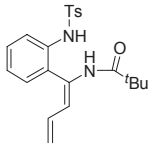
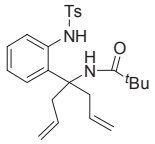
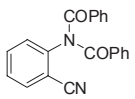
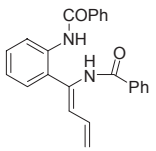
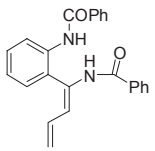
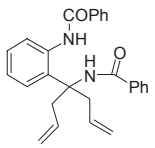
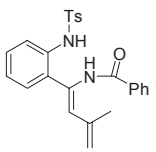
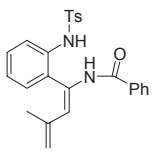
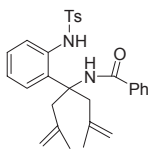


Figure 1

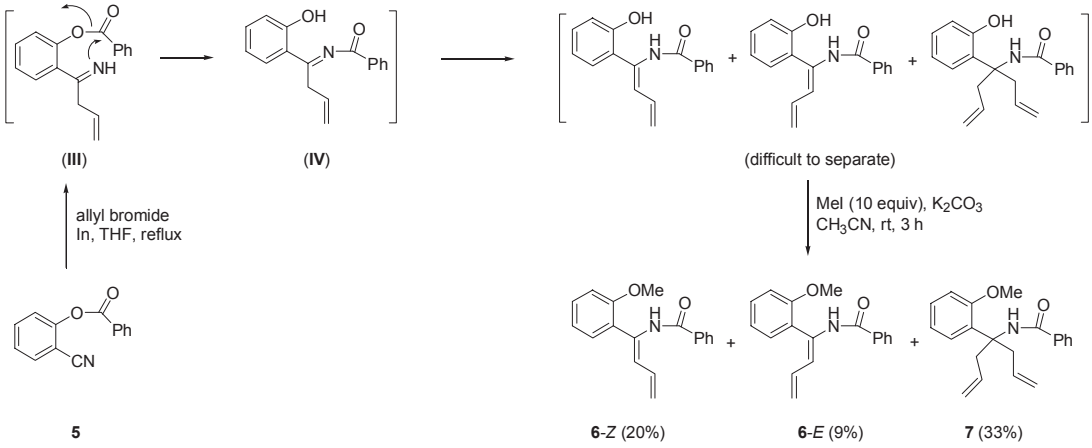
the formations of **2a**-**4a** is shown in Scheme 2. Initial attack of allylindium reagents to the nitrile of **1a** produced an imine intermediate (**I**), which abstracts a benzoyl group to form *N*-benzoylimine intermediate (**II**). The carbon atom of *N*-benzoylimine (**II**) is electrophilic and was attacked by allylindium reagents to produce diallyl amide **4a**, while 1,3-H shift of (**II**) produced a mixture of conjugated dienamides **2a** (*Z*) and **3a** (*E*).[5,6] The stereochemistry of double bond was assigned by NOE experiments with **2b** and **3b** (*vide infra*, Figure 1).

Encouraged by the results, we examined the synthesis of

Table 1. In-mediated allylation of nitrile derivatives **1a-e**

entry	substrate (%)[a]	product (%)[b]		
1	 **1a** (75)	 **2a** (35)	 **3a** (6)	 **4a** (19)
2	 **1b** (71)	 **2b** (31)	 **3b** (12)	 **4b** (22)
3[c]	 **1c** (70)	 **2c** (12)	 **3c** (-)	 **4c** (43)
4	 **1d** (78)	 **2d** (46)	 **3d** (9)	 **4d** (-)
5	 **1e** (70)	 **2e** (22)	 **3e** (26)	 **4e** (7)
6[d]	**1a**	 **2f** (22)	 **3f** (25)	 **4f** (-)

[a]Starting materials were prepared from 2-cyanoaniline derivatives (see Experimental). [b]Conditions: substrate (0.5 mmol), allyl bromide (4.0 equiv), In (2.0 equiv), THF, reflux, 30 min. [c]R = OMe. [d]Methallyl bromide was used.



Scheme 3

dienamides **2b-f** and **3b-f** by the reaction of similar nitrile derivatives **1b-e**. Starting materials **1b-e** were prepared easily from 2-aminobenzonitrile derivatives according to the reported methods,[4] and the allylation reactions of **1b-e** with allylindium (or methallylindium) reagents were carried out under the same conditions. The results are summarized in Table 1. The reaction of **1b** showed very similar results (entry 2) with those of the substrate **1a**. The reaction of dimethoxy derivative **1c** produced diallyl amide **4c** as the major product (entry 3) along with dienamide **2c** in low yield (12%). The results stated that the allylic proton in the corresponding *N*-benzoylimine intermediate (such as **II** in Scheme 2) is less acidic due to the presence of an electron-releasing *p*-methoxy group, thus isomerization to dienamides was retarded while the second allylation occurred in a larger extent to produce **4c** as the major product. The highest yield of dienamide **2d** (46%) was obtained in the reaction of pivaloyl derivative **1d** (entry 4). Dibenzoyl derivative **1e** also showed similar results; however, the proportion of a *E*-dienamide **3e** increased (entry 5). The reaction of **1a** and methallyl bromide also produced dienamides **2f** and **3f** in reasonable yields (entry 6); however, dimethallyl derivative **4f** was not formed presumably due to increased steric crowdedness.

As described above, the stereochemistry of dienamides was confirmed by NOE experiments with **2b** and **3b**, as shown in Figure 1. We chose compounds **2b** and **3b** due to the presence of aromatic singlet protons, H_e and H_e'.[7] Based on the NOE data, the stereochemistry of **2b** and **3b** was confirmed as **2b**-*Z* and **3b**-*E*, respectively (Figure 1). The protons H_a-H_d in **2a-f** and H_a'-H_c' in **3a-f** appeared at 4.91 - 6.58 ppm, while H_d' protons in **3a-f** appeared in the aromatic region (> 7.00 ppm) and overlapped with the aromatic protons.

As a next experiment, we examined the benzoate derivative **5** under the same reaction conditions, as shown in Scheme 3. As expected, the phenol moiety acted as a leaving group[8] to produce *N*-benzoylimine intermediate (**IV**). The second allylation and isomerization of the double bond produced a mixture of three compounds; however, separation of these compounds was very difficult. Thus we converted them into their methyl ethers by methylation (MeI, K_2CO_3), and we obtained three compounds **6**-*Z* (20%), **6**-*E* (9%), and **7** (33%).

In summary, various dienamide derivatives were synthesized in reasonable yields from benzonitriles having an amide moiety at the *ortho*-position, *via* the sequential (i) In-mediated allylation of nitrile moiety to form an imine intermediate, (ii) intramolecular quenching of an acyl group by the imine intermediate, and (iii) a proton transfer to dienamide.

Experimental Section

Synthesis of starting materials 1a-e and 5. The starting materials **1a-d** was prepared by the reaction of the corresponding 2-aminobenzonitriles in two steps in good yields: (i) tosylation (TsCl, pyridine, 100 °C, 6 h)[4a] and (ii) acylation (RCOCl, Et_3N, CH_2Cl_2, 0 °C to rt, 3 h).[4b,c] Compound **1e** was prepared by the reaction of 2-aminobenzonitrile and benzoyl chloride in the presence of K_2CO_3 in CH_3CN at room temperature for 36 h.[4c] Compound **5** was prepared by benzoylation (PhCOCl, K_2CO_3, CH_3CN, rt, 3 h) of 2-cyanophenol.[4d] The yields and the spectroscopic data of starting materials are as follows.

Compound 1a: 75%; white solid, mp 184 - 185 °C; IR (film) 2231, 1701, 1368, 1173 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.46 (s, 3H), 7.16-7.21 (m, 2H), 7.28-7.33 (m, 1H), 7.36 (d, J = 8.1 Hz, 2H), 7.39-7.45 (m, 3H), 7.48-7.50 (m, 1H), 7.56-7.62 (m, 2H), 7.79-8.00 (m, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.69, 114.60, 115.70, 128.07, 128.65, 129.46, 129.69, 129.74, 131.77, 132.58, 133.23, 133.41, 133.59, 134.48, 139.02, 145.68, 168.71; ESIMS *m*/*z* 399 (M^++Na).

Compound 1b: 71%; white solid, mp 198 - 199 °C; IR (film) 2234, 1703, 1371, 1173 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.46 (s, 3H), 7.20-7.25 (m, 2H), 7.32-7.47 (m, 6H), 7.52-7.58 (m, 2H), 7.95-7.98 (m, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.74, 114.47, 115.83, 128.28, 128.73, 129.59, 129.75, 132.05, 133.07, 133.17, 133.75 (2C), 134.25, 135.87, 137.64, 145.94, 168.46; ESIMS *m*/*z* 433 (M^++Na).

Compound 1c: 70%; white solid, mp 155 - 156 °C; IR (film) 2227, 1701, 1518, 1360, 1172 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.43 (s, 3H), 3.82 (s, 3H), 3.88 (s, 3H), 6.90 (s, 1H), 6.97 (s, 1H), 7.20 (t, J = 7.2 Hz, 2H), 7.29-7.35 (m, 1H), 7.36 (d, J = 8.1 Hz, 2H), 7.46 (d, J = 7.2 Hz, 2H), 8.00 (d, J = 8.4 Hz, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.50, 56.08, 56.40, 105.95,

113.58, 114.93, 115.80, 127.93, 128.31, 129.28, 129.56, 131.59, 132.96, 133.30, 134.35, 145.46, 149.44, 152.49, 168.65; ESIMS *m/z* 459 (M^++Na).

Compound 1d: 78%; white solid, mp 159 - 160 °C; IR (film) 2232, 1692, 1363, 1172 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 1.00 (s, 9H), 2.45 (s, 3H), 7.33 (d, *J* = 8.1 Hz, 2H), 7.42 (dd, *J* = 7.8 and 1.5 Hz, 1H), 7.61 (td, *J* = 7.5 and 1.5 Hz, 1H), 7.69 (td, *J* = 7.8 and 1.8 Hz, 1H), 7.81 (dd, *J* = 7.5 and 1.8 Hz, 1H), 7.92-7.95 (m, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 22.01, 28.64, 43.73, 116.51, 116.90, 129.59, 130.23, 130.73, 132.97, 133.45, 134.35, 135.32, 138.46, 145.47, 178.78; ESIMS *m/z* 379 (M^++Na).

Compound 1e: 70%; white solid, mp 181 - 182 °C; IR (film) 2229, 1697, 1671, 1449, 1254 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 7.24 (dd, *J* = 7.8 and 0.9 Hz, 1H), 7.28-7.35 (m, 4H), 7.37-7.44 (m, 3H), 7.52 (td, *J* = 7.8 and 1.8 Hz, 1H), 7.71-7.79 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 112.37, 116.22, 128.43, 128.55, 129.07, 129.75, 132.64, 133.70, 133.86, 134.29, 142.61, 172.71; ESIMS *m/z* 349 (M^++Na).

Typical procedure for the allylation of 1a. A mixture of **1a** (188 mg, 0.5 mmol), allyl bromide (242 mg, 2.0 mmol), and indium powder (114 mg, 1.0 mmol) in THF (1.5 mL) was heated to reflux for 30 min under nitrogen atmosphere. After the usual aqueous workup and column chromatographic purification process (hexanes/CH_2Cl_2/EtOAc, 7:1:1), we obtained compound **2a** (74 mg, 35%), compound **3a** (13 mg, 6%), and compound **4a** (44 mg, 19%). Other compounds were synthesized similarly, and the spectroscopic data are as follows.

Compound 2a: 35%; pale yellow oil; IR (film) 3333, 1644, 1479, 1335, 1158 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.33 (s, 3H), 5.19 (dd, *J* = 17.4 and 1.2 Hz, 1H), 5.24 (d, *J* = 10.2 Hz, 1H), 5.51 (dd, *J* = 10.8 and 0.6 Hz, 1H), 6.36-6.49 (m, 1H), 7.05 (td, *J* = 7.5 and 1.2 Hz, 1H), 7.10-7.16 (m, 3H), 7.25 (ddd, *J* = 8.7, 7.2 and 1.2 Hz, 1H), 7.40-7.46 (m, 2H), 7.50 (br s, 1H), 7.51-7.58 (m, 2H), 7.60-7.64 (m, 2H), 7.82-7.85 (m, 2H), 8.04 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.42, 120.74, 121.73, 124.50, 127.17, 127.56, 128.62, 129.26, 129.45, 129.53, 129.93, 130.14, 130.58, 131.03, 132.31, 132.80, 135.25, 136.80, 143.31, 166.88; ESIMS *m/z* 441 (M^++Na). Anal. Calcd for $C_{24}H_{22}N_2O_3S$: C, 68.88; H, 5.30; N, 6.69. Found: C, 68.97; H, 5.63; N, 6.45.

Compound 3a: 6%; pale yellow oil; IR (film) 3333, 1651, 1488, 1336, 1159 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.14 (s, 3H), 5.03 (dq, *J* = 10.2 and 0.9 Hz, 1H), 5.37 (ddd, *J* = 16.8, 1.8 and 0.6 Hz, 1H), 5.67-5.79 (m, 1H), 6.78 (br s, 1H), 7.04-7.07 (m, 3H), 7.13-7.23 (m, 2H), 7.34-7.57 (m, 6H), 7.62-7.69 (m, 4H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.29, 119.57, 121.22, 121.54, 125.30, 126.98, 127.37, 127.91, 128.81, 129.54, 130.00, 130.26, 131.04, 131.96, 132.11, 134.06, 134.90, 136.25, 144.00, 165.84; ESIMS *m/z* 441 (M^++Na). Anal. Calcd for $C_{24}H_{22}N_2O_3S$: C, 68.88; H, 5.30; N, 6.69. Found: C, 69.04; H, 5.42; N, 6.57.

Compound 4a: 19%; pale yellow oil; IR (film) 3306, 1655, 1493, 1336, 1161 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.33 (s, 3H), 2.89 (dd, *J* = 13.5 and 6.6 Hz, 2H), 3.01 (dd, *J* = 13.5 and 8.1 Hz, 2H), 5.03-5.09 (m, 4H), 5.41-5.54 (m, 2H), 6.32 (br s, 1H), 7.06 (td, *J* = 7.5 and 1.5 Hz, 1H), 7.11-7.14 (m, 2H), 7.16 (td, *J* = 7.5 and 1.8 Hz, 1H), 7.28 (dd, *J* = 7.8 and 1.5 Hz, 1H), 7.37 (dd, *J* = 8.1 and 1.5 Hz, 1H), 7.41-7.47 (m, 2H), 7.50-7.55 (m, 1H), 7.58-7.63 (m, 2H), 7.77-7.81 (m, 2H), 8.29 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.44, 39.67, 60.51, 120.08, 120.22, 124.11, 127.01, 127.14, 127.68, 127.94, 128.80, 129.63, 131.52, 132.11 (2C), 133.87, 134.96, 136.90, 143.81, 167.59; ESIMS *m/z* 483 (M^++Na). Anal. Calcd for $C_{27}H_{28}N_2O_3S$: C, 70.41; H, 6.13; N, 6.08. Found: C, 70.33; H, 6.46; N, 5.91.

Compound 2b: 31%; pale yellow oil; IR (film) 3331, 1645, 1482, 1334, 1163 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.34 (s, 3H), 5.17 (dd, *J* = 17.4 and 0.6 Hz, 1H), 5.23 (d, *J* = 10.2 Hz, 1H), 5.42 (d, *J* = 11.4 Hz, 1H), 6.35-6.47 (m, 1H), 7.11 (d, *J* = 2.4 Hz, 1H), 7.12 (d, *J* = 8.1 Hz, 2H), 7.19 (dd, *J* = 8.7 and 2.4 Hz, 1H), 7.39-7.44 (m, 2H), 7.50 (d, *J* = 8.7 Hz, 1H), 7.50-7.56 (m, 1H), 7.58-7.61 (m, 2H), 7.78 (br s, 1H), 7.81-7.84 (m, 2H), 8.17 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.46, 121.49, 123.26, 127.17, 127.58, 128.69, 129.10, 129.17, 129.58, 129.74, 129.81, 130.04, 130.20, 132.48, 132.54, 132.69, 134.01, 136.57, 143.56, 167.09; ESIMS *m/z* 475 (M^++Na). Anal. Calcd for $C_{24}H_{21}ClN_2O_3S$: C, 63.64; H, 4.67; N, 6.18. Found: C, 63.98; H, 4.89; N, 6.01.

Compound 3b: 12%; pale yellow oil; IR (film) 3336, 1652, 1485, 1330, 1163 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.18 (s, 3H), 5.04-5.08 (m, 1H), 5.36 (dd, *J* = 16.8 and 1.2 Hz, 1H), 5.64-5.76 (m, 1H), 6.99 (br s, 1H), 7.07 (d, *J* = 8.1 Hz, 2H), 7.18 (d, *J* = 2.7 Hz, 1H), 7.24 (d, *J* = 10.8 Hz, 1H), 7.24 (br s, 1H), 7.30 (dd, *J* = 8.7 and 2.4 Hz, 1H), 7.42-7.47 (m, 2H), 7.52-7.58 (m, 2H), 7.62-7.64 (m, 2H), 7.68-7.71 (m, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.32, 120.34, 122.53, 123.05, 127.07, 127.32, 128.80, 129.23, 129.64, 129.77, 129.93, 130.15, 130.37, 131.44, 132.25, 133.64, 133.76, 136.04, 144.18, 166.12; ESIMS *m/z* 475 (M^++Na). Anal. Calcd for $C_{24}H_{21}ClN_2O_3S$: C, 63.64; H, 4.67; N, 6.18. Found: C, 64.02; H, 4.90; N, 5.96.

Compound 4b: 22%; pale yellow oil; IR (film) 3311, 1655, 1487, 1386, 1162 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.34 (s, 3H), 2.82 (dd, *J* = 13.8 and 6.6 Hz, 2H), 2.95 (dd, *J* = 13.5 and 8.1 Hz, 2H), 5.03-5.12 (m, 4H), 5.39-5.53 (m, 2H), 6.35 (br s, 1H), 7.12 (dd, *J* = 8.7 and 2.4 Hz, 1H), 7.12-7.15 (m, 2H), 7.24 (d, *J* = 2.4 Hz, 1H), 7.32 (d, *J* = 8.7 Hz, 1H), 7.40-7.46 (m, 2H), 7.50-7.59 (m, 3H), 7.76-7.79 (m, 2H), 8.28 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.45, 39.37, 60.13, 120.69, 121.08, 127.01, 127.12, 127.81, 127.85, 128.84, 129.65, 129.73, 131.49, 132.27, 133.48, 133.52, 133.64, 136.47, 144.11, 167.58; ESIMS *m/z* 518 (M^++Na).

Compound 2c: 12%; pale yellow oil; IR (film) 3327, 1644, 1513, 1346, 1160 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.35 (s, 3H), 3.77 (s, 3H), 3.82 (s, 3H), 5.13 (dd, *J* = 17.1 and 0.9 Hz, 1H), 5.21 (dd, *J* = 10.5 and 0.9 Hz, 1H), 5.33 (dd, *J* = 11.1 and 0.6 Hz, 1H), 6.33-6.46 (m, 1H), 6.63 (s, 1H), 7.06 (s, 1H), 7.13-7.16 (m, 2H), 7.41-7.47 (m, 2H), 7.50 (br s, 1H), 7.51-7.60 (m, 3H), 7.74 (br s, 1H), 7.81-7.85 (m, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.46, 55.94, 56.00, 107.67, 112.16, 120.37, 124.52, 127.35, 127.49, 128.07, 128.69, 128.71, 129.47, 130.17, 130.74, 132.32, 133.00, 136.67, 143.34, 146.43, 149.28, 166.56; ESIMS *m/z* 501 (M^++Na).

Compound 4c: 43%; pale yellow solid, mp 160 - 161 °C; IR (film) 3319, 3276, 1655, 1519, 1338, 1160 cm^{-1}; ^1H NMR ($CDCl_3$, 300 MHz) δ 2.35 (s, 3H), 2.85 (dd, *J* = 13.5 and 6.6 Hz, 2H), 3.01 (dd, *J* = 13.5 and 7.8 Hz, 2H), 3.69 (s, 3H), 3.82

(s, 3H), 5.04-5.09 (m, 4H), 5.39-5.53 (m, 2H), 6.42 (br s, 1H), 6.77 (s, 1H), 6.87 (s, 1H), 7.14-7.17 (m, 2H), 7.40-7.46 (m, 2H), 7.49-7.54 (m, 1H), 7.61 (dt, J = 8.4 and 1.8 Hz, 2H), 7.72 (br s, 1H), 7.76-7.79 (m, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.41, 40.14, 55.53, 56.03, 60.33, 106.63, 111.42, 119.90, 126.13, 126.98, 127.30, 127.52, 128.72, 129.62, 131.94, 132.39, 134.11, 137.00, 143.87, 145.65, 147.81, 167.43; ESIMS *m*/*z* 543 (M^++Na).

Compound 2d: 46%; white solid, mp 113 - 114 °C; IR (film) 3360, 1644, 1493, 1335, 1159 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.24 (s, 9H), 2.37 (s, 3H), 5.11 (d, J = 16.8 Hz, 1H), 5.23 (d, J = 10.2 Hz, 1H), 5.30 (d, J = 9.6 Hz, 1H), 6.26-6.39 (m, 1H), 6.99-7.04 (m, 3H), 7.18-7.29 (m, 3H), 7.54 (d, J = 8.1 Hz, 1H), 7.65 (d, J = 8.1 Hz, 2H), 8.14 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.41, 27.41, 39.03, 120.50, 121.66, 124.30, 127.20, 129.04, 129.33, 129.45 (2C), 130.23, 130.29, 131.21, 135.29, 137.01, 143.22, 178.38; ESIMS *m*/*z* 421 (M^++Na).

Compound 3d: 9%; pale yellow oil; IR (film) 3356, 1655, 1496, 1337, 1160 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.21 (s, 9H), 2.38 (s, 3H), 4.91-4.95 (m, 1H), 5.27 (dd, J = 16.8 and 1.2 Hz, 1H), 5.56-5.69 (m, 1H), 6.60 (br s, 1H), 7.09-7.18 (m, 3H), 7.22 (br s, 1H), 7.22-7.33 (m, 3H), 7.51 (d, J = 8.1 Hz, 1H), 7.72-7.75 (m, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.52, 27.41, 39.69, 118.82, 119.82, 121.74, 124.61, 127.23, 127.47, 129.67, 130.02, 130.14, 130.99, 132.21, 135.14, 136.61, 143.93, 177.69; ESIMS *m*/*z* 421 (M^++Na).

Compound 2e: 22%; pale yellow solid, mp 118 - 119 °C; IR (film) 3271, 1656, 1650, 1552, 1479, 1448 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 5.25 (dd, J = 10.2 and 1.2 Hz, 1H), 5.37 (dd, J = 16.8 and 1.2 Hz, 1H), 6.23 (d, J = 11.1 Hz, 1H), 6.45-6.58 (m, 1H), 7.10 (td, J = 7.2 and 1.2 Hz, 1H), 7.25-7.36 (m, 4H), 7.40-7.46 (m, 3H), 7.48-7.57 (m, 3H), 7.75 (br s, 1H), 7.84-7.87 (m, 2H), 8.13-8.16 (m, 1H), 8.93 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 120.76, 123.32, 124.40, 127.38, 127.60, 128.40, 128.52, 129.27, 129.49, 129.71, 130.30, 130.73, 131.16, 131.66, 132.21, 132.83, 134.23, 136.23, 165.86, 166.97; ESIMS *m*/*z* 391 (M^++Na).

Compound 3e: 26%; pale yellow oil; IR (film) 3277, 1670, 1651, 1520, 1450 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 5.08-5.12 (m, 1H), 5.38 (dd, J = 16.8 and 1.2 Hz, 1H), 6.03-6.16 (m, 1H), 7.18 (td, J = 7.5 and 1.2 Hz, 1H), 7.31-7.55 (m, 9H), 7.56 (br s, 1H), 7.71-7.74 (m, 2H), 7.80-7.83 (m, 2H), 8.35 (dd, J = 8.4 and 0.9 Hz, 1H), 8.57 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 119.46, 122.17, 122.33, 124.75, 127.00, 127.14, 128.72 (2C), 129.52, 130.07, 131.92, 132.10, 132.51, 133.94, 134.36, 136.02, 165.72, 166.61 (two carbons were overlapped); ESIMS *m*/*z* 391 (M^++Na).

Compound 4e: 7%; pale yellow oil; IR (film) 3306, 1673, 1651, 1519, 1449 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 2.98-3.13 (m, 4H), 5.08-5.13 (m, 4H), 5.60-5.74 (m, 2H), 6.36 (br s, 1H), 7.21-7.31 (m, 3H), 7.34-7.47 (m, 5H), 7.48-7.56 (m, 1H), 7.63-7.71 (m, 4H), 8.01 (dd, J = 8.1 and 1.2 Hz, 1H), 9.08 (br s, 1H) ; ^{13}C NMR ($CDCl_3$, 75 MHz) δ 40.67, 61.05, 120.27, 125.39, 125.76, 126.80, 126.95, 127.39, 128.12, 128.67, 128.77, 131.74, 132.06, 132.64, 133.34, 133.84, 134.98, 135.27, 165.32, 166.95; ESIMS *m*/*z* 433 (M^++Na).

Compound 2f: 22%; colorless oil; IR (film) 3350, 1631, 1594, 1338, 1162 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.87 (s, 3H), 2.33 (s, 3H), 4.98 (s, 1H), 5.10 (s, 1H), 5.26 (s, 1H), 7.03-7.17 (m, 4H), 7.21-7.26 (m, 1H), 7.42 (t, J = 7.5 Hz, 2H), 7.50-7.58 (m, 2H), 7.65 (d, J = 8.1 Hz, 2H), 7.70 (br s, 1H), 7.78 (d, J = 7.2 Hz, 2H), 8.06 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.46, 22.19, 118.67, 121.79, 124.53, 127.20, 127.43, 128.72, 129.07, 129.14, 129.49, 129.80, 129.93, 131.72, 132.29, 132.93, 135.04, 136.96, 139.60, 143.32, 166.51; ESIMS *m*/*z* 455 (M^++Na).

Compound 3f: 25%; pale yellow solid, mp 110 - 111 °C; IR (film) 3341, 1646, 1513, 1337, 1159 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 1.29 (s, 3H), 2.14 (s, 3H), 4.92-4.93 (m, 2H), 6.85 (br s, 1H), 7.04 (d, J = 8.1 Hz, 2H), 7.10 (td, J = 7.5 and 1.2 Hz, 1H), 7.20-7.23 (m, 2H), 7.28-7.34 (m, 1H), 7.40-7.46 (m, 2H), 7.50-7.59 (m, 3H), 7.66-7.70 (m, 4H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.25, 21.32, 119.92, 120.39, 124.53, 126.41, 127.03, 127.28, 128.60, 128.70, 128.72, 129.46, 130.04, 130.13, 132.02, 133.96, 135.35, 136.50, 139.26, 143.83, 166.17; ESIMS *m*/*z* 455 (M^++Na).

Synthesis of 6 and 7. A stirred mixture of 2-cyanophenyl benzoate (**5**, 112 mg, 0.5 mmol), allyl bromide (242 mg, 2.0 mmol), and indium (114 mg, 1.0 mmol) in THF (1.5 mL) was heated to reflux for 30 min. After cooling to room temperature, the reaction mixture was poured in dilute HCl solution and extracted with diethyl ether. After removal of solvents, the crude products were subjected to the methylation conditions. To the solution of this crude product mixture in CH_3CN (2 mL) was added MeI (710 mg, 5.0 mmol) and K_2CO_3 (138 mg, 1.0 mmol), and the reaction mixture was stirred at room temperature for 3 h. After the usual aqueous workup and column chromatographic purification process (hexanes/CH_2Cl_2/EtOAc, 10:3:1), we obtained compound **6**-*Z* (28 mg, 20%), **6**-*E* (13 mg, 9%) and **7** (53 mg, 33%).

Compound 6-*Z*: 20%; pale yellow solid, mp 106 - 107 °C; IR (film) 3301, 1655, 1509, 1483 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.83 (s, 3H), 5.23 (dd, J = 10.2 and 1.8 Hz, 1H), 5.37 (dd, J = 16.8 and 1.5 Hz, 1H), 6.30 (d, J = 10.8 Hz, 1H), 6.53-6.66 (m, 1H), 6.87 (d, J = 5.1 Hz, 1H), 6.94-6.99 (m, 1H), 7.25-7.30 (m, 1H), 7.42-7.53 (m, 4H), 7.85 (d, J = 7.2 Hz, 2H), 8.06 (br s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 55.63, 110.85, 118.68, 121.06, 125.99, 127.14 (2C), 127.27, 128.56, 129.40, 129.68, 131.55, 132.39, 134.67, 156.48, 164.94; ESIMS *m*/*z* 302 (M^++Na).

Compound 6-*E*: 9%; pale yellow oil; IR (film) 3311, 1660, 1517, 1488 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.86 (s, 3H), 4.98 (ddd, J = 10.2, 2.1 and 0.6 Hz, 1H), 5.30 (dq, J = 16.8 and 1.2 Hz, 1H), 6.19-6.32 (m, 1H), 6.97-7.03 (m, 2H), 7.31-7.55 (m, 7H), 7.73-7.76 (m, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 55.75, 111.43, 116.63, 119.43, 120.70, 124.50, 126.78, 128.64, 130.29, 131.49, 132.27, 133.71, 133.75, 135.35, 156.83, 165.44; ESIMS *m*/*z* 302 (M^++Na).

Compound 7: 33%; pale yellow oil; IR (film) 3359, 1664, 1518, 1487 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.08 (dd, J = 13.8 and 7.8 Hz, 2H), 3.27 (ddt, J = 13.8, 6.6 and 1.2 Hz, 2H), 3.82 (s, 3H), 5.03-5.17 (m, 4H), 5.55-5.68 (m, 2H), 6.86 (br s, 1H), 6.90-6.96 (m, 2H), 7.21-7.28 (m, 2H), 7.39-7.51 (m, 3H), 7.75-7.78 (m, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 40.03, 55.40, 61.17, 111.93, 118.41, 120.63, 126.70, 128.30, 128.33, 128.48, 130.09, 131.06, 134.22, 135.90, 156.87, 166.24; ESIMS *m*/*z*

344 (M^++Na).

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7. Actually, the proton H_e appeared as a doublet due to a small meta-coupling (J = 2.4 Hz) at 7.11 ppm, while the proton H_e' also appeared as a doublet (J = 2.7 Hz) at 7.18 ppm.
8. When we used *N*-allyl-*N*-benzoyl derivative as a substrate instead of *N*-tosyl-*N*-benzoyl derivative **1a**, we could not obtain the products, presumably because the *N*-allylphenyl group is not a good leaving group as compared to the *N*-tosylphenyl moiety in the case of **1a**. The reaction showed sluggish reactivity and much of the starting materials were decomposed to many intractable polar compounds.