JOC Article

N,*N*-Dichloro-2-nitrobenzenesulfonamide as the Electrophilic Nitrogen Source for Direct Diamination of Enones

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N,*N*-Dichloro-*o*-nitrobenzenesulfonamide (2-NsNCl$_2$) was found to be an effective electrophilic nitrogen source for the direct diamination of α,*β*-unsaturated ketones without the use of any metal catalysts. The reaction is very convenient to carry out without the protection of inert gases. Molecular sieves (4 Å) and temperature were found to play key roles in controlling the formations of 3-trichloromethyl and dichloromethyl imidazoline products (16 examples). The 2-Ns-protection group of the resulting diamine products can be easily cleaved under mild Fukuyama's conditions. A new mechanism hypothesis of [2+3] cyclization and *N*-chlorination has been proposed to explain the product structures, particularly their regio- and stereochemistry.

The vicinal diamine functionality is extremely important for organic chemistry, medicinal chemistry, and pharmaceutical research.[1,2] This functionality exists in many biologically important compounds. Enantiomerically pure diamines have been utilized as chiral auxiliaries and chiral ligands for asymmetric synthesis and catalysis.[3−6] The development of efficient synthetic approaches to this functionality in regio- and stereoselective fashions represents a challenging topic, especially when the functionalized olefins such as cinnamic esters and α,*β*-unsaturated ketones are employed as the substrates. Recently, we have discovered two new diamination reactions of olefins.[7,8] The first reaction was carried out in a tandem manner with *N*,*N*-dichloro-2-nitrobenzenesulfonamide (2-NsNCl$_2$) and acetonitrile as the nitrogen sources without any catalysts.[7] The diamination with alkyl cinnamates as substrates resulted in anti alkyl N^{α}-Ns, N^{β}-Ac diaminophenylpropionates. The latter diamination was achieved by using *N*,*N*-dichloro-*p*-toluenesulfonamide (4-TsNCl$_2$) and acetonitrile as the nitrogen sources in the presence of the catalytic complex of rhodium(II) heptafluorobutyrate or iron(III) trichloride with triphenylphosphine.[8] The reaction afforded imidazoline products at first and can generate α,*β*-differentiated vicinal diamines after acidic hydrolysis (Scheme 1).[9]

In the continuing studies of this new imidazolization reaction, we found that the diamination can proceed to completion at room temperature without the use of any metal catalysts in prolonged reaction time when α,*β*-unsaturated ketones were employed as the substrates.[10] This new finding prompted us to utilize the analogous nitrogen/halogen sources, such as 2-NsNCl$_2$, 4-NsNCl$_2$, and 2,4-di-NsNCl$_2$, for the noncatalyzed dimination reaction. The advantages of this modification are based on the fact that the nitrobenzenesulfonyl protecting group of the product can be more easily cleaved by using PhSH and K_2CO_3 in DMF at room temperature, which was developed by Fukuyama.[11] In addition, 2-NsNCl$_2$ is much more stable than 4-TsNCl$_2$ and can be stored at room temperature for several months. In this paper, we report the first 2-NsNCl$_2$-based diamination of α,*β*-unsaturated

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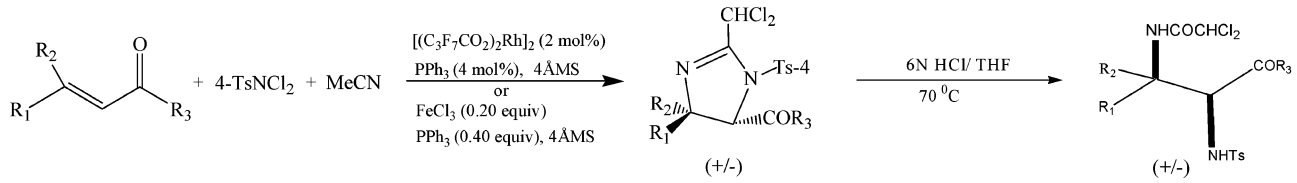
SCHEME 1



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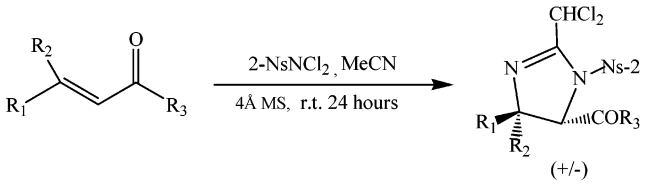


ketones in the absence of any catalysts (Scheme 2), with the results summarized in Tables 1 and 2.

Results and Discussion

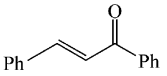
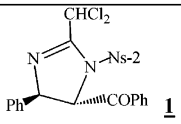
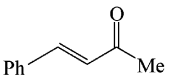
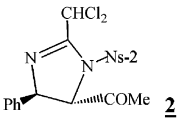
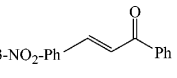
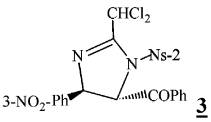
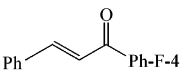
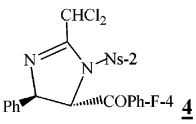
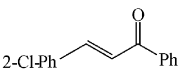
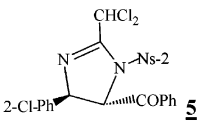
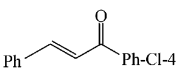
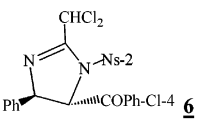
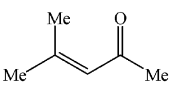
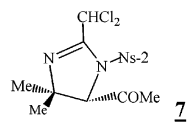
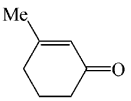
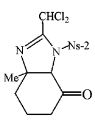
The direct diamination reaction can be carried out simply by mixing reactants in a one-pot operation at room temperature. Since there are no sensitive catalysts involved, the reaction can thus be performed without the special protection by inert gases. In addition, the crude product mixture is much easier to work up and can be purified by column chromatography as compared to that of the catalyst involved diamination reactions.[8]

As shown in Table 1, the reaction showed a good scope of ketone substrates. Both aromatic and aliphatic α,*β*-unsaturated ketones can be employed as the olefin substrates. Regarding aromatic ketones, as anticipated, the more electronic deficient 3-nitrochalcone and 2-chlorochalcone showed slower reaction rates and resulted in lower chemical yields. In both cases, haloamine product was obtained as the major side product with about 25% yield. For 3-nitrochalcone, only a trace amount of desired product was obtained even after several days at room temperature, which made it necessary to carry out the reaction at increased temperature (50 °C) to achieve satisfied reaction rate and yield. Interestingly, an electron-withdrawing group on the α-phenyl ring can benefit the chemical yields (entries 4 and 6).

Aliphatic ketones showed faster reaction rate, and the reaction can be finished within 8 h at room temperature for mesityl oxide. However, for aliphatic ketone substrates this diamination reaction is still limited to *β*,*β*-disubstituted α,*β*-unsaturated aliphatic ketones at the current stage. While 3-methyl-2-cyclohexen-1-one (entry 8) can give 73% yield after 24 h at room temperature for the reaction, 2-cyclohexen-1-one resulted in no desired product at all even after 3 days at room temperature and then 24 h at 50 °C.

The more electronic deficient characteristic of 2-$NsNCl_2$ makes it more reactive and efficient than 4-$TsNCl_2$ for the direct diamination of α,*β*-unsaturated ketones as revealed by the results in Table 1. For example, chalcone and 4′-chlorochalcone gave 71% and 86% chemical yields as compared to the yields of 60% and 63%, respectively, which were generated for diamination by using 4-$TsNCl_2$ for the same α,*β*-unsaturated ketone. Moreover, 3-nitrochalcone can give 62% chemical yield after 20 h at 50 °C

TABLE 1. Results of Direct Diamination of α,*β*-Unsaturated Ketones with 2-$NsNCl_2$ To Afford 1-*o*-Nitrobenzenesulfonyl-3-dichloromethyl-4,5-imidazolines

Entry	Substrate	Product (+/-)	Yield (%)
1		 **1**	71
2		 **2**	66
3[a]		 **3**	62
4		 **4**	83
5		 **5**	62
6		 **6**	86
7[b]		 **7**	79
8		 **8**	73

[a] Reaction was carried out at 50 °C for 20 h. [b] Reaction was carried out at rt for 8 h.

for 2-$NsNCl_2$ whereas no product was obtained even after 3 days at 50 °C when 4-$TsNCl_2$ was employed.

In this new system, 1.5 equiv of 2-$NsNCl_2$ was proved to be sufficient for the reaction to achieve good chemical yields. Using a larger amount (2.0 equiv) of 2-$NsNCl_2$ resulted in a faster reaction rate, but no obvious improvement on chemical yield. Based on this result and our latest study on $TsNH_2$/NCS-based diamination reaction,[12] the previous mechanism hypothesis should be

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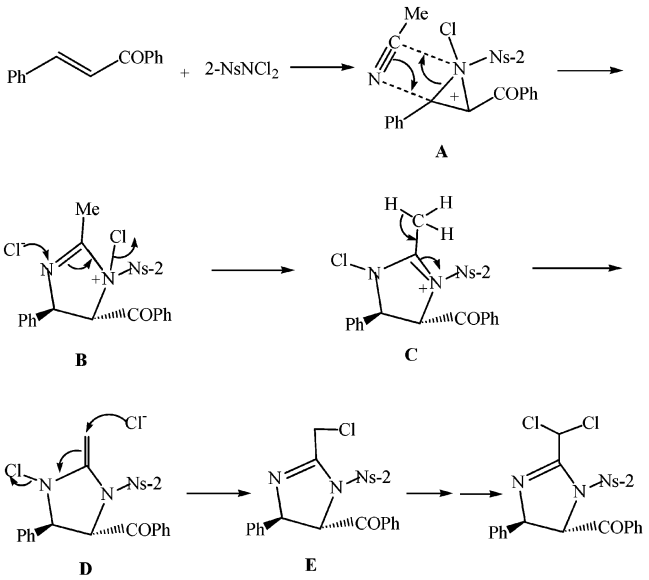
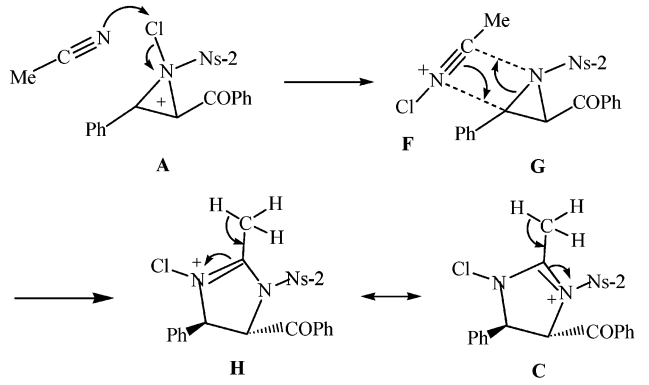
SCHEME 3



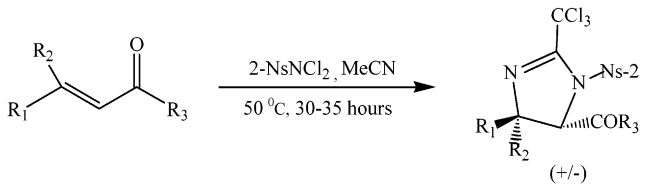
SCHEME 4



modified (Scheme 3). The first step of this reaction is believed to be the same as that of the metal-catalyzed diamination through the electrophilic addition for the formation of *N*-(*o*-nosyl),*N*-chloroaziridinium intermediate (**A**).[8] The next step of the aziridinium ring opening could proceed through the [2+3] cyclic addition reaction between acetonitrile and *N*-(*o*-nosyl)aziridinium intermediate (**A**) to directly form *1N*-(*o*-nosyl)imidazolinium (**B**).[12] This step controls both regioselectivity and anti stereoselectivity of diamine products. The following steps are the same as the previous suggested,[8] i.e. the 1,3-displacement of *1N*-chlorine of **B** gives rise to *1N*-(*o*-nosyl),*3N*-chloroimidazolinium (**C**). Deprotonation of the 2-methyl group of **C** gives methylene scaffold **D**, which enables the second S_N2'-type displacement to afford 1-*o*-nitrobenzenesulfonyl-2-chloromethyl-4-phenyl-5-methyloxycarbonylimidazoline (**E**), which is then converted into the final imidazoline product through chlorination of *3N* of intermediate **E** and further similar steps from **C** to **E**. Since 2-$NsNCl_2$ is an organic oxidant, it could oxidize Cl^- to Cl_2 which gives chlorination of intermediate **E** on its *3N* position.

Another possible [2+3] cycloaddition pathway is shown in Scheme 4. In this mechanism, acetonitrile could attack the chlorine instead of the *β*-carbon center of the aziridinium intermediate. This is in fact a type of S_N2 substitution to give *N*-chloro nitrilium (**F**) and aziridine

SCHEME 5



(**G**) intermediates. These two intermediates then proceed to the [2+3] cycloaddition reaction to result in intermediate **H**, which is a resonance structure of **C**. The following steps are the same as those from **C** to the final products as shown in Scheme 3.

Compared to our previous catalytic and noncatalytic systems,[8,10] molecular sieves were found to play even more important roles in the present system. Although there is no big difference whether molecular sieves were used for certain substrates such as chalcone and *trans*-4-phenyl-3-buten-2-one, for aliphatic ketones, 3-nitrochalcone, 4′-fluorochalcone, and 4′-chlorochalcone, the 1-*o*-nitrobenzenesulfonyl-3-trichloromethyl-4,5-imidazolines instead of 1-*o*-nitrobenzenesulfonyl-3-dichloromethyl-4,5-imidazolines were predominantly generated if no molecular sieves were used.

Encouraged by these results and our previous study that provides a novel access to 1-*p*-toluenesulfonyl-3-trichloromethyl-4,5-imidazolines,[13] we attempted to continue the third chlorination to further convert the $-CHCl_2$ group of 1-*o*-nitrobenzenesulfonyl-3-dichloromethyl-4,5-imidazoline products into its $-CCl_3$ counterpart. In this case, the N^{β}-trichloroacetyl group of the final α,*β*-differentiated vicinal diamine product (Scheme 1) should be cleaved more easily upon treating with $NaBH_4$ in EtOH. In fact, the N^{β}-trichloroacetyl group has been a common protective group in organic synthesis.[14] In this paper, we also report the preliminary results of the direct diamination reaction of α,*β*-unsaturated ketones to provide 1-*o*-nitrobenzenesulfonyl-3-trichloromethyl-4,5-imidazoline products (Scheme 5 and Table 2).

The study was initiated with use of chalcone as the substrate by performing the reaction at enhanced temperature (50 °C). While 1-*o*-nitrobenzenesulfonyl-3-dichloromethyl-4,5-imidazoline was still produced as the major product after 5 h, almost the same amount of 1-*o*-nitrobenzenesulfonyl-3-trichloromethyl-4,5-imidazoline as that of 1-*o*-nitrobenzenesulfonyl-3-dichloromethyl-4,5-imidazoline was observed after 12 h at this temperature. After 30 h the 1-*o*-nitrobenzenesulfonyl-3-trichloromethyl-4,5-imidazoline was predominantly generated with no 1-*o*-nitrobenzenesulfonyl-3-dichloromethyl-4,5-imidazoline left in the reaction mixture. A stoichiometric amount (1.5 equiv) of 2-$NsNCl_2$ resulted in the desired products, but the yields were relatively low (<60%). Using 2.5 equiv of 2-$NsNCl_2$ proved to improve the chemical yields by 30−40%. However, using a larger amount (3.0 equiv) of 2-$NsNCl_2$ resulted in no further improvement on chemical yields.

As anticipated, aliphatic α,*β*-unsaturated ketone showed a faster reaction rate. It needs only 11 h at room

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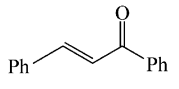
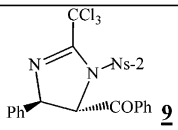
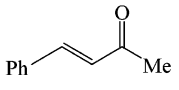
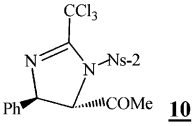
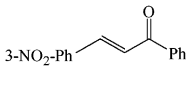
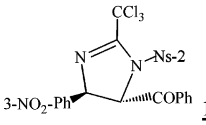
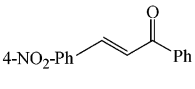
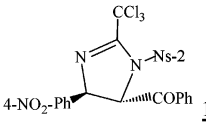
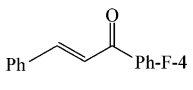
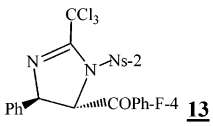
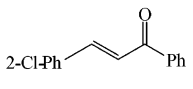
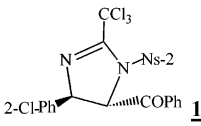
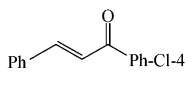
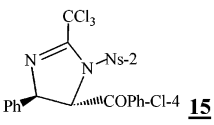
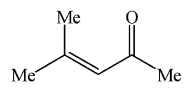
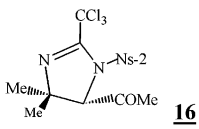
TABLE 2. Results of Direct Diamination of α,β-Unsaturated Ketones with 2-NsNCl$_2$ To Afford 1-*o*-Nitrobebzenesulfonyl-3-trichloromethyl-4,5-imidazolines[a]

Entry	Substrate	Product (+/-)	Yield (%)
1		 **9**	75
2		 **10**	61
3		 **11**	84
4		 **12**	86
5		 **13**	80
6		 **14**	77
7		 **15**	78
8*		 **16**	71

[a] The asterisk identifies the reaction that was carried out at room temperature for 11 h.

temperature to finish the reaction for mexityl oxide. In fact, many more unknown side products were generated when the reaction was carried out at 50 °C for this substrate. At this stage, it is not clear why the more electronic deficient 3-nitrochalcone, 4-nitrochalcone, and 2-chlorochalcone (entries 3, 4, and 6 in Table 2) can benefit the formation of 1-*o*-nitrobenzenesulfonyl-3-trichloromethyl-4,5-imidazoline as compared to the relative low yields of 1-*o*-nitrobenzenesulfonyl-3-dichloromethyl-4,5-imidazoline from the same substrates (entries 3 and 5 in Table 1).

It is interesting to find that formation of 1-*o*-nitrobenzenesulfonyl-3-trichloromethyl-4,5-imidazolines was inhibited when 4 Å molecular sieves were present in the reaction system. For example, the reaction between 3-nitrochalcone and 2-NsNCl$_2$ gave no 1-*o*-nitrobenzenesulfonyl-3-trichloromethyl-4,5-imidazoline, but 1-*o*-nitrobenzenesulfonyl-3-dichloromethyl-4,5-imidazoline, even after 2 days at 50 °C when 4 Å molecular sieves were employed.

In conclusion, a new direct diamination reaction of α,β-unsaturated ketones with 2-NsNCl$_2$ has been established. The generation of 1-*o*-nitrobenzenesulfonyl-3-dichloromethyl-4,5-imidazolines and 1-*o*-nitrobenzenesulfonyl-3-trichloromethyl-4,5-imidazolines can be effectively controlled. The nitrogen source, *N*,*N*-dichloro-*o*-nitrobenzenesulfonamide (2-NsNCl$_2$), which can be readily synthesized from *o*-nitrobenzenesulfonamide and commercial bleach, showed greater reactivity and efficiency than 4-TsNCl$_2$ for the reaction. The reaction is convenient to perform simply by mixing an α,β-unsaturated ketone and the two nitrogen sources together at room temperature without special protection by inert gases. Molecular sieves and temperature were found to play important roles in controlling the formation of desired products.

Experimental Section

General Information. NMR spectra were recorded at 500 MHz for ^{1}H NMR and 125 MHz for ^{13}C NMR. $CDCl_3$ was the only solvent used for the NMR analysis, with TMS as the internal standard. High-resolution mass spectral analysis was conducted by IonSpec Ultman FTMS Instrument. Column Chromatography was performed with silica gel Merk 60 (230−400 mesh).

All reactions were carried out with freshly distilled acetonitrile from CaH_2 under nitrogen atmosphere. Other commercial chemicals were used without purification, and their stoichiometries were calculated based on the reported purities from the manufactures.

Typical Procedure for Preparation of 1-*o*-Nitrobenzenesulfonyl-3-dichloromethyl-4,5-imidazolines Represented by Entry 1 of Table 2. Into a dry vial was loaded 104 mg of chalcone (0.50 mmol), 200 mg of 4 Å molecular sieves, and 3.0 mL of freshly distilled CH_3CN. To the resulting solution was added 203 mg of 2-NsNCl$_2$ (0.75 mmol) and the mixture was stirred at room temperature for 24 h at which point the reaction was finished as revealed by GC or ^{1}H NMR. The 4 Å molecular sieves were filtered off and washed with EtOAc (5 mL). The solution was concentrated directly without quenching and purified by flash chromatography (acetone/hexane, v/v, 1/6) to give 184 mg (71% yield) of pure product as a white solid.

Typical Procedure for Preparation of 1-*o*-Nitrobenzenesulfonyl-3-trichloromethyl-4,5-imidazolines Represented by Entry 1 of Table 2. Into a dry vial was loaded 104 mg of chalcone (0.50 mmol) and 3.0 mL of freshly distilled CH_3CN. To the resulting solution was added 338 mg of 2-NsNCl$_2$ (1.25 mmol) and the mixture was stirred at 50 °C for 30 h at which point the reaction was finished as revealed by GC or ^{1}H NMR. The reaction mixture was concentrated directly without quenching and purified by flash chromatography (EtOAc/hexane, v/v, 1/5) to give 206 mg (75% yield) of pure product as a white solid.

1: Isolated as a white solid (184 mg, 71% yield). Mp 161−163 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.24−8.30 (m, 1H), 7.80−7.86 (m, 2H), 7.70−7.80 (m, 3H), 7.62−7.70 (m, 1H), 7.46−7.53 (m, 2H), 7.28−7.35 (m, 3H), 7.20 (s, 1H), 7.05−7.14 (m, 2H), 5.73 (d, J = 4.0 Hz, 1H), 5.10 (d, J = 4.0 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 192.7, 156.4, 147.9, 137.9, 135.2, 134.5, 133.0, 132.6, 132.0, 131.2, 129.2, 129.1, 129.0, 128.9, 126.5, 125.1, 72.3, 72.2, 62.4. HRMS (MALDI-FTMS) m/z (M^+ + 1) found 518.0348, calcd for $C_{23}H_{17}N_3O_5SCl_2$ 518.0339.

2: Isolated as a white solid (150 mg, 66% yield). Mp 134−136 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.93−8.00 (dd, J = 8.0, 1.5 Hz, 1H), 7.66−7.77 (m, 2H), 7.55−7.65 (m, 1H), 7.13 (s, 1H), 7.00−7.10 (m, 3H), 6.94−7.00 (m, 2H), 5.22 (d, J = 3.5 Hz, 1H), 4.23 (d, J = 3.5 Hz, 1H), 2.50 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 205.4, 156.8, 147.5, 139.0, 135.5, 132.8, 132.6, 129.2, 128.7, 128.0, 125.6, 125.5, 75.7, 71.7, 63.5, 26.3.

3: Isolated as a white solid (175 mg, 62% yield). Mp 128−130 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.21−8.27 (dd, J = 8.0, 1.0 Hz, 1H), 8.14−8.21 (m, 1H), 7.88−7.92 (m, 1H), 7.24−7.88 (m, 5H), 7.66−7.73 (m, 1H), 7.52−7.58 (m, 3H), 7.45−7.51 (m, 1H), 7.20 (s, 1H), 5.64 (d, J = 4.0 Hz, 1H), 5.20 (d, J = 4.0 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 192.1, 157.9, 148.6, 147.8, 140.1, 135.6, 134.8, 132.8, 132.8, 132.7, 132.2, 130.7, 130.3, 129.3, 128.8, 125.7, 123.8, 121.5, 71.8, 70.9, 62.2.

4: Isolated as a white solid (221 mg, 83% yield). Mp 124−126 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.25−8.30 (m, 1H), 7.83−7.90 (m, 2H), 7.73−7.83 (m, 3H), 7.28−7.36 (m, 3H), 7.13−7.21 (m, 3H), 7.06−7.12 (m, 2H), 5.69 (d, J = 4.0 Hz, 1H), 5.08 (d, J = 4.0 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.3, 167.5, 165.5, 156.4, 147.9, 137.8, 135.3, 132.6, 132.0, 131.8, 131.7, 131.2, 129.3, 129.1, 126.5, 125.1, 116.6, 116.4, 72.4, 72.3, 62.4.

5: Isolated as a white solid (170 mg, 62% yield). Mp 142−144 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.16−8.20 (m, 1H), 7.80−7.86 (m, 2H), 7.74−7.80 (m, 2H), 7.68−7.74 (m, 1H), 7.58−7.66 (m, 1H), 7.42−7.49 (m, 2H), 7.29−7.35 (dd, J = 7.5, 1.5 Hz, 1H), 7.17−7.28 (m, 2H), 7.08−7.17 (m, 2H), 5.71 (d, J = 5.0 Hz, 1H), 5.55 (d, J = 5.0 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 193.7, 157.2, 147.7, 135.9, 135.3, 134.3, 133.6, 132.6, 132.5, 132.2, 130.9, 129.9, 129.8, 129.0, 128.9, 128.2, 127.6, 125.2, 70.7, 69.1, 62.4.

6: Isolated as a white solid (237 mg, 86% yield). Mp 150−152 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.22−8.30 (m, 1H), 7.70−7.86 (m, 5H), 7.43−7.51 (m, 2H), 7.29−7.38 (m, 3H), 7.19 (s, 1H), 7.03−7.12 (m, 2H), 5.67 (d, J = 4.0 Hz, 1H), 5.07 (d, J = 4.0 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.6, 156.3, 147.8, 141.1, 137.7, 135.3, 132.6, 131.9, 131.2, 131.0, 130.2, 129.5, 129.2, 129.0, 126.4, 125.1, 77.2, 72.2, 62.3.

7: Isolated as a white solid (161 mg, 79% yield). Mp 170−172 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.13−8.21 (m, 1H), 7.80−7.96 (m, 3H), 6.92 (s, 1H), 3.89 (s, 1H), 2.37 (s, 3H), 1.29 (s, 3H), 0.98 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 205.4, 153.5, 147.8, 135.7, 133.2, 132.9, 129.6, 125.7, 77.2, 70.4, 63.2, 30.0, 27.8, 23.0. HRMS (MALDI-FTMS) m/z ($M^+ + 1$) found 408.0177, calcd for $C_{14}H_{15}N_3O_5SCl_2$ 408.0182.

8: Isolated as a white solid (130 mg, 73% yield). Mp 144 °C dec. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.18−8.30 (m, 1H), 7.82−7.90 (m, 3H), 6.92 (s, 1H), 3.87 (s, 1H), 2.69−2.81 (m, 1H), 2.31−2.45 (m, 1H), 2.05−2.15 (m, 1H), 1.84−2.05 (m, 2H), 1.60−1.70 (m, 1H), 1.30 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 206.1, 154.9, 148.1, 135.4, 133.6, 132.7, 129.8, 125.2, 74.2, 73.3, 62.7, 36.4, 34.0, 27.4, 18.6.

9: Isolated as a white solid (206 mg, 75% yield). Mp 180−182 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.36−8.46 (m, 1H), 7.94−7.80 (m, 2H), 7.64−7.74 (m, 4H), 7.50−7.58 (m, 2H), 7.38−7.46 (m, 3H), 7.22−7.28 (m, 2H), 6.24 (d, J = 3.0 Hz, 1H), 5.20 (d, J = 3.0 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 192.6, 158.5, 147.8, 136.4, 134.6, 134.5, 132.8, 132.7, 132.2, 131.7, 129.3, 129.2, 129.2, 129.0, 126.6, 124.8, 73.9, 71.3. HRMS (MALDI-FTMS) m/z ($M^+ + 1$) found 551.9934, calcd for $C_{23}H_{16}N_3O_5SCl_3$ 551.9949.

10: Isolated as a white solid (150 mg, 61% yield). Mp 159−161 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.83−7.90 (m, 1H), 7.61−7.67 (m, 2H), 7.39−7.46 (m, 1H), 7.28−7.38 (m, 3H), 7.18−7.25 (m, 2H), 5.39 (d, J = 3.0 Hz, 1H), 5.06 (d, J = 3.0 Hz, 1H), 2.46 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 203.8, 156.9, 148.0, 138.0, 134.8, 132.1, 131.7, 130.0, 129.1, 128.5, 125.9, 124.8, 77.3, 77.2, 69.8, 26.4.

11: Isolated as a white solid (252 mg, 84% yield). Mp 144−146 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.41−8.47 (m, 1H), 8.25−8.30 (m, 1H), 8.07−8.11 (m, 1H), 7.95−8.01 (m, 2H), 7.70−7.80 (m, 4H), 7.55−7.70 (m, 4H), 6.25 (d, J = 2.5 Hz, 1H), 5.29 (d, J = 2.5 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.9, 160.2, 148.5, 147.6, 138.4, 135.0, 134.8, 132.6, 132.5, 132.4, 132.2, 130.6, 129.4, 128.9, 125.0, 124.0, 121.9, 77.2, 73.5, 70.2.

12: Isolated as a white solid (258 mg, 86% yield). Mp 170−172 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.39−8.46 (m, 1H), 8.27−8.33 (m, 2H), 7.94−7.99 (m, 2H), 7.69−7.81 (m, 4H), 7.56−7.62 (m, 2H), 7.41−7.46 (m, 2H), 6.25 (d, J = 3.0 Hz, 1H), 5.29 (d, J = 3.0 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 192.0, 160.4, 148.3, 147.6, 143.1, 135.0, 134.8, 132.7, 132.6, 132.5, 132.3, 129.4, 128.9, 127.7, 125.1, 124.5, 77.2, 73.4, 70.5.

13: Isolated as a white solid (228 mg, 80% yield). Mp 150−152 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.36−8.46 (m, 1H), 7.96−8.04 (m, 2H), 7.68−7.76 (m, 3H), 7.38−7.48 (m, 3H), 7.19−7.25 (m, 4H), 6.19 (d, J = 3.0 Hz, 1H), 5.17 (d, J = 3.0 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.1, 167.5, 165.5, 158.5, 147.8, 136.2, 134.7, 132.7, 132.3, 131.9, 131.8, 131.7, 129.4, 129.3, 126.6, 124.9, 116.6, 116.4, 77.2, 73.7, 71.4.

14: Isolated as a white solid (225 mg, 77% yield). Mp 172−174 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.30−8.37 (m, 1H), 7.90−7.98 (m, 2H), 7.66−7.72 (m, 3H), 7.59−7.65 (m, 1H), 7.44−7.52 (m, 2H), 7.39−7.43 (m, 1H), 7.31−7.39 (m, 2H), 7.27−7.31 (m, 1H), 6.17 (d, J = 3.0 Hz, 1H), 5.76 (d, J = 3.0 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 193.7, 159.3, 147.7, 134.7, 134.4, 134.1, 133.4, 132.8, 132.4, 132.3, 131.6, 130.3, 130.0, 129.3, 128.8, 128.4, 127.7, 124.9, 77.2, 72.1, 67.8.

15: Isolated as a white solid (228 mg, 78% yield). Mp 151−153 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.40−8.46 (m, 1H), 7.88−7.94 (m, 2H), 7.68−7.78 (m, 3H), 7.51−7.58 (m, 2H), 7.38−7.48 (m, 3H), 7.20−7.26 (m, 2H), 6.19 (d, J = 3.0 Hz, 1H), 5.17 (d, J = 3.0 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.5, 158.6, 147.8, 141.2, 136.2, 134.8, 132.7, 132.3, 131.9, 131.1, 130.3, 129.6, 129.4, 129.3, 126.6, 124.9, 77.2, 73.8, 71.4.

16: Isolated as a white solid (157 mg, 71% yield). Mp 166−168 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.24−8.30 (m, 1H), 7.74−7.86 (m, 3H), 4.68 (s, 1H), 2.30 (s, 3H), 1.39 (s, 3H), 1.32 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 203.5, 154.6, 148.1, 135.1, 132.3, 132.0, 131.7, 125.1, 78.7, 77.2, 69.6, 28.6, 28.4, 23.4. HRMS (MALDI-FTMS) m/z ($M^+ + 1$) found 441.9788, calcd for $C_{14}H_{14}N_3O_5SCl_3$ 441.9792.

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Supporting Information Available: ^{1}H and ^{13}C NMR spectra of all pure products. This material is available free of charge via the Internet at http://pubs.acs.org.

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