PREPARATION AND STRUCTURE OF *C,C,N*-TRIARYL SUBSTITUTED IMINE: $TiCl_4$–1,4-DIAZABICYCLO[2.2.2]OCTANE-MEDIATED IMINATION OF 1-AROYL-2,7-DIMETHOXYNAPHTHALENE AND SPATIAL ORGANIZATION OF THE PRODUCED IMINE MOLECULE IN CRYSTAL

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$TiCl_4$–DABCO-mediated reaction of 1-monoaroylated 2,7-dimethoxynaphthalene compound and aromatic amine afforded triaryl-substituted imine compounds with/without cleavage of a methoxy group on the starting naphthalene compound. Three aromatic rings of methyl ether-cleaved imine molecule in crystal are accumulated perpendicularly to each other in crystal.

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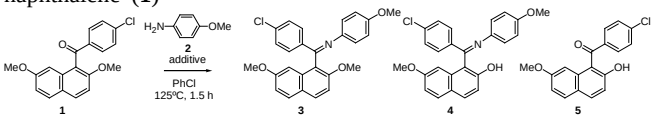
Introduction

Non-coplanarly organized aromatic-rings accumulating compounds, e.g., biphenyls and binaphthyls, have been demonstrated as unique building blocks in construction for many functional materials.[1-8] Thus, organic reaction affording novel molecular motifs of non-coplanarly organized aromatic-rings accumulating compounds with minute spatial structural characterization have attracted attention of the chemists in the wide-range of organic molecular science and polymer materials fields. Recently, the authors have reported specific and characteristic electrophilic aromatic aroylation of naphthalene derivatives. In this reaction, two aroyl groups are regioselectively and effectively introduced at the 1,8-positions of the naphthalene ring accompanying with acid-mediated retroaroylation.[9] The 1-monoaroylated naphthalenes, which correspond to the intermediates in the diaroylation, are also obtained by choice of acidic mediator.[10] According to X-ray crystal structure analyses, the aroyl groups in these *peri*-aroylated naphthalene compounds are attached in a non-coplanar fashion to the naphthalene rings.[11-15] In a natural consequence, the authors have planned introduction of additional aromatic ring planes to the core of the aroylnaphthalene molecules to realize more crowded inner spatial situation in aromatic-rings accumulating molecule. As one of the molecular transformation approaches to obtain such spatial organization, the authors designed conversion of ketonic carbonyl group in 1-monoaroylnaphthalene to imino moiety by the reaction with aromatic amines. This attempt has led the authors to reveal novel reaction behaviour of *peri*-aroylated 2,7-dimethoxynaphthalene derivatives and the unique spatial organization of the resulting imine compounds in crystal. Herein, the authors report imination reaction of 1-monoaroylnaphthalene with aromatic amine, i.e., introduction reaction of the third aromatic ring to a naphthalene molecule of non-coplanarly organized two-aromatic-rings accumulating structure and discuss the reaction mechanism. In addition, the authors introduce the spatial organization features of the resulting triarylimine molecule.

Results and discussion

Table 1 shows the results of reaction of 1-(4-chlorobenzoyl)-2,7-dimethoxynaphthalene (**1**) with *p*-anisidine (**2**). When molecular sieves 4A[14] was added, no reaction proceeded (entry 2) as well as the reaction without additive compounds (entry 1). In *p*-toluenesulfonic acid (TsOH)-mediated reaction,[15] imine **3** was slightly obtained with recovery of starting material **1** (entry 3). $TiCl_4$–1,4-diazabicyclo[2.2.2]octane (DABCO)-mediated reaction[16] moderately afforded imine **3** (14 %) in a similar manner of TsOH-mediated one, whereas the reaction also gave the methyl–oxygen bond cleaved species, i.e., imine **4** (22 %) and 1-monoaroylnaphtahlene **5** (14 %) (entry 4).

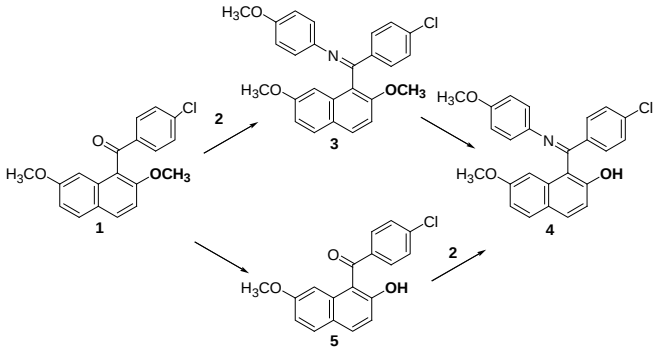
Table 1. Imination of 1-(4-chlorobenzoyl)-2,7-dimethoxy-naphthalene[a] (**1**)



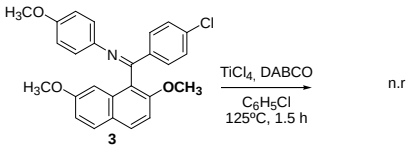
Entry	Additive	Product distribution (%)[b]			
		1	**3**	**4**	**5**
1	None	100	0	0	0
2	MS4A[c]	100	0	0	0
3	TsOH[d]	90	10(6)	0	0
4	$TiCl_4$,DABCO[e]	50(44)	14(10)	22(10)	14(8)

[a]Reaction conditions: 1-(4-chlorobenzoyl)naphthalene (**1**, 1.0 mmol), *p*-anisidine (**2**, 1.1 mmol), chlorobenzene (5 mL). [b]Calculated on the basis of ^{1}H NMR spectra. Isolated yields are given in parentheses. [c]MS4A (100 mg). [d]TsOH (*p*-toluenesulfonic acid; 0.1 mmol). [e]$TiCl_4$ (1.7 mmol), 1,4-diazabicyclo[2.2.2]octane (DABCO; 3.3 mmol).

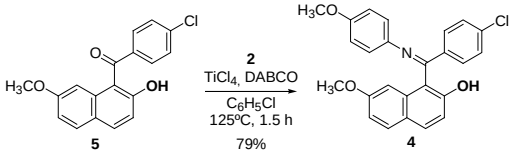
There are two possible reaction routes for imine **4,** i.e., methyl–oxygen bond cleavage reaction of imine **3** and imination of 2-hydroxy-7-methoxy-1-monoaroylnaphthalene **5** (Scheme 1)**.** Imine **3** formed no ether-cleaved products by treatment with $TiCl_4$–DABCO mixture (Scheme 2).



Scheme 1

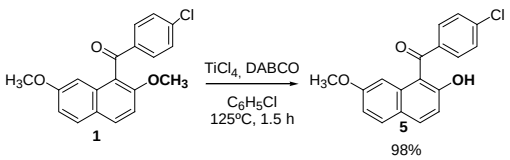


Scheme 2

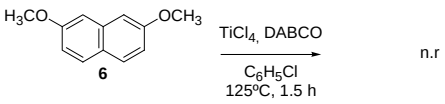


Scheme 3

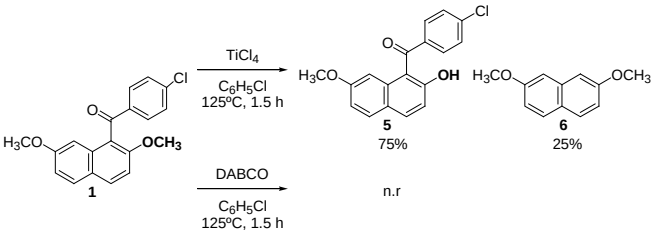
On the other hand, the methyl ether-cleaved 1-monoaroylnaphthalene **5** was transformed into imine **4** in a high yield (79 %) when $TiCl_4$, DABCO, and amine **2** were treated as entry 4 in Table 1 (Scheme 3). These results strongly indicate that imine **4** was formed via the latter reaction route. In other words, imination of 1-monoaroylated 2-hydroxy-7-methoxynaphthalene **5** readily proceeds than that of the parent compound, 1-monoaroylated 2,7-dimethoxynaphthalene **1**. 1-Monoaroylnaphthalene **1** was converted quantitatively to the methyl ether-cleaved 1-monoaroylnaphthalene **5** by the aid of $TiCl_4$–DABCO mixture in the absence of amines (Scheme 4). On the contrary, no reaction occurred by the same treatment of 2,7-dimethoxynaphthalene (Scheme 5). Furthermore, reaction of 1-monoaroylnaphthalene **1** in monochlorobenzene at 125°C for 1.5 h with $TiCl_4$ yielded 1-monoaroylnaphthalene **5** (75 %) and 2,7-dimethoxynaphthalene **6** (25 %), whereas that with DABCO formed no products (Scheme 6).



Scheme 4

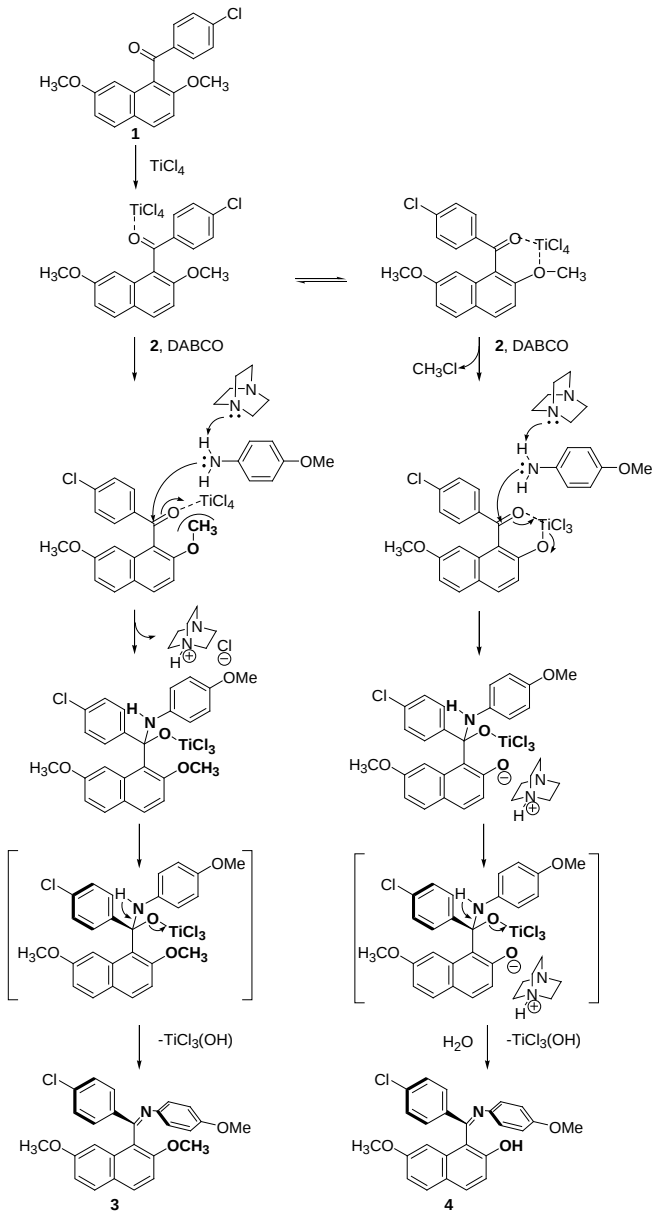


Scheme 5



Scheme 6

Based on these results, this methyl ether cleavage reaction is obviously promoted by $TiCl_4$. It is widely recognized that $TiCl_4$ rarely catalyzes scission of aryl methyl bonds except for that some special assistance. So, it's strongly suggested that this $TiCl_4$ promoted cleavage of aryl methyl ether should be assisted by neighboring group effect of the adjacent aroyl substituent, probably by coordination of the heteroatoms of the substituents to titanium atom.[17]



Scheme 7

Scheme 7 well-explains the plausible reaction mechanism. The $TiCl_4$–DABCO-mediated imination of 1-monoaroylnaphthalene **1** to imine **3** presumably proceeds via three steps: 1) the carbonyl oxygen coordinates to titanium atom of $TiCl_4$, 2) nucleophilic attack of the nitrogen atom of aniline to $TiCl_4$-activated ketonic carbonyl group of 1-monoaroylnaphthalene **1** proceeds with simultaneous abstraction of proton from the adduct by DABCO, and 3) deprotonation from nitrogen atom of hemiaminal forms imino moiety.

As the carbonyl carbon atom of 1-monoaroylnaphthalene **1** is sterically hindered, the second step of nucleophilic attack of amine is considered essentially rate-determining step for total imination reaction. So, the aroyl group-assisted methyl ether-cleavage reaction of 1-monoaroylnaphthalene **1** presumably undergo with comparable susceptibility as well as the nucleophilic attack of the amine **2** to the ketonic carbonyl carbon. As the attack of amine **2** to the carbonyl carbon of methyl ether-cleaved-1-monoaroylnaphthalene **5** thus obtained should be less affected by steric hindrance than the parent compound **1**, it smoothly affords imine **4**.

Figure 1 displays the crystal structure of analogous imine **7**, which has no methoxy group on the *N*-linked benzene. In the crystal of analogous imine **7**, two molecules of imine **7** form a 2:1 set with a DABCO molecule. Each of the aromatic rings is connected almost perpendicularly against two other aromatic rings. The dihedral angles of the *C*-linked 4-chlorophenyl ring and the *N*-linked phenyl ring with the naphthalene ring are 80.39(6)° and 82.35(6)°, respectively. The dihedral angle between *C*- and *N*-linked benzene rings is 87.09(7)°.

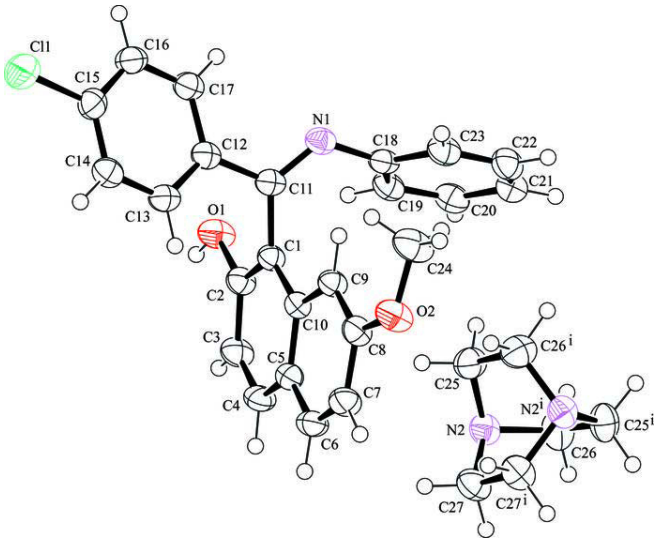


Figure 1. Molecular structure of analogous imine **7**, with the atom-labeling scheme and displacement ellipsoids drawn at the 50% probability level [Symmetry code (i)1-x, y, 3/2-z].

Conclusively, $TiCl_4$–DABCO-mediated imination of 1-monoaroylated 2,7-dimethoxynaphthalene successfully yield *C,C,N*-triaryl substituted imine compounds with/without cleavage of 2-positioned methoxy group. In crystal of an imine compound, the three aromatic rings are situated perpendicularly to each other realizing stable spatial organization.

Experimental

All reagents were of commercial quality and were used as received. Solvents were dried and purified using standard techniques.

Measurements

^{1}H NMR spectra were recorded on a JEOL JNM-AL300 spectrometer (300 MHz) and a JEOL ECX400 spectrometer (400 MHz). Chemical shifts are expressed in ppm relative to internal standard of Me_4Si (δ 0.00). ^{13}C NMR spectra were recorded on a JEOL JNM-AL300 spectrometer (75 MHz). Chemical shifts are expressed in ppm relative to internal standard of $CDCl_3$ (δ 77.0). IR spectra were recorded on a JASCO FT/IR-4100 spectrometer. Elemental analyses were performed on a Yanaco CHN CORDER MT-5 analyzer. High-resolution FAB mass spectra were recorded on a JEOL MStation (MS700) ion trap mass spectrometer in positive ion mode.

X-ray Crystallography

For the crystal structure determination, the single-crystal of the compound $C_{24}H_{18}ClNO_2 \cdot 0.5C_6H_{12}N_2$ was used for data collection on a four-circle Rigaku RAXIS RAPID diffractometer (equipped with a two-dimensional area IP detector). The graphite-mono-chromated Cu Kα radiation (λ = 1.54187 Å) was used for data collection. The lattice parameters were determined by the least-squares methods on the basis of all reflections with $F^2 > 2\sigma(F^2)$. The data collection and cell refinement were performed using *PROCESS-AUTO* software. The data reduction was performed using *CrystalStructure*. The structures were solved by direct methods using *SIR2004* and refined by a full-matrix least-squares procedure using the program *SHELXL97*. All H atoms were found in a difference map and were subsequently refined as riding atoms, with the aromatic C–H = 0.95 Å and methyl C–H = 0.98 Å, and with $U_{iso}(H) = 1.2U_{eq}(C)$.

Synthetic procedures of 1-(4-chlorobenzoyl)-2,7-dimethoxy-naphthalene (1)

To a solution of 2,7-dimethoxynaphthalene (**6**, 0.200 mmol, 68.2 mg) and 4-chlorobenzoyl chloride (0.22 mmol, 38.5 mg) in dichloromethane (0.5 mL), $AlCl_3$ (0.22 mmol, 29.3 mg) was added by portions at 0°C under nitrogen atmosphere. After the reaction mixture was stirred at r.t. for 3 h, it was poured into iced water (20 mL) and the mixture was extracted with $CHCl_3$ (15 mL×3). The combined extracts were washed with 2 M aq. NaOH, saturated aq. NaCl and dried over anhydrous magnesium sulfate. The solvent was removed under reduced pressure to give powdery product. The crude product was purified by recrystallization (hexane, isolated yield 78 %).

1-(4-Chlorobenzoyl)-2,7-dimethoxynaphthalene (1)

Colourless needles (hexane), Mp 121.5–122 °C; IR (KBr): 1667, 1628, 1586, 1512 cm^{-1}; ^1H NMR δ (300 MHz, $CDCl_3$): 7.87 (1H, d, *J* =9.0 Hz), 7.78 (2H, d, *J* = 8.4 Hz), 7.72 (1H, d, *J* = 9.0 Hz), 7.39 (2H, d, *J* = 8.4 Hz), 7.16 (1H, d, *J* = 9.0 Hz), 7.02 (1H, dd, *J* = 2.4, 9.0 Hz), 6.78 (1H, d, *J* = 2.4 Hz), 3.79 (3H, s), 3.73 (3H, s) ppm; ^{13}C NMR δ (75 MHz, $CDCl_3$): 196.81, 158.96, 155.02, 139.71, 136.45, 132.94, 131.28, 130.87, 129.72, 128.86, 124.34, 121.06, 117.15, 110.05, 101.88, 56.239, 55.168 ppm; Calcd for $C_{19}H_{15}O_3Cl$: C, 69.83%; H, 4.63%; Found: C, 69.61%; H, 4.74%.

Imination of 1-(4-chlorobenzoyl)-2,7-dimethoxynaphthalene (1)

To a solution of 1-(4-chlorobenzoyl)-2,7-dimethoxynaphthalene (**1**, 0.2 mmol, 65.4 mg) in monochlorobenzene (1 mL), mixtures of aniline (0.22 mmol, 20.5 mg), $TiCl_4$ (0.33 mmol, 62.4 mg), DABCO (1.32 mmol, 148.0 mg) and monochlorobenzene (1 mL) were added by portions at 90°C under nitrogen atmosphere. After the reaction mixture was stirred at 125 °C for 1.5 h, the resulting solution was filtrated to remove the precipitate. The solvent was removed under reduced pressure to give crude material. The crude product was purified by silicagel column chromatography (chloroform; isolated yield: imine **3**, 10 %; imine **4**, 10 %, 2-hydroxy compound **5**, 8 %).

Spectral data and elemental analyses

Imine 3

Colourless blocks ($CHCl_3$/hexane) Mp. 174–175 °C, IR (KBr) 1625, 1502, 1238, 1029, 830 cm^{-1}; ^1H NMR δ (300 MHz, $CDCl_3$): 7.72 (1H, d, *J* = 9.0 Hz), 7.66 (2H, d, *J* = 8.4 Hz), 7.60 (1H, d, *J* = 9.0 Hz), 7.29 (2H, d, *J* = 8.4 Hz), 7.25 (1H, d, *J* = 9.0 Hz), 7.02 (1H, d, *J* = 9.0 Hz), 6.92 (1H, dd, *J* = 9.0, 2.4 Hz), 6.74 (2H, d, *J* = 8.8 Hz), 6.68 (1H, d, *J* = 2.4 Hz), 6.53 (2H, d, *J* = 8.8 Hz), 3.72 (3H, s), 3.70 (3H, s), 3.60 (3H, s) ppm; ^{13}C NMR δ (75 MHz, $CDCl_3$): 163.86, 158.73, 156.27, 154.96, 144.33, 138.11, 136.46, 132.80, 130.46, 129.80, 129.51, 128.64, 124.06, 121.15, 118.58, 116.85, 113.40, 109.87, 102.72, 56.11, 55.32, 55.23 ppm; HRMS (FAB; *m*-nitrobenzyl alcohol [*m*-NBA]) m/z: $[M+H]^+$; Calcd for $C_{26}H_{23}O_3NCl$, 432.1371; Found 432.1366; Anal. Calcd for $C_{26}H_{23}O_3NCl$: C 72.15%, H 5.11%. Found: C 72.30%, H 5.13%.

Imine 4

Colourless blocks ($CHCl_3$/hexane), Mp. 184–185 °C; IR (KBr) 3407, 1626, 1502, 1225, 1207, 826 cm^{-1}; ^1H NMR δ (300 MHz, $CDCl_3$): 7.71 (d, *J* = 8.8 Hz, 1H), 7.69 (d, *J* = 8.8 Hz, 2H), 7.64 (d, *J* = 8.8 Hz, 1H), 7.62 (d, *J* = 9.2 Hz, 1H), 7.53 (d, *J* = 9.2 Hz, 1H), 7.31 (d, *J* = 8.8 Hz, 2H), 7.27 (d, *J* = 8.8 Hz, 2H), 7.09 (d, *J* = 8.4 Hz, 2H), 7.03 (d, *J* = 8.8 Hz, 1H), 6.94 (dd, *J* = 2.4, 9.2 Hz, 1H), 6.87 (d, *J* = 7.6 Hz, 1H), 6.84 (d, *J* = 10.0 Hz, 2H), 6.77 (dd, *J* = 2.4, 8.6 Hz, 1H), 6.72 (m, 4H), 6.66 (d, *J* = 2.4 Hz, 1H), 6.57 (d, *J* = 9.2 Hz, 2H), 6.21 (d, *J* = 2.4 Hz, 1H), 3.76 (s, 3H), 3.69 (s, 3H), 3.64 (s, 3H), 3.20 (s, 3H) ppm; ^1H NMR δ (300 MHz, DMSO-d_6): 10.01 (s, 1H), 7.67–7.56 (m, 5H), 7.41 (d, *J* = 8.4 Hz, 2H), 6.97 (d, *J* = 8.7 Hz, 1H), 6.84–6.75 (m, 3H), 6.57 (d, *J* = 8.7 Hz, 2H), 6.46 (d, J = 2.1 Hz, 1H), 3.59 (s, 3H), 3.52 (s, 3H) ppm; ^{13}C NMR δ (75 MHz, $CDCl_3$): 169.19, 166.95, 162.91, 158.94, 157.82, 157.11, 157.01, 150.87, 143.50, 137.98, 137.64, 137.03, 135.45, 135.35, 135.20, 134.36, 133.38, 131.05, 130.68, 130.33, 129.88, 129.69, 129.24, 128.85, 124.55, 124.14, 123.72, 121.73, 118.59, 116.33, 116.15, 114.96, 114.52, 114.14, 113.84, 111.37, 106.53, 103.58, 55.45, 55.26, 55.24, 54.44 ppm; HRMS (FAB; *m*-NBA) m/z: $[M+H]^+$; Calcd for $C_{25}H_{21}O_3NCl$, 418.1162; Found 418.2110; Anal. Calcd for $C_{26}H_{23}O_3NCl$: C 71.97 %, H 4.87 %. Found: C 71.85 %, H 4.82 %

1-(4-Chlorobenzoyl)-2-hydroxy-7-methoxynaphthalene (5)

Yellow platelets (hexane), Mp. 118–118.5 °C; IR (KBr): 3434, 1623, 1583, 1513, 1214, 843 cm^{-1}; ^1H NMR δ (300 MHz, $CDCl_3$): 11.35 (s, 1H), 7.85 (d, 1H, *J* = 9.0 Hz), 7.63 (d, 1H, *J* = 9.0 Hz), 7.58 (d, 2H, *J* = 8.7 Hz), 7.40 (d, 2H, *J* = 8.7 Hz), 7.07 (d, 1H, *J* = 9.0 Hz), 6.91 (dd, 1H, *J* = 2.4, 9.0 Hz), 6.58 (d, 1H, *J* = 2.4 Hz), 3.37 (s, 3H) ppm; ^{13}C NMR δ (75 MHz, $CDCl_3$): 199.1, 162.6, 158.2, 138.8, 138.7, 136.5, 133.8, 130.7, 130.2, 128.9, 123.7, 116.4, 115.8, 113.4, 106.5, 54.5 ppm; Anal. Calcd for $C_{18}H_{13}ClO_3$: C 69.13, H 4.19. Found: C 69.11, H 4.09.

Imine 7

Colourless blocks ($CHCl_3$/hexane), Mp. 172–173 °C; IR (KBr): 3407, 2937, 2592, 1625, 1585, 1509, 1227 cm^{-1}; ^1H NMR δ (300 MHz, DMSO-d_6): 10.13, (s, 1H), 7.66–7.60 (m, 4H), 7.44 (d, 2H), 7.00 (t, 2H), 6.95 (d, H), 6.86–6.76 (m, 4H), 6.52 (d, 1H), 3.64 (s, 3H), 3.29 (s, 6H) ppm; ^{13}C NMR δ (75 MHz, DMSO-d_6): 164.4, 158.2, 153.7, 151.0, 137.6, 135.7, 132.2, 130.3, 130.0, 129.7, 128.7, 128.2, 123.8, 122.9, 119.2, 115.1, 115.0, 114.9, 102.6, 55.1, 47.3 ppm; HRMS (FAB; *m*-NBA) m/z: $[M+H]^+$; Calcd for $C_{24}H_{19}ClNO_2$, 388.1110; Found, 388.1104.

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