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KF-alumina-mediated Bargellini reaction

Md. Rumum Rohman, Bekington Myrboh *

Department of Chemistry, North-Eastern Hill University, Mawlai-Mawkynroh, Shillong 793 022, India

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KF-alumina was found to be an efficient base for the synthesis of sterically hindered α-substituted carboxylic acids. A series of Bargellini reactions were performed by using various substituted anilines, phenols, and thiophenols as nucleophiles with ketones in the presence of chloroform and KF-alumina as a base. All the compounds were fully characterized.

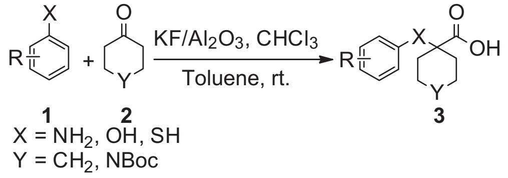
Bargellini reaction provides a multi component, atom efficient synthesis of molecules with significantly increased complexity, diversity, and functionality. The condensation of phenols with chloroform and acetone in the presence of sodium hydroxide to give α-phenoxyisobutyric acids was first reported by Bargellini.[1] The application of Bargellini reaction includes the preparation of griseofulvin analogs by Korger.[2a] Recently, Butcher and Hurst reported an important extension of the Bargellini reaction for the synthesis of drugs in the pharmaceutical industry.[2b]

Although, there are number of methods reported for the Bargellini reaction using different nucleophiles other than phenols, for example, (i) potassium amide and sodium azide,[3] (ii) aromatic amines as nucleophile,[2b] however, in all these reported methods either sodium or potassium hydroxide was used as a base. To our knowledge there is no method reported with an alternative base. Therefore, there is still scope for the development of a better alternative method which might proceed under mild, environmentally benign, and clean reaction condition.

In recent years, the use of inorganic solid-supported regents has become popular due to their characteristic properties such as enhanced reactivity and selectivity, a straight forward work-up procedure and milder reaction conditions.[4] Among these inorganic solid supports, potassium fluoride coated with alumina (KF/Al_2O_3) has been used extensively because of its easy accessibility and strong basic nature. KF/Al_2O_3 derives its basicity from the formation of KOH in the initial preparation of the solid-supported material by the reaction of KF with alumina support.[5] Some of the reported reactions which use the KF/Al_2O_3 combination include the Knoevenagel condensation,[6a] the Henry reaction,[6b] the Darzens reaction,[6c] the Wittig reaction,[6d] the Biginelli reaction,[7] alkylation,[8] and elimination reaction.[9] Therefore, we decided to use KF/Al_2O_3 as a base and/or a source for the $^{-}$OH ion in the Bargellini reaction in combination with chloroform as a source of carbon for the incorporation of the carboxylic group.

Herein, we report on a convenient KF/Al_2O_3-promoted Bargellini reaction from cyclic ketones and various nucleophiles such as substituted aniline, phenols, and thiophenols under mild reaction conditions (Scheme 1).

In the preliminary experiment, the reaction of **1a** with chloroform in the presence of KF/Al_2O_3 in ethanol proceeded slow and afforded the product in a very low yield, while the reaction in toluene led to the formation of the desired compound **3a** in high yield. For example, when 3-chloroaniline (**1a**) (2 mmol) was treated with cyclohexanone (**2a**) (6 mmol) in the presence of chloroform (8 mmol) and KF/Al_2O_3 (6 g, 40% KF in Al_2O_3) as a base in dry toluene, **3a** was obtained in 91% yield. A number of substituted aromatic anilines (**1b**–**f**) were reacted with cyclohexanone to demonstrate the generality of the reaction in presence of KF/Al_2O_3. Similarly, the reaction of nucleophile **1a** with the *N*-^{t}butyloxycarbonyl-protected piperidone (**2g**) in the presence of KF/Al_2O_3 underwent smoothly in 12 h giving product **3g** with a very high purity. The



Scheme 1.

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* Corresponding author. Tel.: +91 364 2722612; fax: +91 364 2228213.
E-mail address: bmyrboh@nehu.ac.in (B. Myrboh).

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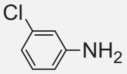
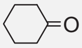
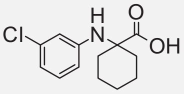
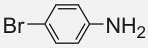
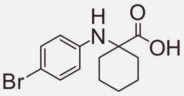
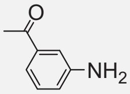
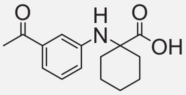
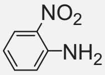
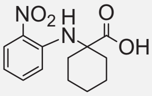
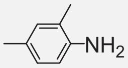
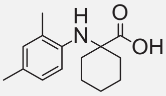
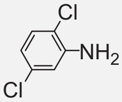
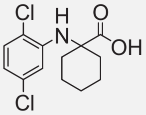
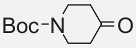
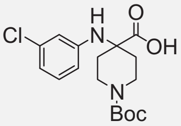
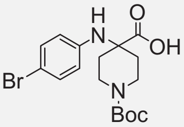
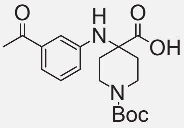
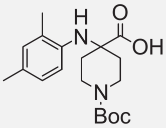
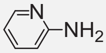
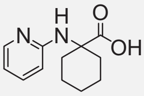
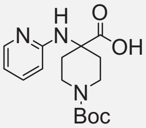
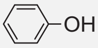
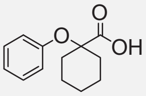
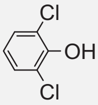
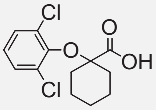
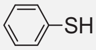
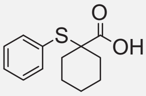
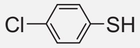
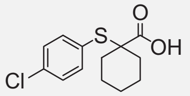
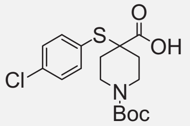
Table 1
KF/Al_2O_3 assisted Bargellini reaction of anilines, phenols, thiophenols via Scheme 1

Entry	Substrate **1**	Substrate **2**	Product **3**[b]	Yield[a] (%)
a				91
b		**2a**		65
c		**2a**		56
d		**2a**		58
e		**2a**		90
f		**2a**		78
g	**1a**			72
h	**1b**	**2g**		58
i	**1c**	**2g**		60
j	**1e**	**2g**		73
k		**2a**		68
l	**1k**	**2g**		75
m		**2a**		67[c]
n		**2a**		75[c]
o		**2a**		73

(*continued on next page*)

Table 1 (*continued*)

Entry	Substrate **1**	Substrate **2**	Product **3**[b]	Yield[a] (%)
p		**2a**		80
q	**1p**	**2g**		65

[a] Isolated yields.

[b] Products have been characterized by recording IR, ^{1}H NMR and ^{13}C NMR.

[c] THF as a solvent.

present procedure was then employed for the condensation of various substituted anilines (entries **1h**–**j**, Table 1) and *N*-^{t}butyloxycarbonyl-protected piperidone (**2g**) to give the corresponding Bargellini compounds (**3h**–**j**) in good to excellent yields.

In order to test the scope of KF/Al_2O_3 base, we treated heterocyclic nucleophile 2-aminopyridine (**1k**) with **2a** and **2g**, which successfully resulted in the formation of compound **3k** and **3l** in 68% and 75% yield, respectively. Furthermore, this method is extended to phenols and thiophenols (**1m**–**q**) to furnish the desired products (**3m**–**q**) and the results are summarized in Table 1.[11] It may be noted that the reactions of substrates **1m** and **1n** with compound **2a** afforded the products **3m** and **3n**, respectively, in poor yields in dry toluene whereas the same reactions in tetrahydrofuran as solvent afforded **3m** and **3n** in good yields. This may be due to the insolubility of the starting phenols (**1m**–**n**). All the products were confirmed by IR, ^{1}H, and ^{13}C NMR spectral studies (Table 1).[12] It is important to highlight that the compounds **3m**–**n** were obtained from **1m–n** in 67% and 75% yield, respectively, while the substituted phenols were reported to give low yields with **2a** and **2g** by using NaOH base thus indicating that the present protocol is much more effective.[2b]

It is noteworthy to mention that there is no side reaction observed for the nucleophile having the keto group (entries c and i); also the use of KF/Al_2O_3 as a base is tolerated in the presence of other functional groups while the protecting group *N*-^{t}butyloxycarbonyl is not affected under the experimental conditions.

Although the mechanistic details remain ambiguous, the KF/Al_2O_3-promoted reaction might proceed through deprotonation of chloroform followed by nucleophilic attack on the ketone yielding dichloro epoxide. The N–C bond is formed via the opening of dichloro epoxide by the nucleophile to give an acid chloride. Subsequently, the hydrolysis of the acid chloride would lead to the formation of the desired compound.

In summary, KF/Al_2O_3 was found to be a useful solid support base for the Bargellini reaction which is an important alternative to the Strecker reaction.[10] The present KF/Al_2O_3-promoted Bargellini reaction introduces the use of an alternative base and provides a simple procedure and good yields under mild reaction conditions.

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11. *General experimental procedure*: To a solution of nucleophiles (2 mmol) in dry toluene, KF/Al_2O_3 (4.5–6 g, 40% by weight) *N*-^{t}butyloxycarbonyl-4-piperidone or cyclohexanone (6 mmol) was added. Then, chloroform (8 mmol) was added drop wise over a period of 45 min at room temperature. The resulting reaction mixture was stirred at the same temperature under nitrogen atmosphere for 10–16 h. The reaction mixture was diluted with water (5 mL) and filtered through a celite bed. The residue was washed thoroughly with water (3 × 5 mL). The combined filtrate was separated and the aqueous layer was washed with diethyl ether (2 × 10 mL). The aqueous layer was acidified to ~pH 3 with aqueous HCl (3 N) and extracted with ethyl acetate (3 × 10 mL). The combined ethyl acetate extract was washed with brine (15 mL) and dried over anhydrous Na_2SO_4. The organic layer was filtered and evaporated in vacuo to obtain a solid compound. In some cases the solid compound obtained was further purified by crystallization or by silica gel (60–120 mesh) column chromatography using ethyl acetate and hexane eluents.
12. *Spectroscopic data for compound* (**3a**): Off white solid; mp 100–103 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.43–2.05 (m, 10H), 5.59 (br, s, 1H), 6.73 (d, 1H, *J* = 7.6 Hz), 6.86 (s, 1H), 6.91 (d, 1H, *J* = 7.6 Hz), 7.13 (t, 1H, *J* = 8.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 20.95, 24.96, 32.22, 58.55, 112.07, 112.55, 115.08, 130.05, 133.13, 148.01, 176.90; IR (KBr): 3402, 3269, 3069, 2956, 2936, 2920, 2878, 2855, 1706, 1595, 1521, 1479, 1466, 1453, 1418, 1366, 1314, 1301, 1270, 1227 cm^{-1}. MS (AP+) calcd for $C_{13}H_{16}ClNO_2$ 253.09, found *m/z* 253.9 $[M+H]^+$; CHN analysis for $C_{13}H_{16}ClNO_2$; Theoretical calcd: C, 61.54; H, 6.36; Cl, 13.97; N, 5.52; O, 12.61; Found: C, 61.73; H, 6.27; N, 5.40. *Compound* (**3b**): Light yellow solid; mp 120–122 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.30–1.90 (m, 10H), 6.52 (d, 2H, *J* = 8.4 Hz), 6.75 (br, s, 1H), 7.20 (d, 2H, *J* = 8.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 21.20, 24.97, 32.07, 61.24, 112.56, 118.50, 132.03, 142.11, 178.96; IR (KBr): 3434, 2942, 2927, 2857, 1697, 1593, 1499, 1460, 1444, 1321, 1288, 1254, 1167 cm^{-1}; CHN analysis for $C_{13}H_{16}BrNO_2$; Theoretical calcd: C, 52.36; H, 5.41; Br, 26.80; N, 4.70; O, 10.73; Found: C, 52.66; H, 5.30; N, 4.55. *Compound* (**3c**): Light yellowish white solid; mp 120–123 °C (uncorrected); ^{1}H NMR

(400 MHz, CDC_{l3}): δ = 1.14–1.82 (m, 10H), 2.30 (s, 3H), 6.66 (d, 1H, *J* = 6.8 Hz), 7.02 (t, 1H, *J* = 7.6 Hz), 7.10 (s, 1H) 7.16 (d, 1H, *J* = 7.6 Hz); ^{13}C NMR (100 MHz, CDC_{l3}): δ = 22.10, 25.91, 27.53, 33.08, 61.91, 116.99, 121.06, 121.77, 130.29, 138.84, 144.61, 179.84, 199.48; IR (KBr): 3548, 3476, 3415, 3249, 2999, 2962, 2950, 2933, 2857, 1689, 1601, 1588, 1515, 1484, 1451, 1418, 1360, 1314, 1272, 1223, 1209, 1158, 1140, 887, 810 cm^{-1}; MS (AP+) calcd for $C_{15}H_{19}NO_3$ 261.14, found *m*/*z* 262.2 [M+H]$^+$; CHN analysis $C_{15}H_{19}NO_3$; Theoretical calcd: C, 68.94; H, 7.33; N, 5.36; O, 18.37; Found: C, 69.19; H, 7.18; N, 5.25. *Compound* (**3d**): Yellow solid; mp 124–127 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.30–2.24 (m, 10H), 6.63 (d, 1H, *J* = 8.8 Hz), 6.71 (t, 1H, *J* = 7.6 Hz), 7.37 (t, 1H, *J* = 8 Hz), 8.22 (d, 1H, *J* = 8.4 Hz), 8.47 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 20.99, 24.99, 32.55, 59.78, 115.48, 116.35, 127.34, 133.11, 135.71, 142.95, 180.43; IR (KBr): 3551, 3476, 3414, 3391, 3235, 2942, 2864, 2650, 1707, 1615, 1576, 1504, 1444, 1423, 1348, 1328, 1300, 1268, 1248, 1196, 1164 cm^{-1}; CHN analysis for $C_{13}H_{16}N_2O_4$; Theoretical calcd: C, 59.08; H, 6.10; N, 10.60; O, 24.22; Found: C, 59.18; H, 6.01; N, 10.55. *Compound* (**3e)** Light brown solid; mp 70–73 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.19–2.32 (m, 13 H), 2.39 (s, 3H), 6.39 (d, 1H, *J* = 8.0 Hz), 6.83–7.30 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 17.48, 17.71, 20.59, 21.41, 25.28, 31.72, 60.76, 115.26, 124.35, 127.45, 131.33, 131.79, 139.17, 178.84; IR (KBr): 3548, 3416, 3236, 2965, 2924, 2857, 1710, 1637, 1618, 1589, 1560, 1514, 1454, 1389, 1353, 1314, 1287 cm^{-1}; MS (ES+) calcd for $C_{15}H_{21}NO_2$ 247.16, found *m*/*z* 248.0 [M+H]$^+$; CHN analysis for $C_{15}H_{21}NO_2$; Theoretical calcd: C, 72.84; H, 8.56; N, 5.66; O, 12.94; Found: C, 72.79; H, 8.65; N, 5.72. *Compound* (**3f**): Yellow sticky solid; ^{1}H NMR (400 MHz, DMSO-d_6): δ = 1.43–2.12 (m, 10H), 4.96 (s, 1H), 6.47 (d, 1H, *J* = 2.4 Hz), 6.68 (d, 1H, *J* = 8.8 Hz), 7.33 (d, 1H, *J* = 8.4 Hz), 12.60 (br, s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 20.97, 25.05, 32.03, 62.93, 114.08, 118.52, 118.92, 130.04, 133.20, 141.40, 179.63; IR ($CHCl_3$): 3424, 3018, 2940, 2861, 1709,1709, 1593, 1509, 1451, 1415, 1278, 1215, 1156, 1082 cm^{-1}; MS (AP+) calcd for $C_{13}H_{15}Cl_2NO_2$ 287.05, found *m*/*z* 288.0 [M+H]$^+$; CHN analysis for $C_{13}H_{15}Cl_2NO_2$; Theoretical calcd: C, 54.18; H, 5.25; Cl, 24.61; N, 4.86; O, 11.10; Found: C, 54.49; H, 5.06; N, 4.43. *Compound* (**3g**): Yellowish white solid; 118–121 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.45 (m, 9H), 2.01–2.18 (m, 4H), 3.42–3.58 (m, 4H), 4.31 (br, s, 1H), 6.71 (m, 1H), 6.83 (s, 1H), 6.89 (d, 1H, *J* = 7.2 Hz), 7.13 (t, 1H, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, DMSO-d_6): δ = 27.99, 57.12, 78.73, 112.19, 112.75, 115.66, 130.23, 133.23, 147.73, 153.84, 176.01; IR (KBr): 3551, 3475, 3415, 3347, 2978, 2927, 2871, 2855, 1699, 1662, 1638, 1618, 1596, 1485, 1408, 1368, 1328, 1291, 1253, 1174, 1159 cm^{-1}; CHN analysis for $C_{17}H_{23}ClN_2O_4$; Theoretical calcd: C, 57.54; H, 6.53; Cl, 9.99; N, 7.89; O, 18.04; Found: C, 57.73; H, 6.46; N, 6.02. *Compound* (**3h**): See Ref. 2b. *Compound* (**3i**): White solid; mp 110–113 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.45 (s, 9H), 1.97–1.99 (m, 2H), 2.12–2.14 (m, 2H), 2.53 (s, 3H), 3.26 (t, 2H, *J* = 10.4 Hz), 3.73–3.75 (m, 2H), 5.98 (br, s, 1H), 6.82 (d, 1H, *J* = 6.8 Hz), 7.21–7.35 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 26.82, 28.58, 32.56, 46.52, 58.59, 80.43, 115.13, 119.67, 120.32, 129.61, 138.18, 145.16, 155.10, 178.05, 199.04; IR (KBr): 3552, 3478, 3414, 3356, 3237, 2982, 2929, 1686, 1677, 1639, 1617, 1603, 1591, 1479, 1453, 1417, 1367, 1325, 1281, 1247, 1161 cm^{-1}; CHN analysis for $C_{19}H_{26}N_2O_5$; Theoretical calcd: C, 62.97; H, 7.23; N, 7.73; O, 22.07; Found: C, 63.37; H, 7.00; N, 7.69. *Compound* (**3j**): Off white solid; mp 120–123 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.45 (s, 9H), 1.99–2.17 (m, 4H), 2.19 (s, 3H), 2.22 (s, 3H), 3.17 (t, 2H, *J* = 8.0 Hz), 3.79 (m, 2H), 6.23 (br, s, 1H), 6.43 (d, 1H, *J* = 8.0 Hz), 6.85 (d, 1H, *J* = 7.6 Hz), 6.92 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 17.87, 20.54, 28.58, 32.36, 39.71, 58.38, 80.28, 114.31, 124.90, 127.29, 128.81, 131.81, 139.48, 154.97, 179.34; IR (KBr): 3552, 3480, 3415, 3363, 3236, 2978, 2930, 2870, 1702, 1677, 1638, 1619, 1521, 1454, 1408, 1367, 1316, 1282, 1248, 1160, 1131 cm^{-1}; CHN analysis for $C_{19}H_{28}N_2O_4$; Theoretical calcd: C, 65.49; H, 8.10; N, 8.04; O, 18.37; Found: C, 65.29; H, 8.05; N, 8.13. *Compound* (**3k**): Off white solid; mp 135–137 °C; ^{1}H NMR (400 MHz, CD_3OD): δ = 1.40–2.02 (m, 10H), 6.73 (t, 1H, *J* = 6.4 Hz), 6.87 (d, 1H, *J* = 8.8 Hz), 7.64–7.68 (m, 1H), 7.92 (d, 1H, *J* = 5.2 Hz); ^{13}C NMR (100 MHz, CD_3OD): δ = 22.81, 26.59, 33.88, 62.72, 113.80, 113.84, 141.35, 141.51, 156.67, 179.21; IR (KBr): 3237, 3154, 3122, 3089, 2945, 2922, 2858, 2848, 1672, 1634, 1609, 1541, 1460, 1446, 1384, 1337, 1297, 1272, 1252 cm^{-1}; MS (AP+) calcd for $C_{12}H_{16}N_2O_2$ 220.12, found *m*/*z* 221.9 [M+H]$^+$; CHN analysis for $C_{12}H_{16}N_2O_2$; Theoretical calcd: C, 65.43; H, 7.32; N, 12.72; O, 14.53; Found: C, 65.63; H, 7.17; N, 12.85. *Compound* (**3l**): Off white solid; mp 120–122 °C; ^{1}H NMR (400 MHz, CD_3OD): δ = 1.36 (s, 9H), 2.06–1.94 (m, 4H), 3.20–3.21 (m, 2H), 3.56–3.62 (m, 2H), 6.58 (t, 1H, *J* = 6.4 Hz), 6.69 (d, 1H, *J* = 8.4 Hz), 7.46–7.50 (m, 1H), 7.83 (d, 1H, *J* = 4.8 Hz); ^{13}C NMR (100 MHz, CD_3OD): δ = 20.81, 28.69, 33.50, 60.25, 81.21, 113.03, 114.12, 140.45, 143.47, 156.44, 157.32, 175.29, 178.21; IR (KBr): 3413, 3272, 3118, 2980, 2938, 2858, 1702, 1672, 1637, 1614, 1539, 1481, 1412, 1394, 1376, 1283, 1249, 1154 cm^{-1}; MS (ES+) calcd for $C_{16}H_{23}N_3O_4$ 321.17, found *m*/*z* 322.2 [M+H]$^+$; CHN analysis for $C_{16}H_{23}N_3O_4$: Theoretical calcd: C, 59.80; H, 7.21; N, 13.08; O, 19.91; Found: C, 60.10; H, 7.11; N, 13.23. *Compound* (**3m**): White solid; mp 84–87 °C (uncorrected); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.35–2.20 (m, 10H), 6.90–7.29 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 20.45, 24.44, 31.56, 79.50, 118.16, 121.68, 128.78, 153.97, 178.39; IR (KBr): 3552, 3477, 3416, 3237, 2929, 2857, 1703, 1638, 1618, 1597, 1495, 1449, 1406, 1292, 1269, 1227, 1146 cm^{-1}; CHN analysis for $C_{13}H_{16}O_3$: Theoretical calcd: C, 70.89; H, 7.32; O, 21.79; Found: C, 70.47; H, 7.39. *Compound* (**3n**): White solid; mp 54–57 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.55–2.00 (m, 10H), 6.97 (t, 1H, *J* = 8.0 Hz), 7.28 (d, 2H, *J* = 8.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 21.42, 25.38, 26.83, 27.09, 78.98, 125.09, 129.09, 129.83, 180.10; IR (KBr): 3552, 3473, 3413, 3072, 2938, 2876, 2667, 1709, 1638, 1617, 1564, 1469, 1446, 1407, 1381, 1287, 1273, 1248, 1216, 1192, 1160,1084, 1060, 1043, 1004 cm^{-1}; MS (ES+) calcd for $C_{13}H_{14}Cl_2O_3$ 288.03, found *m*/*z* 288.4 [M+H]$^+$; CHN analysis for $C_{13}H_{14}Cl_2O_3$: Theoretical calcd: C, 54.00; H, 4.88; Cl, 24.52; O, 16.60; Found: C, 54.30; H, 4.97. *Compound* (**3o**): White crystalline solid; mp 50–53 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.35–2.11 (m, 10H), 7.30–7.52 (m, 5H), 9.20 (br, s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 23.50, 25.22, 33.83, 55.34, 128.67, 129.54, 130.13, 136.98, 179.06; IR (KBr): 3414, 3070, 2968, 2937, 2855, 1694, 1639, 1473, 1451, 1438, 1406, 1306, 1286, 1264, 1253, 1242 cm^{-1}; MS (ES+) calcd for $C_{13}H_{16}O_2S$ 236.09, found *m*/*z* 236.8 [M+H]$^+$; CHN analysis for $C_{13}H_{16}O_2S$: Theoretical calcd: C, 66.07; H, 6.82; O, 13.54; S, 13.57; Found: C, 66.37; H, 6.69. *Compound* (**3p**) White solid; mp 109–112 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.35–2.10 (m, 10H), 7.29 (d, 2H, *J* = 8.4 Hz), 7.43 (d, 2H, *J* = 8.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 23.48, 25.15, 33.80, 55.48, 128.66, 128.95, 136.13, 138.14, 178.40; IR (KBr): 3552, 3477, 3414, 3230, 2960, 2935, 2857, 1724, 1688, 1638, 1617, 1574, 1474, 1448, 1387, 1285, 1279, 1216, 1183, 1152, 1130, 1090, 1013, 815 cm^{-1}; MS (ES+) calcd for $C_{13}H_{15}ClO_2S$ 270.05, found *m*/*z* 271.2 [M+H]$^+$; CHN analysis for $C_{13}H_{15}ClO_2S$: Theoretical calcd: C, 57.66; H, 5.58; Cl, 13.09; O, 11.82; S, 11.84; Found: C, 57.86; H, 5.47. *Compound* (**3q**): White solid; mp 148–151 °C (uncorrected); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.46 (s, 9H), 1.74–1.80 (m, 2H), 2.05–2.09 (m, 2H), 3.14–3.20 (m, 2H), 3.79–3.82 (m, 2H), 7.31 (d, 2H, *J* = 8.4 Hz), 7.42 (d, 2H, *J* = 8.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 28.40, 32.69, 53.58, 80.12, 127.76, 129.19, 136.54, 138.16, 154.71, 176.78; IR (KBr): 3547, 3416, 3006, 2972, 2921, 2865, 2750, 2661, 1714, 1631, 1477, 1462, 1444, 1390, 1368, 1344, 1293, 1265, 1226, 1166, 1092, 1023, 1014, 823 cm^{-1}; MS (ES+) calcd for $C_{17}H_{22}ClNO_4S$ 371.10, found *m*/*z* 372.3 [M+H]$^+$; CHN analysis for $C_{17}H_{22}ClNO_4S$: Theoretical calcd: C, 54.91; H, 5.96; Cl, 9.53; N, 3.77; O, 17.21; S, 8.62; Found: C, 55.45; H, 6.10; N, 3.64.