# $BiCl_3$-catalysed nucleophilic substitution of Baylis–Hillman adducts with alcohols

**Jian Li, Xiaotao Liu, Peichao Zhao and Xueshun Jia***

*Department of Chemistry, Shanghai University, Shanghai 200444, P.R. China*

An efficient nucleophilic substitution of Baylis–Hillman adducts with alcohols catalysed by 10 mol% $BiCl_3$, affords functionalised ethers. Water was the only side product.

**Keywords:** Baylis–Hillman adduct, nucleophilic substitution, alcohol, functionalised ether, $BiCl_3$

The Morita–Baylis-Hillman (MBH) reaction is a powerful carbon–carbon bond-forming method in organic synthesis.[1-3] The MBH reaction generates molecules possessing hydroxy, alkenyl, and electron-withdrawing groups in close proximity, making it valuable in a number of stereoselective transformation processes[4-8] including the syntheses of biologically active molecules and natural products.[9-14] However, the acetates of the Baylis–Hillman adducts are predominantly used in these transformations since the direct substitution of hydroxyl group of Baylis–Hillman adducts is usually difficult. Recently, Trost *et al.* have described an efficient intramolecular nucleophilic substitution of Baylis–Hillman acetates catalysed by $(Pd(\pi\text{-allyl})Cl)_2$ in the presence of additive $N(Hex)_4Cl$.[15] However, the complex methodology and the high cost of the catalyst are a barrier to its large-scale application. These processes inevitably produce a stoichiometric amount of acetic acid as waste. Moreover, most transformations occurred at the alkenyl carbon to give linear products.[16-28] As a result, the direct use of Baylis–Hillman alcohols in organic synthesis without acetylation continues to be a challenge and the development of a general, efficient, and readily available catalyst for the nucleophilic substitution of Baylis–Hillman adducts is highly desirable. We continue to be interested in exploring the versatility of alcohols as nucleophiles in the conversion of Baylis–Hillman adducts.[29-31] We now report an efficient and selective substitution of unmodified Baylis–Hillman adducts with alcohols catalysed by $BiCl_3$ to afford functionalised ethers (Scheme 1).

Our initial experiment was carried out with the Baylis–Hillman adduct **1a** and methanol as model substrates in the presence of $BiCl_3$. The substitution reaction proceeded smoothly under reflux with acetonitrile as solvent. As expected, both the corresponding substitution product **3aa** (61%) and its linear isomer **4aa** (28%) were isolated. A series of experiments were then conducted to achieve the optimal conditions. We found that only 10 mol% $BiCl_3$ was sufficient to promote the conversion without the exclusion of moisture or air from the reaction mixture. On the other hand, the substitution reaction showed a remarkable solvent effect. For instance, when 1, 4-dioxan was used as the solvent, no reaction occurred even under reflux, while the DMF gave a very complicated mixture. The optimal reaction condition was finally confirmed. Subsequently, various structurally diverse alcohols were treated with the MBH adduct **1a** under these conditions (Table 1, entries 1–7). All the reactions proceeded smoothly and finished within 10 hours. The conversion showed good regioselectivity and the substitution products **3** were obtained as the major product.

A variety of Baylis–Hillman adducts were screened to test the scope of the reaction. The results were summarised in Table 1.[32] In most cases, the substitution reactions catalysed by $BiCl_3$ worked well under the optimal conditions. However, the reaction of Baylis–Hillman adducts with electron-withdrawing groups proceeded quite slowly (Table 1, entries 20–22). In particular, 4-nitro substituted Baylis–Hillman adducts did not react with alcohols even after 72 h under reflux. In addition, the 2-chloro substituted Baylis–Hillman adduct was sterically hindered and the substrate was recovered completely after 48 hours.

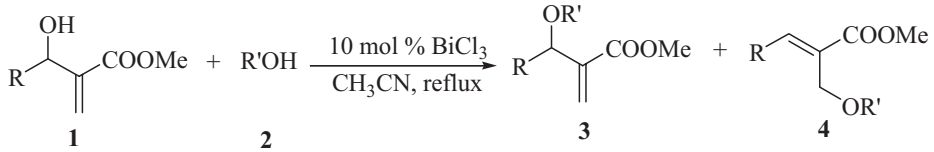
With regard to the mechanism, we believe that the presence of $BiCl_3$ facilitates the substitution of the hydroxyl group in Baylis–Hillman adducts. A related carbon cation intermediate may be involved, and further studies on details of mechanism are underway in our laboratory.

In summary, we have developed a general and efficient method for the nucleophilic substitution of Baylis–Hillman adducts with alcohols using Bismuth (III) catalyst. This protocol allowed the efficient syntheses of many functionalised ethers. Typically the reactions proceeded under mild conditions in the absence of strong acid or base and could be carried out in the presence of moisture. Finally this conversion was also a green method since water is the only side product.

## Experimental

$^1H$ NMR spectra were measured in $CDCl_3$ on a Brucker AC – 500 (500 MHz) spectrometer with TMS as the internal standard. $^{13}C$ NMR spectra were measured in $CDCl_3$ on a Brucker AC – 125(125 MHz) spectrometer with TMS as the internal standard. IR spectra were measured with a Perkin Elmer FT-IR-1600 spectrometer. Mass spectra were determined with a HP 5989A mass spectrometer. Elemental analyses were performed on Elemantar Vario EL instrument.

*General procedure:* Alcohol **2 (**3 mmol) and $BiCl_3$ (10 mol%) 30 mg was added to a stirred solution of Baylis–Hillman adduct **1** (1 mmol) in $CH_3CN$ (2 ml). The resulting mixture was allowed to react under reflux until the reaction was complete. Subsequently, 0.1 M HCl (2 ml) was added to quench the reaction which was then extracted with $CH_2Cl_2$ (5 ml × 3). The organic phase was washed with saturated brine (5 ml), water (5 ml) and dried over anhydrous $Na_2SO_4$. The solution was filtered and the solvent was removed under reduced

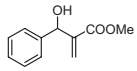
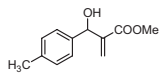
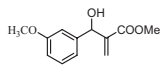
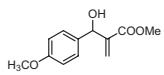
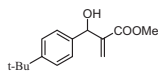
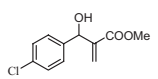



**1** **2** **3** **4**

**Scheme 1**

* Correspondent. E-mail: xsjia@mail.shu.edu.cn

**Table 1** $BiCl_3$-catalysed nucleophilic substitution of Baylis–Hillman adducts

| Entry | Baylis–Hillman Adduct **1** | Alcohol **2** | Time/h | Isolated yield/% **3** | **4** (E:Z)[a] |
|---|---|---|---|---|---|
| 1 | | $CH_3OH$ **2a** | 10 | 61 | 28 (1.5:1) |
| 2 | | $C_2H_5OH$ **2b** | 10 | 52 | 33 (3:1) |
| 3 | |  **2c** | 10 | 48 | 30 (3.3:1) |
| 4 |  |  **2d** | 10 | 25 | 11 (3.3:1) |
| 5 | **1a** |  **2e** | 10 | 47 | 29 (3.1:1) |
| 6 | |  **2f** | 10 | 46 | 27 (3.3:1) |
| 7 | |  **2g** | 6 | 56 | 32 (4:1) |
| 8 |  | $C_2H_5OH$ | 0.5 | 51 | 41 (3:1) |
| 9 | |  | 0.5 | 47 | 21 (3:1) |
| 10 | **1b** |  | 0.5 | 62 | 31 (5:1) |
| 11 |  | $C_2H_5OH$ | 2 | 49 | 39 (>99:1) |
| 12 | |  | 2 | 47 | 20 (>99:1) |
| 13 | **1c** |  | 2 | 50 | 29 (>99:1) |
| 14 |  | $C_2H_5OH$ | 5 min | 52 | 39 (4:1) |
| 15 | |  | 5 min | 48 | 32 (6:1) |
| 16 | **1d** |  | 5 min | 54 | 36 (>99:1) |
| 17 |  | $C_2H_5OH$ | 0.5 | 53 | 41 (3:1) |
| 18 | |  | 0.5 | 45 | 28 (3:1) |
| 19 | **1e** |  | 0.5 | 55 | 38 (3:1) |
| 20 |  | $C_2H_5OH$ | 24 | 25 | 44 (3.3:1) |
| 21 | |  | 24 | 27 | 15 (3.3:1) |
| 22 | **1f** |  | 24 | 29 | 48 (3.3:1) |

[a]The ratio was mainly determined by $^1H$ NMR data.

pressure to give the crude products, which were purified by column chromatography using ethyl acetate and petroleum ether (1:10) as eluent.

The products were identified by IR, $^1H$ and $^{13}C$ NMR, mass spectra and elemental analyses. The stereoselectivity was determined on the basis of the olefin proton signal which was also used to establish the ratio. Generally, the *E*-isomer appears downfield while the *Z*-isomer usually appears upfield.[32]

**3aa**: Oil. $^1H$ NMR (500 MHz, $CDCl_3$) δ (ppm): 7.36–7.26 (m, 5H), 6.34 (t, 1H, *J* = 1.0 Hz), 5.94 (t, 1H, *J* = 1.5 Hz), 5.13 (s, 1H), 3.70 (s, 3H), 3.32 (s, 3H); $^{13}C$ NMR (500 $MH_z$, $CDCl_3$) δ (ppm):166.46, 141.19, 139.57, 128.47, 128.05, 127.67, 125.06, 81.09, 57.20, 51.95; HRMS(EI) *m/z* Calcd for $C_{12}H_{14}O_3$ 206.0943; Found:206.0937.

**4aa**: Oil. $^1H$ NMR (500 MHz, $CDCl_3$) δ (ppm): 7.94 (s, 1H), 7.53–7.50 (m, 2H), 7.44–7.39 (m, 3H), 4.24 (s, 2H), 3.85 (s, 3H), 3.44 (s, 3H); $^{13}C$ NMR (500 $MH_z$, $CDCl_3$) δ (ppm): 168.27, 144.95, 134.86, 129.98, 129.55, 128.76, 128.70, 66.69, 58.48, 52.38; IR (film)/$cm^{-1}$: 2949, 1715, 1631, 1091, 769, 698. Anal: Calcd. for $C_{13}H_{16}O_3$ C, 69.88; H, 6.84; Found C, 70.03; H, 6.95%

**3ab**: Oil. $^1H$ NMR (500 MHz, $CDCl_3$) δ (ppm): 7.36–7.24 (m, 5H), 6.32 (t, 1H, *J* = 1.0 Hz), 5.93 (t, 1H, *J* = 1.5 Hz), 5.25 (s, 1H), 3.69 (s, 3H), 3.51–3.43 (q, 2H, *J* = 6.0 Hz), 1.20 (t, 3H, *J* = 7.5 Hz); Anal: Calcd. for $C_{13}H_{16}O_3$ C, 70.89; H, 7.32; Found C, 70.72; H, 7.35%.

**4ab**: Oil. $^1H$ NMR (500 MHz, $CDCl_3$) δ (ppm): 7.93 (s, 1H), 7.55–7.54 (m, 2H), 7.43–7.38 (m, 3H), 4.28 (s, 2H), 3.84 (s, 3H), 3.61 (q, 2H, *J* = 7.0 Hz), 1.27 (t, 3H, *J* = 7.5 Hz). IR (film)/$cm^1$: 2975, 2951, 2873, 1716, 1632, 1574, 769, 699; Anal: Calcd. for $C_{13}H_{16}O_3$ C, 70.89; H, 7.32; Found C, 70.81; H, 7.22%.

**3ac**: Oil. IR(film)/cm 2972, 1724, 1630, 1378, 1060, 760, 703; $^1H$ NMR (500 MHz, $CDCl_3$) δ (ppm): 7.36–7.25 (m, 5H), 6.31–6.30 (t, 1H, *J* = 1.0 Hz), 5.90 (t, 1H, *J* = 1.5 Hz), 5.38 (s, 1H), 3.70 (s, 3H), 3.64–3.57 (m, 1H), 1.20 (d, 3H, *J* = 6.0 MHz), 1.14 (d, 3H, *J* = 6.5 Hz); $^{13}C$ NMR (500 $MH_z$, $CDCl_3$) δ (ppm): 166.69, 142.51, 140.71, 128.38, 127.77, 127.67, 125.47, 76.35, 69.86, 51.88, 22.83, 21.95; Anal: Calcd. for $C_{14}H_{18}O_3$ C, 71.77; H, 7.74. Found C, 71.82; H, 7.60%.

**4ac**: Oil. IR(KBr)/$cm^{-1}$: 2971, 2876, 1717, 1633, 1575, 1117, 768, 698; $^1H$ NMR (500 MHz, $CDCl_3$) δ (ppm): 7.91 (s, 1H), 7.58–7.36 (m, 5H), 4.28 (s, 2H), 3.84 (s, 3H), 3.76–3.70 (m, 1H), 1.25 (d, 3H, *J* = 6.0 Hz), 1.20 (d, 3H, *J* = 6.0 Hz). Anal: Calcd. for $C_{14}H_{18}O_3$ C, 71.77; H, 7.74. Found C, 71.65; H, 7.56%.

**3ad**: Oil. IR (film)/$cm^{-1}$: 2975, 1723, 1629, 1492, 702; $^1H$ NMR (500 MHz, $CDCl_3$) δ (ppm): 7.36–7.19 (m, 5H), 6.28 (q, 1H, *J* = 1.0 Hz), 6.02 (t, 1H, *J* = 1.5 Hz), 5.48 (s, 1H), 3.69 (s, 3H), 1.19 (s, 9H). Anal: Calcd. for $C_{15}H_{20}O_3$ C, 72.55; H, 8.12. Found C, 72.46; H, 8.02%.

**4ad**: Oil. IR(KBr)/$cm^{-1}$: 2958, 1718, 1635, 1061, 759, 697; $^1H$ NMR (500 MHz, $CDCl_3$) 7.90 (s, 1H), 7.62–7.31 (m, 5H), 4.23 (s, 2H), 3.82 (s, 3H), 1.30 (s, 9H). Anal: Calcd. for $C_{15}H_{20}O_3$ C, 72.55; H, 8.12. Found C, 72.49; H, 8.03%.

**3ae**: Oil. IR (film)/$cm^{-1}$:2956, 2932, 2869, 1724, 1630, 1438, 761, 702; $^1H$ NMR (500 MHz, $CDCl_3$) 7.36–7.24 (m, 5H), 6.31 (t, 1H, *J* = 1.0 Hz), 5.92 (t, 1H, *J* = 1.5 Hz), 3.69 (s, 3H), 3.45–3.35 (m, 2H), 1.59–1.53 (m, 2H) 1.40–0.68 (m, 5H); Anal: Calcd. for $C_{15}H_{20}O_3$ C, 72.55; H, 8.12; Found C, 72.59; H, 8.07%.

**4ae**: Oil. IR (KBr)/$cm^{-1}$:2955, 1717, 1632, 1377, 1091, 769, 697; $^1H$ NMR (500 MHz, $CDCl_3$) 7.93 (s, 1H), 7.56–7.38 (m, 5H), 4.27 (s, 2H), 3.84 (s, 3H), 3.56–3.50 (m, 2H), 1.65–1.59 (m, 2H), 1.57–1.36 (m, 2H), 0.93 (t, 3H, *J* = 7.5 Hz); Anal: Calcd. for $C_{15}H_{20}O_3$ C, 72.55; H, 8.12; Found C, 72.38; H, 8.22%.

**3af**: Oil. $^1H$ NMR (500 MHz, $CDCl_3$) 7.38–7.25 (m, 5H), 6.34 (d, 1H, *J* = 1.0 Hz), 5.96 (t, 1H, *J* = 1.25 Hz), 5.30 (s, 1H), 3.72–3.60 (m, 7H); $^{13}C$ NMR (125 $MH_z$, $CDCl_3$) δ (ppm): 166.33, 140.98, 139.24, 128.53, 128.23, 127.68, 125.65, 79.64, 69.38, 52.00, 42.94; Anal: Calcd. for $C_{13}H_{15}ClO_3$ C, 61.30; H, 5.94. Found C, 61.25; H, 5.99%.

**4af**: Oil. IR (film)/$cm^{-1}$: 2954, 2864, 1719, 1631, 1493, 844, 817, 763, 703; $^1H$ NMR (500 MHz, $CDCl_3$) 7.97 (s, 1H), 7.60–7.39 (m, 5H), 4.36 (s, 2H), 3.85 (s, 3H), 3.83 (t, 2H, *J* = 6.0 Hz), 3.69 (t, 2H,

$J$ = 5.5 Hz); Anal: Calcd. for $C_{13}H_{15}ClO_3$ C, 61.30; H, 5.94. Found C, 61.36; H, 5.90%.

**3ag**: IR (film)/cm$^{-1}$: 2951, 2868, 1722, 1630, 1604, 739, 699; $^1$H NMR (500 MHz, $CDCl_3$) 7.40–7.26 (m, 10H), 6.35 (s, 1H), 6.02 (m, 1 Hz), 5.34 (s, 1H), 4.47 (s, 2H), 3.66 (s, 3H); $^{13}$C NMR (125 MHz, $CDCl_3$) δ (ppm): 166.33, 141.32, 139.64, 138.21, 128.44, 128.41, 128.02, 127.82, 127.73, 127.67, 125.30, 78.63, 70.84, 51.86; Anal: Calcd. for $C_{18}H_{18}O_3$ C, 76.57; H, 6.43; Found C, 76.46; H, 6.49%.

**4ag**: Oil. IR (film)/cm$^{-1}$: 3029, 1715, 1632, 1577, 1068, 741, 698; $^1$ H NMR (500 MHz, $CDCl_3$) 7.93 (s, 1H) 7.39–7.24 (m, 10H), 4.62 (s, 2H), 4.34 (s, 2H), 3.06 (s, 3H); Anal: Calcd. for $C_{18}H_{18}O_3$ C, 76.57; H, 6.43; Found C, 76.55; H, 6.44%.

**3bb**: Oil. IR (film)/cm$^{-1}$: 2976, 2952, 2873, 1725, 1631, 1512, 814; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.24 (d, 2H, $J$ = 8.0 Hz), 7.12 (d, 2H, $J$ = 8.0 Hz), 6.30 (m, 1H), 5.93 (s, 1H), 5.21 (s, 1H), 3.67 (s, 3H), 3.45 (q, 2H, $J$ = 7.5 Hz), 2.32 (s, 3H), 1.19 (t, 3H, $J$ = 7.0 Hz); $^{13}$C NMR (125 MHz $CDCl_3$) δ (ppm): 166.44, 141.62, 137.44, 137.04, 129.02, 127.50, 124.70, 78.86, 64.59, 51.74, 21.17, 15.32; Anal: Calcd. for $C_{14}H_{18}O_3$ C, 71.77; H, 7.74; Found C, 71.80; H, 7.72%.

**4bb**: Oil. IR (film)/cm$^{-1}$: 2872, 1715, 1631, 1091, 814; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.90 (s, 1H), 7.45 (d, 2H, $J$ = 8.0 Hz), 7.21 (d, 2H, $J$ = 8.5 Hz), 4.29 (s, 2H), 3.82 (s, 3H), 3.60 (q, 2H, $J$ = 6.5 Hz), 2.37 (s, 3H), 1.28 (t, 3H, $J$ = 6.0 Hz); Anal: Calcd. for $C_{14}H_{18}O_3$ C, 71.77; H, 7.74; Found C, 71.79; H, 7.68%.

**3bc**: Oil. IR (film)/cm$^{-1}$: 2972, 2927, 1725, 1631, 1512, 813; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.24 (d, 2H, $J$ = 8.0 Hz), 7.12 (d, 2H, $J$ = 8.0 Hz), 6.30 (q, 1H, $J$ = 1.0 Hz), 5.90 (t, 1H, $J$ = 1.5 Hz), 5.34 (s, 1H), 3.70 (s, 3H), 3.58 (m, 1H), 2.32 (s, 3H), 1.19 (d, 3H, $J$ = 6.0 Hz), 1.14 (d, 3H, $J$ = 7.0 Hz); Anal: Calcd. for $C_{15}H_{20}O_3$ C, 72.55; H, 8.12; Found C, 72.50; H, 8.14%.

**4bc**: Oil. IR (film)/cm$^{-1}$: 2972, 1716, 1632, 1375, 1122, 812; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.89 (s, 1H), 7.48 (d, 2H, $J$ = 8.0 Hz), 7.20 (d, 2H, $J$ = 8.0 Hz), 4.28 (s, 2H), 3.81 (s, 3H), 3.76-3.69 (m, 1H), 2.37 (s, 3H), 1.25 (t, 6H, $J$ = 6.0 Hz); Anal: Calcd. for $C_{15}H_{20}O_3$ C, 72.55; H, 8.12; Found C, 72.59; H, 8.09%.

**3bg**: Oil. IR (film)/cm$^{-1}$: 2950, 2922, 2865, 1722, 1630, 819; $^1$H NMR (500 MHz, $CDCl_3$) 7.30–7.13 (m, 9H), 6.33 (s, 1H), 6.02 (t, 1H, $J$ = 1.25 Hz), 5.30 (s, 1H), 4.45 (q, 2H, $J$ = 1.5 Hz), 3.64 (s, 3H), 2.32 (s, 3H); Anal: Calcd. for $C_{19}H_{20}O_3$ C, 77.00; H, 6.80; Found C, 76.95; H, 6.88%.

**4bg**: Oil. IR (film)/cm$^{-1}$: 2975, 2894, 2839, 1723, 1631, 712, 788; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.90 (s, 1H), 7.42–7.19 (m, 9H), 4.62 (s, 2H), 4.35 (s, 2H), 3.81 (s, 3H), , 2.35 (s, 3H); Anal: Calcd. for $C_{19}H_{20}O_3$ C, 77.00; H, 6.80; Found C, 77.22; H, 6.76%.

**3cb**: Oil. IR (film)/cm$^{-1}$: 2975, 2894, 2839, 1723, 1631, 712, 788; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.26–7.22 (m, 1H), 6.95–6.90 (m, 2H), 6.82–6.80 (m, 1H), 6.32 (t, 1H, $J$ = 1.0 Hz), 5.90 (t, 1H, $J$ = 1.25 Hz), 5.23 (s, 1H), 3.79 (s, 3H), 3.71 (s, 3H), 3.52–3.45 (m, 2H), 1.21 (t, 3H, $J$ = 7.0 Hz); Calcd. for $C_{14}H_{18}O_4$ C, 67.18; H, 7.25; Found C, 67.21; H, 7.31%.

**4cb**: Oil. $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm):7.90 (s, 2H), 7.32 (t, 1H, $J$ = 7.75 Hz), 7.16 (d, 1H, $J$ = 7.5 Hz), 7.11 (d, 1H, $J$ = 7.5 Hz), 6.95–6.93 (m, 1H), 4.29 (s, 2H), 3.84 (s, 3H), 3.83 (s, 3H), 3.62 (q, 2H, $J$ = 10.5 Hz), 1.28 (t, 3H, $J$ = 7.0 Hz); Anal: Calcd. for $C_{14}H_{18}O_4$ C, 67.18; H, 7.25; Found C, 67.33; H, 7.31%.

**3cc**: Oil. IR (film)/cm$^{-1}$: 2972, 1723, 1630, 1603, 1379, 1150, 758, 711; $^1$H NMR (500MHz, $CDCl_3$) δ (ppm): 7.26–7.22 (m, 1H), 6.95–6.91 (m, 2H), 6.81–6.79 (m, 1H), 6.30 (d, 1H, $J$ = 0.5 Hz), 5.87 (t, 1H, $J$ = 2.5 Hz), 5.36 (s, 1H), 3.79 (s, 3H), 3.71 (s, 3H), 3.62–3.55 (m, 1H), 1.20 (d, 3H, $J$ = 6.0 Hz), 1.15 (d, 3H, $J$ = 6.0 Hz); Calcd. for $C_{15}H_{20}O_4$ C, 68.16; H, 7.63; Found C, 68.13; H, 7.67%.

4cc: Oil. IR (film)/cm$^{-1}$: 2971, 1715, 1633, 1375, 792, 693; 1H NMR (500MHz, CDCl3) δ(ppm): 7.88 (s, 1H), 7.32 (t, 1H, J = 8.0 Hz), 7.18–7.13 (m, 2H), 4.30 (s, 2H), 3.84 (s, 3H), 3.83 (s, 3H), 3.77–3.72 (m, 1H), 1.24 (d, 6H, J = 6.0 Hz); Anal: Calcd. for C15H20O4 C, 68.16; H, 7.63; Found C, 68.25; H, 7.69%.

**3cg***:* Oil. IR (film)/cm$^{-1}$: 2951, 2837, 1717, 1633, 1602, 775, 738, 700; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.34–7.22 (m, 7H), 6.98 (d, 1H, $J$ = 7.5 Hz), 6.94 (d, 1H, $J$ = 7.5 Hz), 6.84–6.81 (m, 1H), 6.35 (t, 1H, $J$ = 1.0 Hz), 6.00 (t, 1H, $J$ = 1.5 Hz), 5.32 (s, 1H), 4.51–4.46 (m, 2H), 3.78 (s, 3H), 3.68 (s, 3H); $^{13}$C NMR (125MHz, $CDCl_3$) δ (ppm):166.35, 159.71, 141.25, 141.23, 138.20, 129.44, 128.41, 127.78, 127.68, 125.48, 120.24, 113.48, 113.19, 78.49, 70.93, 55.26, 51.89; Anal: Calcd. for $C_{19}H_{20}O_4$ C, 73.06; H, 6.45; Found C, 73.17; H, 6.58%.

**4cg**: Oil. IR (film)/cm$^{-1}$: 3029, 1710, 1632, 1067, 850, 738; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.92 (s, 1H), 7.39–7.25 (m, 7H), 7.14–7.09 (m, 2H), 4.63 (s, 2H), 4.36 (s, 2H), 3.83 (s, 3H), 3.78 (s, 3H); Anal: Calcd. for $C_{19}H_{20}O_4$ C, 73.06; H, 6.45; Found C, 73.17; H, 6.26%.

**3db**: Oil. IR (film)/cm$^{-1}$: 2954, 2840, 1722, 1610, 1088, 825; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.26 (d, 2H, $J$ = 7.0 Hz), 6.85 (d, 2H, $J$ = 7.5 Hz), 6.30 (t, 1H, $J$ = 1.25 Hz), 5.94 (t, 1H, $J$ = 1.5 Hz), 5.19 (s, 1H), 3.79 (s, 3H), 3.69 (s, 3H), 1.20 (t, 3H, $J$ = 6.5 Hz); Anal: Calcd. for $C_{14}H_{18}O_4$ C, 67.18; H, 7.25; Found C, 67.25; H, 7.20%.

**4db**: Oil. IR (film)/cm$^{-1}$: 2951, 2872, 1711, 1628, 1603, 1089, 841; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.89 (s, 1H), 7.54 (q, 2H, $J$ = 4.5 Hz), 6.93 (q, 2H, $J$ = 4.5 Hz), 4.30 (s, 2H), 3.83 (s, 3H), 3.82 (s, 3H), 3.62 (q, 2H, $J$ = 6.0 Hz), 1.28 (t, 3H, $J$ = 6.0 Hz); Anal: Calcd. for $C_{14}H_{18}O_4$ C, 67.18; H, 7.25; Found C, 67.12; H, 7.32%.

**3dc**: Oil. IR (film)/cm$^{-1}$: 2970, 1722, 1610, 1586, 1061, 839; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.276 (d, 2H, $J$ = 7.5 Hz), 6.87 (d, 2H, $J$ = 7.5 Hz), 6.30 (d, 1H, $J$ = 1.0 Hz), 5.91 (t, 1H, $J$ = 1.5 Hz), 5.32 (s, 1H), 3.79 (s, 3H), 3.70 (s, 3H), 3.61–3.56 (m, 1H), 1.18 (d, 3H, $J$ = 6.0 Hz), 1.14 (d, 3H, $J$ = 6.0 Hz); Anal: Calcd. for $C_{15}H_{20}O_4$ C, 68.16; H, 7.63; Found C, 68.21; H, 7.57%.

**4dc**: Oil. IR(film)/cm$^{-1}$: 2971, 1712, 1629, 1604, 1055, 839; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm):, 7.88 (s, 1H), 7.58–7.56 (m, 2H), 6.93 (q, 2H, $J$ = 4.5 Hz), 4.30 (s, 2H), 3.83 (s, 3H), 3.82 (s, 3H), 3.77–3.71 (m, 1H), 1.18 (d, 6H, $J$ = 6.5 Hz); Anal: Calcd. for $C_{15}H_{20}O_4$ C, 68.16; H, 7.63; Found C, 68.20; H, 7.59%.

**3dg**: Oil. IR (film)/cm$^{-1}$: 3030, 1721, 1629, 1608, 1067, 827; $^1$H NMR (500 MHz, $CDCl_3$) 7.34–7.26 (m, 7H), 6.88–6.87 (q, 2H, $J$ = 1.0 Hz), 6.34 (t, 1H, $J$ = 1.25 Hz), 6.04 (t, 1H, $J$ = 1.75 Hz), 5.28 (s, 1H), 4.46 (d, 2H, $J$ = 3.0 Hz), 3.80 (s, 3H), 3.68 (s, 3H); Anal: Calcd. for $C_{19}H_{20}O_4$ C, 73.06; H, 6.45; Found C, 73.18; H, 6.26%.

**4dg**: Oil. IR (film)/cm$^{-1}$: 3030, 1709, 1269, 1603, 1066, 782, 741, 700; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.89 (s, 1H), 7.50 (dd, 2H, $J$ = 7.0 Hz), 7.41–7.30 (m, 5H), 6.86 (dd, 2H, $J$ = 7.0 Hz), 4.64 (s, 2H), 4.37 (s, 2H), 3.81 (s, 3H), 3.68 (s, 3H); Anal: Calcd. for $C_{19}H_{20}O_4$ C, 73.06; H, 6.45; Found C, 72.88; H, 6.58%.

**3eb**: Oil. IR (film)/cm$^{-1}$: 2964, 2870, 1725, 1631, 1091, 823; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.33 (d, 2H, $J$ = 8.5 Hz), 7.27 (d, 2H, $J$ = 8.0 Hz), 6.31 (t, 1H, $J$ = 0.5 Hz), 5.94 (t, 1H, $J$ = 1.5 Hz), 5.24 (s, 1H), 3.69 (s, 3H), 3.52–3.42 (m, 2H), 1.29 (s, 9H), 1.20 (t, 3H, $J$ = 7.0 Hz); Anal: Calcd. for $C_{17}H_{24}O_3$ C, 73.88; H, 8.75; Found C, 73.93; H, 8.77%.

**4eb**: Oil. IR (film)/cm$^{-1}$: 2967, 1716, 1632, 1609, 1366, 836; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.91 (s, 1H), 7.50 (d, 2H, $J$ = 8.5 Hz), 7.44 (t, 2H, $J$ = 8.0 Hz), 4.30 (s, 2H), 3.82 (s, 3H), 3.64–3.60 (m, 2H), 1.34 (s, 9H), 1.28 (m, 3H); Anal: Calcd. for $C_{17}H_{24}O_3$ C, 73.88; H, 8.75; Found C, 73.76; H, 8.79%.

**3ec**: Oil. IR (film)/cm$^{-1}$: 2977, 2871, 1726, 1631, 1462, 820; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.32 (d, 2H, $J$ = 8.0 Hz), 7.26 (d, 2H, $J$ = 8.0 Hz), 6.30 (d, 1H, $J$ = 2.5 Hz), 5.91 (t, 1H, $J$ = 2.5 Hz), 5.37 (s, 1H), 3.69 (s, 3H), 3.64–3.57 (m, 1H), 1.29 (s, 9H), 1.18 (d, 3H, $J$ = 6.5 Hz), 1.15 (d, 3H, $J$ = 6.5 Hz); $^{13}$C NMR (125 MHz, $CDCl_3$) δ (ppm): 166.73, 150.47, 142.17, 137.50, 127.21, 125.28, 125.26, 76.00, 69.63, 51.83, 34.58, 31.46, 22.74, 21.99; Anal: Calcd. for $C_{18}H_{26}O_3$ C, 74.45; H, 9.02; Found C, 74.42; H, 9.23%.

**4ec**: Oil. $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.89 (s, 1H, ), 7.26 (d, 2H, $J$ = 8.5 Hz), 7.43 (d, 2H, $J$ = 8.5 Hz), 4.30 (t, 1H, $J$ = 4.5 Hz), 3.83 (s, 3H), 1.33 (s, 9H), 1.26 (d, 6H, $J$ = 6.0 Hz); Anal: Calcd. for $C_{18}H_{26}O_3$ C, 74.45; H, 9.02; Found C, 74.38; H, 9.15. **3eg**: $^1$H NMR (500 MHz, $CDCl_3$) 7.36–7.26 (m, 9H), 6.35 (d, 1H, $J$ = 1.0 Hz), 6.03 (t, 1H, $J$ = 1.5 Hz), 5.33 (s, 1H), 4.47 (m, 2H), 3.67 (s, 3H), 1.30 (s, 9H); Anal: Calcd. for $C_{22}H_{26}O_3$ C, 78.07; H, 7.74; Found C, 78.20; H, 7.63%.

**4eg**: Oil. IR (film)/cm$^{-1}$: 3030, 1715, 1629, 1608, 1109, 839, 737, 699; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.92 (s, 1H), 7.46–7.33 (m, 9H), 4.63 (s, 2H), 4.36 (s, 2H), 3.81 (s, 3H), 1.33 (s, 9H); Anal: Calcd. for $C_{22}H_{26}O_3$ C, 78.07; H, 7.74; Found C, 78.21; H, 7.69%.

**3fb**: Oil. IR (film)/cm$^{-1}$: 2973, 2828, 2896, 1724, 1631, 1596, 818; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.29 (s, 4H), 6.33 (t, 1H, $J$ = 1.0 Hz), 5.96 (t, 1H, $J$ = 1.5 Hz), 5.20 (s, 1H), 3.70 (s, 3H), 3.52–3.40 (m, 2H), 1.20 (t, 3H, $J$ = 7.0 Hz); Anal: Calcd. for $C_{13}H_{15}ClO_3$ C, 61.30; H, 5.94; Found C, 61.26; H, 6.03%.

**4fb**: Oil. IR (film)/cm$^{-1}$: 2958, 2925, 1718, 1632, 1091, 815; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.87 (s, 1H), 7.49 (dd, 2H, $J$ = 8.5 Hz), 7.49 (dd, 2H, $J$ = 8.5 Hz), 4.25 (s, 2H), 3.84 (s, 3H), 3.63–3.57 (m, 2H), 1.26 (t, 3H, $J$ = 7.0 Hz); Anal: Calcd. for $C_{13}H_{15}ClO_3$ C, 61.30; H, 5.94; Found C, 61.36; H, 6.01%.

**3fc**: Oil. IR (film)/cm$^{-1}$: 2972, 2929, 1721, 1630, 1596, 818; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.29 (s, 4H), 6.31 (t, 1H, $J$ = 1.0 Hz), 5.92 (t, 1H, $J$ = 1.25 Hz), 5.33 (s, 1H), 3.70 (s, 3H), 3.62–3.55 (m, 1H), 1.18 (d, 3H, $J$ = 6.0 Hz), 1.12 (d, 3H, $J$ = 6.5 Hz); Anal: Calcd. for $C_{14}H_{17}ClO_3$ C, 62.57; H, 6.38; Found C, 62.41; H, 6.47%.

**4fc**: Oil. IR (film)/cm$^{-1}$: 2971, 1718, 1634, 1592, 1376, 1094, 811; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.85 (s, 1H), 7.52 (m, 2H, $J$ = 5.3 Hz), 7.38 (d, 2H), 4.25 (s, 2H), 3.83 (s, 3H), 3.75–3.69 (m, 1H), 1.24 (d, 6H, $J$ = 6.0 Hz); Anal: Calcd. for $C_{14}H_{17}ClO_3$ C, 62.57; H, 6.38; Found C, 62.53; H, 6.39%.

**3fg**: Oil. IR (film)/cm$^{-1}$: 3031, 1720, 1631, 1595, 1088, 820, 737, 698; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.33–7.27 (m, 9H), 6.36 (t, 1H, $J$ = 1.0 Hz), 6.06 (t, 1H, $J$ = 0.8 Hz), 4.62 (s, 2H), 3.77 (s, 2H) $^{13}$C NMR (125 MHz, $CDCl_3$) δ (ppm): 166.16, 140.95, 138.34, 137.95, 133.81, 129.22, 128.67, 128.51, 127.83, 127.76, 125.48, 77.94, 70.92, 51.97; Anal: Calcd. for $C_{18}H_{17}ClO_3$ C, 68.25; H, 5.41; Found C, 68.17; H, 5.47%.

**4fg**: Oil. IR (film)/cm$^{-1}$: 3030, 2918, 2861, 1713, 1632, 1591, 1089, 844, 737, 700; $^1$H NMR (500 MHz, $CDCl_3$) δ (ppm): 7.86 (s, 1H), 7.45–7.35 (m, 9H), 4.62 (s, 2H), 4.30 (s, 2H), 3.83 (s, 3H); Anal: Calcd. for $C_{18}H_{17}ClO_3$ C, 68.25; H, 5.41; Found C, 68.13; H, 5.56%.

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