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Graphical Abstract

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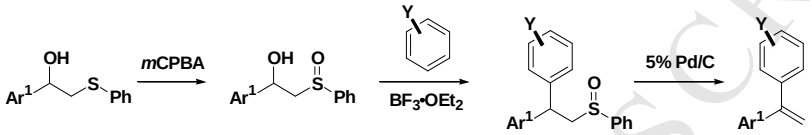

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Synthesis of 1,1-Diarylethylenes

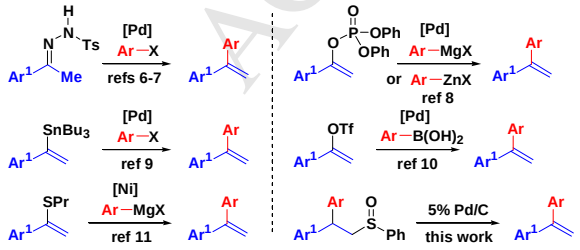
Meng-Yang Chang, Yi-Hsuan Huang and Heui-Sin Wang*
Department of Medicinal and Applied Chemistry, Kaohsiung Medical University, Kaohsiung 807, Taiwan

Abstract—A facile route toward 1,1-diarylethylenes **6** has been developed in good yields via *m*CPBA-promoted oxidation of β-hydroxysulfides **2**, $BF_3 \cdot OEt_2$-mediated Friedel-Crafts reaction of the resulting β-hydroxysulfoxides **3** with oxygenated benzenes **4**, followed by Pd/C-mediated [2,3]-sigmatropic rearrangement of sulfoxides **5**. The protocol provides a short-term, easy-operational, inexpensive reagent, mild condition and rapidly obtainable transformation.

1. Introduction

Substituted germinal 1,1-diarylethylenes are present in many pharmacophores,[1] including tamoxifen,[2] bexarotene,[3] *iso*-combretastatin A (*iso*CA-4),[4] and ratanhine.[5] The use of Wittig oelfination of diarylketone and Grignard addition of arylketone followed by dehydration are two common and traditional protocols for the synthesis of 1,1-diarylethylenes. Recently, Alami and Barluenga have developed a series of syntheses of diversified 1,1-diarylethylenes via palladium-mediated cross-coupling of hydrozone with aryl halides.[6-7] Other efficient approaches for preparing substituted 1,1-diarylethylenes have been reported via various palladium complexes promoting cross-coupling as the major pathways, such as (i) the $PdCl_2$-catalyzed Kumada-Corriu reaction of styryl phosphates with ArMgX,[8a] (ii) the Pd_2dba_3 or $Pd(dba)_2$-catalyzed Negishi reaction of styryl phosphates with ArZnX,[8b-c] (iii) the $Pd(OAc)_2$ or $Pd(Ph_3P)_4$-catalyzed Still reaction of styryl stannanes with ArX,[9] and (iv) the $Pd(Ph_3P)_2Cl_2$-catalyzed Suzuki-Miyaura reaction of styryl triflates with $ArB(OH)_2$.[10] Another route to nickel-mediated Kumada-type cross-coupling styryl sulfides with ArMgX has been documented.[11]

Scheme 1. Synthetic routes of 1,1-diarylethylenes



Keywords: 1,1-Diarylethylenes; Sigmatropic rearrangement; Sulfoxides.
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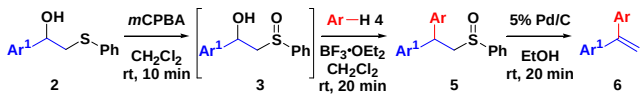
2. Results and discussion

Based on our observations, we found that transition metal mediated cross-coupling reactions provide some dominant access to substituted 1,1-diarylethylenes among these methodologies, as shown in Scheme 1. To the best of our knowledge, for the synthesis of 1,1-diarylethylenes, no examples on Pd/C-mediated intramolecular [2,3]-sigmatropic rearrangement of sulfoxide has been reported. Herein, we describe a highly effective three-step synthetic route towards substituted 1,1-diarylethylenes **6** bearing the electron-withdrawing aryl group, the electron-neutral aryl group or the electron-donating aryl groups (Ar^1 = Ph, 4-MeC_6H_4, 2-naphthalene, 4-PhC_6H_4, 4-FC_6H_4, 4-$MeOC_6H_4$; Ar-H = 1,3-$(MeO)_2C_6H_4$, 1,2-$(MeO)_2C_6H_4$, 1,2-$CH_2O_2C_6H_4$, 1,2,3-$(MeO)_3C_6H_3$), including (i) a *m*CPBA (*meta*-chloroperoxybenzoic acid) promoted oxidation of β-hydroxysulfides **2**[12] (prepared by $NaBH_4$ mediated reduction of β-ketosulfides **1** at rt for 10 min) at rt for 10 min, (ii) a $BF_3 \cdot OEt_2$ mediated Friedel-Crafts reaction of β-hydroxysulfoxides **3** with oxygenated benzenes **4** at rt 20 min and (iii) a Pd/C-mediated intramolecular [2,3]-sigmatropic rearrangement of sulfoxides **5** at rt for 20 min (Scheme 2).

Scheme 2. Our synthetic route of 1,1-diarylethylenes **6**

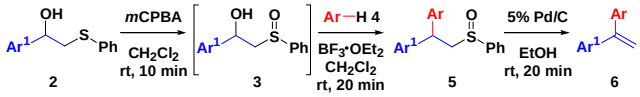


Ar^1 = Ph, 4-MeC_6H_4, 2-naphthalene, 4-PhC_6H_4, 4-FC_6H_4, 4-$MeOC_6H_4$
Ar-H = 1,3-$(MeO)_2C_6H_4$, 1,2-$(MeO)_2C_6H_4$, 1,2-$CH_2O_2C_6H_4$, 1,2,3-$(MeO)_3C_6H_3$

To generate skeleton **6**, the facile and simple methodology provides a short-term, easy-operational, inexpensive reagent, mild condition and rapidly obtainable transformation by a simple three-step synthetic sequence starting with a selective oxidation between a hydroxyl and

sulfide group, followed by a benzylic introduction of oxygenated arenes and then, a sulfoxide elimination within 1 h under open-vessel room temperature conditions. The key building blocks in numerous valuable bioactive intermediates has led to the development of sulfoxide-based synthetic approaches to the targets,[13-14] for example, Pradilla et al. developed a base-promoted intramolecular S_N2' cyclization of sulfinyl dienols.[15] On the basis of observations, a sulfoxide-based synthetic route of 1,1-diarylethylenes with the diversified aryl substituents is developed.

Table 1. Synthesis of diarylmethyl sulfoxides **5a-x** and 1,1-diarylethylenes **6a-x**[a-b]



entry	**2**, Ar^1 =	**4**, Ar-H =	**5**, (%)[c]	**6**, (%)[c]
1	**2a**, Ph	**4a**, 1,3-$(MeO)_2C_6H_4$	**5a**, 80	**6a**, 89
2	**2a**, Ph	**4b**, 1,2-$CH_2O_2C_6H_4$	**5b**, 87	**6b**, 80
3	**2a**, Ph	**4c**, 1,2-$(MeO)_2C_6H_4$	**5c**, 86	**6c**, 82
4	**2a**, Ph	**4d**, 1,2,3-$(MeO)_3C_6H_3$	**5d**, 90	**6d**, 89
5	**2b**, 4-MeC_6H_4	**4a**, 1,3-$(MeO)_2C_6H_4$	**5e**, 78	**6e**, 81
6	**2b**, 4-MeC_6H_4	**4b**, 1,2-$CH_2O_2C_6H_4$	**5f**, 83	**6f**, 80
7	**2b**, 4-MeC_6H_4	**4c**, 1,2-$(MeO)_2C_6H_4$	**5g**, 81	**6g**, 74
8	**2b**, 4-MeC_6H_4	**4d**, 1,2,3-$(MeO)_3C_6H_3$	**5h**, 88	**6h**, 86
9	**2c**, 2-naphthyl	**4a**, 1,3-$(MeO)_2C_6H_4$	**5i**, 80	**6i**, 81
10	**2c**, 2-naphthyl	**4b**, 1,2-$CH_2O_2C_6H_4$	**5j**, 84	**6j**, 76
11	**2c**, 2-naphthyl	**4c**, 1,2-$(MeO)_2C_6H_4$	**5k**, 83	**6k**, 80
12	**2c**, 2-naphthyl	**4d**, 1,2,3-$(MeO)_3C_6H_3$	**5l**, 92	**6l**, 85
13	**2d**, 4-PhC_6H_4	**4a**, 1,3-$(MeO)_2C_6H_4$	**5m**, 74	**6m**, 78
14	**2d**, 4-PhC_6H_4	**4b**, 1,2-$CH_2O_2C_6H_4$	**5n**, 82	**6n**, 74
15	**2d**, 4-PhC_6H_4	**4c**, 1,2-$(MeO)_2C_6H_4$	**5o**, 80	**6o**, 80
16	**2d**, 4-PhC_6H_4	**4d**, 1,2,3-$(MeO)_3C_6H_3$	**5p**, 87	**6p**, 81
17	**2e**, 4-FC_6H_4	**4a**, 1,3-$(MeO)_2C_6H_4$	**5q**, 72	**6q**, 76
18	**2e**, 4-FC_6H_4	**4b**, 1,2-$CH_2O_2C_6H_4$	**5r**, 80	**6r**, 87
19	**2e**, 4-FC_6H_4	**4c**, 1,2-$(MeO)_2C_6H_4$	**5s**, 80	**6s**, 82
20	**2e**, 4-FC_6H_4	**4d**, 1,2,3-$(MeO)_3C_6H_3$	**5t**, 84	**6t**, 83
21	**2f**, 4-$MeOC_6H_4$	**4a**, 1,3-$(MeO)_2C_6H_4$	**5u**, 85	**6u**, 82
22	**2f**, 4-$MeOC_6H_4$	**4b**, 1,2-$CH_2O_2C_6H_4$	**5v**, 90	**6v**, 78
23	**2f**, 4-$MeOC_6H_4$	**4c**, 1,2-$(MeO)_2C_6H_4$	**5w**, 90	**6w**, 78
24	**2f**, 4-$MeOC_6H_4$	**4d**, 1,2,3-$(MeO)_3C_6H_3$	**5x**, 93	**6x**, 82

[a]The synthesis of **5** was run on a 1.0 mmol scale with **2**, *m*CPBA (freshly purified, 173 mg, 1.0 equiv), CH_2Cl_2 (10 mL), 10 min, rt; then **4** (1.0 equiv), $BF_3{\cdot}OEt_2$ (142 mg, 1.0 mmol), 20 min, rt.
[b]The synthesis of **6** was run on a 0.5 mmol scale with **5**, 5% Pd/C (100 mg), EtOH (10 mL), 20 min, rt.
[c]Isolated yields.

Our preliminary investigation started with an oxidation of **2a** (Ar^1 = Ph) in CH_2Cl_2 with 3.0 equiv of commercially available *m*CPBA (70~75%) as an oxidant at rt for 60 min, which resulted in 50% β-ketosulfone, 30% β-hydroxysulfone and 12% β-hydroxysulfoxide **3a**. The low yield of **3a** was attributed to over-oxidation of *m*CPBA and a longer reaction time. To address this concern, the purity (washed by PH = 7.4 buffer solution) and equivalent of *m*CPBA was adjusted (3.0 → 1.0 equiv) and time was shortened (60 → 10 min). The reaction conditions provided **3a** in a quantitative yield with no side products. Furthermore, treatment of **3a** with a 2.0 equiv of 1,3-dimethoxybenzene (**4a**) produced isomers **5a** (80%) with a 1:1 ratio in the presence of $BF_3{\cdot}OEt_2$ (1.0 equiv) at rt for 20 min. We assumed that two diastereoisomers are a result of two chiral centers (carbon and sulfur atom) in the molecule **5a** by a two-step route. There are different position on aromatic **4a** could possibly participate in the Friedel-Crafts reaction of **3a**, and this might lead to different isomers of **5a**. However, we found that only para-position of methoxy group on **4a** participated Friedel-Crafts reaction of **3a** to generate **5a**. During the procedure, no other isomers were observed.[16] Sulfoxide elimination of **5a** under refluxing toluene condition was examined next but traditional thermolysis of **5a** with two isomers afforded **6a** in a 40% yield along with 32% of an unknown polymer for 10 h. In a subsequent attempt, 5% Pd/C (100 mg) was introduced as a catalyst to improve the reaction reactivity. Pleasingly, the isolated yield of **6a** was increased to 89%, and the reaction temperature and time were also decreased to rt and 20 min. Increasing the amounts of 5% Pd/C (200 mg) also generated similar yields of **6a** (92%). To make three-step sequence more practical, Pd/C-mediated elimination of crude **5a** was examined. Compared with the above work (for **5a**, 80%; for **6a**, 89%), a lower yield of **6a** (55%) was provided.

According to the above synthetic sequences (*m*CPBA-promoted oxidation, $BF_3{\cdot}OEt_2$-mediated Friedel-Crafts reaction with oxygenated benzenes and Pd/C-catalyzed sulfoxide elimination), we explored the substrate scope, and the results are shown in Table 1. To adjust the Ar^1 group of **2a-f** (Ar^1 = Ph, 4-MeC_6H_4, 2-naphthalene, 4-PhC_6H_4, 4-FC_6H_4, 4-$MeOC_6H_4$) and Ar-H group of **4a-d** (Ar-H = 1,3-$(MeO)_2C_6H_4$, 1,2-$(MeO)_2C_6H_4$, 1,2-$CH_2O_2C_6H_4$, 1,2,3-$(MeO)_3C_6H_3$), **5a-x**, with an unseparated mixture (ratio 1:1 to 2:1), were provided in a range of 72~92% yields, as shown in entries 1-24. For the Ar^1 groups of **2**, the phenyl ring, with an electron-donating 4-methoxyphenyl group (for **5u-x**) provided better yields than the electron-withdrawing 4-fluorophenyl group (**5q-t**), and the phenyl ring, with an electron-neutral substituent, such as Ph (**5a-d**), 4-MeC_6H_4 (**5e-h**), 4-PhC_6H_4 (**5i-l**), and 2-naphthalene (**5m-p**) also provided modest to good yields. For the substituents of Ar-H **4** in particular, **4d** with a 1,2,3-trimethoxyphenyl ring produced better results than **4a-c**, with two oxygenated motifs. With the optimized conditions in hand, Pd/C-mediated sulfoxide elimination of **5a-x** led to **6a-x** in modest to good yields. All entries 1-24 performed successfully in preparing a skeleton of 1,1-diarylethylenes. The structural framework of **6w** was determined by single-crystal X-ray crystallography (Figure 1).[17]

Figure 1: X-ray structure of **6w**

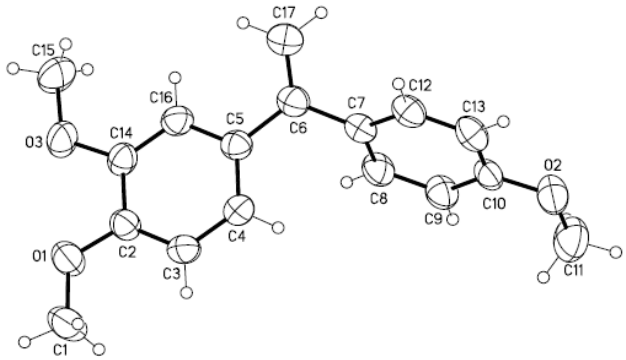
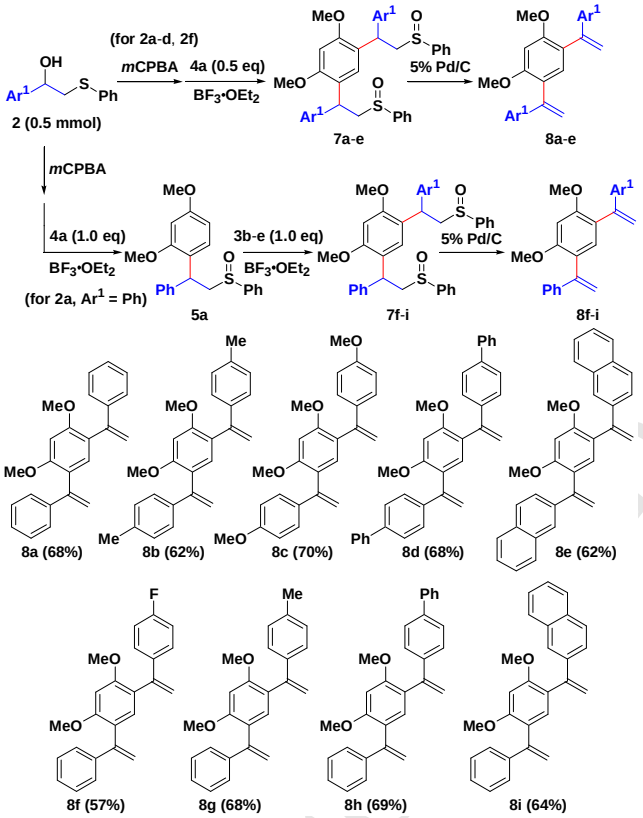


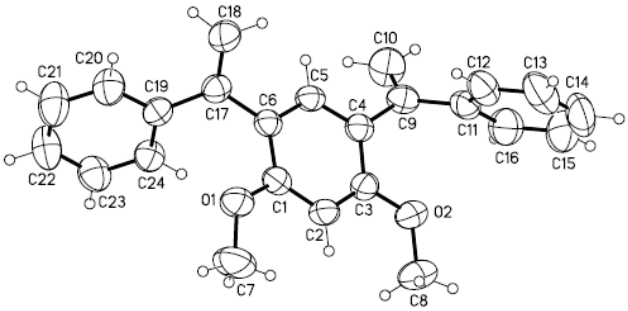
Table 2. Synthesis of 1,3-bis(1-arylethenyl)benzenes **8a-i**[a-c]



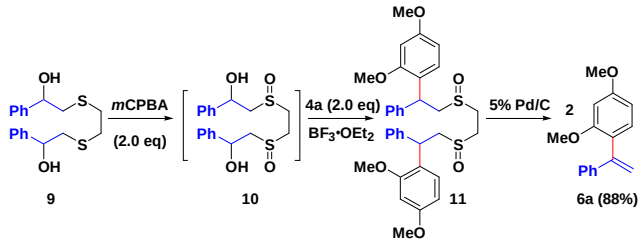
[a]The synthesis of **8a-e** was run on a 0.5 mmol scale with **2a-d** or **2f**, *m*CPBA (freshly purified, 87 mg, 1.0 equiv), CH_2Cl_2 (10 mL), 10 min, rt; **4a** (35 mg, 0.5 equiv), $BF_3{\cdot}OEt_2$ (71 mg, 1.0 equiv), 20 min, rt; 5% Pd/C (100 mg), EtOH (10 mL), 20 min, rt.
[b]The synthesis of **8f-i** was run on a 0.5 mmol scale with **2a** (115 mg), *m*CPBA (freshly prepared, 87 mg, 1.0 equiv), CH_2Cl_2 (10 mL), 10 min, rt; **4a** (69 mg, 1.0 equiv), $BF_3{\cdot}OEt_2$ (71 mg, 1.0 equiv), 20 min, rt; **3b-e** (1.0 equiv), $BF_3{\cdot}OEt_2$ (71 mg, 1.0 equiv), 20 min, rt; 5% Pd/C (100 mg), EtOH (10 mL), 20 min, rt.
[c]Isolated yields.

To show the potential application of the current three-step protocol, we embarked on the synthesis of branched 1,3-bis(1-arylethenyl)benzenes. For the formation of novel functionalized materials, this core skeleton was also a key monomer of styrene via tandem polymerization.[18] Very limited routes appeared in the literature for establishing the branched skeleton using some traditional functional group transformations such as Grignard methylation of 1,3-diaroylbenzene followed by dehydration or double Wittig olefination of 1,3-diaroylbenzene. As shown in Table 2, our analysis indicates that symmetrical **8a-e** were generated by oxidation of **2a-d** or **2f** with *m*CPBA, double Friedel-Crafts reaction with **4a** in the presence of $BF_3{\cdot}OEt_2$, and Pd/C-catalyzed sulfoxide elimination of **7a-f** in 62-70% yields of the three-step route. For the unsymmetrical **8f-i**, a similar route performed well via intermediates **7f-i**. The provided yields were distributed in a range of 57-69% yields. The structure of **8a** was determined by single-crystal X-ray crystallography (Figure 2).[17]

Figure 2: X-ray structure of **8a**



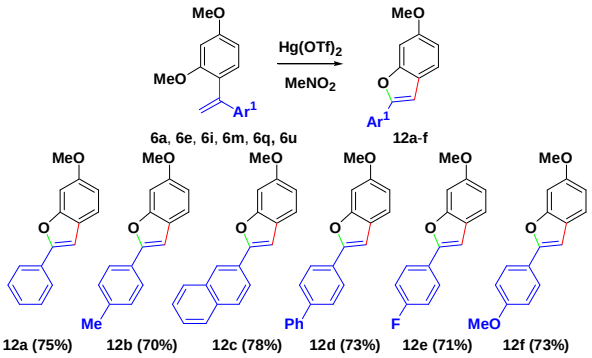
Scheme 3. Synthesis of 1-(3,4-dimethoxyphenyl)-1-phenylethylene **6a**



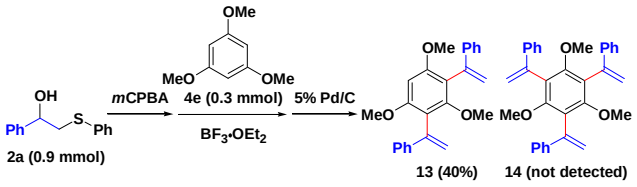
Changing the starting substrate from **2a** with a phenyl group (thiophenol) to **9** with an alkyl group (1,2-ethanedithiol), the three-step route provided **6a** in an 88% yield, as shown in Scheme 3. Interestingly, treatment of **9** with 2.0 equivalents of *m*CPBA yielded intermediate **10** with a bis-sulfoxide group, and no sulfone motif was generated. By the involvement of **4a** (2.0 equiv), **11** was formed via a double intermolecular Friedel-Crafts reaction. After the removal of sulfoxide, two equivalents of **6a** were obtained. In order to explore the application of 1,1-diarylethylenes **6**, synthesis of the benzofuran skeleton was further tested. Development of a new single-step route for simultaneous bond formation and ring-construction of benzofurans still represented a continuing need in the organic synthetic field.[19] However, intramolecular annulation was also a popular route to such benzofurans among the existing methods.[19-20] As shown in Scheme 4, treatment of **6a**, **6e**, **6l**, **6m**, **6q** and **6u** with 10 mol% of

$Hg(OTf)_2$ in $MeNO_2$ afforded **12a-f** with a benzofuran skeleton in modest yields (70-78%) via one-pot intramolecular cycloisomerization.

Scheme 4. Synthesis of benzofurans **12a-f**



Scheme 5. Synthesis of 1,3-bis(1-phenylethenyl)benzene **13**

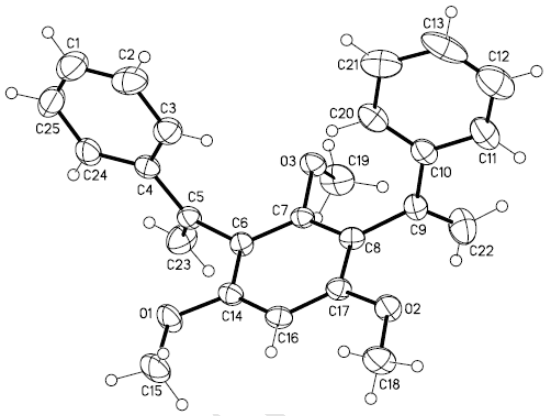


By the current three-step route, the installation of the tris-styryl group to the benzene skeleton was studied. Controlling the involvement of 1,3,5-trimethoxybenzene (**4e**. 1.0 equiv), **2a** (3.0 equiv) was converted to **13** in a 40% yield via the above method, as shown in Scheme 5. Under the reaction conditions, no desired **14** was observed. Increasing the amounts of **2a** (5 equiv), in attempts to afford **14** still failed due to the decreased ability of the electron-donating methoxy group and more steric hindrance of the third styryl motif. The structural framework of **13** was determined by single-crystal X-ray crystallography (Figure 3).[17]

3. Conclusion

In summary, we have developed a short-term, easy-operational, inexpensive reagent, mild condition and rapidly obtainable synthesis of substituted 1,1-diarylethylenes **6** and **8** in moderate to good yields via an *m*CPBA-promoted oxidation of β-hydroxysulfides **2**, a $BF_3{\cdot}OEt_2$-mediated Friedel-Crafts reaction of the resulting β-hydroxysulfoxides **3** with oxygenated benzenes **4**, followed by a Pd/C-mediated [2,3]-sigmatropic rearrangement of sulfoxides **5**. The structures of the key products were confirmed by X-ray crystallography. Synthesis of the benzofuran skeleton was further developed via $Hg(OTf)_2$-mediated intramolecular annulation of 1,1-diarylethylenes **6**. Further investigation regarding synthetic applications of β-hydroxysulfides will be conducted and published in due course.

Figure 3: X-ray structure of **13**



4. Experimental section

4.1. General. All other reagents and solvents were obtained from commercial sources and used without further purification. Reactions were routinely carried out under an atmosphere of dry nitrogen with magnetic stirring. Products in organic solvents were dried with anhydrous magnesium sulfate before concentration in vacuo. Melting points were determined with a SMP3 melting apparatus. ^1H and ^{13}C NMR spectra were recorded on a Varian INOVA-400 spectrometer operating at 400 and at 100 MHz, respectively. Chemical shifts (δ) are reported in parts per million (ppm) and the coupling constants (*J*) are given in Hertz. High resolution mass spectra (HRMS) were measured with a mass spectrometer Finnigan/Thermo Quest MAT 95XL. X-ray crystal structures were obtained with an Enraf-Nonius FR-590 diffractometer (CAD4, Kappa CCD).

*4.2. A representative synthetic procedure of compounds **5a-x** is as follows:* Commercially available *m*CPBA (Alfa, 70~75%, 50 g) was dissolved in ether (250 mL) and washed with buffer solution (4 × 250 mL, pH = 7.5; 410 mL of 0.1 M NaOH, 250 mL of 0.2 M KH_2PO_4 and 340 mL of water). The ether layer was dried and carefully evaporated under reduced pressure to give ca. 30 g pure *m*CPBA (CAUTION! potential explosive).[21] Freshly purified *m*CPBA (173 mg, 1.0 mmol) was added to a solution of β-hydroxysulfides **2a-f** (1.0 mmol) in CH_2Cl_2 (10 mL) at rt. The reaction mixture was stirred at rt for 10 min. Oxygenated benzenes **4a-d** (1.0 mmol) was added to the reaction mixture at rt. Then, $BF_3{\cdot}OEt_2$ (142 mg, 1.0 mmol) was added to the reaction mixture at rt. After the reaction mixture was stirred at rt for 20 min, saturated $NaHCO_3$ solution (10 mL) was added to the reaction mixture. The reaction mixture was extracted with CH_2Cl_2 (3 x 20 mL). The combined organic layers were washed with brine, dried, filtered and evaporated to afford crude product under reduced pressure. Purification on silica gel (hexanes/EtOAc = 3/1~1/1) afforded **5a-x**.

*4.2.1. Compound (**5a**).* Two isomers (ratio ~ 1:1); Yield = 80% (293 mg); HRMS (ESI, M^++1) calcd for $C_{22}H_{23}O_3S$ 367.1368, found 367.1372; ^1H NMR (400 MHz, $CDCl_3$): δ 7.64-7.59 (m, 2H), 7.53-7.46 (m, 3H), 7.34-7.16 (m, 5H),

7.12 (d, *J* = 8.4 Hz, 1/2H), 7.08 (d, *J* = 8.0 Hz, 1/2H), 6.50-6.40 (m, 2H), 4.80 (dd, *J* = 6.0, 10.0 Hz, 1/2H), 4.74 (dd, *J* = 6.4, 10.0 Hz, 1/2H), 3.78 (s, 3/2H), 3.76 (s, 3/2H), 3.75 (s, 3/2H), 3.72 (s, 3/2H), 3.60-3.54 (m, 1H), 3.49-3.39 (m, 1H).

*4.2.2. Compound (**5b**).* Two isomers (ratio ~ 1:1); Yield = 87% (305 mg); HRMS (ESI, M^++1) calcd for $C_{21}H_{19}O_3S$ 351.1055, found 351.1059; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.63-7.60 (m, 2H), 7.53-7.47 (m, 3H), 7.37-7.17 (m, 5H), 6.86 (dd, *J* = 1.6, 8.0 Hz, 1/2H), 6.79 (d, *J* = 7.6 Hz, 1/2 H), 6.78 (d, *J* = 2.0 Hz, 1/2H), 6.70 (br s, 1H), 6.68 (d, *J* = 7.6 Hz, 1/2H), 5.93 (d, *J* = 1.2 Hz, 1/2H), 6.92 (d, *J* = 1.6 Hz, 1/2H), 5.88 (d, *J* = 1.2 Hz, 1/2H), 5.88 (d, *J* = 1.2 Hz, 1/2H), 4.54 (dd, *J* = 4.8, 10.8 Hz, 1/2H), 4.49 (dd, *J* = 5.6, 10.8 Hz, 1/2H), 3.47-3.30 (m, 2H).

*4.2.3. Compound (**5c**).* Two isomers (ratio ~ 1:1); Yield = 86% (315 mg); HRMS (ESI, M^++1) calcd for $C_{22}H_{23}O_3S$ 367.1368, found 367.1369; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.61-7.58 (m, 2H), 7.50-7.45 (m, 3H), 7.37-7.32 (m, 2H), 7.28-7.15 (m, 3H), 6.92-6.82 (m, 3/2H), 6.76-6.71 (m, 3/2H), 4.56 (dd, *J* = 5.2, 10.8 Hz, 1/2H), 4.51 (dd, *J* = 5.2, 10.8 Hz, 1/2H), 3.85 (s, 3/2H), 3.84 (s, 3/2H), 3.80 (s, 3/2H), 3.79 (s, 3/2H), 3.48-3.34 (m, 2H).

*4.2.4. Compound (**5d**).* Two isomers (ratio ~ 1:1); Yield = 90% (356 mg); HRMS (ESI, M^++1) calcd for $C_{23}H_{25}O_4S$ 397.1474, found 397.1480; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.64-7.59 (m, 2H), 7.52-7.45 (m, 3H), 7.31-7.15 (m, 5H), 6.97 (d, *J* = 8.8 Hz, 1/2H), 6.88 (d, *J* = 8.4 Hz, 1/2H), 6.67 (d, *J* = 8.4 Hz, 1/2H), 6.59 (d, *J* = 8.4 Hz, 1/2H), 4.80 (dd, *J* = 6.0, 10.0 Hz, 1/2H), 4.74 (t, *J* = 8.4 Hz, 1/2H), 3.84 (s, 3H), 3.81 (s, 3/2H), 3.80 (s, 3/2H), 3.63 (s, 3/2H), 3.61 (s, 3/2H), 3.49 (d, *J* = 8.4 Hz, 1H), 3.43 (dd, *J* = 10.0, 12.8 Hz, 1H).

*4.2.5. Compound (**5e**).* Two isomers (ratio ~ 1:1); Yield = 78% (296 mg); HRMS (ESI, M^++1) calcd for $C_{23}H_{25}O_3S$ 381.1524, found 381.1530; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.64-7.59 (m, 2H), 7.53-7.46 (m, 3H), 7.23-7.02 (m, 5H), 6.48-6.40 (m, 2H), 4.76 (dd, *J* = 6.0, 10.0 Hz, 1/2H), 4.67 (dd, *J* = 6.8, 9.2 Hz, 1/2H), 3.78 (s, 3/2H), 3.76 (s, 3/2H), 3.75 (s, 3/2H), 3.72 (s, 3/2H), 3.58-3.36 (m, 2H), 2.31 (s, 3/2H), 2.28 (s, 3/2H).

*4.2.6. Compound (**5f**).* Two isomers (ratio ~ 1:1); Yield = 83% (302 mg); HRMS (ESI, M^++1) calcd for $C_{22}H_{21}O_3S$ 365.1212, found 365.1215; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.63-7.61 (m, 2H), 7.53-7.48 (m, 3H), 7.23-7.07 (m, 4H), 6.87-6.69 (m, 3H), 5.93 (d, *J* = 1.6 Hz, 1/2H), 5.91 (d, *J* = 1.6 Hz, 1/2H), 5.87 (d, *J* = 1.2 Hz, 1/2H), 5.87 (d, *J* = 1.2 Hz, 1/2H), 4.51-4.45 (m, 1H), 3.46-3.29 (m, 2H), 2.34 (s, 3/2H), 2.29 (s, 3/2H).

*4.2.7. Compound (**5g**).* Two isomers (ratio ~ 1:1); Yield = 81% (308 mg); HRMS (ESI, M^++1) calcd for $C_{23}H_{25}O_3S$ 381.1524, found 381.1531; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.62-7.58 (m, 2H), 7.51-7.45 (m, 3H), 7.24-7.06 (m, 4H), 6.91-6.71 (m, 3H), 4.53-4.47 (m, 1H), 3.85 (s, 3/2H), 3.84 (s, 3/2H), 3.80 (s, 3/2H), 3.79 (s, 3/2H), 3.47-3.33 (m, 2H), 2.32 (s, 3/2H), 2.27 (s, 3/2H).

*4.2.8. Compound (**5h**).* Two isomers (ratio ~ 1:1); Yield = 88% (361 mg); HRMS (ESI, M^++1) calcd for $C_{24}H_{27}O_4S$ 411.1630, found 411.1633; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.64-7.60 (m, 2H), 7.54-7.47 (m, 3H), 7.20 (d, *J* = 8.4 Hz, 1H), 7.14-7.11 (m, 2H), 7.08 (d, *J* = 8.0 Hz, 1H), 6.94 (d, *J* = 8.8 Hz, 1/2H), 6.87 (d, *J* = 8.8 Hz, 1/2 H), 6.66 (d, *J* = 8.8 Hz, 1/2H), 6.59 (d, *J* = 8.8 Hz, 1/2H), 4.77 (dd, *J* = 6.0, 10.0 Hz, 1/2H), 4.68 (dd, *J* = 6.8, 9.6 Hz, 1/2H), 3.84 (s, 3/2H), 3.83 (s, 3/2H), 3.81 (s, 3H), 3.66 (s, 3/2H), 3.63 (s, 3/2H), 3.50-3.34 (m, 2H), 2.31 (s, 3/2H), 2.28 (s, 3/2H).

*4.2.9. Compound (**5i**).* Two isomers (ratio ~ 2:1); Yield = 80% (333 mg); HRMS (ESI, M^++1) calcd for $C_{26}H_{25}O_3S$ 417.1524, found 417.1526; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.82-7.61 (m, 6H), 7.54-7.35 (m, 5H), 7.14-7.11 (m, 1H), 6.50-6.41 (m, 3H), 4.98 (dd, *J* = 6.0, 10.0 Hz, 1/3H), 4.89 (dd, *J* = 6.8, 9.6 Hz, 2/3H), 3.79 (s, 2H), 3.77 (s, 1H), 3.76 (s, 1H), 3.73 (s, 2H), 3.67-3.48 (m, 2H).

*4.2.10. Compound (**5j**).* Two isomers (ratio ~ 1:1); Yield = 84% (336 mg); HRMS (ESI, M^++1) calcd for $C_{25}H_{21}O_3S$ 401.1212, found 401.1215; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.86-7.61 (m, 6H), 7.53-7.30 (m, 6H), 6.93 (dd, *J* = 1.6, 8.0 Hz, 1/2H), 6.83 (d, *J* = 1.6 Hz, 1/2H), 6.82 (d, *J* = 8.0 Hz, 1/2H), 6.76 (dd, *J* = 1.6, 8.0 Hz, 1/2H), 6.75 (s, 1/2H), 6.72 (d, *J* = 8.0 Hz, 1/2H), 5.94 (d, *J* = 1.2 Hz, 1/2H), 5.92 (d, *J* = 1.2 Hz, 1/2H), 5.88 (d, *J* = 1.6 Hz, 1/2H), 5.87 (d, *J* = 1.2 Hz, 1/2H), 4.73-4.68 (m, 1H), 3.59-3.41 (m, 2H).

*4.2.11. Compound (**5k**).* Two isomers (ratio ~ 2:1); Yield = 83% (345 mg); HRMS (ESI, M^++1) calcd for $C_{26}H_{25}O_3S$ 417.1524, found 417.1528; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.86-7.61 (m, 6H), 7.53-7.31 (m, 6H), 6.96 (dd, *J* = 2.0, 8.4 Hz, 1/3H), 6.88 (d, *J* = 8.4 Hz, 2/3H), 6.87 (d, *J* = 2.0 Hz, 1/3H), 6.82 (dd, *J* = 2.0, 8.4 Hz, 2/3H), 6.78 (s, 2/3 H), 6.77 (s, 1/3H), 4.76-4.70 (m, 1H), 3.87 (s, 2H), 3.85 (s, 2H), 3.82 (s, 1H), 3.80 (s, 1H), 3.61-3.44 (m, 2H).

*4.2.12. Compound (**5l**).* Two isomers (ratio ~ 1:1); Yield = 92% (410 mg); HRMS (ESI, M^++1) calcd for $C_{27}H_{27}O_4S$ 447.1630, found 447.1633; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.83-7.61 (m, 6H), 7.55-7.34 (m, 6H), 7.00 (d, *J* = 8.4 Hz, 1/2H), 6.95 (d, *J* = 8.8 Hz, 1/2H), 6.68 (d, *J* = 8.8 Hz, 1/2H), 6.61 (d, *J* = 8.4 Hz, 1/2H), 4.99 (dd, *J* = 6.0, 10.0 Hz, 1/2H), 4.89 (dd, *J* = 6.8, 10.0 Hz, 1/2H), 3.85 (s, 3H), 3.82 (s, 3/2H), 3.81 (s, 3/2H), 3.63 (s, 3/2H), 3.61 (s, 3/2H), 3.66-3.47 (m, 2H).

*4.2.13. Compound (**5m**).* Two isomers (ratio ~ 2:1); Yield = 74% (327 mg); HRMS (ESI, M^++1) calcd for $C_{28}H_{27}O_3S$ 443.1681, found 443.1688; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.67-7.30 (m, 14H), 7.17 (d, *J* = 8.4 Hz, 1/3H), 7.12 (d, *J* = 8.0 Hz, 2/3H), 6.52-6.42 (m, 2H), 4.84 (dd, *J* = 6.4, 10.0 Hz, 2/3H), 4.80 (dd, *J* = 6.0, 9.6 Hz, 1/3H), 3.80 (s, 1H), 3.78 (s, 2H), 3.77 (s, 2H), 3.76 (s, 1H), 3.66-3.58 (m, 1H), 3.53-3.43 (m, 1H).

*4.2.14. Compound (**5n**).* Two isomers (ratio ~ 1:1); Yield = 82% (349 mg); HRMS (ESI, M^++1) calcd for $C_{27}H_{23}O_3S$ 427.1368, found 427.1371; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.66-7.29 (m, 14H), 6.92 (dd, *J* = 2.0, 8.0 Hz, 1/2H), 6.85

(d, *J* = 1.6 Hz, 1/2H), 6.83 (d, *J* = 8.0 Hz, 1/2H), 6.76 (m, 3/2H), 6.94 (d, *J* = 1.2 Hz, 1/2H), 6.93 (d, *J* = 1.2 Hz, 1/2H), 6.90 (d, *J* = 1.2 Hz, 1/2H), 6.88 (d, *J* = 1.2 Hz, 1/2H), 4.64-4.55 (m, 1H), 3.51-3.37 (m, 2H).

*4.2.15. Compound (**5o**).* Two isomers (ratio ~ 1:1); Yield = 80% (354 mg); HRMS (ESI, M^++1) calcd for $C_{28}H_{27}O_3S$ 443.1681, found 443.1685; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.65-7.29 (m, 14H), 6.97 (dd, *J* = 2.0, 8.0 Hz, 1/2H), 6.90 (br s, 1/2H), 6.89 (d, *J* = 8.0 Hz, 1/2H), 6.88 (d, *J* = 2.0 Hz, 1/2H), 6.81 (dd, *J* = 2.0, 8.0 Hz, 1/2H), 6.78 (dd, *J* = 2.0, 8.0 Hz, 1/2H), 4.64 (dd, *J* = 5.2, 10.8 Hz, 1/2H), 4.59 (dd, *J* = 5.6, 10.4 Hz, 1/2H), 3.87 (s, 3/2H), 3.86 (s, 3/2H), 3.82 (s, 3/2H), 3.81 (s, 3/2H), 3.53-3.40 (m, 2H).

*4.2.16. Compound (**5p**).* Two isomers (ratio ~ 1:1); Yield = 87% (411 mg); HRMS (ESI, M^++1) calcd for $C_{29}H_{29}O_4S$ 473.1787, found 473.1792; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.68-7.29 (m, 14H), 7.03 (d, *J* = 8.8 Hz, 1/2H), 6.93 (d, *J* = 8.8 Hz, 1/2H), 6.71 (d, *J* = 8.4 Hz, 1/2H), 6.62 (d, *J* = 8.8 Hz, 1/2H), 4.89 (dd, *J* = 6.0, 10.0 Hz, 1/2H), 4.84 (t, *J* = 8.4 Hz, 1/2H), 3.87 (s, 3/2H), 3.85 (s, 3/2H), 3.84 (s, 3/2H), 3.82 (s, 3/2H), 3.71 (s, 3/2H), 3.70 (s, 3/2H), 3.55-3.43 (m, 2H).

*4.2.17. Compound (**5q**).* Two isomers (ratio ~ 1:1); Yield = 72% (276 mg); HRMS (ESI, M^++1) calcd for $C_{22}H_{22}FO_3S$ 385.1274, found 385.1278; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.62-7.57 (m, 2H), 7.52-7.46 (m, 3H), 7.29-7.26 (m, 1H), 7.21-7.18 (m, 1H), 7.10 (d, *J* = 8.4 Hz, 1/2H), 7.03 (d, *J* = 8.0 Hz, 1/2H), 7.00-6.91 (m, 2H), 6.49-6.39 (m, 2H), 4.77 (dd, *J* = 5.6, 18.8 Hz, 1/2H), 4.72 (dd, *J* = 2.4, 18.8 Hz, 1/2H), 3.79 (s, 3/2H), 3.77 (s, 3/2H), 3.74 (s, 3/2H), 3.73 (s, 3/2H), 3.57-3.48 (m, 1H), 3.41-3.31 (m, 1H).

*4.2.18. Compound (**5r**).* Two isomers (ratio ~ 1:1); Yield = 80% (294 mg); HRMS (ESI, M^++1) calcd for $C_{21}H_{18}FO_3S$ 369.0961, found 369.0962; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.61-7.58 (m, 2H), 7.51-7.47 (m, 3H), 7.30-7.26 (m, 1H), 7.17-7.13 (m, 1H), 7.05-7.00 (m, 1H), 6.96-6.91 (m, 1H), 6.83 (dt, *J* = 1.6 Hz, 8.0 Hz, 1/2H), 6.78 (d, *J* = 8.0 Hz, 1/2H), 6.74 (d, *J* = 1.6 Hz, 1/2H), 6.70 (dd, *J* = 0.4, 8.0 Hz, 1/2H), 6.66 (d, *J* = 1.6 Hz, 1/2H), 6.64 (s, 1/2H), 5.91 (d, *J* = 1.2 Hz, 1H), 5.87 (d, *J* = 1.6 Hz, 1H), 4.55-4.47 (m, 1H), 3.42-3.27 (m, 2H).

*4.2.19. Compound (**5s**).* Two isomers (ratio ~ 1:1); Yield = 80% (307 mg); HRMS (ESI, M^++1) calcd for $C_{22}H_{22}FO_3S$ 385.1274, found 385.1278; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.59-7.55 (m, 2H), 7.48-7.42 (m, 3H), 7.31-7.26 (m, 1H), 7.16-7.13 (m, 1H), 7.03-6.99 (m, 1H), 6.93-6.88 (m, 1H), 6.86 (d, *J* = 2.0 Hz, 1/2H), 6.84 (d, *J* = 8.4 Hz, 1/2H), 6.78 (d, *J* = 2.0 Hz, 1/2H), 6.74 (d, *J* = 8.4 Hz, 1/2H), 6.71 (dd, *J* = 2.0, 8.4 Hz, 1/2H), 6.66 (d, *J* = 2.0 Hz, 1/2H), 4.56-4.48 (m, 1H), 3.83 (s, 3/2H), 3.82 (s, 3/2H), 3.78 (s, 3/2H), 3.77 (s, 3/2H), 3.44-3.29 (m, 2H).

*4.2.20. Compound (**5t**).* Two isomers (ratio ~ 1:1); Yield = 84% (348 mg); HRMS (ESI, M^++1) calcd for $C_{23}H_{24}FO_4S$ 415.1379, found 415.1382; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.62-7.58 (m, 2H), 7.52-7.45 (m, 3H), 7.29-7.26 (m, 1H), 7.21-7.17 (m, 1H), 7.00 (d, *J* = 8.4 Hz, 1/2H), 6.97-6.91 (m, 2H), 6.84 (d, *J* = 8.8 Hz, 1/2H), 6.67 (d, *J* = 8.4 Hz, 1/2H), 6.58 (d, *J* = 8.8 Hz, 1/2H), 4.81-4.71 (m, 1H), 3.84 (s, 3/2H), 3.83 (s, 3/2H), 3.80 (s, 3/2H), 3.79 (s, 3/2H), 3.63 (s, 3H), 3.50-3.30 (m, 2H).

*4.2.21. Compound (**5u**).* Two isomers (ratio ~ 1:1); Yield = 85% (337 mg); HRMS (ESI, M^++1) calcd for $C_{23}H_{25}O_4S$ 397.1474, found 397.1481; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.63-7.58 (m, 2H), 7.50-7.43 (m, 3H), 7.25 (d, *J* = 8.8 Hz, 1H), 7.17 (d, *J* = 8.8 Hz, 1H), 7.09 (d, *J* = 8.4 Hz, 1/2H), 7.05 (d, *J* = 9.2 Hz, 1/2H), 6.84 (d, *J* = 8.8 Hz, 1H), 6.80 (d, *J* = 8.4 Hz, 1H), 6.47-6.39 (m, 2H), 4.77 (dd, *J* = 6.0, 10.4 Hz, 1/2H), 4.66 (dd, *J* = 6.8, 10.0 Hz, 1/2H), 3.75 (s, 3/2H), 3.74 (s, 3/2H), 3.73 (s, 3H), 3.72 (s, 3/2H), 3.70 (s, 3/2H), 3.57-3.33 (m, 2H).

*4.2.22. Compound (**5v**).* Two isomers (ratio ~ 1:1); Yield = 90% (342 mg); HRMS (ESI, M^++1) calcd for $C_{22}H_{21}O_4S$ 381.1161, found 381.1163; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.61-7.58 (m, 2H), 7.49-7.45 (m, 3H), 7.24 (d, *J* = 8.8 Hz, 1H), 7.11 (d, *J* = 8.8 Hz, 1H), 6.90-6.75 (m, 4H), 6.67 (br s, 1H), 5.89 (d, *J* = 1.2 Hz, 1/2H), 5.88 (d, *J* = 1.2 Hz, 1/2H), 5.84 (s, 1H), 4.46 (dd, *J* = 5.6, 12.0 Hz, 1H), 3.76 (s, 3/2H), 3.72 (s, 3/2H), 3.42-3.27 (m, 2H).

*4.2.23. Compound (**5w**).* Two isomers (ratio ~ 1:1); Yield = 90% (356 mg); HRMS (ESI, M^++1) calcd for $C_{23}H_{25}O_4S$ 397.1474, found 379.1479; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.60-7.58 (m, 2H), 7.50-7.44 (m, 3H), 7.25 (d, *J* = 8.8 Hz, 1H), 7.12 (d, *J* = 8.8 Hz, 1H), 6.89-6.69 (m, 5H), 4.50-4.46 (m, 1H), 3.84 (s, 3/2H), 3.83 (s, 3/2H), 3.79 (s, 3/2H), 3.78 (s, 3/2H), 3.77 (s, 3/2H), 3.72 (s, 3/2H), 3.44-3.30 (m, 2H).

*4.2.24. Compound (**5x**).* Two isomers (ratio ~ 1:1); Yield = 93% (396 mg); HRMS (ESI, M^++1) calcd for $C_{24}H_{27}O_5S$ 427.1579, found 427.1582; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.63-7.57 (m, 2H), 7.51-7.43 (m, 3H), 7.23 (d, *J* = 8.4 Hz, 1H), 7.15 (d, *J* = 8.4 Hz, 1H), 6.93 (d, *J* = 8.8 Hz, 1H), 6.85 (d, *J* = 8.8 Hz, 1H), 6.84 (d, *J* = 8.4 Hz, 1/2H), 6.79 (d, *J* = 8.8 Hz, 1/2H), 6.65 (d, *J* = 8.4 Hz, 1/2H), 6.57 (d, *J* = 8.4 Hz, 1/2H), 4.76 (dd, *J* = 5.6, 10.4 Hz, 1/2H), 4.66 (t, *J* = 8.4 Hz, 1/2H), 3.82 (s, 3/2H), 3.81 (s, 3/2H), 3.79 (s, 3/2H), 3.78 (s, 3/2H), 3.74 (s, 3/2H), 3.72 (s, 3/2H), 3.64 (s, 3/2H), 3.62 (s, 3/2H), 3.45 (d, *J* = 8.0 Hz, 1H), 3.42-3.30 (m, 1H).

*4.3. A representative synthetic procedure of compounds **6a-x** is as follows:* 5% Pd/C (100 mg) was added to a solution of **5** (0.5 mmol) in EtOH (10 mL) at rt. The reaction mixture was stirred at rt for 20 min. The reaction mixture was filtered and washed by CH_2Cl_2 (2 x 10 mL). The combined organic layers were dried, filtered and evaporated to afford crude product under reduced pressure. Purification on silica gel (hexanes/EtOAc = 10/1~5/1) afforded **6a-x**.

*4.3.1. Compound (**6a**).* Yield = 89% (107 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{16}H_{17}O_2$ 241.1229, found 241.1232; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.33-7.25 (m, 5H), 7.17 (d, *J* = 8.0 Hz, 1H), 6.54-6.50 (m, 2H), 5.68 (d, *J* = 1.6 Hz, 1H), 5.32 (d, *J* = 1.6 Hz, 1H), 3.85 (s, 3H),

3.63 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 160.59, 158.11, 146.64, 141.48, 131.65, 129.65, 127.93 (2x), 127.16, 126.41 (2x), 115.05, 104.19, 99.00, 55.53, 55.34.

*4.3.2. Compound (**6b**).* Yield = 80% (90 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{15}H_{13}O_2$ 225.0916, found 225.0920; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.37-7.32 (m, 5H), 6.85 (d, *J* = 1.6 Hz, 1H), 6.84 (dd, *J* = 1.6, 8.0 Hz, 1H), 6.78 (d, *J* = 8.0 Hz, 1H), 5.98 (s, 2H), 5.40 (d, *J* = 1.2 Hz, 1H), 3.37 (d, *J* = 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 149.60, 147.24, 141.60, 135.73, 129.04, 128.30 (2x), 128.12 (2x), 127.70, 122.00, 113.35, 108.63, 107.91, 101.05.

*4.3.3. Compound (**6c**).* Yield = 82% (98 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{16}H_{17}O_2$ 241.1229, found 241.1232; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.39-7.33 (m, 5H), 6.91 (dd, *J* = 2.0, 8.8 Hz, 1H), 6.90 (s, 1H), 6.84 (d, *J* = 8.8 Hz, 1H), 5.43 (d, *J* = 1.2 Hz, 1H), 5.40 (d, *J* = 1.2 Hz, 1H), 3.91 (s, 3H), 3.84 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 149.68, 148.78, 148.51, 141.55, 134.29, 128.25 (2x), 128.06 (2x), 127.66, 120.88, 113.11, 111.39, 110.70, 55.84, 55.81.

*4.3.4. Compound (**6d**).* Yield = 89% (120 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{17}H_{19}O_3$ 271.1334, found 271.1336; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.35-7.25 (m, 5H), 6.99 (d, *J* = 8.4 Hz, 1H), 6.70 (d, *J* = 8.4 Hz, 1H), 5.63 (d, *J* = 1.6 Hz, 1H), 5.32 (d, *J* = 1.6 Hz, 1H), 3.90 (s, 3H), 3.87 (s, 3H), 3.53 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.46, 151.53, 146.91, 142.21, 141.84, 129.00, 127.96 (2x), 127.30, 126.54 (2x), 125.08, 115.18, 106.78, 60.68, 60.40, 55.88.

*4.3.5. Compound (**6e**).* Yield = 81% (103 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{17}H_{19}O_2$ 255.1385, found 255.1388; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.23 (d, *J* = 8.4 Hz, 2H), 7.17 (dd, *J* = 0.8, 8.0 Hz, 1H), 7.11 (d, *J* = 8.0 Hz, 2H), 6.53 (dd, *J* = 2.4, 8.0 Hz, 1H), 6.53 (br s, 1H), 5.68 (d, *J* = 1.6 Hz, 1H), 5.28 (d, *J* = 1.6 Hz, 1H), 3.86 (s, 3H), 3.66 (s, 3H), 2.36 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 160.49, 158.11, 146.38, 138.55, 136.84, 131.62, 128.64 (2x), 126.28 (2x), 123.98, 114.21, 104.14, 98.98, 55.56, 55.29, 21.07.

*4.3.6. Compound (**6f**).* Yield = 80% (95 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{16}H_{15}O_2$ 239.1072, found 239.1074; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.25 (d, *J* = 8.4 Hz, 2H), 7.13 (d, *J* = 8.4 Hz, 2H), 6.90-6.80 (m, 3H), 5.93 (s, 2H), 5.31 (d, *J* = 1.2 Hz, 1H), 5.28 (d, *J* = 1.2 Hz, 1H), 2.33 (s, 3H).

*4.3.7. Compound (**6g**).* Yield = 74% (94 mg); Colorless solid; mp = 109-110 °C (recrystallized from hexanes and EtOAc); HRMS (ESI, M^++1) calcd for $C_{17}H_{19}O_2$ 255.1385, found 255.1392; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.28 (d, *J* = 8.0 Hz, 2H), 7.16 (d, *J* = 8.0 Hz, 2H), 6.92 (dd, *J* = 2.0, 8.4 Hz, 1H), 6.91 (s, 1H), 6.84 (d, *J* = 8.4 Hz, 1H), 5.38 (s, 2H), 3.91 (s, 3H), 3.85 (s, 3H), 2.39 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 149.48, 148.66, 148.42, 138.59, 137.39, 134.42, 128.72 (2x), 128.08 (2x), 120.82, 112.41, 111.36, 110.60, 55.77, 55.74, 21.06.

*4.3.8. Compound (**6h**).* Yield = 86% (122 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{18}H_{21}O_3$ 285.1491, found 285.1493; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.21 (d, *J* = 8.4 Hz, 2H), 7.10 (d, *J* = 8.0 Hz, 2H), 6.95 (d, *J* = 8.8 Hz, 1H), 6.68 (d, *J* = 8.4 Hz, 1H), 5.60 (d, *J* = 1.6 Hz, 1H), 5.24 (d, *J* = 1.6 Hz, 1H), 3.89 (s, 3H), 3.86 (s, 3H), 3.54 (s, 3H), 2.34 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.43 (2x), 151.64, 146.68, 142.29, 138.94, 137.13, 129.25, 128.75 (2x), 126.48 (2x), 125.15, 114.48, 106.82, 60.80, 60.57, 21.12.

*4.3.9. Compound (**6i**).* Yield = 81% (117 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{20}H_{19}O_2$ 291.1385, found 291.1386; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.80-7.72 (m, 2H), 7.30 (d, *J* = 8.8 Hz, 1H), 7.66 (d, *J* = 1.6 Hz, 1H), 7.52 (dd, *J* = 1.6, 8.8 Hz, 1H), 7.43-7.39 (m, 2H), 7.21 (d, *J* = 8.0 Hz, 1H), 6.54 (dd, *J* = 2.8, 8.4 Hz, 1H), 6.51 (d, *J* = 2.4 Hz, 1H), 5.80 (d, *J* = 1.6 Hz, 1H), 5.40 (d, *J* = 1.2 Hz, 1H), 3.85 (s, 3H), 3.58 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 160.68, 158.19, 146.60, 138.93, 133.35, 132.80, 131.75, 128.20, 127.46, 127.42, 125.83, 125.58, 125.36, 124.89, 123.75, 115.66, 104.23, 99.01, 55.53, 55.34.

*4.3.10. Compound (**6j**).* Yield = 76% (104 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{19}H_{15}O_2$ 275.1072, found 275.1077; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.87-7.81 (m, 4H), 7.52-7.49 (m, 3H), 6.91 (dd, *J* = 2.0, 5.2 Hz, 1H), 6.88 (d, *J* = 1.6 Hz, 1H), 6.82 (d, *J* = 8.0 Hz, 1H), 6.00 (s, 2H), 5.52 (d, *J* = 1.2 Hz, 1H), 5.51 (d, *J* = 0.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 149.58, 147.55, 147.32, 139.00, 135.71, 133.24, 132.94, 128.15, 127.63, 127.56, 127.27, 126.45, 126.13, 126.00, 122.12, 113.90, 108.74, 107.98, 101.08.

*4.3.11. Compound (**6k**).* Yield = 80% (116 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{20}H_{19}O_2$ 291.1385, found 291.1386; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.88-7.80 (m, 3H), 7.60-7.32 (m, 4H), 6.98-6.94 (m, 2H), 6.87 (d, *J* = 8.4 Hz, 1H), 5.54 (d, *J* = 1.6 Hz, 1H), 5.53 (d, *J* = 1.2 Hz, 1H), 3.93 (s, 3H), 3.84 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 149.66, 148.83, 148.54, 136.51, 134.27, 129.34, 128.71, 128.11, 127.55, 127.52, 127.21, 126.42, 126.08, 125.95, 120.96, 113.67, 111.45, 110.74, 55.84, 55.81.

*4.3.12. Compound (**6l**).* Yield = 85% (136 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{21}H_{21}O_3$ 321.1491, found 321.1493; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.84-7.77 (m, 2H), 7.81 (d, *J* = 8.8 Hz, 1H), 7.71 (d, *J* = 1.6 Hz, 1H), 7.56 (dd, *J* = 1.6, 8.8 Hz, 1H), 7.46-7.44 (m, 2H), 7.04 (d, *J* = 8.4 Hz, 1H), 6.73 (d, *J* = 8.4 Hz, 1H), 5.78 (d, *J* = 1.6 Hz, 1H), 5.42 (d, *J* = 1.6 Hz, 1H), 3.93 (s, 3H), 3.89 (s, 3H), 3.52 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.59, 151.67, 146.82, 142.31, 139.22, 133.25, 132.83, 128.98, 128.13, 127.58, 127.49, 125.96, 125.69, 125.48, 125.21, 124.96, 115.82, 106.90, 60.75, 60.54, 55.95.

*4.3.13. Compound (**6m**).* Yield = 78% (123 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{22}H_{21}O_2$ 317.1542,

found 317.1538; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.67-7.64 (m, 2H), 7.59-7.54 (m, 2H), 7.49-7.34 (m, 5H), 7.24 (d, *J* = 8.0 Hz, 1H), 6.58 (dd, *J* = 2.4, 8.0 Hz, 1H), 6.57 (br s, 1H), 5.79 (d, *J* = 1.2 Hz, 1H), 5.38 (d, *J* = 1.2 Hz, 1H), 3.89 (s, 3H), 3.69 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 160.63, 158.10, 140.79, 140.37, 139.84, 131.65, 128.68 (2x), 127.11, 126.88 (2x), 126.80 (2x), 126.62 (2x), 126.16, 123.68, 115.04, 104.21, 98.98, 55.53, 55.31.

*4.3.14. Compound (**6n**).* Yield = 74% (111 mg); Colorless solid; mp = 99-100 °C (recrystallized from hexanes and EtOAc); HRMS (ESI, M^++1) calcd for $C_{21}H_{17}O_2$ 301.1229, found 301.1230; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.64-7.56 (m, 4H), 7.48-7.34 (m, 5H), 6.88 (d, *J* = 0.8 Hz, 1H), 6.87 (dd, *J* = 1.2, 7.6 Hz, 1H), 6.80 (dd, *J* = 1.2, 7.6 Hz, 1H), 5.99 (s, 2H), 5.43 (d, *J* = 1.2 Hz, 1H), 5.41 (d, *J* = 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 149.20, 147.52, 147.30, 140.71, 140.57, 140.52, 128.77 (2x), 135.68, 128.68 (2x), 127.32, 127.02 (2x), 126.85 (2x), 122.07, 113.40, 108.72, 107.97, 101.08.

*4.3.15. Compound (**6o**).* Yield = 80% (126 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{22}H_{21}O_2$ 317.1542, found 317.1543; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.67-7.55 (m, 4H), 7.50-7.32 (m, 5H), 6.97 (dd, *J* = 2.0, 8.0 Hz, 1H), 6.96 (br s, 1H), 6.88 (d, *J* = 8.0 Hz, 1H), 5.49 (d, *J* = 1.6 Hz, 1H), 5.43 (d, *J* = 1.2 Hz, 1H), 3.93 (s, 3H), 3.87 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 149.20, 148.76, 148.48, 140.40, 136.45, 134.16, 129.30, 128.68 (2x), 128.59 (2x), 127.24, 126.86 (2x), 126.71 (2x), 120.89, 113.11, 111.39, 110.68, 55.78 (2x).

*4.3.16. Compound (**6p**).* Yield = 81% (140 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{23}H_{23}O_3$ 347.1647, found 347.1648; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.65 (d, *J* = 8.0 Hz, 2H), 7.60 (d, *J* = 8.0 Hz, 2H), 7.49-7.44 (m, 4H), 7.39-7.35 (m, 1H), 7.04 (d, *J* = 8.4 Hz, 1H), 6.74 (d, *J* = 8.4 Hz, 1H), 5.74 (d, *J* = 1.2 Hz, 1H), 5.38 (d, *J* = 1.2 Hz, 1H), 3.94 (s, 3H), 3.93 (s, 3H), 3.63 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.49, 151.55, 146.36, 142.21, 140.68, 140.62, 140.03, 128.86, 128.64 (2x), 127.11, 126.93 (2x), 126.82 (2x), 126.65 (2x), 125.10, 115.18, 106.83, 60.71, 60.53, 55.87.

*4.3.17. Compound (**6q**).* Yield = 76% (98 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{16}H_{16}FO_2$ 259.1134, found 259.1139; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.37-7.32 (m, 2H), 7.23 (d, *J* = 7.6 Hz, 1H), 7.05-6.99 (m, 2H), 6.59 (dd, *J* = 2.8, 8.4 Hz, 1H), 6.57 (br s, 1H), 5.67 (d, *J* = 1.2 Hz, 1H), 5.36 (d, *J* = 1.2 Hz, 1H), 3.88 (s, 3H), 3.66 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.08 (d, *J* = 244.1 Hz), 160.68, 157.93, 145.70, 137.59 (d, *J* = 3.0 Hz), 131.47, 127.90 (d, *J* = 8.3 Hz, 2x), 123.40, 114.68, 114.59 (d, *J* = 21.2 Hz, 2x), 104.14, 98.85, 55.23, 55.10.

*4.3.18. Compound (**6r**).* Yield = 87% (105 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{15}H_{12}FO_2$ 243.0821, found 243.0823; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.34-7.30 (m, 2H), 7.06-7.01 (m, 2H), 6.83-6.77 (m, 3H), 5.98 (s, 2H), 5.38 (d, *J* = 0.8 Hz, 1H), 5.32 (d, *J* = 0.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.47 (d, *J* = 244.8 Hz), 148.58, 148.54, 147.35, 137.63 (d, *J* = 3.0 Hz), 135.50, 129.89 (d, *J* = 8.4 Hz, 2x), 121.92, 114.97 (d, *J* = 20.5 Hz, 2x), 113.25, 108.51, 107.94, 101.08.

*4.3.19. Compound (**6s**).* Yield = 82% (106 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{16}H_{16}FO_2$ 259.1134, found 259.1138; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.34-7.30 (m, 2H), 7.03-6.99 (m, 2H), 6.87 (dd, *J* = 2.0, 8.8 Hz, 1H), 6.86 (br s, 1H), 6.82 (d, *J* = 8.8 Hz, 1H), 5.38 (d, *J* = 0.8 Hz, 1H), 5.33 (d, *J* = 1.2 Hz, 1H), 3.89 (s, 3H), 3.83 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.34 (d, *J* = 244.8 Hz), 148.57, 148.46, 137.53 (d, *J* = 3.7 Hz), 136.43, 129.78 (d, *J* = 7.5 Hz, 2x), 129.44, 120.71, 114.83 (d, *J* = 21.2 Hz, 2x), 112.92, 111.17, 110.63, 55.74, 55.70.

*4.3.20. Compound (**6t**).* Yield = 83% (120 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{17}H_{18}FO_3$ 289.1240, found 289.1245; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.31-7.26 (m, 2H), 7.01-6.95 (m, 3H), 6.68 (d, *J* = 8.4 Hz, 1H), 5.55 (d, *J* = 1.6 Hz, 1H), 5.27 (d, *J* = 1.2 Hz, 1H), 3.89 (s, 3H), 3.86 (s, 3H), 3.54 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.15 (d, *J* = 244.8 Hz), 153.57, 151.39, 145.94, 142.20, 137.91 (d, *J* = 3.0 Hz), 128.66, 128.05 (d, *J* = 7.5 Hz, 2x), 124.94, 114.94, 114.71 (d, *J* = 21.3 Hz, 2x), 106.81, 60.61, 60.36, 55.79.

*4.3.21. Compound (**6u**).* Yield = 82% (111 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{17}H_{19}O_3$ 271.1334, found 271.1335; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.25 (d, *J* = 8.8 Hz, 2H), 7.15 (dd, *J* = 0.8, 8.0 Hz, 1H), 6.82 (d, *J* = 8.8 Hz, 2H), 6.52 (dd, *J* = 2.4, 8.0 Hz, 1H), 6.51 (s, 1H), 5.61 (d, *J* = 1.6 Hz, 1H), 5.20 (d, *J* = 1.6 Hz, 1H), 3.85 (s, 3H), 3.81 (s, 3H), 3.65 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 160.48, 158.90, 158.06, 145.92, 133.97, 132.13, 131.58, 127.52 (2x), 123.99, 113.27 (2x), 104.13, 98.94, 55.56, 55.31, 55.15.

*4.3.22. Compound (**6v**).* Yield = 78% (99 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{16}H_{15}O_3$ 255.1021, found 255.1022; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.28 (d, *J* = 8.8 Hz, 2H), 6.89-6.77 (m, 5H), 5.97 (s, 2H), 5.30 (d, *J* = 1.2 Hz, 1H), 5.29 (d, *J* = 1.2 Hz, 1H), 3.83 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.30, 149.04, 147.41, 147.16, 136.02, 134.06, 129.40 (2x), 121.96, 113.45 (2x), 112.04, 108.69, 107.86, 101.01, 55.24.

*4.3.23. Compound (**6w**).* Yield = 78% (105 mg); Colorless solid; mp = 102-103 °C (recrystallized from hexanes and EtOAc); HRMS (ESI, M^++1) calcd for $C_{17}H_{19}O_3$ 271.1334, found 271.1336; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.30 (d, *J* = 8.8 Hz, 2H), 6.92-6.82 (m, 5H), 5.33 (d, *J* = 1.2 Hz, 1H), 5.31 (d, *J* = 1.2 Hz, 1H), 3.90 (s, 3H), 3.84 (s, 3H), 3.83 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.25, 149.11, 148.67, 148.42, 134.57, 133.99, 129.36 (2x), 120.82, 113.40 (2x), 111.76, 111.42, 110.63, 55.82, 55.78, 55.18. Single-crystal X-Ray diagram: crystal of compound **6w** was grown by slow diffusion of EtOAc into a solution of compound **6w** in CH_2Cl_2 to yield colorless prisms. The compound crystallizes in the monoclinic crystal system, space group P 21/c, *a* = 13.4937(12) Å, *b* = 16.3772(15) Å, *c* = 6.6323(5) Å, *V* = 1435.9(2) Å^3, *Z* = 4, d_{calcd}= 1.250

g/cm^3, F(000) = 576, 2θ range 1.540~26.437^o, R indices (all data) R1 = 0.0814, wR2 = 0.1178.

*4.3.24. Compound (**6x**).* Yield = 82% (123 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{18}H_{21}O_4$ 301.1440, found 301.1445; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.26 (d, J = 8.8 Hz, 2H), 6.96 (d, J = 8.4 Hz, 1H), 6.84 (d, J = 8.8 Hz, 2H), 6.68 (d, J = 8.4 Hz, 1H), 5.56 (d, J = 1.6 Hz, 1H), 5.20 (d, J = 1.6 Hz, 1H), 3.88 (s, 3H), 3.87 (s, 3H), 3.79 (s, 3H), 3.57 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.93, 153.27, 151.43, 146.12, 142.10, 134.19, 129.08, 127.56 (2x), 124.97, 113.40, 113.22 (2x), 106.70, 60.60, 60.42, 55.76, 54.97.

*4.4. A representative synthetic procedure of compounds **8a-e** is as follows:* Freshly prepared *m*CPBA (87 mg, 0.5 mmol) was added to a solution of **2a-d** or **2f** (0.5 mmol) in CH_2Cl_2 (10 mL) at rt. The reaction mixture was stirred at rt for 10 min. **4a** (35 mg, 0.25 mmol) was added to the reaction mixture at rt. Then, $BF_3{\cdot}OEt_2$ (71 mg, 0.5 mmol) was added to the reaction mixture at rt. After the reaction mixture was stirred at rt for 20 min, saturated $NaHCO_3$ solution (10 mL) was added to the reaction mixture. The reaction mixture was extracted with CH_2Cl_2 (3 x 20 mL). The combined organic layers were washed with brine, dried, filtered and evaporated to afford crude product under reduced pressure. Without further purification, 5% Pd/C (100 mg) was added to the resulting reaction mixture in EtOH (10 mL) at rt. The reaction mixture was stirred at rt for 20 min. The reaction mixture was filtered and washed by CH_2Cl_2 (2 x 10 mL). The combined organic layers were dried, filtered and evaporated to afford crude product under reduced pressure. Purification on silica gel (hexanes/EtOAc = 10/1~5/1) afforded **8a-e**.

*4.4.1. Compound (**8a**).* Yield = 68% (116 mg); Colorless solid; mp = 105-106 ^{o}C (recrystallized from hexanes and EtOAc); HRMS (ESI, M^++1) calcd for $C_{24}H_{23}O_2$ 343.1698, found 343.1702; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.44-7.41 (m, 4H), 7.38-7.29 (m, 6H), 7.23 (s, 1H), 6.57 (s, 1H), 5.75 (d, J = 1.6 Hz, 2H), 5.41 (d, J = 1.6 Hz, 2H), 3.73 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.69 (2x), 146.38 (2x), 141.38 (2x), 133.57 (2x), 127.91 (4x), 127.16 (2x), 126.38 (4x), 123.05, 115.24 (2x), 96.26, 55.76 (2x). Single-crystal X-Ray diagram: crystal of compound **8a** was grown by slow diffusion of EtOAc into a solution of compound **8a** in CH_2Cl_2 to yield colorless prisms. The compound crystallizes in the monoclinic crystal system, space group C 2/c, a = 28.8343(16) Å, b = 11.4926(6) Å, c = 23.0676(13) Å, V = 7574.7(7) Å^3, Z = 16, d_{calcd}= 1.208 g/cm^3, F(000) = 2944, 2θ range 1.425~26.437^o, R indices (all data) R1 = 0.1101, wR2 = 0.1990.

*4.4.2. Compound (**8b**).* Yield = 62% (115 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{26}H_{27}O_2$ 371.2011, found 371.2018; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.32 (d, J = 8.0 Hz, 4H), 7.17 (d, J = 8.0 Hz, 4H), 6.58 (s, 2H), 5.73 (d, J = 1.2 Hz, 2H), 5.35 (d, J = 1.2 Hz, 2H), 3.75 (s, 6H), 2.41 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.61 (2x), 146.13 (2x), 138.45 (2x), 136.82 (2x), 133.59 (2x), 128.63 (4x), 126.27 (4x), 123.20, 114.39 (2x), 96.29, 55.82 (2x), 21.07 (2x).

*4.4.3. Compound (**8c**).* Yield = 70% (141 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{26}H_{27}O_4$ 403.1909, found 403.1915; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.27 (d, J = 8.8 Hz, 4H), 7.11 (s, 1H), 6.82 (d, J = 8.8 Hz, 4H), 6.50 (s, 1H), 5.60 (d, J = 1.6 Hz, 2H), 5.21 (d, J = 1.2 Hz, 2H), 3.81 (s, 6H), 3.70 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.94 (2x), 157.63 (2x), 145.74 (2x), 134.01 (2x), 133.61 (2x), 127.58 (4x), 123.32, 113.55 (2x), 113.33 (4x), 96.35, 55.94 (2x), 55.22 (2x).

*4.4.4. Compound (**8d**).* Yield = 68% (168 mg); Colorless solid; mp = 180-181 ^{o}C (recrystallized from hexanes and EtOAc); HRMS (ESI, M^++1) calcd for $C_{36}H_{31}O_2$ 495.2324, found 495.2326; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.67-7.58 (m, 8H), 7.49-7.33 (m, 10H), 7.25 (s, 1H), 6.59 (s, 1H), 5.80 (d, J = 1.2 Hz, 2H), 5.42 (d, J = 1.2 Hz, 2H), 3.76 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.79 (2x), 145.89 (2x), 140.80 (2x), 140.33 (2x), 139.90 (2x), 133.65 (2x), 128.70 (4x), 127.13 (2x), 126.90 (4x), 126.84 (4x), 126.67 (4x), 123.01, 115.33 (2x), 96.27, 55.87 (2x). Single-crystal X-Ray diagram: crystal of compound **8d** was grown by slow diffusion of EtOAc into a solution of compound **8d** in CH_2Cl_2 to yield colorless prisms. The compound crystallizes in the triclinic crystal system, space group P - 1, a = 8.414(10) Å, b = 12.311(14) Å, c = 27.28(3) Å, V = 2808(6) Å^3, Z = 4, d_{calcd}= 1.170 g/cm^3, F(000) = 1048, 2θ range 1.502~26.141^o, R indices (all data) R1 = 0.1260, wR2 = 0.1471.

*4.4.5. Compound (**8e**).* Yield = 62% (137 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{32}H_{27}O_2$ 443.2011, found 443.2015; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.88-7.80 (m, 8H), 7.62 (dd, J = 2.0, 8.8 Hz, 2H), 7.52-7.46 (m, 4H), 7.32 (s, 1H), 6.61 (s, 1H), 5.87 (d, J = 1.2 Hz, 2H), 5.51 (d, J = 1.6 Hz, 2H), 3.73 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.90 (2x), 146.37 (2x), 138.95 (2x), 133.81 (2x), 133.35 (2x), 132.82 (2x), 128.21 (2x), 127.49 (2x), 127.45 (2x), 125.86 (2x), 125.61 (2x), 125.39 (2x), 124.95 (2x), 123.03, 115.97 (2x), 96.27, 55.86 (2x).

*4.5. A representative synthetic procedure of compounds **8f-i** is as follows:* Freshly prepared *m*CPBA (87 mg, 0.5 mmol) was added to a solution of **2a** (115 mg, 0.5 mmol) in CH_2Cl_2 (10 mL) at rt. The reaction mixture was stirred at rt for 10 min. **4a** (69 mg, 0.5 mmol) was added to the reaction mixture at rt. Then, $BF_3{\cdot}OEt_2$ (71 mg, 0.5 mmol) was added to the reaction mixture at rt. After the reaction mixture was stirred at rt for 20 min, **3b-e** (0.5 mmol) and $BF_3{\cdot}OEt_2$ (71 mg, 0.5 mmol) in CH_2Cl_2 (1 mL) was added to the reaction mixture at rt. Saturated $NaHCO_3$ solution (10 mL) was added to the reaction mixture. The reaction mixture was extracted with CH_2Cl_2 (3 x 20 mL). The combined organic layers were washed with brine, dried, filtered and evaporated to afford crude product under reduced pressure. Without further purification, 5% Pd/C (100 mg) was added to the resulting reaction mixture in EtOH (10 mL) at rt. The reaction mixture was stirred at rt

for 20 min. The reaction mixture was filtered and washed by CH_2Cl_2 (2 x 10 mL). The combined organic layers were dried, filtered and evaporated to afford crude product under reduced pressure. Purification on silica gel (hexanes/EtOAc = 10/1~5/1) afforded **8f-i**.

*4.5.1. Compound (**8f**).* Yield = 57% (103 mg); Colorless solid; mp = 94-95 ^oC (recrystallized from hexanes and EtOAc); HRMS (ESI, M^++1) calcd for $C_{24}H_{22}FO_2$ 361.1604, found 361.1608; ^1H NMR (400 MHz, $CDCl_3$): δ 7.43-7.29 (m, 7H), 7.22 (s, 1H), 7.06-7.00 (m, 2H), 6.56 (s, 1H), 5.75 (d, *J* = 1.6 Hz, 1H), 5.66 (d, *J* = 1.2 Hz, 1H), 5.41 (d, *J* = 1.2 Hz, 1H), 5.38 (d, *J* = 1.2 Hz, 1H), 3.73 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.13 (d, *J* = 244.1 Hz), 157.83, 157.60, 146.32, 145.46, 141.34, 137.56 (d, *J* = 3.0 Hz), 133.45, 127.96 (d, *J* = 9.1 Hz, 2x), 127.91 (2x), 127.18, 126.36 (2x), 123.09, 122.76, 115.26, 114.99, 114.67 (d, *J* = 21.2 Hz, 2x), 96.16, 55.71, 55.65. Single-crystal X-Ray diagram: crystal of compound **8f** was grown by slow diffusion of EtOAc into a solution of compound **8f** in CH_2Cl_2 to yield colorless prisms. The compound crystallizes in the monoclinic crystal system, space group P 21/n, *a* = 10.9062(8) Å, *b* = 23.0224(16) Å, *c* = 15.7346(11) Å, *V* = 3927.7(5) $Å^3$, *Z* = 8, d_{calcd}= 1.219 g/cm^3, *F*(000) = 1520, 2θ range 1.574~26.427^o, R indices (all data) R1 = 0.1704, wR2 = 0.1560.

*4.5.2. Compound (**8g**).* Yield = 68% (121 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{25}H_{25}O_2$ 357.1855, found 357.1859; ^1H NMR (400 MHz, $CDCl_3$): δ 7.37-7.24 (m, 7H), 7.14 (s, 1H), 7.11 (d, *J* = 8.4 Hz, 2H), 6.51 (s, 1H), 5.68 (d, *J* = 1.6 Hz, 1H), 5.70 (d, *J* = 1.6 Hz, 1H), 5.34 (d, *J* = 1.2 Hz, 1H), 5.28 (d, *J* = 1.2 Hz, 1H), 3.71 (s, 3H), 3.69 (s, 3H), 2.35 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.75, 157.63, 146.44, 146.14, 141.45, 138.47, 136.93, 133.64, 128.69 (2x), 127.95 (2x), 127.19, 126.44 (2x), 126.31 (2x), 123.30, 123.09, 115.27, 114.47, 96.35, 55.93, 55.86, 21.13.

*4.5.3. Compound (**8h**).* Yield = 69% (144 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{30}H_{27}O_2$ 419.2011, found 419.2020; ^1H NMR (400 MHz, $CDCl_3$): δ 7.64-7.61 (m, 2H), 7.56-7.54 (m, 2H), 7.46-7.27 (m, 10H), 7.18 (s, 1H), 6.53 (s, 1H), 5.75 (d, *J* = 1.2 Hz, 1H), 5.70 (d, *J* = 1.6 Hz, 1H), 5.36 (d, *J* = 1.2 Hz, 1H), 5.35 (d, *J* = 1.6 Hz, 1H), 3.72 (s, 3H), 3.70 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.79, 157.75, 146.41, 145.92, 141.42, 140.84, 140.33, 139.91, 133.65, 128.71 (2x), 127.97 (2x), 127.23, 127.15, 126.93 (2x), 126.83 (2x), 126.68 (2x), 126.44 (2x), 123.14, 122.98, 115.33, 115.30, 96.29, 55.90, 55.87.

*4.5.4. Compound (**8i**).* Yield = 64% (125 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{28}H_{25}O_2$ 393.1855, found 393.1859; ^1H NMR (400 MHz, $CDCl_3$): δ 7.87-7.81 (m, 3H), 7.77 (d, *J* = 1.6 Hz, 1H), 7.60 (dd, *J* = 1.6, 8.4 Hz, 1H), 7.51-7.46 (m, 1H), 7.44-7.29 (m, 7H), 6.58 (s, 1H), 5.86 (d, *J* = 1.6 Hz, 1H), 5.74 (d, *J* = 1.6 Hz, 1H), 5.49 (d, *J* = 1.6 Hz, 1H), 5.42 (d, *J* = 1.6 Hz, 1H), 3.75 (s, 3H), 3.70 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.82, 146.42, 146.37, 141.46, 138.92, 133.72, 133.35, 132.82, 128.66, 128.21, 127.97 (2x), 127.49, 127.44, 127.22, 126.46 (2x), 125.84, 125.60, 125.37, 124.93, 123.14, 123.02, 115.92, 115.35, 96.32, 55.85 (2x).

*4.6. A representative synthetic procedure of compounds **12a-f** is as follows:* $Hg(OTf)_2$ (50 mg, 0.1 mmol) was added to a solution of **6a**, **6e**, **6l**, **6m**, **6q** and **6u** (0.5 mmol) in $MeNO_2$ (5 mL) at 25 ^oC. The reaction mixture was stirred at 25 ^oC for 8 h. The reaction mixture was concentrated and extracted with CH_2Cl_2 (3 x 10 mL). The combined organic layers were washed with brine, dried, filtered and evaporated to afford crude product under reduced pressure. Purification on silica gel (hexanes/EtOAc = 20/1~8/1) afforded **12a-f**.

*4.6.1. Compound (**12a**).*[22a] Yield = 75% (84 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{15}H_{13}O_2$ 225.0916, found 225.0917; ^1H NMR (400 MHz, $CDCl_3$): δ 7.75 (d, *J* = 8.8 Hz, 1H), 7.74 (s, 1H), 7.69-7.65 (m, 2H), 7.52-7.48 (m, 2H), 7.42-7.37 (m, 1H), 7.12 (d, *J* = 2.4 Hz, 1H), 6.99 (dd, *J* = 2.4, 8.8 Hz, 1H), 3.90 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.14, 156.81, 140.27, 132.17, 128.88 (2x), 127.32, 127.30 (2x), 122.06, 120.50, 119.75, 112.04, 96.13, 55.65.

*4.6.2. Compound (**12b**).* Yield = 70% (83 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{16}H_{15}O_2$ 239.1072, found 239.1079; ^1H NMR (400 MHz, $CDCl_3$): δ 7.69 (d, *J* = 8.4 Hz, 1H), 7.69 (s, 1H), 7.54 (d, *J* = 8.0 Hz, 2H), 7.28 (d, *J* = 8.4 Hz, 2H), 7.08 (d, *J* = 2.4 Hz, 1H), 6.95 (dd, *J* = 2.4, 8.8 Hz, 1H), 3.88 (s, 3H), 2.42 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.10, 156.79, 140.03, 137.13, 129.60 (2x), 129.24, 127.21 (2x), 121.97, 120.54, 119.94, 111.97, 96.13, 55.71, 21.22.

*4.6.3. Compound (**12c**).* Yield = 78% (107 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{19}H_{15}O_2$ 275.1072, found 275.1078; ^1H NMR (400 MHz, $CDCl_3$): δ 8.12 (s, 1H), 7.94 (d, *J* = 8.8 Hz, 1H), 7.90 (dt, *J* = 1.6, 8.4 Hz, 2H), 7.84 (s, 1H), 7.83 (d, *J* = 8.8 Hz, 1H), 7.74 (dd, *J* = 1.6, 8.4 Hz, 1H), 7.56-7.59 (m, 2H), 7.12 (d, *J* = 2.4 Hz, 1H), 7.00 (dd, *J* = 2.4, 8.8 Hz, 1H), 3.91 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.22, 156.93, 140.71, 133.70, 132.63, 129.64, 128.56, 127.90, 127.74, 126.40, 125.90, 125.67 (2x), 122.07, 120.63, 119.82, 112.16, 96.20, 55.71.

*4.6.4. Compound (**12d**).* Yield = 73% (110 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{21}H_{17}O_2$ 301.1229, found 301.1223; ^1H NMR (400 MHz, $CDCl_3$): δ 7.81-7.67 (m, 8H), 7.54-7.51 (m, 2H), 7.45-7.41 (m, 1H), 7.15 (d, *J* = 2.0 Hz, 1H), 7.03 (dd, *J* = 2.4, 8.8 Hz, 1H), 3.92 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.16, 156.86, 140.95, 140.36, 140.08, 131.15, 128.79 (2x), 127.54 (2x), 127.33, 127.18, 126.93 (2x), 121.64, 120.53, 119.68, 112.10, 96.15, 96.15, 55.62.

*4.6.5. Compound (**12e**).* Yield = 71% (86 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{15}H_{12}FO_2$ 243.0821, found 243.0822; ^1H NMR (400 MHz, $CDCl_3$): δ 7.67 (s, 1H), 7.64 (d, *J* = 8.8 Hz, 1H), 7.60-7.57 (m, 2H), 7.19-7.14 (m, 2H), 7.08 (d, *J* = 2.4 Hz, 1H), 6.96 (dd, *J* = 2.4, 8.8 Hz,

1H), 3.88 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.16 (d, *J* = 244.9 Hz), 158.21, 156.75, 140.10, 128.87 (d, *J* = 8.4 Hz, 2x), 128.17 (d, *J* = 3.0 Hz), 121.18, 120.23, 119.66, 115.85 (d, *J* = 21.2 Hz, 2x), 112.15, 96.13, 55.67.

*4.6.6. Compound (**12f**).*[22b] Yield = 73% (93 mg); Colorless gum; HRMS (ESI, M^++1) calcd for $C_{16}H_{15}O_3$ 255.1021, found 254.0934; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.71 (d, *J* = 8.8 Hz, 1H), 7.68 (s, 1H), 7.59 (d, *J* = 8.8 Hz, 2H), 7.11 (d, *J* = 2.0 Hz, 1H), 7.04 (d, *J* = 8.8 Hz, 2H), 6.98 (dd, *J* = 2.0, 8.8 Hz, 1H), 3.89 (s, 3H), 3.88 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.94, 158.04, 156.69, 139.59, 128.37 (2x), 124.51, 121.58, 120.38, 119.94, 114.30 (2x), 111.86, 96.06, 55.56, 55.18.

*4.7. Compound (**13**).* Freshly prepared *m*CPBA (156 mg, 0.9 mmol) was added to a solution of **2a** (207 mg, 0.9 mmol) in CH_2Cl_2 (10 mL) at rt. The reaction mixture was stirred at rt for 10 min. **4e** (50 mg, 0.3 mmol) was added to the reaction mixture at rt. Then, $BF_3{\cdot}OEt_2$ (130 mg, 0.9 mmol) was added to the reaction mixture at rt. After the reaction mixture was stirred at rt for 20 min, saturated $NaHCO_3$ solution (10 mL) was added to the reaction mixture. The reaction mixture was extracted with CH_2Cl_2 (3 x 20 mL). The combined organic layers were washed with brine, dried, filtered and evaporated to afford crude product under reduced pressure. Without further purification, 5% Pd/C (100 mg) was added to the resulting reaction mixture in EtOH (10 mL) at rt. The reaction mixture was stirred at rt for 20 min. The reaction mixture was filtered and washed by CH_2Cl_2 (2 x 10 mL). The combined organic layers were dried, filtered and evaporated to afford crude product under reduced pressure. Purification on silica gel (hexanes/EtOAc = 10/1~5/1) afforded **13**. Yield = 40% (45 mg); Colorless solid; mp = 100-102 °C (recrystallized from hexanes and EtOAc); HRMS (ESI, M^++1) calcd for $C_{25}H_{25}O_3$ 373.1804, found 373.1805; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.42-7.40 (m, 4H), 7.33-7.23 (m, 6H), 6.43 (s, 1H), 5.98 (d, *J* = 1.2 Hz, 2H), 5.35 (d, *J* = 1.2 Hz, 2H), 3.77 (s, 6H), 3.35 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.88 (2x), 157.49, 141.25 (2x), 140.96 (2x), 128.05 (4x), 127.18 (2x), 125.83 (4x), 117.28 (2x), 116.59 (2x), 91.85, 61.03, 56.00 (2x). Single-crystal X-Ray diagram: crystal of compound **13** was grown by slow diffusion of EtOAc into a solution of compound **13** in CH_2Cl_2 to yield colorless prisms. The compound crystallizes in the orthorhombic crystal system, space group P n a 21, *a* = 20.8499(13) Å, *b* = 12.3895(7) Å, *c* = 7.9367(4) Å, *V* = 2050.2(2) Å^3, *Z* = 4, d_{calcd}= 1.207 g/cm^3, *F*(000) = 792, 2θ range 1.912~26.398°, R indices (all data) R1 = 0.1245, wR2 = 0.1742.

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Supplementary Material

Experimental procedure and scanned photocopies of NMR ($CDCl_3$) spectral data were supported.