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Phosphorous Acid Catalyzed Alkylation of Phenols with Alkenes

Shaofeng Wu,[a] Jianyu Dong,[b] Dan Zhou,[a] Wan Wang,[a] Long Liu,[a,c] and Yongbo Zhou,[a,*]

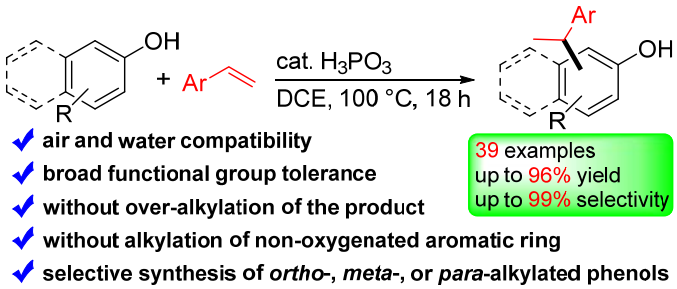
[a]College of Chemistry and Chemical Engineering, Hunan University, Changsha 410082, China

[b]Department of Educational Science, Hunan First Normal University, Changsha 410205, China

[c]Key Laboratory of Ministry of Education for Advanced Materials in Tropical Island Resources, School of Chemical Engineering and Technology, Hainan University, Haikou 570228, China

*E-mail: zhouyb@hnu.edu.cn.

Supporting Information Placeholder

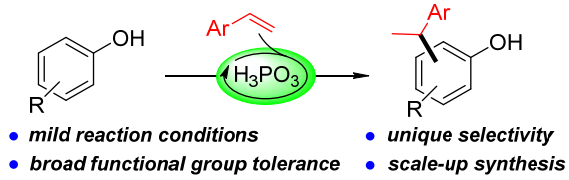


ABSTRACT: A H_3PO_3 catalyzed alkylation of phenols with alkenes is achieved in a facile, efficient, and selective manner. The reaction shows a unique selectivity, i.e., excellent regioselectivity, thorough suppression of over-alkylation, without alkylation of simple phenyl ring, and can selectively prepare *ortho*-, *meta*-, or *para*-alkylated phenol derivatives with good to excellent yields. This merit along with mild reaction conditions, sensitive functional group tolerance, and scale-up synthesis, as well as late-modification of phenolic bioactive compounds make it an ideal and practical alternative for the modification of phenols.

Introduction

Phosphorous acid (H_3PO_3) is an affordable, readily available, relatively lowly acidic and corrosive Brønsted acid. Compared with organophosphorus acids that are extensively used in organic synthesis,[1] H_3PO_3 catalysis is underdeveloped.[2,3] Over the past years, we have focused our research interest on H_3PO_3 catalysis, and have acknowledged that H_3PO_3 could act as both Lewis acid and base, which often shows interesting effects in some acid catalyzed reactions.[3] Herein, as a result of our continued interest in H_3PO_3 catalysis, we report a facile, efficient and selective alkylation reaction of phenols with alkenes toward various alkylated phenols (Scheme 1).

Scheme 1. Selective Alkylation of Phenols with Alkenes via H_3PO_3 Catalysis



Phenol derivatives are among the most basic chemicals and are widely applied in pharmaceuticals, agrochemicals, dyes, and adhesives, as well as polymeric materials.[4] For example, phenolic resin that is derived from a simple phenol is consumed at a rate of millions tons per year (Figure 1). In this regard, the facile and selective functionalization of simple phenols, which would enhance the diversity and applications of these compounds, is of great importance.

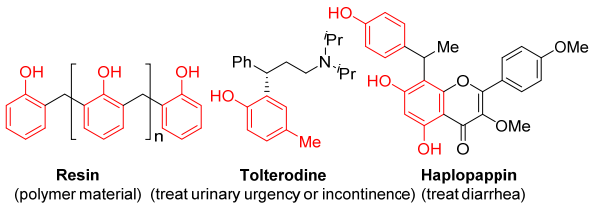


Figure 1. Representative phenol derivatives.

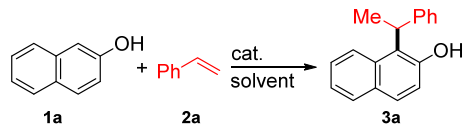
Among the numerous efforts on the selective functionalization of phenols,[5] the catalytic alkylation of phenols with alkenes[6–12] is one of the most promising approaches because it could form industrially useful alkylated phenols directly from easily available starting materials.[9] Typically, the reaction proceeds via Friedel-Crafts type alkylation, which is generally catalyzed by strong Lewis acids ($TiCl_4$, $AlCl_3$, $FeCl_3$, and $ZnBr_2$) and Brønsted acids (HF and H_2SO_4).[6,7] Acidic materials such as graphene,[8] zeolite,[10] mesoporous and nanoporous materials[11] as well as amberlyst resin[12] have also been success-

fully developed as catalysts in this reaction. Recently, the transition metal (Rh-,[13] Ir-,[14] and Re-[15]) catalyzed addition of phenols to alkenes via C–H bond activation has emerged as a good alternative to this type of reaction. Despite notable advances, these reported methods generally suffer from some drawbacks, such as harsh reaction conditions, the requirement of an excess of one substrate (2–10 equiv), poor functional group compatibility, and/or tedious preparation of the catalyst materials. Therefore, due to the extensive applications of alkylated phenols, the development of new methods of alkylation to address these issues is highly desirable.

Results and Discussion

Fortunately, by the direct treatment of 2-naphthol (**1a**) with styrene (**2a**, 1.2 equiv) in the presence of H_3PO_3 (20 mol %, 50% aq.) in DCE at 100 ºC under N_2, the desired *ortho*-alkylated product 1-(1-phenylethyl)naphthalen-2-ol (**3a**) was produced in 92% GC yield with >96% position-selectivity (Table 1, entry 2). The investigations of the catalytic performance of other acid catalysts showed that the phosphorus-containing inorganic acids had unique performance for the electrophilic addition reaction (Table 1, entries 1–3). In comparison, typical Brønsted acids and Lewis acids, such as $H_2C_2O_4$, TsOH, H_2SO_4, TFA, HOAc, $FeCl_3$, $CuCl_2$, and $AlCl_3$ that are efficient catalysts in other catalytic systems[6,7] were not compatible under the mild reaction conditions (Table 1, entries 4–11). This result demonstrated an attractive merit of H_3PO_3 catalysis, which allowed for the reaction taking place under mild conditions. The reaction proceeded smoothly in weakly polar solvents such as PhCl, hexane, and toluene (Table 1,

Table 1. Optimization of the Reaction Conditions[a]



1a 2a 3a

entry	cat.	solvent	temp (°C)	yield (%)[b]
1	50% H_3PO_2	DCE	100	47
2	50% H_3PO_3	DCE	100	92
3	50% H_3PO_4	DCE	100	71
4	$H_2C_2O_4$	DCE	100	trace
5	TsOH	DCE	100	10
6	H_2SO_4	DCE	100	trace
7	TFA	DCE	100	trace
8	HOAc	DCE	100	nd
9	$FeCl_3$	DCE	100	trace
10	$CuCl_2$	DCE	100	trace
11	$AlCl_3$	DCE	100	8
12	50% H_3PO_3	PhCl	100	85
13	50% H_3PO_3	hexane	100	61
14	50% H_3PO_3	toluene	100	68
15	50% H_3PO_3	CH_3CN	100	nd
16	50% H_3PO_3	DMF	100	nd
17[c]	50% H_3PO_3	DCE	100	69
18	50% H_3PO_3	DCE	120	83
19	50% H_3PO_3	DCE	80	49
20[d]	50% H_3PO_3	DCE	100	92

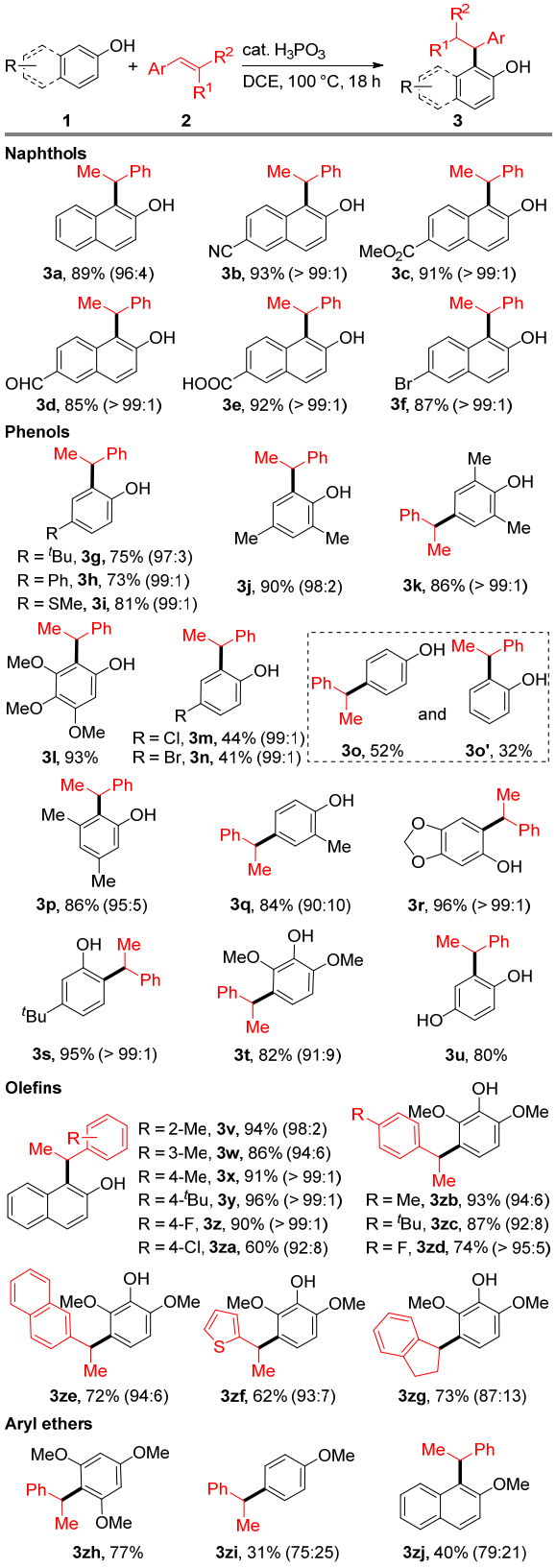
[a]Reaction conditions: **1a** (0.4 mmol), **2a** (0.48 mmol, 1.2 equiv), catalyst (20 mol %) in solvent (2.0 mL) for 18 h under N_2. [b]GC yield using tridecane as an internal standard. [c]catalyst (10 mol %). [d]Under air.

entries 12–14), whereas it did not occur in strongly polar solvents (CH_3CN and DMF; Table 1, entries 15 and 16). A 69% yield of **3a** was obtained by a half loading of H_3PO_3 (10 mol %, Table 1, entry 17). Reaction temperature was also examined, but no better results were observed (Table 1, entries 18 and 19). In view of the oxidation potential of phenols, we finally investigated the effect of air on the reaction. Surprisingly, a comparable yield of **3a** (92%) was obtained (Table 1, entry 20 vs entry 2) by conduction of this reaction under air. This well compatibility of both water- and air-conditions demonstrated the easy operation of this alkylation reaction.

With the optimized conditions in hand, the scope and generality of this reaction were investigated. As shown in Scheme 2, this H_3PO_3-catalyzed reaction produced the alkylated products in good to excellent yields with a broad substrate scope and remarkable functional group tolerance. The reaction of 2-naphthol (**1a**) with styrene (**2a**) gave the product **3a** in an 89% isolated yield. For 2-naphthols, valuable functional groups such as CN (**3b**), CO_2Me (**3c**), CHO (**3d**), COOH (**3e**), and Br (**3f**) were tolerated, furnishing the corresponding products in 85–93% yields with excellent selectivity (>99%). Notably, although CN (**3b**) and CO_2Me (**3c**) are easily hydrolyzed, and CHO (**3d**) can react with phenols under strong acidic conditions, they were well tolerated. The compatibility of our conditions with CHO and COOH is useful and is the first report of this type of reaction. In addition to naphthols, phenols with electron-donating groups were also good substrates for the reaction, and the corresponding single-alkylated products were obtained in 73–93% yields (**3g–l**) with tolerance of methyl, methoxy, thiomethyl, *tert*-butyl, and phenyl groups. Phenols with electron-withdrawing groups gave lower yields of the products (**3m**, 44%; **3n**, 41%).

The reaction showed an interesting selectivity. Reaction of the simplest phenol with **2a** under the optimized conditions gave the *para*-alkylated product (**3o**) in 52% yield with the *ortho*-alkylated product (**3o'**) in 32% yield, which was consistent with other reaction systems.[6,7] In a sharp contrast, when 3,5-dimethylphenol that possesses both *ortho*- and *para*- electrophilic sites was adopted in this reaction, an 86% yield of the *ortho*-alkylated product (**3p**) was obtained with 95% regioselectivity, and only a trace amount of the *para*-alkylated product was observed. Interestingly, the reaction of *o*-cresol that has an *ortho*-methyl group showed *para*-selectivity, and the *para*-alkylated product (**3q**) was obtained in an 84% yield with 90% regioselectivity. Notably, sesame phenol, which has similar reactivity at the 2- and 6-positions, showed >99% selectivity for the 6-position in the reaction (**3r**). Excellent 6-position selectivity (>99%) has also been observed for the substrate 3-*tert*-butyl phenol (**3s**). For 2,6-dimethoxyphenol, the *meta*-alkylated product (**3t**) was predominately obtained (82% yield with 91% selectivity), and this different regioselectivity may be due to the OMe. It should be noted that although alkylation products are more electron-rich, the over-alkylation products were either not observed or only observed in trace amounts (<1%) in the above reactions. The unique selectivity was probably due to the dual roles of the phosphorous acid (*vide infra*) and might be applied to selective synthesis of *ortho*-, *meta*-, or *para*-alkylated products, which cannot be easily obtained by other methods.[6–12] This catalytic system was also suitable for polyhydroxy phenols. For example, hydroquinone

Scheme 2. Substrate Scope[a,b]

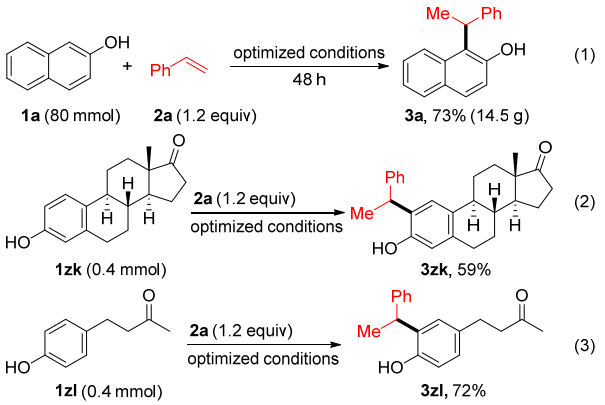


[a]Reaction conditions: **1** (0.4 mmol), **2** (0.48 mmol, 1.2 equiv), H_3PO_3 (20 mol %) in DCE (2.0 mL) at 100 ºC for 18 h, under air. [b]Isolated yield of **3**. Regioselectivity in paradigms (major product/minor products) was determined by GC.

was successfully transformed to the alkylated *p*-benzenediol (**3u**) in 80% yield.

With respect to alkenes, terminal alkenes bearing both electron donating groups such as Me (**3v**–**x**) and ^{t}Bu (**3y**) and electron withdrawing groups such as F (**3z**) and Cl (**3za**) on the phenyl ring reacted smoothly with 2-naphthol to produce the corresponding *ortho*-alkylated products in 60–96% yields. Additionally, treatment of substituted terminal alkenes with 2,6-dimethoxyphenol gave the corresponding *meta*-alkylated products in satisfactory yields (74–93%, **3zb**–**zd**). Sterically bulky naphthyl alkene and heteroaryl alkenes exemplified by thienyl alkene also reacted with 2,6-dimethoxyphenol, and the desired *meta*-alkylated products (**3ze** and **3zf)** were produced in 72% and 62% yields, respectively. In addition to terminal alkenes, the reaction of internal alkenes with phenol was also successful. For example, upon treatment of indene with 2,6-dimethoxyphenol, the 4-alkylated-2,6-dimethoxyphenol product (**3zg**) was produced in 73% yield. Additionally, aryl ethers could also be alkylated, although lower yields were observed (**3zh**–**zj**). Notably, the alkylation of the simple phenyl rings was not observed in all of the reactions.

Scheme 3. Synthetic Utility

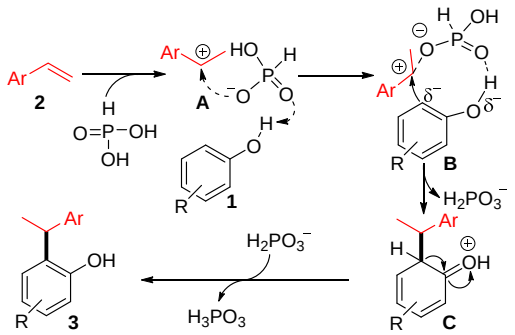


To further explore the utility of this H_3PO_3-catalytic system, a scale-up reaction (80 mmol) of **1a** with **2a** was conducted. After prolonging the reaction time (48 h), a good yield of **3a** (73%, 14.5 g) was obtained, which allows for potential industrial applications of this transformation (Scheme 3, eq. 1). Estrone is a key intermediate for the synthesis of estrogens such as estradiol or ethinyloestradiol, and the alkylation of estrone is relevant to drug modification. Satisfactorily, when estrone **1zk** was reacted with **2a** under the optimized conditions, the product (**3zk**) was obtained in 59% yield (Scheme 3, eq. 2). Additionally, raspberry ketone **1zl** could also be alkylated to product **3zl** in 72% yield (Scheme 3, eq. 3).

Although the detailed reaction mechanism remains unclear, we propose a possible mechanism (exemplified by *ortho*-alkylation of phenols) on the basis of the above observations and literature reports.[1] As shown in Scheme 4, the reaction proceeds via Friedel-Crafts type alkylation. Alkene **2** reacts with phosphorous acid (H_3PO_3) to form carbenium ion intermediate **A**, releasing phosphorous anion ($H_2PO_3^-$). The interaction of $H_2PO_3^-$ with phenol **1** and **A** forms intermediate **B**,[1] which undergoes intramolecular electrophilic addition, forming intermediate **C**. Finally, deprotonation of **C** gives the desired product **3**. It is noted that the reaction position of the intramolecular electrophilic addition of **B** is sensitive to the

steric and electronic nature the substituents on the aryl rings for this reaction, which can lead to *ortho*-, *meta*-, or *para*-regioselectivity, respectively.

Scheme 4. Possible Reaction Mechanism



In conclusion, we have developed a facile and efficient alkylation reaction for phenols with alkenes that yields alkylated phenols by using the affordable, stable, readily available, relatively lowly acidic and weakly corrosive H_3PO_3 as the catalyst. H_3PO_3 probably acts as both Lewis acid and base. These effects allow for the reaction to occur with high efficiency under very simple conditions, in which the commonly used catalysts are ineffective. The reaction shows a broad substrate scope and outstanding functional group tolerance. In particular, this represents the first reported reaction of its type to show compatibility with CHO and COOH groups. Excellent regioselectivity is observed for positions that have similar reactivity, and alkylation of simple aryl rings and over-alkylation is thoroughly suppressed for the reaction. Thus, all of the *ortho*-, *meta*-, and *para*-alkylated phenol derivatives can be selectively prepared by this method. The scale-up reaction and the late-modification of the medical intermediates estrone and raspberry ketone have also been successfully conducted. Taking into account the merits of the reaction, such as mild reaction conditions, broad scope of the substrates, nearly equivalent molar ratio of the substrates, broad functional group tolerance, high regioselectivity, and scale-up synthesis, as well as late-modification of phenolic bioactive compounds, this convenient method offers an ideal and practical alternative for the modification of phenols.

Experimental Section

General Information

The reactions were carried out in Schlenk tubes of 25 mL. The heat source is IKA magnetic stirrer with RCT Basic. Reagents were used as received unless otherwise noted. Column chromatography was performed using Silica Gel 60 (300–400 mesh). The reactions were monitored by GC and GC-MS, GC-MS results were recorded on GC-MS QP 2010, and GC analysis was performed on GC 2010 plus. The ^1H and ^{13}C NMR spectra were recorded on a Brucker ADVANCE III spectrometer at 400 MHz and 100 MHz respectively, and chemical shifts were reported in parts per million (ppm). The electron ionization (EI) method was used as the ionization method for the HRMS measurement, and the mass analyzer type is TOF for EI. All solvents and reagents were purchased from Energy Chemical, Alfa Aesar, and Aladdin.

General Experimental Procedure

An Schlenk tube of 25 mL equipped with a magnetic stir bar was charged with phenol **1** (0.4 mmol), alkene **2** (0.48 mmol, 1.2 equiv), H_3PO_3 (50% aq. 20 mol %), DCE (2.0 mL). The reaction mixture was heated at 100 °C for 18 h. After completion of the reaction, the reaction mixture was cooled to room temperature, and the volatiles were removed under reduced pressure. The crude reaction mixture was purified over silica-gel (300–400 mesh) column chromatography using petroleum ether, ethyl acetate, or dichloromethane as eluent.

Characterization Data for the Products

1–(1–Phenylethyl)–2–naphthalenol (3a).[16] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a pale yellow oil in 89% yield (88.3 mg). ^1H NMR (400 MHz, $CDCl_3$): δ 8.03 (d, J = 8.6 Hz, 1H), 7.79 (d, J = 8.0 Hz, 1H), 7.66 (d, J = 8.7 Hz, 1H), 7.45 (t, J = 7.2 Hz, 1H), 7.39 – 7.31 (m, 5H), 7.26 – 7.22 (m, 1H), 6.99 (d, J = 8.8 Hz, 1H), 5.17 (q, J = 6.8 Hz, 1H), 1.78 (d, J =7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 151.5, 143.7, 132.8, 129.7, 129.0, 128.8, 128.7, 127.1, 126.7, 126.5, 123.8, 123.1, 122.7, 119.3, 34.8, 17.1.

6–isocyano–1–(1–phenylethyl) naphthalen–2–ol (3b). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a pale yellow oil in 93% yield (101.6 mg). ^1H NMR (400 MHz, $CDCl_3$): δ 8.15 (s, 1H), 8.03 (d, J = 9.2 Hz, 1H), 7.71 (d, J = 8.8 Hz, 1H), 7.53 (d, J = 8.8 Hz, 1H), 7.35 – 7.34 (m, 4H), 7.28 – 7.25 (m, 1H), 7.15 (d, J = 8.8 Hz, 1H), 5.63 (s, 1H), 5.16 (q, J = 6.8 Hz, 1H), 1.78 (d, J = 6.8 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 154.3, 143.1, 134.9, 134.6, 129.3, 129.1, 128.5, 127.0, 126.9, 126.9, 124.4, 124.2, 120.9, 119.5, 106.0, 34.7, 17.2. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{19}H_{15}NO$: 273.1154; found: 273.1150.

methyl 6–hydroxy–5–(1–phenylethyl)–2–naphthoate (3c). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a pale yellow oil in 91% yield (111.4 mg). ^1H NMR (400 MHz, $CDCl_3$): δ 8.54 (s, 1H), 8.04 – 7.98 (m, 2H), 7.76 (d, J = 8.8 Hz, 1H), 7.37 – 7.31 (m, 4H), 7.26 – 7.23 (m, 1H), 7.09 (d, J = 8.8 Hz, 1H), 5.56 (bs, 1H), 5.19 (q, J = 6.8 Hz, 1H), 3.96 (s, 3H), 1.79 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 167.5, 153.8, 143.4, 135.4, 132.0, 130.2, 129.0, 128.6, 127.1, 126.7, 125.8, 124.4, 124.1, 123.1, 120.0, 52.2, 34.8, 17.2. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{20}H_{18}O_3$: 306.1256; found: 306.1250.

6-hydroxy-5-(1-phenylethyl)-2-naphthaldehyde (3d). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a pale yellow oil in 85% yield (93.8 mg). ^1H NMR (400 MHz, $CDCl_3$): δ 10.10 (s, 1H), 8.29 (s, 1H), 8.10 (d, J = 8.8 Hz, 1H), 7.92 (d, J = 8.6 Hz, 1H), 7.83 (d, J = 8.8 Hz, 1H), 7.37 – 7.33 (m, 4H), 7.28 – 7.25 (m, 1H), 7.15 – 7.13 (m, 1H), 5.65 (s, 1H), 5.21 (q, J = 6.8 Hz, 1H), 1.80 (d, J = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 192.2, 154.6, 143.1, 136.4, 135.5, 131.5, 130.5, 129.1, 128.7, 127.1, 126.9, 124.6, 123.9, 123.6,

120.4, 34.9, 17.2. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{19}H_{16}O_2$: 276.1150; found: 276.1146.

6-hydroxy-5-(1-phenylethyl)-2-naphthoic acid (3e). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a colorless oil in 92% yield (107.5 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.64 (s, 1H), 8.07 (s, 2H), 7.80 (d, *J* = 8.7 Hz, 1H), 7.39 – 7.25 (m, 5H), 7.10 (d, *J* = 8.8 Hz, 1H), 5.20 (q, *J* = 7.2 Hz, 1H), 1.80 (d, *J* = 6.8 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 172.1, 154.0, 143.3, 135.8, 132.9, 130.4, 129.1, 128.6, 127.1, 126.8, 126.1, 124.1, 123.9, 123.1, 120.2, 34.9, 17.1. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{19}H_{16}O_3$: 292.1099; found: 292.1097.

6–bromo–1–(1–phenylethyl) naphthalen–2–ol (3f).[17] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a brown oil in 87% yield (113.8 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.92 (s, 1H), 7.86 (d, *J* = 9.2 Hz, 1H), 7.55 (d, *J* = 8.8 Hz, 1H), 7.48 (d, *J* = 9.2 Hz, 1H), 7.34 – 7.30 (m, 4H), 7.26 – 7.22 (m, 1H), 7.00 (d, *J* = 8.8 Hz, 1H), 5.13 – 5.09 (m, 1H), 5.06 (s, 1H), 1.76 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 151.7, 143.3, 131.4, 130.9, 130.6, 129.6, 129.0, 127.7, 127.0, 126.8, 124.7, 124.2, 120.3, 116.7, 34.8, 17.2.

4–(tert–butyl)–2–(1–phenylethyl) phenol (3g).[11c] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a colorless oil in 75% yield (76.2 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.30 – 7.23 (m, 5H), 7.20 – 7.16 (m, 1H), 7.12 (d, *J* = 8.0 Hz, 1H), 6.65 (d, *J* = 8.4 Hz, 1H), 4.61 (s, 1H), 4.34 (q, *J* = 7.2 Hz, 1H), 1.63 (d, *J* = 7.2 Hz, 3H), 1.29 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 151.0, 145.5, 143.4, 131.0, 128.6, 127.5, 126.3, 124.9, 124.1, 115.4, 39.2, 34.2, 31.6, 21.0.

3–(1–phenylethyl)–[1,1'–biphenyl]–4–ol (3h). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a colorless oil in 73% yield (80.0 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.55 – 7.53 (m, 2H), 7.48 (s, 1H), 7.40 (t, *J* = 7.2 Hz, 2H), 7.35 – 7.29 (m, 6H), 7.21 (s, 1H), 6.79 (d, *J* = 8.4 Hz, 1H), 4.76 (s, 1H), 4.41 (q, *J* = 7.2 Hz, 1H), 1.67 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 152.9, 145.1, 141.1, 134.0, 132.1, 128.7, 128.7, 127.5, 126.8, 126.6, 126.5, 126.2, 116.3, 38.9, 21.0. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{20}H_{18}O$: 274.1358; found: 274.1353.

4-(methylthio)-2-(1-phenylethyl)phenol (3i). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (10/1) to afford a colorless oil in 81% yield (79.1 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.35 – 7.31 (m, 2H), 7.29 – 7.26 (m, 4H), 7.13 (dd, *J* = 8.3 Hz, *J* = 2.3 Hz, 1H), 6.74 (d, *J* = 8.3 Hz, 1H), 4.74 (s, 1H), 4.36 (q, *J* = 7.2 Hz, 1H), 2.47 (s, 3H), 1.65 (d, *J* = 7.4 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 152.0, 144.8, 132.7, 128.9, 128.8, 128.7, 128.0, 127.5, 126.6, 116.8, 38.9, 20.9, 18.1. HRMS (EI) m/z: [M]+ calcd. for $C_{15}H_{16}OS$: 244.0922; found: 244.0917.

2,4–dimethyl–6–(1–phenylethyl)phenol (3j).[7d] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a colorless oil in 90% yield (81.4 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.30 – 7.24 (m, 4H), 7.21 – 7.17 (m, 1H), 6.91 (s, 1H), 6.83 (s, 1H), 4.41 (s, 1H), 4.29 (q, *J* = 7.2 Hz, 1H), 2.26 (s, 3H), 2.14 (s, 3H), 1.60 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 149.4, 145.4, 131.1, 129.5, 129.3, 128.7, 127.5, 126.4, 126.0, 123.9, 39.1, 21.2, 20.7, 15.8.

2,6–dimethyl–4–(1–phenylethyl) phenol (3k).[7d] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a colorless oil in 86% yield (77.7 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.25 – 7.16 (m, 5H), 6.82 – 6.81 (m, 2H), 4.51 (s, 1H), 4.02 – 4.01 (m, 1H), 2.17 (s, 6H), 1.59 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 150.3, 146.9, 138.0, 128.3, 127.7, 127.5, 125.8, 122.8, 44.0, 22.1, 16.0.

3,4,5–trimethoxy–2–(1–phenylethyl) phenol (3l). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a colorless oil in 93% yield (107.1 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.36 – 7.30 (m, 4H), 7.22 – 7.19 (m, 1H), 6.15 (s, 1H), 4.77 (s, 1H), 4.71 (q, *J* = 7.2 Hz, 1H), 3.83 (s, 3H), 3.78 (s, 3H), 3.74 (s, 3H), 1.65 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 152.2, 151.9, 150.2, 144.2, 136.1, 128.7, 127.1, 126.3, 118.5, 97.2, 61.1, 60.9, 55.7, 33.3, 17.8. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{17}H_{20}O_4$: 288.1362; found: 288.1367.

4-chloro-2-(1-phenylethyl)phenol (3m).[11a] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a white solid in 44% yield (40.8 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.30 – 7.26 (m, 2H), 7.24 – 7.16 (m, 4H), 7.04 (dd, *J* = 8.5, 2.6 Hz, 1H), 6.61 (d, *J* = 8.5 Hz, 1H), 4.79 (s, 1H), 4.30 (q, *J* = 7.2 Hz, 1H), 1.58 (d, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 151.8, 144.5, 133.8, 128.8, 127.8, 127.4, 127.2, 126.7, 125.7, 117.2, 38.7, 20.8.

4-bromo-2-(1-phenylethyl)phenol (3n).[11a] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (10/1) to afford a colorless oil in 41% yield (45.3 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.35 – 7.27 (m, 3H), 7.26 – 7.16 (m, 4H), 6.62 (d, *J* = 8.5 Hz, 1H), 4.86 (s, 1H), 4.31 (q, *J* = 7.2 Hz, 1H), 1.60 (d, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 152.5, 144.4, 134.3, 130.7, 130.2, 128.8, 127.4, 126.7, 117.7, 113.1, 38.7, 20.9.

4-(1-phenylethyl)phenol (3o).[18] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a colorless oil in 52% yield (41.2 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.28 – 7.24 (m, 2H), 7.19 – 7.14 (m, 3H), 7.05 (d, *J* = 7.6 Hz, 2H), 6.71 (d, *J* = 7.2 Hz, 2H), 5.18 (s, 1H), 4.07 (q, *J* = 6.8 Hz, 1H), 1.58 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 153.4, 146.7, 138.7, 128.7, 128.3, 127.5, 125.9, 115.1, 43.8, 22.0.

2-(1-phenylethyl)phenol (3o').[8a] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a colorless oil in 32% yield (25.3 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.18 – 7.09 (m, 6H), 7.02 – 6.98 (m, 1H), 6.85 – 6.83 (m, 1H), 6.60 (d, *J* = 8.0 Hz, 1H), 4.73 (s, 1H), 4.42 – 4.06 (m, 1H), 1.52 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 153.2, 145.3, 131.9, 128.6, 127.9, 127.5, 127.4, 126.4, 120.8, 115.9, 38.6, 21.0.

3,5–dimethyl–2–(1–phenylethyl)phenol (3p). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a colorless oil in 86% yield (77.7 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.30 – 7.27 (m, 4H), 7.20 – 7.19 (m, 1H), 6.60 (s, 1H), 6.39 (s, 1H), 4.57 – 4.54 (m, 2H), 2.31 (s, 3H), 2.20 (s, 3H), 1.64 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 154.0, 143.9, 137.0, 136.8, 128.7, 127.9, 126.9, 126.4, 123.9, 115.8, 36.0, 20.8, 20.5, 16.8. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{16}H_{18}O$: 226.1358; found: 226.1352.

2–methyl–4–(1–phenylethyl)phenol (3q).[7d] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a colorless oil in 84% yield (71.2 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.20 – 7.17 (m, 2H), 7.13 – 7.08 (m, 3H), 6.87 (s, 1H), 6.83 (d, *J* = 8.0 Hz, 1H), 6.57 (d, *J* = 8.4 Hz, 1H), 4.78 (s, 1H), 3.96 (q, *J* = 6.4 Hz, 1H), 2.10 (s, 3H), 1.50 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 151.9, 146.8, 138.6, 130.2, 128.3, 127.5, 126.0, 125.9, 123.6, 114.7, 43.9, 22.0, 15.9.

6-(1-phenylethyl)benzo[d][1,3]dioxol-5-ol (3r).[20] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ ethyl acetate (5/1) to afford a colorless oil in 96% yield (92.9 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 – 7.11 (m, 5H), 6.73 (s, 1H), 6.36 (s, 1H), 5.88 (d, *J* = 2.6 Hz, 2H), 4.45 (s, 1H), 4.27 (q, *J* = 7.2 Hz, 1H), 1.57 (d, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 147.7, 146.2, 145.3, 141.6, 128.7, 127.3, 126.5, 124.2, 107.3, 101.0, 98.8, 38.5, 21.2.

5-(tert-butyl)-2-(1-phenylethyl)phenol (3s). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (10/1) to afford a colorless oil in 95% yield (96.5 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.32 – 7.23 (m, 4H), 7.20 (d, *J* = 6.7 Hz, 1H), 7.16 (d, *J* = 8.1 Hz, 1H), 6.95 (d, *J* = 8.1 Hz, 1H), 6.77 (d, *J* = 1.5 Hz, 1H), 4.60 (dd, *J* = 8.9, 4.2 Hz, 1H), 4.31 (q, *J* = 6.9 Hz, 1H), 1.61 (dd, *J* = 7.3, 0.6 Hz, 3H), 1.28 (d, *J* = 0.7 Hz, 9H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 152.9, 151.0, 145.5, 128.7, 127.5, 127.4, 126.4, 117.7, 113.3, 38.6, 34.3, 31.3, 21.1. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{18}H_{22}O$: 254.1671; found: 254.1667.

2,6–dimethoxy–3–(1–phenylethyl)phenol (3t). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a colorless oil in 82% yield (84.6 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.27 – 7.22 (m, 4H), 7.16 – 7.13 (m, 1H), 6.70 – 6.60 (m, 2H), 5.51 (s, 1H), 4.46 (q, *J* = 7.2 Hz, 1H), 3.86 (s, 3H), 3.65 (s, 3H), 1.57 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 146.8, 146.1, 144.9, 138.6, 132.7, 128.1, 127.5, 125.7, 117.5, 106.1, 60.4, 56.1, 37.7, 21.6. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{16}H_{18}O_3$: 258.1256; found: 258.1250.

2-(1-phenylethyl)benzene-1,4-diol (3u).[19] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a colorless oil in 80% yield (68.5 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.29 – 7.17 (m, 5H), 6.70 (s, 1H), 6.61 – 6.53 (m, 2H), 5.09 (s, 1H), 4.64 (s, 1H), 4.32 (q, *J* = 7.2 Hz, 1H), 1.56 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 149.5, 147.0, 145.1, 133.6, 128.6, 127.5, 126.4, 116.9, 114.9, 113.7, 38.6, 20.9.

1–(1–(o–tolyl)ethyl)naphthalen–2–ol (3v). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a colorless oil in 94% yield (98.5 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.17 (d, *J* = 8.4 Hz, 1H), 7.79 (d, *J* = 8.0 Hz, 1H), 7.75 (d, *J* = 7.6 Hz, 1H), 7.63 (d, *J* = 8.8 Hz, 1H), 7.54 (t, *J* = 7.2 Hz, 1H) 7.40 – 7.34 (m, 2H), 7.26 – 7.16 (m, 2H) , 6.92 (d, *J* = 8.8 Hz, 1H), 5.25 (s, 1H), 5.06 (q, *J* = 6.8 Hz, 1H), 1.91 (s, 3H), 1.78 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 151.9, 141.5, 138.6, 132.5, 131.7, 129.6, 129.1, 128.7, 127.6, 127.0, 126.0, 125.3, 123.0, 121.8, 121.3, 119.6, 34.5, 19.9, 18.2. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{19}H_{18}O$: 262.1358; found: 262.1354.

1–(1–(m–tolyl)ethyl)naphthalen–2–ol (3w). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a colorless oil in 86% yield (90.1 mg). ^{1}H NMR (400 MHz, $CDCl_3$): 8.07 (d, *J* = 8.4 Hz, 1H), 7.80 (d, *J* = 8.0 Hz, 1H), 7.67 (d, *J* = 8.8 Hz, 1H), 7.48 (t, *J* = 7.6 Hz, 1H), 7.37 – 7.33 (m, 1H), 7.26 – 7.19 (m, 3H), 7.08 – 7.07 (m, 1H), 7.00 (d, *J* = 8.8 Hz, 1H), 5.13 (q, *J* = 7.2 Hz, 1H), 4.98 (s, 1H), 2.30 (s, 3H), 1.75 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 151.6, 143.4, 138.9, 132.8, 129.6, 129.0, 128.8, 128.6, 128.0, 127.7, 126.6, 124.0, 123.8, 123.1, 122.5, 119.5, 34.8, 21.5, 17.0. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{19}H_{18}O$: 262.1358; found: 262.1352.

1–(1–(p–tolyl)ethyl)naphthalen–2–ol (3x).[16] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a colorless oil in 91% yield (95.4 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.06 (d, *J* = 7.6 Hz, 1H), 7.79 (d, *J* = 6.0 Hz, 1H), 7.65 (d, *J* = 8.0 Hz, 1H), 7.48 – 7.45 (m, 1H), 7.35 – 7.27 (m, 3H), 7.14 (d, *J* = 6.0 Hz, 2H), 6.99 (d, *J* = 5.6 Hz, 1H), 5.13 – 5.11 (m, 1H), 4.98 (s, 1H), 2.32 (s, 3H), 1.75 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 151.6, 140.3, 136.5, 132.8, 129.8, 129.6, 128.8, 128.6, 127.0, 126.5, 123.9, 123.8, 123.0, 122.5, 122.5, 119.4, 34.5, 21.0, 17.1.

1–(1–(4–(tert–butyl)phenyl)ethyl)naphthalen–2–ol (3y).[16] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a pale yellow oil in 96% yield (116.7 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.07 (d, *J* = 8.4 Hz, 1H), 7.80 (d, *J* =

8.0 Hz, 1H), 7.67 (d, *J* = 8.8 Hz, 1H), 7.48 (t, *J* = 7.6 Hz, 1H), 7.38 – 7.31 (m, 5H), 7.00 (d, *J* = 8.8 Hz, 1H), 5.13 (q, *J* = 7.2 Hz, 1H), 4.96 (s, 1H), 1.76 (d, *J* = 7.2 Hz, 3H), 1.30 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 151.7, 149.9, 140.1, 132.9, 129.7, 128.8, 128.6, 126.8, 126.6, 126.1, 123.8, 123.1, 122.5, 119.5, 34.4, 31.3, 17.1.

1–(1–(4–fluorophenyl)ethyl)naphthalen–2–ol (3z). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a pale yellow oil in 90% yield (95.8 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.97 (d, *J* = 7.2 Hz, 1H), 7.79 (d, *J* = 8.0 Hz, 1H), 7.66 (d, *J* = 8.8 Hz, 1H), 7.436 (t, *J* = 6.8 Hz, 1H), 7.35 – 7.20 (m, 3H), 7.01 – 6.99 (m, 3H), 5.14 – 5.12 (m, 1H), 4.93 (s, 1H), 1.78 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 161.5 (d, $J_{C\text{-}F}$ = 235.6 Hz), 151.3, 139.7 (d, $J_{C\text{-}F}$ = 3.2 Hz), 132.7, 129.7, 128.9, 128.8, 128.6 (d, $J_{C\text{-}F}$ = 7.9 Hz), 126.5, 123.5, 123.1, 122.8, 119.1, 115.5 (d, $J_{C\text{-}F}$ = 21.0 Hz), HRMS (EI) m/z: $[M]^+$ calcd. for $C_{18}H_{15}FO$: 266.1107; found: 266.1102.

1–(1–(4–chlorophenyl)ethyl)naphthalen–2–ol (3za).[16] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a brown oil in 60% yield (67.7 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.93 (d, *J* = 8.4 Hz, 1H), 7.78 (d, *J* = 8.0 Hz, 1H), 7.66 (d, *J* = 8.8 Hz, 1H), 7.42 (t, *J* = 7.2 Hz, 1H), 7.32 (t, *J* = 7.6 Hz, 1H), 7.26 – 7.23 (m, 4H), 6.99 (d, *J* = 8.8 Hz, 1H), 5.12 (q, *J* = 7.2 Hz, 1H), 4.86 (s, 1H), 1.78 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 151.2, 142.8, 132.7, 132.1, 129.8, 128.9, 128.8, 128.8, 128.5, 126.6, 123.40, 123.2, 122.9, 118.9, 34.3, 17.3.

2,6-dimethoxy-3-(1-(p-tolyl)ethyl)phenol (3zb). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a pale yellow oil in 93% yield (101.2 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.13 – 7.05 (m, 4H), 6.69 – 6.59 (m, 2H), 5.50 (s, 1H), 4.43 (q, *J* = 7.2 Hz, 1H), 3.85 (s, 3H), 3.68 (s, 3H), 2.29 (s, 3H), 1.55 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 146.0, 144.9, 143.8, 138.5, 135.1, 132.9, 128.8, 127.4, 117.5, 106.2, 60.5, 56.1, 37.2, 21.7, 20.9. HRMS (EI) m/z: [M]+ calcd. for $C_{17}H_{20}O_3$: 272.1412; found:272.1410.

2,6-dimethoxy-3-(1-(4-(tert-butyl)phenyl)ethyl)-phenol (3zc). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a pale yellow oil in 87% yield (109.3 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.28 – 7.16 (m, 4H), 7.69 – 6.59 (m, 2H), 5.53 (s, 1H), 4.44 (q, *J* = 6.8 Hz, 1H), 3.84 (s, 3H), 3.69 (s, 3H), 1.56 (d, *J* = 7.2 Hz, 3H), 1.28 (s, 9H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 148.4, 146.0, 144.9, 143.5, 138.5, 133.0, 127.1, 125.0, 117.5, 106.2, 60.4, 56.1, 37.0, 34.3, 31.4, 21.6. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{20}H_{26}O_3$: 314.1882; found: 314.1886.

2,6-dimethoxy-3-(1-(4-fluorophenyl)ethyl)-phenol (3zd). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a pale yellow oil in 74% yield (81.7 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.36 – 7.04 (m, 2H), 6.93 (t, *J* = 8.4 Hz, 2H), 6.67 – 6.60 (m, 2H), 5.55 (s, 1H), 4.43 (q, *J* = 7.2 Hz, 1H), 3.84 (s, 3H), 3.65 (s, 3H), 1.54 (d, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 161.0 (d, *J* = 243.4 Hz), 146.2, 144.9, 142.5 (d, *J* = 3.1 Hz), 138.6, 132.4, 128.8 (d, *J* = 7.7 Hz), 117.2, 114.8 (d, *J* = 21.0 Hz), 106.0, 60.3, 56.1, 37.1, 21.7. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{16}H_{17}FO_3$: 276.1162; found: 276.1168.

2,6–dimethoxy–3–(1–(naphthalen–2–yl)ethyl)phenol (3ze). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a pale yellow oil in 72% yield (88.7 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.78 – 7.68 (m, 4H), 7.45 – 7.33 (m, 3H), 6.70 – 6.60 (m, 2H), 5.52 (s, 1H), 4.63 (q, *J* = 6.8 Hz, 1H), 3.85 (s, 3H), 3.67 (s, 3H), 1.66 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 146.2, 145.0, 144.2, 138.6, 133.5, 132.5, 132.0, 127.7, 127.5, 127.0, 125.8, 125.1, 117.7, 106.2, 60.5, 56.2, 37.7, 21.5. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{20}H_{20}O_3$: 308.1412; found: 308.1417.

2,6-dimethoxy-3-(1-(thiophen-2-yl)ethyl)phenol (3zf). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a pale yellow oil in 62% yield (65.5 mg). ^{1}H NMR (400 MHz, $CDCl_3$): 7.11 – 7.10 (m, 1H), 6.90 (s, 1H), 6.81 (s, 1H), 6.71 – 6.61 (m, 2H), 4.70 (q, *J* = 6.8 Hz, 1H), 3.86 (s, 3H), 3.81 (s, 3H), 1.64 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 151.3, 146.2, 144.6, 138.4, 132.4, 126.4, 123.4, 123.1, 117.5, 106.4, 60.8, 56.1, 33.2, 23.0. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{14}H_{16}O_3S$: 264.0820; found: 264.0824.

2,6–dimethoxy–3–(2,3–dihydro–1H–inden–1–yl)–phenol (3zg). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/ethyl acetate (5/1) to afford a brown oil in 73% yield (78.8 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.26 (d, *J* = 7.2 Hz, 1H), 7.17 – 7.08 (m, 2H), 6.95 (d, *J* = 7.2 Hz, 1H), 6.56 – 6.43 (m, 2H), 5.69 (s, 1H), 4.67 (t, *J* = 8.4 Hz, 1H), 3.85 (s, 3H), 3.81 (s, 3H), 3.06 – 2.89 (m, 2H), 2.58 – 2.53 (m, 1H), 2.04 – 1.94 (m, 1H); ^{13}C NMR (101 MHz, $CDCl_3$): 146.9, 146.0, 145.6, 144.3, 138.3, 131.6, 126.2, 126.1, 124.6, 124.1, 118.2, 106.6, 60.9, 56.1, 44.1, 35.8, 31.7. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{17}H_{18}O_3$: 270.1256; found: 270.1250.

1,3,5-trimethoxy-2-(1-phenylethyl)benzene (3zh).[18] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (2/1) to afford a white solid in 77% yield (83.8 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.28 – 7.19 (m, 4H), 7.11 – 7.07 (m, 1H), 6.12 (s, 2H), 4.74 (q, *J* = 7.2 Hz, 1H), 3.78 (s, 3H), 3.68 (s, 6H), 1.63 (d, *J* = 7.6 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): 159.4, 159.0, 146.6, 127.5, 127.2, 124.8, 115.9, 91.4, 55.7, 55.2, 32.9, 17.7.

1-methoxy-4-(1-phenylethyl)benzene (3zi).[7d] The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether to afford a colorless oil in 31% yield

(26.3 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.26 (d, *J* = 8.4 Hz, 2H), 7.21 – 7.12 (m, 5H), 6.82 (d, *J* = 8.0 Hz, 2H), 4.10 (q, *J* = 7.2 Hz, 1H), 3.77 (s, 3H), 1.61 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 157.8, 146.8, 138.5, 128.5, 128.3, 127.5, 125.9, 113.7, 55.2, 43.9, 22.0.

2-methoxy-1-(1-phenylethyl)naphthalene (3zj). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether to afford a colorless oil in 40% yield (41.9 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.78 – 7.76 (m, 1H), 7.70 – 7.67 (m, 2H), 7.24 – 7.13 (m, 7H), 7.07 – 7.03 (m, 1H), 5.20 (q, *J* = 7.2 Hz, 1H), 3.70 (s, 3H), 1.74 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 154.9, 146.0, 132.5, 130.0, 128.7, 128.4, 128.1, 127.9, 127.0, 125.9, 125.1, 124.4, 123.1, 114.7, 56.8, 34.5, 18.0. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{19}H_{18}O$: 262.1358; found: 262.1353.

(8R,9S,13S,14S)-3-hydroxy-13-methyl-2-(1-phenylethyl)-6,7,8,9,11,12,13,14,15,16-decahydro-17H-cyclopenta[a]phenanthren-17-one (3zk). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a pale yellow oil in 59% yield (88.3 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.46 – 6.73 (m, 6H), 6.42 (s, 1H), 5.09 (m, 1H), 4.29 (s, 1H), 2.74 (s, 2H), 2.52 – 1.72 (m, 8H), 1.54 – 1.33 (m, 8H), 0.82 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 221.6, 151.3, 145.7, 135.5, 131.6, 129.6, 128.5, 127.4, 126.1, 124.9, 115.9, 50.3, 48.1, 44.1, 38.4, 35.9, 31.5, 29.0, 26.5, 26.0, 21.5, 21.0, 13.8. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{26}H_{30}O_2$: 374.2246; found: 374.2240.

4-(4-hydroxy-3-(1-phenylethyl)phenyl)butan-2-one (3zl). The title compound was prepared according to the general procedure and purified by column chromatography on silica gel and eluted with petroleum ether/dichloromethane (1/1) to afford a pale yellow oil in 72% yield (77.2 mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.32 – 7.16 (m, 5H), 7.03 (s, 1H), 6.91 (d, *J* = 8.1 Hz, 1H), 6.66 (d, *J* = 8.1 Hz, 1H), 4.73 (s, 1H), 4.34 (q, *J* = 7.1 Hz, 1H), 2.83 (t, *J* = 7.5 Hz, 2H), 2.72 (t, *J* = 7.5 Hz, 2H), 2.12 (s, 3H), 1.61 (d, *J* = 7.3 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 208.5, 151.7, 145.3, 133.1, 132.0, 128.6, 127.8, 127.5, 127.0, 126.4, 116.0, 45.5, 38.7, 30.1, 29.2, 20.9. HRMS (EI) m/z: $[M]^+$ calcd. for $C_{18}H_{20}O_2$: 268.1463; found: 268.1458.

Associated Content

Supporting Information

Copies of ^{1}H and ^{13}C spectroscopies. This material is available free of charge via the Internet at http://pubs.acs.org.

Author Information

Corresponding Author

*E-mail: zhouyb@hnu.edu.cn.

ORCID

Jianyu Dong: 0000-0003-2161-1372
Yongbo Zhou: 0000-0002-3540-8618

Notes

The authors declare no competing financial interest.

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