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Environmentally benign syntheses of flavanones

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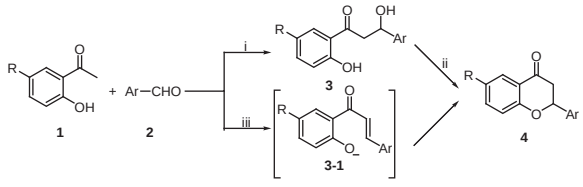
ABSTRACT

Mild and environmentally benign methods for the syntheses of flavanones are described. The reaction of *o*-hydroxyacetophenones (**1**) and benzaldehydes (**2**) in water in the presence of DABCO at room temperature gave 3-hydroxy-1-(2-hydroxylphenyl)-3-arylpropan-1-ones (**3a**–**i**) as intermediates. Followed by an intramolecular dehydration of the **3a**–**i** with the modified Mitsunobu's reaction, the target flavanones (**4a**–**i**) were obtained. Moreover, the reaction of **1** and **2** at the same conditions but at reflux gave flavanones in one pot with good yields.

1. Introduction

Flavanones, which exhibited broad spectra of biological activities have attracted the interest of chemists from earlier stages to the present. The major reported biological activities include neuron protection,[1] anti-tumor,[2,3] anti-metastasis,[4] antimicrobial,[5] antioxidant,[6] anti-inflammatory,[7] and antiviral activity,[8] as well as others. Flavanones, which have chemical structure embedded with 2-aryl chroman-4-one skeleton, are widely distributed in plants[9] and available from synthetic sources. The major and commonly reported synthetic methods for flavanones usually involve the Claisen–Schmidt reaction of *o*-hydroxyacetophenones with benzaldehydes to produce chalcone intermediates using diverse catalysts,[10–14] and then cyclization with various bases,[15] acids,[16] and others.[17] Recently, the reaction of *o*-hydroxyacetophenones with benzaldehydes using LDA in THF and then cyclization with the Mitsunobu's reaction was reported by Lee, et al.[18] Despite numerous methods reported, many disadvantages on flavanone synthesis still exist, such as by-products contamination, tedious reaction conditions, or using toxic, corrosive, and environmentally unfriendly reagents. Therefore to develop a new synthetic method with environmental concerns and efficiency for flavanones is essential and significant. Our strategy is to carry out the Claisen–Schmidt reaction of *o*-hydroxyacetophenones with benzaldehydes utilizing tertiary amine as base and water as solvent to yield the keto-ols as the major products. Then, followed by the cyclization of the given keto-ols using the modified Mitsunobu's reaction,[19] [DIAD (diisopropylazodicarboxylate), TPP (triphenylphosphine), and Et_3N] to afford the title compounds. Furthermore, when the Claisen–Schmidt reaction described above was carried out at the reflux condition for 20 h, it directly provided the desired flavanones without needs to isolate the intermediate chalcones. Our synthetic strategy for flavanones is depicted in Scheme 1.



a. R = H, Ar = C_6H_5
b. R = H, Ar = 4-FC_6H_4
c. R = H, Ar = 4-ClC_6H_4
d. R = H, Ar = 4-BrC_6H_4
e. R = H, Ar = 3-BrC_6H_4
f. R = H, Ar = 4-$NO_2C_6H_4$
g. R = H, Ar = 3-$NO_2C_6H_4$
h. R = Cl, Ar = 4-FC_6H_4
i. R = Cl, Ar = 4-BrC_6H_4

Scheme 1. Benign syntheses of flavanones (a) via the Claisen–Schmidt reaction and the Mitsunobu's reaction, and (b) one-pot reaction from **1** and **2**. Reagents and Conditions: i. DABCO, H_2O, rt, 3 days, 70–92%; ii. DIAD, TPP, Et_3N, THF, 0 °C–rt, 5 hr, 75–84%; iii. DABCO, H_2O, reflux, 20 hr, 67-78%

2. Results and discussion

In order to find out the best condition for giving the intermediates 1-(2-hydroxyphenyl)-3-aryl-3-hydroxy-1-propanones

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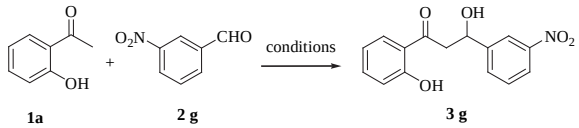
(**3a**–**i**), the reaction of *o*-hydroxyacetophenones (**1a**) with benzaldehydes (**2g**) utilizing various tertiary amines, such as DABCO, DBU, or TEA as reaction base and water or ethanol as solvent were investigated. After careful examining, the reaction results were summarized in Table 1.

Table 1
The reaction of **1a** with **2g** in various conditions to undergo the Claisen–Schmidt reaction to yield **3g**[a]



1a **2 g** **3 g**

Entry	Solvent	Tertiary amine	Yield (%)
1	H_2O	[b]DABCO (3 equiv)	92
2	EtOH	DABCO (3 equiv)	71
3	H_2O	DABCO (1 equiv)	80
4	EtOH	DABCO (1 equiv)	60
5	H_2O	[c]DBU (3 equiv)	69
6	EtOH	DBU (3 equiv)	59
7	H_2O	DBU (1 equiv)	56
8	EtOH	DBU (1 equiv)	42
9	H_2O	[d] TEA (3 equiv)	73
10	EtOH	TEA (3 equiv)	70
11	H_2O	TEA (1 equiv)	72
12	EtOH	TEA (1 equiv)	69

[a] The reaction is carried out at room temperature for 3 days.
[b] DABCO=1,4-diazabicyclo[2.2.2.]octane.
[c] DBU=1,8-diazabicyclo[5.4.0]undec-7-ene.
[d] TEA=triethylamine.

From Table 1, we found that using DABCO (3 equiv; as base) in water at room temperature was an optimal condition for the Claisen–Schmidt reaction of **1a** with **2g** to yield **3g** (entry 1). Using 1 equiv amine bases, however, lower yields were found (entries 3, 4, 7, 8, 11, and 12). Moreover, the reactive trend of solvents is H_2O>EtOH (entries 1 and 2; 5 and 6; 9 and 10), and in amine bases is DABCO>TEA>DBU (entries 1, 9, and 5). Based on the best reaction condition we obtained, 3-aryl-3-hydroxy-1-(2-hydroxylaryl)-propan-1-ones (**3a**–**i**) were given in yields of 70–92%, respectively. Depending on their correct spectroscopic data and elemental analysis, the structures of **3a**–**i** were verified. The physical and spectra data of **3a**–**i** are summarized as follows (Table 2).

Because dehydration process occurred in the EI-MS, the [M^+−18] molecular ion peak was often found in compound **3a**–**i**. In order to further confirm the structures of **3a**–**i**, the X-ray analysis of 1-(2-hydroxyphenyl)-3-(3-bromophenyl)-3-hydroxylpropanone (**3e**) was carried out. Compound **3e** clearly possesses the expected skeleton with two almost orthogonal aryl rings. The ketone group and the phenolic hydroxyl group assume the *syn* configuration obviously due to hydrogen bonding interaction. The resulting ORTEP, coincident with structure **3e**, was depicted as Fig. 1.[20]

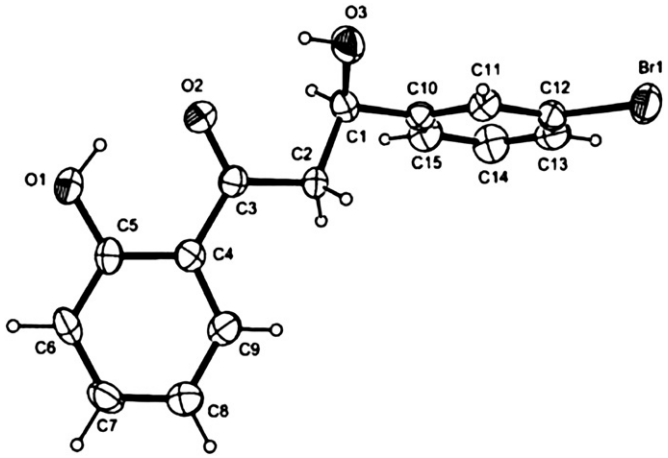
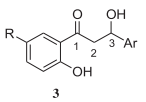


Fig. 1. ORTEP of 1-(2-hydroxyphenyl)-3-(3-bromophenyl)-3-hydroxylpropanone (**3e**).

Subsequently, compounds **3a**–**i** were cyclized by the modified Mitsunobu's reaction using DIAD, TPP, and triethylamine as dehydration reagents to give the desired flavanones (**4a**–**i**) in 75–84% yields. All prepared flavanones have satisfactory physical and spectral data to support the correctness of structures. Especially, in their ^{1}H NMR spectra, the typical signals of methylene hydrogen atoms (H-3a and H-3b) displayed ABX type splitting pattern. This fact offers proof for the flavanones structure. Take **4b** as an example, two nearby double doublet signals in the ^{1}H NMR spectrum were observed at δ 2.88 and δ 3.07 with coupling constants 16.8, 2.8 Hz and 16.8, 13.2 Hz, respectively. This totally agrees with the expected pattern for H-3a and H-3b. Furthermore, the double doublet signal at δ 5.48 with coupling constants 13.2 and 2.8 Hz was again consistent with the expected pattern for H-2, which coupled with H-3a and H-3b. Moreover, in order to reduce the reaction wastes and to increase the efficiency of the reaction, the synthesis of flavanones (**4a**–**i**) was accomplished through one-pot reaction of *o*-hydroxyacetophenones with benzaldehydes. Meanwhile, several model reactions were designed to investigate the scope and limitation of one-pot reaction (Table 3).

Table 2
The physical and spectra data of **3a**–**i**



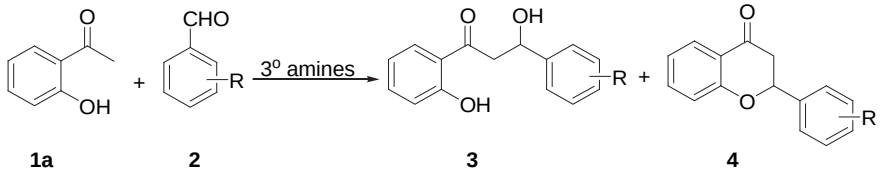
3

a. R = H, Ar = C_6H_5
b. R = H, Ar = 4-FC_6H_4
c. R = H, Ar = 4-ClC_6H_4
d. R = H, Ar = 4-BrC_6H_4
e. R = H, Ar = 3-BrC_6H_4
f. R = H, Ar = 4-$NO_2C_6H_4$
g. R = H, Ar = 3-$NO_2C_6H_4$
h. R = Cl, Ar = 4-FC_6H_4
i. R = Cl, Ar = 4-BrC_6H_4

Compd	Yield (%)	MP (°C)	H-3[a] dd (*J*)	H_a-2[a] dd (*J*)	H_b-2[a] dd (*J*)	C=O	EI-MS M^+−18
3a	70	108–109 (108–110)[21]	5.37 (9.2, 3.0)	3.36 (17.6, 3.0)	3.46 (17.6, 9.2)	C=O[b]	224
3b	80	119–120 (120)[21]	5.35 (8.8, 2.8)	3.33 (17.6, 2.8)	3.42 (17.6, 8.8)	205.4	242
3c	74	121–122 (122)[21]	5.35 (8.8, 3.2)	3.34 (17.6, 3.2)	3.41 (17.6, 8.8)	205.3	258
3d	77	145–146 (145)[21]	5.33 (8.8, 3.2)	3.34 (17.6, 3.2)	3.41 (17.6, 8.8)	205.2	301
3e[c]	76	129–130[c]	5.34 (8.8, 3.2)	3.36 (17.6, 3.2)	3.42 (17.6, 8.8)	205.1	301
3f	91	153–154 (156)[22]	5.48 (m)	3.42 (m)	3.52 (m)	205.1	269
3g	92	130–131 (127–129)[22]	5.49 (m)	3.45 (m)	3.45 (m)	204.6	269
3h[c]	79	149–150[c]	5.35 (9.2, 3.2)	3.29 (17.6, 3.2)	3.41 (17.6, 9.2)	204.7	276
3i[c]	77	150–151[c]	5.33 (8.8, 3.2)	3.28 (17.6, 3.2)	3.40 (17.6, 9.2)	204.4	335

[a] Measured in ^{1}H NMR ($CDCl_3$, 400 MHZ).
[b] Measured in ^{13}C NMR ($CDCl_3$, 100 MHZ).
[c] New compound.

Table 3
Investigation the scope and limitation of the one-pot reaction using various tertiary amines[a]



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

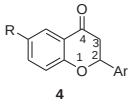
Entry	3° Amine (3 equiv)	Yield (%)[b] **3**	Yield (%) **4**
1 (R=H)	DABCO	19	67
2	DBU	38	21
3	TEA	24	59
4[c]	DMAP	15	38
5 (R= 3-Br)	DABCO	17	69
6	DBU	46	28
7	TEA	32	64
8	DMAP	29	43
9 (R= 3-NO_2)	DABCO	20	76
10	DBU	53	32
11	TEA	21	73
12	DABCO	15	66
13 (R=4-Br)	DABCO	19	70
14 (R=4-NO_2)	DABCO	20	78
15[d] (R=4-OMe)	DABCO	0	0

[a] The reaction was carried out at reflux in water for 20 h.
[b] Compounds were isolated and purified by column chromatography.
[c] DMAP=*N*,*N*-dimethylaminopyridine.
[d] Recovery starting material.

As shown in Table 3, the reaction using DABCO (3 equiv) as base, water as solvent and reflux promoted the reaction of **1** with **2** in one pot to give **4** in yields of 67–76% (entries 1, 5, and 9). On the other hand DBU a sterically hindered base[23] used as a reaction base rendered reduced yields of **4** (21–32%) (entries 2, 6, and 10). As reaction base TEA, which is less soluble in water afforded the expected **4** in 59–73% yields (entries 3, 7, and 11). Parallelly, using DMAP a weak base as reaction base compound **4** was afforded in slightly lower yields (38–66%) (entries 4, 8, and 12). Resulting from our experimental results, BABCO was found to be a better base than other tertiary bases in running one-pot reaction of **1** and **2** to yield **4**. Thus, the trend of reaction base is DABCO>TEA>DMAP>DBU.

Besides the reaction bases, the structure of benzaldehydes, which may influence the reaction of **1** with **2** to yield **4** was investigated. Therefore various benzaldehydes (**2**) were explored to react with *o*-hydroxyacetophenone (**1a**) (entries 1, 5, 9, and 13–15) to figure out the scope and limitation. We found that benzaldehydes bearing an electron-withdrawing group worked well under the presence of DABCO (3 equiv) at reflux in water for 20 h, the reactions proceeded successfully to afford the flavanones **4** in good yields (entries 5, 9, and 13–14). Obviously, benzaldehyde with the electron-donating group to react with compound **1a** (entry 15), no desired product was detected but with the recovery of starting material. Apparently, for benzaldehydes (**2**) with an electron-withdrawing group facilitates the one-pot reaction, and with an electron-donating group decreases the reaction. Therefore, depending on the results of our investigation, the effect of substituents of benzaldehydes in this one-pot reaction can be deduced as the following trend: 4-NO_2>3-NO_2>4-Br>3-Br>H>>4-OCH_3. All flavanones obtained from one-pot reaction and from two-steps are identical by comparing their physical and spectral data. The physical and spectra data of **4a**–**i** were summarized in Table 4.

Table 4
The physical and the selected spectral data of **4a**–**i**



4

a. R = H, Ar = C_6H_5
b. R = H, Ar = 4-FC_6H_4
c. R = H, Ar = 4-ClC_6H_4
d. R = H, Ar = 4-BrC_6H_4
e. R = H, Ar = 3-BrC_6H_4
f. R = H, Ar = 4-$NO_2C_6H_4$
g. R = H, Ar = 3-$NO_2C_6H_4$
h. R = Cl, Ar = 4-FC_6H_4
i. R = Cl, Ar = 4-BrC_6H_4

Compd	Yield (%)	MP (°C)	H-2 dd (*J*)	H_a-3 dd (*J*)	H_b-3 dd (*J*)	C=O	EI-MS M^+
4a	75[a] (67)[b]	70–71 (73–75)[24]	5.49 (13.2, 2.8)	2.90 (16.8, 2.8)	3.10 (16.8, 13.2)	192.0	224
4b	75 (71)	79–80 (78–79)[24]	5.48 (13.2, 2.8)	2.88 (16.8, 2.8)	3.07 (16.8, 13.2)	191.8	242
4c	78 (70)	85–86 (84–85)[18]	5.47 (13.2, 3.2)	2.88 (17.2, 3.2)	3.05 (17.2, 13.2)	191.5	258
4d	79 (70)	116–117(115.8–119)[3]	5.46 (13.2, 2.8)	2.88 (16.8, 3.2)	3.04 (16.8, 13.2)	191.5	301
4e[c]	77 (69)	102–103	5.45 (13.2, 2.8)	2.89 (16.8, 3.2)	3.04 (16.8, 13.6)	191.4	301
4f	79 (78)	120–121(118–119)[25]	5.62 (12.4, 3.6)	2.96 (16.8, 3.6)	3.04 (16.8, 12.4)	190.7	269
4g	84 (76)	145–146 (142)[22]	5.61 (12.8, 3.2)	2.96 (16.8, 3.2)	3.08 (16.8, 12.8)	190.8	269
4h[c]	82 (74)	149–150	5.46 (13.2, 2.8)	2.89 (16.8, 2.8)	3.06 (16.8, 13.2)	190.6	276
4i[c]	80 (72)	151–152	5.44 (12.8, 3.2)	2.89 (16.8, 3.2)	3.02 (16.8, 12.8)	190.4	335

[a] Isolated yields from column chromatography after the reaction of **3** with the Mitzunobu's reaction.
[b] Isolated yields obtained from the reaction of **1** and **2** in one pot.
[c] New compounds.

3. Conclusion

We have successfully developed environmentally benign syntheses for flavanones. In our synthetic procedures, no corrosive acids or bases and no catalyst were used. Most importantly, we have demonstrated that the use of water as the solvent and DABCO as the base for the Claisen–Schmidt reaction at room temperature to prepare intermediate 3-aryl-3-hydroxy-1-(2-hydroxylaryl) propan-1-ones as well as the cyclization to yield flavanones using the modified Mitsunobu's reagent. Moreover, at the same conditions but at reflux avoided to isolate keto-ols (**3**) and chalcones provides a mild, concise, efficient, and one pot method for flavanones.

4. Experimental

4.1. General

Melting points (Yanaco micro melting-point apparatus) were uncorrected. ^{1}H NMR and ^{13}C NMR spectra were obtained on a Varian Unity plus 400 Spectrometer. Chemical shifts were measured in parts per million with respect to TMS. IR spectra were run on a Perkin–Elmer spectrometer. Elemental analyses were recorded on a Heraeus CHN-O Rapid analyzer. Mass spectra were recorded on a Chem/hp/middle spectrometer connected to a Hewlett Packard series II model gas-liquid chromatography. HRMS spectra were performed on a JEOL JMS SX/SX 102A instrument. Silica gel (230–400 mesh) for column chromatography and precoated silica-gel plates (60 F-254) for TLC were purchased from E. Merck Co. UV light (254 nm) was used to detect spots on TLC plates after development.

*4.1.1. General procedure for the preparation of 3-aryl-3-hydroxy-1-(2-hydroxylaryl)propan-1-ones (**3a**–**i**).* The mixture of 2-hydroxyacetophenones (**1a**,**b**) (7.3 mmol) and benzaldehydes (**2a**–**i**) (7.3 mmol) in H_2O (30 mL) was stirred, and then added DABCO (2.45 g, 21.9 mmol). The resulting mixture was continually stirred at room temperature for 3 days. Then, the reaction mixture was extracted with dichloromethane (3×50 mL). The resulting extracts were combined, washed with brine, and dried over anhydrous $MgSO_4$ in sequence. After filtration, the filtrate was concentrated in vacuo to give crude **3a**–**i**. The given crude products were further purify from silica-gel column chromatography (ethyl acetate/*n*-hexane=1:5) to yield pure **3a**–**i**.

*4.1.1.1. 3-Hydroxy-1-(2-hydroxyphenyl)-3-phenylpropan-1-one (**3a**).* Compound **3a** (1.69 g, 70%) was obtained as colorless crystals, mp=108–109 °C (lit.[21] mp 108–110 °C); R_f=0.58 (ethyl acetate/*n*-hexane=1:3); IR (KBr) cm^{-1}: 1634 (C=O) and 3466 (OH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.25 (s, 1H, ArCO–CH_aH_bCHOH), 3.36 (dd, J=17.6, 3.0 Hz, 1H, ArCOCH_aH$_b$–CHOH), 3.46 (dd, J=17.6, 9.2 Hz, 1H, ArCOCH$_a$$H_b$CHOH), 5.37 (dd, J=9.2, 3.0 Hz, 1H, ArCOCH$_a$H$_b$CHOH), 6.89 (td, J=8.0, 0.8 Hz, 1H, ArH), 7.00 (dt, J=8.4, 0.8 Hz, 1H, ArH), 7.32 (td, J=8.8, 1.6 Hz, 1H, ArH), 7.44 (m, 5H, ArH), 7.70 (dd, J=8.0, 1.6 Hz, 1H, ArH), 12.1 (s, 1H, ArOH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 47.1, 69.8, 118.7, 119.1, 119.4, 125.7, 127.9, 128.7, 130.0, 136.9, 142.7, 162.6, 205.4; EIMS (70 eV) *m*/*z* (rel intensity, %) 224 (M^+, –18, 57), 223 (100), 147 (35), 120 (23), 105 (20), 93 (20), 92 (27), 78 (14). Anal. Calcd for $C_{15}H_{14}O_3$: C, 74.36; H, 5.82. Found: C, 73.86; H, 5.85.

*4.1.1.2. 3-(4-Fluorophenyl)-3-hydroxy-1-(2-hydroxyphenyl) -propan-1-one (**3b**).* Compound **3b** (2.08 g, 80%) was obtained as colorless crystals, mp=119–120 °C (lit.[21] mp 120 °C); R_f=0.74 (ethyl acetate/*n*-hexane=1:3); IR (KBr) cm^{-1}: 1637 (C=O) and 3269 (OH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.33 (dd, J=17.6, 3.2 Hz, 1H, ArCO-CH_aH$_b$CHOH), 3.39 (s, 1H, ArCOCH$_a$H$_b$CHOH), 3.42 (dd, J=17.6, 8.8 Hz, 1H, ArCOCH$_a$$H_b$CHOH), 5.35 (dd, J=8.8, 3.2 Hz, 1H, ArCO-CH$_a$H$_b$CHOH), 6.89 (td, J=8.4, 1.2 Hz, 1H, ArH), 7.01 (dd, J=8.4, 0.8 Hz, 1H, ArH), 7.08 (m, 2H, Ar′H), 7.42 (m, 2H, ArH), 7.50 (td, J=8.4, 1.2 Hz, 1H, ArH), 7.70 (dd, J=8.0, 1.2 Hz, 1H, ArH), 12.0 (s, 1H, ArOH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 47.1, 69.3, 115.5 (d, J=21.2 Hz), 118.7, 119.2, 119.3, 127.4 (d, J=7.6 Hz), 130.0, 137.0, 138.4 (d, J=3.0 Hz), 162.3 (d, J=224.0 Hz), 162.6, 205.3; EI-MS (70 eV) *m*/*z* (rel intensity, %) 242 (M^+, –18, 56), 241 (100), 225 (21), 147 (29), 123 (16), 121 (33), 120 (16), 92 (15). Anal. Calcd for $C_{15}H_{13}FO_3$: C, 69.22; H, 5.03. Found: C, 68.82; H, 5.01.

*4.1.1.3. 3-(4-Chlorophenyl)-3-hydroxy-1-(2-hydroxyphenyl)-propan-1-one (**3c**).* Compound **3c** (1.50 g, 74%) was obtained as colorless crystals, mp=121–122 °C (lit.[21] mp 122 °C); R_f=0.54 (ethyl acetate/*n*-hexane=1:3); IR (KBr) cm^{-1}: 1635 (C=O) and 3525 (OH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.34 (dd, J=17.6, 3.2 Hz, 1H, ArCO-CH_aH$_b$CHOH), 3.39 (s, 1H, ArCOCH$_a$H$_b$–CHOH), 3.41 (dd, J=17.6, 8.8 Hz, 1H, ArCOCH$_a$$H_b$CHOH), 5.35 (dd, J=8.8, 3.2 Hz, 1H, ArCO-CH$_a$H$_b$CHOH), 6.89 (td, J=8.0, 1.2 Hz, 1H, ArH), 7.01 (dd, J=8.4, 1.2 Hz, 1H, ArH), 7.37 (m, 4H, ArH), 7.50 (td, J=8.4, 1.6 Hz, 1H, ArH), 7.68 (dd, J=8.4, 2.0 Hz, 1H, ArH), 12.0 (s, 1H, ArOH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 47.0, 69.2, 118.7, 119.2, 119.3, 127.1, 128.8, 129.9, 133.5, 137.0, 141.1, 162.6, 205.2; EIMS (70 eV) *m*/*z* (rel intensity, %) 258 (M^+, –18, 60), 257 (100), 147 (72), 121 (35), 120 (29), 102 (35), 92 (37), 75 (26). Anal. Calcd for $C_{15}H_{13}ClO_3$: C, 65.11; H, 4.74. Found: C, 65.14; H, 4.70.

*4.1.1.4. 3-(4-Bromophenyl)-3-hydroxy-1-(2-hydroxyphenyl) propan-1-one (**3d**).* Compound **3d** (1.82g, 77%) was obtained as colorless crystals, mp=145–146 °C (lit.[21] mp 145 °C); R_f=0.67 (ethyl acetate/*n*-hexane=1:3); IR (KBr) cm^{-1}: 1630 (C=O) and 3519 (OH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.34 (dd, J=17.6, 3.2 Hz, 1H, ArCOCH_aH$_b$-CHOH), 3.39 (s, 1H, ArCOCH$_a$H$_b$–CHOH), 3.41 (dd, J=17.6, 8.8 Hz, 1H, ArCOCH$_a$$H_b$CHOH), 5.33 (dd, J=8.8, 3.2 Hz, 1H, ArCOCH$_a$H$_b$CHOH), 6.89 (td, J=8.0, 1.2 Hz, 1H, ArH), 7.01 (dd, J=8.8, 1.2 Hz, 1H, ArH), 7.32 (m, 1H, Ar′H), 7.50 (td, J=8.4, 1.6 Hz, 1H, ArH), 7.68 (dd, J=8.0, 1.6 Hz, 1H, ArH), 12.0 (s, 1H, ArOH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 47.0, 69.2, 118.7, 119.2, 119.3, 121.6, 127.5, 130.0, 131.7, 137.1, 141.7, 162.6, 205.1; EIMS (70 eV) *m*/*z* (rel intensity, %) 303 (M^+, –18, 100), 302 (66), 301 (85), 223 (60), 207 (43), 148 (43), 147 (79), 121 (46), 103 (60). Anal. Calcd for $C_{15}H_{13}BrO_3$: C, 56.10; H, 4.08. Found: C, 56.05; H, 4.10.

*4.1.1.5. 3-(3-Bromophenyl)-3-hydroxy-1-(2-hydroxyphenyl) propan-1-one (**3e**).* Compound **3e** (1.56 g, 76%) was obtained as colorless crystals, mp=129–130 °C; R_f=0.44 (ethyl acetate/*n*-hexane=1:3); IR (KBr) cm^{-1}: 1641 (C=O) and 3464 (OH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.33 (s, 1H, ArCOCH$_a$H$_b$CHOH), 3.36 (dd, J=17.6, 3.2 Hz, 1H, ArCOCH_aH$_b$CHOH), 3.42 (dd, J=17.6, 8.8 Hz, 1H, ArCO-CH$_a$$H_b$CHOH), 5.34 (dd, J=8.8, 3.2 Hz, 1H, ArCOCH$_a$H$_b$CHOH), 6.90 (td, J=8.4, 1.2 Hz, 1H, ArH), 7.00 (m, 1H, ArH), 7.47 (m, 5H, ArH), 7.69 (dd, J=8.0, 1.6 Hz, 1H, ArH), 12.0 (s, 1H, ArOH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 47.0, 69.1, 118.7, 119.2, 122.8, 124.4, 128.9, 130.0, 130.2, 130.9, 137.1, 143.6, 144.9, 162.6, 205.1; EIMS (70 eV) *m*/*z* (rel intensity, %) 303 (M^+, –18, 39), 302 (34), 301 (34), 224 (20), 147 (100), 120 (41), 103 (20), 92 (38). Anal. Calcd for $C_{15}H_{13}BrO_3$: C, 56.10; H, 4.08. Found: C, 56.12; H, 4.11.

*4.1.1.6. 3-Hydroxy-1-(2-hydroxyphenyl)-3-(4-nitrophenyl)-propan-1-one (**3f**).* Compound **3f** (1.79 g, 91%) was obtained as colorless crystals, mp=153–154 °C (lit.[22] mp 156 °C); R_f=0.44 (ethyl acetate/*n*-hexane=1:3); IR (KBr) cm^{-1}: 1640 (C=O) and 3529 (OH); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.41 (s, 1H, ArCOCH$_a$H$_b$CH–OH), 3.42 (m, 1H, ArCOCH_aH$_b$CHOH), 3.52 (m, 1H, ArCO–CH$_a$$H_b$CHOH), 5.48 (m, 1H, ArCOCH$_a$H$_b$CHOH), 6.90 (td, J=8.4, 1.2 Hz, 1H, ArH), 7.02 (dd, J=8.4, 1.2 Hz, 1H, ArH), 7.51 (m, 1H, ArH), 7.65 (td, J=8.8, 1.6 Hz, 3H, ArH), 8.25 (dd, J=8.8, 1.6 Hz, 2H, ArH), 12.0 (s, 1H, ArOH); ^{13}C NMR

($CDCl_3$, 100 MHz) δ 46.79, 68.93, 118.8, 119.1, 119.3, 123.9, 126.6, 129.9, 137.3, 147.9, 149.8, 162.6, 204.6; EIMS (70 eV) *m*/*z* (rel intensity, %) 269 (M^+, −18, 43), 268 (66), 252 (24), 207 (40), 148 (27), 147 (74), 120 (53), 93 (100). Anal. Calcd for $C_{15}H_{13}NO_5$: C, 62.72; H, 4.56; N, 4.88. Found: C, 62.66; H, 4.61; N, 4.84.

*4.1.1.7. 3-Hydroxy-1-(2-hydroxyphenyl)-3-(3-nitrophenyl) -propan-1-one (**3g**).* Compound **3g** (1.82 g, 92%) was obtained as colorless crystals, mp=130–131 °C (lit.[22] mp 127–129 °C); R_f=0.44 (ethyl acetate/*n*-hexane=1:3); IR (KBr) cm^{-1}: 1638 (C=O) and 3529 (OH); ^1H NMR ($CDCl_3$, 400 MHz) δ 3.45 (m, 1H, ArCOCH_aH$_b$-CHOH), 3.45 (m, 1H, ArCOCH$_a$$H_b$CHOH), 5.49 (m, 1H, ArCOCH$_2$-C*H*OH), 6.91 (td, *J*=8.4, 1.2 Hz, 1H, ArH), 7.02 (dd, *J*=8.4, 1.2 Hz, 1H, ArH), 7.52 (td, *J*=8.4, 1.6 Hz, 1H, ArH), 7.57 (t, *J*=8.0 Hz, 1H, ArH), 7.69 (dd, *J*=8.4, 2.0 Hz, 1H, ArH), 7.80 (m, 1H, ArH), 8.18 (m, 1H, ArH), 8.34 (t, *J*=1.6 Hz, 1H, ArH), 12.0 (s, 1H, ArOH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 46.8, 68.8, 118.8, 119.1, 119.3, 120.9, 122.8, 129.6, 129.9, 131.9, 137.3, 144.7, 148.4, 162.6, 204.7; EIMS (70 eV) *m*/*z* (rel intensity, %) 269 (M^+, −18, 74), 268 (89), 148 (69), 147 (100), 122 (67), 120 (82), 93 (34), 92 (93). Anal. Calcd for $C_{15}H_{13}NO_5$: C, 62.72; H, 4.56; N, 4.88. Found: C, 62.67; H, 4.59; N, 4.82.

*4.1.1.8. 1-(5-Chloro-2-hydroxyphenyl)-3-(4-fluorophenyl)-3-hydroxypropan-1-one (**3h**).* Compound **3h** (1.70 g, 79%) was obtained as colorless crystals, mp=93–94 °C; R_f=0.67 (ethyl acetate/*n*-hexane=1:3); IR (KBr) cm^{-1}: 1640 (C=O) and 3432 (OH); ^1H NMR ($CDCl_3$, 400 MHz) δ 3.12 (s, 1H, ArCOCH$_a$H$_b$CHOH), 3.29 (dd, *J*=17.6, 3.2 Hz, 1H, ArCOCH_aH$_b$CHOH), 3.41 (dd, *J*=17.6, 9.2 Hz, 1H, ArCO-CH$_a$$H_b$CHOH), 5.35 (dd, *J*=9.2, 3.2 Hz, 1H, ArCOCH$_a$H$_b$C*H*OH), 6.97 (d, *J*=8.8 Hz, 1H, ArH), 7.08 (td, *J*=9.2, 2.8 Hz, 2H, ArH), 7.42 (m, 3H, ArH), 7.65 (d, *J*=2.4 Hz, 1H, ArH), 11.9 (s, 1H, ArOH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 47.3, 69.1, 115.6 (d, *J*=21.2 Hz), 119.8, 120.4, 123.9, 127.4 (d, *J*=8.4 Hz), 129.2, 136.9, 138.2, 161.0 (d, *J*=256.9 Hz), 163.6, 204.4; EIMS (70 eV) *m*/*z* (rel intensity, %) 276 (M^+, −18, 99), 275 (100), 183 (33), 181 (53), 156 (31), 155 (31), 154 (78), 122 (29). Anal. Calcd for $C_{15}H_{12}ClFO_3$: C, 61.13; H, 4.10. Found: C, 61.10; H, 4.11.

*4.1.1.9. 3-(4-Bromophenyl)-1-(5-chloro-2-hydroxyphenyl)-3-hydroxypropan-1-one (**3i**).* Compound **3i** (1.98 g, 77%) was obtained as colorless crystals, mp=103–104 °C; R_f=0.61 (ethyl acetate/*n*-hexane=1:3); IR (KBr) cm^{-1}: 1638 (C=O) and 3447 (OH); ^1H NMR ($CDCl_3$, 400 MHz) δ 3.15 (s, 1H, ArCOCH$_a$H$_b$CHO*H*), 3.28 (dd, *J*=17.6, 3.2 Hz, 1H, ArCOCH_aH$_b$CHOHAr′), 3.40 (dd, *J*=17.6, 9.2 Hz, 1H, ArCOCH$_a$$H_b$CHOH), 5.33 (dd, *J*=8.8, 3.2 Hz, 1H, ArCOCH$_a$H$_b$C*H*OH), 6.97 (d, *J*=8.8 Hz, 1H, Ar–H), 7.31 (td, *J*=8.8, 2.4 Hz, 2H, Ar–H), 7.44 (dd, *J*=8.8, 2.4 Hz, 1H, ArH), 7.52 (td, *J*=9.2, 2.4 Hz, 2H, ArH), 7.63 (d, *J*=2.4 Hz, 1H, ArH), 11.9 (s, 1H, ArOH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 47.1, 69.1, 119.8, 120.4, 121.8, 123.9, 127.4, 129.1, 131.8, 136.9, 141.4, 161.0, 204.2; EIMS (70 eV) *m*/*z* (rel intensity, %) 337 (M^+, −18, 66), 336 (44), 335 (46), 183 (46), 182 (66), 181 (100), 154 (79), 102 (51). Anal. Calcd for $C_{15}H_{12}BrClO_3$: C, 50.66; H, 3.40. Found: C, 50.49; H, 3.38.

*4.1.2. General procedure for the preparation of flavavones (**4a**–**i**).* Under argon, the solution of **3a**–**i** (1.6 mmol), TPP (0.46 g, 1.6 mmol), and Et_3N (0.18 g, 1.6 mmol) in THF (20 mL) at 0 °C was stirred and added DIAD (0.43 g, 1.9 mmol) in drops. The resulting mixture was continually stirred from 0 °C to room temperature for 5 h. After concentration in vacuo, the obtained residue was further purified from silica-gel column chromatography (ethyl acetate/*n*-hexane=1:10) to give pure **4a**–**i**.

*4.1.2.1. Flavanone (**4a**).* Compound **4a** (0.27 g, 75%) was obtained as colorless crystals, mp=70–71 °C (lit.[24] mp 73–75 °C); R_f=0.53 (ethyl acetate/*n*-hexane=1:4); IR (KBr) cm^{-1}:1688 (C=O); ^1H NMR ($CDCl_3$, 400 MHz) δ 2.90 (dd, *J*=16.8, 2.8 Hz, 1H, Ha-3), 3.10 (dd, *J*=16.8, 13.2 Hz, 1H, Hb-3), 5.49 (dd, *J*=13.2, 2.8 Hz, 1H, H-2), 7.06 (m, 2H, ArH), 7.47 (m, 5H, ArH), 7.94 (dd, *J*=8.4, 2.0 Hz, 1H, ArH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 44.7, 79.6, 118.1, 120.9, 121.6, 126.1, 127.0, 128.8, 128.9, 136.2, 138.7, 161.5, 192.0; EIMS (70 eV) *m*/*z* (rel intensity, %) 224 (M^+, 56), 223 (100), 147 (62), 120 (47), 104 (26), 92 (78), 78(29), 63 (22). Anal. Calcd for $C_{15}H_{12}O_2$: C, 80.34; H, 5.39. Found: C, 80.02; H, 5.47.

*4.1.2.2. 4′-Fluoroflavanone (**4b**).* Compound **4b** (0.31 g, 75%) was obtained as colorless crystals, mp=79–80 °C (lit.[24] mp 78–79 °C); R_f=0.48 (ethyl acetate/*n*-hexane=1:4); IR (KBr) cm^{-1}: 1695 (C=O); ^1H NMR ($CDCl_3$, 400 MHz) δ 2.88 (dd, *J*=16.8, 2.8 Hz, 1H, Ha-3), 3.07 (dd, *J*=16.8, 13.2 Hz, 1H, Hb-3), 5.48 (dd, *J*=13.2, 2.8 Hz, 1H, H-2), 7.10 (m, 4H, ArH), 7.47 (m, 2H, ArH), 7.52 (td, *J*=8.4, 1.6 Hz, 1H, ArH), 7.93 (dd, *J*=8.0, 2.0 Hz, 1H, ArH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 44.7, 78.9, 115.8 (d, *J*=21.3 Hz), 118.1, 120.9, 121.8, 127.1, 128.0 (d, *J*=8.3 Hz), 134.6, 136.3, 161.4, 162.8 (d, *J*=246.3 Hz), 191.8; EIMS (70 eV) *m*/*z* (rel intensity, %) 242 (M^+, 56), 241 (87), 147 (43), 122 (41), 121 (36), 120 (67), 92 (100), 63 (23). Anal. Calcd for $C_{15}H_{11}FO_2$: C, 74.37; H, 4.58. Found: C, 74.31; H, 4.58.

*4.1.2.3. 4′-Chloroflavanone (**4c**).* Compound **4c** (0.32 g, 78%) was obtained as colorless crystals, mp=85–86 °C (lit.[18] mp 84–85 °C); R_f=0.48 (ethyl acetate/*n*-hexane=1:4); IR (KBr) cm^{-1}: 1692 (C=O); ^1H NMR ($CDCl_3$, 400 MHz) δ 2.88 (dd, *J*=17.2, 3.2 Hz, 1H, Ha-3), 3.05 (dd, *J*=17.2, 13.2 Hz, 1H, Hb-3), 5.47 (dd, *J*=13.2, 3.2 Hz, 1H, H-2), 7.07 (m, 2H, ArH), 7.42 (m, 4H, ArH), 7.52 (td, *J*=8.4, 1.6 Hz, 1H, ArH), 7.93 (dd, *J*=8.0, 2.0 Hz, 1H, ArH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 44.6, 78.8, 118.1, 120.9, 121.8, 127.1, 127.5, 129.0, 134.6, 136.3, 137.2, 161.3, 191.5; ^{13}C NMR ($CDCl_3$, 100 MHz) δ 44.58, 78.80, 118.1, 120.9, 121.8, 127.1, 127.5, 129.0, 134.6, 136.3, 137.2, 161.3, 191.5; EIMS (70 eV) *m*/*z* (rel intensity, %) 258 (M^+, 71), 257 (100), 223 (29), 147 (66), 138 (37), 120 (67), 103 (37), 92 (75). Anal. Calcd for $C_{15}H_{11}ClO_2$: C, 69.64; H, 4.29. Found: C, 69.53; H, 4.30.

*4.1.2.4. 4′-Bromoflavanone (**4d**).* Compound **4d** (0.38 g, 79%) was obtained as colorless crystals, mp=116–117 °C (lit.[3] mp 115.8–119 °C); R_f=0.49 (ethyl acetate/*n*-hexane=1:4); IR (KBr) cm^{-1}: 1687 (C=O); ^1H NMR ($CDCl_3$, 400 MHz) δ 2.88 (dd, *J*=16.8, 3.2 Hz, 1H, Ha-3), 3.04 (dd, *J*=16.8, 13.2 Hz, 1H, Hb-3), 5.46 (dd, *J*=13.2, 2.8 Hz, 1H, H-2), 7.07 (m, 2H, ArH), 7.37 (dd, *J*=8.4, 1.6 Hz, 2H, ArH), 7.56 (td, *J*=8.4, 1.6 Hz, 1H, ArH), 7.57 (dd, *J*=8.4, 2.0 Hz, 2H, ArH), 7.93 (dd, *J*=8.0, 2.0 Hz, 1H, ArH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 44.5, 78.8, 118.1, 120.9, 121.8, 122.7, 127.1, 127.8, 132.0, 136.3, 137.8, 161.3, 191.5; EIMS (70 eV) *m*/*z* (rel intensity, %) 303 (M^+, 45), 302 (26), 301 (39), 223 (49), 147 (88), 120 (62), 103 (72), 93(100). Anal. Calcd for $C_{15}H_{11}BrO_2$: C, 59.43; H, 3.66. Found: C, 59.36; H, 3.71.

*4.1.2.5. 3′-Bromoflavanone (**4e**).* Compound **4e** (0.37 g, 77%) was obtained as colorless crystals, mp=102–103 °C; R_f=0.50 (ethyl acetate/*n*-hexane=1:4); IR (KBr) cm^{-1}: 1692 (C=O); ^1H NMR ($CDCl_3$, 400 MHz) δ 2.89 (dd, *J*=16.8, 3.2 Hz, 1H, Ha-3), 3.04 (dd, *J*=16.8, 13.6 Hz, 1H, Hb-3), 5.45 (dd, *J*=13.2, 2.8 Hz, 1H, H-2), 7.08 (m, 2H, ArH), 7.31 (t, *J*=8.0 Hz, 1H, ArH), 7.53 (m, 2H, ArH), 7.68 (t, *J*=1.6 Hz, 1H, ArH), 7.93 (dd, *J*=8.4, 2.0 Hz, 1H, ArH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 44.6, 78.7, 118.1, 120.8, 121.9, 122.9, 124.6, 127.1, 129.2, 130.4, 131.8, 136.3, 141.1, 161.2, 191.4; EIMS (70 eV) *m*/*z* (rel intensity, %) 303 (M^+, 43), 302 (36), 301 (33), 148 (28), 147 (100), 121 (24), 120 (45), 92 (49). Anal. Calcd for $C_{15}H_{11}BrO_2$: C, 59.43; H, 3.66. Found: C, 59.40; H, 3.65.

*4.1.2.6. 4′-Nitroflavanone (**4f**).* Compound **4f** (0.34 g, 79%) was obtained as colorless crystals, mp=120–121 °C (lit.[25] mp 118–119 °C); R_f=0.35 (ethyl acetate/*n*-hexane=1:4); IR (KBr) cm^{-1}:

1691 (C=O); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.96 (dd, J=16.8, 3.6 Hz, 1H, Ha-3), 3.04 (dd, J=16.8, 12.4Hz, 1H, Hb-3), 5.62 (dd, J=12.4, 3.6 Hz, 1H, H-2), 7.11(m, 2H, ArH), 7.56 (td, J=8.4, 1.6 Hz, 1H, ArH), 7.69 (dd, J=8.4, 2.0 Hz, 2H, ArH), 7.95 (dd, J=8.0, 2.0 Hz, 1H, ArH), 8.31 (dd, J=8.8, 2.0 Hz, 2H, ArH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 44.6, 78.3, 118.0, 120.9, 122.2, 124.1, 126.8, 127.2, 136.5, 136.3, 148.8, 160.9, 190.7; EIMS (70 eV) m/z (rel intensity, %) 269 (M^+, 33), 268 (49), 252 (18), 147 (91), 121 (20), 120 (53), 93 (100), 64 (13). Anal. Calcd for $C_{15}H_{11}NO_4$: C, 66.91; H, 4.12; N, 5.20. Found: C, 66.82; H, 4.13; N, 5.10.

*4.1.2.7. 3′-Nitroflavanone (**4g**).* Compound **4g** (0.36 g, 84%) was obtained as colorless crystals, mp=145–146 °C (lit.[22] mp 142 °C); R_f=0.31(ethyl acetate/*n*-hexane=1:4); IR (KBr) cm^{-1}:1693 (C=O); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.96 (dd, J=16.8, 3.2 Hz, 1H, Ha-3), 3.08 (dd, J=16.8, 12.8 Hz, 1H, Hb-3), 5.61 (dd, J=12.8, 3.2 Hz, 1H, H-2), 7.11 (m, 2H, ArH), 7.56 (td, J=8.4, 1.6 Hz, 1H, ArH), 7.64 (t, J=8.0 Hz, 1H, ArH), 7.81 (m, 1H, ArH), 7.95 (dd, J=8.0, 1.6 Hz, 1H, ArH), 8.26 (m, 1H, ArH), 8.42 (t, J=2.0 Hz, 1H, ArH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 44.6, 78.2, 118.1, 120.7, 121.2, 122.2, 123.6, 127.2, 129.9, 131.9, 136.5, 140.9, 148.6, 160.9, 190.8; EIMS (70 eV) m/z (rel intensity, %) 269 (M^+, 35), 268 (39), 147 (100), 121 (33), 120 (66), 92 (99), 64 (19), 63 (23). Anal. Calcd for $C_{15}H_{11}NO_4$: C, 66.91; H, 4.12; N, 5.20. Found: C, 66.51; H, 4.20; N, 5.13.

*4.1.2.8. 6-Chloro-4′-fluoroflavanone (**4h**).* Compound **4h** (0.36 g, 82%) was obtained as colorless crystals, mp=145–146 °C; R_f=0.31 (ethyl acetate/*n*-hexane=1:4); IR (KBr) cm^{-1}:1701 (C=O); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.89 (dd, J=16.8, 2.8 Hz, 1H, Ha-3), 3.06 (dd, J=16.8, 13.2 Hz, 1H, Hb-3), 5.46 (dd, J=13.2, 2.8 Hz, 1H, H-2), 7.01 (d, J=8.4 Hz, 1H, ArH), 7.14 (td, J=8.8, 2.0 Hz, 2H, ArH), 7.45 (m, 3H, ArH), 7.89 (d, J=2.4 Hz, 1H, ArH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 44.3, 79.1, 115.9 (d, J=21.2 Hz), 119.8, 121.6, 126.4, 127.3, 128.0 (d, J=8.4 Hz), 134.1, 136.1, 159.8, 162.9 (d, J=246.3 Hz), 190.6; EIMS (70 eV) m/z (rel intensity, %) 276 (M^+, 91), 275 (77), 181 (36), 156 (37), 155 (27), 154 (100), 126 (40), 122 (40). Anal. Calcd for $C_{15}H_{10}ClFO_2$: C, 65.11; H, 3.64. Found: C, 65.05; H, 3.63.

*4.1.2.9. 6-Chloro-4′-bromoflavanone (**4i**).* Compound **4i** (0.43 g, 80%) was obtained as colorless crystals, mp =151–152 °C; R_f=0.32 (ethyl acetate/*n*-hexane=1:4); IR (KBr) cm^{-1}:1689 (C=O); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.89 (dd, J=16.8, 3.2 Hz, 1H, Ha-3), 3.02 (dd, J=16.8, 12.8 Hz, 1H, Hb-3), 5.44 (dd, J=12.8, 3.2 Hz, 1H, H-2), 7.01 (d, J=8.8 Hz, 1H, ArH), 7.35 (m, 2H, ArH), 7.46 (dd, J=8.8, 2.0 Hz, 1H, ArH), 7.57 (dd, J=8.8, 2.0 Hz, 2H, ArH), 7.88 (d, J=2.4 Hz, 1H, ArH); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 44.2, 79.1, 119.8, 121.6, 122.9, 126.4, 127.4, 127.8, 132.1, 136.1, 137.3, 159.7, 190.4; EIMS (70 eV) m/z (rel intensity, %) 337 (M^+, 60), 336 (50), 335 (41), 184 (64), 182 (78), 181 (74), 154 (100), 103 (51). Anal. Calcd for $C_{15}H_{10}BrClO_2$: C, 53.37; H, 2.99. Found: C, 53.47; H, 3.02.

*4.1.3. General procedure for the preparation of flavanones (**4a**–**i**) from o-hydroxyacetophenones (**1a**,**b**) and benzaldehydes (**2a**–**i**) in one pot.* The mixture of 2-hydroxyacetophenones (**1a**,**b**) (10 mmol) and benzaldehydes (**2a**–**i**) (10 mmol) was stirred, and then DABCO (3.36 g, 30 mmol) was added. The resulting mixture was continually stirred and heated to the reflux for 20 h. Then, the reaction mixture was extracted with CH_2Cl_2 (3×50 mL). The resulting extracts were combined, washed with brine, dried over anhydrous $MgSO_4$ in sequence. After filtration, the filtrate was concentrated in vacuo to give crude **4a**–, which were further purified by silica-gel column chromatography (EtOAc/*n*-hexane=1:5). Pure flavanones **4a** (67%), **4b** (71%), **4c** (70%), **4d** (70%), **4e** (69%), **4f** (78%), **4g** (76%), **4h** (74%), and **4i** (72%) were obtained, respectively.

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20. The CIF file of crystal **3e** has been deposited at the Cambridge Crystallographic Centre (CCDC), UK, and received the CCDC no. 791334. The X-ray crystallographic study of **3e** is summarized as follows. Crystal data: $C_{15}H_{13}BrO_3$, M=321.16, monoclinic system, space group $P2_1/n$, a=5.3393 (1) Å, b=8.5377 (17) Å, c=29.789 (6) Å, β=92.52 (3)°, V=1357.0 (5) Å^3, Z=4, d=1.572 g/cm^3. A crystal of dimensions 0.70×0.42×0.30 mm was used for measurements on a RIGAKU AFC7S diffractometer with a graphite monochromator (ω scans, $2\theta_{max}$=45.0°), Mo Kα radiation (λ=0.71073 Å). The total number of independent reflections measured was 1243, of which 774 were observed ($|F|^2 \geq 2\sigma|F|^2$). The crystal structure was solved by the direct method and expanded using difference Fourier techniques, further refined by the program SHEXTL 97 and full-matrix least-squares calculations. Final indices: R_f=0.0701, R_w=0.0819 (w=1/$[\sigma^2(F_{o^2})+(0.1692P)^2]$ where $P=(F_{o^2}+2F_{c^2})/3$).
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