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Palladium-Catalyzed Decarboxylative Arylation of Benzoylacrylic Acids toward the Synthesis of Chalcones

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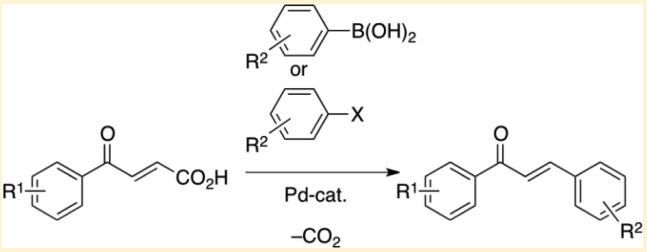
Supporting Information

ABSTRACT: It has been found that readily available 3-benzoylacrylic acids undergo palladium-catalyzed decarboxylative arylation with arylboronic acids in the presence of a copper salt oxidant to produce chalcone derivatives. The decarboxylative arylation could also be achieved using aryl halides as the alternative aryl source to expand the applicable scope.



The palladium-catalyzed intermolecular coupling reactions of organic halides with alkenes (Mizoroki–Heck reactions) or organometallic reagents (cross-coupling) have been recognized as highly important tools in modern organic synthesis.[1] Recently, the decarboxylative coupling reactions using carboxylic acids as coupling partners have been rapidly developed because such substrates are easy to store and handle and are more readily available in some cases, compared to halides or alkenes.[2] As building blocks, arenecarboxylic,[3] heteroarenecarboxylic,[4] acrylic,[5] propiolic,[6] and α-ketocarboxylic acids[7] can be employed for the promising coupling reactions. Among them, the reactions of acrylic acids have been less explored, and only limited examples using several cinnamic acids have been reported.[5]

Meanwhile, 3-benzoylacrylic acids are known to be easily prepared via various routes, including the Friedel–Crafts acylation of arenes with maleic acid anhydrides. However, these acids have, to our knowledge, never been employed in decarboxylative cross-coupling. In the context of our study of the catalytic coupling of carboxylic acids,[8] we have succeeded in finding that 3-benzoylacrylic acids readily undergo decarboxylative arylation upon treatment with arylboronic acids or aryl halides under palladium catalysis to produce various substituted chalcones. Chalcones are one of the major classes of natural products and exhibit a wide range of biological activities.[9] Conventionally, they have been synthesized through Claisen–Schmidt condensation.[10] However, the reaction efficiency and substituent tolerance are usually low because of the strongly basic conditions. Although Mizoroki–Heck[11] and carbonylative Mizoroki–Heck reactions[12] have been developed for chalcone syntheses, their utilization has been limited because of the limited availability of aryl vinyl ketones and the necessity of pressurized carbon monoxide, respectively.

In an initial attempt, 3-benzoylacrylic acid (**1a**) (0.4 mmol) was treated with an excess amount of (4-methylphenyl)boronic acid (**2a**) (0.8 mmol) in the presence of $Pd(OAc)_2$ (0.02 mmol), $Cu(OAc)_2{\cdot}H_2O$ (1.6 mmol), and K_2CO_3 (1.6 mmol) as the catalyst, oxidant, and additive, respectively, in DMF (2.5 mL) at 120 °C for 5 h under N_2. As a result, the decarboxylative arylation effectively proceeded to afford the corresponding chalcone, (*E*)-1-phenyl-3-(4-methylphenyl)prop-2-en-1-one (**3a**), in 87% yield (entry 1 in Table 1). Other additives such as NaOAc and LiOAc were less effective than K_2CO_3 (entries 2 and 3, respectively). Decreasing the amount of K_2CO_3 (entry 4), $Cu(OAc)_2{\cdot}H_2O$ (entry 5), or **2a** (entry 6) somewhat lowered the product yield in each case. At 100 °C, the yield slightly decreased (entry 7). Even when the reaction was conducted using a catalytic amount (20 mol %) of $Cu(OAc)_2{\cdot}H_2O$ in air, **3a** was obtained, albeit with a moderate yield (entry 8). It was confirmed that the reaction did not proceed at all in the absence of $Pd(OAc)_2$ (entry 9).

With the optimized reaction conditions in hand, we next examined the reactions of **1a** with various arylboronic acids **2** (Table 2). A series of 4-substituted phenylboronic acids possessing electron-donating groups (entries 2–5) and electron-withdrawing groups (entries 6 and 7) as well as an unsubstituted one (entry 1) efficiently underwent the reaction with **1a** to afford the corresponding chalcones in good yields. The reaction with 4-fluorophenylboronic acid (**2g**) also proceeded smoothly, although product **3g** was contaminated by a small amount of the *Z* isomer (entry 6). One exception is the case with a highly electron-deficient boronic acid such as **2i**: the reaction was considerably more sluggish, presumably because of its low reactivity to transmetalation, producing **3i** in a low yield (entry 8). It should be noted that aminochalcones such as **3d** and **3e** are of particular interest because of their luminescence properties as well as their utility as important intermediates for constructing organic electroluminescent devices.[13] While 3-substituted phenylboronic acids could be

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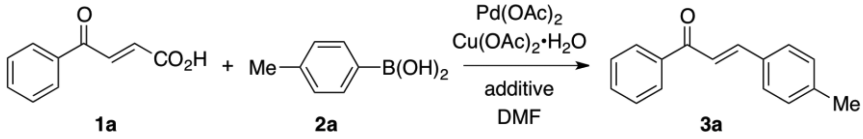
Table 1. Reaction of 3-Benzoylacrylic Acid (1a) with (4-Methylphenyl)boronic Acid (2a)[a]

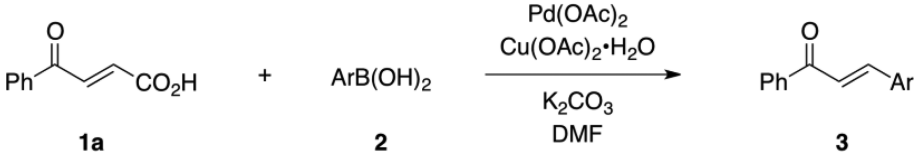


1a 2a 3a

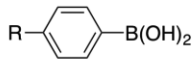
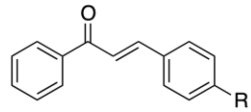
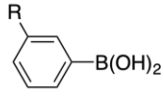
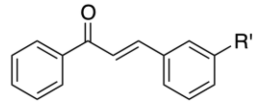
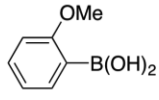
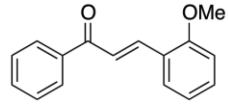
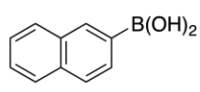
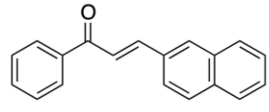
entry	additive (mmol)	yield of **3a** (%)[b]
1	K_2CO_3 (1.6)	87 (72)
2	NaOAc (1.6)	33
3	LiOAc (1.6)	63
4	K_2CO_3 (0.8)	74
5[c]	K_2CO_3 (1.6)	53
6[d]	K_2CO_3 (1.6)	48
7[e]	K_2CO_3 (1.6)	74
8[f]	K_2CO_3 (1.6)	40
9[g]	K_9CO_3 (1.6)	0

[a]Reaction conditions: [**1a**]:[**2a**]:[$Pd(OAc)_2$]:[$Cu(OAc)_2·H_2O$] = 0.4:0.8:0.02:1.6 (in mmol), DMF (2.5 mL) at 120 °C for 5 h under N_2. [b]GC yield based on the amount of **1a** used. Value in parentheses indicates isolated yield. [c]With $Cu(OAc)_2·H_2O$ (0.88 mmol). [d]With **2a** (0.48 mmol). [e]At 100 °C. [f]With $Cu(OAc)·H_2O$ (0.08 mmol) under air. [g]Without $Pd(OAc)_2$.

Table 2. Reaction of 3-Benzoylacrylic Acid (1a) with Arylboronic Acids 2[a]



1a 2 3

entry	**2**	**3**, % yield[b]
		
1	**2b**: R = H	**3b**: R = H, 83
2	**2c**: R = OMe	**3c**: R = OMe, 89
3	**2d**: R = NMe_2	**3d**: R = NMe_2, 70
4	**2e**: R = NPh_2	**3e**: R = NPh_2, 79
5	**2f**: R = *t*-Bu	**3f**: R = *t*-Bu, 66
6	**2g**: R = F	**3g**:[c] R = F, 79
7	**2h**: R = Cl	**3h**: R = Cl, 71
8	**2i**: R = CO_2Me	**3i**: R = CO_2Me, 19[d]
		
9	**2j**: R = Me	**3j**: R = Me, 63
10	**2k**: R = OMe	**3k**: R = OMe, 70
		
11	**2l**	**3l**, 12[d]
		
12	**2m**	**3m**, 90

[a]Reaction conditions: [**1a**]:[**2**]:[$Pd(OAc)_2$]:[$Cu(OAc)_2$]:[K_2CO_3] = 0.4:0.8:0.02:1.6:1.6 (in mmol), DMF (2.5 mL) at 120 °C for 4−5 h under N_2. [b]Isolated yield. [c]*E*:*Z* = 97:3. [d]GC yield.

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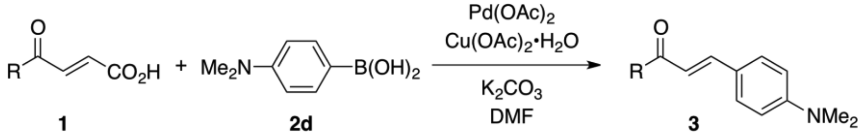
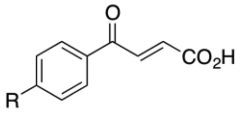
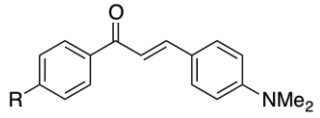
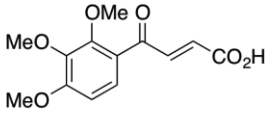
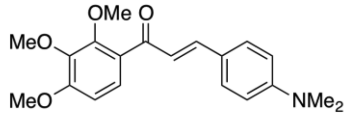
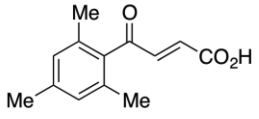
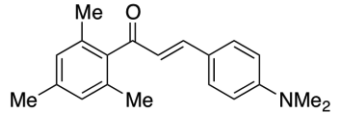
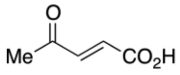
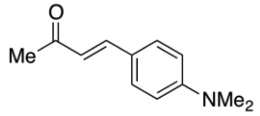
Table 3. Reaction of 3-Acylacrylic Acids 1 with (4-Dimethylaminophenyl)boronic Acid (2d)[a]



1 2d 3

entry	1	3, % yield[b]
1	 **1b**: R = Me	 **3n**: R = Me, 69
2	**1c**: R = OMe	**3o**: R = OMe, 55
3	**1d**: R = Cl	**3p**: R = Cl, 77
4	**1e**: R = F	**3q**: R = F, 74
5	 **1f**	 **3r**, 48
6	 **1g**	 **3s**, 41
7	 **1h**	 **3t**, 59

[a]Reaction conditions: [**1**]:[**2d**]:[$Pd(OAc)_2$]:[$Cu(OAc)_2$]:[K_2CO_3] = 0.4:0.8:0.02:1.6:1.6 (in mmol), DMF (2.5 mL) at 120 °C for 4−5 h under N_2. [b]Isolated yield.

employed similarly (entries 9 and 10), the 2-substituted acid showed poor reactivity (entry 11). The reaction of **1a** with 2-naphthylboronic acid (**2m**) proceeded smoothly to produce a benzo-fused chalcone **3m** in 90% yield (entry 12).

A number of 3-(4-substituted benzoyl)acrylic acids **1b−e** also underwent the coupling with **2d** to produce 4,4′-disubstituted chalcones **3n−q** (entries 1−4 in Table 3). Highly substituted chalcones **3r** and **3s** could be prepared through the reactions of **1f** and **1g** with **2d** (entries 5 and 6, respectively). An aliphatic acid, 3-acetylacrylic acid (**1h**), also reacted with **2d** smoothly to afford **3t** (entry 7).

The decarboxylative arylation of 3-benzoylacrylic acid (**1a**) could also be realized by treatment with aryl halides **4** and a base under palladium catalysis. In contrast to the conditions for the reactions with arylboronic acids, the use of an excess amount of **1a** gave better results. Thus, the reaction of **1a** (0.8 mmol) with 4-bromotoluene (**4a**) (0.4 mmol) proceeded effectively in the presence of $Pd(OAc)_2$ (0.02 mmol), (4-$MeC_6H_4)_3P$ (0.08 mmol), and NaOAc (1.6 mmol) as the catalyst, ligand, and base, respectively, in DMF (2.5 mL) at 120 °C under N_2 to produce **3a** in 87% yield (entry 1 in Table 4). The use of PPh_3 in place of (4-$MeC_6H_4)_3P$ in the reaction of bromobenzenes possessing an electron-donating group at their *para*-position decreased the product yield because of the contamination of a phenyl group from the ligand to form a small amount of **3b**. Under conditions using JohnPhos (0.04 mmol, JohnPhos = 2-(di-*tert*-butylphosphino)biphenyl) as the ligand, the yield of **3a** significantly decreased (entry 2).

As described above, the arylation reactions using sterically hindered and highly electron-deficient arylboronic acids were sluggish (entries 8 and 11 in Table 2). To our delight, the reactions using aryl halides were found to be complementary in overcoming such limitations. The reaction of **1a** with 2-iodoanisole (**4b**) proceeded smoothly under conditions using (4-$MeC_6H_4)_3P$ as a ligand to produce chalcone **3l** in an improved yield (entry 3 in Table 4 vs entry 11 in Table 2), albeit with the contamination of a geometrical isomer to a minor extent. Bromobenzenes possessing electron-withdrawing groups such as ethoxycarbonyl (**4c**), acetyl (**4d**), cyano (**4e**), or formyl (**4f**) groups also underwent coupling with **1a** to produce **3u−x** in 59−85% yields (entries 4−7 in Table 4). In the latter two cases, the catalyst system with JohnPhos (0.04 mmol) as the ligand gave better results.

The decarboxylative arylation reactions of 3-acylacrylic acids appear to proceed through steps similar to those in the related reactions of cinnamic acids.[5a] An arylpalladium intermediate,

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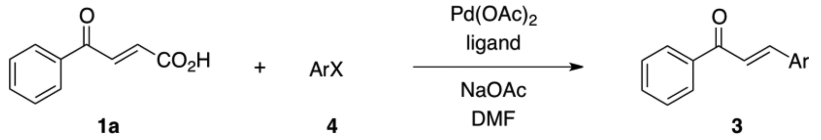
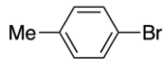
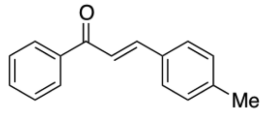
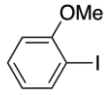
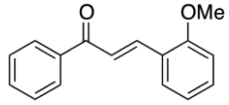
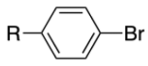
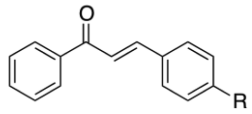
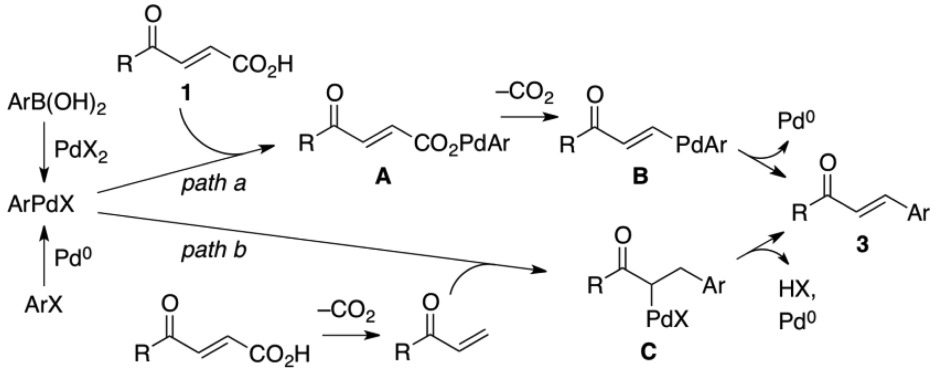
Table 4. Reaction of 3-Benzoylacrylic Acid (1a) with Aryl Halides 4[a]



entry	4	ligand (mmol)	3, % yield[b]
			
1	**4a**	$(4\text{-MeC}_6\text{H}_4)_3\text{P}$ (0.08)	**3a**, 87
2		JohnPhos (0.04)	**3a**, 40[c]
			
3	**4b**	$(4\text{-MeC}_6\text{H}_4)_3\text{P}$ (0.08)	**3l**,[d] 64
			
4	**4c**: R = CO_2Et	$(4\text{-MeC}_6\text{H}_4)_3\text{P}$ (0.08)	**3u**: R = CO_2Et, 85
5	**4d**: R = Ac	$(4\text{-MeC}_6\text{H}_4)_3\text{P}$ (0.08)	**3v**: R = Ac, 80
6	**4e**: R = CN	JohnPhos (0.04)	**3w**: R = CN, 64
7	**4f**: R = CHO	JohnPhos (0.04)	**3x**: R = CHO, 59

[a]Reaction conditions: [**1a**]:[**4**]:[$Pd(OAc)_2$]:[NaOAc] = 0.8:0.4:0.02:1.6 (in mmol), DMF (2.5 mL) at 120 °C for 4 h under N_2. [b]Isolated yield. [c]GC yield. [d]*E*:*Z* = 95:5.

Scheme 1. Plausible Mechanism for the Arylation of 1



generated in situ via transmetalation between a PdX_2 species and **2** or oxidative addition of **4** to a Pd^0 species, undergoes ligand exchange with acid **1** to give **A** (path a in Scheme 1). The subsequent decarboxylation and reductive elimination afford **3**. In the former case, a pathway through prior coordination of **1**, decarboxylation, and transmetalation with **2** to form **B** cannot be excluded. Another possible reaction sequence may involve the initial decarboxylation of **1** to form the corresponding vinyl ketone, which then undergoes insertion into the ArPdX species and *β*-hydrogen elimination as in Mizoroki–Heck type reactions (path b). In the reaction with **2**, Pd^0 species may be reoxidized to PdX_2 by a Cu^{II} oxidant.

It was confirmed that considerable amounts of vinyl ketones were detected by GC–MS during the reactions of **1**. Actually, treatment of vinyl ketone **5** with **2a** and **4a** under standard conditions gave **3a** in 25 and 61% yields, respectively (Scheme 2). As the yield of **3a** is considerably lower than that in the reaction with **1a** in each case, part of **5** is considered to be consumed by unidentified side reactions. These facts suggest that both the sequences, paths a and b, may participate. No matter which sequence is predominant, the direct use of 3-acylacrylic acids **1** rather than the corresponding vinyl ketones appears to be advantageous because of the ready availabilities and stabilities of 3-acylacrylic acids.

In summary, we have demonstrated that the decarboxylative arylation of 3-acylacrylic acids can be performed effectively under palladium catalysis. The procedure provides simple synthetic routes to chalcones from readily available building blocks.

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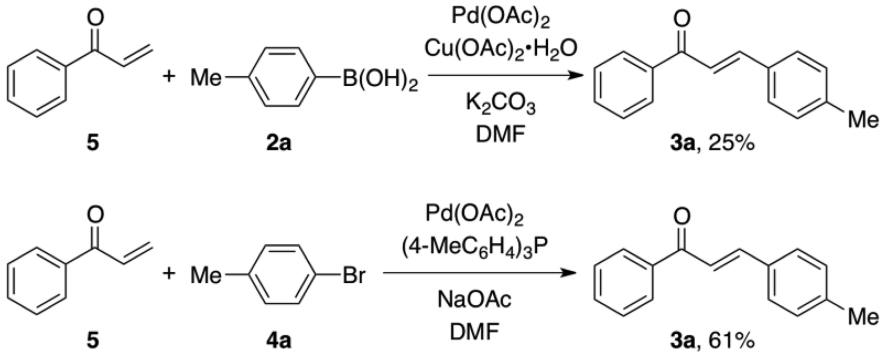
Scheme 2. Reaction of 5 with 2a[a] or 4a[b]



[a]Reaction conditions: [**5**]:[**2a**]:[$Pd(OAc)_2$]:[$Cu(OAc)_2$]:[K_2CO_3] = 0.4:0.8:0.02:1.6:1.6 (in mmol), DMF (2.5 mL) at 120 °C for 4 h under N_2. [b]Reaction conditions: [**5**]:[**4a**]:[$Pd(OAc)_2$]:[$(4\text{-}MeC_6H_4)_3P$]:[NaOAc] = 0.8:0.4:0.02:0.08:1.6 (in mmol), DMF (2.5 mL) at 120 °C for 6 h under N_2.

EXPERIMENTAL SECTION

General. ^1H and ^{13}C NMR spectra were recorded at 400 and 100 MHz for $CDCl_3$ solutions. HRMS data were obtained by EI using a double-focusing mass spectrometer, unless noted. GC analysis was carried out using a silicon OV-17 column (i.d. 2.6 mm × 1.5 m). The structures of all products listed below were unambiguously determined by ^1H and ^{13}C NMR with the aid of NOE, COSY, HMQC, and HMBC experiments.

Substituted 3-benzoylacrylic acids **1e**−**g**[14] and **1h**[15] and vinyl ketone **5**[16] were prepared according to published procedures. Other starting materials were commercially available.

General Procedure for the Reaction of 3-Acylacrylic Acid 1 with Arylboronic Acid 2. To a 20 mL two-necked round-bottomed flask with a reflux condenser, a balloon, and a rubber cup were added 3-acylacrylic acid **1** (0.4 mmol), arylboronic acid **2** (0.8 mmol), $Pd(OAc)_2$ (0.02 mmol, 4.5 mg), $Cu(OAc)_2·H_2O$ (1.6 mmol, 319 mg), 1,2-diphenylethane (ca. 40 mg) as the internal standard, and DMF (2.5 mL). Then the resulting mixture was stirred under nitrogen at 120 °C (bath temperature) for 4−5 h. After being cooled, the reaction mixture was quenched with water and extracted with ethyl acetate (20 mL, three times). The combined organic layer was dried over Na_2SO_4. After evaporation of the solvents under vacuum, product **3** was isolated by column chromatography on silica gel using hexane/ethyl acetate (91:9, v/v) as eluant.

*(E)-4-Methylchalcone (**3a**).* mp 90−91 °C (lit.[13e] mp 98 °C), 64 mg (72%); ^1H NMR (400 MHz, $CDCl_3$) δ 3.08 (s, 3H), 7.23 (d, J = 7.8 Hz, 2H), 7.48−7.61 (m, 6H), 7.80 (d, J = 15.6 Hz, 1H), 8.00−8.04 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.6, 121.1, 128.52, 128.54, 128.6, 129.8, 131.2, 132.7, 138.4, 141.2, 145.0, 190.7; HRMS m/z (M^+) calcd for $C_{16}H_{14}O$ 222.1045, found 222.1047.

*(E)-Chalcone (**3b**).* mp 52−54 °C (lit.[13e] mp 56−58 °C), 69 mg (83%); ^1H NMR (400 MHz, $CDCl_3$) δ 7.40−7.44 (m, 3H), 7.49−7.66 (m, 6H), 7.82 (d, J = 15.6 Hz, 1H), 8.01−8.04 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 122.1, 128.5, 128.6, 128.7, 129.0, 130.6, 132.9, 134.9, 138.2, 144.9, 190.6; HRMS m/z (M^+) calcd for $C_{15}H_{12}O$ 208.0888 found 208.0891.

*(E)-4-Methoxychalcone (**3c**).* mp 74−75 °C (lit.[13e] mp 75−76 °C), 85 mg (89%); ^1H NMR (400 MHz, $CDCl_3$) δ 3.86 (s, 3H), 6.92−6.95 (m, 2H), 7.42 (d, J = 15.6 Hz, 1H), 7.48−7.62 (m, 5H), 7.79 (d, J = 16.0 Hz, 1H), 8.00−8.02 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 55.5, 114.5, 119.8, 127.7, 128.5, 128.6, 130.3, 132.6, 138.6, 144.8, 161.7, 190.7; HRMS m/z (M + H^+) calcd for $C_{16}H_{15}O_2$ 239.1067 found 239.1064.

*(E)-4-(Dimethylamino)chalcone (**3d**).* mp 110−111 °C (lit.[17] mp 111−113 °C), 70 mg (70%); ^1H NMR (400 MHz, $CDCl_3$) δ 3.04 (s, 6H), 6.69 (d, J = 9.2 Hz, 2H), 7.34 (d, J = 15.6 Hz, 1H), 7.46−7.50 (m, 2H), 7.53−7.56 (m, 3H), 7.79 (d, J = 15.6 Hz, 1H), 7.99−8.01 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 40.2, 111.9, 117.0, 122.7, 128.4, 128.5, 130.5, 132.2, 139.1, 145.9, 152.1, 190.8; HRMS m/z (M + H^+) calcd for $C_{17}H_{18}NO$ 252.1383, found 252.1394.

*(E)-4-(Diphenylamino)chalcone (**3e**).* mp 131−132 °C (lit.[18] mp 131 °C), 119 mg (79%); ^1H NMR (400 MHz, $CDCl_3$) δ 7.00−7.28 (m, 8H), 7.28−7.33 (m, 4H), 7.39 (d, J = 15.6 Hz, 1H), 7.46−7.52 (m, 4H), 7.54−7.59 (m, 1H), 7.77 (d, J = 15.6 Hz, 1H), 7.99−8.02 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 119.4, 121.6, 124.2, 125.5, 127.9, 128.4, 128.6, 129.6, 129.8, 132.5, 138.7, 144.8, 146.9, 150.2, 190.6; HRMS m/z (M + H^+) calcd for $C_{27}H_{22}NO$ 376.1696, found 376.1693.

*(E)-4-tert-Butylchalcone (**3f**).*[19] oil, 70 mg (66%); ^1H NMR (400 MHz, $CDCl_3$) δ 1.34 (s, 9H), 7.45 (d, J = 8.7 Hz, 2H), 7.48−7.52 (m, 2H), 7.50 (d, J = 15.6 Hz, 1H), 7.56−7.60 (m, 3H), 7.81 (d, J = 15.6 Hz, 1H), 8.00−8.03 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 31.2, 35.0, 121.4, 126.0, 128.4, 128.5, 128.6, 132.2, 132.7, 138.4, 144.9, 154.3, 190.8; HRMS m/z (M^+) calcd for $C_{19}H_{20}O$ 264.1514, found 264.1512.

*4-Fluorochalcone (**3g**).* E:Z = 97:3, 71 mg (79%);[20] ^1H NMR (400 MHz, $CDCl_3$) δ 7.09−7.14 (m, 2H), 7.47 (d, J = 15.6 Hz, 1H), 7.49−7.53 (m, 2H), 7.57−7.66 (m, 3H), 7.78 (d, J = 15.6 Hz, 1H), 8.00−8.03 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 116.2 (d, J = 21.4 Hz), 121.8 (d, J = 2.3 Hz), 128.5, 128.7, 130.4 (d, J = 8.4 Hz), 131.2 (d, J = 3.1 Hz), 132.9, 138.2, 143.6, 164.1 (d, J = 250.3 Hz), 190.4; HRMS m/z (M^+) calcd for $C_{15}H_{11}FO$ 226.0794, found 226.0797.

*(E)-4-Chlorochalcone (**3h**).* mp 111−112 °C (lit.[20] mp 113−114 °C), 69 mg (71%); ^1H NMR (400 MHz, $CDCl_3$) δ 7.38−7.40 (m, 2H), 7.48−7.53 (m, 2H), 7.55 (d, J = 15.6 Hz, 1H), 7.56−7.62 (m, 3H), 7.76 (d, J = 15.6 Hz, 1H), 8.00−8.03 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 122.5, 128.5, 128.7, 129.3, 129.6, 133.0, 133.4, 136.5, 138.1, 143.4, 190.3; HRMS m/z (M^+) calcd for $C_{15}H_{11}ClO$ 242.0498, found 242.0497.

*(E)-3-Methylchalcone (**3j**).* mp 59−61 °C (lit.[21] mp 64 °C), 56 mg (63%); ^1H NMR (400 MHz, $CDCl_3$) δ 2.39 (s, 3H), 7.22 (d, J = 7.3 Hz, 1H), 7.28−7.33 (m, 1H), 7.43−7.60 (m, 6H), 7.79 (d, J = 16.0 Hz, 1H), 8.02 (d, J = 7.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.3, 121.9, 125.7, 128.5, 128.6, 128.8, 129.0, 131.4, 132.7, 134.8, 138.2, 138.6, 145.1, 190.6; HRMS m/z (M^+) calcd for $C_{16}H_{14}O$ 222.1045, found 222.1047.

*(E)-3-Methoxychalcone (**3k**).* mp 62−63 °C (lit.[22] mp 59−61 °C), 66 mg (70%); ^1H NMR (400 MHz, $CDCl_3$) δ 3.86 (s, 3H), 6.97 (dd, J = 2.3 Hz, 7.8 Hz, 1H), 7.16 (m, 1H), 7.24 (d, J = 7.8 Hz, 1H), 7.34 (t, J = 7.8 Hz, 1H), 7.49−7.54 (m, 3H), 7.56−7.61 (m, 1H), 7.77 (d, J = 15.6 Hz, 1H), 8.00−8.03 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 55.3, 113.4, 116.3, 121.1, 122.4, 128.5, 128.6, 129.9, 132.8, 136.2, 138.2, 144.7, 159.9, 190.5; HRMS m/z (M^+) calcd for $C_{16}H_{14}O_2$ 238.0994, found 238.0993.

*2-Methoxychalcone (**3l**).* E:Z = 95:5, 61 mg (64%):[23] ^1H NMR (400 MHz, $CDCl_3$) δ 3.90 (s, 3H, E), 6.62 (d, J = 12.8 Hz, 1H, Z), 6.94 (d, J = 8.2 Hz, 1H), 6.99 (dd, J = 7.8 Hz, 7.8 Hz, 1H, E), 7.35−7.40 (m, 1H, E), 7.44−7.51 (m, 2H, E), 7.55−7.65 (m, 3H, E), 7.91−7.93 (m, 2H, Z), 8.02−8.04 (m, 2H, E), 8.12 (d, J = 15.6 Hz, 1H, E); ^{13}C NMR (100 MHz, $CDCl_3$) δ 55.6, 111.3, 120.8, 122.9, 124.0, 128.6

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(overlapped), 129.3, 131.8, 132.6, 138.6, 140.5, 158.9, 191.2; HRMS m/z (M + H$^+$) calcd for $C_{16}H_{15}O_2$ 239.1067, found 239.1075.

*(E)-3-(Naphthalen-2-yl)-1-phenylprop-2-en-1-one (**3m**).* mp 158−159 °C (lit.[20] mp 158−160 °C), 93 mg (90%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50−7.56 (m, 4H), 7.58−7.62 (m, 1H), 7.65 (d, J = 15.6 Hz, 1H), 7.81 (dd, J = 8.7 Hz, 1.4 Hz, 1H), 7.82−7.90 (m, 3H), 7.98 (d, J = 16.0 Hz, 1H), 8.03−8.08 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 122.2, 123.7, 126.8, 127.4, 127.9, 128.6, 128.7 (2C, overlapped), 128.8, 130.7, 132.4, 132.9, 133.4, 134.4, 138.3, 145.0, 190.6; HRMS m/z (M + H$^+$) calcd for $C_{19}H_{15}O$ 259.1117, found 259.1117.

*(E)-4-(Dimethylamino)-4′-methylchalcone (**3n**).* mp 117−119 °C (lit.[17] mp 124−125 °C), 73 mg (69%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.42 (s, 3H), 3.02 (s, 6H), 6.68 (d, J = 8.7 Hz, 2H), 7.28 (d, J = 8.2 Hz, 2H), 7.34 (d, J = 15.1 Hz, 1H), 7.54 (d, J = 9.2 Hz, 2H), 7.79 (d, J = 15.0 Hz, 1H), 7.92 (d, J = 8.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.6, 40.1, 118.8, 116.9, 122.7, 128.4, 129.1, 130.3, 136.4, 142.8, 145.5, 151.9, 190.1; HRMS m/z (M$^+$) calcd for $C_{18}H_{19}NO$ 265.1467, found 265.1463.

*(E)-4-(Dimethylamino)-4′-methoxychalcone (**3o**).* mp 128−129 °C (lit.[17] mp 129−131 °C), 62 mg (55%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.03 (s, 6H), 3.88 (s, 3H), 6.69 (d, J = 8.7 Hz, 2H), 6.96 (d, J = 8.7 Hz, 2H), 7.35 (d, J = 15.6 Hz, 1H), 7.55 (d, J = 8.7 Hz, 2H), 7.79 (d, J = 15.1 Hz, 1H), 8.02 (d, J = 9.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 40.1, 55.4, 111.8, 113.6, 116.6, 122.8, 130.2, 130.5, 131.8, 144.9, 151.9, 162.9, 188.9; HRMS m/z (M$^+$) calcd for $C_{18}H_{19}NO_2$ 281.1416, found 281.1412.

*(E)-4-(Dimethylamino)-4′-chlorochalcone (**3p**).*[24] mp 137−139 °C, 88 mg (77%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.04 (s, 6H), 6.67−6.69 (m, 2H), 7.28 (s, J = 15.6 Hz, 1H), 7.43−7.45 (m, 2H), 7.52−7.55 (m, 2H), 7.79 (d, J = 15.6 Hz, 1H), 7.93−7.95 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 40.1, 111.7, 116.1, 122.4, 128.7, 129.7, 130.5, 137.3, 138.4, 146.3, 152.1, 189.2; HRMS m/z (M$^+$) calcd for $C_{17}H_{16}ClNO$ 285.0920, found 285.0920.

*(E)-4-(Dimethylamino)-4′-fluorochalcone (**3q**).*[25] mp 105−107 °C, 80 mg (74%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.03 (s, 6H), 6.67−6.70 (m, 2H), 7.12−7.17 (m, 2H), 7.31 (d, J = 15.6 Hz, 1H), 7.54 (d, J = 8.7 Hz, 2H), 7.79 (d, J = 15.6 Hz, 1H), 8.00−8.06 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 40.0, 111.7, 115.4 (d, J = 21.9 Hz), 116.2, 122.4, 130.4, 130.7 (d, J = 8.6 Hz), 135.3 (d, J = 2.9 Hz), 146.0, 152.0, 165.2 (d, J = 251.7 Hz), 188.9; HRMS m/z (M$^+$) calcd for $C_{17}H_{16}FNO$ 269.1216, found 269.1211.

*(E)-4-(Dimethylamino)-2′,3′,4′-trimethoxychalcone (**3r**).*[10] mp 88−89 °C, 66 mg (48%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.03 (s, 6H), 3.90−3.91 (m, 9H), 6.68 (d, J = 7.7 Hz, 2H), 7.74 (d, J = 9.2 Hz, 1H), 7.27 (d, J = 15.6 Hz, 1H), 7.43 (d, J = 8.7 Hz, 1H), 7.51 (d, J = 8.7 Hz, 2H), 7.64 (d, J = 16.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 40.1, 56.1, 61.1, 62.1, 107.1, 111.8, 121.6, 122.8, 125.4, 127.6, 130.3, 142.1, 144.6, 151.8, 153.3, 156.3, 191.3; HRMS m/z (M + H$^+$) calcd for $C_{20}H_{24}NO_4$ 342.1700, found 342.1698.

*(E)-4-(Dimethylamino)-2′,4′,6′-trimethylchalcone (**3s**).* oil, 48 mg (41%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.19 (s, 6H), 2.32 (s, 3H), 3.02 (s, 6H), 6.65 (d, J = 8.7 Hz, 2H), 6.75 (d, J = 16.0 Hz, 1H), 6.87 (s, 2H), 7.10 (d, J = 16.0 Hz, 1H), 7.39 (d, J = 8.7 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.3, 21.1, 40.1, 111.8, 122.0, 123.5, 128.2, 130.4, 134.1, 137.7, 137.8, 147.8, 152.1, 201.3; HRMS m/z (M + H$^+$) calcd for $C_{20}H_{24}NO$ 294.1852, found 294.1858.

*(E)-4-(4-(Dimethylamino)phenyl)-3-buten-2-one (**3t**).* mp 135−137 °C (lit.[26] mp 138−139 °C), 45 mg (59%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.34 (s, 3H), 3.03 (s, 6H), 6.54 (d, J = 16.5 Hz, 1H), 6.67 (d, J = 8.7 Hz, 2H), 7.42−7.48 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 27.1, 40.1, 111.8, 121.9, 122.4, 130.0, 144.4, 151.9, 198.5; HRMS m/z (M + H$^+$) calcd for $C_{12}H_{16}NO$ 190.1226, found 190.1235.

*(E)-4-(Ethoxycarbonyl)chalcone (**3u**).* mp 77−79 °C (lit.[18] mp 82−83 °C), 95 mg (85%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.42 (t, J = 7.4 Hz, 3H), 4.40 (q, J = 6.9 Hz, 2H), 7.50−7.54 (m, 2H), 7.59−7.63 (m, 1H), 7.61 (d, J = 15.6 Hz, 1H), 7.70 (d, J = 8.2 Hz, 2H), 7.82 (d, J = 15.6 Hz, 1H), 8.02−8.05 (m, 2H), 8.08−8.10 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.4, 61.3, 124.1, 128.3, 128.6, 128.8, 130.2, 131.9, 133.1, 137.9, 139.0, 143.3, 166.0, 190.2; HRMS m/z (M + H$^+$) calcd for $C_{18}H_{17}O_3$ 281.1172, found 281.1175.

*(E)-4-Acetylchalcone (**3v**).* mp 104−106 °C (lit.[27] mp 88 °C), 80 mg (80%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.63 (s, 3H), 7.50−7.54 (m, 2H), 7.59−7.63 (m, 1H), 7.62 (d, J = 15.6 Hz, 1H), 7.73 (d, J = 8.2 Hz, 2H), 7.82 (d, J = 15.6 Hz, 1H), 8.00 (d, J = 8.2 Hz, 2H), 8.02−8.05 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 26.7, 124.1, 128.4, 128.5, 128.7, 128.9, 133.1, 137.8, 138.1, 139.2, 143.0, 190.0, 197.3; HRMS m/z (M$^+$) calcd for $C_{17}H_{14}O_2$ 250.0994, found 250.0996.

*(E)-4-Cyanochalcone (**3w**).* mp 148−149 °C (lit.[18] mp 159−160 °C), 60 mg (64%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50−7.55 (m, 2H), 7.61 (d, J = 16.0 Hz, 1H), 7.60−7.64 (m, 1H), 7.69−7.74 (m, 4H), 7.78 (d, J = 16.0 Hz, 1H), 8.01−8.04 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 113.4, 118.3, 125.0, 128.5, 128.6, 128.7, 132.6, 133.2, 137.5, 139.1, 142.0, 189.7; HRMS m/z (M$^+$) calcd for $C_{16}H_{11}NO$ 233.0841, found 233.0842.

*(E)-4-Formylchalcone (**3x**).* mp 105−106 °C (lit.[18] mp 125 °C), 56 mg (59%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51−7.55 (m, 2H), 7.60−7.65 (m, 1H), 7.65 (d, J = 15.6 Hz, 1H), 7.79−7.86 (m, 3H), 7.94 (d, J = 8.2 Hz, 2H), 8.03−8.05 (m, 2H), 10.06 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 124.8, 128.6., 128.75, 128.83, 130.2, 133.2, 137.3, 137.7, 140.6, 142.8, 190.0, 191.4; HRMS m/z (M$^+$) calcd for $C_{16}H_{12}O_2$ 236.0837, found 236.0839.

■ ASSOCIATED CONTENT

Supporting Information

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

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Notes

The authors declare no competing financial interest.

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