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$KMnO_4$/AcOH-mediated C3-selective direct arylation of coumarins with arylboronic acids

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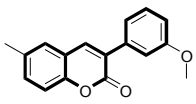
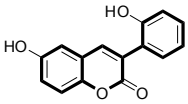
An efficient protocol for $KMnO_4$/AcOH-mediated dehydrogenative direct radical arylation of coumarins with arylboronic acids to afford 3-arylcoumarin derivatives is described. A similar reaction system is also applicable to the 3-arylation of quinolinone derivatives. These $KMnO_4$/AcOH-mediated coupling reactions occur regioselectively at the C3 position of coumarins and quinolinones. Some notable features of this method are high efficiency, moderate to good yield, and a broad groups tolerance.

Introduction

Coumarins are significant natural products, which display wide and interesting pharmacological properties such as anti-breast cancer, anti-HIV, anti-Alzheimer, vasorelaxant and anti-aggregatory activities.[1] Coumarin derivatives have proven to be useful skeletons in organic synthesis as valuable building blocks and in pharmaceuticals due to their biological and physical properties. In particular, 3-arylcoumarin represents an important structural element in a selective monoamine oxidase B (MAO-B) inhibitor,[2] a horseradish peroxidase (HRP) inhibitor,[3] an inhibitor of HIV-1 replication[4] (**Scheme 1**). As a result of their expressive structural diversity, 3-arylcoumarins have been found some possible applications in treatment of allergic disorders, as HSP90 C-terminal inhibitors and strong inhibitors of antigen-induced RBL-2H3 mast cell degranulation.[5] Moreover, 3-arylcoumarin derivatives are also important class of fluorophores and found their application as fluorescent labels in complex biological systems.[6] Despite the importance of 3-arylcoumarins, the synthesis of 3-arylcoumarins is difficult due to the regioselective bias of 4-arylation of coumarins.[7] Thus, the development of novel, efficient, and regioselective methods for the construction of 3-arylcoumarins will be of great value in screening of novel functional active molecules.



MAO-B inhibitor



HRP inhibitor

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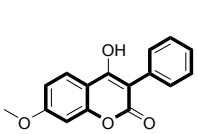
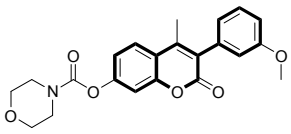
† Electronic Supplementary Information (ESI) available. Part of the experimental dedail, and NMR spectra data See DOI: 10.1039/x0xx00000x



Inhibitor of HIV-1 replication



Vipirinin, HIV-1 inhibitor

Scheme 1. Examples of 3-arylcoumarins medical intermediate

The general methods for the preparation of 3-arylcoumarins were based on the palladium-catalyzed Suzuki-type coupling reaction or Heck reaction. Matos group reported a method toward 3-arylcoumarins by the Suzuki coupling reaction of 3-chlorocoumarin and phenylboronic acid in the presence of palladium complex and sodium carbonate at 110 °C for 2-3 h in 55-65 % yields.[8] Wu group synthesized 3-arylcoumarins using 3-bromocoumarin derivatives and phenylboronic acid in the presence of palladium complex and base, and Matsuura group used 3-bromocoumarin and aromatic compounds by photo-catalyzed coupling reaction to obtain 3-arylcoumarin derivatives.[9] Jafarpour and Messaoudi groups describeda synthetic method for the preparation of 3-arylcoumarin by a palladium-catalyzed decarboxylative coupling of coumarin-3-carboxylic acids and aryl halides.[10] Knochel group used the 3-zincated coumarin and 4-substituted iodobenzenes through Pd-catalyzed Negishi cross-coupling reaction to obtain 3-arylcoumarins (**Scheme 2** a).[11] Direct functionalization through metal-catalyzed double C–H activation reactions have began to emerge as an alternative route for C–C bond formation.[12] A direct arylation approach allows for the construction of C–C bonds without the need for prior functionalization of coupling partners via metalation. A synthetic method of 3-arylcoumarins was described using coumarins and arenesulfonyl chlorides or sodium arenesulfinates via palladium-catalyzed direct C–H functionalization, $Cu(OAc)_2$ as the oxidant for 24 h.[13] Yadav group described a direct 3-

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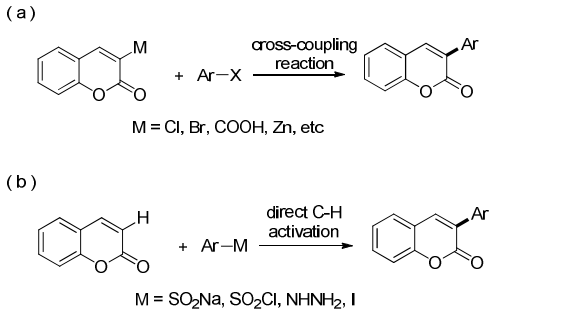
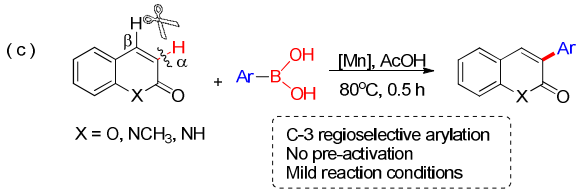
arylation of coumarins by the reaction of coumarins and phenylhydeazine using K_2CO_3 as the base in DMSO solvent for 4-24 h.[14] You group reported synthesis of 3-arylcoumarins to use coumarins and aromatic compounds by $Pd(OAc)_2$-catalyzed coupling reaction and $(NH_4)_2S_2O_8$ for the oxidant in TFA for 24 h.[15] Jafarpour group described a $Pd(OAc)_2$-catalyzed dehydrogenative 3-arylaction of coumarins using coumarins and aryl compounds for the materials, and trifluoroacetic acid anhydride (TFAA) as the solvent at 120 °C for 16 h.[16] 3-Arylcoumarins were also achieved by $Pd(PPh_3)_4$-catalyzed Heck coupling reactions between coumarins and aryliodides using AgOAc for the base for 72 h (**Scheme 2** b).[17] Other procedures for the synthesis of 3-arylcoumarins involving cyclization reactions such as Pechmann, or Perkin reactions have been published as well.[18] Although all the above methodologies have been utilized effectively for 3-arylcoumarins, some problems exist with these procedures, such as: (1) the prefunctionalization, and narrow scope of substrates; (2) use of toxic ligands, strong acid solvent, high temperatures, long reaction time and poor yields. Therefore, developing a general and applicable strategy for a variety of 3-arylcoumarins is highly desirable.

Previous works:



This work:

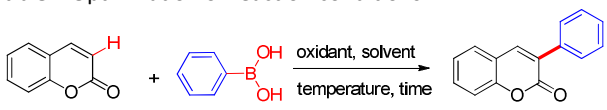


Scheme 2. Synthesis of 3-arylcoumarins and 3-arylquinolines

Recently, radical C–H functionalization of innately reactive heterocycles has re-emerged as an avenue for selective, early or late stage functionalization of pharmaceutically important precursors and products.[19] Metal-promoted radical reactions have been achieved substantially utilizing a variety of aryl coupling partners, in which one of the well-known examples of this application is the $Mn(OAc)_3$-mediated reaction. Manganese(III) acetate is a one-electron oxidant, largely used as a radical generator that can lead to C–C bond forming reactions.[20] But, Manganese(III) acetate is not stable, and it occurs easily disproportionated reaction to Manganese(II) and Manganese(IV). The potassium permanganate/acetic acid system in an organic solvent is a powerful substitute for Manganese(III) acetate.[21] Guided by recent studies on Manganese(III)-promoted hemolytic aromatic substitution (HAS) using arylboronic acid as C-radical precursors, we decided to investigate the modular synthesis of 3-arylcoumarins by this approach. Herein, we disclose a $KMnO_4$/AcOH-mediated dehydrogenative direct and regioselective radical arylation of coumarins with arylboronic acids to afford 3-arylcoumarin derivatives in good to high yield (**Scheme 2** c).

Results and discussion

Table 1 Optimization of reaction conditions[a]



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

Entry	Oxidant (eq.)	Solvent	Temp (°C)	Time (h)	Yield[b] (%)
1[c]	–	CH_3CN	90	1.0	43
2[d]	–	CH_3CN	90	1.0	22
3	$CuSO_4$ (0.2)	CH_3CN	90	1.0	0
4	$FeCl_3·6H_2O$ (0.2)	CH_3CN	90	1.0	32
5	$KMnO_4$ (0.2)	CH_3CN	90	1.0	40
6	MnO_2 (0.2)	CH_3CN	90	1.0	28
7	$MnSO_4$ (0.2)	CH_3CN	90	1.0	0
8	$Mn(OAc)_2$ (0.2)	CH_3CN	90	1.0	0
9	$KMnO_4$ (0.2)	C_2H_5OH	80	1.0	0
10	$KMnO_4$ (0.2)	DCE	90	1.0	0
11	$KMnO_4$ (0.2)	DMF	120	1.0	0
12	$KMnO_4$ (0.2)	Dioxane	90	1.0	0
13	$KMnO_4$ (0.2)	AcOH	120	1.0	50
14	$KMnO_4$ (2.0)	AcOH	20	1.0	30
15	$KMnO_4$ (2.0)	AcOH	40	1.0	55
16	$KMnO_4$ (2.0)	AcOH	60	1.0	62
17	$KMnO_4$ (2.0)	AcOH	80	1.0	80
18	$KMnO_4$ (2.0)	AcOH	100	1.0	78
19	$KMnO_4$ (2.0)	AcOH	80	0.25	70
20	**$KMnO_4$** (2.0)	**AcOH**	**80**	**0.5**	**85**
21	$KMnO_4$ (2.0)	AcOH	80	2.0	78

[a] Reaction conditions: coumarins **1a** (0.5 mmol, 73 mg), phenylboronic acid **2a** (1.0 mmol, 122 mg), oxidant in solvent (20 mL).
[b] Isolated yield.
[c] $PdCl_2$ (0.1 eq) was used as the catalyst.
[d] $Pd(OAc)_2$ (0.1 eq) was used as the catalyst.

Our initial experiments showed that using a $PdCl_2$ or $Pd(OAc)_2$ as the catalyst without the oxidant, coumarin **1a** occurred with phenylboronic acid **2a** to obtain 3-phenyl coumarin **3a** with a

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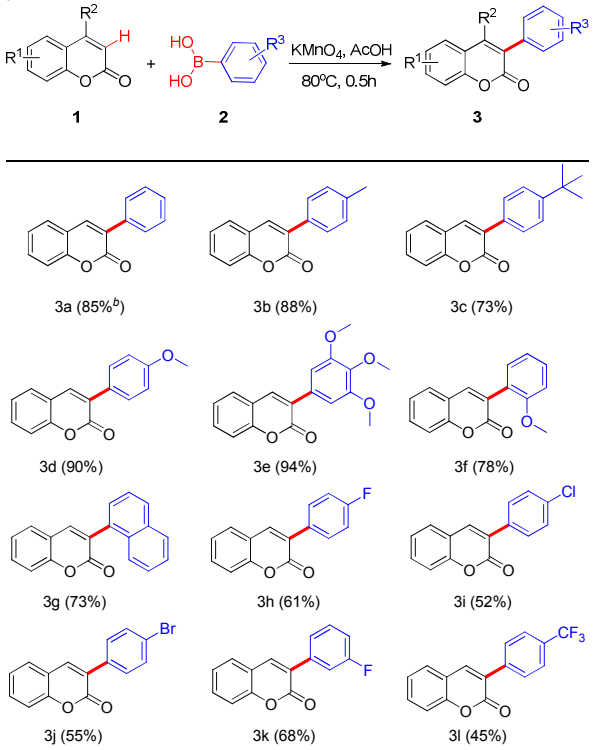
low yield (43% and 22%) (**Table 1**, entries 1 and 2). Various oxidants including $CuSO_4$, $FeCl_3·6H_2O$, $KMnO_4$, MnO_2, $MnSO_4$, and $Mn(OAc)_2$ were added to the reaction system without the catalyst, respectively. $CuSO_4$, $MnSO_4$, and $Mn(OAc)_2$ were found to be ineffective (**Table 1**, entries 3, 7 and 8). When $FeCl_3·6H_2O$, $KMnO_4$, and MnO_2 were used however selective phenylation of coumarin at C-3 was pleasingly achieved albeit in 32%, 40%, and 28% (**Table 1**, entries 4-6). Among various oxidants screened, $KMnO_4$ proved to the most effective. This fact showed that the oxidant was crucial to the coupling efficiency in C–H activation reactions. Subsequently, only the oxidant $KMnO_4$ was used to promote the reaction without any catalyst. The solvent also affected the coupling reaction of coumarin and phenylboronic acid. No product was found with C_2H_5OH, DCE, DMF or dioxane as solvent (**Table 1**, entries 9-12), and only low yield was obtained when CH_3CN was employed (**Table 1**, entry 5), where AcOH turned out to be the most appropriate (**Table 1**, entry 13). The amount of $KMnO_4$ was also screened. To our delight, the yield was improved to 75% when 2.0 eq $KMnO_4$ was used, which indicated that the $KMnO_4$ played an important role in this reaction (**Table S1**, Supporting Information). The ratio of substrates coumarin and phenylboronic acid was investigated, and the ratio 1:2 of coumarin and phenylboronic acid proved to be best result (**Table S2**, Supporting Information). When the reaction temperature was increased from 20 °C to 80 °C, the yield of **3a** was enhanced from 30% to 80% (**Table 1**, entries 14-18). However, the product yields dramatically dropped if the reaction temperature continued to be increased, and 80 °C was found to be best choice. Various reaction times were also examined, 0.5 h proved to the best appropriate and the yield was 85% (**Table 1**, entries 18-21).

With the optimum conditions in hand (**Table 1**, entry 20), we next sought to explore the scope of coumarins and arylboronic acids reaction for the construction of 3-arylcoumarins (**Table 2**). Accordingly, coumarin and various substituted arylboronic acids possessing electron-donating and withdrawing groups were employed in the reaction (**Table 2**, 3a-r). The results showed that arylboronic acids with various groups including alkyl, methoxy, halogeno, carbonyl, cyano group, aldehyde group, and amide group were tolerated, and the reactions were highly regioselective, where in all cases 4-arylcoumarins were not observed. The crystallization of compound **3j** from EtOAc gave a single crystal suitable for X-ray analysis. It illustrates the molecular structure of the substituted 3-arylcoumarin **3j** (**Figure 1**). Moreover, arylboronic acids with electron-donating groups (-CH_3, -$C(CH_3)_3$, -OCH_3, etc) could promote the coupling reaction, and give better yields than those with electron-withdrawing groups (-F, -Cl, -Br, -CF_3, -$COCH_3$, -CN, -CHO, etc). Especially, 3,4,5-trimethoxy phenylboronic acid could react with coumarin, giving 94% yield (**Table 2**, 3e), where an almost quantitative yield was established. In addition, *ortho*-methoxy phenylboronic acid and α-naphthaleneboronic acid underwent smoothly this coupling reaction to generate the corresponding products **3f** and **3g** in good yield. The fact showed that the steric hindrance of arylboronic acids did not obviously affect this transformation. Gratifying, aliphatic boric acid, isopropyl boric acid could also react with coumarin to obtain 3-isopropylcoumarin **3zz**. Unfortunately, benzyl acid failed to deliver the desired products with the current reaction system. Various substituted coumarins were also found to be amenable to this direct C–H functionalization reaction. Arylation of coumarins bearing alkyl and alkoxy proceeded smoothly leading to 3-arylcoumarins scaffolds **3s**, **3u**, and **3w** in 72-93% yields. The highest yield 93% was obtained in transformation of 4-methyl-7-ethyloxycoumarin to its related product **3w** with an almost quantitative yield. We were pleased to see that even sensitive functionalities such as hydroxyl and amino groups were also tolerated and the coupling reactions proceeded with no requisite for protection of these groups (**3t**, **3x** and **3y**). This feature is ubiquitous in hydroxycoumarin and aminocoumarin based biologically active products, which eliminates the requirement of protection and deprotection of hydroxyl and amino groups. Unfortunately, coumarin possessing an electron-withdrawing group such as -NO_2 at the C6 position gave the desired product **3v** in poor yield. It is worthy of note that these standard reaction conditions were also applied to 4-substituted coumarins, affording the corresponding products **3w**, **3x** and **3y** in 93%, 48% and 49% yields, respectively. Moreover, the reaction of 3-acetyl coumarin with phenylboronic acid led to the formation of 3-phenylcoumarin derivative **3z** with moderate yield (44%). These results indicated the steric hinderance of coumarins played a weak role in this reaction.

Table 2 Synthesis of 3-arylcoumarins from coumarins and arylboronic acids[a]



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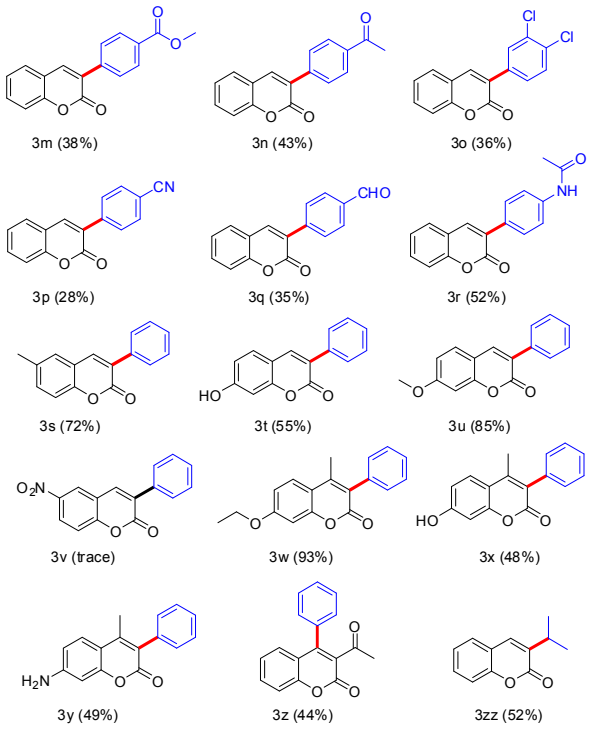


[a] Reaction conditions: a solution of $KMnO_4$ (1.0 mmol, 158 mg) in 20 mL AcOH was stirred under reflux until the purple color of $KMnO_4$ turn brown (20 min). After the reaction was cooled to room temperature, coumarins **1** (0.5 mmol) and arylboronic acid **2** (1.0 mmol) were added and the reaction was continued at 80 °C for 0.5 h.
[b] Isolated yields.

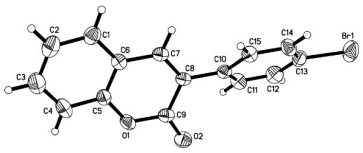
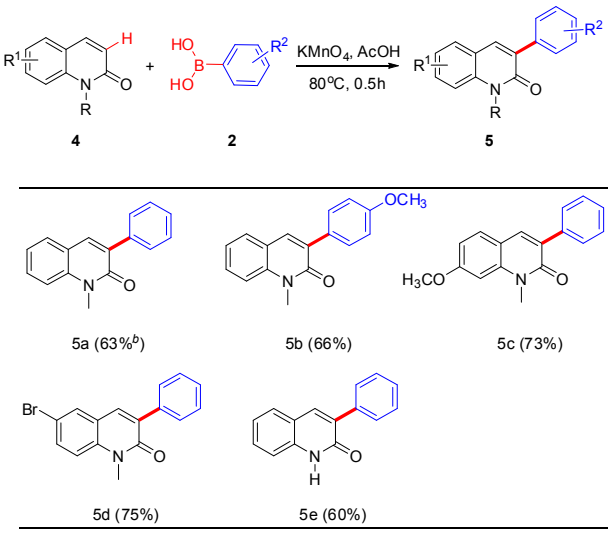


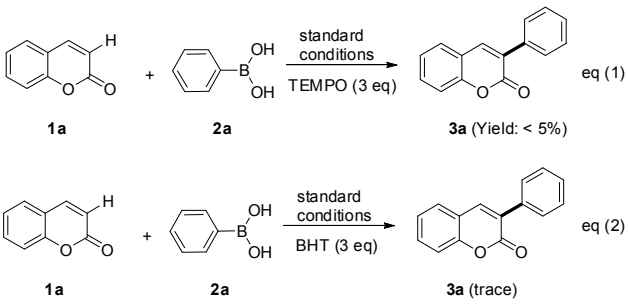
Figure 1 X-ray crystal structure of **3j**

In order to further explore the generality of this procedure, a series of quinolinone derivatives was also investigated under the optimal conditions (**Table 3**). We were pleased to observe that the C3 position of quinolinone derivatives were exclusively arylated, affording 3-arylquinolinones in 60-75% yields. Notably, *N*-methyl quinolinones with electron-rich (OCH_3) and electron-poor (Br) groups on the phenyl ring were tolerated under these coupling conditions in good yield. Quinolinone with a bromine substituent also underwent the arylation reaction and resulted in **5d** with an intact halo group to serve as a good precursor for further functionalizations. It was noteworthy that 2-quinolinone with a sensitive amide group was also tolerated and the coupling reaction proceeded with no requisite for protection of this group (**5e**).

Table 3 Synthesis of 3-arylquinolinones from 2-quinolinones and arylboronic acids[a]



[a] Reaction conditions: a solution of $KMnO_4$ (1.0 mmol, 158 mg) in 20 mL AcOH was stirred under reflux until the purple color of $KMnO_4$ turn brown (20 min). After the reaction was cooled to room temperature, quinolinones **4** (0.5 mmol) and arylboronic acid **2** (1.0 mmol) were added and the reaction was continued at 80 °C for 0.5 h.
[b] Isolated yields.



Scheme 3 Mechanistic investigations of the dehydrogenative radical coupling reaction

To investigate the reaction mechanism, some control experiments were conducted (**Scheme 3**). A < 5% yield of **3a** was obtained in the presence of the radical inhibitor (2,2,6,6-tetramethylpiperidin-1-yl)oxidanyl (TEMPO) (eq 1), and a trace yield of **3a** was produced when the radical scavenger butyleret hydroxytoluene (BHT) was added (eq 2). These results could indicate that the reaction might proceed *via* a radical pathway. On the basis of these data and previous studies,[19b, 21] a possible reaction mechanism for the current manganese(III)-mediated C3-position direct radical arylation of coumarins was proposed as shown in **Scheme 4**. The formation of Mn(III) species could be explained via the reaction of $KMnO_4$ with HOAc.[21] The reaction of boronic acid **A** with Mn(III) salt generates aryl or alkyl radical **B**,[19b, 20b] which attacks selectively

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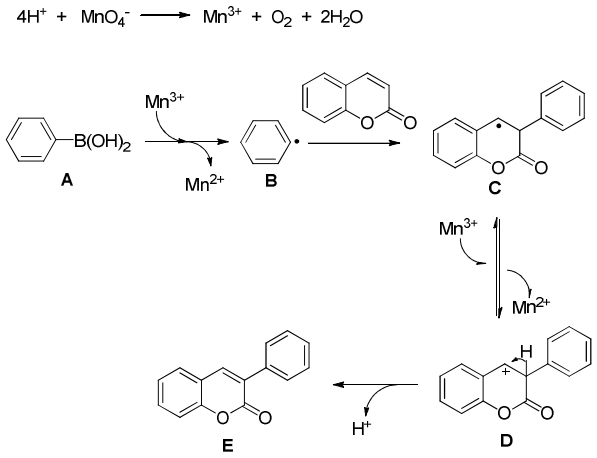
C3-position of coumarin to give the carbon radical **C** stabilized by the conjugation with phenyl group. Subsequently, a single-electron transfer (SET) from **C** to Mn(III) would release the intermediate **D**, simultaneously Mn(III) was reduced into Mn(II). After that, the intermediate **D** loses a proton to produce the C3-functionalized coumarin **E**.



Scheme 4 Proposed reaction mechanism

Conclusions

In conclusion, we have successfully developed a versatile and regioselective arylation of coumarins and quinolinones with arylboronic acids. This protocol provides a valuable approach to synthesize of biologically interesting 3-arylcoumarins via $KMnO_4$/AcOH-mediated dehydrogenative direct radical coupling reaction. This reaction is high efficiency, moderate to good yield, and a broad functional groups tolerance.

Experimental

General information

Anhydrous solvents were obtained by standard procedure. All substrates purchased from *J* & *K* Scientific Ltd. were used without further purification. Column chromatography was performed using 200-300 mesh silica with the indicated solvent system according to standard techniques. Analytical thin-layer chromatography (TLC) was performed on precoated, glass-backed silica gel plates. Visualization of the developed chromatogram was performed by UV absorbance (254 nm or 365 nm). Nuclear magnetic resonance spectra were recorded on Bruker Avance 400 MHz spectrometer. Chemical shifts for ^{1}H NMR spectra are recorded in parts per million from tetramethylsilane. Data were reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, m = multiplet and br = broad), coupling constant in Hz and integration. Chemical shifts for ^{13}C NMR spectra were recorded in parts per million from tetramethylsilane. High resolution mass spectra (HR MS) were obtained on Q-TOF instrument using the ESI technique. IR spectra were recorded on Shimadazu IR-408 Fourier transform infrared spectrophotometer using a thin film supported on KBr pellets. Melting points were measured on an XT4A microscopic apparatus uncorrected.

General procedure for synthesis of 3-aryl coumarin derivatives 3 (3-aryl quinolinone derivatives 5)

In a 50 mL Schlenk tube, a solution of $KMnO_4$ (1.0 mmol, 158 mg) in 20 mL AcOH was stirred under reflux until the purple color of $KMnO_4$ turn brown (20 min). After the reaction was cooled to room temperature, coumarins **1** (or quinolin derivatives **4**) (0.5 mmol) and arylboronic acid **2** (1.0 mmol) were added and the reaction was continued at 80 ^{o}C for 0.5 h (monitored by TLC). The reaction mixture was diluted with EtOAc, and neutralized with the saturated $NaHCO_3$. The resulting organic phase was dried over anhydrous $NaSO_4$ and concentrated under vacuum. The crude product was purified by silica gel column chromatography using ethyl acetate/ petroleum ether (1:5 to 2:1) as eluant to obtain the desired product **3** (or **5**).

3-Phenyl-2H-chromen-2-one (**3a**)

Colorless solid, mp 138-139 ^{o}C (EtOAc) [lit.,[18c] mp 136-137 ^{o}C]. IR (KBr) ν(cm^{-1}): 1716 (C=O), 1601, 1454 (Ar-), 1117 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.81 (s, 1H), 7.71-7.69 (m, 2H), 7.53 (t, J_{H-H} = 8.0 Hz, 2H), 7.47-7.40 (m, 3H), 7.36 (d, J_{H-H} = 8.0 Hz, 3H), 7.29 (td, J_{H-H} = 7.5 Hz, J_{H-H} = 1.0 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 160.6, 153.5, 139.9 (CH), 134.7, 131.4 (CH), 128.8 (CH), 128.6 (CH), 128.5 (CH), 128.3, 127.9 (CH), 124.5 (CH), 119.7, 116.4 (CH). MS (ESI) m/z: 223.2 $[M + H]^+$ (calcd for $C_{15}H_{11}O_2^+$ 223.0).

3-(p-Tolyl)-2H-chromen-2-one (**3b**)

Colorless solid, mp 160-161 ^{o}C (EtOAc) [lit.,[18c] 158-159 ^{o}C]. IR (KBr) ν(cm^{-1}): 1716 (C=O), 1610, 1452 (Ar-), 1113 (C–O). ^{1}H NMR (400 MHz, DMSO) δ: 8.19 (s, 1H), 7.75 (d, J_{H-H} = 7.6 Hz, 1H), 7.63-7.58 (m, 3H), 7.41 (d, J_{H-H} = 8.2 Hz, 1H), 7.36 (t, J_{H-H} = 7.5 Hz, 1H), 7.25 (d, J_{H-H} = 8.0 Hz, 2H), 2.34 (s, 3H). ^{13}C NMR (100 MHz, DMSO) δ: 160.2, 153.2, 140.3 (CH), 138.5, 132.1, 131.9 (CH), 129.2 (CH), 128.9 (CH), 128.7 (CH), 127.1, 125.0 (CH), 119.9, 116.2 (CH), 21.2 (CH_3). MS (ESI) m/z: 237.3 $[M + H]^+$ (calcd for $C_{16}H_{13}O_2^+$ 237.0).

3-(4-(Tert-butyl)phenyl)-2H-chromen-2-one (**3c**)

White solid, mp 159-160 ^{o}C (EtOAc) [lit.,[22] 154 ^{o}C]. IR (KBr) ν(cm^{-1}): 2960 (-CH_3), 1716 (C=O), 1603, 1450 (Ar-), 1124 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.78 (s, 1H), 7.65 (d, J_{H-H} = 8.5 Hz, 1H), 7.53-7.50 (m, 2H), 7.46 (d, J_{H-H} = 8.5 Hz, 2H), 7.34 (d, J_{H-H} = 8.0 Hz, 1H), 7.27 (td, J_{H-H} = 7.5 Hz, J_{H-H} = 1.0 Hz, 1H), 1.34 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 160.7, 153.4, 152.0, 139.3 (CH), 131.8, 131.2 (CH), 128.3, 128.2 (CH), 127.8 (CH), 125.4 (CH), 124.4 (CH), 119.7, 116.4 (CH), 34.7, 31.2 (CH_3). MS (ESI) m/z: 279.2 $[M + H]^+$ (calcd for $C_{19}H_{19}O_2^+$ 279.1).

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3-(4-Methoxyphenyl)-2H-chromen-2-one **(3d)**

Colorless solid, mp 138-139 °C (EtOAc) [lit.,[18c] 140-141 °C]. IR (KBr) ν(cm^{-1}): 2918 (-CH_3), 1716 (C=O), 1608, 1514, 1452 (Ar-), 1252, 1128 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.74 (s, 1H), 7.66 (d, J_{H-H} = 8.9 Hz, 2H), 7.52-7.46 (m, 2H), 7.33 (d, J_{H-H} = 8.2 Hz, 1H), 7.27 (td, J_{H-H} = 7.5 Hz, J_{H-H} = 1.1 Hz, 1H), 6.96 (d, J_{H-H} = 8.9 Hz, 2H), 2.83 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 160.8, 160.1, 153.2, 138.5 (CH), 131.0 (CH), 129.8 (CH), 127.8, 127.7 (CH), 127.1, 124.4 (CH), 119.8, 116.3 (CH), 113.9 (CH), 55.3 (CH_3). MS (ESI) m/z: 253.4 $[M + H]^+$ (calcd for $C_{16}H_{13}O_3^+$ 253.0).

3-(3,4,5-Trimethoxyphenyl)-2H-chromen-2-one **(3e)**

White solid, mp 147-148 °C (EtOAc) [lit.,[16] 145-147 °C]. IR (KBr) ν(cm^{-1}): 2964, 2941 (-CH_3), 1716 (C=O), 1606, 1588, 1508, 1450 (Ar-), 1242, 1126 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.81 (s, 1H), 7.56-7.50 (m, 2H), 7.33 (d, J_{H-H} = 8.2 Hz, 1H), 7.29 (td, J_{H-H} = 7.4 Hz, J_{H-H} = 1.0 Hz, 1H), 6.94 (s, 2H), 3.91 (s, 6H), 3.89 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 160.5, 153.3, 153.0, 139.5 (CH), 138.7, 131.4 (CH), 130.1, 128.0, 127.9 (CH), 124.5 (CH), 119.5, 116.3 (CH), 106.0 (CH), 60.8 (CH_3), 56.2 (CH_3). MS (ESI) m/z: 313.0 $[M + H]^+$ (calcd for $C_{18}H_{17}O_5^+$ 313.1).

3-(2-Methoxyphenyl)-2H-chromen-2-one **(3f)**

White solid, mp 138-139 °C (EtOAc) [lit.,[23] 140-141 °C]. IR (KBr) ν(cm^{-1}): 1722 (C=O), 1608, 1491, 1456 (Ar-), 1246, 1130 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.73 (s, 1H), 7.49 (d, J_{H-H} = 7.4 Hz, 2H), 7.38-7.34 (m, 3H), 7.27 (t, J_{H-H} = 7.4 Hz, 1H), 7.02 (t, J_{H-H} = 7.5 Hz, 1H), 6.99 (d, J_{H-H} = 8.2 Hz, 1H), 3.82 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 160.2, 157.3, 153.7, 141.7 (CH), 131.1 (CH), 130.7 (CH), 130.2 (CH), 127.8 (CH), 126.6, 124.2 (CH), 124.1, 120.6 (CH), 119.5, 116.5 (CH), 111.4 (CH), 55.7 (CH_3). MS (ESI) m/z: 253.2 $[M + H]^+$ (calcd for $C_{16}H_{13}O_3^+$ 253.1).

3-(Naphthalen-1-yl)-2H-chromen-2-one **(3g)**

Yellow solid, mp 145-146 °C (EtOAc) [lit.,[23] 154-156 °C]. IR (KBr) ν(cm^{-1}): 1712 (C=O), 1606, 1454 (Ar-), 1132 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.89 (td, J_{H-H} = 6.8 Hz, J_{H-H} = 1.9 Hz, 2H), 7.78 (s, 1H), 7.77 (dd, J_{H-H} = 8.2 Hz, J_{H-H} = 1.3 Hz, 1H), 7.56-7.46 (m, 6H), 7.43 (t, J_{H-H} = 8.5 Hz, 1H), 7.30 (td, J_{H-H} = 7.6 Hz, J_{H-H} = 1.1 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 160.8, 154.0, 142.8 (CH), 133.7, 132.7, 131.7 (CH), 131.6, 129.4 (CH), 128.6 (CH), 128.3, 128.0 (CH), 127.7 (CH), 126.5 (CH), 126.1 (CH), 125.3 (CH), 125.1 (CH), 124.6 (CH), 119.3, 116.7 (CH). MS (ESI) m/z: 273.2 $[M + H]^+$ (calcd for $C_{19}H_{13}O_2^+$ 273.1).

3-(4-Fluorophenyl)-2H-chromen-2-one **(3h)**

White Colorless solid, mp 188-189 °C (EtOAc) [lit.,[18c] 196-197 °C]. IR (KBr) ν(cm^{-1}): 1712 (C=O), 1604, 1514, 1454 (Ar-), 1236 (C–F), 1128 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.79 (s, 1H), 7.71-7.68 (m, 2H), 7.53 (td, J_{H-H} = 7.5 Hz, J_{H-H} = 1.4 Hz, 2H), 7.36 (d, J_{H-H} = 8.1 Hz, 1H), 7.30 (td, J_{H-H} = 8.5 Hz, J_{H-H} = 1.0 Hz, 1H), 7.15-7.11 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 163.1(d, J_{F-C} = 247.3 Hz), 160.5, 153.4, 139.7 (CH), 131.5 (CH), 130.7 (d, J_{F-C} = 3.1 Hz), 130.4 (d, J_{F-C} = 8.1 Hz, CH), 127.9 (CH), 127.3, 124.6 (CH), 119.5, 116.5 (CH), 115.5 (d, J_{F-C} = 3.1 Hz, CH). ^{19}F NMR (376 MHz, $CDCl_3$) δ: -112.3. MS (ESI) m/z: 241.1 $[M + H]^+$ (calcd for $C_{15}H_{10}FO_2^+$ 241.0).

3-(4-Chlorophenyl)-2H-chromen-2-one **(3i)**

White crystalline solid, mp 190-191 °C (EtOAc) [lit.,[22] 193 °C]. IR (KBr) ν(cm^{-1}): 1711 (C=O), 1608, 1489, 1452 (Ar-), 1098 (C–O), 748 (C–Cl). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.81 (s, 1H), 7.65 (d, J_{H-H} = 8.5 Hz, 2H), 7.55-7.51 (m, 2H), 7.40 (d, J_{H-H} = 8.6 Hz, 2H), 7.35 (d, J_{H-H} = 8.6 Hz, 1H), 7.30 (td, J_{H-H} = 8.5 Hz, J_{H-H} = 0.9 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 160.4, 153.5, 139.9 (CH), 134.9, 133.0, 131.7 (CH), 129.8 (CH), 128.7 (CH), 128.0 (CH), 127.1, 124.6 (CH), 119.5, 116.5 (CH). MS (ESI) m/z: 257.3 $[M + H]^+$ (calcd for $C_{15}H_{10}ClO_2^+$ 257.0).

3-(4-Bromophenyl)-2H-chromen-2-one **(3j)**

Colorless solid, mp 189-190 °C (EtOAc) [lit.,[18c] 188-189 °C]. IR (KBr) ν(cm^{-1}): 1712 (C=O), 1610, 1487, 1450 (Ar-), 1012 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.81 (s, 1H), 7.60-7.52 (m, 6H), 7.35 (d, J_{H-H} = 8.7 Hz, 1H), 7.30 (td, J_{H-H} = 8.6 Hz, J_{H-H} = 1.0 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 160.2, 153.5, 139.9 (CH), 133.5, 131.7 (CH), 131.6 (CH), 130.1 (CH), 128.0 (CH), 127.1, 124.6 (CH), 123.1, 119.5, 116.5 (CH). MS (ESI) m/z: 301.1 $[M + H]^+$ (calcd for $C_{15}H_{10}BrO_2^+$ 301.0).

3-(3-Fluorophenyl)-2H-chromen-2-one **(3k)**

Colorless solid, mp 173-174 °C. IR (KBr) ν(cm^{-1}): 1709 (C=O), 1610, 1588, 1456 (Ar-), 1180 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.83 (s, 1H), 7.54 (t, J_{H-H} = 7.4 Hz, 2H), 7.47 (t, J_{H-H} = 7.5 Hz, 2H), 7.43-7.39 (m, 1H), 7.36 (d, J_{H-H} = 8.6 Hz, 1H), 7.30 (d, J_{H-H} = 7.9 Hz, 1H), 7.09 (td, J_{H-H} = 8.6 Hz, J_{H-H} = 1.8 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 162.6(d, J_{F-C} = 244.4 Hz), 160.2, 153.5, 140.4 (CH), 136.6 (d, J_{F-C} = 8.2 Hz), 131.8 (CH), 130.0 (d, J_{F-C} = 8.2 Hz, CH), 128.1 (CH), 127.0 (d, J_{F-C} = 2.2 Hz, CH), 124.6 (CH), 124.1 (d, J_{F-C} = 2.9 Hz, CH), 119.4, 116.5 (CH), 115.8 (d, J_{F-C} = 8.8 Hz, CH), 115.6 (d, J_{F-C} = 10.7 Hz, CH). ^{19}F NMR (376 MHz, $CDCl_3$) δ: -112.6. HR MS (ESI) m/z: 241.0655 $[M + H]^+$ (calcd for $C_{15}H_{10}FO_2^+$ 241.0659).

3-(4-(Trifluoromethyl)phenyl)-2H-chromen-2-one **(3l)**

White solid, mp 197-198 °C (EtOAc) [lit.,[18c] 196-197 °C]. IR (KBr) ν(cm^{-1}): 1709 (C=O), 1608, 1456, 1356 (Ar-), 1101 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.88 (s, 1H), 7.83 (d, J_{H-H} = 8.1 Hz, 2H), 7.70 (d, J_{H-H} = 8.2 Hz, 2H), 7.59-7.55 (m, 2H), 7.38 (d, J_{H-H} = 8.7 Hz, 1H), 7.33 (td, J_{H-H} = 8.5 Hz, J_{H-H} = 1.0 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 160.2, 153.7, 140.9 (CH), 138.2, 132.1 (CH), 130.7 (d, J_{F-C} = 31.2 Hz), 128.9 (CH), 128.2 (CH), 128.0, 126.9, 125.4 (d, J_{F-C} = 3.7 Hz, CH), 124.7 (CH), 119.3, 116.6 (CH). ^{19}F NMR (376 MHz, $CDCl_3$) δ: -62.7. MS (ESI) m/z: 291.2 $[M + H]^+$ (calcd for $C_{16}H_{10}F_3O_2^+$ 291.0).

Methyl 4-(2-oxo-2H-chromen-3-yl)benzoate **(3m)**

Colorless solid, mp 209-210 °C (EtOAc) [lit.,[18c] 209-210 °C]. IR (KBr) ν(cm^{-1}): 1716, 1682 (C=O), 1604, 1454 (Ar-), 1109 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.11 (dd, J_{H-H} = 8.4 Hz, J_{H-H} = 1.8 Hz, 2H), 7.89 (s, 1H), 7.80 (dd, J_{H-H} = 8.3 Hz, J_{H-H} = 1.8 Hz, 2H), 7.57 (td, J_{H-H} = 7.5 Hz, J_{H-H} = 1.6 Hz, 2H), 7.39 (d, J_{H-H} = 8.6 Hz, 1H), 7.32 (t, J_{H-H} = 7.1 Hz,

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1H), 3.94 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 166.6, 160.1, 153.7, 140.8 (CH), 139.1, 131.9 (CH), 130.2, 129.7 (CH), 128.5 (CH), 128.1 (CH), 127.3, 124.7 (CH), 119.4, 116.5 (CH), 52.2 (CH_3). MS (ESI) m/z: 281.3 $[M + H]^+$ (calcd for $C_{17}H_{13}O_4^+$ 281.1).

3-(4-Acetylphenyl)-2H-chromen-2-one **(3n)**

Colorless solid, mp 217-218 °C (EtOAc) [lit.,[24] 225-227 °C]. IR (KBr) ν(cm^{-1}): 2920 (-CH_3), 1730, 1676 (C=O), 1604, 1574, 1454 (Ar-), 1111 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.02 (d, J_{H-H} = 8.2 Hz, 2H), 7.90 (s, 1H), 7.82 (d, J_{H-H} = 8.2 Hz, 2H), 7.57 (t, J_{H-H} = 7.6 Hz, 2H), 7.38(d, J_{H-H} = 8.2 Hz, 1H), 7.32 (t, J_{H-H} = 7.5 Hz, 1H), 2.63 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 197.5, 160.1, 153.7, 140.8 (CH), 139.2, 137.0, 132.0 (CH), 128.7 (CH), 128.4, 128.1 (CH), 127.1, 124.7 (CH), 119.4, 116.5 (CH), 26.7 (CH_3). MS (ESI) m/z: 265.3 $[M + H]^+$ (calcd for $C_{17}H_{13}O_3^+$ 265.1).

3-(3,4-Dichlorophenyl)-2H-chromen-2-one **(3o)**

Yellow solid, mp 233-234 °C (EtOAc) [lit.,[25] 191-192 °C]. IR (KBr) ν(cm^{-1}): 1697 (C=O), 1606, 1473, 1452 (Ar-), 1028 (C–O), 752 (C–Cl). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.84-7.83 (m, 2H), 7.61-7.51 (m, 4H), 7.38 (d, J_{H-H} = 8.6 Hz, 1H), 7.32 (td, J_{H-H} = 7.7 Hz, J_{H-H} = 0.6 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 160.0, 153.6, 140.4 (CH), 134.5, 133.1, 132.7, 132.0 (CH), 130.4 (CH), 130.3 (CH), 128.1 (CH), 127.8 (CH), 125.9, 124.7 (CH), 119.2, 116.6 (CH). MS (ESI) m/z: 291.2 $[M + H]^+$ (calcd for $C_{15}H_9Cl_2O_2^+$ 291.0).

4-(2-Oxo-2H-chromen-3-yl)benzonitrile **(3p)**

Light yellow solid, mp 239-240 °C (EtOAc) [lit.,[26] 152-154 °C]. IR (KBr) ν(cm^{-1}): 1709 (C=O), 1614, 1446 (Ar-), 1115 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.90 (s, 1H), 7.85 (d, J_{H-H} = 8.4 Hz, 2H), 7.74 (d, J_{H-H} = 8.4 Hz, 2H), 7.59 (d, J_{H-H} = 7.5 Hz, 2H), 7.39 (d, J_{H-H} = 8.4 Hz, 1H), 7.34 (td, J_{H-H} = 8.4 Hz, J_{H-H} = 0.7 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 159.9, 153.7, 141.3 (CH), 139.1 (CH), 132.4 (CH), 132.2 (CH), 129.2 (CH), 128.3 (CH), 126.4, 124.8 (CH), 119.2, 118.5, 116.6 (CH), 112.4. MS (ESI) m/z: 248.2 $[M + H]^+$ (calcd for $C_{16}H_{10}NO_2^+$ 248.0).

4-(2-Oxo-2H-chromen-3-yl)benzaldehyde **(3q)**

Colorless solid, mp 202-203 °C (EtOAc). IR (KBr) ν(cm^{-1}): 1710 (C=O), 1611, 1434 (Ar-), 1113 (C–O). ^{1}H NMR (400 MHz, DMSO) δ: 10.06 (s, 1H), 8.41 (s, 1H), 8.01-7.96 (m, 4H), 7.82 (d, J_{H-H} = 7.5 Hz, 1H), 7.66 (t, J_{H-H} = 7.5 Hz, 1H), 7.46 (d, J_{H-H} = 8.3 Hz, 1H), 7.41 (t, J_{H-H} = 7.5 Hz, 1H). ^{13}C NMR (100 MHz, DMSO) δ: 193.2 (CHO), 159.8, 153.6, 142.5 (CH), 140.9, 136.2, 132.8 (CH), 129.7 (CH), 129.6 (CH), 129.4 (CH), 126.2, 125.2 (CH), 119.7, 116.4 (CH). HR MS (ESI) m/z: 251.0707 $[M + H]^+$ (calcd for $C_{16}H_{11}NO_3^+$ 251.0703).

N-(4-(2-Oxo-2H-chromen-3-yl)phenyl)acetamide **(3r)**

Light yellow solid. IR (KBr) ν(cm^{-1}): 3300 (NH), 1708 (C=O), 1660 (C=O), 1605, 1430 (Ar-). ^{1}H NMR (400 MHz, DMSO) δ: 10.08 (s, 1H), 8.17 (s, 1H), 7.93 (s, 1H), 7.76 (dd, J_{H-H} = 7.7 Hz, J_{H-H} = 1.1 Hz, 1H), 7.70 (dd, J_{H-H} = 7.1 Hz, J_{H-H} = 1.9 Hz, 1H), 7.60 (td, J_{H-H} = 7.8 Hz, J_{H-H} = 1.4Hz, 1H), 7.42-7.33 (m, 4H). ^{13}C NMR (100 MHz, DMSO) δ: 168.9, 160.0, 153.4, 140.9 (CH), 139.6, 135.4, 132.1 (CH), 129.0 (CH), 128.9 (CH), 127.2, 125.0 (CH), 123.6 (CH), 119.8, 119.7 (CH), 119.6 (CH), 116.2 (CH), 24.4 (CH_3). HR MS (ESI) m/z: 280.0966 $[M + H]^+$ (calcd for $C_{17}H_{14}NO_3^+$ 280.0968).

6-Methyl-3-phenyl-2H-chromen-2-one **(3s)**

Colorless solid, mp 148-149 °C (EtOAc) [lit.,[15] 149-150 °C]. IR (KBr) ν(cm^{-1}): 2916, 2848 (-CH_3), 1720 (C=O), 1616, 1577, 1448 (Ar-), 1111 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.74 (s, 1H), 7.70-7.67 (m, 2H), 7.46-7.37 (m, 3H), 7.33-7.31 (m, 2H), 7.24 (dd, J_{H-H} = 7.4 Hz, J_{H-H} = 1.6 Hz, 1H), 2.41 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 160.8, 151.6, 139.9 (CH), 134.8, 134.1, 132.4 (CH), 128.7 (CH), 128.5 (CH), 128.4 (CH), 128.2, 127.7 (CH), 119.4, 116.1 (CH), 20.8 (CH_3). MS (ESI) m/z: 237.2 $[M + H]^+$ (calcd for $C_{16}H_{13}O_2^+$ 237.1).

7-Hydroxy-3-phenyl-2H-chromen-2-one **(3t)**

White solid, mp 201-202 °C (EtOAc) [lit.,[16] 203-204 °C]. IR (KBr) ν(cm^{-1}): 3228 (-OH), 1680 (C=O), 1615, 1595, 1570, 1445 (Ar-), 1080 (C–O). ^{1}H NMR (400 MHz, DMSO) δ: 10.66 (s, 1H), 8.15 (s, 1H), 7.69 (d, J_{H-H} = 7.3 Hz, 2H), 7.60 (d, J_{H-H} = 8.5 Hz, 1H), 7.43 (d, J_{H-H} = 7.6 Hz, 2H), 7.37 (t, J_{H-H} = 7.3 Hz, 1H), 6.82 (dd, J_{H-H} = 8.5 Hz, J_{H-H} = 2.2 Hz, 1H), 6.76 (d, J_{H-H} = 2.0 Hz, 1H). ^{13}C NMR (100 MHz, DMSO) δ: 161.7, 160.6, 155.3, 141.6 (CH), 135.6, 130.4 (CH), 128.7 (CH), 128.6 (CH), 128.5 (CH), 122.6, 113.8 (CH), 112.4 (CH), 102.2 (CH). MS (ESI) m/z: 239.1 $[M + H]^+$ (calcd for $C_{15}H_{11}O_3^+$ 239.0).

7-Methoxy-3-phenyl-2H-chromen-2-one **(3u)**

Light yellow solid, mp 119-120 °C (EtOAc) [lit.,[18c] 118-119 °C]. IR (KBr) ν(cm^{-1}): 3053, 2970 (-CH_3), 1716 (C=O), 1614, 1506, 1464, 1439 (Ar-), 1120 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.75 (s, 1H), 7.68 (d, J_{H-H} = 8.4 Hz, 2H), 7.45-7.41 (m, 3H), 7.39-7.35 (m, 1H), 6.87-6.84 (m, 2H), 3.87 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 162.6, 160.8, 155.3, 139.9 (CH), 135.0, 128.8 (CH), 128.4 (CH), 124.8, 113.3, 112.7 (CH), 100.4 (CH), 55.7 (CH_3). MS (ESI) m/z: 253.3 $[M + H]^+$ (calcd for $C_{16}H_{13}O_3^+$ 253.1).

7-Ethoxy-4-methyl-3-phenyl-2H-chromen-2-one **(3w)**

Yellow solid, mp 117-118 °C. IR (KBr) ν(cm^{-1}): 3062, 2979, 2947 (-CH_3), 1712 (C=O), 1604, 1508, 1385, 1361 (Ar-), 1074 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.52 (d, J_{H-H} = 8.8 Hz, 1H), 7.41 (d, J_{H-H} = 7.0 Hz, 2H), 7.35 (d, J_{H-H} = 7.3 Hz, 1H), 7.29-7.25 (m, 2H), 6.85 (dd, J_{H-H} = 8.8 Hz, J_{H-H} = 2.5 Hz, 1H), 6.79 (d, J_{H-H} = 2.2 Hz, 1H), 4.06 (q, J_{H-H} = 7.0 Hz, 2H), 2.23 (s, 3H), 1.43 (t, J_{H-H} = 7.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 161.7, 161.3, 154.3, 148.0, 134.7, 130.2 (CH), 128.3 (CH), 127.9 (CH), 126.1 (CH), 124.0, 113.9, 112.6 (CH), 101.0 (CH), 64.1 (CH_2), 16.5 (CH_3), 14.6 (CH_3). HR MS (ESI) m/z: 281.1175 $[M + H]^+$ (calcd for $C_{18}H_{17}O_3^+$ 281.1172).

7-Hydroxy-4-methyl-3-phenyl-2H-chromen-2-one **(3x)**

White solid, mp 231-232 °C (EtOAc) [lit.,[27] 225-227 °C]. IR (KBr) ν(cm^{-1}): 3228 (-OH), 1682 (C=O), 1614, 1593, 1577, 1446 (Ar-), 1078

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(C–O). ^{1}H NMR (400 MHz, DMSO) δ: 10.5 (s, -OH), 7.61 (d, J_{H-H} = 8.8 Hz, 1H), 7.43 (t, J_{H-H} = 7.5 Hz, 2H), 7.36 (t, J_{H-H} = 7.2 Hz, 1H), 7.28 (d, J_{H-H} = 6.9 Hz, 2H), 6.83 (dd, J_{H-H} = 8.8 Hz, J_{H-H} = 2.2 Hz, 1H), 6.74 (d, J_{H-H} = 2.2 Hz, 1H), 2.17 (s, 3H). ^{13}C NMR (100 MHz, DMSO) δ: 161.3, 160.7, 154.3, 148.7, 135.3, 130.7 (CH), 128.4 (CH), 128.0 (CH), 127.5 (CH), 122.7, 113.4 (CH), 112.8, 102.3 (CH), 16.7 (CH_3). MS (ESI) m/z: 253.2 $[M + H]^+$ (calcd for $C_{16}H_{13}O_3^+$ 253.1).

7-Amino-4-methyl-3-phenyl-2H-chromen-2-one **(3y)**

Light yellow solid, mp 281-282 °C (EtOAc) [lit.,[28] 280-281 °C]. IR (KBr) ν(cm^{-1}): 3420 (NH_2), 2985 (CH_3), 1708 (C=O), 1613, 1445 (Ar-), 1117 (C–O). ^{1}H NMR (400 MHz, DMSO) δ: 7.47 (d, J_{H-H} = 8.7 Hz, 1H), 7.42 (t, J_{H-H} = 7.5 Hz, 2H), 7.35 (t, J_{H-H} = 7.3Hz, 1H), 7.25 (d, J_{H-H} = 7.0 Hz, 2H), 6.60 (dd, J_{H-H} = 8.7 Hz, J_{H-H} = 2.0 Hz, 1H), 6.46 (d, J_{H-H} = 2.0 Hz, 1H), 6.13 (bs, 2H), 2.14 (s, 3H). ^{13}C NMR (100 MHz, DMSO) δ: 161.1, 154.9, 153.2, 149.1, 135.8, 130.9 (CH), 128.4 (CH), 127.7 (CH), 127.2 (CH), 120.1, 111.8 (CH), 109.5, 98.7 (CH), 16.6 (CH_3). MS (ESI) m/z: 252.3 $[M + H]^+$ (calcd for $C_{16}H_{14}NO_2^+$ 252.1).

3-Acetyl-4-phenyl-2H-chromen-2-one **(3z)**[29]

Colorless solid, mp 141-142 °C. IR (KBr) ν(cm^{-1}): 3052, 2982 (-CH_3), 1728, 1693 (C=O), 1608, 1562, 1448, 1363 (Ar-), 1049 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.60-7.56 (m, 1H), 7.52-7.50 (m, 3H), 7.40 (d, J_{H-H} = 8.3 Hz, 1H), 7.32-7.30 (m, 2H), 7.22 (d, J_{H-H} =4.1 Hz, 1H), 2.24 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 199.0, 158.4, 153.4, 151.8, 132.7 (CH), 132.5, 129.6 (CH), 128.8 (CH), 128.5 (CH), 128.1 (CH), 127.7, 124.6 (CH), 119.4 (CH), 117.0 (CH), 31.1 (CH_3). MS (ESI) m/z: 265.1 $[M + H]^+$ (calcd for $C_{17}H_{13}O_3^+$ 265.0).

3-Isopropyl-2H-chromen-2-one **(3zz)**

Colorless solid, mp 47-48 °C (EtOAc) [lit.,[30] 54-55 °C]. IR (KBr) ν(cm^{-1}): 2987, 2956, 2871 (-CH_3, -CH_2), 1707 (C=O), 1610, 1452 (Ar-), 1387, 1190 (C–O). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.47-7.44 (m, 3H), 7.30 (d, J_{H-H} = 8.6 Hz, 1H), 7.25 (t, J_{H-H} = 7.5 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 161.4, 152.8, 135.9 (CH), 135.7, 130.4 (CH), 127.2 (CH), 124.1 (CH), 119.5, 116.3 (CH), 28.7 (CH), 21.4 (CH_3). MS (ESI) m/z: 189.1 $[M + H]^+$ (calcd for $C_{12}H_{13}O_2^+$ 189.0).

1-Methyl-3-phenylquinolin-2(1H)-one **(5a)**

White solid, mp 134-135 °C (EtOAc) [lit.,[31] 135-137 °C]. IR (KBr) ν(cm^{-1}): 3049, 3032 (-CH_3), 1645 (C=O), 1591, 1454 (Ar-). ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.77 (s, 1H), 7.70 (dd, J_{H-H} = 7.0 Hz, J_{H-H} = 1.4 Hz, 2H), 7.59-7.25 (m, 2H), 7.42 (t, J_{H-H} = 7.5 Hz, 2H), 7.35 (t, J_{H-H} = 8.4 Hz, 2H), 7.22 (t, J_{H-H} = 7.3 Hz, 1H), 3.77 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 161.5, 139.6, 136.8 (CH), 132.4, 130.3 (CH), 128.9 (CH), 128.8 (CH), 128.1 (CH), 128.0 (CH), 122.2 (CH), 120.7, 114.0 (CH), 29.9 (CH_3). MS (ESI) m/z: 236.2 $[M + H]^+$ (calcd for $C_{16}H_{14}NO^+$ 236.1).

3-(4-Methoxyphenyl)-1-methylquinolin-2(1H)-one **(5b)**

Pale yellow solid, mp 113-114 °C (EtOAc) [lit.,[31] 114-116 °C]. IR (KBr) ν(cm^{-1}): 3032, 2952 (-CH_3), 1637 (C=O), 1604, 1598, 1510, 1458 (Ar-), 1246, 1178, 1030. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.73 (s, 1H), 7.67 (dd, J_{H-H} = 7.0 Hz, J_{H-H} = 1.9 Hz, 2H), 7.56 (dd, J_{H-H} = 7.8 Hz, J_{H-H} = 1.0 Hz, 1H), 7.51 (td, J_{H-H} = 7.2 Hz, J_{H-H} = 1.4 Hz, 1H), 7.32 (d, J_{H-H} = 8.5 Hz, 1H), 7.21 (td, J_{H-H} = 7.2 Hz, J_{H-H} = 0.6 Hz, 1H), 6.95 (d, J_{H-H} = 8.8 Hz, 2H), 3.83 (s, 3H), 3.76 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 161.6, 159.5, 139.3, 135.7 (CH), 131.9, 130.2 (CH), 129.9 (CH), 129.2, 128.6 (CH), 122.1 (CH), 120.8, 113.9 (CH), 113.6 (CH), 55.3 (CH_3), 29.9 (CH_3). MS (ESI) m/z: 266.2 $[M + H]^+$ (calcd for $C_{17}H_{16}NO_2^+$ 266.1).

7-Methoxy-1-methyl-3-phenylquinolin-2(1H)-one **(5c)**

Light yellow solid, mp 134-135 °C. IR (KBr) ν(cm^{-1}): 2979, 2927 (-CH_3), 1645 (C=O), 1616, 1595, 1508, 1454 (Ar-), 1248, 1211, 1036. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.70-7.67 (m, 3H), 7.48 (d, J_{H-H} = 8.6 Hz, 1H), 7.40 (td, J_{H-H} = 7.2 Hz, J_{H-H} = 1.2 Hz, 2H), 7.35-7.31 (m, 1H), 6.81 (dd, J_{H-H} = 8.6 Hz, J_{H-H} = 2.2 Hz, 1H), 6.76 (d, J_{H-H} = 2.2 Hz, 1H), 3.90 (s, 3H), 3.72 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 161.8, 161.6, 141.2, 137.0, 136.7 (CH), 130.2 (CH), 129.2, 128.8 (CH), 128.1 (CH), 127.7 (CH), 114.9, 109.8 (CH), 98.4 (CH), 55.6 (CH_3), 29.9 (CH_3). HR MS (ESI) m/z: 266.1179 $[M + H]^+$ (calcd for $C_{17}H_{16}NO_2^+$ 266.1176).

6-Bromo-1-methyl-3-phenylquinolin-2(1H)-one **(5d)**

Pale yellow solid, mp 175-176 °C (EtOAc) [lit.,[31] 176-178 °C]. IR (KBr) ν(cm^{-1}): 2954, 2924 (-CH_3), 1647 (C=O), 1579, 1487, 1444, 1415 (Ar-), 1228, 1209, 1118. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.73 (d, J_{H-H} = 2.2 Hz, 1H), 7.70-7.67 (m, 3H), 7.63 (dd, J_{H-H} = 8.9 Hz, J_{H-H} = 2.2 Hz, 1H), 7.44 (t, J_{H-H} = 7.6 Hz, 2H), 7.40-7.37 (m, 1H), 7.25 (d, J_{H-H} = 6.7 Hz, 1H), 3.77 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 161.1, 138.5, 136.3, 135.3 (CH), 133.7, 132.9 (CH), 130.8 (CH), 128.9 (CH), 128.4 (CH), 128.2 (CH), 122.2, 115.7 (CH), 114.9, 30.1 (CH_3). MS (ESI) m/z: 314.1 $[M + H]^+$ (calcd for $C_{16}H_{13}BrNO^+$ 314.0).

3-Phenylquinolin-2(1H)-one **(5e)**

White solid, mp 226-227 °C (EtOAc) [lit.,[31] 228-230 °C]. IR (KBr) ν(cm^{-1}): 3428 (-NH), 1635 (C=O), 1610, 1464, 1454 (Ar-), 1120, 1028. ^{1}H NMR (400 MHz, DMSO) δ: 11.96 (s, 1H), 8.10 (s, 1H), 7.77-7.72 (m, 3H), 7.50 (td, J_{H-H} = 8.3 Hz, J_{H-H} = 1.2 Hz, 1H), 7.45-7.41 (m, 2H), 7.40 (d, J_{H-H} = 7.3 Hz, 1H), 7.34 (d, J_{H-H} = 8.1 Hz, 1H), 7.20 (td, J_{H-H} = 7.9 Hz, J_{H-H} = 0.8 Hz, 1H). ^{13}C NMR (100 MHz, DMSO) δ: 161.5, 138.8, 138.0 (CH), 136.7, 131.9, 130.6 (CH), 129.1 (CH), 128.6 (CH), 128.4 (CH), 128.3 (CH), 122.3 (CH), 120.0, 115.1 (CH). MS (ESI) m/z: 222.3 $[M + H]^+$ (calcd for $C_{15}H_{12}NO^+$ 222.1).

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Graphic Abstract

$KMnO_4$/AcOH-mediated C3-selective direct arylation of coumarins with arylboronic acids

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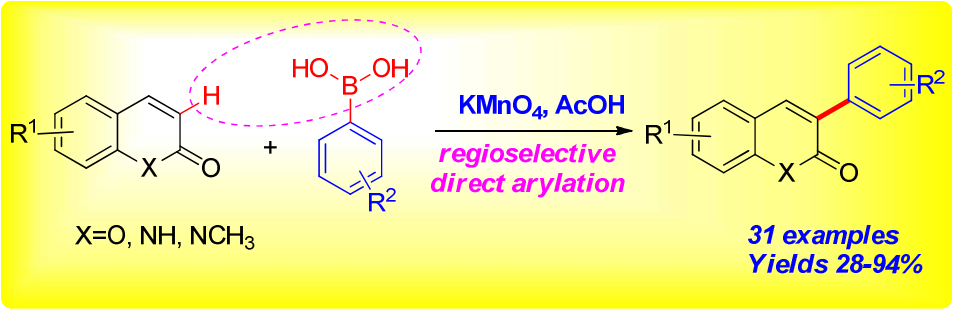

An efficient protocol for $KMnO_4$/AcOH-mediated *C*3-direct radical arylation of coumarins with arylboronic acids to afford 3-arylcoumarin derivatives is described.