Synthesis D. Wang et al. Paper

Transition-Metal-Free One-Pot Tandem Synthesis of 4-Quinolone and 4*H*-Thiochromen-4-one Derivatives Through Sequential Nucleophilic Addition–Elimination–S_NAr Reaction

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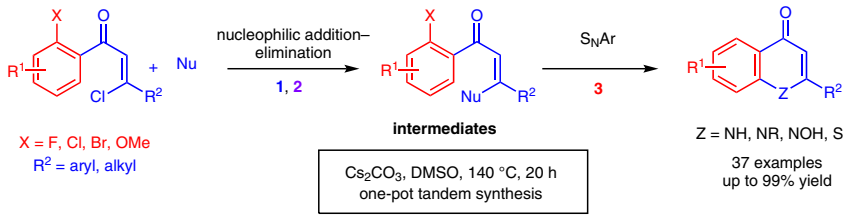

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Abstract 4-Quinolone and 4*H*-thiochromen-4-one derivatives are readily synthesized in a tandem one-pot manner in good to excellent yields. Starting from (*Z*)-β-chlorovinyl ketones, an intermolecular nucleophilic addition of amines or sodium hydrogen sulfide to (*Z*)-β-chlorovinyl ketones was followed by elimination of chlorine anion to give *Z*-enamine or thioenol intermediates, which can be transformed to 4-quinolone or 4*H*-thiochromen-4-one products through intramolecular S_NAr reaction, respectively.

Key words quinolones, 4*H*-thiochromen-4-ones, nucleophilic addition, elimination, S_NAr, tandem synthesis, transition-metal-free

Nitrogen-containing heterocycles are frequently found in a variety of biologically active molecules that can be used in therapeutic areas.[1] Specifically, 4-quinolone derivatives have attracted considerable attention from organic and medicinal chemists due to their diverse biological activity. Several quinolone compounds, such as oxolinic acid, ciprofloxacin, pefloxacin, and ofloxacin, have emerged as potent antibiotics (Figure 1).[2] More recently, certain 4-quinolone derivatives have been explored as potent drug candidates as antibacterial,[3] antitumor,[4] antimalarial,[5] antidiabetic,[6] antiviral,[7] and HIV-1 integrase inhibitors.[8]

Given the importance of these heterocycles in medical chemistry, the development of synthetic methodology to access 4-quinolone derivatives is continually imperative. To date, numerous methods have been reported for the synthesis of quinolones.[9] The most frequently used approaches are based on various cyclocondensation strategies, such as the Camps,[10] Conrad–Limpach,[11] Gould–Jacobs,[12] and Niementowski cyclization.[13] Often these synthetic methods are typically carried out under extremely harsh conditions,

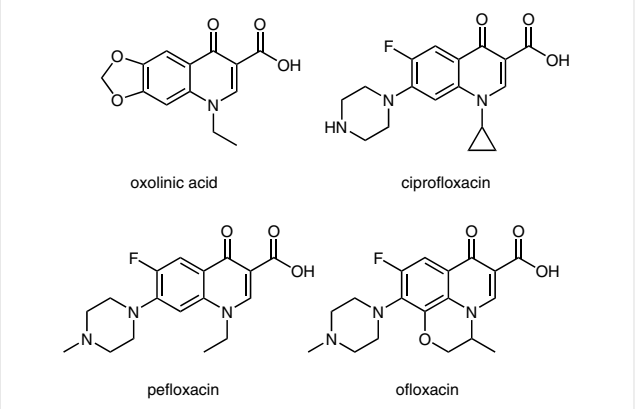
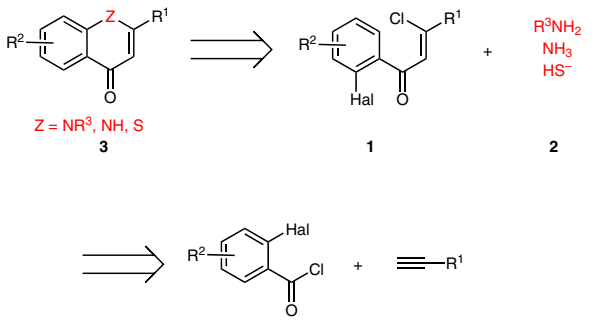


Figure 1 Representative potent antibiotics containing the 4-quinolone moiety

including temperatures of 250 °C or strong acids such as polyphosphoric acid or Eaton's reagent. As a result, the required harsh conditions dramatically limit the substrate scope of these transformations. To develop more milder and novel processes for the construction of the 4-quinolone frameworks, much effort has been focused on the development of transition-metal-catalyzed (such as Pd,[14] Cu,[15] and Au[16]) cyclization methodologies in the past decade. Despite significant progress, transition-metal-catalyzed synthetic methods are expensive and often require specially designed ligands. Another disadvantage is the need to remove metal-related impurities from products, an important issue in the synthesis of pharmaceutical molecules. Transition-metal-free C–N bond formation[17] is also known to occur either by nucleophilic aromatic substitutions[18] or aryne-type intermediates[19] in the presence of a base.

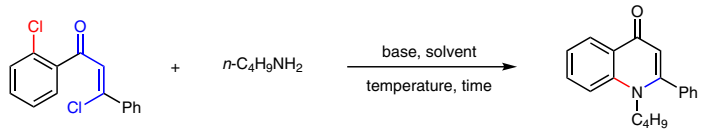


Scheme 1 Retrosynthetic analysis of 4-quinolones and 4*H*-thiochromen-4-ones

As part of our continuing effort to construct heterocycles via transition-metal-catalyzed[20] or base-mediated[21] reactions, we set out to design an efficient base-promoted one-pot tandem synthesis of substituted 4-quinolone and 4*H*-thiochromen-4-one derivatives. Retrosynthetically, the formation of 4-quinolones or 4*H*-thiochromen-4-ones **3** in a one-pot metal-free manner can be perceived through sequential nucleophilic addition–elimination–S_NAr reaction of various nucleophiles **2** (amine, ammonium hydroxide, hydroxylamine, and hydrosulfide) to (*Z*)-β-chlorovinyl aromatic ketones **1** in the presence of base (Scheme 1). These (*Z*)-β-chlorovinyl aromatic ketones, valuable synthetic intermediates for the synthesis of various heterocyclic compounds,[22] are easily accessible by iron-catalyzed regio- and stereoselective addition of acid chlorides to alkynes.[23]

On the basis of our previous work in palladium-catalyzed reactions,[14j] we envisioned that target molecules could be obtained through base-promoted intramolecular aromatic nucleophilic substitution of the enamine intermediates formed in situ with aryl halides. To explore this proposed process, (*Z*)-β-chlorovinyl aromatic ketone **1a** and *n*-butylamine (**2a**) were chosen as model substrates. As shown in Table 1, the reaction of **1a** and **2a** provided the desired product **3aa** in 97% yield in the presence of Cs_2CO_3 in

Table 1 Optimization of One-Pot Tandem Reaction Conditions[a]



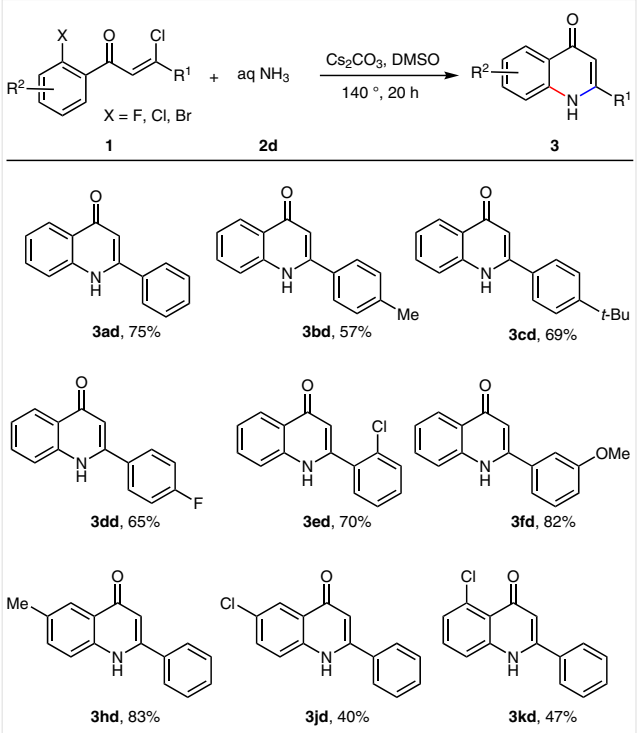
Entry	Base	Solvent	Temp (°C)	Time (h)	Yield (%)[b]
1	Cs_2CO_3	DMSO	140	20	97
2	$NaHCO_3$	DMSO	140	20	7
3	Na_2CO_3	DMSO	140	20	9
4	K_2CO_3	DMSO	140	20	13
5	KOH	DMSO	140	20	31
6	K_3PO_4	DMSO	140	20	37
7	NaO*t*-Bu	DMSO	140	20	41
8	KO*t*-Bu	DMSO	140	20	72
9	NaOH	DMSO	140	20	85
10	Cs_2CO_3	DMSO	80	20	12
11	Cs_2CO_3	DMSO	100	20	33
12	Cs_2CO_3	DMSO	120	20	44
13	Cs_2CO_3	DMSO	140	8	72
14	Cs_2CO_3	DMSO	140	12	81
15	Cs_2CO_3	DMSO	140	24	96
16	Cs_2CO_3	DMF	140	20	93
17	Cs_2CO_3	DMA	140	20	95
18	Cs_2CO_3	toluene	140	20	36
19	Cs_2CO_3	1,4-dioxane	140	20	25
20	Cs_2CO_3	THF	110	20	trace

[a] Reaction conditions: **1a** (0.2 mmol, 1.0 equiv), *n*-$BuNH_2$ (**2a**; 0.24 mmol, 1.2 equiv), base (2 equiv), solvent (2 mL).
[b] Yield of isolated product after chromatography.

DMSO at 140 °C for 20 hours (Table 1, entry 1). Among the other bases examined, KO*t*-Bu (entry 8) and NaOH (entry 9) were proved to be the most efficient bases, providing the corresponding product in 72% and 85% yield, respectively. However, $NaHCO_3$, Na_2CO_3, K_2CO_3, KOH, K_3PO_4, and NaO*t*-Bu gave diminished yields from 7% to 41% (entries 2–7). A set of experiments were then carried out to reveal the crucial role of the reaction temperature (entries 1, 10–12). The results showed that with the increase of reaction temperature, much higher yields were obtained for this process (97% vs 44% at 140 °C and 120 °C, entries 1 and 12). Investigation of the effect of time on the reaction showed that higher yields can be obtained by prolonging the reaction time from 8 to 24 hours (entries 13–15). A survey of reaction media showed that the use of polar solvents such as DMSO, DMF, and DMA provided better results than those obtained in toluene, 1,4-dioxane, and THF (entries 1, 16–20). In addition, it is worth noting that the reaction can be carried out on a 1.0 mmol scale without compromising the yield. The microwave-assisted tandem cyclization provided the corresponding product **3aa** in 85% yield within 30 minutes at 140 °C.

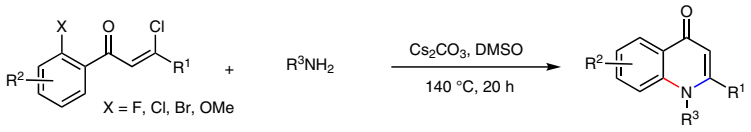
With the optimized reaction conditions in hand, we then explored the scope and generality of this one-pot tandem reaction. In general, the optimized reaction conditions (Cs_2CO_3/DMSO) were broadly applicable and tolerated a wide variety of substitution patterns and functionalities (including Me, *t*-Bu, MeO, F, and Cl). Using *n*-butylamine (**2a**) as the nucleophilic reagent, the scope of (*Z*)-β-chlorovinyl aromatic ketones was examined first. As revealed in Table 2, a wide array of ketone substrates **1a–k** was amenable to the protocol, delivering *N*-butyl-4-quinolone derivatives **3aa–ka** in good to excellent yields. For substituent R^1, substrates containing either electron-donating (Table 2, entries 2, 3, and 6) or electron-withdrawing groups (entries 4 and 5), or bearing *para*- (entries 2–4), *ortho*- (entry 5), or *meta*-substituents (entry 6) on the aryl ring can be smoothly converted into the corresponding products in excellent yields. In addition, this method was compatible with substrates substituted with alkyl groups (entry 7). The influence of the *ortho*-substituted halogen on the aromatic ketone moiety was then investigated. All the substrates, with different halogen substituents such as F, Cl, and Br, smoothly underwent the cyclization to afford the desired product in high to excellent yields (entries 1–11). Furthermore, dihalo-substituted ketone substrate **1k** afforded the corresponding quinolones **3ka** in 83% yield with competitive reactions specifically occurring on the fluorine atom (entry 11). The cleavage of aromatic C–O bond from alkyl aryl ether substrate **1n** was investigated, which gave the corresponding cyclized product in 81% yield (entry 12). For substituent R^2, 2-bromo aromatic ketones containing either electron-donating groups (entries 8 and 9) or an electron-withdrawing group (entry 10) at the *para*-position can also be transformed into the desired products **3ha–ja**. Unlike R^1, R^2 has much impact on the outcomes of the reaction, with electron rich aromatics providing higher yields than its electron-poor analogues (entries 8–10). π-Deficient heterocyclic substrate **1o** is also examined, the corresponding product **3oa** can be obtained in high yield (93%, entry 13). Additionally, **1a** can be smoothly converted into the desired products with other aliphatic amine $MeNH_2{\cdot}H_2O$ (**2b**) (entry 14), aniline (**2c**) (entry 15), and hydroxylamine hydrochloride (**2f**) (entry 16) in 78%, 64%, and 34% yield, respectively.

We then demonstrated the ability of ammonium hydroxide as the nucleophile to undergo base-mediated sequential Michael addition–elimination–S_NAr reaction to form 4-quinolones. Gratifyingly, a variety of substituents (such as Me, *t*-Bu, MeO, F, and Cl) on the substrates **1** were tolerated and this one-pot tandem protocol was applicable to the synthesis of N-unsubstituted-4-quinolone derivatives **3ad–kd** in 40–83% yields (Scheme 2). Similarly, the substrates with different halogen leaving groups can be smoothly transformed to the desired products (**3ad–fd**, X = Cl; **3hd** and **3jd**, X = Br, **3kd**, X = F). Dihalo-substituted substrate **1k** afforded the cyclized product **3kd** in 47% yield with S_NAr specifically occurring on the fluorine atom.



Scheme 2 Tandem synthesis of N-unsubstituted-4-quinolone derivatives. *Reagents and conditions*: **1** (0.2 mmol), NH_4OH (**2d**; 1.0 mmol), Cs_2CO_3 (0.4 mmol), DMSO (2 mL), 140 °C, 20 h; yield of isolated product after chromatography is shown.

Table 2 One-Pot Synthesis of N-Substituted-4-quinolone Derivatives[a]



1 2 3

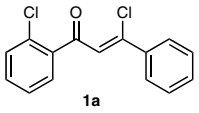
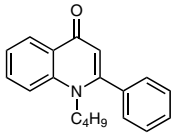
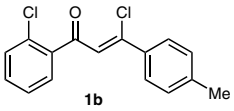
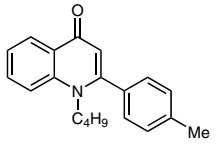
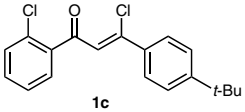
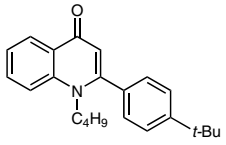
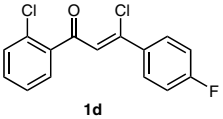
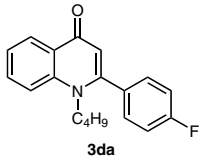
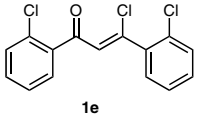
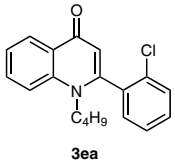
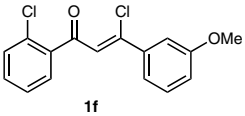
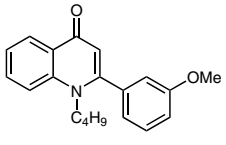
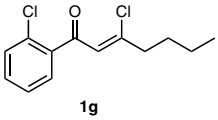
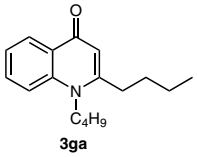
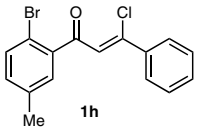
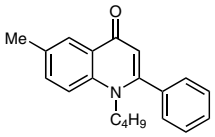
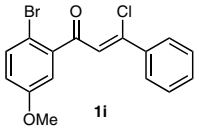
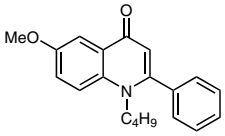
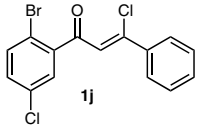
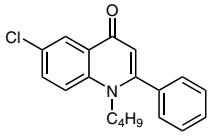
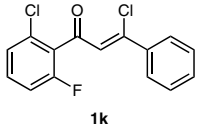
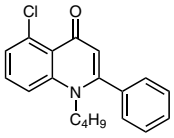
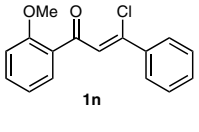
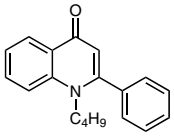
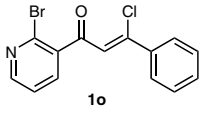
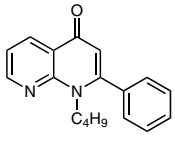
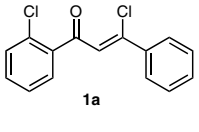
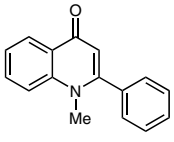
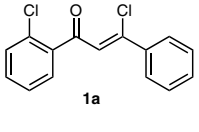
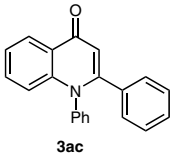
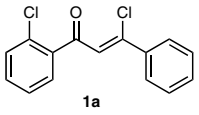
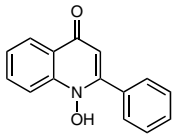
Entry	Substrate **1**	Amine **2**	Product **3**	Yield (%)[b]
1	 **1a**	$C_4H_9NH_2$ **2a**	 **3aa**	97
2	 **1b**	$C_4H_9NH_2$ **2a**	 **3ba**	96
3	 **1c**	$C_4H_9NH_2$ **2a**	 **3ca**	97
4	 **1d**	$C_4H_9NH_2$ **2a**	 **3da**	61
5	 **1e**	$C_4H_9NH_2$ **2a**	 **3ea**	85
6	 **1f**	$C_4H_9NH_2$ **2a**	 **3fa**	73
7	 **1g**	$C_4H_9NH_2$ **2a**	 **3ga**	74

Table 2 (continued)

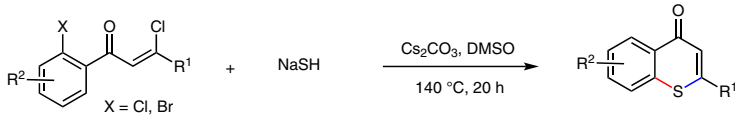
Entry	Substrate **1**	Amine **2**	Product **3**	Yield (%)[b]
8	 **1h**	$C_4H_9NH_2$ **2a**	 **3ha**	99
9	 **1i**	$C_4H_9NH_2$ **2a**	 **3ia**	70
10	 **1j**	$C_4H_9NH_2$ **2a**	 **3ja**	58
11	 **1k**	$C_4H_9NH_2$ **2a**	 **3ka**	83
12	 **1n**	$C_4H_9NH_2$ **2a**	 **3na (3aa)**	81
13	 **1o**	$C_4H_9NH_2$ **2a**	 **3oa**	93
14[c]	 **1a**	$MeNH_2$ **2b**	 **3ab**	78
15	 **1a**	$PhNH_2$ **2c**	 **3ac**	64

Entry	Substrate **1**	Amine **2**	Product **3**	Yield (%)[b]
16[d]	 **1a**	$NH_2OH·HCl$ **2f**	 **3af**	34

[a] Reaction conditions: **1** (0.2 mmol), amine **2** (0.24 mmol), Cs_2CO_3 (0.4 mmol), DMSO (2 mL), 140 °C, 20 h.
[b] Yield of isolated product after chromatography.
[c] $MeNH_2·H_2O$ was used.
[d] The starting material **1a** was recovered in 40% yield.

4*H*-Thiochromen-4-one can be regarded as the thio homologue of the core constituent of 4-quinolones and flavones. Such frameworks are as well potential drug candidates as antibacterial,[24] antibiotic,[25] antimicrobial and antifungal,[26] and anticarcinogenic agents[27] and serve as building blocks for the synthesis of biological active molecules. Consequently, the construction of this valuable structural unit has received considerable attention.[28] Finally, when the scope of nucleophile reagent was extended to sodium hydrogen sulfide, a variety of diversely substituted 4*H*-thiochromen-4-one derivatives can also be smoothly obtained in good yields under the optimized conditions (Table 3). For the olefin-linked aryl moiety, the electronic nature of the aromatic motifs did not seem to affect the efficiency of this transformation, both electron-donating (Table 3, entries 3–5, and 7) and electron-withdrawing (entries 6, 8, and 9) substituents can be incorporated at the *para*-, *meta*-, and *ortho*-position (48–95% yields). Additionally, substrate **1g** substituted with an alkyl group can smoothly undergo sequential nucleophilic addition–elimination–cyclization to afford the desired product in 69% yield (entry 10). For the ketone-linked aryl moiety, substrate **1h** with an electron-donating group provided much higher yield than **1j** with an electron-withdrawing group (97% vs 33%, entries 11 and 12).

Table 3 Tandem Synthesis of 4*H*-Thiochromen-4-one Derivatives[a]



1 **2e** **3**

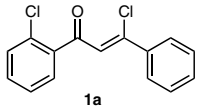
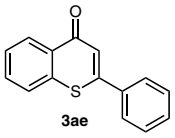
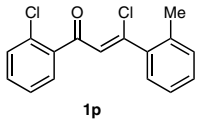
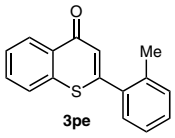
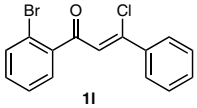
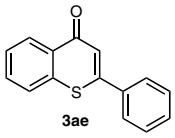
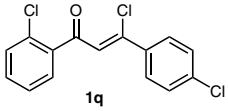
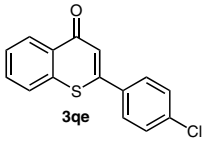
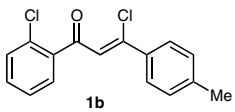
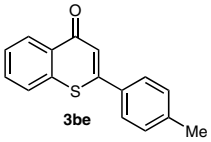
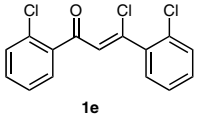
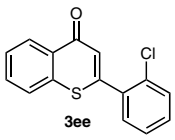
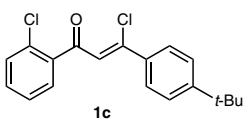
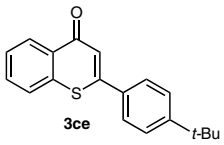
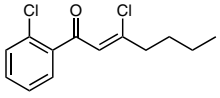
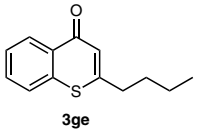
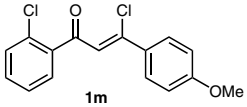
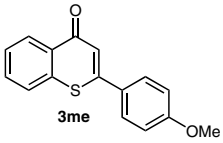
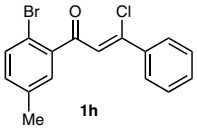
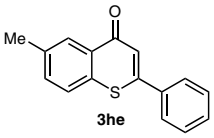
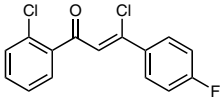
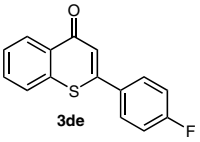
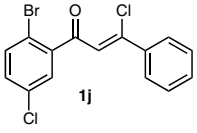
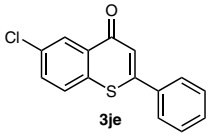
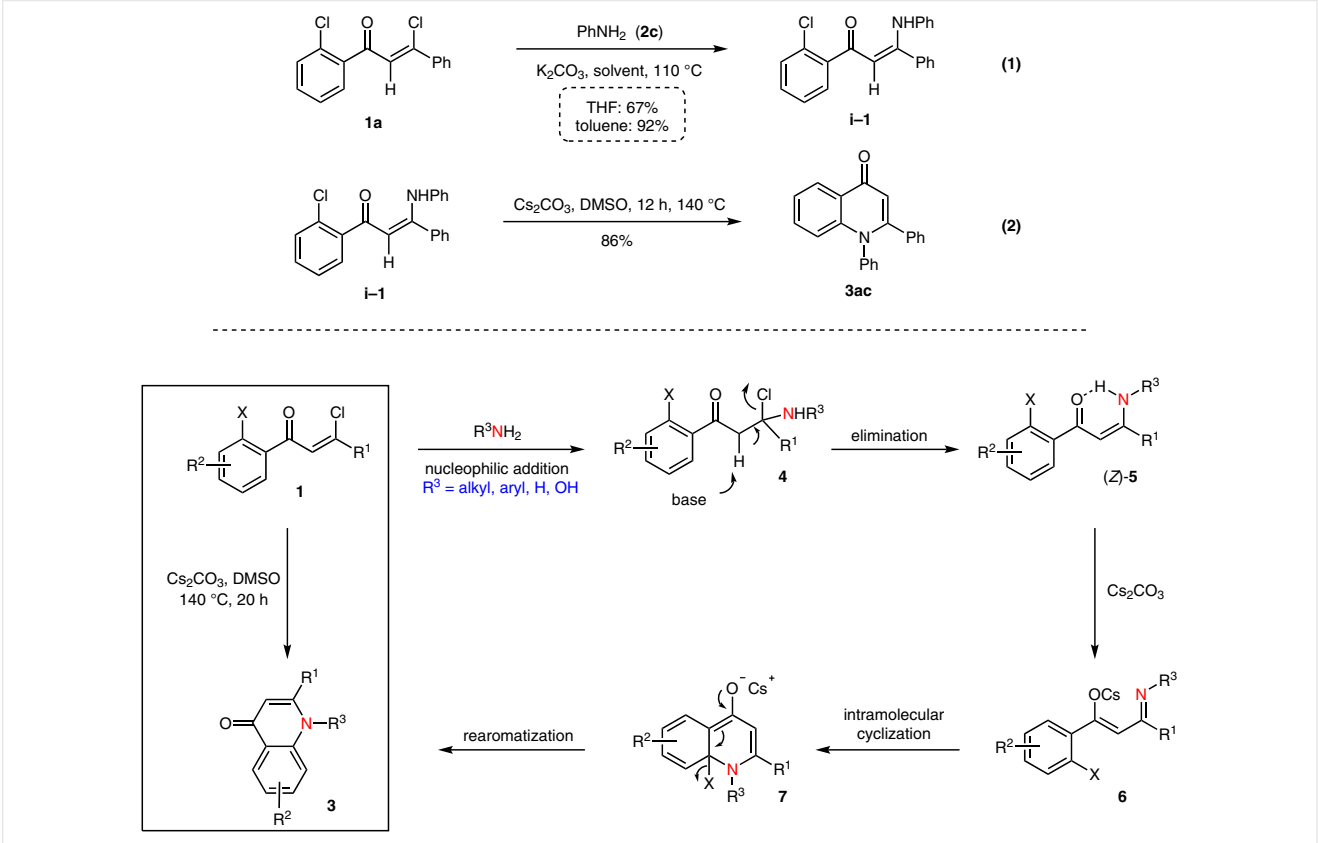
Entry	Substrates **1**	Products **3**	Yield (%)[b]	Entry	Substrates **1**	Products **3**	Yield (%)[b]
1	 **1a**	 **3ae**	46	7	 **1p**	 **3pe**	86
2	 **1l**	 **3ae**	95	8	 **1q**	 **3qe**	75
3	 **1b**	 **3be**	78	9	 **1e**	 **3ee**	95

Table 3 (continued)

Entry	Substrates **1**	Products **3**	Yield (%)[b]	Entry	Substrates **1**	Products **3**	Yield (%)[b]
4	 **1c**	 **3ce**	81	10	 **1g**	 **3ge**	69
5	 **1m**	 **3me**	73	11	 **1h**	 **3he**	97
6	 **1d**	 **3de**	48	12	 **1j**	 **3je**	33

[a] Reaction conditions: **1** (0.2 mmol), NaSH (**2e**; 0.24 mmol), Cs_2CO_3 (0.4 mmol), DMSO (2 mL), 140 °C, 20 h.
[b] Yield of isolated product after chromatography.



Scheme 3 Proposed mechanism for sequential nucleophilic addition–elimination–S_NAr process

To gain further insight into the mechanism of the reaction, two sets of control experiments were conducted. First, the reaction of **1a** and aniline **2c** was carried out in THF and toluene using K_2CO_3 as the base, to afford the enamine intermediate **i-1** in 67% and 92% yield, respectively (Scheme 3, Eq. 1). Second, intermediate **i-1** can be efficiently transformed into 4-quinolone **3ac** in DMSO with Cs_2CO_3 as the base (Scheme 3, Eq. 2). On the basis of the above results, a proposed reaction mechanism is shown in Scheme 3. The nucleophilic addition of nucleophiles **2** to (*Z*)-β-chlorovinyl aromatic ketone **1** took place to form intermediate **4**, which underwent the elimination of halogen anion in the presence of a base to give the *Z*-enamine intermediate **5**.[14j] Subsequently, enolization of the carbonyl group in **5** formed imine intermediate **6** in the presence of Cs_2CO_3 and the species **7** was generated via intramolecular cyclization of **6**. Finally, rearomatization of **7** by elimination of CsX provided the target product **3**.[29]

In conclusion, we have developed an efficient protocol for the one-pot tandem synthesis of 4-quinolone and 4*H*-thiochromen-4-one derivatives in good to excellent yields. The process is based on intermolecular nucleophilic addition of nucleophiles to (*Z*)-β-chlorovinyl aromatic ketones and subsequent elimination of chlorine anion to give *Z*-enamines or thioenol intermediates, completed by base-promoted intramolecular nucleophilic aromatic substitution. The success of the reaction heavily relies on the careful selection of proper base and solvent. The use of Cs_2CO_3 as the base in polar solvents was found to be essential for the efficient formation of products. The result presented here should be of considerable interest for valuable synthetic drugs for medicinal chemistry.

All chemicals were purchased from commercial supplies and used without further purification, unless otherwise stated. Solvents were dried and purified according to the standard procedures before use. (*Z*)-β-Chlorovinyl aromatic ketones were prepared from the corresponding acid chlorides and alkynes according the literature methods.[23] All reactions were carried out in dried glassware, and monitored by TLC. Yields refer to isolated yields of compounds. Melting points were determined on a melting point apparatus in open capillaries and are uncorrected. ^{1}H NMR spectra were recorded on a Bruker 400 or 600 MHz spectrometer and ^{13}C NMR spectra were recorded at 100 or 150 MHz. Unless otherwise stated $CDCl_3$ and DMSO-d_6 were used as solvent. Chemical shifts (δ) are given in parts per million (ppm) downfield relative to $CDCl_3$ (^{1}H NMR: $CDCl_3$ at 7.26 ppm; ^{13}C NMR: $CDCl_3$ at 77.2 ppm) and DMSO-d_6 (^{1}H NMR: DMSO-d_6 at 2.50 ppm; ^{13}C NMR: DMSO-d_6 at 39.5 ppm). Standard abbreviations are used to report splitting patterns. Coupling constants are given in hertz (Hz). High-resolution mass spectra were recorded on a Bruker BIO TOF Q mass spectrometer.

Intermediate (*Z*)-1-(2-Chlorophenyl)-3-phenyl-3-(phenylamino)prop-2-en-1-one (i-1)[14j]

A 10 mL Schlenk tube equipped with a magnetic stirring bar was charged with (*Z*)-3-chloro-1-(2-chlorophenyl)-3-phenylprop-2-en-1-one (**1a**; 0.4 mmol, 1.0 equiv), aniline (**2c**; 0.48 mmol, 1.2 equiv), and K_2CO_3 (110.4 mg, 0.8 mmol, 2.0 equiv), then toluene or THF (4.0 mL) was added via syringe at r.t. The tube was sealed and kept in a preheated oil bath at 110 °C for 12 h. Finally, the mixture was cooled to r.t., quenched with H_2O (5 mL), and diluted with EtOAc (10 mL). The layers were separated and the aqueous layer was extracted with EtOAc (2 × 5 mL). The combined organic extracts were dried (anhyd Na_2SO_4), filtered, and concentrated in vacuo. The crude product was then purified by flash chromatography on silica gel (Type H), eluting with EtOAc/PE (1:20); white solid; yield: 122.5 mg (92%); mp 122–124 °C.

^{1}H NMR ($CDCl_3$, 400 MHz): δ = 12.65 (s, 1 H), 7.59–7.56 (m, 1 H), 7.43–7.29 (m, 8 H), 7.14 (t, *J* = 8.0 Hz, 2 H), 7.01 (t, *J* = 7.2 Hz, 1 H), 6.82 (d, *J* = 7.6 Hz, 2 H), 5.79 (s, 1 H).

^{13}C NMR ($CDCl_3$, 100 MHz): δ = 190.7, 161.4, 140.9, 139.2, 135.3, 131.0, 130.5, 130.3, 129.9, 129.5, 128.8, 128.6, 128.5, 126.8, 124.5, 123.5, 100.9.

4-Quinolones and 4*H*-Thiochromen-4-ones 3; General Procedure

A 10 mL Schlenk tube equipped with a magnetic stirring bar was charged with β-chlorovinyl aromatic ketone **1** (0.2 mmol, 1.0 equiv), amine **2** (0.24 mmol, 1.2 equiv) or ammonia (**2e**; 1.0 mmol, 5.0 equiv) or NaHS (**2e**; 0.24 mmol, 1.2 equiv), and Cs_2CO_3 (130.4 mg, 0.4 mmol, 2.0 equiv), then DMSO (2.0 mL) was added via syringe at r.t. The tube was sealed and kept in a preheated oil bath at 140 °C for 20 h. Finally, the mixture was cooled to r.t., quenched with H_2O (5 mL), and diluted with EtOAc (10 mL). The layers were separated and the aqueous layer was extracted with EtOAc (2 × 5 mL). The combined organic extracts were dried (anhyd Na_2SO_4), filtered, and concentrated in vacuo. The crude product was then purified by flash chromatography on silica gel (Type H), eluting with 20–60% EtOAc/PE.

1-Butyl-2-phenylquinolin-4(1*H*)-one (3aa)[14j,15b]

Light yellow solid; yield: 53.7 mg (97%); mp 73–75 °C

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.52 (d, *J* = 8.0 Hz, 1 H), 7.69 (t, *J* = 7.8 Hz, 1 H), 7.55–7.50 (m, 4 H), 7.42–7.39 (m, 3 H), 6.24 (s, 1 H), 4.01 (t, *J* = 8.0 Hz, 2 H), 1.69–1.62 (m, 2 H), 1.20–1.11 (m, 2 H), 0.76 (t, *J* = 8.0 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 177.3, 154.5, 140.6, 136.1, 132.1, 129.4, 128.7, 128.3, 127.4, 127.1, 123.5, 116.3, 112.9, 47.9, 30.8, 19.7, 13.4.

1-Butyl-2-(*p*-tolyl)quinolin-4(1*H*)-one (3ba)[14j]

Yellow solid; yield: 55.9 mg (96%); mp 85–87 °C.

^{1}H NMR (600 MHz, $CDCl_3$): δ = 8.51 (d, *J* = 7.7 Hz, 1 H), 7.68 (t, *J* = 7.2 Hz, 1 H), 7.55 (d, *J* = 8.5 Hz, 1 H), 7.38 (t, *J* = 6.6 Hz, 1 H), 7.33–7.27 (m, 4 H), 6.23 (s, 1 H), 4.03 (t, *J* = 7.8 Hz, 2 H), 2.44 (s, 3 H), 1.64 (br, 2 H), 1.17–1.14 (m, 2 H), 0.77 (t, *J* = 6.9 Hz, 3 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 177.3, 154.8, 140.6, 139.4, 133.2, 132.1, 129.4, 128.2, 127.3, 126.9, 123.4, 116.4, 112.9, 47.9, 30.8, 21.4, 19.7, 13.5.

1-Butyl-2-[4-(*tert*-butyl)phenyl]quinolin-4(1*H*)-one (3ca)

Light yellow solid; yield: 64.6 mg (97%); mp 140–142 °C.

IR (KBr): 2956, 1624, 1597, 1484, 1421, 1179, 843, 763 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.51 (d, *J* = 8.0 Hz, 1 H), 7.70–7.65 (m, 1 H), 7.55–7.48 (m, 3 H), 7.38 (t, *J* = 7.4 Hz, 1 H), 7.32 (d, *J* = 7.2 Hz, 2 H), 6.24 (s, 1 H), 4.04 (t, *J* = 8.0 Hz, 2 H), 1.69–1.61 (m, 2 H), 1.38 (s, 9 H), 1.20–1.11 (m, 2 H), 0.73 (t, *J* = 7.2 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 177.4, 154.8, 152.6, 140.7, 133.1, 132.0, 128.1, 127.4, 127.0, 125.6, 123.4, 116.3, 112.9, 47.8, 34.8, 31.3, 30.7, 19.6, 13.3.

ESI-MS: *m*/*z* = 333 [M$^+$], 334 [M + 1]$^+$.

HRMS-ESI: *m*/*z* [M + Na]$^+$ calcd for $C_{23}H_{27}NONa$: 356.1990; found: 356.1952.

1-Butyl-2-(4-fluorophenyl)quinolin-4(1*H*)-one (3da)[9h,14j]

Yellow solid; yield: 36 mg (61%); mp 98–100 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.50 (d, *J* = 8.0 Hz, 1 H), 7.69 (t, *J* = 7.8 Hz, 1 H), 7.54 (d, *J* = 8.7 Hz, 1 H), 7.43–7.16 (m, 5 H), 6.20 (s, 1 H), 4.01 (t, *J* = 8.0 Hz, 2 H), 1.68–1.61 (m, 2 H), 1.22–1.13 (m, 2 H), 0.78 (t, *J* = 7.3 Hz, 3 H).

^{13}C NMR ($CDCl_3$, 100 MHz): δ = 177.3, 163.2 (d, $^1J_{C,F}$ = 249 Hz), 153.5, 140.6, 132.3, 132.1 (d, $^4J_{C,F}$ = 3.0 Hz), 130.3 (d, $^3J_{C,F}$ = 8.0 Hz), 127.4, 127.1, 123.7, 116.2, 115.9 (d, $^2J_{C,F}$ = 22.0 Hz), 113.1, 47.9, 30.8, 19.7, 13.4.

1-Butyl-2-(2-chlorophenyl)quinolin-4(1*H*)-one (3ea)[9h,14j]

White solid; yield: 52.9 mg (85%); mp 141–143 °C.

^{1}H NMR (600 MHz, $CDCl_3$): δ = 8.53 (d, *J* = 7.9 Hz, 1 H), 7.71 (t, *J* = 7.9 Hz, 1 H), 7.55–7.52 (m, 2 H), 7.47 (t, *J* = 7.2 Hz, 1 H), 7.44–7.40 (m, 3 H), 6.19 (s, 1 H), 4.14–4.07 (m, 1 H), 3.78–3.73 (m, 1 H), 1.79–1.71 (m, 1 H), 1.56–1.49 (m, 1 H), 1.22–1.11 (m, 2 H), 0.75 (t, *J* = 7.3 Hz, 3 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 177.6, 151.2, 140.4, 134.8, 132.9, 132.3, 131.0, 130.6, 129.9, 127.4, 127.2, 127.1, 123.6, 116.2, 112.8, 47.7, 30.4, 19.7, 13.4.

1-Butyl-2-(3-methoxyphenyl)quinolin-4(1*H*)-one (3fa)[14j]

Yellow solid; yield: 44.8 mg (73%); mp 97–99 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.52 (d, *J* = 8.0 Hz, 1 H), 7.69 (t, *J* = 7.7 Hz, 1 H), 7.54 (d, *J* = 8.7 Hz, 1 H), 7.40 (t, *J* = 7.8 Hz, 2 H), 7.04–6.92 (m, 3 H), 6.25 (s, 1 H), 4.03 (t, *J* = 8.0 Hz, 2 H), 3.86 (s, 3 H), 1.72–1.64 (m, 2 H), 1.21–1.15 (m, 2 H), 0.79 (t, *J* = 7.2 Hz, 3 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 177.4, 159.6, 154.4, 140.6, 137.2, 132.2, 129.9, 127.4, 127.1, 123.6, 120.6, 116.3, 114.9, 114.0, 112.6, 55.5, 48.0, 30.9, 19.7, 13.5.

1,2-Dibutylquinolin-4(1*H*)-one (3ga)[14j]

Yellow solid; yield: 38 mg (74%); mp 91–9 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.46 (d, *J* = 8.0 Hz, 1 H), 7.64 (t, *J* = 7.8 Hz, 1 H), 7.49 (d, *J* = 8.7 Hz, 1 H), 7.34 (t, *J* = 7.4 Hz, 1 H), 6.27 (s, 1 H), 4.13 (t, *J* = 8.0 Hz, 2 H), 2.69 (t, *J* = 7.7 Hz, 2 H), 1.82–1.65 (m, 4 H), 1.54–1.44 (m, 4 H), 1.06–0.96 (m, 6 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 177.7, 154.6, 140.8, 132.0, 126.9, 126.8, 123.2, 115.6, 110.9, 46.0, 33.6, 31.0, 30.9, 22.5, 20.0, 13.8, 13.7.

1-Butyl-6-methyl-2-phenylquinolin-4(1*H*)-one (3ha)[14j]

Light yellow solid; yield: 57.6 mg (99%); mp 110–112 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.31 (s, 1 H), 7.54–7.42 (m, 5 H), 7.42–7.35 (m, 2 H), 6.21 (s, 1 H), 4.00 (t, *J* = 8.0 Hz, 2 H), 2.48 (s, 3 H), 1.67–1.60 (m, 2 H), 1.19–1.10 (m, 2 H), 0.75 (t, *J* = 7.3 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 177.2, 154.2, 138.7, 136.2, 133.6, 133.4, 129.3, 128.7, 128.3, 127.3, 126.3, 116.2, 112.6, 47.9, 30.8, 20.8, 19.7, 13.4.

1-Butyl-6-methoxy-2-phenylquinolin-4(1*H*)-one (3ia)[14j]

Yellow solid; yield: 43 mg (70%); mp 108–111 °C.

^{1}H NMR (600 MHz, $CDCl_3$): δ = 7.91 (s, 1 H), 7.50–7.49 (m, 4 H), 7.40–7.39 (m, 2 H), 7.32 (d, *J* = 8.9 Hz, 1 H), 6.23 (s, 1 H), 4.02 (t, *J* = 7.8 Hz, 2 H), 3.96 (s, 3 H), 1.69–1.60 (m, 2 H), 1.17–1.11 (m, 2 H), 0.75 (t, *J* = 7.2 Hz, 3 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 176.7, 156.1, 153.7, 136.1, 135.2, 129.4, 128.7, 128.6, 128.4, 122.9, 118.1, 111.9, 105.8, 55.9, 48.1, 31.0, 19.7, 13.4.

1-Butyl-6-chloro-2-phenylquinolin-4(1*H*)-one (3ja)[14j]

Yellow solid; yield: 36 mg (58%); mp 87–89 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.46 (s, 1 H), 7.61 (d, *J* = 8.0 Hz, 1 H), 7.51–7.47 (m, 4 H), 7.40–7.38 (m, 2 H), 6.22 (s, 1 H), 4.00 (t, *J* = 8.0 Hz, 2 H), 1.67–1.59 (m, 2 H), 1.19–1.10 (m, 2 H), 0.76 (t, *J* = 7.2 Hz, 3 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 176.1, 154.8, 139.0, 135.7, 132.4, 129.8, 129.6, 128.8, 128.4, 128.3, 126.3, 118.2, 113.1, 48.2, 30.7, 19.6, 13.4.

1-Butyl-5-chloro-2-phenylquinolin-4(1*H*)-one (3ka)

Yellow solid; yield: 49 mg (83%); mp 164–166 °C.

IR (KBr): 2958, 2929, 1624, 1590, 1465, 1397, 1066 cm^{-1}.

^{1}H NMR (600 MHz, $CDCl_3$): δ = 7.52–7.49 (m, 4 H), 7.44 (d, *J* = 8.0 Hz, 1 H), 7.41–7.37 (m, 2 H), 7.35 (d, *J* = 7.6 Hz, 1 H), 6.21 (s, 1 H), 3.98 (t, *J* = 8.0 Hz, 2 H), 1.64–1.59 (m, 2 H), 1.16–1.08 (m, 2 H), 0.74 (t, *J* = 7.4 Hz, 3 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 176.9, 153.4, 143.2, 135.6, 134.9, 131.1, 129.5, 128.8, 128.3, 126.6, 124.0, 115.4, 115.1, 48.7, 30.4, 19.6, 13.4.

ESI-MS: *m*/*z* = 311 [M$^+$], 312 [M + 1]$^+$.

HRMS-ESI: *m*/*z* [M + Na]$^+$ calcd for $C_{19}H_{18}ClNONa$: 334.0975; found: 334.0987.

1-Butyl-2-phenyl-1,8-naphthyridin-4(1*H*)-one (3oa)

Yellow solid; yield: 51.7 mg (93%); mp 112–113 °C.

IR (KBr): 3056, 2960, 1639, 1592, 1489, 1412, 1257, 708 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.76–8.73 (m, 2 H), 7.57–7.46 (m, 3 H), 7.46–7.37 (m, 2 H), 7.46–7.38 (m, 2 H), 7.34 (dd, *J* = 7.7, 4.6 Hz, 1 H), 6.26 (s, 1 H), 4.29 (t, *J* = 7.2 Hz, 2 H), 1.79–1.36 (m, 2 H), 1.31–0.95 (m, 2 H), 0.71 (t, *J* = 7.4 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 177.6, 155.4, 152.1, 150.6, 135.7, 135.6, 129.5, 128.6, 128.3, 121.6, 119.6, 113.5, 46.5, 31.5, 19.7, 13.4.

ESI-MS: *m*/*z* = 278 [M$^+$], 279 [M + 1]$^+$.

HRMS-ESI: *m*/*z* [M + H]$^+$ calcd for $C_{18}H_{19}N_2O$: 279.1497; found: 279.1493.

1-Methyl-2-phenylquinolin-4(1*H*)-one (3ab)[14j,30a]

White solid; yield: 36.7 mg (78%); mp 61–63 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.50 (d, *J* = 7.0 Hz, 1 H), 7.71–7.69 (m, 1 H), 7.56–7.41 (m, 7 H), 6.29 (s, 1 H), 3.60 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 177.5, 154.7, 141.9, 135.9, 132.3, 129.6, 128.8, 128.6, 126.9, 126.7, 123.6, 116.0, 112.7, 37.3.

1,2-Diphenylquinolin-4(1*H*)-one (3ac)[14j,15b]

White solid; yield: 38 mg (64%); mp 279–281 °C.

^{1}H NMR (600 MHz, $CDCl_3$): δ = 8.51 (d, *J* = 7.9 Hz, 1 H), 7.46 (t, *J* = 7.5 Hz, 1 H), 7.37–7.31 (m, 4 H), 7.19–7.15 (m, 7 H), 6.91 (d, *J* = 8.6 Hz, 1 H), 6.44 (s, 1 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 177.9, 154.0, 142.6, 139.1, 135.7, 131.9, 130.0, 129.6, 129.2, 129.0, 128.6, 127.9, 126.2, 126.1, 123.8, 118.1, 112.5.

2-Phenylquinolin-4(1*H*)-one (3ad)[9d,15a,30b]

Light yellow solid; yield: 33 mg (75%); mp 256–258 °C.

^{1}H NMR (600 MHz, DMSO-d_6): δ = 11.79 (br, 1 H), 8.07 (d, *J* = 7.8 Hz, 1 H), 7.79–7.77 (m, 2 H), 7.74 (d, *J* = 8.3 Hz, 1 H), 7.65–7.61 (m, 1 H), 7.56–7.49 (m, 3 H), 7.30 (t, *J* = 7.2 Hz, 1 H), 6.33 (s, 1 H).

^{13}C NMR (150 MHz, DMSO-d_6): δ = 176.8, 150.3, 140.6, 134.1, 131.9, 130.5, 129.0, 127.4, 124.7, 124.6, 123.4, 118.9, 107.2.

***N*-Hydroxy-2-phenylquinolin-4(1*H*)-one (3ae)**[30c]

Light yellow solid; yield: 16.2 mg (34%); mp 226–228 °C.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 12.10 (br, 1 H), 8.12 (d, *J* = 7.9 Hz, 1 H), 7.95–7.89 (m, 3 H), 7.66 (t, *J* = 7.5 Hz, 1 H), 7.56 (br, 3 H), 7.33 (t, *J* = 7.4 Hz, 1 H), 6.41 (s, 1 H).

^{13}C NMR (151 MHz, DMSO-d_6): δ = 176.5, 150.4, 141.1, 134.4, 131.5, 130.3, 128.9, 127.5, 124.8, 124.6, 123.2, 119.4, 107.0.

2-(*p*-Tolyl)quinolin-4(1*H*)-one (3bd)[30d]

Light yellow solid; yield: 26.8 mg (57%); mp 287–289 °C.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 11.65 (s, 1 H), 8.10 (d, *J* = 7.6 Hz, 1 H), 7.79–7.73 (m, 3 H), 7.69–7.65 (m, 1 H), 7.40 (d, *J* = 8.0 Hz, 2 H), 7.34 (t, *J* = 7.4 Hz, 1 H), 6.33 (d, *J* = 1.4 Hz, 1 H), 2.41 (s, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 182.2, 155.1, 145.7, 145.6, 137.0, 136.5, 134.8, 132.5, 130.1, 129.9, 128.4, 123.9, 112.2, 26.1.

2-[4-(*tert*-Butyl)phenyl]quinolin-4(1*H*)-one (3cd)

Light yellow solid; yield: 38.2 mg (69%); mp 297–299 °C.

IR (KBr): 3435, 2924, 1635, 1498, 1048, 668 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 11.66 (s, 1 H), 8.10 (d, *J* = 8.0 Hz, 1 H), 7.76 (t, *J* = 7.5 Hz, 3 H), 7.67 (t, *J* = 7.5 Hz, 1 H), 7.62 (d, *J* = 8.2 Hz, 2 H), 7.34 (t, *J* = 7.5 Hz, 1 H), 6.33 (s, 1 H), 1.35 (s, 9 H).

^{13}C NMR (151 MHz, $CDCl_3$): δ = 182.2, 158.5, 155.2, 145.7, 136.9, 136.7, 132.6, 132.3, 131.2, 131.1, 130.9, 130.1, 112.3, 39.9, 36.2.

ESI-MS: *m*/*z* = 277 [M$^+$], 278 [M + 1]$^+$.

HRMS-ESI: *m*/*z* [M + Na]$^+$ calcd for $C_{19}H_{19}NONa$: 300.1364; found: 300.1334.

2-(4-Fluorophenyl)quinolin-4(1*H*)-one (3dd)[30d]

Light yellow solid; yield: 31.1 mg (65%); mp 322–325 °C.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 11.73 (s, 1 H), 8.11 (d, *J* = 7.4 Hz, 1 H), 7.93–7.90 (m, 2 H), 7.77–7.75 (m, 1 H), 7.70–7.67 (m, 1 H), 7.47–7.43 (m, 2 H), 7.37–7.33 (m, 1 H), 6.34 (s, 1 H).

^{13}C NMR (150 MHz, DMSO-d_6): δ = 176.9, 163.3 (d, $^1J_{C,F}$ = 248 Hz), 149.0, 140.4, 131.9, 130.6 (d, $^4J_{C,F}$ = 3 Hz), 129.9 (d, $^3J_{C,F}$ = 9 Hz), 124.8, 124.7, 123.3, 118.7, 116.0 (d, $^2J_{C,F}$ = 23 Hz), 107.4.

2-(2-Chlorophenyl)quinolin-4(1*H*)-one (3ed)[9d,14d]

Yellow solid, yield: 35.7 mg (70%); mp 208–210 °C.

^{1}H NMR (600 MHz, DMSO-d_6): δ = 11.96 (s, 1 H), 8.07 (d, *J* = 8.0 Hz, 1 H), 7.63–7.54 (m, 4 H), 7.52 (t, *J* = 7.1 Hz, 1 H), 7.46 (t, *J* = 7.4 Hz, 1 H), 7.30 (t, *J* = 7.4 Hz, 1 H), 5.98 (s, 1 H).

^{13}C NMR (150 MHz, DMSO-d_6): δ = 176.8, 148.2, 140.1, 133.9, 132.0, 131.7, 131.5, 131.1, 129.8, 129.0, 127.6, 124.8, 123.4, 118.5, 109.8.

2-(3-Methoxyphenyl)quinolin-4(1*H*)-one (3fd)[14d]

Yellow solid; yield: 41.2 mg (82%); mp 242–244 °C.

^{1}H NMR (600 MHz, DMSO-d_6): δ = 11.70 (s, 1 H), 8.11 (d, *J* = 8.0 Hz, 1 H), 7.78 (d, *J* = 8.3 Hz, 1 H), 7.69 (t, *J* = 7.6 Hz, 1 H), 7.52 (t, *J* = 7.9 Hz, 1 H), 7.41–7.34 (m, 3 H), 7.16 (d, *J* = 8.0 Hz, 1 H), 6.37 (s, 1 H), 3.88 (s, 3 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 182.2, 164.8, 155.0, 145.7, 140.8, 137.1, 130.1, 128.6, 128.4, 125.0, 124.7, 124.0, 118.1, 117.9, 112.7, 60.6.

6-Methyl-2-phenylquinolin-4(1*H*)-one (3hd)[9d,30b]

Yellow solid, yield: 39 mg (83%); mp 290–292 °C.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 11.67 (s, 1 H), 7.91–7.83 (m, 3 H), 7.69–7.51 (m, 5 H), 6.31 (s, 1 H), 2.43 (s, 3 H).

^{13}C NMR (150 MHz, DMSO-d_6): δ = 176.8, 149.6, 138.6, 134.3, 133.2, 132.5, 130.4, 129.0, 127.4, 124.8, 124.0, 118.6, 107.0, 20.8.

6-Chloro-2-phenylquinolin-4(1*H*)-one (3jd)[30e,f]

Light yellow solid; yield: 20.4 mg (40%); mp 348–350 °C.

^{1}H NMR (600 MHz, DMSO-d_6): δ = 11.91 (s, 1 H), 8.04 (d, *J* = 2.4 Hz, 1 H), 7.86–7.80 (m, 3 H), 7.75–7.73 (m, 1 H), 7.62–7.61 (m, 3 H), 6.40 (s, 1 H).

^{13}C NMR (150 MHz, DMSO-d_6): δ = 175.7, 150.4, 139.1, 133.9, 132.0, 130.7, 129.0, 127.9, 127.5, 125.9, 123.7, 121.2, 107.5.

5-Chloro-2-phenylquinolin-4(1*H*)-one (3kd)

Yellow solid; yield: 22.5 mg (47%); mp 296–298 °C.

IR (KBr): 3439, 2923, 2852, 1634, 1605, 1591, 1548, 1506 cm^{-1}.

^{1}H NMR (600 MHz, DMSO-d_6): δ = 11.85 (s, 1 H), 7.87–7.85 (m, 2 H), 7.81 (d, *J* = 8.3 Hz, 1 H), 7.58–7.54 (m, 4 H), 7.28 (d, *J* = 7.6 Hz, 1 H), 6.36 (s, 1 H).

^{13}C NMR (150 MHz, DMSO-d_6): δ = 175.9, 149.3, 143.8, 133.8, 131.7, 131.3, 130.4, 128.9, 127.4, 125.7, 120.9, 118.9, 109.1.

ESI-MS: *m*/*z* = 255 [M$^+$], 256 [M + 1]$^+$.

HRMS-ESI: *m*/*z* [M + Na]$^+$ calcd for $C_{15}H_{10}ClNONa$: 278.0349; found: 278.0357.

2-Phenyl-4*H*-thiochromen-4-one (3ae)[28b,c]

Yellow solid; yield: 21.9 mg (46%, Table 3, entry 1) and 45.2 mg (95%, Table 3, entry 2); mp 125–126 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.55 (d, *J* = 7.9 Hz, 1 H), 7.70–7.60 (m, 4 H), 7.57–7.50 (m, 4 H), 7.24 (s, 1 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 180.9, 153.1, 137.7, 136.6, 131.6, 130.9, 130.9, 129.3, 128.6, 127.8, 127.0, 126.5, 123.5.

2-(*p*-Tolyl)-4*H*-thiochromen-4-one (3be)[30g]

Yellow solid; yield: 39.3 mg (78%); mp 118–119 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.54 (d, *J* = 8.0 Hz, 1 H), 7.67–7.51 (m, 5 H), 7.30 (d, *J* = 8.0 Hz, 2 H), 7.23 (s, 1 H), 2.43 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 180.9, 153.1, 141.3, 137.7, 133.8, 131.5, 131.0, 123.0, 128.6, 127.7, 126.8, 126.5, 122.9, 21.4.

2-[4-(*tert*-Butyl)phenyl]-4*H*-thiochromen-4-one (3ce)[28c]

Yellow solid; yield: 47.6 mg (81%); mp 101–103 °C.

^{1}H NMR (600 MHz, $CDCl_3$): δ = 8.46 (d, *J* = 8.0 Hz, 1 H), 7.56–7.53 (m, 3 H), 7.52 (t, *J* = 6.7 Hz, 1 H), 7.47–7.43 (m, 3 H), 7.17 (s, 1 H), 1.28 (s, 9 H).

^{13}C NMR (151 MHz, $CDCl_3$): δ = 179.9, 153.4, 152.0, 136.7, 132.6, 130.5, 129.9, 127.5, 126.6, 125.6, 125.4, 125.2, 121.8, 33.9, 30.1.

2-(4-Methoxyphenyl)-4*H*-thiochromen-4-one (3me)[28b,c]

Yellow solid; yield: 39.1 mg (73%); mp 125–127 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.53 (d, *J* = 7.9 Hz, 1 H), 7.68–7.58 (m, 4 H), 7.56–7.51 (m, 1 H), 7.20 (s, 1 H), 7.01 (d, *J* = 8.7 Hz, 2 H), 3.87 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 180.9, 161.9, 152.7, 137.6, 131.5, 130.9, 128.9, 128.6, 128.3, 127.6, 126.4, 122.2, 114.7, 55.5.

2-(4-Fluorophenyl)-4*H*-thiochromen-4-one (3de)[28b,l]

Yellow solid; yield: 24.6 mg (48%); mp 158–160 °C.

^{1}H NMR (600 MHz, $CDCl_3$): δ = 8.55 (d, *J* = 8.0 Hz, 1 H), 7.70–7.63 (m, 4 H), 7.56 (t, *J* = 7.3 Hz, 1 H), 7.22–7.17 (m, 3 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 180.80, 164.3 (d, $^1J_{C,F}$ = 251 Hz), 151.81, 137.45, 132.7 (d, $^4J_{C,F}$ = 3 Hz), 131.74, 130.83, 129.0 (d, $^3J_{C,F}$ = 9 Hz), 128.66, 127.92, 126.48, 123.48, 116.5 (d, $^2J_{C,F}$ = 22.5 Hz).

2-(*o*-Tolyl)-4*H*-thiochromen-4-one (3pe)[30h]

Yellow solid; yield: 43.4 mg (86%); mp 96–98 °C.

^{1}H NMR (600 MHz, $CDCl_3$): δ = 8.58 (d, *J* = 8.0 Hz, 1 H), 7.65–7.60 (m, 2 H), 7.56 (t, *J* = 6.6 Hz, 1 H), 7.39–7.27 (m, 4 H), 6.92 (s, 1 H), 2.39 (s, 3 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 180.5, 153.6, 138.4, 136.1, 135.7, 131.6, 131.0, 130.9, 129.9, 129.1, 128.7, 127.8, 126.3, 126.3, 126.1, 19.9.

2-(4-Chlorophenyl)-4*H*-thiochromen-4-one (3qe)[28c,30g,i]

White solid; yield: 40.8 mg (75%); mp 166–168 °C.

^{1}H NMR (600 MHz, $CDCl_3$): δ = 8.53 (d, *J* = 8.0 Hz, 1 H), 7.66–7.60 (m, 4 H), 7.55 (t, *J* = 7.2 Hz, 1 H), 7.47 (d, *J* = 7.6 Hz, 2 H), 7.19 (s, 1 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 180.7, 151.6, 137.4, 137.1, 135.0, 131.8, 130.8, 129.6, 128.7, 128.2, 128.0, 126.5, 123.6.

2-(2-Chlorophenyl)-4*H*-thiochromen-4-one (3ee)[30g]

White solid; yield: 51.7 mg (95%); mp 129–130 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.58 (d, *J* = 8.0 Hz, 1 H), 7.66–7.60 (m, 2 H), 7.58–7.54 (m, 1 H), 7.53–7.51 (m, 1 H), 7.46–7.35 (m, 3 H), 7.02 (s, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 180.4, 150.4, 138.2, 135.2, 132.6, 131.7, 131.1, 130.9, 130.7, 130.5, 128.7, 127.9, 127.2, 127.1, 126.3.

2-Butyl-4*H*-thiochromen-4-one (3ge)[28c]

Yellow solid; yield: 30.1 mg (69%); mp 95–97 °C.

^{1}H NMR (600 MHz, $CDCl_3$): δ = 8.50 (d, *J* = 8.0 Hz, 1 H), 7.59–7.57 (m, 2 H), 7.53–7.48 (m, 1 H), 6.87 (s, 1 H), 2.68 (t, *J* = 7.6 Hz, 2 H), 1.75–1.70 (m, 2 H), 1.46–1.39 (m, 2 H), 0.96 (t, *J* = 7.3 Hz, 3 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 180.7, 156.6, 137.8, 131.3, 131.0, 128.6, 127.5, 126.2, 124.1, 37.2, 31.9, 22.0, 13.8.

6-Methyl-2-phenyl-4*H*-thiochromen-4-one (3he)[30c]

Light yellow solid; yield: 48.9 mg (97%); mp 150–152 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.35 (s, 1 H), 7.70–7.64 (m, 2 H), 7.55–7.42 (m, 5 H), 7.22 (s, 1 H), 2.48 (s, 3 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 180.9, 153.0, 138.1, 136.7, 134.7, 133.0, 130.8, 130.7, 129.3, 128.3, 127.0, 126.4, 123.3, 21.4.

6-Chloro-2-phenyl-4*H*-thiochromen-4-one (3je)[28a]

White solid; yield: 18 mg (33%); mp 189–191 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.53 (s, 1 H), 7.69 (d, *J* = 8.0 Hz, 2 H), 7.63–7.58 (m, 2 H), 7.53–7.52 (m, 3 H), 7.25 (s, 1 H).

^{13}C NMR (150 MHz, $CDCl_3$): δ = 179.7, 153.3, 136.3, 135.8, 134.4, 132.1, 132.0, 131.1, 129.4, 128.3, 128.0, 127.0, 123.3.

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Supporting Information

Supporting information for this article is available online at https://doi.org/10.1055/s-0036-1588466.

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