Iodocyclization of *N*-Aryl-3-phenylpropiolamides by I_2/CAN: A Convenient Route for the Selective Synthesis of Quinolin-2-ones

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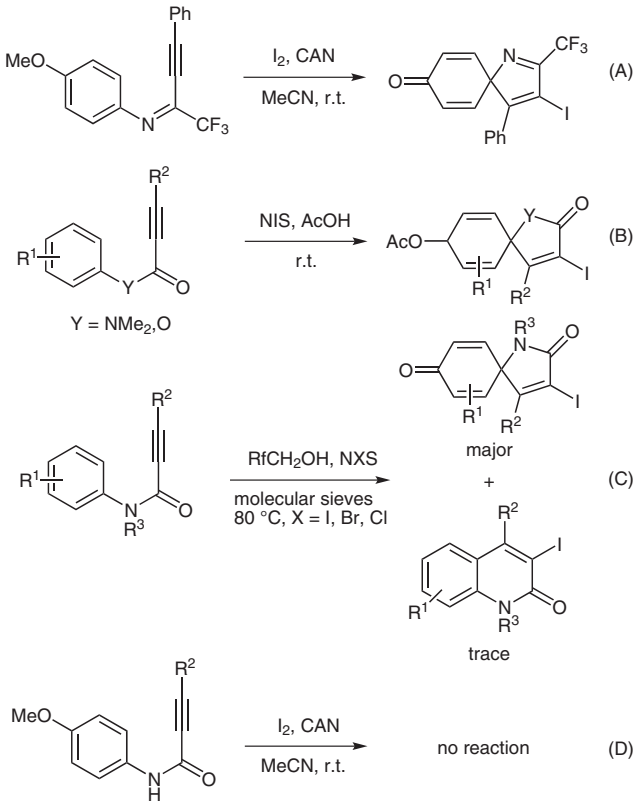
Abstract: A general method has been developed for the selective synthesis of 3-iodoquinolin-2-ones and spiro[4.5]trienes via intramolecular iodocyclization of *N*-(*ortho*-substituted aryl)-3-phenylpropiolamides using iodine/cerium(IV) ammonium nitrate reagent under mild reaction conditions. The electronic effect of *ortho*-substituents (electron-rich and electron-deficient group) triggers the two different reaction pathways resulting to iodocyclized quinolin-2-one and *ipso*-iodocyclized spiro-type compounds.

Key words: iodocyclization, quinolin-2-ones, alkynes, heterocycles, spiro compounds

The quinoline ring system is an important constituent of natural products and is used in the design of many synthetic compounds with pharmaceutical interest. Among the known protocols, the electrophilic cyclization of aryl-substituted alkynes has provided an extremely useful route for the construction of quinolines and isoquinolines under mild condition.[1] The pioneering work of Larock[2] and others[3] on the electrophilic cyclization of functionally substituted alkynes has proved that this protocol offers a promising route to not only quinolines and isoquinolines, but to a wide variety of heterocyclic and carbocyclic compounds as well. In the reported methods, iodine monochloride, iodine/sodium hydrogen carbonate, or *N*-iodosuccinimide are usually employed as an iodine source for the intramolecular electrophilic iodocyclization. Recently, we have reported that 2-(perfluoroalkyl)quinolines can be synthesized in good to excellent yield by electrophilic cyclization of perfluoroalkyl propargyl imines using iodine/cerium(IV) ammonium nitrate in acetonitrile at room temperature.[4] In this report, interestingly the aryl ring bearing active *para*-substituents (OMe), *N*-4-methoxyphenyl perfluoroalkyl propargyl imines showed selective *ipso*-cyclization to an azaspiro compound in excellent yield [Scheme 1 (A)]. Indeed, the same results were reported by the groups of Fanghanel,[5] Larock,[6] and Li[7] for the iodocyclization of *N*-(*para*-substituted aryl)propiolamides to *ipso*-cyclized azaspiro compounds using iodine and iodine monochloride as electrophiles. Thus, it was generalized that the *ipso*-cyclization can be achieved from arylalkynes bearing active *para*-substituents, such as methoxy and *N*,*N*-dimethylamino groups. However, Li et al. reported an alternative method for the electrophilic *ipso*-cyclization of *para*-unactivated arylalkynes in the presence of *N*-iodosuccinimide and acetic acid [Scheme 1 (B)].



Scheme 1

In continuation of our previous investigation of the iodocyclization of perfluoroalkyl propargyl imines/amines,[4] we started to examine the iodocyclization of other substrates (non-perfluoroalkyl-substituted compounds). We first focused on the cyclization of *N*-(4-methoxyphenyl)-3-phenylpropiolamide by iodine/cerium(IV) ammonium nitrate in acetonitrile at room temperature, but no desired product was obtained [Scheme 1 (D)]. Stimulated by our previous observation and the unforeseen results of *N*-(4-methoxyphenyl)-3-phenylpropiolamide prompted us to study the electrophilic iodocyclization of *N*-(*ortho*-substituted and unsubstituted aryl)-3-phenylpropiolamides by iodine/cerium(IV) ammonium nitrate reagents. In this context, very recently Li et al. have reported the electro-

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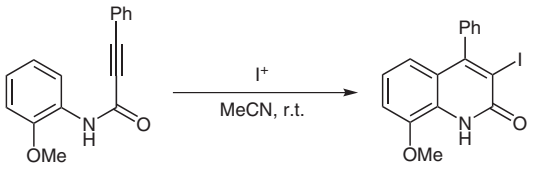
philic *ipso*-halocyclization of *N*-arylpropynamides with polyfluoroalkyl alcohols and halosuccinimide as a nucleophile and halide source respectively for the synthesis of 8-(polyfluoroalkoxy)azaspiro[4.5]trienes as the major product with trace amounts of phenylquinolin-2(1*H*)-ones[8] [Scheme 1 (C)]. Here, we wish to report that *ortho*-substituted (electron-rich group) and unsubstituted *N*-aryl-3-phenylpropiolamides can undergo electrophilic iodocyclization with iodine/cerium(IV) ammonium nitrate to selectively yield 3-iodo-phenylquinolin-2-ones in good to excellent yields. Furthermore, we report that *ortho*-substituted (electron-deficient groups) *N*-aryl-3-phenylpropiolamides can afford selectively spiro[4.5]triene compounds in the presence of iodine/cerium(IV) ammonium nitrate in good to excellent yields. We assume that the rational behind the adoption of two different reaction pathways depends on the electronic environment in the aromatic ring. The *ortho*-substituted phenylpropiolamides and *N*-aryl-3-phenylpropiolamides were prepared in good to excellent yields from phenylpropiolic acid and substituted anilines using dicyclohexylcarbodiimide as coupling agent.[9,10]

To find the standard experimental procedure, as a model reaction, we selected *N*-(2-methoxyphenyl)-3-phenylpropiolamide (**1b**) as the substrate and iodine monochloride, molecular iodine, and iodine/cerium(IV) ammonium nitrate as iodine source in acetonitrile at room temperature.

Table 1 Screening of Iodine, Iodine Monochloride and Iodine/Cerium(IV) Ammonium Nitrate in the Iodocyclization of Phenylpropiolamide **1b**[a]



1b **2b**

Entry	I^+ (equiv)	CAN (equiv)	Time (h)	Yield[b] (%)
1	I_2 (2.0)	1.0	6	47
2	I_2 (2.0)	2.0	4	65
3	I_2 (3.0)	2.0	3	65
4	I_2 (2.0)	2.0	6	43
5	I_2 (1.0)	0	24	0
6	ICl	0	24	trace

[a] Reaction conditions: **1b** (0.25 mmol), I_2 and CAN, 0.1 M MeCN, r.t.
[b] Isolated yield of **2b**.

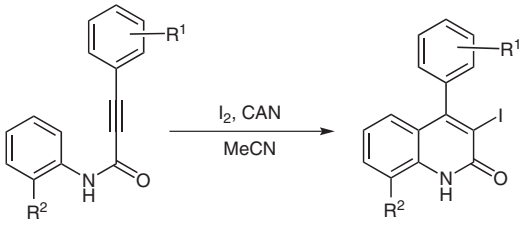
With the recent success in iodocyclization of the perfluoroalkyl propargyl imines,[4] the iodocyclization of *N*-(2-methoxyphenyl)-3-phenylpropiolamide (**1b**) was examined using iodine (2.0 equiv)/cerium(IV) ammonium nitrate (1.0 equiv) in 0.1 M acetonitrile at room temperature and the desired product quinolin-2-one **2b** was obtained in 47% isolated yield (Table 1, entry 1). Subsequently, the optimal conditions for iodine and cerium(IV) ammonium nitrate to afford the maximum product yield of **2b** were identified. The highest yield (65%) was obtained with 2.0 equivalents of iodine and 2.0 equivalents of cerium(IV) ammonium nitrate in 0.1 M acetonitrile at room temperature (entry 2). Iodocyclization was also carried out with iodine (2.0 equiv) in acetonitrile at room temperature, no cyclized product **2b** was obtained whereas with a strong electrophile, when iodine monochloride was employed a negligible amount of product **2b** was formed (entries 5 and 6).

To investigate the scope of the reaction, the effect of various *ortho*-substituted groups on the aniline moiety were examined. The electron-donating and electron-withdrawing behavior of the substituents has varying effect on the product yields. The electron-donating substituents such as the methoxy, and *tert*-butyl group afforded **2b–d** good to excellent yields (Table 2, entries 2–4) whereas strong electron-withdrawing substituents such as trifluoromethyl and fluorine were found to be inactive in the cyclization reactions (entry 5). The effect of substituents on the alkynyl phenyl was also examined for **1f–h** and it was found that they cyclized to give **2f–h** in good yields (entries 6–8). Among the aliphatic alkynes, **1i** and **1j**, only methyl-substituted alkyne **1i** could undergo facile iodocyclization in moderate yields (entry 9). We have also examined the effect of *meta*-substituted group on the aniline moiety **1k**; however, no cyclization was observed in this reaction (entry 11).

Interestingly, when phenyl, bromo, and chloro groups in the *ortho* position of the aniline **1l–n** were used, spiro[4.5]triene products **3l–n** were obtained in moderate to good yields (Table 3, entries 1–3). Arylalkyne **1o** having methyl group at terminal alkyne was an unsuitable substrate for the *ipso*-iodocyclization under our optimized reaction conditions (entry 4).

These results are contradictory to the results obtained by Li et al. in which *N*-(4-methoxyphenyl)-*N*-methyl-3-phenylpropynamide underwent *ipso*-iodocyclization but gave the 1-azaspiro[4.5]decane-2,8-dione devoid of the trifluoromethyl group in the spirocyclic motif.[8] The role of 2,2,2-trifluoroethanol ascribed by Li et al. in the reaction was as a strong nucleophile that attacked the *para* position of aniline and assisted in *ipso*-cyclization. However, in the present study, the source of oxygen was ascertained by conducting a controlled reaction with (2-bromophenyl)-3-phenylpropiolamide and iodine/cerium(IV) ammonium nitrate in dry acetonitrile under identical experimental conditions and found that bromo-substituted spiro[4.5]trienes formed in only 7% yield. This observation suggests that water may be the possible source of oxygen. To confirm the role of water, the reaction was conducted in the presence of acetic acid (2 equiv) with *N*-(2-bromophenyl)-3-phenylpropiolamide using iodine/cerium(IV) ammonium nitrate in dry acetonitrile and this gave the 8-acetoxy-substituted spiro[4.5]triene in 72% (*cis*/*trans* 40:60) (Scheme 2).

Table 2 Iodocyclization of *N*-Aryl-3-phenylpropiolamides **1a–k**[a]



1a–k **2a–i**

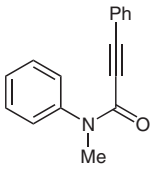
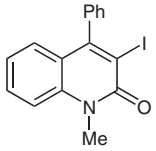
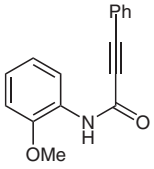
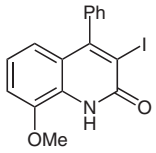
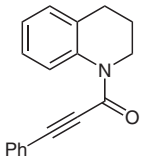
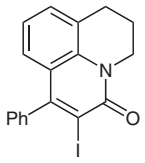
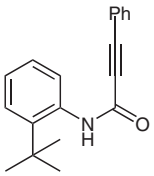
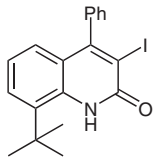
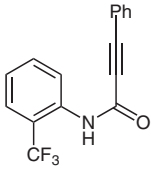
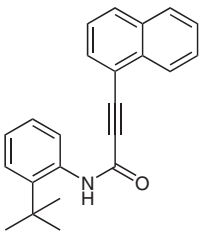
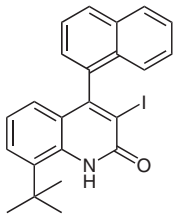
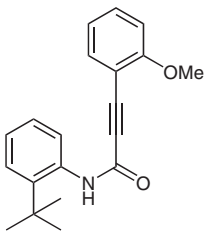
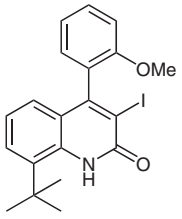
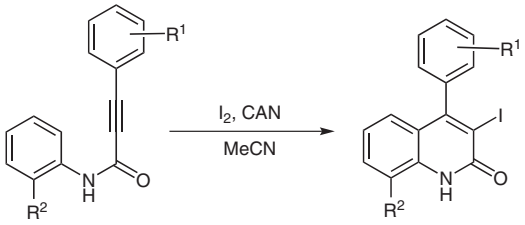
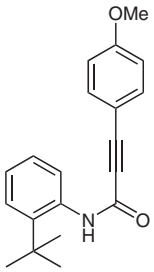
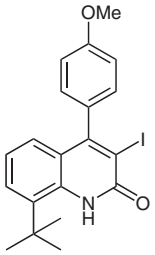
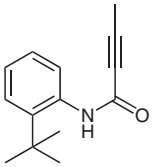
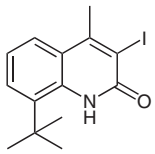
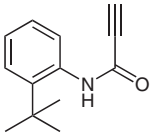
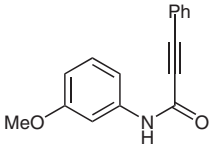
Entry	Arylalkyne **1**	Product **2**	Time (h)	Yield[b] (%)
1	**1a** 	**2a** 	4	62
2	**1b** 	**2b** 	4	65
3	**1c** 	**2c** 	3	88
4	**1d** 	**2d** 	3	93
5	**1e** 	–[c]	24	0
6	**1f** 	**2f** 	3	75
7	**1g** 	**2g** 	3	84

Table 2 Iodocyclization of *N*-Aryl-3-phenylpropiolamides **1a–k**[a] (continued)



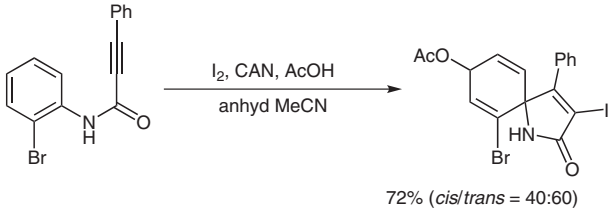
1a–k **2a–i**

Entry	Arylalkyne **1**	Product **2**	Time (h)	Yield[b] (%)
8	**1h** 	**2h** 	3	78
9	**1i** 	**2i** 	4	66
10	**1j** 	–[c]	24	0
11	**1k** 	–[c]	24	0

[a] Reaction conditions: **1a–k** (0.25 mmol), I_2 (0.5 mmol), CAN (0.5 mmol), MeCN (5 mL), r.t.
[b] Isolated yield. All products are characterized by NMR spectroscopy and mass spectrometry.
[c] No reaction.

The *N*-methyl substrate, *N*-methyl-*N*,3-diphenylpropiolamide (**1a**), also underwent clean cyclization and this result provided an interesting contrast to the substrates that do not bear a *meta*- or *para*-methoxy group and have an unsubstituted NH group that do not cyclize under the same conditions [Table 2, entry 1 vs. entry 11, and Scheme 1 (**D**)]. The *ortho* groups in combination with the NH group have a pronounced effect on the cyclization reaction which may be attributed to the steric size of the *ortho* group, which imposes a conformational change on the amide and brings it closer to the arene ring for cyclization. Similarly, the *ortho* effect must be more than an electronic effect, as if this were the case the *meta*- and *para*-methoxy compounds would also cyclize.

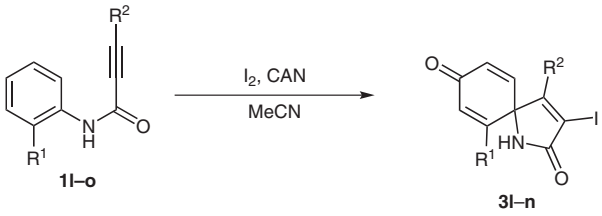
The phenyl-substituted spiro[4.5]triene **3l** (Table 3, entry 1) was fully characterized by various spectroscopic tools and the structure was confirmed by a single-crystal X-ray diffraction study (Figure 1).[11] The plausible mechanism for the formation of spiro[4.5]trienes can be explained with the initial formation of an iodonium intermediate **I** by electrophilic attack of the iodine cation which is generated in situ by activation with cerium(IV) ammonium nitrate, on the C≡C bond of the propargylic aniline (Scheme 3). The presence of an electron-withdrawing group in the *ortho* position activates the *para* position and facilitates nucleophilic OH substitution at the *para* posi-



72% (*cis*/*trans* = 40:60)

Scheme 2 *ipso*-Iodocyclization of *N*-(2-bromophenyl)-3-phenylpropiolamide in the presence of iodine/cerium(IV) ammonium nitrate and acetic acid

Table 3 ipso-Iodocyclization of *N*-Aryl-3-phenylpropiolamides **1l–n**[a]



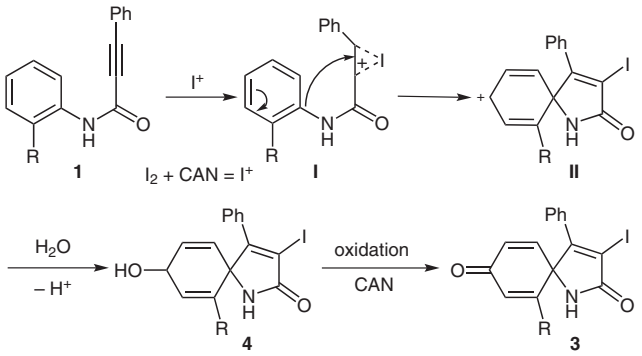
Entry	1	R^1	R^2	3	Time (h)	Yield[b] (%)
1	**1l**	Ph	Ph	**3l**	3	89
2	**1m**	Br	Ph	**3m**	3	91
3	**1n**	Cl	Ph	**3n**	5	67
4	**1o**	Br	Me	–	24	0

[a] Reaction conditions: **1l–o** (0.25 mmol), I_2 (0.5 mmol), CAN (0.5 mmol), MeCN (5 mL), r.t.
[b] Isolated yield of **3l–n**. All products are characterized by NMR and mass spectroscopy.

tion of the aryl moiety in **II**. As discussed earlier, the trace amounts of water present in the reaction system plays an important role in this step. The subsequent oxidation of the hydroxy group in **4** to the carbonyl group affords spiro[4.5]triene-type compounds **3**. It is believed that cerium(IV) ammonium nitrate acts as an efficient and convenient activator for iodine during the activation process through the reduction of Ce(IV) to Ce(III).[4,12]

The one-electron oxidizing property of cerium(IV) ammonium nitrate is well-illustrated in the oxidative addition reactions of electrophilic radicals to alkenes, enabling intermolecular and intramolecular carbon–carbon and carbon–heteroatom bond formation.[13] Cerium(IV) ammonium nitrate also oxidizes secondary alcohols into ketones and benzylic alcohols into aldehydes.[14] The oxidation of a carbonyl group to corresponding radical cation is also well established through one-electron transfer by cerium(IV) ammonium nitrate.[14]

The plausible mechanism for iodocyclization of *N*-aryl-3-phenylpropiolamide **1** presented herein is outlined in Scheme 4 and can be explained with initial formation of iodonium intermediate **I**. The intramolecular *ortho* cyclization of the aniline aromatic ring with the activated triple bond results in the formation of corresponding 3-iodoquinolin-2(1*H*)-one **2**.



Scheme 3 Plausible mechanism for the formation of spiro-type compounds

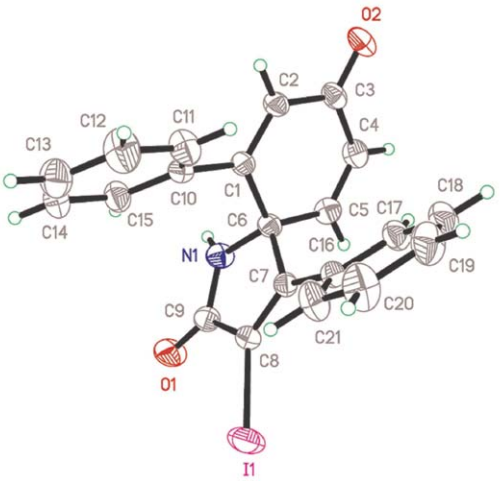
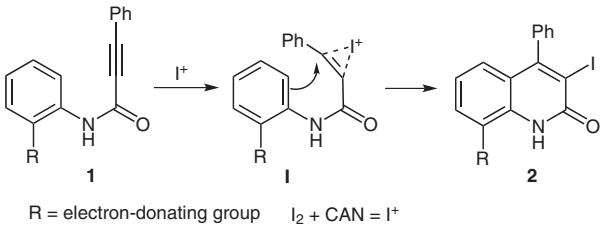


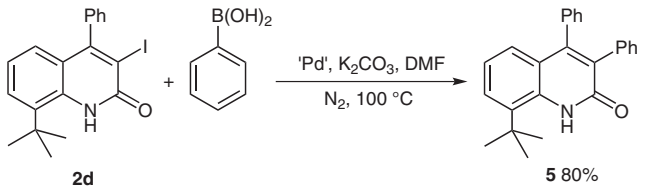
Figure 1 ORTEP diagram of phenyl-substituted spiro[4.5]triene **3l**



Scheme 4 Plausible mechanism for the formation of 3-iodoquinolin-2(1*H*)-ones

From the above studies, it can be generalized that under the experimental conditions, the electron-donating group at the *ortho* position of arylalkynes or unsubstituted phenylalkyne can selectively undergo iodocyclization to 3-iodoquinolin-2-one compounds whereas with electron-withdrawing group at the *ortho* position of arylalkynes they can undergo cyclization to afford 3-iodospiro[4.5]triene compounds.

The presence of the iodide functional group at the 3-position of the quinoline ring provides an opportunity to explore the scope of the chemistry. 3-Iodoquinolin-2(1*H*)-one **2d** underwent facile Suzuki coupling with phenylboronic acid catalyzed by bis(triphenylphosphine)palladium(II) dichloride to afford highly substituted 8-*tert*-butyl-3,4-diphenylquinolin-2(1*H*)-one (**5**) in good yield (80%) (Scheme 5).



Scheme 5 Suzuki coupling of 3-iodoquinol-2(1*H*)-one with boronic acid

In conclusion, we have developed an efficient and simple methodology for the selective synthesis of quinolin-2(1*H*)-ones and spiro[4.5]trienes using two different electronic environments at the *ortho*-position of arylalkynes using the iodine/cerium(IV) ammonium nitrate system. The iodocyclization by iodine/cerium(IV) ammonium nitrate showed considerable synthetic advantages, in terms of mild reaction conditions, simplicity of the reaction process and good-to-excellent yields.

All chemicals were purchased from Aldrich and were used as received. All solvents used were analytical grade and were used as received from Merck India Pvt. Ltd. ^{1}H and ^{13}C spectra were recorded on a Bruker, Avance 300 (300 MHz ^{1}H and 75 MHz ^{13}C) spectrometer at r.t. with respect to TMS and $CDCl_3$ for ^{1}H and ^{13}C NMR, respectively; residual $CHCl_3$ (^{1}H: δ = 7.25 ppm; ^{13}C: δ = 77 ppm). Acme silica gel (60–120 mesh) was used for column chromatography and TLC was performed on Merck precoated silica gel 60-F254 plates.

Iodocyclization of *N*-Arylpropiolamides 1; General Procedure

N-Arylpropiolamide (0.25 mmol), I_2 (2 equiv), and CAN (2 equiv) were added to a reaction vessel containing MeCN (5 mL). The mixture was stirred at r.t. for the required time and was then diluted with EtOAc (30 mL), and washed with sat. aq $Na_2S_2O_3$ (25 mL). The organic layer was separated and the aqueous layer was extracted with fresh EtOAc (2 × 30 mL). The combined organic layers were dried (anhyd Na_2SO_4). The solvent was evaporated under reduced pressure and the products were purified by column chromatography (silica gel, hexane–EtOAc, 10:1) to afford pure product.

3-Iodo-1-methyl-4-phenylquinolin-2(1*H*)-one (2a)

Yield: 55 mg (62%); white solid; mp 172–174 °C.

IR (KBr): 1633 cm^{-1}.

^{1}H NMR (300 MHz): δ = 7.58–7.46 (m, 4 H), 7.38 (d, *J* = 8.5 Hz, 1 H), 7.20 (d, *J* = 7.6 Hz, 2 H), 7.11 (d, *J* = 7.7 Hz, 1 H), 7.08–7.00 (m, 1 H), 3.89 (s, 3 H).

^{13}C NMR (75.5 MHz): δ = 159.07, 156.29, 141.14, 139.48, 131.03, 128.86, 128.71, 128.58, 128.36, 122.34, 121.41, 114.16, 101.40, 31.69.

MS (ESI): *m*/*z* = 362 [M + H]$^+$.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{16}H_{13}INO$: 362.0041; found: 362.0036.

3-Iodo-8-methoxy-4-phenylquinolin-2(1*H*)-one (2b)

Yield: 61 mg (65%); yellow solid; mp 124–126 °C.

IR (KBr): 3411, 1729 cm^{-1}.

^{1}H NMR (300 MHz): δ = 8.58 (d, *J* = 8.88 Hz, 1 H), 8.2 (br s, 1 H), 7.93 (dd, *J* = 9.07, 2.27 Hz, 1 H), 7.76 (d, *J* = 2.27 Hz, 1 H), 7.62 (s, 1 H), 7.60 (d, *J* = 1.32 Hz, 1 H), 7.49–7.35 (m, 3 H), 4.07 (s, 3 H).

^{13}C NMR (75.5 MHz): δ = 166.04, 150.85, 147.24, 143.57, 133.12, 132.72, 130.68, 128.65, 119.48, 119.03, 117.63, 105.31, 83.08, 56.46.

MS (ESI): *m*/*z* = 378 [M + H]$^+$.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{16}H_{13}INO_2$: 377.9913; found: 377.9902.

6-Iodo-7-phenyl-2,3-dihydro-1*H*,5*H*-pyrido[3,2,1-*ij*]quinolin-5-one (2c)

Yield: 85 mg (88%); white solid; mp 174–176 °C.

IR (KBr): 1631 cm^{-1}.

^{1}H NMR (300 MHz): δ = 7.55–7.45 (m, 3 H), 7.30–7.26 (m, 1 H), 7.19 (dd, *J* = 7.55, 1.7 Hz, 2 H), 6.95–6.90 (m, 2 H), 4.33 (t, *J* = 5.85, 2 H), 8.04 (t, *J* = 6.23 Hz, 2 H), 2.24–2.14 (d, *J* = 6.04 Hz, 2 H).

^{13}C NMR (75.5 MHz): δ = 158.52, 156.07, 141.36, 136.17, 130.22, 128.59, 128.40, 128.26, 126.73, 124.77, 121.82, 121.24, 101.09, 44.47, 27.66, 20.77.

MS (ESI): *m*/*z* = 388 [M + H]$^+$.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{18}H_{15}INO$: 388.0198; found: 388.0202.

8-*tert*-Butyl-3-iodo-4-phenylquinolin-2(1*H*)-one (2d)

Yield: 94 mg (93%); white solid; mp 210–212 °C.

IR (KBr): 3274, 1651 cm^{-1}.

^{1}H NMR (300 MHz): δ = 9.16 (br s, 1 H), 7.56–7.46 (m, 4 H), 7.22–7.18 (m, 2 H), 6.98–6.93 (m, 2 H), 4.61 (s, 9 H).

^{13}C NMR (75.5 MHz): δ = 158.91, 158.65, 141.51, 135.77, 134.04, 128.71, 128.55, 128.51, 128.13, 127.11, 122.30, 121.53, 99.38, 34.12, 30.59.

MS (ESI): *m*/*z* = 404 [M + H]$^+$.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{19}H_{19}INO$: 404.0511; found: 404.0509.

8-*tert*-Butyl-3-iodo-4-naphthalen-1-ylquinolin-2(1*H*)-one (2f)

Yield: 85 mg (75%); white solid; mp 286–288 °C.

IR (KBr): 3274, 1650 cm^{-1}.

^{1}H NMR (300 MHz): δ = 9.24 (br s, 1 H), 7.96 (dd, *J* = 8.31, 3.78 Hz, 1 H), 7.61 (t, *J* = 7.58 Hz, 1 H), 7.54–7.46 (m, 2 H), 7.38 (d, *J* = 3.59 Hz, 2 H), 7.30 (d, *J* = 6.79 Hz, 1 H), 6.85 (t, *J* = 7.55 Hz, 1 H), 6.75 (d, *J* = 8.12 Hz, 1 H), 1.65 (s, 9 H).

^{13}C NMR (75.5 MHz): δ = 158.74, 154.75, 147.62, 138.99, 134.16, 133.57, 132.20, 128.99, 128.66, 128.53, 127.18, 126.86, 126.58, 126.43, 126.20, 125.52, 125.05, 122.5, 100.77.

MS (ESI): *m*/*z* = 454 [M + H]$^+$.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{23}H_{21}INO$: 454.0667; found: 454.0660.

8-*tert*-Butyl-3-iodo-4-(2-methoxyphenyl)quinolin-2(1*H*)-one (2g)

Yield: 91 mg (84%); white solid; mp 196–198 °C.

IR (KBr): 3303, 1642 cm^{-1}.

^{1}H NMR (300 MHz): δ = 9.11 (br s, 1 H), 7.74 (dd, *J* = 9.07, 2.27 Hz, 1 H), 7.51–7.48 (m, 1 H), 7.34 (d, *J* = 2.27 Hz, 1 H), 7.06–6.92 (m, 3 H), 6.82 (d, *J* = 9.07 Hz, 1 H), 3.76 (s, 3 H), 1.61 (s, 9 H).

^{13}C NMR (75.5 MHz): δ = 158.59, 155.66, 154.99, 139.00, 138.98, 137.64, 135.74, 134.10, 132.49, 128.51, 128.50, 126.31, 122.44, 113.85, 82.48, 55.87, 34.11, 30.59.

MS (ESI): *m*/*z* = 434 [M + H]$^+$.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{20}H_{21}INO_2$: 434.0617; found: 434.0618.

8-*tert*-Butyl-3-iodo-4-(4-methoxyphenyl)quinolin-2(1*H*)-one (2h)

Yield: 84 mg (78%); white solid; mp 199–201 °C.

IR (KBr): 3295 cm^{-1}.

^{1}H NMR (300 MHz): δ = 9.17 (br s, 1 H), 7.53–7.42 (m, 1 H), 7.13–6.88 (m, 6 H), 3.84 (s, 3 H), 1.51 (s, 9 H).

^{13}C NMR (75.5 MHz): δ = 159.61, 158.80, 158.70, 139.00, 137.11, 135.40, 134.01, 129.53, 128.43, 127.20, 122.24, 114.03, 100.00, 55.29, 34.11, 30.59.

MS (ESI): *m*/*z* = 434 [M + H]$^+$.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{20}H_{21}INO_2$: 434.0617; found: 434.0597.

8-*tert*-Butyl-3-iodo-4-methylquinolin-2(1*H*)-one (2i)
Yield: 56 mg (66%); white solid; mp 206–208 °C.

IR (KBr): 1640, 3303 cm^{-1}.

^{1}H NMR (300 MHz): δ = 9.02 (br s, 1 H), 7.66 (d, *J* = 8.309 Hz, 1 H), 7.52 (dd, *J* = 7.554, 1.511 Hz, 1 H), 7.15–7.08 (m, 1 H), 2.82 (s, 3 H), 1.57 (s, 9 H).

^{13}C NMR (75.5 MHz): δ = 158.36, 153.57, 135.2, 134.35, 128.35, 124.15, 122.42, 120.57, 100.45, 34.09, 30.6, 26.69.

MS (ESI): *m*/*z* = 342 [M + H]$^+$.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{14}H_{17}INO$: 342.0354; found: 342.0343.

3-Iodo-4,6-diphenyl-1-azaspiro[4.5]deca-3,6,9-triene-2,8-dione (3l)
Yield: 98 mg (89%); white solid; mp 190–192 °C.

IR (KBr): 3322, 1716, 1657 cm^{-1}.

^{1}H NMR (300 MHz): δ = 7.57 (br s, 1 H), 7.42–7.27 (m, 7 H), 7.26 (dd, *J* = 5.86, 1.46 Hz, 1 H), 7.18 (s, 1 H), 7.16 (s, 1 H), 6.57 (dd, *J* = 10.26, 1.46 Hz, 1 H), 6.42–6.37 (m, 2 H).

^{13}C NMR (75.5 MHz): δ = 184.93, 170.23, 160.35, 154.31, 145.85, 135.69, 131.48, 130.44, 130.20, 129.95, 128.63, 128.60, 127.77, 127.40, 97.62, 68.69, 29.64.

MS (ESI): *m*/*z* = 462 [M + Na]$^+$.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{21}H_{14}INNaO_2$: 461.9967; found: 461.9959.

6-Bromo-3-iodo-4-phenyl-1-azaspiro[4.5]deca-3,6,9-triene-2,8-dione (3m)
Yield: 100 mg (91%); brown solid; mp 196–198 °C.

IR (KBr): 3305, 1723, 1653 cm^{-1}.

^{1}H NMR (300 MHz): δ = 7.45–7.35 (m, 3 H), 7.32–7.24 (m, 2 H), 7.03 (br s, 1 H), 6.83–6.75 (m, 2 H), 6.39 (d, *J* = 9.82 Hz, 1 H).

^{13}C NMR (75.5 MHz): δ = 182.15, 170.14, 159.81, 143.89, 143.62, 135.71, 130.93, 130.41, 128.79, 127.57, 98.74, 70.20.

MS (ESI): *m*/*z* = 464 [M + Na]$^+$.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{15}H_9BrINNaO_2$: 463.8759; found: 463.8739.

6-Chloro-3-iodo-4-phenyl-1-azaspiro[4.5]deca-3,6,9-triene-2,8-dione (3n)
Yield: 66 mg (67%); white solid; mp 188–190 °C.

IR (KBr): 3184, 1702, 1663 cm^{-1}.

^{1}H NMR (300 MHz): δ = 8.12 (br s, 1 H), 7.55–7.35 (m, 3 H), 7.32–7.21 (m, 2 H), 6.74 (d, *J* = 9.82 Hz, 1 H), 6.53 (d, *J* = 1.51 Hz, 1 H), 6.40 (dd, *J* = 9.82, 1.51 Hz, 1 H).

^{13}C NMR (75.5 MHz): δ = 182.93, 159.56, 150.47, 143.54, 131.56, 130.91, 130.572, 130.42, 128.83, 127.47, 98.62, 69.64, 29.66.

MS (ESI): *m*/*z* = 420 [M + Na]$^+$.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{15}H_9ClNNaO_2$: 419.9264; found: 419.9244.

8-*tert*-Butyl-3,4-diphenylquinolin-2(1*H*)-one (5)
Yield: 71 mg (80%); white solid; mp 259–260 °C.

IR (KBr): 3257, 1650 cm^{-1}.

^{1}H NMR (300 MHz): δ = 9.15 (br s, 1 H), 7.47 (d, *J* = 7.55 Hz, 1 H), 7.37–7.18 (m, 3 H), 7.18–7.02 (m, 8 H), 7.02–6.92 (m, 1 H), 1.64 (s, 9 H).

^{13}C NMR (75.5 MHz): δ = 161.13, 150.42, 136.7, 135.82, 134.93, 133.71, 131.23, 130.58, 129.70, 128.77, 127.89, 127.71, 127.62, 127.48, 126.97, 126.79, 121.71, 34.14, 30.64.

MS (ESI): *m*/*z* = 354 [M + H]$^+$.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{25}H_{24}NO$: 354.1857; found: 354.1875.

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