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ScienceDirect
Tetrahedron 63 (2007) 5406–5414
Tetrahedron

A novel three-component reaction for the synthesis of new 4-azafluorenone derivatives

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Received 8 November 2006; revised 17 April 2007; accepted 18 April 2007
Available online 24 April 2007

Abstract—Reaction of arylidenemalononitriles, 1,3-indanedione, and mercaptoacetic acid or 4-methylbenzenethiol is successfully carried out using microwave heating. It is an efficient and promising synthetic strategy to build the indenopyridine skeleton.
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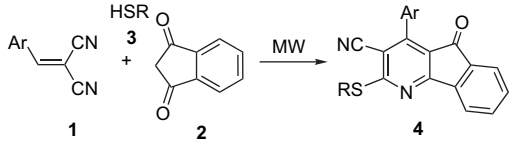
1. Introduction

Combinatorial chemistry is increasingly applied for the discovery of novel biologically active compounds.[1] In this context, multicomponent reactions (MCRs) are a powerful tool in the modern drug discovery process in terms of lead finding and lead optimization,[2] but the range of easily accessible and functionalized small heterocycles is rather limited. The development of new, rapid, and robust routes toward focused libraries of such heterocycles is therefore of great importance.[3]

The 4-azafluorenone (5*H*-indeno[1,2-*b*]pyridin-5-one) alkaloids from *Annonaceae* species comprise a small but biologically intriguing group of alkaloids.[4] 4-Azafluorenone derivatives are found to exhibit adenosine A2a receptor binding and phosphodiesterase inhibiting activities for the treatment of neurodegenerative disorders and inflammation-related diseases.[5] They also act as calcium antagonistic agents[6] and herbicides.[7] Because of their biological activities, these compounds have distinguished themselves as heterocycles of profound chemical and biological significance. As a result, the synthesis of these molecules has attracted considerable attention.[8]

Several approaches have been developed for the synthesis of 5*H*-indeno[1,2-*b*]pyridin-5-ones: oxidative thermal rearrangement of 2-indanone oxime *O*-ally1 ethers;[9] direct cyclization of 2-aryl-3-methylpyridines to give 5*H*-indeno[1,2-*b*]pyridines followed by oxidation;[10a] cyclization of 2-aryl-3-nicotinic acids by use of polyphosphoric acid.[10] Other way to build 5*H*-indeno[1,2-*b*]pyridin-5-ones is the extrusion of organophosphorus compound.[11] However, even these methods are still not satisfactory in view of using toxic catalyst, narrow application scope of substrates, harsh reaction conditions, generality, and operational complexity due to the occurrence of several side reactions. Thus, an efficient procedure is still strongly desired for the synthesis of these important heterocyclic compounds.

In continuation of our recent interest in the construction of heterocyclic scaffolds,[12] we developed a novel, three-component reaction between arylidenemalononitrile **1**, 1,3-indanedione **2**, and mercaptoacetic acid (or 4-methylbenzenethiol) **3** under microwave (MW) irradiation to afford a series of new heterocyclic compounds, the poly-substituted indeno[1,2-*b*]pyridines **4**, with new substituents such as mercapto group or *p*-tolylthio present in position 2 of the indeno[1,2-*b*]pyridine skeleton (Scheme 1).



Scheme 1.

2. Results and discussion

Initially, we screened various conditions for the one-pot, three-component reaction of arylidenemalononitrile, 1,3-indanedione, and mercaptoacetic acid at 100 °C under microwave irradiation (Scheme 2 and Table 1). Among various

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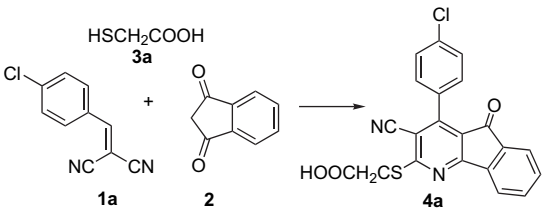
doi:10.1016/j.tet.2007.04.053



Scheme 2.

Table 1. Optimization of reaction conditions of compound **4a**

Entry	Solvent[a]	T (°C)	Time (min)	Yield[b] (%)
1	HOAc	100	10	48
2	Glycol	100	10	57
3	EtOH	100	12	51
4	Water	100	14	32
5	DMF	100	10	64
6	DMF	90	15	43
7	DMF	110	8	79
8	DMF	120	6	87
9	DMF	130	6	85

[a] The volume of solvent is 1.0 mL.
[b] Isolated yields.

polar solvents tested, glacial acetic acid (HOAc), glycol, ethanol, and water gave poor to moderate yields of the expected product (Table 1, entries 1–4). The best solvent was found to be *N*,*N*-dimethylformamide (DMF). In this solvent, indeno[1,2-*b*]pyridine (**4a**) was obtained with the best yield [**4a**; Table 1, entry 5]. To further optimize the reaction conditions, the reaction was carried out at temperatures ranging from 90 to 130 °C, with an increment of 10 °C each time. The yield of product **4a** was increased and the reaction time was shortened as the temperature was increased from 90 to 120 °C (Table 1, entries 5–8). However, further increase of the temperature to 130 °C failed to improve the yield of product **4a** (Table 1, entry 9). Therefore, 120 °C was chosen as the reaction temperature for all further microwave-assisted reactions.

The use of these optimal microwave experimental conditions [DMF, 120 °C] to the reactions of different arylidenemalononitriles afforded good yields of indeno[1,2-*b*]pyridine-5-ones, with mercapto and cyano groups present in positions 2 and 3 of the indeno[1,2-*b*]pyridine nucleus, respectively. To test the scope of arylidenemalononitriles, 1,3-indanedione and mercaptoacetic acid were used as model substrates, and the results (Table 2, entries 1–7) indicated that arylidenemalononitrile bearing functional groups such as chloro, bromo, fluoro, or methoxy are suitable for the reaction. We have also observed electronic effects, that is, arylidenemalononitriles with electron-withdrawing groups (Table 2, entries 1–4) reacted rapidly, while electron-rich groups (Table 2, entries 5–7) decreased the reactivity, requiring longer reaction time.

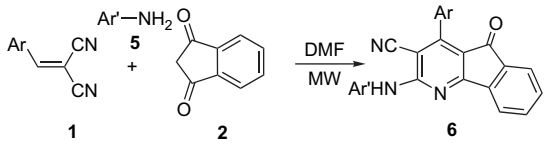
In order to expand the scope of this method, the replacement of mercaptoacetic acid **3a** with 4-methylbenzenethiol **3b** was examined. To our delight, under the optimized conditions described above, the reactions proceeded steadily to afford a series of new poly-substituted indeno[1,2-*b*]pyridines in good to excellent yields (Table 2, entries 9–13). The encouraging results led to the further investigation of other nucleophiles, whose nucleophilicity is similar to that of 4-methylbenzenethiol. As a representative, arylamines **5** reacted smoothly. A series of new poly-substituted indeno[1,2-*b*]pyridines **6** were obtained (Scheme 3). The results showed

Table 2. Microwave synthesis of poly-substituted indeno[1,2-*b*]pyridines **4** and **6**

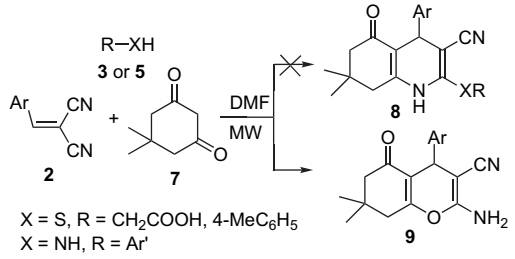
Entry	Product	**1**	Ar	**3** or **5**	R (or Ar′)	Time (min)	Yield[a] (%)	Mp (°C)
1	**4a**	**1a**	4-ClC_6H_4	**3a**	CH_2COOH	6	87	292–294
2	**4b**	**1b**	4-BrC_6H_4	**3a**	CH_2COOH	6	89	>300
3	**4c**	**1c**	4-FC_6H_4	**3a**	CH_2COOH	6	84	297–298
4	**4d**	**1d**	3,4-$Cl_2C_6H_3$	**3a**	CH_2COOH	4	87	>300
5	**4e**	**1e**	3,4-$OCH_2OC_6H_3$	**3a**	CH_2COOH	8	83	>300
6	**4f**	**1f**	4-$MeOC_6H_4$	**3a**	CH_2COOH	10	80	273–274
7	**4g**	**1g**	4-MeC_6H_4	**3a**	CH_2COOH	10	81	275–276
8	**4h**	**1h**	2-Thienyl	**3a**	CH_2COOH	12	82	268–270
9	**4i**	**1a**	4-ClC_6H_4	**3b**	4-MeC_6H_4	6	85	262–264
10	**4j**	**1c**	4-FC_6H_4	**3b**	4-MeC_6H_4	6	83	273–275
11	**4k**	**1i**	3-$NO_2C_6H_4$	**3b**	4-MeC_6H_4	4	88	245–247
12	**4l**	**1e**	3,4-$OCH_2OC_6H_3$	**3b**	4-MeC_6H_4	8	81	>300
13	**4m**	**1f**	4-$MeOC_6H_4$	**3b**	4-MeC_6H_4	7	79	295–297
14	**6a**	**1a**	4-ClC_6H_4	**5a**	4-MeC_6H_4	4	91	301–303
15	**6b**	**1b**	4-BrC_6H_4	**5a**	4-MeC_6H_4	5	84	>300
16	**6c**	**1i**	3-$NO_2C_6H_4$	**5a**	4-MeC_6H_4	5	88	263–265
17	**6d**	**1j**	4-$NO_2C_6H_4$	**5a**	4-MeC_6H_4	6	86	>300
18	**6e**	**1d**	3,4-$Cl_2C_6H_3$	**5a**	4-MeC_6H_4	4	89	292–294
19	**6f**	**1a**	4-ClC_6H_4	**5b**	C_6H_5	5	84	299–300
20	**6g**	**1b**	4-BrC_6H_4	**5b**	C_6H_5	4	86	>300
21	**6h**	**1j**	4-$NO_2C_6H_4$	**5b**	C_6H_5	4	89	>300
22	**6i**	**1k**	C_6H_5	**5b**	C_6H_5	6	78	279–281
23	**6j**	**1h**	2-Thienyl	**5b**	C_6H_5	8	81	211–212
24	**6k**	**1i**	3-$NO_2C_6H_4$	**5c**	4-ClC_6H_4	5	87	282–284
25	**6l**	**1j**	4-$NO_2C_6H_4$	**5c**	4-ClC_6H_4	6	84	>300
26	**6m**	**1a**	4-ClC_6H_4	**5d**	4-OHC_6H_4	6	82	>300
27	**6n**	**1j**	4-$NO_2C_6H_4$	**5d**	4-OHC_6H_4	4	84	>300

[a] Isolated yields.

that the scope of the reaction is quite broad in regard to the arylamines. Not only arylamines containing either electron-donating groups or electron-withdrawing groups can be used, aniline also gave excellent results.



Scheme 3.



Scheme 4.

In a further test, dimedone **7** was employed instead of 1,3-indanedione **2** to react with **1** and **3** or aromatic amines **5**. Surprisingly, we could not get the expected poly-substituted quinolines **8** in any cases. Instead, the chromenes **9** were obtained, which have been reported by Wang and Balalaie (Scheme 4).[13] The results are summarized in Table 3. The pK_a value of 1,3-indanedione (pK_a=7.2)[14] is higher than that of dimedone (pK_a=5.2).[14] We think that the pK_a of the 1,3-dicarbonyl compounds plays a critical role to the success of the reaction. This stimulated us to look for some other 1,3-dicarbonyl compounds with higher pK_a as substrates. As a representative, we selected 2,4-pentanedione (pK_a=9.0)[15] to test our hypothesis. Unfortunately, we failed to get the expected compounds, 2-substituted pyridine derivatives.

Additionally, to demonstrate the purely nonthermal microwave effects, the same temperature was applied to synthesize some of the products **4** and **6** under classical heating (CH) conditions. The results listed in Table 4 showed the specific activation of this reaction under microwave heating. Simultaneously, the reaction time was strikingly shortened to minutes from hours required in traditional heating condition, and the yields were increased obviously too. The reason may be attributed to the consequence of both thermal effects and specific effects induced by the microwave field.[16] The reactants in these MCRs contain dipoles and proceed via relatively polar intermediates, which enhance their interaction with MW and consequently benefit significantly from MW irradiation in regard to more efficient reaction time, yield, and product purity.

Table 3. Microwave synthesis of compounds **9**

Entry	Product	Ar	Yield[a] (%)
1	**9a**	4-ClC_6H_4	89
2	**9b**	4-BrC_6H_4	90
3	**9c**	3,4-$OCH_2OC_6H_3$	82
4	**9d**	4-MeOC_6H_4	83
5	**9e**	4-MeC_6H_4	79

[a] Isolated yields.

Table 4. The synthesis of some of compounds **4** and **6** under both MW and CH conditions (120 °C)

Entry	**4** or **6**	MW		CH	
		Time (min)	Yield[a] (%)	Time (h)	Yield[a] (%)
1	**4a**	6	87	4	75
2	**4e**	8	83	3	54
3	**4f**	10	80	2	49
4	**4k**	4	88	4	51
5	**6a**	4	91	4	56
6	**6i**	6	78	4	41
7	**6k**	5	87	3	39
8	**6n**	4	84	4	47

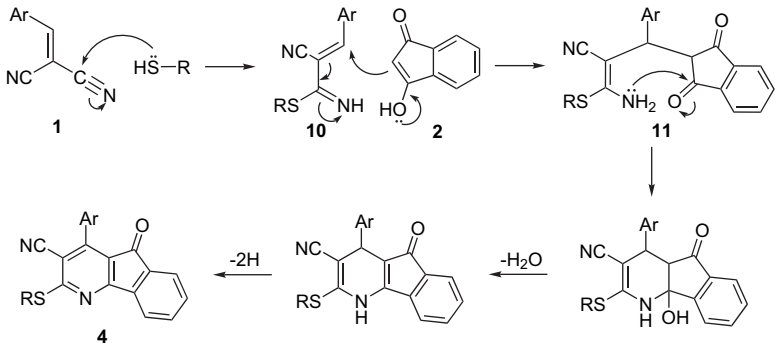
[a] Isolated yields.

The structures of all the synthesized compounds were established on the basis of their spectroscopic data. The IR spectrum of compound **4g** showed strong absorptions at 2220 cm^{-1} due to CN (triple bond) group, and 1772 and 1717 cm^{-1} due to C=O groups. The ^{1}H NMR spectrum of **4g** showed a singlet at δ 2.43 due to –CH_3, and a singlet at δ 4.24 due to CH_2. The IR spectrum of compound **6b** showed strong absorptions at 3306 cm^{-1}, which was due to NH group, and 2213 cm^{-1} due to CN (triple bond) group, and 1713 cm^{-1} due to C=O. The ^{1}H NMR spectrum of **6b** showed a singlet at δ 2.35 due to –CH_3, and a singlet at δ 9.90 due to NH proton (exchanged with D_2O).

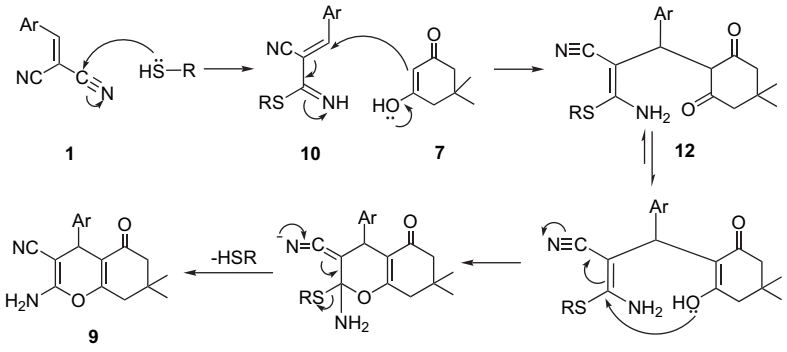
A reasonable mechanism for the formation of the product **4** is outlined in Scheme 5. The formation of the product **4** is expected to proceed via initial nucleophilic attack of SH to CN group to afford compound **10**, which further undergoes in situ Michael addition with 1,3-indanedione **2** to give open-chain intermediate **11**, which is subsequently cyclized and dehydrogenated to afford the aromatized product **4**. We propose a mechanism similar to that of Reddy and Chen[17] for base-promoted synthesis of organosulfur compounds. This type of dehydrogenation was well precedented.[18] The formation of the product **9** is likely to proceed via initial nucleophilic reaction and Michael addition to yield intermediate **12**, which is similar to the formation of intermediate **11**. Because the pK_a value of dimedone (pK_a=5.2)[14] is lower than that of 1,3-indanedione (pK_a=7.2),[14] the enolization of dimedone is easier than that of 1,3-indanedione. Therefore, the intermediate **12** undergoes isomerization, addition, and elimination, as shown in Scheme 6, to give products **9**.

3. Conclusion

In summary, we have demonstrated a rapid and direct method that offered a simple and efficient route for one-pot, three-component synthesis of highly functionalized indeno[1,2-*b*]pyridin-5-one derivatives in good to excellent yields. In addition, the procedure offers several advantages including operational simplicity, and increased safety for small-scale high-speed synthesis that make it a useful and attractive process for the synthesis of these compounds. Moreover, a series of indeno[1,2-*b*]quinoline derivatives may prove to be of biological interest to provide new classes of biological active compounds for biomedical screening.



Scheme 5.



Scheme 6.

4. Experimental

4.1. General

Microwave irradiation was carried out with microwave reactor Emrys™ Creator from Personal Chemistry, Uppsala, Sweden. Melting points were determined in open capillaries and were uncorrected. IR spectra were taken on a FTIR-Tensor 27 spectrometer in KBr pellets and reported in cm^{-1}. ^1H NMR spectra were measured on a Bruker DPX 400 MHz spectrometer in DMSO-d_6 with chemical shift (δ) given in parts per million relative to TMS as internal standard. Element analysis was determined by using a Perkin–Elmer 240c elemental analysis instrument.

4.1.1. General procedure for the synthesis of compounds 4 and 6 with microwave irradiation. In a 10-mL Emrys™ reaction vial, arylidenemalononitrile (**1**, 1 mmol), 1,3-indanedione (**2**, 1 mmol), thioglycolic acid or 4-methylbenzenethiol (**3**, 1.2 mmol) or arylamine (**5**, 1.2 mmol), and DMF (1.0 mL) were mixed and then capped. The mixture was heated for a given period as listed in Table 2 at 120 °C under microwave irradiation (initial power of 100 W and maximum power of 200 W). Upon completion, as monitored by TLC, the reaction mixture was cooled to room temperature. The solid was collected by Büchner filtration and washed with EtOH (95%), and subsequently dried and recrystallized from DMF to give the pure product.

4.1.2. General procedure for the synthesis of a part of compounds 4 and 6 with conventional heating. A mixture containing arylidenemalononitrile (**1**, 1 mmol), 1,3-indanedione (**2**, 1 mmol), mercaptoacetic acid or 4-methylbenzenethiol (**3**, 1.2 mmol) or arylamine (**5**, 1.2 mmol), and DMF (1.0 mL) was introduced into a 10-mL Emrys™ reaction vial, capped and then stirred at 120 °C (oil bath temperature) for the specific time. The subsequent work-up produce was the same as that of the above microwave irradiation condition.

4.1.2.1. [4-(4-Chlorophenyl)-3-cyano-5-oxo-5*H*-indeno-[1,2-*b*]pyridin-2-ylthio]acetic acid (4a). Yellow solid; IR (KBr, ν, cm^{-1}): 3072, 2998, 2923, 2217, 1773, 1717, 1595, 1572, 1382, 1266, 1174, 1059, 833, 748.

^1H NMR (400 MHz) (δ, ppm): 13.01 (br s, 1H, COOH), 7.90–7.79 (m, 2H, ArH), 7.71–7.63 (m, 6H, ArH), 4.26 (s, 2H, CH_2); ^{13}C NMR (100 MHz) (δ, ppm): 188.08, 169.97, 168.91, 166.24, 150.13, 141.02, 135.49, 135.27, 133.63, 131.24, 131.11, 130.81, 124.34, 123.97, 122.36, 120.42, 115.13, 104.46, 33.47.

Anal. Calcd for $C_{21}H_{11}ClN_2O_3S$: C, 62.00; H, 2.73; N, 6.89; S, 7.88. Found: C, 62.24; H, 2.89; N, 6.67; S, 7.71.

4.1.2.2. [4-(4-Bromophenyl)-3-cyano-5-oxo-5*H*-indeno-[1,2-*b*]pyridin-2-ylthio]acetic acid (4b). Yellow solid; IR (KBr, ν, cm^{-1}): 2926, 2219, 1772, 1719, 1606, 1543, 1382, 1188, 1011, 765.

^1H NMR (400 MHz) (δ, ppm): 13.01 (br s, 1H, COOH), 7.89 (d, J=7.2 Hz, 1H, ArH), 7.84–7.80 (m, 1H, ArH), 7.78 (d, J=8.8 Hz, 2H, ArH), 7.71–7.66 (m, 2H, ArH), 7.59 (d, J=8.8 Hz, 2H, ArH), 4.26 (s, 2H, CH_2); ^{13}C NMR (100 MHz) (δ, ppm): 188.22, 169.66, 169.04, 166.34, 149.93, 140.57, 135.72, 135.54, 133.40, 131.51, 131.31, 130.77, 124.17, 124.14, 122.01, 120.19, 114.91, 104.99, 33.53.

Anal. Calcd for $C_{21}H_{11}BrN_2O_3S$: C, 55.89; H, 2.46; N, 6.21; S, 7.11. Found: C, 55.61; H, 2.61; N, 6.12; S, 7.35.

4.1.2.3. [4-(4-Fluorophenyl)-3-cyano-5-oxo-5*H*-indeno-[1,2-*b*]pyridin-2-ylthio]acetic acid (4c). Yellow solid; IR (KBr, ν, cm^{-1}): 3074, 2927, 2215, 1771, 1713, 1605, 1506, 1216, 1160, 995, 750.

^1H NMR (400 MHz) (δ, ppm): 12.98 (br s, 1H, COOH), 7.87 (d, J=8.0 Hz, 1H, ArH), 7.81 (t, J=7.2 Hz, 1H, ArH), 7.71–7.66 (m, 2H, ArH), 7.50–7.47 (m, 2H, ArH), 7.43–7.39 (m, 2H, ArH), 4.25 (s, 2H, CH_2); ^{13}C NMR (100 MHz) (δ, ppm): 187.94, 169.84, 169.09, 166.31, 154.76, 149.87, 142.10, 140.52, 135.55, 133.37, 131.13, 129.34, 129.21, 124.71, 120.29, 115.21, 114.78, 114.59, 110.13, 104.84, 33.34.

Anal. Calcd for $C_{21}H_{11}FN_2O_3S$: C, 64.61; H, 2.84; N, 7.18; S, 8.21. Found: C, 64.84; H, 2.59; N, 7.41; S, 8.09.

4.1.2.4. [4-(3,4-Dichlorophenyl)-3-cyano-5-oxo-5*H*-indeno[1,2-*b*]pyridin-2-ylthio]acetic acid (4d). Yellow solid; IR (KBr, ν, cm^{-1}): 3066, 2217, 1773, 1715, 1609, 1575, 1466, 1203, 1006, 750.

^1H NMR (400 MHz) (δ, ppm): 12.99 (br s, 1H, COOH), 8.90 (s, 1H, ArH), 8.03–7.99 (m, 2H, ArH), 7.82–7.77 (m, 2H, ArH), 7.60–7.53 (m, 2H, ArH), 4.26 (s, 2H, CH_2); ^{13}C NMR (100 MHz) (δ, ppm): 188.13, 169.87, 168.93, 166.25, 150.01, 140.57, 136.41, 135.97, 135.41, 134.82, 133.54, 132.87, 132.59, 131.71, 130.65, 124.16, 124.08, 120.34, 114.89, 104.79, 33.58.

Anal. Calcd for $C_{21}H_{10}Cl_2N_2O_3S$: C, 57.16; H, 2.28; N, 6.35; S, 7.27. Found: C, 57.38; H, 2.14; N, 6.47; S, 7.05.

4.1.2.5. [4-(Benzo[*d*][1,3]dioxol-5-yl)-3-cyano-5-oxo-5*H*-indeno[1,2-*b*]pyridin-2-ylthio]acetic acid (4e). Yellow solid; IR (KBr, ν, cm^{-1}): 3010, 2934, 2908, 2216, 1769, 1716, 1541, 1489, 1242, 1035, 769.

^1H NMR (400 MHz) (δ, ppm): 12.97 (br s, 1H, COOH), 7.86 (d, J=7.2 Hz, 1H, ArH), 7.81 (t, J=7.2 Hz, 1H, ArH), 7.69–7.62 (m, 2H, ArH), 7.23 (s, 1H, ArH), 7.15–7.09 (m, 2H, ArH), 6.17 (s, 2H, CH_2), 4.23 (s, 2H, CH_2); ^{13}C NMR (100 MHz) (δ, ppm): 188.23, 169.70, 168.99, 166.33, 150.87, 149.19, 147.10, 140.52, 135.55, 133.37, 131.13, 127.34, 124.91, 124.03, 121.91, 120.20, 115.21, 110.13, 108.21, 105.22, 101.86, 33.54.

Anal. Calcd for $C_{22}H_{12}N_2O_5S$: C, 63.46; H, 2.90; N, 6.73; S, 7.70. Found: C, 63.23; H, 2.98; N, 6.69; S, 7.57.

4.1.2.6. [4-(4-Methoxyphenyl)-3-cyano-5-oxo-5*H*-indeno[1,2-*b*]pyridin-2-ylthio]acetic acid (4f). Yellow solid; IR (KBr, ν, cm^{-1}): 3057, 3002, 2931, 2840, 2219, 2219, 1715, 1605, 1510, 1443, 1262, 1175, 1061, 993, 837, 770.

^1H NMR (400 MHz) (δ, ppm): 13.01 (br s, 1H, COOH), 7.86 (d, J=7.2 Hz, 1H, ArH), 7.80 (t, J=7.2 Hz, 1H, ArH), 7.67–7.64 (m, 2H, ArH), 7.59 (d, J=8.8 Hz, 2H, ArH), 7.10 (d, J=8.8 Hz, 2H, ArH), 4.24 (s, 2H, CH_2), 3.87 (s, 3H, OCH_3); ^{13}C NMR (100 MHz) (δ, ppm): 187.86, 169.94, 168.74, 166.09, 163.43, 150.11, 140.38, 138.41, 135.24, 133.53, 131.49, 129.91, 124.27, 124.18, 122.36, 115.06, 113.47, 104.42, 54.89, 33.23.

Anal. Calcd for $C_{22}H_{14}N_2O_4S$: C, 65.66; H, 3.51; N, 6.96; S, 7.97. Found: C, 65.84; H, 3.40; N, 6.72; S, 7.81.

4.1.2.7. [4-*p*-Tolyl-3-cyano-5-oxo-5*H*-indeno[1,2-*b*]-pyridin-2-ylthio]acetic acid (4g). Yellow solid; IR (KBr, ν, cm^{-1}): 3012, 2930, 2220, 1772, 1717, 1609, 1540, 1267, 1177, 957, 764.

^1H NMR (400 MHz) (δ, ppm): 13.04 (br s, 1H, COOH), 7.87 (d, J=7.6 Hz, 1H, ArH), 7.81 (t, J=7.0 Hz, 1H, ArH), 7.67–7.62 (m, 2H, ArH), 7.50 (d, J=8.0 Hz, 2H, ArH), 7.36 (d, J=8.0 Hz, 2H, ArH), 4.24 (s, 2H, CH_2), 2.43 (s, 3H, CH_3); ^{13}C NMR (100 MHz) (δ, ppm): 187.82, 169.30, 168.96, 167.01, 149.44, 148.81, 140.43, 135.27, 133.97, 131.08, 128.76, 128.47, 126.21, 124.77, 123.59, 122.65, 115.02, 104.72, 33.51, 21.03.

Anal. Calcd for $C_{22}H_{14}N_2O_3S$: C, 68.38; H, 3.65; N, 7.25; S, 8.30. Found: C, 68.17; H, 3.71; N, 7.35; S, 8.43.

4.1.2.8. [4-(Thiophen-2-yl)-3-cyano-5-oxo-5*H*-indeno-[1,2-*b*]pyridin-2-ylthio]acetic acid (4h). Yellow solid; IR (KBr, ν, cm^{-1}): 3088, 3006, 2927, 2220, 1766, 1714, 1605, 1543, 1256, 1013, 761.

^1H NMR (400 MHz) (δ, ppm): 13.08 (br s, 1H, COOH), 8.00 (d, J=5.2 Hz, 1H, thienyl-H), 7.93 (d, J=7.2 Hz, 1H, thienyl-H), 7.87 (d, J=7.6 Hz, 1H, ArH), 7.83–7.80 (m, 2H, ArH), 7.59–7.56 (m, 1H, ArH), 7.30 (t, J=4.4 Hz, 1H, thienyl-H), 4.25 (s, 2H, CH_2); ^{13}C NMR (100 MHz) (δ, ppm): 188.35, 169.91, 168.69, 166.21, 150.23, 140.48, 136.11, 135.67, 131.46, 129.27, 127.58, 125.67, 124.32, 123.81, 122.15, 120.88, 114.76, 104.87, 33.46.

Anal. Calcd for $C_{19}H_{10}N_2O_3S_2$: C, 60.30; H, 2.66; N, 7.40; S, 16.95. Found: C, 60.51; H, 2.81; N, 7.31; S, 16.84.

4.1.2.9. 2-(*p*-Tolylthio)-4-(4-chlorophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (4i). Yellow solid; IR (KBr, ν, cm^{-1}): 3067, 2218, 1719, 1607, 1540, 1381, 1278, 1089, 1014, 832, 750.

^1H NMR (400 MHz) (δ, ppm): 7.81 (t, J=6.8 Hz, 1H, ArH), 7.75–7.71 (m, 2H, ArH), 7.70–7.66 (m, 4H, ArH), 7.61 (d, J=8.0 Hz, 2H, ArH), 7.41 (d, J=8.0 Hz, 2H, ArH), 7.37 (d, J=7.2 Hz, 1H, ArH), 2.45 (s, 3H, CH_3); ^{13}C NMR (100 MHz) (δ, ppm): 187.21, 168.71, 161.02, 150.44, 140.11, 136.81, 136.04, 134.86, 134.41, 132.81, 132.13, 131.72, 130.23, 128.56, 126.02, 123.58, 122.34, 120.99, 117.56, 114.73, 109.17, 20.69.

Anal. Calcd for $C_{26}H_{15}ClN_2OS$: C, 71.15; H, 3.44; N, 6.38; S, 7.31. Found: C, 71.39; H, 3.57; N, 6.27; S, 7.49.

4.1.2.10. 2-(*p*-Tolylthio)-4-(4-fluorophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (4j). Yellow solid; IR (KBr, ν, cm^{-1}): 3079, 3021, 2216, 1717, 1603, 1540, 1510, 1259, 1241, 1165, 990, 756.

^{1}H NMR (400 MHz) (δ, ppm): 7.73–7.69 (m, 4H, ArH), 7.66 (d, J=7.2 Hz, 1H, ArH), 7.61 (d, J=8.0 Hz, 2H, ArH), 7.44–7.40 (m, 4H, ArH), 7.37 (d, J=7.6 Hz, 1H, ArH), 2.45 (s, 3H, CH_3); ^{13}C NMR (100 MHz) (δ, ppm): 187.20, 167.89, 160.35, 154.26, 142.98, 139.82, 136.34, 136.11, 134.43, 132.43, 131.98, 130.88, 130.82, 129.59, 129.49, 127.31, 125.59, 124.06, 114.84, 114.28, 113.05, 110.98, 94.44, 21.19.

Anal. Calcd for $C_{26}H_{15}FN_2OS$: C, 73.92; H, 3.58; N, 6.63; S, 7.59. Found: C, 73.71; H, 3.47; N, 6.84; S, 7.71.

4.1.2.11. 2-(*p*-Tolylthio)-4-(3-nitrophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (4k). Yellow solid; IR (KBr, ν, cm^{-1}): 3074, 2223, 1716, 1615, 1556, 1529, 1351, 1261, 1018, 805, 764.

^{1}H NMR (400 MHz) (δ, ppm): 8.58 (s, 1H, ArH), 8.48–8.46 (m, 1H, ArH), 7.82 (d, J=7.6 Hz, 1H, ArH), 7.90 (t, J=8.0 Hz, 1H, ArH), 7.73 (t, J=7.6 Hz, 1H, ArH), 7.69–7.61 (m, 4H, ArH), 7.43 (d, J=8.0 Hz, 2H, ArH), 7.40 (d, J=8.0 Hz, 1H, ArH), 2.46 (s, 3H, CH_3); ^{13}C NMR (100 MHz) (δ, ppm): 188.68, 166.89, 158.04, 152.62, 149.01, 147.97, 140.86, 136.41, 135.97, 133.87, 135.7, 130.84, 130.63, 128.29, 125.62, 125.13, 124.75, 123.68, 122.08, 121.61, 120.83, 115.32, 107.62, 21.69.

Anal. Calcd for $C_{26}H_{15}N_3O_3S$: C, 69.48; H, 3.36; N, 9.35; S, 7.13. Found: C, 69.61; H, 3.25; N, 9.47; S, 7.05.

4.1.2.12. 2-(*p*-Tolylthio)-4-(benzo[*d*][1,3]dioxol-6-yl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (4l). Yellow solid; IR (KBr, ν, cm^{-1}): 3089, 2913, 2219, 1720, 1622, 1557, 1540, 1499, 1237, 1030, 821, 748.

^{1}H NMR (400 MHz) (δ, ppm): 7.76 (t, J=8.0 Hz, 2H, ArH), 7.67 (d, J=7.2 Hz, 1H, ArH), 7.61 (d, J=8.0 Hz, 2H, ArH), 7.42 (d, J=8.0 Hz, 2H, ArH), 7.36 (d, J=7.6 Hz, 1H, ArH), 7.23 (s, 1H, ArH), 7.16–7.14 (m, 1H, ArH), 7.11 (d, J=7.6 Hz, 1H, ArH), 6.18 (s, 2H, CH_2), 2.45 (s, 3H, CH_3); ^{13}C NMR (100 MHz) (δ, ppm): 188.03, 167.74, 160.24, 153.91, 149.79, 147.06, 140.47, 140.22, 136.36, 135.79, 134.52, 133.16, 130.28, 127.69, 126.60, 124.99, 124.02, 123.59, 123.38, 119.38, 117.64, 114.04, 110.09, 101.86, 21.18.

Anal. Calcd for $C_{27}H_{16}N_2O_3S$: C, 72.31; H, 3.60; N, 6.25; S, 7.15. Found: C, 72.54; H, 3.79; N, 6.41; S, 7.32.

4.1.2.13. 2-(*p*-Tolylthio)-4-(4-methoxyphenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (4m). Yellow solid; IR (KBr, ν, cm^{-1}): 3058, 2954, 2924, 2218, 1718, 1605, 1510, 1263, 1178, 1087, 808, 761.

^{1}H NMR (400 MHz) (δ, ppm): 7.89 (d, J=8.4 Hz, 2H, ArH), 7.69 (d, J=8.0 Hz, 2H, ArH), 7.66–7.64 (m, 1H, ArH), 7.60 (d, J=8.4 Hz, 2H, ArH), 7.41 (d, J=7.6 Hz, 2H, ArH), 7.36 (d, J=7.2 Hz, 1H, ArH), 7.11 (d, J=8.8 Hz, 2H, ArH), 3.88 (s, 3H, OCH_3), 2.45 (s, 3H, CH_3); ^{13}C NMR (100 MHz) (δ, ppm): 186.47, 165.91, 163.37, 163.27, 158.88, 145.55, 136.71, 136.46, 134.76, 134.46, 132.88, 133.22, 131.72, 126.02, 123.58, 122.34, 120.99, 117.56, 116.74, 114.39, 108.19, 54.83, 19.59.

Anal. Calcd for $C_{27}H_{18}N_2O_2S$: C, 74.63; H, 4.18; N, 6.45; S, 7.38. Found: C, 74.41; H, 4.33; N, 6.27; S, 7.54.

4.1.2.14. 2-(*p*-Tolylamino)-4-(4-chlorophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (6a). Yellow solid; IR (KBr, ν, cm^{-1}): 3315, 3037, 2217, 1704, 1613, 1575, 1384, 1242, 1158, 838, 763.

^{1}H NMR (400 MHz) (δ, ppm): 9.91 (s, 1H, NH), 7.71–7.68 (m, 2H, ArH), 7.64–7.61 (m, 6H, ArH), 7.59 (d, J=8.4 Hz, 2H, ArH), 7.24 (d, J=8.4 Hz, 2H, ArH), 2.35 (s, 3H, CH_3); ^{13}C NMR (100 MHz) (δ, ppm): 187.69, 168.35, 160.09, 152.59, 140.54, 136.37, 135.87, 134.96, 134.05, 132.85, 131.27, 131.19, 129.08, 128.80, 123.83, 123.51, 123.21, 121.52, 115.87, 115.17, 90.78, 20.70.

Anal. Calcd for $C_{26}H_{16}ClN_3O$: C, 74.02; H, 3.82; N, 9.96. Found: C, 74.29; H, 3.68; N, 9.79.

4.1.2.15. 2-(*p*-Tolylamino)-4-(4-bromophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (6b). Yellow solid; IR (KBr, ν, cm^{-1}): 3306, 2213, 1713, 1610, 1571, 1520, 1240, 1009, 813, 763.

^{1}H NMR (DMSO-d_6) (δ, ppm): 9.90 (s, 1H, NH), 7.76 (d, J=8.4 Hz, 2H, ArH), 7.70–7.68 (m, 2H, ArH), 7.61–7.60 (m, 2H, ArH), 7.58 (d, J=8.4 Hz, 2H, ArH), 7.53 (d, J=8.4 Hz, 2H, ArH), 7.24 (d, J=8.4 Hz, 2H, ArH), 2.35 (s, 3H, CH_3); ^{13}C NMR (100 MHz) (δ, ppm): 187.70, 168.34, 160.10, 152.70, 140.51, 136.40, 135.90, 134.99, 134.07, 132.83, 131.29, 131.21, 129.10, 128.88, 123.81, 123.59, 123.29, 121.50, 115.82, 115.19, 90.87, 20.78.

Anal. Calcd for $C_{26}H_{16}BrN_3O$: C, 66.97; H, 3.46; N, 9.01. Found: C, 66.89; H, 3.54; N, 9.17.

4.1.2.16. 2-(*p*-Tolylamino)-4-(3-nitrophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (6c). Yellow solid; IR (KBr, ν, cm^{-1}): 3333, 2205, 1711, 1682, 1602, 1557, 1530, 1349, 1208, 797, 771.

^{1}H NMR (DMSO-d_6) (δ, ppm): 10.00 (s, 1H, NH), 8.49 (s, 1H, ArH), 8.44 (d, J=8.0 Hz, 1H, ArH), 8.07 (d, J=7.6 Hz, 1H, ArH), 7.90–7.86 (m, 1H, ArH), 7.70–7.62 (m, 4H, ArH), 7.59 (d, J=8.4 Hz, 2H, ArH), 7.25 (d, J=8.4 Hz, 2H, ArH), 2.35 (s, 3H, CH_3); ^{13}C NMR (100 MHz) (δ, ppm): 187.77, 170.47, 160.10, 147.50, 140.56, 136.43, 135.88, 135.12, 134.37, 134.20, 133.62, 133.21, 132.94, 130.03, 129.15, 127.71, 124.73, 124.34, 123.66, 123.41, 121.59, 115.40, 90.89, 20.79.

Anal. Calcd for $C_{26}H_{16}N_4O_3$: C, 72.21; H, 3.73; N, 12.96. Found: C, 72.39; H, 3.59; N, 12.81.

4.1.2.17. 2-(*p*-Tolylamino)-4-(4-nitrophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (6d). Yellow solid; IR (KBr, ν, cm^{-1}): 3323, 3078, 2214, 1703, 1678, 1608, 1564, 1521, 1349, 1159, 856, 767, 722.

^{1}H NMR (DMSO-d_6) (δ, ppm): 9.99 (s, 1H, NH), 8.40 (d, J=8.8 Hz, 2H, ArH), 7.87 (d, J=8.8 Hz, 2H, ArH), 7.72–7.70 (m, 1H, ArH), 7.62–7.61 (m, 2H, ArH), 7.59 (d, J=8.4 Hz, 2H, ArH), 7.56–7.55 (m, 1H, ArH), 7.25 (d,

J=8.4 Hz, 2H, ArH), 2.35 (s, 3H, CH_3); ^{13}C NMR (100 MHz) (δ, ppm): 187.61, 168.47, 160.32, 155.17, 151.59, 148.82, 140.53, 135.89, 134.82, 132.98, 130.76, 129.14, 126.84, 126.38, 124.60, 123.70, 123.35, 123.02, 121.62, 114.23, 89.67, 20.81.

Anal. Calcd for $C_{26}H_{16}N_4O_3$: C, 72.21; H, 3.73; N, 12.96. Found: C, 72.43; H, 3.57; N, 12.82.

4.1.2.18. 2-(*p*-Tolylamino)-4-(3,4-dichlorophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (6e). Yellow solid; IR (KBr, ν, cm^{-1}): 3312, 2215, 1711, 1611, 1569, 1522, 1376, 1240, 945, 763.

^{1}H NMR (DMSO-d_6) (δ, ppm): 9.97 (s, 1H, NH), 7.71 (s, 1H, ArH), 7.85 (d, J=8.4 Hz, 1H, ArH), 7.71–7.68 (m, 2H, ArH), 7.63–7.61 (m, 3H, ArH), 7.58 (d, J=8.4 Hz, 2H, ArH), 7.25 (d, J=8.4 Hz, 2H, ArH), 2.35 (s, 3H, CH_3); ^{13}C NMR (100 MHz) (δ, ppm): 187.69, 168.26, 160.01, 154.28, 151.03, 140.48, 136.40, 135.82, 135.09, 133.42, 132.94, 132.75, 131.28, 130.99, 130.56, 129.50, 129.13, 128.90, 123.67, 123.40, 121.58, 114.71, 90.80, 20.80.

Anal. Calcd for $C_{26}H_{15}Cl_2N_3O$: C, 68.43; H, 3.31; N, 9.21. Found: C, 68.21; H, 3.49; N, 9.09.

4.1.2.19. 2-(Phenylamino)-4-(4-chlorophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (6f). Yellow solid; IR (KBr, ν, cm^{-1}): 3327, 3059, 2221, 1704, 1608, 1571, 1527, 1495, 1385, 1280, 1156, 934, 813, 744.

^{1}H NMR (DMSO-d_6) (δ, ppm): 9.95 (s, 1H, NH), 7.73 (d, J=8.4 Hz, 2H, ArH), 7.71–7.70 (m, 2H, ArH), 7.63–7.61 (m, 6H, ArH), 7.44 (t, J=8.0 Hz, 2H, ArH), 7.22 (t, J=7.4 Hz, 1H, ArH); ^{13}C NMR (100 MHz) (δ, ppm): 187.71, 168.27, 160.05, 152.67, 140.52, 136.35, 134.86, 132.86, 131.66, 131.11, 128.67, 128.42, 128.29, 124.81, 123.78, 123.41, 123.33, 121.52, 115.78, 115.56, 91.31.

Anal. Calcd for $C_{25}H_{14}ClN_3O$: C, 73.62; H, 3.46; N, 10.30. Found: C, 73.81; H, 3.62; N, 10.19.

4.1.2.20. 2-(Phenylamino)-4-(4-bromophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (6g). Yellow solid; IR (KBr, ν, cm^{-1}): 3275, 2221, 1705, 1608, 1570, 1527, 1384, 1203, 1011, 934, 767.

^{1}H NMR (DMSO-d_6) (δ, ppm): 9.97 (s, 1H, NH), 7.77 (d, J=8.4 Hz, 2H, ArH), 7.74–7.70 (m, 4H, ArH), 7.63–7.62 (m, 2H, ArH), 7.53 (d, J=8.4 Hz, 2H, ArH), 7.54 (t, J=8.0 Hz, 2H, ArH), 7.22 (t, J=7.4 Hz, 1H, ArH); ^{13}C NMR (100 MHz) (δ, ppm): 187.72, 168.27, 160.04, 152.69, 140.51, 138.55, 136.35, 135.03, 132.86, 132.04, 131.29, 131.21, 128.66, 128.41, 124.81, 123.41, 123.32, 121.52, 115.77, 115.49, 91.21.

Anal. Calcd for $C_{25}H_{14}BrN_3O$: C, 66.39; H, 3.12; N, 9.29. Found: C, 66.58; H, 3.01; N, 9.48.

4.1.2.21. 2-(Phenylamino)-4-(4-nitrophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (6h). Yellow solid; IR (KBr, ν, cm^{-1}): 3340, 2204, 1710, 1610, 1567, 1481, 1349, 1277, 1158, 937, 759, 728.

^{1}H NMR (DMSO-d_6) (δ, ppm): 10.06 (s, 1H, NH), 8.41 (d, J=8.8 Hz, 2H, ArH), 7.88 (d, J=8.8 Hz, 2H, ArH), 7.74–7.72 (m, 4H, ArH), 7.63–7.62 (m, 2H, ArH), 7.45 (t, J=8.0 Hz, 2H, ArH), 7.23 (t, J=7.4 Hz, 1H, ArH); ^{13}C NMR (100 MHz) (δ, ppm): 187.63, 168.24, 159.98, 151.61, 151.09, 148.46, 140.56, 139.56, 138.48, 135.18, 133.01, 130.76, 128.77, 128.71, 124.96, 123.53, 123.34, 121.65, 115.57, 115.24, 91.01.

Anal. Calcd for $C_{25}H_{14}N_4O_3$: C, 71.77; H, 3.37; N, 13.39. Found: C, 71.94; H, 3.51; N, 13.18.

4.1.2.22. 2-(Phenylamino)-4-phenyl-5-oxo-5*H*-indeno-[1,2-*b*]pyridine-3-carbonitrile (6i). Yellow solid; IR (KBr, ν, cm^{-1}): 3313, 3052, 2209, 1711, 1606, 1560, 1496, 1477, 1443, 1361, 1240, 1154, 936, 752.

^{1}H NMR (DMSO-d_6) (δ, ppm): 9.91 (s, 1H, NH), 7.74 (d, J=8.0 Hz, 2H, ArH), 7.71–7.70 (m, 2H, ArH), 7.61–7.56 (m, 7H, ArH), 7.44 (t, J=7.8 Hz, 2H, ArH), 7.21 (t, J=7.4 Hz, 1H, ArH); ^{13}C NMR (100 MHz) (δ, ppm): 187.72, 168.30, 160.11, 154.05, 140.53, 138.63, 136.35, 134.97, 132.83, 129.95, 129.12, 128.66, 128.41, 128.13, 124.74, 123.74, 123.36, 123.27, 121.47, 115.93, 115.57, 91.49.

Anal. Calcd for $C_{25}H_{15}N_3O$: C, 80.41; H, 4.05; N, 11.25. Found: C, 80.19; H, 4.21; N, 11.13.

4.1.2.23. 2-(Phenylamino)-4-(thiophen-2-yl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (6j). Yellow solid; IR (KBr, ν, cm^{-1}): 3301, 2208, 1711, 1606, 1559, 1497, 1387, 1329, 753, 704.

^{1}H NMR (DMSO-d_6) (δ, ppm): 9.92 (s, 1H, NH), 7.95 (d, J=4.8 Hz, 1H, thiophenyl-H), 7.71 (t, J=7.6 Hz, 4H, ArH), 7.65–7.61 (m, 2H, ArH), 7.59 (d, J=3.6 Hz, 1H, thiophenyl-H), 7.44 (t, J=8.0 Hz, 2H, ArH), 7.29 (t, 1H, J=4.4 Hz, thiophenyl-H), 7.21 (t, J=7.4 Hz, 1H, ArH); ^{13}C NMR (100 MHz) (δ, ppm): 187.71, 168.39, 160.34, 155.02, 145.28, 140.48, 138.64, 136.24, 134.87, 132.84, 129.37, 127.52, 126.74, 124.21, 123.72, 123.15, 121.45, 121.23, 115.92, 115.39, 90.56.

Anal. Calcd for $C_{23}H_{13}N_3OS$: C, 72.80; H, 3.45; N, 11.07; S, 8.45. Found: C, 72.97; H, 3.34; N, 11.21; S, 8.34.

4.1.2.24. 2-(4-Chlorophenylamino)-4-(3-nitrophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (6k). Yellow solid; IR (KBr, ν, cm^{-1}): 3331, 3089, 2204, 1714, 1686, 1611, 1584, 1537, 1520, 1491, 1351, 1210, 950, 808.

^{1}H NMR (DMSO-d_6) (δ, ppm): 10.15 (s, 1H, NH), 8.50 (s, 1H, ArH), 8.45 (d, J=8.4 Hz, 1H, ArH), 8.07 (d, J=7.6 Hz, 1H, ArH), 7.88 (t, J=7.8 Hz, 1H, ArH), 7.77 (d, J=8.8 Hz, 2H, ArH), 7.75–7.73 (m, 2H, ArH), 7.63–7.62 (m, 2H, ArH), 7.50 (d, J=8.8 Hz, 2H, ArH); ^{13}C NMR (100 MHz) (δ, ppm): 188.03, 167.91, 161.59, 154.71, 151.38, 148.32, 140.19, 139.46, 136.21, 134.39, 132.83, 131.74, 131.28, 130.17, 129.91, 129.22, 125.41, 123.34, 121.61, 115.53, 115.27, 114.58, 89.59.

Anal. Calcd for $C_{25}H_{13}ClN_4O_3$: C, 66.31; H, 2.89; N, 12.37. Found: C, 66.19; H, 2.97; N, 12.19.

4.1.2.25. 2-(4-Chlorophenylamino)-4-(4-nitrophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (6l). Yellow solid; IR (KBr, ν, cm^{-1}): 3322, 3064, 2215, 1712, 1686, 1608, 1565, 1492, 1384, 1280, 1089, 1003, 814, 737.

^1H NMR (DMSO-d_6) (δ, ppm): 10.15 (s, 1H, NH), 8.44 (d, J=8.8 Hz, 2H, ArH), 8.41 (d, J=8.4 Hz, 2H, ArH), 7.88–7.84 (m, 2H, ArH), 7.77 (d, J=8.8 Hz, 2H, ArH), 7.74 (d, J=8.4 Hz, 2H, ArH), 7.72–7.63 (m, 1H, ArH), 7.51–7.45 (m, 1H, ArH); ^{13}C NMR (100 MHz) (δ, ppm): 187.68, 168.13, 161.02, 154.97, 152.58, 148.12, 140.38, 139.62, 136.01, 134.46, 132.94, 131.76, 130.23, 129.55, 125.51, 123.21, 121.48, 115.59, 115.13, 114.20, 89.99.

Anal. Calcd for $C_{25}H_{13}ClN_4O_3$: C, 66.31; H, 2.89; N, 12.37. Found: C, 66.58; H, 2.99; N, 12.27.

4.1.2.26. 2-(4-Hydroxyphenylamino)-4-(4-chlorophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (6m). Red solid; IR (KBr, ν, cm^{-1}): 3338, 3296, 2217, 1696, 1608, 1551, 1501, 1431, 1287, 1052, 947, 779.

^1H NMR (DMSO-d_6) (δ, ppm): 9.79 (s, 1H, NH), 9.48 (s, 1H, OH), 7.69–7.57 (m, 8H, ArH), 7.44 (d, J=8.4 Hz, 2H, ArH), 6.82 (d, J=8.4 Hz, 2H, ArH); ^{13}C NMR (100 MHz) (δ, ppm): 187.65, 168.46, 160.31, 155.06, 152.66, 140.49, 136.49, 134.88, 134.77, 132.76, 131.81, 131.09, 129.69, 128.26, 125.65, 123.18, 121.45, 115.88, 115.16, 114.70, 90.25.

Anal. Calcd for $C_{25}H_{14}ClN_3O_2$: C, 70.84; H, 3.33; N, 9.91. Found: C, 70.67; H, 3.51; N, 9.80.

4.1.2.27. 2-(4-Hydroxyphenylamino)-4-(4-nitrophenyl)-5-oxo-5*H*-indeno[1,2-*b*]pyridine-3-carbonitrile (6n). Red solid; IR (KBr, ν, cm^{-1}): 3348, 3300, 2222, 1690, 1620, 1564, 1510, 1344, 1236, 1158, 937, 757.

^1H NMR (DMSO-d_6) (δ, ppm): 9.99 (s, 1H, NH), 9.50 (s, 1H, OH), 8.40 (d, J=8.8 Hz, 2H, ArH), 7.86 (d, J=8.8 Hz, 2H, ArH), 7.71–7.69 (m, 2H, ArH), 7.61–7.59 (m, 2H, ArH), 7.45 (d, J=8.8 Hz, 2H, ArH), 6.83 (d, J=8.8 Hz, 2H, ArH); ^{13}C NMR (100 MHz) (δ, ppm): 187.54, 168.41, 160.22, 155.16, 151.58, 148.40, 146.89, 140.52, 139.72, 136.47, 135.01, 132.89, 130.72, 129.58, 125.73, 123.30, 121.56, 115.57, 115.18, 114.69, 89.94.

Anal. Calcd for $C_{25}H_{14}N_4O_4$: C, 69.12; H, 3.25; N, 12.90. Found: C, 69.34; H, 3.18; N, 12.86.

4.1.3. General procedure for the synthesis of compounds 9 with microwave irradiation. In a 10-mL Emrys™ reaction vial, arylidenemalononitrile (**1**, 1 mmol), dimedone (**7**, 1 mmol), thioglycolic acid or 4-methylbenzenethiol (**3**, 1.2 mmol) or arylamine (**5**, 1.2 mmol), and DMF (1.0 mL) were mixed and then capped. The mixture was heated for 4–6 min at 120 °C under microwave irradiation (initial power of 100 W and maximum power of 200 W). Upon completion, as monitored by TLC, the reaction mixture was cooled to room temperature. The solid was collected by Büchner filtration and washed with water, and subsequently dried and recrystallized from EtOH (95%) to give the pure product.

4.1.3.1. 2-Amino-4-(4-chlorophenyl)-5,6,7,8-tetrahydro-7,7-dimethyl-5-oxo-4*H*-chromene-3-carbonitrile (9a). White crystals; mp 210–211 °C (lit.[13a] 207–209 °C).

4.1.3.2. 2-Amino-4-(4-bromophenyl)-5,6,7,8-tetrahydro-7,7-dimethyl-5-oxo-4*H*-chromene-3-carbonitrile (9b). White crystals; mp 206–207 °C (lit.[13b] 203–205 °C).

4.1.3.3. 2-Amino-4-(benzo[*d*][1,3]dioxol-5-yl)-5,6,7,8-tetrahydro-7,7-dimethyl-5-oxo-4*H*-chromene-3-carbonitrile (9c). Pale yellow crystals; mp 214–215 °C (lit.[13a] 208–210 °C).

4.1.3.4. 2-Amino-4-(4-methoxyphenyl)-5,6,7,8-tetrahydro-7,7-dimethyl-5-oxo-4*H*-chromene-3-carbonitrile (9d). White crystals; mp 199–200 °C (lit.[13a] 198–200 °C).

4.1.3.5. 2-Amino-4-*p*-tolyl-5,6,7,8-tetrahydro-7,7-dimethyl-5-oxo-4*H*-chromene-3-carbonitrile (9e). White crystals; mp 218–220 °C (lit.[13b] 223–225 °C).

Acknowledgements

We are grateful to financial support from the National Science Foundation of China (no. 20672090) and Natural Science Foundation of the Jiangsu Province (no. BK2006033).

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