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ORIGINAL PAPER

Silica sodium carbonate: the most efficient catalyst for the one-pot synthesis of indeno[1,2-*b*]quinoline and spiro [chromene-4,3′-indoline]-3-carbonitriles under solvent-free condition

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Abstract A new silica sodium carbonate-assisted convenient and efficient strategy for the synthesis of indeno[1,2-*b*]quinoline and spiro[chromene-4,3′-indoline]-3-carbonitriles derivatives in solvent-free media is described. The reactions can be performed at low catalyst loadings with excellent functional group tolerance. The catalyst can be easily recovered and reused for the next reaction for at least three runs without any significant impact on the yields of the products. The easy recovery of the catalyst and high yield of the products make the protocol attractive, sustainable, and economic.

Keywords Silica sodium carbonate · Indeno[1,2-b]quinoline · Spiro[chromene-4,3′-indoline]-3-carbonitriles · One-pot · Solvent free

Introduction

Heterocycles are ubiquitous in natural products, pharmaceuticals, organic materials, and numerous functional molecules. Therefore, the interest for developing new, versatile, and efficient synthesis of heterocycles has always been a challenge in the synthetic community [1]. Indeno[1,2-*b*]quinoline and its derivatives are very useful compounds in various fields of chemistry, including biological and pharmacological chemistry. Some of these compounds exhibit antimalarials [2], antitumor agents [3, 4], new potential topo I/II inhibitors [5, 6], steroid reductase inhibitors [7], acetylcholinesterase inhibitors [8], 5-HT-receptor binding [9], and anti-inflammatory activities [10]. In recent years, numerous protocols for preparation of indeno[1,2-*b*]quinoline have been developed in different ways by using acetic acid [11], *p*-toluenesulfonic acid [12] with microwave irradiations, ionic liquid [bmim][BF_4] [13], heteropolyacid $H_{14}[NaP_5W_{30}O_{110}]$ [14], and TiO_2 [15, 16] as a catalyst. These reported methodologies produce good results in many instances. However, some of the synthetic strategies suffer with certain limitations such as expensive catalysts, low yields of products, long reaction times, tedious procedures for preparations of catalysts, tedious work-up conditions, and all are failed to show oxidized product. Hence, the development of efficient, simple, easy work-up, and environmentally benign protocol using a recyclable catalyst and solvent-free condition for the synthesis of indeno[1,2-*b*]quinoline derivatives is still desirable and in demand. In the recent years, heterogeneous catalysts have found increased application in organic synthesis as they are efficient, easily recovered and recycled [17, 18]. Although supported catalysts are available on different supports, including charcoal, alumina, silica, and polymer, silica has many other advantages such as no swelling, good mechanical and thermal stability, and ease of scalability. It is evident from the previous literature that silica-supported catalyst has invoked enormous interest as a potential green, heterogenous, and eco-friendly catalyst to construct carbon–carbon and carbon-heteroatom bonds in various organic transformations [19–21]. In this connection, silica sodium carbonate (SSC) has invoked tremendous attention as a green and heterogenous catalyst.

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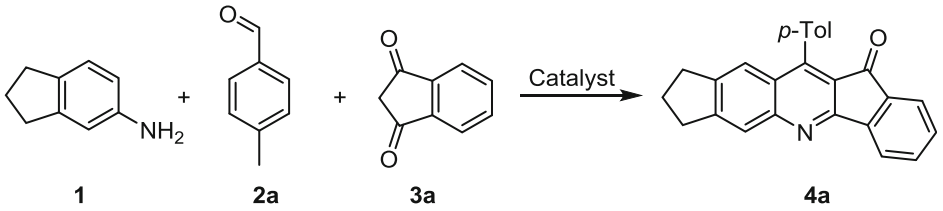
Table 1 Optimization of catalysts, solvents, and temperature in the synthesis of **4a**

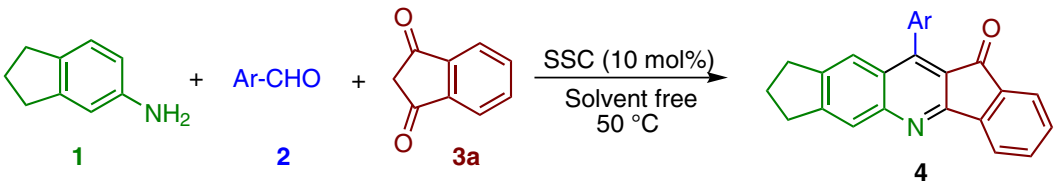


No.	Catalyst (10 mol%)	Solvent	Temp./°C	Time/h	Yield[a]/%
1	–	–	50	8	22
2	$FeCl_3{\cdot}SiO_2$	Ethanol	80	8	35
3	SiO_2	Neat	100	6	38
4	$TiO_2{\cdot}SiO_2$	Ethylene glycol	120	3	65
5	Cu–Sn (200 mesh, 100 mg)	Methanol	80	5	50
6	$Zn(OTf)_2$	Ethanol	80	4	55
7	SSC	Ethanol	80	3	90
8	SSC	Neat	80	0.83	94
9	SSC	Neat	70	0.83	90
10	$BF_3{\cdot}SiO_2$	Neat	50	3	75
11	Li(OTf)	Neat	50	3	60
12	$SnCl_2{\cdot}2H_2O$	Neat	50	2	65
13	$FeCl_3{\cdot}SiO_2$	Neat	50	3	85
14	STA	Neat	50	2	80
15	SSC	Water	100	2	80
16	SSC	DMF	160	3	82
17	SSC	Methanol	80	4	85
18	SSC	Ethylene glycol	120	3	82
19	SSC	ACN	50	2	86
20	SSC	Toluene	50	2.5	88
21	SSC	THF	80	2	85
22	SSC (5 mol%)	Neat	50	0.5	90
23	SSC (20 mol%)	Neat	50	0.5	88

Reaction condition: 2,3-dihydro-1*H*-inden-5-amine (1 mmol), 4-methylbenzaldehyde (1 mmol), 2*H*-indene-1,3-dione (1 mmol), catalyst (10 mol%)

[a] Isolated yield

Scheme 1



The use of the SSC catalyst has several advantages over a conventional catalyst, such as its ease of handling (as a bench top catalyst), stable, inexpensive, recyclability, and reusability. Despite its great importance, few paper reported on its catalytic application in organic synthesis [22].

In continuation of our research in exploring new [23] and practical multicomponent reactions to synthesize useful heterocyclic compounds [24–26], we disclosed a novel methodology for synthesis of indeno[1,2-*b*]quinoline by condensation of 2,3-dihydro-1*H*-inden-5-amine with aromatic aldehydes and 2*H*-indene-1,3-dione in the presence of silica sodium carbonate under solvent-free condition at 50 °C (Scheme 1).

Results and discussion

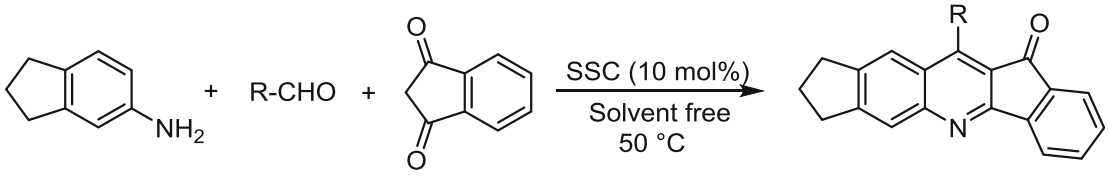
To optimize the reaction condition, we began our examination of the reaction of 2,3-dihydro-1*H*-inden-5-amine, 4-methylbenzaldehyde, and 2*H*-indene-1,3-dione in the presence of different catalysts and solvents (Table 1). To establish the real effectiveness of the catalyst for the synthesis of indeno[1,2-*b*]quinoline derivatives, the test reaction was performed without catalyst in neat condition at 50 °C. It was found that only a 22 % amount of product was obtained in the absence of catalyst even after 8 h (Table 1, entry 1).

In search of effective, eco-friendly, and efficient, reusable catalytic system for this reaction, the same test reaction was performed with different supported metal Lewis acid catalysts such as Cu–Sn (200 mesh, 100 mg), $FeCl_3{\cdot}SiO_2$, SiO_2, STA, $BF_3{\cdot}SiO_2$ $Zn(OTf)_2$, SSC, Li(OTf), $SnCl_2{\cdot}2H_2O$, and $TiO_2{\cdot}SiO_2$. Among all screened catalysts, SSC gave the best result in view of yield and reaction time (Table 1, entry 8). In contrast, Cu–Sn (200 mesh, 100 mg), STA, SiO_2, $Zn(OTf)_2$, $ZnCl_2$, Li(OTf), and $SnCl_2{\cdot}2H_2O$ did not afford the desired product in good yields (Table 1, entries 2–6, 11, 12). SSC was shown to be more effective than STA in terms of yield and time for completion of the reaction (Table 1, entries 8 and 14).

To assess the effect of solvents on this reaction, we screened different solvents such as toluene, EtOH, ACN, DMF, ethylene glycol, methanol, water, and THF. It was observed that under solvent condition required longer times (2–4 h) to afford comparable yields (Table 1, entries 15–21). When the reaction was performed under solvent-free conditions, high yield of target product was obtained (Table 1, entry 8). Moreover, we found that the yields were affected by the amount of SSC loaded. When 10, 5, and 20 mol% of SSC were used, the yields were 94, 90, and 88 %, respectively (Table 1, entries 8, 22, 23). Therefore, 10 mol% of SSC was sufficient and optimal quantity for the completion of the reaction.

Thus, we selected the optimized reaction condition to examine the universality of this catalyst application with different electron-rich and -deficient substrates. It was gratifying to observe that most of the tested substrates

Table 2 Synthesis of indeno[1,2-*b*]quinoline catalyzed by SSC



1 **2** **3a** **4a-4k**

Entry	R	Product	Time/min	Yield[a]/%	M.p./°C
1	4-Me-C_6H_4	**4a**	50	94	260–262
2	2-Cl-6-F-C_6H_3	**4b**	56	90	190–192
3	4-F-C_6H_4	**4c**	48	91	246–248
4	4-Cl-C_6H_4	**4d**	55	96	274–276
5	4-Br-C_6H_4	**4e**	49	95	286–288
6	2-Br-C_6H_4	**4f**	43	89	220–222
7	2-NO_2-C_6H_4	**4g**	40	90	278–280
8	C_6H_5	**4h**	42	95	238–240
9	2-Me-C_6H_4	**4i**	46	91	266–268
10	4-*i*-Pr-C_6H_4	**4j**	51	88	264–266
11	*i*-Pr	**4k**	17 h	NR	–

Reaction condition: 2,3-dihydro-1*H*-inden-5-amine (1 mmol), aldehyde (1 mmol), 2*H*-indene-1,3-dione (1 mmol), SSC (10 mol%) at 50 °C

NR no reaction

[a] Isolated yield

Scheme 2

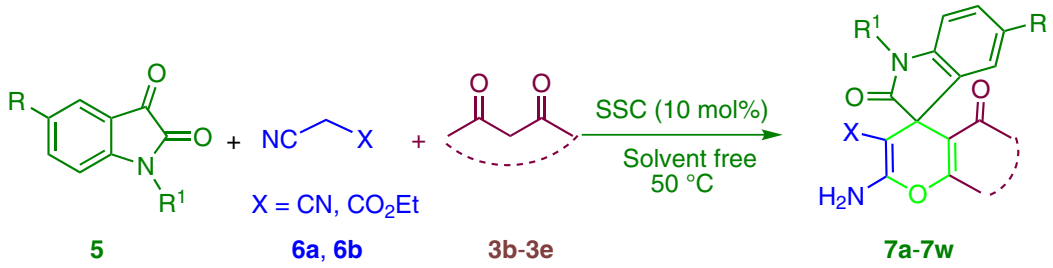


Table 3 Detection of the reaction conditions

Entry	Amount of cat./mol%	Time/min	Yield[a]/%
1	–	540	No reaction
2	5	300	30
3	10	10	96
4	15	10	96

Reaction conditions: isatins (1 mmol), malononitrile (1 mmol), dimedone (1 mmol) at 50 °C

[a] Isolated yield

exhibited satisfactory reactivity profiles, in all cases leading to a cyclization sequence that easily afforded the target structures (Table 2). Various substituted aldehydes undergo the reaction in the presence of catalytic amount of SSC (10 mol%) in neat condition at 50 °C. Compared with aromatic aldehydes, aliphatic aldehydes do not afford targeted product indeno[1,2-*b*]quinoline (Table 2, entry 11).

On the other hand, to check the efficiency of the silica sodium carbonate, we used SSC catalyst for the synthesis of spiro[chromene-4,3′-indoline]-3-carbonitriles by one-pot condensation of isatin, malononitrile/ethyl cyanoacetate, and cyclic 1,3-dicarbonyl compounds (Scheme 2). Many methods have been developed for the construction of spiro[chromene-4,3′-indoline]-3-carbonitrile building blocks [27–35]. Although these methods insure good results in many instances, there is still a great demand for rapid and environment-friendly catalytic reaction conditions; for our best knowledge, nobody reported synthesis spiro[chromene-4,3′-indoline]-3-carbonitriles using silica sodium carbonate as a heterogeneous catalyst under solvent-free condition.

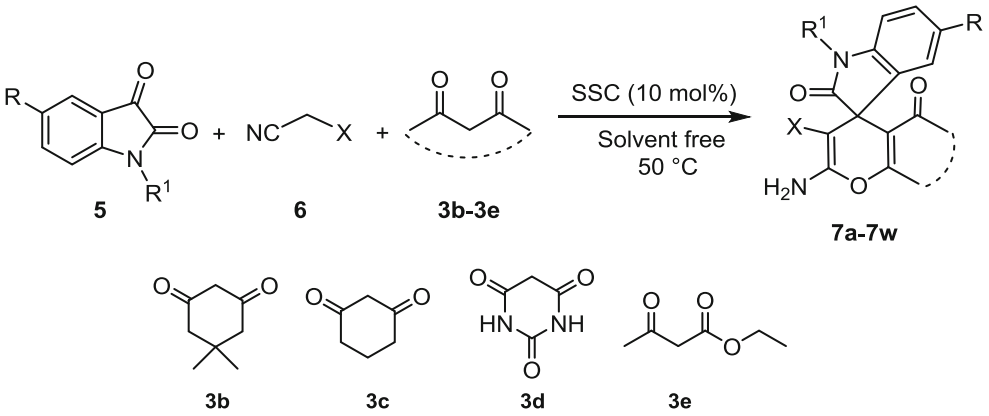
First, a mixture of isatin, dimedone, and malononitrile at 50 °C solvent-free condition was chosen as a model reaction to detect whether the use of SSC as catalyst was efficient and to investigate the optimized conditions. The results are summarized in Table 3.

Increasing the amount of catalyst from 5 to 10 mol% could improve the reaction significantly. Inspired by the results, we changed the amount of the catalyst from 10 to 15 mol%, finding that 10 mol% of SSC was good enough (Table 3). The optimized conditions were used to construct a variety of spiro[chromene-4,3′-indoline]-3-carbonitrile derivatives. It was found that this method is effective with a variety of isatin, malononitrile/ethyl cyanoacetate, and 1,3-dicarbonyl compounds (Table 4). All the structures of synthesized compounds **4a**–**4j** and **7a**–**7w** have been ascertained on the basis of ^{1}H NMR, ^{13}C NMR, and HRMS data.

A possible mechanism for the indeno[1,2-*b*]quinoline cyclic ring formation is outlined in Scheme 3. The cyclization looks to proceed as a domino sequence of Knoevenagel condensation and Michael-type addition reaction using catalytic amount of SSC which in all step acted as an accelerator. The well-known reaction of 2*H*-indene-1,3-dione with benzaldehyde leads to the formation of the standard 2-benzylidene-2*H*-indene-1,3-dione adducts **8**, which then could undergo Michael-type addition reaction with 1*H*-inden-5-amine **1** to form an adduct **9**. The adduct **9** formed could then cyclized intramolecularly to give **10**, which could then lose water, followed by air oxidation to afford indeno[1,2-*b*]quinoline ring systems **4**.

The reusability of the SSC catalyst is one of the most important benefits and makes it useful for commercial applications as well. Thus, the recovery and reusability of the catalyst were investigated. The recyclability of the catalyst was checked with the model reaction (Table 5, entries 1–4). The catalyst was recovered after completion of the first fresh run, the reaction mixture cooled to room temperature, and then ethyl acetate was added. The product was dissolved in ethyl acetate and catalyst was separated by filtration. The recovered catalyst was dried at 70 °C for 12 h and tested in up to three more fresh substrates under the same conditions. The catalyst showed excellent recyclability in all these reactions (Table 5), as the reaction times and yield remained almost the same without having a loss of catalytic activity.

Table 4 Synthesis of spiro[chromene-4,3′-indoline]-3-carbonitriles catalyzed by SSC



Entry	R	R^1	X	Dicarb.	Product	Time/min	Yield[a]/%	M.p./ °C	
								Found	Reported
1	H	H	CN	**3b**	**7a**	10	96	297–300	296–298 [27]
2	Cl	H	CN	**3b**	**7b**	10	95	288–289	288–290 [28]
3	NO_2	H	CN	**3b**	**7c**	10	96	>300	>300 [29]
4	F	H	CN	**3b**	**7d**	10	92	288–290	–
5	H	Bn	CN	**3b**	**7e**	15	94	272–274	271–273 [27]
6	H	H	CO_2Et	**3b**	**7f**	30	78	234–236	232–235 [27]
7	CH_3	H	CN	**3b**	**7g**	10	92	279–280	278–280 [30]
8	H	H	CN	**3c**	**7h**	10	96	305–307	>300 [28]
9	F	H	CN	**3c**	**7i**	10	94	307–310	–
10	CH_3	H	CN	**3c**	**7j**	10	90	301–303	>300 [28]
11	H	Bn	CN	**3b**	**7k**	15	92	292–294	291–293 [28]
12	Cl	H	CN	**3c**	**7l**	20	92	291–293	–
13	NO_2	H	CO_2Et	**3c**	**7m**	20	94	305–307	>300 [28]
14	H	H	CN	**3d**	**7n**	20	93	274–275	273–275 [31–35]
15	NO_2	H	CN	**3d**	**7o**	20	93	291–293	–
16	Cl	H	CN	**3d**	**7p**	20	90	289–290	–
17	F	H	CN	**3d**	**7q**	22	88	287–289	–
18	H	Bn	CN	**3d**	**7r**	25	85	291–293	–
19	Cl	H	CO_2Et	**3d**	**7s**	45	83	298–300	–
20	NO_2	H	CO_2Et	**3d**	**7t**	50	86	295–298	–
21	CH_3	H	CN	**3d**	**7u**	20	89	288–291	–
22	H	H	CN	**3e**	**7v**	23	87	255–257	258–260 [33]
23	Cl	H	CN	**3e**	**7w**	27	85	257–259	256–258 [33]

Reaction conditions: isatins (1 mmol), malononitrile (1 mmol), 1,3-dicarbonyl compounds (1 mmol) and SSC (10 mol%) at 50 °C

[a] Isolated yield

Conclusion

In this work, we have described a successful strategy for the efficient and convenient preparation of indeno[1,2-*b*]quinoline using silica sodium carbonate as catalyst in neat condition by intramolecular cyclization of 2,3-dihydro-1*H*-inden-5-amine, aldehyde, and 2*H*-indene-1,3-dione. It was suggested that silica sodium carbonate shows high catalytic activity. Moreover, silica sodium carbonate also used for the synthesis of spiro[chromene-4,3′-indoline]-3-carbonitriles, and can be easily recovered and reused for at least three runs without any significant impact on the yield of the products. The current strategy offers several advantages such as high yields and purity of products, low amount of catalyst, safe, cheap, and environmentally benign, and an easy experimental work-up

Scheme 3

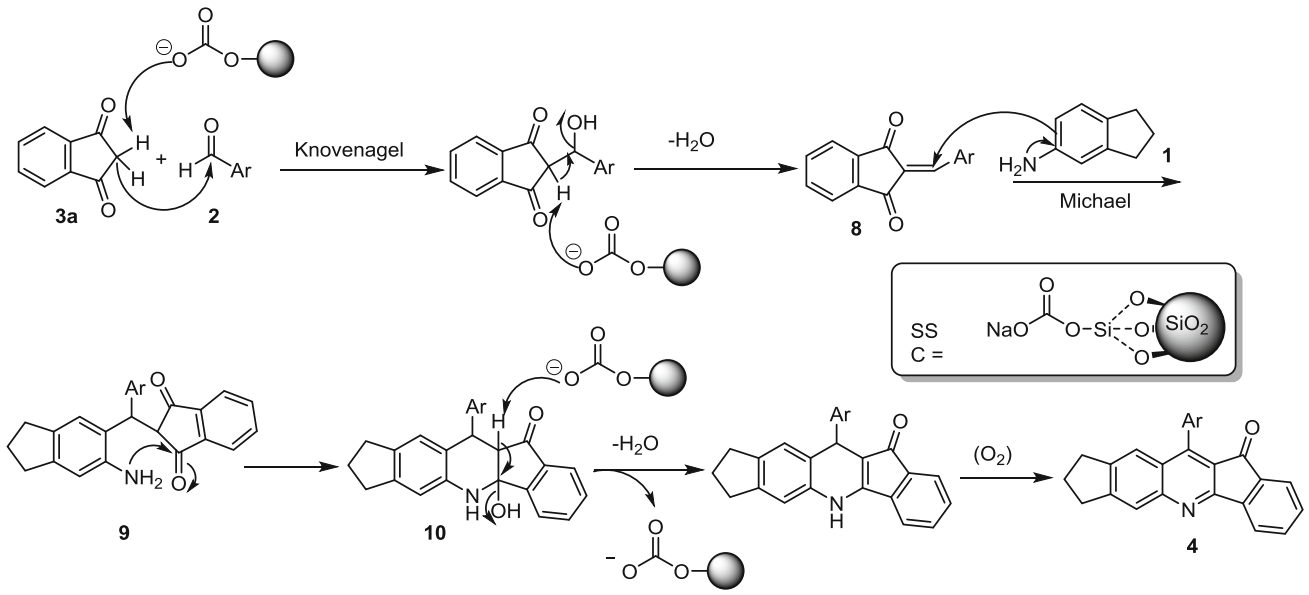


Table 5 Recycling and reuse of SSC on the synthesis of **4a**

Entry	Reaction cycle	Yield[a]/%
1	First (fresh run)	94
2	Second cycle	93
3	Third cycle	92
4	Fourth cycle	92

[a] Isolated yield

procedure. Furthermore, we are trying our best to develop more reaction by using SSC as a catalyst in an environmental way and the related work is underway in our laboratory.

Experimental

Chemicals were purchased from Aldrich and Alfa Aesar Chemical Companies. NMR spectra were recorded in parts per million (ppm) in DMSO-d_6 and $CDCl_3$ on a Jeol JNM ECP 400 NMR instrument using TMS as internal standard. Mass spectra were recorded on a Jeol JMS-700 mass spectrometer. All melting points were determined using open capillaries on an Electrothermal-9100 (Japan) instrument.

Two-step preparation of SSC

Silica sodium carbonate was prepared by adopting the literature [22].

Step 1: To a 250 cm^3 round bottom flask equipped with a reflux condenser, in which the hose interface was connected to a pot of water, 10 g of silica gel 60 (63–200 μm) that was previously dried at 120 °C for 6 h was added. Then 40 cm^3 of thionyl chloride was added dropwise to this flask which was perched in an ice bath (caution). After the addition of thionyl chloride, the reaction mixture was removed from the ice bath and stirred for 0.5 h in room temperature and 48 h under reflux conditions. Afterwards, the reaction mixture was filtrated to obtain silica chloride.

Step 2: To a stirred 250 cm^3 round bottom flask containing 10 g of sodium bicarbonate and 25 cm^3 of *n*-hexane under reflux conditions, 10 g of silica chloride (after drying at 120 °C for 6 h) was added. After 24 h, the reaction mixture was filtrated to separate the catalyst and the solid product was washed with 50 cm^3 of distilled water ten times, using 5 cm^3 each time until filtrate became quite neutral, to remove the remaining sodium bicarbonate. Finally, drying at 100 °C for 12 h afforded SSC.

General procedure for indeno[1,2-b]quinolines ***4a–4j***

A mixture of aldehyde (1 mmol), 2*H*-indene-1,3-dione (1 mmol), 2,3-dihydro-1*H*-inden-5-amine (1 mmol), and SSC (10 mol%) was stirred at 50 °C under solvent-free condition. The reactions were followed by thin layer chromatography (TLC) using hexane/ethyl acetate as an eluent. After completion of the reaction, the mixture was washed with ethyl acetate and filtered to recover the catalyst. The filtrate was evaporated, and the crude product was recrystallized from ethanol to afford the pure product.

Used catalyst from different experiments was combined, washed with ethyl acetate, and dried overnight in a vacuum oven and reused.

*General procedure for spiro[chromene-4,3′-indoline]-3-carbonitriles **7a–7w***

A mixture of isatin (1 mmol), malononitrile/ethyl cyanoacetate (1 mmol), 1,3-dicarbonyl compounds (1 mmol), and SSC (10 mol%) was stirred at 50 °C under solvent-free condition. The reactions were followed by thin layer chromatography (TLC) using hexane/ethyl acetate as an eluent. After completion of the reaction, the mixture was washed with ethyl acetate and filtered to recover the catalyst. The filtrate was evaporated, and the crude product was recrystallized from ethanol to afford the pure product.

11-(p-Tolyl)-2,3-dihydrocyclopenta[g]indeno[1,2-b]-quinolin-10(1H)-one (**4a**, $C_{26}H_{19}NO$)

$R_f = 0.33$ (hexane/ethyl acetate 7:3); m.p.: 260–262 °C; ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.08$–2.16 (m, 2H, CH_2), 2.50 (s, 3H, CH_3), 2.92 (t, $J = 7.3$ Hz, 2H, CH_2), 3.08 (t, $J = 7.3$ Hz, 2H, CH_2), 7.31 (d, $J = 8.1$ Hz, 2H, ArH), 7.37 (d, $J = 8.1$ Hz, 2H, ArH), 7.43 (t, $J = 7.4$ Hz, 1H, ArH), 7.48 (s, 1H, ArH), 7.62 (t, $J = 7.7$ Hz, 1H, ArH), 7.66 (d, $J = 7.3$ Hz, 1H, ArH), 7.93 (s, 1H, ArH), 8.06 (d, 1H, $J = 7.7$ Hz, ArH) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 21.61$, 25.98, 32.63. 33.07, 121.42, 122.16, 122.87, 123.67, 124.59, 126.94, 128.91, 129.45, 130.50, 131.15, 135.06, 137.64, 138.66, 143.54, 144.87, 148.02, 150.21, 150.32, 161.37, 190.67 ppm; HRMS (ESI): *m/z* calcd for $C_{26}H_{19}NO$ 361.1466, found 361.1464.

11-(2-Chloro-6-fluorophenyl)-2,3-dihydrocyclopenta[g]indeno[1,2-b]quinolin-10(1H)-one (**4b**, $C_{25}H_{15}ClFNO$)

$R_f = 0.29$ (hexane/ethyl acetate 7:3); m.p.: 190–192 °C; ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.12$–2.19 (m, 2H, CH_2), 2.98 (t, $J = 7.3$ Hz, 2H, CH_2), 3.12 (t, $J = 7.3$ Hz, 2H, CH_2), 7.27 (s, 1H, ArH), 7.41 (d, $J = 7.7$ Hz, 1H, ArH), 7.46 (d, $J = 8.1$ Hz, 1H, ArH), 7.64 (d, 1H, ArH), 7.69 (t, $J = 7.3$ Hz, 1H, ArH), 7.82–7.84 (m, 1H, ArH), 7.95–7.98 (m, 1H, ArH), 8.00 (s, 1H, ArH), 8.11 (d, 1H, $J = 7.7$ Hz, ArH) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 25.95$, 32.65, 33.18, 121.48, 121.68, 123.44, 123.96, 124.92, 125.26, 125.51, 125.91, 128.80, 130.93, 131.34, 135.40, 135.84, 137.61, 142.00, 143.88, 145.67, 150.41, 151.00, 161.12, 190.23 ppm; HRMS (ESI): *m/z* calcd for $C_{25}H_{15}ClFNO$ 399.0826, found 399.0825.

11-(4-Fluorophenyl)-2,3-dihydrocyclopenta[g]indeno-[1,2-b]quinolin-10(1H)-one (**4c**, $C_{25}H_{16}FNO$)

$R_f = 0.33$ (hexane/ethyl acetate 7:3); m.p.: 246–248 °C; ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.11$–2.18 (m, 2H, CH_2), 2.94 (t, $J = 7.3$ Hz, 2H, CH_2), 3.10 (t, $J = 7.3$ Hz, 2H, CH_2), 7.26 (d, $J = 8.8$ Hz, 2H, ArH), 7.38–7.43 (m, 3H, ArH), 7.46 (d, $J = 7.3$ Hz, 1H, ArH), 7.63 (d, $J = 8.4$ Hz, 1H, ArH), 7.67 (d, $J = 7.7$ Hz, 1H, ArH), 7.95 (s, 1H, ArH), 8.07 (d, $J = 7.7$ Hz, 1H, ArH) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 26.98$, 32.67, 33.10, 115.28, 115.49, 121.52, 122.52, 123.77, 124.73, 126.76, 131.29, 131.38, 131.46, 135.24, 137.54, 143.53, 145.18, 146.63, 150.28, 150.58, 161.30, 190.66 ppm; HRMS (ESI): *m/z* calcd for $C_{25}H_{16}FNO$ 365.1215, found 365.1217.

11-(4-Chlorophenyl)-2,3-dihydrocyclopenta[g]indeno-[1,2-b]quinolin-10(1H)-one (**4d**, $C_{25}H_{16}ClNO$)

$R_f = 0.30$ (hexane/ethyl acetate 7:3); m.p.: 274–276 °C; ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.09$–2.17 (m, 2H, CH_2), 2.92 (t, $J = 7.3$ Hz, 2H, CH_2), 3.08 (t, $J = 7.3$ Hz, 2H, CH_2), 7.36 (d, $J = 8.4$ Hz, 2H, ArH), 7.38 (s, 1H, ArH), 7.44 (t, $J = 7.3$ Hz, 1H, ArH), 7.53 (d, $J = 8.4$ Hz, 2H, ArH), 7.61–7.67 (m, 2H, ArH), 7.93 (s, 1H, ArH), 8.06 (d, 1H, ArH) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 25.99$, 32.67, 33.12, 121.51, 122.44, 123.80, 124.79, 126.53, 128.57, 130.94, 131.31, 131.97, 134.98, 135.27, 137.53, 143.59, 145.24, 146.26, 150.32, 150.63, 161.27, 190.59 ppm; HRMS (ESI): *m/z* calcd for $C_{25}H_{16}ClNO$ 381.0920, found 381.0920.

11-(4-Bromophenyl)-2,3-dihydrocyclopenta[g]indeno-[1,2-b]quinolin-10(1H)-one (**4e**, $C_{25}H_{16}BrNO$)

$R_f = 0.32$ (hexane/ethyl acetate 7:3); m.p.: 286–288 °C; ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.12$–2.15 (m, 2H, CH_2), 2.93 (t, $J = 7.3$ Hz, 2H, CH_2), 3.09 (t, $J = 7.3$ Hz, 2H, CH_2), 7.30 (d, $J = 7.3$ Hz, 2H, ArH), 7.39 (s, 1H, ArH), 7.46 (t, $J = 7.7$ Hz, 1H, ArH), 7.62–7.70 (m, 4H, ArH), 7.94 (s, 1H, ArH), 8.06 (d, 1H, $J = 7.7$ Hz, ArH) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 25.93$, 32.62, 33.08, 121.48, 122.03, 122.39, 123.22, 123.74, 124.75, 126.39, 131.20, 131.26, 131.47, 132.44, 135.22, 137.47, 143.52, 145.20, 146.15, 150.23, 150.58, 161.18, 190.50 ppm; HRMS (ESI): *m/z* calcd for $C_{25}H_{16}BrNO$ 425.0415, found 425.0414.

11-(2-Bromophenyl)-2,3-dihydrocyclopenta[g]indeno-[1,2-b]quinolin-10(1H)-one (**4f**, $C_{25}H_{16}BrNO$)

$R_f = 0.31$ (hexane/ethyl acetate 7:3); m.p.: 220–222 °C; ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.11$–2.17 (m, 2H, CH_2), 2.94 (t, $J = 7.3$ Hz, 2H, CH_2), 3.10 (t, $J = 7.7$ Hz, 2H, CH_2), 7.24 (d, 2H, $J = 9.5$ Hz, ArH), 7.38–7.50 (m, 3H, ArH), 7.62–7.68 (m, 2H, ArH), 7.77 (d, $J = 7.7$ Hz, 1H, ArH), 7.98 (s, 1H, ArH), 8.09 (d, $J = 7.7$ Hz, 1H, ArH) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 25.96$, 32.65, 33.17, 121.58, 122.21, 1213.90, 124.77, 126.18, 127.35, 130.19, 130.39, 131.30, 132.87, 135.26, 137.55, 143.85, 145.35, 145.53, 150.41, 150.78, 161.18, 190.29. ppm; HRMS (ESI): *m/z* calcd for $C_{25}H_{16}BrNO$ 425.0415, found 425.0412.

11-(2-Nitrophenyl)-2,3-dihydrocyclopenta[g]indeno-[1,2-b]quinolin-10(1H)-one (**4g**, $C_{25}H_{16}N_2O_3$)
$R_f = 0.30$ (hexane/ethyl acetate 7:3); m.p.: 278–280 °C; ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.10$–2.17 (m, 2H, CH_2), 2.92 (t, $J = 7.3$ Hz, 2H, CH_2), 3.10 (t, $J = 7.3$ Hz, 2H, CH_2), 7.18 (s, 1H, ArH), 7.39 (d, $J = 8.4$ Hz, 1H, ArH), 7.44 (t, $J = 7.3$ Hz, 1H, ArH), 7.64 (d, $J = 7.3$ Hz, 2H, ArH), 7.73 (t, $J = 7.3$ Hz, 1H, ArH), 7.80 (t, $J = 7.3$ Hz, 1H, ArH), 7.99 (s, 1H, ArH), 8.09 (d, $J = 7.3$ Hz, 1H, ArH), 8.37 (d, $J = 9.2$ Hz, 1H, ArH) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 26.79$, 33.47, 33.99, 122.39, 122.51, 124.75, 125.83, 126.73, 130.74, 130.94, 132.17, 132.54, 134.38, 136.25, 144.71, 146.39, 149.29, 151.28, 151.74, 161.84, 190.76. ppm; HRMS (ESI): *m/z* calcd for $C_{25}H_{16}N_2O_3$ 392.1160, found 392.1162.

11-Phenyl-2,3-dihydrocyclopenta[g]indeno[1,2-b]-quinolin-10(1H)-one (**4h**, $C_{25}H_{17}NO$)
$R_f = 0.33$ (hexane/ethyl acetate 7:3); m.p.: 238–240 °C; ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.08$–2.15 (m, 2H, CH_2), 2.91 (t, $J = 7.3$ Hz, 2H, CH_2), 3.07 (t, $J = 7.3$ Hz, 2H, CH_2), 7.41–7.44 (m, 4H, ArH), 7.55–7.57 (m, 3H, ArH), 7.60–7.66 (m, 2H, ArH), 7.93 (s, 1H, ArH), 8.06 (d, 1H, $J = 7.0$ Hz, ArH) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 25.97$, 32.64, 33.08, 121.42, 122.14, 122.79, 123.69, 124.66, 126.79, 128.17, 128.77, 129.45, 131.17, 133.62, 135.08, 137.61, 143.59, 144.95, 147.66, 150.26, 150.37, 161.31, 190.59 ppm; HRMS (ESI): *m/z* calcd for $C_{25}H_{17}NO$ 347.1310, found 347.1311.

11-(o-Tolyl)-2,3-dihydrocyclopenta[g]indeno[1,2-b]-quinolin-10(1H)-one (**4i**, $C_{26}H_{19}NO$)
$R_f = 0.34$ (hexane/ethyl acetate 7:3); m.p.: 266–268 °C; ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.02$ (s, 3H, CH_3), 2.09–2.14 (m, 2H, CH_2), 2.91 (t, $J = 7.0$ Hz, 2H, CH_2), 3.09 (t, $J = 7.0$ Hz, 2H, CH_2), 7.16 (d, $J = 7.3$ Hz, 1H, ArH), 7.24 (s, 1H, ArH), 7.33–7.43 (m, 4H, ArH), 7.61–7.67 (m, 2H, ArH), 7.96 (s, 1H, ArH), 8.08 (d, $J = 7.3$ Hz, 1H, ArH) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 19.81$, 25.97, 32.61, 33.13, 120.52, 121.48, 122.52, 123.74, 124.70, 125.69, 126.86, 128.72, 130.09, 131.20, 133.78, 135.11, 135.95, 137.61, 143.77, 145.12, 147.26, 150.29, 150.58, 161.34, 190.68 ppm; HRMS (ESI): *m/z* calcd for $C_{26}H_{19}NO$ 361.1466, found 361.1466.

11-(4-Isopropylphenyl)-2,3-dihydrocyclopenta[g]indeno[1,2-b]quinolin-10(1H)-one (**4j**, $C_{28}H_{23}NO$)
$R_f = 0.32$ (hexane/ethyl acetate 7:3); m.p.: 264–266 °C; ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 1.37$ (d, 6H, $2CH_3$), 2.07–2.15 (m, 2H, CH_2), 2.91 (t, $J = 7.4$ Hz, 2H, CH_2), 3.01–3.08 (m, 3H, CH_2, CH), 7.35 (d, $J = 8.4$ Hz, 2H, ArH), 7.40–7.44 (m, 3H, ArH), 7.50 (s, 1H, ArH), 7.06 (t, $J = 7.3$ Hz, 1H, ArH), 7.64 (d, $J = 7.3$ Hz, 1H, ArH), 7.91 (s, 1H, ArH), 8.04 (d, $J = 7.7$ Hz, 1H, ArH) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 24.08$, 26.01, 32.67, 33.09, 34.13, 121.43, 122.13, 122.99, 123.65, 124.66, 126.22, 126.96, 128.21, 129.60, 130.76, 131.16, 135.06, 137.66, 143.61, 144.84, 148.12, 149.43, 150.29, 161.40, 190.74 ppm; HRMS (ESI): *m/z* calcd for $C_{28}H_{23}NO$ 389.1779, found 389.1780.

2-Amino-5′-fluoro-7,7-dimethyl-2′,5-dioxo-5,6,7,8-tetrahydrospiro[chromene-4,3′-indoline]-3-carbonitrile (**7d**, $C_{19}H_{16}FN_3O_3$)
$R_f = 0.27$ (hexane/ethyl acetate 6:4); m.p.: 288–290 °C; ^{1}H NMR (400 MHz, DMSO-d_6): $\delta = 1.01$ (s, 3H, CH_3), 1.02 (s, 3H, CH_3), 2.14 (s, 2H, CH_2), 2.54 (s, 2H, CH_2), 6.75–6.78 (m, 1H, ArH), 6.95 (d, $J = 8.8$ Hz, 2H, ArH), 7.29 (s, 2H, NH_2), 10.42 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 27.32$, 27.37, 31.92, 47.32, 49.95, 56.91, 109.82, 109.90, 110.31, 114.24, 117.21, 138.28, 158.85, 164.45, 178.05, 194.98 ppm; HRMS (ESI): *m/z* calcd for $C_{19}H_{16}FN_3O_3$ 353.1175, found 353.1177.

2-Amino-5′-fluoro-2′,5-dioxo-5,6,7,8-tetrahydrospiro[chromene-4,3′-indoline]-3-carbonitrile (**7i**, $C_{17}H_{12}FN_3O_3$)
$R_f = 0.29$ (hexane/ethyl acetate 6:4); m.p.: 307–310 °C; ^{1}H NMR (400 MHz, DMSO-d_6): $\delta = 1.92$ (t, $J = 6.1$ Hz, 2H, CH_2), 2.19–2.24 (m, 2H, CH_2), 2.64 (t, $J = 5.9$ Hz, 2H, CH_2), 6.76 (d, $J = 7.8$ Hz, 1H, ArH), 6.91–6.98 (m, 2H, ArH), 7.28 (s, 2H, NH_2), 10.42 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 19.72$, 26.78, 36.31, 47.40, 57.00, 109.74, 109.82, 111.00, 111.39, 114.44, 117.25, 138.20, 158.71, 166.40, 178.18, 195.13 ppm; HRMS (ESI): *m/z* calcd for $C_{17}H_{12}FN_3O_3$ 325.0863, found 325.0864.

2-Amino-5′-chloro-2′,5-dioxo-5,6,7,8-tetrahydrospiro[chromene-4,3′-indoline]-3-carbonitrile (**7l**, $C_{17}H_{12}ClN_3O_3$)
$R_f = 0.30$ (hexane/ethyl acetate 6:4); m.p.: 291–293 °C; ^{1}H NMR (400 MHz, DMSO-d_6): $\delta = 1.87$–1.98 (m, 2H, CH_2), 2.24 (t, $J = 6.6$ Hz, 2H, CH_2), 2.64 (t, $J = 5.9$ Hz, 2H, CH_2), 6.79 (d, $J = 8.1$ Hz, 1H, ArH), 7.14 (d, $J = 2.2$ Hz, 1H, ArH), 7.18 (dd, $J = 2.2$, 8.1 Hz, 1H, ArH), 7.31 (s, 2H, NH_2), 10.54 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 19.69$, 26.77, 36.28, 47.17, 56.82, 110.54, 111.26, 117.23, 123.46, 125.61, 128.02, 136.57, 140.94, 158.73, 166.56, 177.91, 195.21 ppm; HRMS (ESI): *m/z* calcd for $C_{17}H_{12}ClN_3O_3$ 341.0567, found 341.0568.

7′-Amino-5-nitro-2,2′,4′-trioxo-1,1′,2,2′,3′,4′-hexahydrospiro[3H-indole-3,5′-[5H]pyrano[2,3-d]pyrimidine]-6′-carbonitrile (**7o**, $C_{15}H_8N_6O_6$)
$R_f = 0.31$ (hexane/ethyl acetate 6:4); m.p.: 291–293 °C;^{1}H NMR (400 MHz, DMSO-d_6): $\delta = 7.01$ (d, $J = 8.4$ Hz,

1H, ArH), 8.15 (dd, $J = 2.2$, 8.4 Hz, 1H, ArH), 8.24 (d, $J = 2.2$ Hz, 1H, ArH), 7.55 (s, 2H, NH_2), 11.18 (s, 1H, NH), 11.22 (s, 1H, NH), 12.34 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 46.85$, 56.20, 85.82, 109.43, 116.75, 120.00, 125.90, 134.64, 142.58, 148.63, 149.27, 153.90, 158.66, 161.66, 178.39 ppm; HRMS (ESI): *m/z* calcd for $C_{15}H_8N_6O_6$ 368.0505, found 368.0506.

7′-Amino-5-chloro-2,2′,4′-trioxo-1,1′,2,2′,3′,4′-hexahydrospiro[3H-indole-3,5′-[5H]pyrano[2,3-d]pyrimidine]-6′-carbonitrile (**7p**, $C_{15}H_8ClN_5O_4$)
$R_f = 0.28$ (hexane/ethyl acetate 6:4); m.p.: 289–290 °C; ^{1}H NMR (400 MHz, DMSO-d_6): $\delta = 6.79$ (d, $J = 8.4$ Hz, 1H, ArH), 7.20 (dd, $J = 2.2$, 8.4 Hz, 1H, ArH), 7.33 (d, $J = 2.2$ Hz, 1H, ArH), 7.44 (s, 2H, NH_2), 10.61 (s, 1H, NH), 11.15 (s, 1H, NH), 12.31 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 46.95$, 57.08, 86.28, 110.63, 116.86, 124.15, 125.82, 128.28, 135.61, 141.06, 149.27, 153.59, 158.40, 161.53, 177.51 ppm; HRMS (ESI): *m/z* calcd for $C_{15}H_8ClN_5O_4$ 357.0264, found 357.0265.

7′-Amino-5-fluoro-2,2′,4′-trioxo-1,1′,2,2′,3′,4′-hexahydrospiro[3H-indole-3,5′-[5H]pyrano[2,3-d]pyrimidine]-6′-carbonitrile (**7q**, $C_{15}H_8FN_5O_4$)
$R_f = 0.29$ (hexane/ethyl acetate 6:4); m.p.: 287–289 °C; ^{1}H NMR (400 MHz, DMSO-d_6): $\delta = 6.75$–6.78 (m, 1H, ArH), 6.98 (t, $J = 8.1$ Hz, 1H, ArH), 7.16 (dd, $J = 1.8$, 8.1 H, ArH), 7.42 (s, 2H, NH_2), 10.49 (s, 1H, NH), 11.14 (s, 1H, NH), 12.32 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 47.13$, 57.23, 86.36, 109.87, 111.60, 111.84, 114.47, 114.70, 116.83, 138.29, 149.25, 153.50, 158.34, 161.47, 177.71 ppm; HRMS (ESI): *m/z* calcd for $C_{15}H_8FN_5O_4$ 341.0560, found 341.0561.

7′-Amino-1-benzyl-2,2′,4′-trioxo-1,1′,2,2′,3′,4′-hexahydrospiro[3H-indole-3,5′-[5H]pyrano[2,3-d]pyrimidine]-6′-carbonitrile (**7r**, $C_{22}H_{15}N_5O_4$)
$R_f = 0.27$ (hexane/ethyl acetate 6:4); m.p.: 291–293 °C; ^{1}H NMR (400 MHz, DMSO-d_6): $\delta = 4.88$ (d, $J = 16.1$ Hz, 1H, CH_2), 4.95 (d, $J = 16.1$ Hz, 1H, CH_2), 6.69 (d, $J = 7.7$ Hz, 1H, ArH), 6.97 (t, $J = 7.3$ Hz, 1H, ArH), 7.14 (t, $J = 7.7$, 1H, ArH), 7.23–7.30 (m, 5H, ArH), 7.46–7.47 (m, 4H, NH_2, NH, ArH), 11.21 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 43.30$, 46.41, 57.54, 86.58, 108.83, 116.93, 122.56, 123.63, 126.99, 127.11, 128.29, 128.46, 132.74, 136.01, 142.62, 149.18, 153.50, 158.37, 161.52, 176.31 ppm; HRMS (ESI): *m/z* calcd for $C_{22}H_{15}N_5O_4$ 413.1124, found 413.1125.

Ethyl 7′-amino-5-chloro-2,2′,4′-trioxo-1,1′,2,2′,3′,4′-hexahydrospiro[3H-indole-3,5′-[5H]pyrano[2,3-d]pyrimidine]-6′-carboxylate (**7 s**, $C_{17}H_{13}ClN_4O_6$)
$R_f = 0.27$ (hexane/ethyl acetate 6:4); m.p.: 298–300 °C; ^{1}H NMR (400 MHz, DMSO-d_6): $\delta = 0.79$ (t, $J = 7.3$ Hz, 3H, CH_3), 3.73 (q, $J = 7.3$ Hz, 2H, CH_2), 6.88 (d, $J = 8.8$ Hz, 1H, ArH), 8.00 (d, $J = 2.2$, 1H, ArH), 8.08–8.10 (m, 3H, NH_2, ArH), 10.02 (s, 1H, NH), 11.03 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 12.95$, 46.35, 59.09, 75.48, 88.49, 109.24, 122.96, 124.45, 126.98, 137.32, 142.92, 148.97, 152.31, 158.61, 161.15, 167.16, 176.02 ppm; HRMS (ESI): *m/z* calcd for $C_{17}H_{13}ClN_4O_6$ 404.0523, found 404.0525.

Ethyl 7′-amino-5-nitro-2,2′,4′-trioxo-1,1′,2,2′,3′,4′-hexahydrospiro[3H-indole-3,5′-[5H]pyrano[2,3-d]pyrimidine]-6′-carboxylate (**7t**, $C_{17}H_{13}N_5O_8$)
$R_f = 0.30$ (hexane/ethyl acetate 6:4); m.p.: 295–298 °C; ^{1}H NMR (400 MHz, DMSO-d_6): $\delta = 0.79$ (t, $J = 7.3$ Hz, 3H, CH_3), 3.72 (q, $J = 7.3$ Hz, 2H, CH_2), 6.66 (d, $J = 6.2$ Hz, 1H, ArH), 7.09 (br s, 2H, ArH), 7.99 (s, 2H, NH_2), 10.36 (s, 1H, NH), 10.99 (s, 1H, NH), 12.18 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 13.12$, 46.31, 59.39, 75.01, 88.11, 108.17, 118.73, 125.20, 136.58, 141.77, 149.15, 150.81, 152.83, 159.01, 161.51, 167.04, 180.18 ppm; HRMS (ESI): *m/z* calcd for $C_{17}H_{13}N_5O_8$ 415.0764, found 415.0765.

7′-Amino-5-methyl-2,2′,4′-trioxo-1,1′,2,2′,3′,4′-hexahydrospiro[3H-indole-3,5′-[5H]pyrano[2,3-d]pyrimidine]-6′-carbonitrile (**7u**, $C_{16}H_{11}N_5O_4$)
$R_f = 0.31$ (hexane/ethyl acetate 6:4); m.p.: 288–291 °C; ^{1}H NMR (400 MHz, DMSO-d_6): $\delta = 2.21$ (s, 3H, CH_3), 6.66 (d, $J = 8.4$ Hz, 1H, ArH), 6.94–6.96 (m, 2H, ArH), 7.34 (s, 2H, NH_2), 10.36 (s, 1H, NH), 11.10 (s, 1H, NH) ppm; ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 20.61$, 46.66, 58.02, 86.88, 108.99, 116.96, 124.28, 128.64, 130.58, 133.58, 139.65, 149.23, 153.27, 158.18, 161.39, 177.57 ppm; HRMS (ESI): *m/z* calcd for $C_{16}H_{11}N_5O_4$ 337.0811, found 337.0811.

References

1. Eicher T, Hauptmann S (2003) The chemistry of heterocycles. Wiley-VCH, Weinheim
2. Venugopalan B, Bapat CP, DeSouza EP, DeSouza NJ (1992) Indian J Chem, Sect B 31:35
3. Yamato M, Takeuchi Y, Hashigaki K, Ikeda Y, Chang MR, Takeuchi K, Matsushima M, Tsuruo T, Tashiro T, Tsukagoshi S, Yamashita Y, Nakano H (1989) J Med Chem 32:1295
4. Deady LW, Desneves J, Kaye AJ, Finlay GJ, Baguley BC, Denny WA (2000) Bioorg Med Chem 8:977
5. Deady LW, Kaye AJ, Finlay GJ, Baguley BC, Denny WA (1997) J Med Chem 40:2040
6. Deady LW, Desneves J, Kaye AJ, Thompson M, Finlay GJ, Baguley BC, Denny WA (1999) Bioorg Med Chem 7:2801
7. Brooks JR, Berman C, Hichens M, Primka RL, Reynolds GF, Rasmusson GH (1982) Proc Soc Exp Biol Med 169:67
8. Rampa A, Bisi A, Belluti F, Gobbi S, Valenti P, Andrisano V, Cavrini V, Cavalli A, Recanatini M (2000) Bioorg Med Chem 8:497
9. Anzini M, Cappelli A, Vomero S, Cagnotto A, Skorupska M (1993) Med Chem Res 3:44

10. Quraishi AM, Thakur VR, Dhawan SN (1989) Indian J Chem, Sect B 28B:891
11. Tu SJ, Jiang B, Jia RH, Zhang JY, Zhang Y, Yao CS, Shi F (2006) Org Biomol Chem 4:3664
12. Tu SJ, Jiang B, Jia RH, Zhang JY, Zhang Y, Yao CS (2006) Org Biomol Chem 4:3980
13. Wang XS, Zhang MM, Jiang H, Yao CS, Tu SJ (2007) Tetrahedron 63:4439
14. Heravi MM, Alinejhad H, Bakhtiari K, Daroogheha Z, Bamoharram FF, Derikv F, Alimadadi B (2010) Synth Commun 40:2191
15. Abdolmohammadi S (2013) Chin Chem Lett 24:318
16. Zhou Y-J, Chen D-S, Li Y-L, Liu Y, Wang X-S (2013) Comb Sci 5:498
17. Kantam ML, Roy M, Roya S, Sreedhara B, De RL (2008) Catal Commun 9:2226
18. Murkute AD, Jackson JE, Miller DJ (2011) J Catal 278:189
19. Mennecke K, Kirschning A (2009) Beilstein J Org Chem 5:21
20. Cai M, Zheng G, Zha L, Peng J (2009) Eur J Org Chem 1585
21. Miao T, Wang L (2007) Tetrahedron Lett 48:95
22. Eskandari K, Karami B, Khodabakhshi S (2014) Catal Commun 54:124
23. Mudumala VR, Chinthaparthi RR, Jeong YT (2014) Tetrahedron 70:3762
24. Mudumala VR, Gangireddy CSR, Jeong YT (2012) Tetrahedron 68:6820
25. Atar AB, Jeong YT (2014) Mol Divers 18:389
26. Atar AB, Dindulkar SD, Jeong YT (2013) Monatsh Chem 144:695
27. Mobinikhaledi A, Oroughifar NF, Fard MAB (2011) Synth Commun 41:441
28. Kidwai M, Jahan A, Mishra NK (2012) Appl Catal A 425:35
29. Sarrafi Y, Mehrasbi E, Vahid A, Tajbakhsh M (2012) Chin J Catal 33:1486
30. Anshu D, Anuj KJ, Dharmendra SB (2011) Synth Commun 41:2905
31. Oskooie HA, Heravi MM, Karimi N, Hamidi H (2011) Synth Commun 41:3344
32. Shanthi G, Subbulakshmi G, Perumal PT (2007) Tetrahedron 63:2057
33. Yuling L, Hui C, Chunling S, Daqing S, Shunjun J (2010) J Comb Chem 12:231
34. Guo R-Y, An Z-M, Mo L-P, Wang R-Z, Liu H-X, Wang S-X, Zhang Z-H (2013) Comb Sci 15:557
35. Hasaninejada A, Golzar N, Beyrati M, Zare A, Doroodmand MM (2013) J Mol Catal A: Chem 137:150