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ORIGINAL PAPER

# Highly efficient three-component, one-pot synthesis of dihydropyrano[3,2-*c*]chromene derivatives

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**Abstract** An efficient and convenient method for synthesis of dihydropyrano[3,2-*c*]chromene derivatives by one-pot, three-component reaction of aldehydes, malononitrile, and 4-hydroxycoumarin in the presence of a catalytic amount of hexamethylenetetramine is reported. A variety of dihydropyrano[3,2-*c*]chromene derivatives were obtained in high to excellent yields within short times.

**Keywords** Multicomponent reaction · Aldehydes · Malononitrile · 4-Hydroxycoumarin · Dihydropyrano[3,2-*c*]chromene · Hexamethylenetetramine

## Introduction

Chromene derivatives are a class of important compounds which, due to their biological activity, find wide application in medicinal chemistry [1]. They not only display antihyperglycemic and antidyslipidemic [2], cytotoxic [3], molluscicidal [4], anti-inflammatory [5], and antifungal activities [6], but can also be used as pigments, photoactive materials, and biodegradable agrochemicals [7–9]. In addition, chromenes are components of numerous natural products [10]. Among these known bioactive chromenes, pyrano[3,2-*c*]chromenes are of great interest [11, 12]. They are valuable synthons for synthesis of pharmacological agents [13–15]. Because of this, several synthesis methods have been developed for their preparation. In these procedures, 4-hydroxycoumarin and α-cyanocinnamonitrile were condensed in the presence of various catalysts, such as piperidine [15], triethylbenzylammonium chloride [16], KF-montmorillonite [17], and sodium hydride [18]. However, these methodologies possess some drawbacks, such as long reaction time, multiple synthesis steps, and poor yield.

Currently, multicomponent reactions (MCRs) are being rapidly developed for building highly functionalized organic molecules and pharmacologically important heterocyclic compounds [19–23]. Recently, a one-pot, three-component reaction of aldehydes, alkylnitriles, and 4-hydroxycoumarin has enjoyed wider utilization in the synthesis of pyrano[3,2-*c*]chromenes. A variety of reagents, such as heteropoly-acids [24, 25], ionic liquid [26], magnesium oxide [7, 27], diammonium hydrogen phosphate [28], tetrabutylammonium bromide [29], $KF/Al_2O_3$ [30], and triethylbenzylammonium chloride [31] have been employed to accomplish this transformation. However, some of the reported methods have some disadvantages, such as long reaction times and unsatisfactory yields. Based on their extensive application, it is necessary to further develop an efficient and convenient method to construct such significant heterocyclic compounds.

Development of a catalytic system utilizing inexpensive and commercially available catalysts has been a challenge in organic syntheses. Hexamethylenetetramine (HMT) is a very cheap, nontoxic, and stable reagent. It has been utilized as a catalyst for the Baylis–Hillman reaction [32], transesterification of β-keto esters [33], and regioselective preparation of haloalcohols [34]. As part of our continuing interest in developing novel synthesis methodologies [35–40], we describe herein a simple procedure for synthesis of dihydropyrano[3,2-*c*]chromene derivatives by three-component reaction of aldehydes, malononitrile, and 4-hydroxycoumarin in the presence of a catalytic amount of hexamethylenetetramine (Scheme 1).

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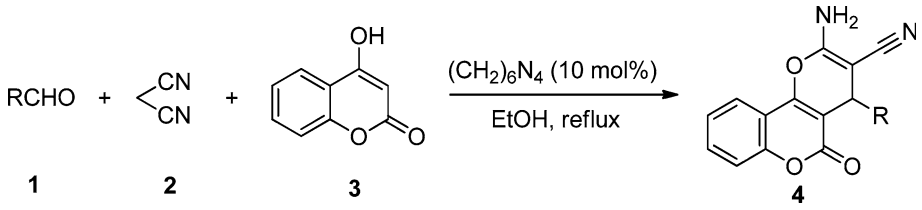
**Scheme 1**




## Results and discussion

Our preliminary investigations were focused on systematic evaluation of different catalysts for the model reaction of 4-chlorobenzaldehyde, malononitrile, and 4-hydroxycoumarin. As shown in Table 1, lower yields of **4m** were obtained when protic acids, such as *p*-toluenesulfonic acid (PTSA), and heteropolyacids, such as silicotungstic acid ($H_4SiW_{12}O_{40}$), were employed in ethanol after reacting for 1 h at reflux temperature (Table 1, entries 1 and 2). In comparison, moderate yields were obtained when the same reaction proceeded in the presence of nanocrystalline metal oxides, such as zinc oxide (ZnO), aluminum oxide ($Al_2O_3$), and aluminum hydroxide [$Al(OH)_3$]. When the reaction was performed in the presence of hexamethylenetetramine, to our delight, it proceeded mildly and rapidly to give the desired product in 95% yield.

Various solvents were also screened to test their efficiency in the reaction at different reflux temperatures, and the results are summarized in Table 2. Ethanol was found to be the best medium for this reaction. The effect of catalyst amount on the yield and rate was also investigated by using different amounts of hexamethylenetetramine. An increase in the quantity of hexamethylenetetramine from 1 to 10 mol% not only decreased the reaction time from 180 to 40 min but also increased product yield from 87% to 95%. This showed that the catalyst concentration plays a major role in the optimization of the product yield. It seems noteworthy to mention that only 30% yield of desired product was formed in the absence of the catalyst, and excessive amount of catalyst (20 mol%) did not increase the yield remarkably.

**Table 1** Influence of different catalysts for the reaction of 4-chlorobenzaldehyde, malononitrile, and 4-hydroxycoumarin

| Entry | Catalyst | Time (min) | Yield (%)[a] |
|---|---|---|---|
| 1 | *p*-Toluenesulfonic acid (PTSA) | 60 | 35 |
| 2 | Silicotungstic acid ($H_4SiW_{12}O_{40}$) | 60 | 38 |
| 3 | Nano zinc oxide (ZnO) | 90 | 49 |
| 4 | Nano aluminum oxide ($Al_2O_3$) | 120 | 48 |
| 5 | Nano aluminum hydroxide [$Al(OH)_3$] | 120 | 71 |
| 6 | Hexamethylenetetramine (HMT) | 40 | 95 |

Reaction conditions: 4-chlorobenzaldehyde (5 mmol), malononitrile (5 mmol), 4-hydroxycoumarin (5 mmol), catalyst (10 mol%), EtOH (10 $cm^3$), reflux

[a] Yields refer to isolated pure products

With the optimal reaction reactions, the substrate scope of this three-component reaction was evaluated in ethanol at reflux temperature in the presence of a catalytic amount (10 mol%) of hexamethylenetetramine. As can be seen from Table 3, aromatic aldehydes having electron-donating as well as electron-withdrawing groups were transformed into the corresponding dihydropyrano[3,2-*c*]chromenes in high to excellent yields within 7–80 min. The substituents at the aromatic ring had no obvious effect on yield or reaction time under the above optimal conditions. It is noteworthy that the methodology worked well for heterocyclic aldehydes, such as thiophene-2-carbaldehyde (Table 3, entry 21). Additionally, aliphatic aldehydes such as cyclohexanecarbaldehyde were also investigated, and the corresponding dihydropyrano [3,2-*c*]chromene was isolated in 90% yield (Table 3, entry 22). Encouraged by this achievement, the versatility of the reaction was explored further by extending the methodology to the synthesis of bis-dihydropyrano[3,2-*c*]chromene. When *m*-phthalaldehyde was treated with two equiv. malononitrile and 4-hydroxycoumarin under similar conditions, the reaction proceeded cleanly to give the corresponding bis-dihydropyrano[3,2-*c*]chromene (**4w**) in 89% yield (Scheme 2).

To show the advantage of this work in comparison with previously reported procedures, synthesis of **4a** was considered as a representative example. As shown in Table 4, the yield/time ratio of our present method is better or comparable with others.

In conclusion, we have developed a simple, efficient approach for synthesis of dihydropyrano[3,2-*c*]chromene derivatives by one-pot, three-component reaction of aldehydes, malononitrile, and 4-hydroxycoumarin in the presence of a catalytic amount of hexamethylenetetramine. This method offers several significant advantages, such as high conversion, clean reaction profile, short reaction time, and inexpensive catalyst. These features make this method an attractive choice for dihydropyrano[3,2-*c*]chromene synthesis.

## Experimental

Melting points were determined on an X-4 apparatus. Infrared (IR) spectra were obtained using a Shimadzu FTIR-8900 spectrometer. Nuclear magnetic resonance

**Table 2** Optimization of reaction conditions

| Entry | Catalyst (mol%) | Solvent | Temperature (°C) | Time (min) | Yield (%)[a] |
|---|---|---|---|---|---|
| 1 | 10 | Dichloromethane | Reflux | 180 | 30 |
| 2 | 10 | Water | Reflux | 140 | 65 |
| 3 | 10 | Dimethylformamide | Reflux | 40 | 90 |
| 4 | 10 | Tetrahydrofuran | Reflux | 120 | 20 |
| 5 | 0 | Ethanol | Reflux | 180 | 30 |
| 6 | 1 | Ethanol | Reflux | 180 | 87 |
| 7 | 3 | Ethanol | Reflux | 50 | 90 |
| 8 | 5 | Ethanol | Reflux | 50 | 91 |
| 9 | 10 | Ethanol | Reflux | 40 | 95 |
| 10 | 20 | Ethanol | Reflux | 40 | 95 |

Reaction conditions: 4-chlorobenzaldehyde (5 mmol), malononitrile (5 mmol), 4-hydroxycoumarin (5 mmol), solvent (10 $cm^3$)

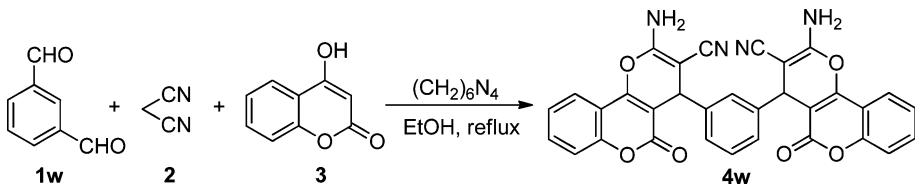
[a] Yields refer to isolated pure products

**Table 3** Scope of the preparation of dihydropyrano[3,2-*c*]chromene derivatives catalyzed by hexamethylenetetramine

| Entry | Aldehydes | Product | Time (min) | Yield (%)[a] | M.p. (°C) | |
|---|---|---|---|---|---|---|
| | | | | | Found | Reported |
| 1 | Benzaldehyde | **4a** | 15 | 92 | 258–259 | 257–259 [27] |
| 2 | 3-Methylbenzaldehyde | **4b** | 20 | 90 | 246–248 | |
| 3 | 4-Methylbenzaldehyde | **4c** | 15 | 91 | 251–252 | 252–254 [17] |
| 4 | 3,4-Dimethylbenzaldehyde | **4d** | 15 | 92 | 232–233 | 231–232 [17] |
| 5 | 2-Methoxybenzaldehyde | **4e** | 20 | 92 | 247–249 | |
| 6 | 4-Methoxybenzaldehyde | **4f** | 70 | 90 | 243–244 | 241–243 [27] |
| 7 | 2,3,4-Trimethoxybenzaldehyde | **4g** | 80 | 91 | 228–230 | |
| 8 | 4-Hydroxybenzaldehyde | **4h** | 60 | 93 | 264–266 | 265–266 [7] |
| 9 | Vanillin | **4i** | 30 | 90 | 253–254 | 252–253 [41] |
| 10 | 2-Fluorobenzaldehyde | **4j** | 45 | 93 | 247–249 | |
| 11 | 2-Chlorobenzaldehyde | **4k** | 35 | 92 | 266–268 | 266–268 [16] |
| 12 | 3-Chlorobenzaldehyde | **4l** | 15 | 93 | 236–237 | 236–237 [17] |
| 13 | 4-Chlorobenzaldehyde | **4m** | 10 | 95 | 263–265 | 263–265 [28] |
| 14 | 3,4-Dichlorobenzaldehyde | **4n** | 20 | 93 | 243–244 | 243–244 [17] |
| 15 | 2-Bromobenzaldehyde | **4o** | 16 | 93 | 295–297 | |
| 16 | 4-Bromobenzaldehyde | **4p** | 15 | 94 | 254–256 | 254–256 [17] |
| 17 | 3-Nitrobenzaldehyde | **4q** | 25 | 95 | 261–262 | 262–264 [28] |
| 18 | 4-Nitrobenzaldehyde | **4r** | 15 | 94 | 258–260 | 258–260 [28] |
| 19 | 2-Cyanobenzaldehyde | **4s** | 10 | 93 | 259–260 | |
| 20 | 4-Cyanobenzaldehyde | **4t** | 7 | 95 | 289–290 | |
| 21 | Thiophene-2-carbaldehyde | **4u** | 60 | 92 | 228–229 | 228 [42] |
| 22 | Cyclohexanecarbaldehyde | **4v** | 30 | 90 | 267–269 | |
| 23 | *m*-Phthalaldehyde | **4w** | 70 | 89 | 281–283 | |

[a] Yields refer to isolated products

**Scheme 2**




(NMR) spectra were taken with a Bruker DRX-500 spectrometer at 500 MHz ($^1$H) and 125 MHz ($^{13}$C) using $(CD_3)_2SO$ as the solvent and tetramethylsilane (TMS) as internal standard. Elemental analysis was carried out on a Vario EL III CHNOS elemental analyzer, and the results obtained agreed favorably with calculated values.

**Table 4** Comparison of hexamethylenetetramine with reported catalysts for synthesis of **4a**

| Catalyst/solvent/temperature (°C) | Time (min) | Yield (%) | Ref |
|---|---|---|---|
| $H_6P_2W_{18}O_{62}\cdot 18H_2O/H_2O$-EtOH/reflux | 30 | 89 | [24] |
| 1,1,3,3-*N*,*N*,*N*′,*N*′-Tetramethylguanidinium trifluoroacetate/solvent free/100 | 60 | 79 | [26] |
| MgO/$H_2O$-EtOH/reflux | 32 | 89 | [27] |
| (*S*)-Proline/$H_2O$-EtOH/reflux | 180 | 72 | [28] |
| Diammonium hydrogen phosphate/solvent free/120 | 20 | 85 | [29] |
| Triethylbenzylammonium chloride/$H_2O$/90 | 600 | 96 | [31] |
| Hexamethylenetetramine/EtOH/reflux | 15 | 92 | This work |

*Representative procedure for synthesis of dihydropyrano[3,2-c]chromene derivatives*

A solution of 703 mg **1 m** (5 mmol), 330 mg malononitrile (5.0 mmol), 810 mg **3** (5.0 mmol), and 70 mg hexamethylenetetramine (0.5 mmol) in 10 $cm^3$ ethanol was stirred under reflux for appropriate time. After completion of the reaction [as monitored by thin-layer chromatography (TLC)], the mixture was cooled to room temperature. The solid product was collected by filtration and washed with water. The crude product was purified by recrystallization from aqueous EtOH to afford 1.75 g **4m** (95%).

Except for compounds **4b**, **4e**, **4g**, **4j**, **4o**, **4s**, **4t**, **4v**, and **4w**, all products are known compounds. The spectroscopic and physical data for all known compounds were found to be identical to those described in the literature.

*2-Amino-4-(3-methylphenyl)-5-oxo-4H,5H-pyrano-[3,2-c]chromene-3-carbonitrile* (**4b**, $C_{20}H_{14}N_2O_3$)
IR (KBr): $\bar{\nu}$ = 3,392, 3,323, 2,198 (CN), 1,705 (C=O), 1,674, 1,602, 1,456, 1,379, 1,212, 1,112, 1,060, 1,001, 765 $cm^{-1}$; $^1$H NMR: $\delta$ = 2.27 (s, 3H, $CH_3$), 4.40 (s, 1H, CH), 7.03–7.06 (m, 3H, ArH), 7.19 (t, $J$ = 8.0 Hz, 1H, ArH), 7.35 (br s, 2H, $NH_2$), 7.47 (d, $J$ = 8.0 Hz, 1H, ArH), 7.50 (t, $J$ = 7.5 Hz, 1H, ArH), 7.72 (t, $J$ = 8.0 Hz, 1H, ArH), 7.91 (d, $J$ = 8.0 Hz, 1H, ArH) ppm; $^{13}$C NMR: $\delta$ = 26.2 ($CH_3$), 42.2 (C-4), 63.4 (C-3), 109.3, 118.2, 121.8 (CN), 124.4, 127.7, 129.9, 130.0, 133.1, 133.2, 133.6, 138.1, 142.9, 148.5, 157.4, 158.6 (C-2), 163.2, 164.8 (C=O) ppm.

*2-Amino-4-(2-methoxyphenyl)-5-oxo-4H,5H-pyrano[3,2-c]-chromene-3-carbonitrile* (**4e**, $C_{20}H_{14}N_2O_4$)
IR (KBr): $\bar{\nu}$ = 3,392, 3,190, 2,191 (CN), 1,708 (C=O), 1,676, 1,604, 1,490, 1,458, 1,382, 1,328, 1,251, 1,112, 1,062, 877, 671 $cm^{-1}$; $^1$H NMR: $\delta$ = 3.72 (s, 3H, OMe), 4.71 (s, 1H, CH), 6.88 (t, $J$ = 7.5 Hz, 1H, ArH), 6.99 (d, $J$ = 8.0 Hz, 1H, ArH), 7.12 (d, $J$ = 7.5 Hz, 1H, ArH), 7.22 (t, $J$ = 8.0 Hz, 1H, ArH), 7.27 (br s, 2H, $NH_2$), 7.46 (d, $J$ = 8.0 Hz, 1H, ArH), 7.51 (t, $J$ = 7.5 Hz, 1H, ArH), 7.72 (t, $J$ = 8.0 Hz, 1H, ArH), 7.91 (d, $J$ = 7.5 Hz, 1H, ArH) ppm; $^{13}$C NMR: $\delta$ = 32.6 (C-4), 56.2 (OMe), 57.3 (C-3), 103.8, 112.2, 113.5, 117.0 (CN), 119.8, 127.0, 122.7, 125.1, 128.9, 129.6, 131.2, 133.2, 152.5, 154.4, 157.6 (C-2), 159.0, 160.0 (C=O) ppm.

*2-Amino-5-oxo-4-(2,3,4-trimethoxyphenyl)-4H,5H-pyrano-[3,2-c]chromene-3-carbonitrile* (**4g**, $C_{22}H_{18}N_2O_6$)
IR (KBr): $\bar{\nu}$ = 3,330, 3,180, 2,192 (CN), 1,701 (C=O), 1,670, 1,612, 1,494, 1,463, 1,377, 1,284, 1,257, 1,112, 1,091, 1,062, 1,010, 761 $cm^{-1}$; $^1$H NMR: $\delta$ = 3.72 (s, 3H, OMe), 3.74 (s, 3H, OMe), 3.77 (s, 3H, OMe), 4.58 (s, 1H, CH), 6.72 (d, $J$ = 8.0 Hz, 1H, ArH), 7.84 (d, $J$ = 8.0 Hz, 1H, ArH), 7.31 (br s, 2H, $NH_2$), 7.46 (d, $J$ = 7.5 Hz, 1H, ArH), 7.50 (t, $J$ = 7.5 Hz, 1H, ArH), 7.71 (t, $J$ = 7.5 Hz, 1H, ArH), 7.90 (d, $J$ = 7.5 Hz, 1H, ArH) ppm; $^{13}$C NMR: $\delta$ = 32.9 (C-4), 56.2 (OMe), 57.9 (C-3), 60.7 (OMe), 61.2 (OMe), 104.3, 108.0, 113.5, 117.0, 119.9, 122.8 (CN), 120.3, 125.2, 128.7, 133.3, 141.9, 151.9, 152.5, 153.2 (C-2), 158.7, 160.0 (C=O) ppm.

*2-Amino-4-(2-fluorophenyl)-5-oxo-4H,5H-pyrano-[3,2-c]chromene-3-carbonitrile* (**4j**, $C_{19}H_{11}FN_2O_3$)
IR (KBr): $\bar{\nu}$ = 3,377, 3,186, 2,196 (CN), 1,708 (C=O), 1,676, 1,604, 1,460, 1,382, 1,116, 1,062, 956, 871, 617 $cm^{-1}$; $^1$H NMR: $\delta$ = 4.72 (s, 1H, CH), 7.14 (d, $J$ = 7.5 Hz, 1H, ArH), 7.13–7.17 (m, 2H, ArH), 7.29–7.32 (m, 2H, ArH), 7.45–7.48 (m, 3H, $NH_2$ + ArH), 7.51 (t, $J$ = 7.5 Hz, 1H, ArH), 7.73 (t, $J$ = 7.5 Hz, 1H, ArH), 7.92 (d, $J$ = 7.5 Hz, 1H, ArH) ppm; $^{13}$C NMR: $\delta$ = 31.7 (C-4), 56.8 (C-3), 103.1, 113.3, 116.0 (d, $^2J_{FC}$ = 21.5 Hz), 117.1, 119.5 (CN), 122.9, 125.1 (d, $^4J_{FC}$ = 2.7 Hz), 129.7 (d, $^3J_{FC}$ = 8.0 Hz), 130.3 (d, $^2J_{FC}$ = 11.8 Hz), 130.7 (d, $^3J_{FC}$ = 3.6 Hz), 133.6, 152.6, 154.4 (C-2), 158.7, 159.9 (C=O), 160.7 (d, $^1J_{FC}$ = 244.1 Hz) ppm.

*2-Amino-4-(2-bromophenyl)-5-oxo-4H,5H-pyrano-[3,2-c]chromene-3-carbonitrile* (**4o**, $C_{19}H_{11}BrN_2O_3$)
IR (KBr): $\bar{\nu}$ = 3,408, 3,178, 2,198 (CN), 1,701 (C=O), 1,676, 1,635, 1,608, 1,458, 1,379, 1,113, 1,062, 877, 617 $cm^{-1}$; $^1$H NMR: $\delta$ = 4.99 (s, 1H, CH), 7.19 (t, $J$ = 8.0 Hz, 1H, ArH), 7.29–7.34 (m, 2H, ArH), 7.46 (br s, 2H, $NH_2$), 7.48 (d, $J$ = 7.5 Hz, 1H, ArH), 7.52 (t, $J$ = 7.5 Hz, 1H, ArH), 7.59 (d, $J$ = 8.0 Hz, 1H, ArH), 7.74 (t, $J$ = 7.5 Hz, 1H, ArH), 7.91 (d, $J$ = 7.5 Hz, 1H, ArH) ppm; $^{13}$C NMR: $\delta$ = 36.9 (C-4), 57.1 (C-3), 103.6,

113.3, 117.1, 119.2 (CN), 123.0, 123.4, 125.2, 128.8, 129.5, 131.1, 133.2, 133.5, 142.4, 152.6, 154.5 (C-2), 158.5, 159.9 (C=O) ppm.

*2-Amino-4-(2-cyanophenyl)-5-oxo-4H,5H-pyrano-[3,2-c]chromene-3-carbonitrile* (**4s**, $C_{20}H_{11}N_3O_3$)
IR (KBr): $\bar{\nu}$ = 3,192, 2,198 (CN), 1,718 (C=O), 1,674, 1,604, 1,456, 1,382, 1,112, 1,062, 1,010, 758, 617 $cm^{-1}$; $^1$H NMR: $\delta$ = 4.81 (s, 1H, CH), 7.44–7.48 (m, 2H, ArH), 7.51–7.54 (m, 2H, ArH), 7.59 (br s, 2H, $NH_2$), 7.66 (t, $J$ = 7.5 Hz, 1H, ArH), 7.74 (t, $J$ = 8.0 Hz, 1H, ArH), 7.81 (d, $J$ = 7.5 Hz, 1H, ArH), 7.92 (d, $J$ = 8.0 Hz, 1H, ArH) ppm; $^{13}$C NMR: $\delta$ = 36.7 (C-4), 56.8 (C-3), 102.4, 111.3, 117.1 (Ar-CN), 117.7 (CN), 119.2, 123.2, 125.3, 128.6, 130.4, 130.5, 133.8, 134.0, 147.4, 152.7, 154.6 (C-2), 158.4, 160.1 (C=O) ppm.

*2-Amino-4-(4-cyanophenyl)-5-oxo-4H,5H-pyrano-[3,2-c]chromene-3-carbonitrile* (**4t**, $C_{20}H_{11}N_3O_3$)
IR (KBr): $\bar{\nu}$ = 3,435, 3,323, 2,235, 2,198 (CN), 1,716 (C=O), 1,676, 1,600, 1,456, 1,375, 1,272, 1,170, 1,112, 1,058, 997, 763 $cm^{-1}$; $^1$H NMR: $\delta$ = 4.60 (s, 1H, CH), 7.46-7.52 (m, 6H, ArH + $NH_2$), 7.73 (t, $J$ = 7.5 Hz, 1H, ArH), 7.78 (t, $J$ = 8.0 Hz, 2H, ArH), 7.91 (d, $J$ = 8.0 Hz, 1H, ArH) ppm; $^{13}$C NMR: $\delta$ = 37.0 (C-4), 56.9 (C-3), 102.8, 109.9, 112.9, 116.6, 118.7 (Ar-CN), 118.8 (CN), 122.6, 124.7, 128.9, 132.5, 133.1, 148.7, 152.2, 153.9 (C-2), 158.0, 159.5 (C=O) ppm.

*2-Amino-4-cyclohexyl-5-oxo-4H,5H-pyrano[3,2-c]-chromene-3-carbonitrile* (**4v**, $C_{19}H_{18}N_2O_3$)
IR (KBr): $\bar{\nu}$ = 3,427, 3,170, 2,189 (CN), 1,720 (C=O), 1,670, 1,631, 1,595, 1,456, 1,388, 1,313, 1,269, 1,090, 1,049, 954, 759 $cm^{-1}$; $^1$H NMR: $\delta$ = 0.95–1.18 (m, 4H, 2 × $CH_2$), 1.30–1.39 (m, 2H, $CH_2$), 1.58–1.75 (m, 5H, 2 × $CH_2$ + CH), 3.28 (d, $J$ = 7.5 Hz, 1H, CH), 7.32 (br s, 2H, $NH_2$), 7.44–7.48 (m, 2H, ArH), 7.70 (t, $J$ = 7.5 Hz, 1H, ArH), 7.82 (d, $J$ = 7.5 Hz, 1H, ArH) ppm; $^{13}$C NMR: $\delta$ = 26.0 ($CH_2$), 26.4 ($CH_2$), 26.6 ($CH_2$), 27.5 (CH), 30.7 ($CH_2$), 37.2 ($CH_2$), 43.7 (C-4), 53.1 (C-3), 105.1, 113.5, 117.0, 121.0 (CN), 122.6, 125.1, 133.2, 152.5, 155.2, 160.5 (C-2), 161.1 (C=O) ppm.

*4,4′-(1,3-phenylene)bis(2-amino-5-oxo-4H,5H-pyrano-[3,2-c]chromene-3-carbonitrile)* (**4w**, $C_{32}H_{18}N_4O_6$)
IR (KBr): $\bar{\nu}$ = 3,327, 3,192, 2,194 (CN), 1,716 (C=O), 1,670, 1,608, 1,456, 1,379, 1,272, 1,172, 1,112, 1,055, 958, 761 $cm^{-1}$; $^1$H NMR: $\delta$ = 4.43 (s, 1H, CH), 4.44 (s, 1H, CH), 7.09–7.18 (m, 3H, ArH), 7.23–7.29 (m, 1H, ArH), 7.39 (br s, 2H, $NH_2$), 7.43 (br s, 2H, $NH_2$), 7.44–7.51 (m, 4H, ArH), 7.68–7.73 (m, 2H, ArH), 7.85–7.89 (m, 2H, ArH) ppm; $^{13}$C NMR: $\delta$ = 37.0 (CH), 37.1 (CH), 58.1, 58.4, 104.2, 104.6, 113.3, 116.9, 117.0, 119.5, 119.6, 122.8, 122.9, 125.0, 125.1, 126.4, 126.7, 127.3, 129.2, 129.3, 133.3, 133.4, 143.7, 143.9, 152.5, 152.6, 153.8, 154.0, 158.4, 158.8, 159.8 (C=O), 159.9 (C=O) ppm.

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