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A simple method for the synthesis of functionalized 6-aryl-6*H*-dibenzo[*b*,*d*]pyran derivatives from 3-nitro-2*H* chromenes

Ping Li, Ling-Ling Luo, Xin-Sheng Li, Jian-Wu Xie *

Zhejiang Key Laboratory for Reactive Chemistry on Solid Surfaces, Department of Chemistry and Life Science, Zhejiang Normal University, Jinhua 321004, China

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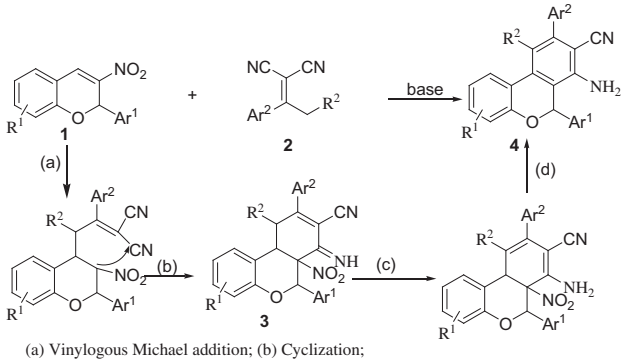
ABSTRACT

The one-pot synthesis of multi-substituted 6-aryl-6*H*-dibenzo[*b*,*d*]pyran derivatives was achieved via vinylogous Michael addition as the key step and domino reactions under mild reaction conditions, employing readily available α,α-dicyanoolefins and 3-nitro-2*H*-chromenes as substrates.

1. Introduction

Development of drug-like heterocycle compounds from simple substrates through domino reactions catalyzed by readily available small organic molecule is one of the emerging areas in modern synthetic chemistry, even though there are already many common synthesis strategies for the construction of C–C, C–N, C–O, C–S and C–X (X=halogen) bonds in structurally diverse natural and non-natural products by conventional methods. The benzopyran unit is the core structure in a plethora of natural products and synthetic compounds.[1] Among of this class of compounds, the dibenzo[*b*,*d*]pyran nucleus constitutes the skeleton of a number of physiologically active natural products as well as drugs,[2] such as cannabinol, a constituent of cannabis, which have been characterized to have this structural unit.[3–5] The dibenzo[*b*,*d*]pyran and their derivatives have attracted strong interest due to their useful biological and pharmacological properties.[6] The dibenzo[*b*,*d*]pyran ring system can also afford an interesting photochemical reaction via the proposed *o*,*o*′-biphenyl quinone intermediate and will be useful as photoswitches.[7–9] Thus, continuous efforts have been devoted to the development of more general and versatile synthetic methodologies for this class of compounds. Apart from the various classical approaches towards the synthesis of the dibenzo[*b*,*d*]pyrans,[6a,9b,10–j] three different strategies developed for their synthesis have been reported recently: Fagnou et al. obtained the dibenzo[*b*,*d*]pyrans by palladium-catalyzed cross-coupling reactions catalyzed with $Pd(OAc)_2$ and 2-(diphenylphosphino)-2′-(*N*,*N*-dimethylamino) biphenyl at 125–145 °C.[11] Wang et al. used a reductive ring opening and cyclization to get the dibenzo[*b*,*d*]pyrans from dibenzofuran.[7] The multi-step synthesis by Finet and Fedorov involved a bismuth-mediated oxidation–*ortho*-arylation–cyclisation sequence for the synthesis of the dibenzo[*b*,*d*]pyran derivatives.[12] In this paper, we describe a one-pot synthesis of multi-substituted 6-aryl-6*H*-dibenzo[*b*,*d*]-pyran derivatives via vinylogous Michael addition as the key step and domino reactions under mild reaction conditions, employing readily available α,α-dicyanoolefins and 3-nitro-2*H*-chromenes as substrates.

Recently, we[13] and other research groups[14] reported that the electron-deficient α,α-dicyanoolefins could behave as good hydride acceptors in conjugate reduction reactions and also act as versatile direct vinylogous donors in asymmetric Michael addition reactions with excellent chemo- and stereoselectivity. The concept of γ-position activation according to strong electron-withdrawing groups was expressed adequately. During our ongoing studies of readily available 3-nitro-2*H*-chromene derivatives **1** and α,α-dicyanoolefins, we envisaged that tandem reactions would be possible between the α,α-dicyanoolefins and 3-nitro-2*H*-chromene derivatives **1**, as outlined in Scheme 1, to provide a straightforward protocol for the synthesis of the multi-substituted 6-aryl-6*H*-dibenzo[*b*,*d*]-pyran derivatives.



(a) Vinylogous Michael addition; (b) Cyclization;
(c) Rearrangement; (d) elimination of the leave group NO_2

Scheme 1. The novel method for the synthesis of benzopyran derivatives.

* Corresponding author. Fax: +86 579 82282610; e-mail address: xiejw@zjnu.cn (J.-W. Xie).

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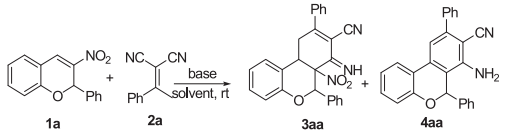
2. Results and discussion

We started our original studies by screening a number of readily available bases and solvents for the domino reactions of 3-nitro-2*H*-chromene **1a** with α,α-dicyanoolefin **2a**. A few of representative results are shown in Table 1. To our delight, the domino reactions proceeded smoothly to provide the desired product **4aa** when the reactions were carried out in the presence of bases (100 mol %) in THF at room temperature (Table 1, entries 1–5). We got the best results when the reaction was catalyzed by triethylamine (entry 5). Somewhat low yields were isolated when the reaction was catalyzed with more strong bases, such as NaOAc, DABCO, DBU and K_2CO_3 (Table 1, entries 1–4). Among the solvents examined, use of DCM gave the best result, affording the desired product **4aa** (71% yield, Table 1, entry 9). Very poor results were observed when the reaction was carried out in other solvents. (Table 1, entries 6–8). In the hope of enhancing the yields, the reaction was refluxed in DCM, unfortunately, the yield was a little decreased (Table 1, entry 10).

Table 1
Screening studies of one-pot tandem reaction of 3-nitro-2*H*-chromene **1a** and α,α-dicyanoolefin **2a**[a]



Entry	Solvent	Base	Yield[b] **4aa**
1	THF	NaOAc	51%
2	THF	DBU	44%
3	THF	DABCO	53%
4	THF	K_2CO_3	37%
5	THF	TEA	59%
6	Ethanol	TEA	31%
7	CH_3CN	TEA	49%
8	Toluene	TEA	46%
9	DCM	TEA	71%
10[c]	DCM	TEA	53%

[a] Unless otherwise noted, reactions performed with 0.2 mmol of **1a**, 0.1 mmol of **2a**, 100 mol % catalyst, in 1 mL solvent at 25 °C for 48 h.
[b] Isolated yield.
[c] Reflux.

With the optimal reaction conditions in hand, we then examined a variety of α,α-dicyanoolefins and 3-nitro-2*H*-chromene derivatives (Fig. 1) to establish the general utility of this novel transformation (Table 2). The reaction scopes proved to be quite broad with respect to both α,α-dicyanoolefins and 3-nitro-2*H*-chromene derivatives. The domino Michael addition/cyclization was generally conducted with 100 mol % of *TEA* in DCM for 48 h. Good yields were obtained in the domino reactions of **2a** and electron-withdrawing substituent on aryl ring of 3-nitro-2*H*-chromene derivatives **1c**–**1d** (entries 3 and 4). On the contrary, an electron-denoting substituent on aryl ring of 3-nitro-2*H*-chromene derivative **1b** tended to decrease the reactivity (entry 2). The substituents on the 2-aryl ring of 3-nitro-2*H*-chromene derivatives have a little effect on the yield and good yields were obtained (entries 6–8) except for the substrate **1e** (entry 5). Notably, the high reactivity was observed for the bulkier nucleophile **2h** (Fig. 1), the domino reactions proceeded smoothly and the product **4ah** was isolated in 43% yield under the same reaction conditions (entry 13). However, reaction of other bulkier α,α-dicyanoolefins **2f** and **2g** (Fig. 1), we cannot get the desired products **4** but **3** under the above conditions (Scheme 2). Although low reactivity was observed for the bulkier nucleophile **2f** and **2g**, the desired products **4** (**4df**, **4ff**, **4gf** and **4ag**) were obtained when the addition products **3** (**3df**, **3ff**, **3gf** and **3ag**) were refluxed in ethanol and catalyzed by 100 mol % NaOAc. In order to get the desired products **4aa**–**4ae** and **4ah** from 3-nitro-2*H*-chromenes **1** and α,α-dicyanoolefins **2** (**2g** and **2f**), the domino reactions were refluxed in ethanol and catalyzed by 100 mol % NaOAc, however, the reactions became complicated in many cases. To establish the structure of **3**, single crystal suitable for X-ray crystallographic analysis was fortunately obtained from **3df** that bears a chlorine atom (Fig. 2).

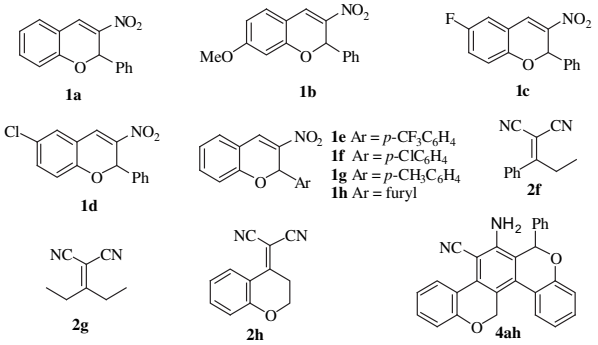
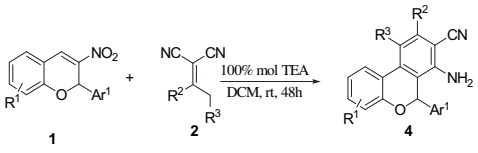


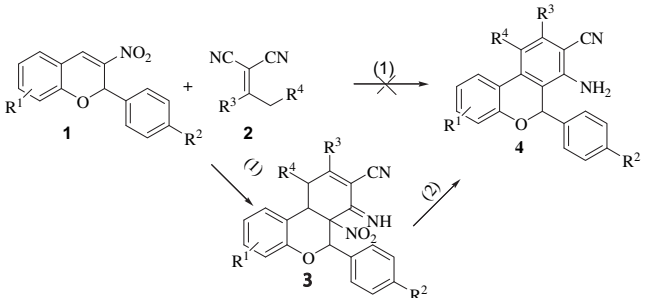
Figure 1. The structure of 3-nitro-2*H*-chromenes (**1**) and α,α-dicyanoolefins (**2**) and structure of **4ah**.

Table 2
The one-pot tandem reaction of 3-nitro-2*H*-chromene **1** and α,α-dicyanoolefin **2**[a]



Entry	**1**	R^2	R3	**2**	Yield[b] (**4**)
1	**1a**	C_6H_5	H	**2a**	71% (**4aa**)
2	**1b**	C_6H_5	H	**2a**	58% (**4ba**)
3	**1c**	C_6H_5	H	**2a**	76% (**4ca**)
4	**1d**	C_6H_5	H	**2a**	72% (**4da**)
5	**1e**	C_6H_5	H	**2a**	41% (**4ea**)
6	**1f**	C_6H_5	H	**2a**	73% (**4fa**)
7	**1g**	C_6H_5	H	**2a**	56% (**4ga**)
8	**1h**	C_6H_5	H	**2a**	74% (**4ha**)
9	**1a**	*p*-ClC_6H_4	H	**2b**	62% (**4ab**)
10	**1a**	*p*-BrC_6H_4	H	**2c**	71% (**4ac**)
11	**1a**	*p*-$CH_3C_6H_4$	H	**2d**	65% (**4ad**)
12	**1a**	*o*-$CH_3OC_6H_4$	H	**2e**	52% (**4ae**)
13	**1a**			**2h**	43% (**4ah**)

[a] All the reactions were performed with 0.2 mmol of **1**, 0.1 mmol of **2**, 100 mol % of *TEA* in 1 mL DCM at 25 °C for 48 h.
[b] Isolated yield.



1	R^2	R^3	**2**	product **4**	yield for two steps
1d	C_6H_5	CH_3	**2f**	**4df**	63%
1f	C_6H_5	CH_3	**2f**	**4ff**	61%
1g	C_6H_5	CH_3	**2f**	**4gf**	68%
1a	Et	CH_3	**2g**	**4ag**	38%

Conditions: (1)Et3N, DCM, rt, 48h; (2) NaAc, TBAB, EtOH

Scheme 2. The domino Michael addition/cyclization catalyzed by NaOAc.

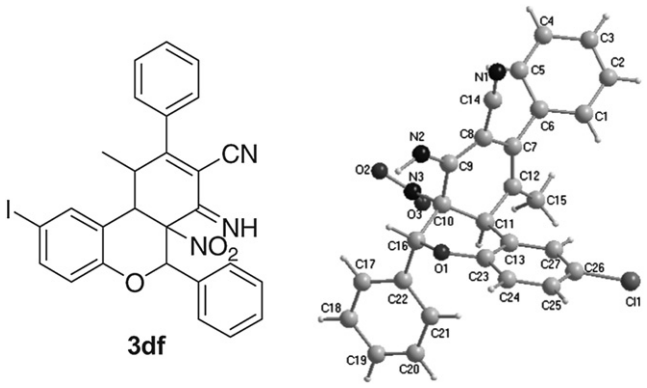


Figure 2. Molecular structure of **3df**.

3. Conclusion

In conclusion, an efficient method for the synthesis of functionalized 6-aryl-6*H*-dibenzo[*b*,*d*]pyran derivatives by domino reactions of 3-nitro-2*H*-chromenes with α,α-dicyanoolefins has been investigated. The one-pot tandem reaction can proceed smoothly under mild conditions and provides pure benzopyran derivatives in moderate to good yield. The reaction's scope proved to be quite broad. Notably, this novel methodology provides facile access to various multifunctional compounds (**3df**, **3ff**, **3gf** and **3ag**) with contiguous many chiral centres that might have important biological and pharmaceutical activities in the future. Current studies are actively underway to extend this novel and efficient methodology to the synthesis of natural products and drugs.

4. Experimental section

4.1. General methods

NMR spectra were recorded with tetramethylsilane as the internal standard. TLC was performed on glass-backed silica plates. Column chromatography was performed using silica gel (200–300 mesh) eluting with ethyl acetate and petroleum ether. ^{1}H NMR spectra were recorded at 400 MHz, and ^{13}C NMR spectra were recorded at 100 MHz (Bruker Avance). Chemical shifts (δ) are reported in parts per million downfield from $CDCl_3$ (δ=7.26 ppm) for ^{1}H NMR and relative to the central $CDCl_3$ resonance (δ=77.0 ppm) for ^{13}C NMR spectroscopy. Coupling constants (J) are given in hertz. ESI-HRMS spectrometer was measured with a Finnigan LCQ^{DECA} ion trap mass spectrometer.

4.2. General procedure for the one-pot tandem reaction of 3-nitro-2*H*-chromenes 1 and α,α-dicyanoolefins 2

4.2.1. General procedure. 3-Nitro-2*H*-chromene **1** (0.2 mmol, 2 equiv) and α,α-dicyanoolefin **2** (0.1 mmol, 1 equiv) were dissolved in 1 mL CH_2Cl_2, then 14 μL triethylamine (0.1 mmol, 1.0 equiv) was added. The reaction mixture was stirred at 25 °C for 48 h. The end of reaction was detected by TLC (ethyl acetate/petroleum ether 1:8). The solvent was removed and flash chromatography on silica gel (ethyl acetate/petroleum ether 1:10) gave **4** as a yellow solid.

*4.2.1.1. 7-Amino-6,9-diphenyl-6H-benzo[c]chromene-8-carbonitrile (**4aa**).* Yellow solid; mp 202.7–204.5 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.76–7.73 (m, 1H), 7.69–7.66 (m, 2H), 7.60–7.50 (m, 4H), 7.37–7.34 (m, 5H), 7.26–7.22 (m, 1H), 7.04–7.01 (m, 1H), 6.93 (d, J=8.1 Hz, 1H), 6.36 (s, 1H) 4.37 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 152.5, 146.3, 145.7, 138.8, 137.0, 134.3, 131.1, 129.2, 128.9, 128.7, 128.6, 127.9, 127.8, 124.0, 122.2, 121.3, 118.4, 117.4, 116.4, 113.7, 74.0; IR (KBr) cm^{-1} 3466, 3359, 3118, 2212, 1718, 1641, 1592, 1555, 1409, 766; ESI-HRMS: calcd for $C_{26}H_{18}N_2NaO$ 397.13137, found 397.13113.

*4.2.1.2. 3-Methoxyl-7-amino-6,9-diphenyl-6H-dibenzo[b,d]pyran-8-carbonitirle (**4ba**).* Yellow solid; mp 195.8–196.9 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.65–7.61 (m, 3H), 7.54–7.47 (m, 3H), 7.34 (s, 5H), 7.23 (s, 1H), 6.58–6.55 (m, 1H), 6.43 (d, J=2.5 Hz, 1H), 6.32 (s, 1H), 4.29 (s, 2H), 3.80–3.77 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 129.2, 129.0, 128.6, 128.5, 127.8, 113.0, 109.0, 103.0, 74.3, 55.3; IR (KBr) cm^{-1} 3503, 3310, 3116, 2206, 1709, 1633, 1557, 1411, 743; ESI-HRMS: calcd for $C_{27}H_{20}N_2NaO_2$ 427.14189, found 427.14170.

*4.2.1.3. 2-Fluoro-7-amino-6,9-diphenyl-6H-dibenzo[b,d]pyran-8-carbonitirle (**4ca**).* Yellow solid; mp 204.5–204.6 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.63–7.60 (m, 2H), 7.54–7.44 (m, 3H), 7.38–7.35 (m, 1H), 733–7.27 (m, 5H), 7.20 (s, 1H), 6.89–6.81 (m, 2H), 6.30 (s, 1H), 4.35 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 158.2, 156.8, 146.3, 145.9, 138.5, 136.6, 129.3, 129.0, 128.9, 128.8, 128.7, 128.5, 127.9, 127.8, 119.6, 119.5, 117.7, 117.5, 117.2, 116.6, 113.7, 110.4, 110.2, 74.0; IR (KBr) cm^{-1} 3448, 3109, 2200, 1697, 1650, 1545, 1417, 749; ESI-HRMS: calcd for $C_{26}H_{18}FN_2O$ 393.14060, found 393.13977.

*4.2.1.4. 2-Chloro-7-amino-6,9-diphenyl-6H-dibenzo[b,d]pyran-8-carbonitirle (**4da**).* Yellow solid; mp 207.4–208.0 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.66–7.61 (m, 3H), 7.52–7.49 (m, 3H), 7.33–7.31 (m, 5H), 729–7.23 (m, 1H), 7.13 (s, 1H), 6.82 (d, J=8.6 Hz, 1H), 6.31 (s, 1H), 4.33 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 151.1, 146.3, 146.0, 138.5, 136.6, 133.1, 130.7, 129.4, 129.0, 128.9, 128.7, 128.5, 127.8, 127.2, 123.8, 122.7, 119.8, 117.1, 116.4, 113.6, 74.2; IR (KBr) cm^{-1} 3398, 3209, 2117, 1698, 1637, 1547, 1513, 1406, 752; ESI-HRMS: calcd for $C_{26}H_{17}ClN_2NaO$ 431.09254, found 431.09216.

*4.2.1.5. 7-Amino-9-phenyl-6-(4-(trifluoromethyl)phenyl)-6H-dibenzo[b,d]pyran-8-carbonitirle (**4ea**).* Yellow solid; mp 196.0–197.0 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.74–7.70 (m, 2H), 7.66–7.64 (m, 3H), 7.59–7.51 (m, 3H), 747–7.41 (m, 4H), 726–7.22 (m, 1H), 704–7.02 (m, 1H), 6.37 (s, 1H), 4.39 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 152.2, 146.3, 146.2, 138.6, 131.3, 128.9, 128.7, 128.6, 128.5, 128.3, 128.1, 127.3, 125.9, 124.1, 123.5, 122.6, 121.2, 118.4, 117.1, 115.5, 113.9, 73.1, 72.9; IR (KBr) cm^{-1} 3471, 3291, 3006, 2206, 1776, 1647, 1555, 1423, 739; ESI-HRMS: calcd for $C_{27}H_{17}F_3N_2NaO$ 465.11895, found 465.11852.

*4.2.1.6. 7-Amino-9-phenyl-6-(4-chlorophenyl)-6H-dibenzo[b,d]pyran-8-carbonitirle (**4fa**).* Yellow solid; mp 190.2–191.5 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.71–7.69 (m, 1H), 7.65–7.62 (m, 2H), 7.56–7.42 (m, 5H), 732–7.27 (m, 3H), 724–7.20 (m, 2H), 702–6.98 (m, 1H), 6.90–6.88 (m, 1H), 6.29 (s, 1H), 4.35 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 152.2, 146.2, 146.0, 138.6, 135.5, 135.1, 134.3, 131.2, 129.3, 129.2, 129.1, 128.8, 128.7, 128.6, 124.0, 122.4, 121.2, 118.4, 117.3, 115.9, 113.8, 73.0; IR (KBr) cm^{-1} 3397, 3106, 2184, 1701, 1632, 1581, 1438, 759; ESI-HRMS: calcd for $C_{26}H_{17}ClN_2NaO$ 431.09264, found 431.09216.

*4.2.1.7. 7-Amino-9-phenyl-6-(4-methylphenyl)-6H-dibenzo[b,d]pyran-8-carbonitirle (**4ga**).* Yellow solid; mp 199.3–191.1 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.70–7.61 (m, 3H), 7.53–7.45 (m, 4H), 7.29 (s, 1H), 721–7.09 (m, 5H), 6.99–6.85 (m, 2H), 6.27 (s, 1H), 4.30 (s, 1H), 2.29 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 134.1, 131.0, 129.7, 128.7, 128.6, 127.8, 123.9, 122.1, 118.4, 117.4, 113.6, 73.9, 21.19; IR (KBr) cm^{-1} 3517, 3361, 2192, 1751, 1639, 1601, 1555, 1394, 710; ESI-HRMS: calcd for $C_{27}H_{20}N_2NaO$ 411.14718, found 411.14678.

*4.2.1.8. 7-Amino-9-phenyl-6-(furan-2-yl)-4-methylphenyl-6H-dibenzo[b,d]-pyran-8-carbonitirle (**4ha**).* Yellow solid; mp 201.4–202.8 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.67–7.64 (m, 1H), 7.55–7.52 (m, 2H), 7.45–7.44 (m, 4H), 731–7.30 (m, 2H), 7.02–7.00 (m, 2H), 6.43 (s, 1H), 6.28 (d, J=1.4 Hz, 1H), 6.13 (d, J=3.3 Hz, 1H) 4.50 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 152.5, 150.7, 146.3, 145.9, 143.8, 138.7, 134.1, 131.1, 131.0, 128.8, 128.7, 128.6, 128.5, 124.0, 122.4, 121.0, 118.2, 117.3, 114.9, 113.8, 110.5, 110.4, 95.9, 67.4; IR (KBr) cm^{-1} 3416, 3317, 3106, 2217, 1709, 1603, 1585, 1500, 691; ESI-HRMS: calcd for $C_{24}H_{16}N_2NaO_2$ 387.11068, found 387.11040.

*4.2.1.9. 7-Amino-6-phenyl-9-(4-chlorophenyl)-6H-dibenzo[b,d]-pyran-8-carbonitirle (**4ab**).* Yellow solid; mp 208.6–210.2 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.70–7.68 (m, 1H), 7.57–7.55 (m, 2H), 7.50–7.47 (m, 2H), 733–7.27 (m, 2H), 7.25–7.21 (m, 3H), 701–6.97 (m, 1H), 6.90–6.88 (m, 1H), 6.31 (s, 1H), 4.34 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 152.5, 146.4, 136.9, 134.4, 131.2, 129.9, 129.2, 129.0, 128.9, 127.8, 123.9, 122.2, 118.5, 117.2, 113.5, 73.9, 29.7; IR (KBr) cm^{-1} 3451, 3306, 3019, 2101, 1705, 1651, 1570, 1395, 718; ESI-HRMS: calcd for $C_{26}H_{17}ClN_2NaO$ 431.09264, found 431.09216.

*4.2.1.10. 7-Amino-6-phenyl-9-(4-bromophenyl)-6H-dibenzo[b,d]-pyran-8-carbonitirle (**4ac**).* Yellow solid; mp 204.3–205.7 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.70–7.64 (m, 3H), 7.50 (d, J=8.4 Hz, 3H), 7.31 (s, 5H), 7.21–7.19 (m, 1H), 701–6.97 (m, 1H), 6.89 (d, J=8.0 Hz, 1H), 6.31 (s, 1H), 4.34 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 152.5, 146.4, 144.4, 134.4, 131.9, 131.2, 130.2, 129.3, 129.0, 127.8, 123.9, 122.2, 118.5, 117.2, 116.7, 113.4, 73.9, 29.7; IR (KBr) cm^{-1} 3391, 3217, 2209, 1684, 1627, 1527, 1461, 673; ESI-HRMS: calcd for $C_{26}H_{17}BrN_2NaO$ 475.0402, found 475.04166.

*4.2.1.11. 7-Amino-6-phenyl-9-(4-methylphenyl)-6H-dibenzo[b,d]-pyran-8-carbonitirle (**4ad**).* Yellow solid; mp 209.1–210.9 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.70 (d, J=7.9 Hz, 2H), 7.54 (d, J=7.9 Hz, 3H), 7.34–7.30 (m, 9H), 7.01–6.99 (m, 2H), 6.89 (d, J=7.9 Hz, 1H), 6.32 (s, 1H), 4.34 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 152.5, 138.7, 137.1, 135.9, 134.2, 131.0, 129.4, 129.2, 128.9, 128.4, 127.8, 123.96, 122.1, 118.4, 113.6, 74.0, 31.9, 29.7, 29.6, 21.3; IR (KBr) cm^{-1} 3415, 3292, 3107, 2017, 1691, 1607, 1537, 1402, 692; ESI-HRMS: calcd for $C_{27}H_{20}N_2NaO$ 411.14711, found 411.14678.

*4.2.1.12. 7-Amino-6-phenyl-9-(2-methoxylphenyl)-6H-dibenzo [b,d]pyran-8-carbonitirle (**4ae**).* Yellow solid; mp 195.6–197.1 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.63 (d, J=7.6 Hz, 2H), 7.33–7.31 (m, 9H), 7.21–7.17 (m, 2H), 6.97–6.87 (m, 2H), 6.32 (s, 1H), 4.27 (s, 2H), 2.27 (d, J=3.8 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 152.5, 145.9, 145.7, 138.6, 134.0, 131.0, 130.4, 129.2, 129.0, 128.7, 127.8, 125.8, 124.0, 122.2, 118.4, 116.8, 114.0, 74.0; IR (KBr) cm^{-1} 3416, 3328, 3105, 2206, 1709, 1637, 1547, 1401, 684; ESI-HRMS: calcd for $C_{27}H_{20}N_2NaO_2$ 427.14221, found 427.14170.

*4.2.1.13. 2-Chloro-7-imino-10-methyl-6a-nitro-6,9-diphenyl-6a,7,10,10a-tetrahydro-6H-benzo[c]chromene-8-carbonitrile (**3df**).* Pale yellow solid; mp 148.0–149.3 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm), 7.43–7.32 (m, 6H), 7.29–7.23 (m, 3H), 7.16 (d, J=6.8 Hz, 4H), 6.95 (d, J=8.7 Hz, 1H), 5.93 (s, 1H), 5.18 (s, 2H), 1.92 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 171.3, 151.4, 136.5, 134.0, 129.9, 129.8, 129.2, 128.9, 128.5, 128.2, 127.3, 126.6, 117.4, 116.9, 60.5, 21.1, 14.2; IR (KBr) cm^{-1} 3347, 3250, 2959, 2202, 1718, 1663, 1565, 1477, 769; ESI-HRMS: calcd for $C_{27}H_{20}ClN_3NaO_3$ 492.10917, found 492.10854.

*4.2.1.14. 6-(4-Chlorophenyl)-7-imino-10-methyl-6a-nitro-9-phenyl-6a,7,10,10a-tetrahydro-6H-benzo[c]chromene-8-carbonitrile (**3ff**).* Pale yellow solid; mp 149.3–150.7 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm), 7.39–6.99 (m, 13H), 5.90 (s, 1H), 5.15 (s, 2H), 4.14 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 152.4, 136.7, 135.7, 132.9, 129.7, 129.2, 129.0, 128.5, 128.3, 128.1, 126.6, 122.4, 116.8, 116.2; IR (KBr) cm^{-1} 3319, 3248, 3027, 2194, 1713, 1651, 1547, 1469, 753; ESI-HRMS: calcd for $C_{27}H_{20}ClN_3NaO_3$ 492.10882, found 492.10854.

*4.2.1.15. 7-Imino-10-methyl-6a-nitro-9-phenyl-6-p-tolyl-6a,7,10,10a-tetrahydro-6H-benzo[c]chromene-8-carbonitrile (**3gf**).* Pale yellow solid; mp 134.6–136.0 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm), 7.37–7.26 (m, 4H), 7.17–6.96 (m, 9H), 5.91 (s, 1H), 5.24 (s, 2H), 4.12–4.10 (m, 1H), 2.31–2.27 (m, 3H), 1.93 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 152.8, 147.9, 139.7, 136.8, 131.4, 129.6, 129.5, 129.2, 128.4, 128.0, 126.6, 126.5, 122.2, 117.0, 116.0, 21.2; IR (KBr) cm^{-1} 3352, 3237, 2916, 2206, 1714, 1647, 1523, 1480, 763; ESI-HRMS: calcd for $C_{28}H_{23}N_3NaO_3$ 472.16364, found 472.16316.

*4.2.1.16. 9-Ethyl-7-imino-10-methyl-6a-nitro-6-phenyl-6a,7,10,10a-tetrahydro-6H-benzo[c]chromene-8-carbonitrile (**3ag**).* Pale yellow solid; mp 129.8–130.6 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm), 7.34–7.25 (m, 4H), 7.22–7.14 (m, 3H), 7.03–6.99 (m, 1H), 6.93 (d, J=8.2 Hz, 1H), 5.67–5.64 (m, 2H), 4.93 (s, 2H), 4.10–4.09 (m, 1H), 3.41–3.38 (m, 1H), 1.73 (d, J=7.1 Hz, 3H), 1.14 (d, J=7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 152.4, 144.9, 134.4, 130.8, 129.5, 128.8, 128.5, 127.6, 127.5, 127.2, 122.2, 121.9, 121.7, 117.3, 116.4, 89.5, 78.4, 40.0, 33.1, 18.8, 13.2; IR (KBr) cm^{-1} 3361, 3272, 2956, 2215, 1727, 1671, 1549, 1418, 773; ESI-HRMS: calcd for $C_{23}H_{21}N_3NaO_3$ 410.14828, found 410.14751.

*4.2.1.17. 14-Amino-1-phenyl-1,7-dihydrobenzo[1,2-c:3,4-c′]dichromene-13-carbonitrile (**4ah**).* Yellow solid; mp 231.0–232.1 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm), 7.37–7.35 (m, 3H), 7.21–7.18 (m, 4H), 7.10–6.94 (m, 6H), 6.30 (s, 1H), 5.47 (d, J=12.9 Hz, 1H), 5.09 (d, J=12.9 Hz, 1H), 4.36 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 145.8, 135.9, 130.8, 129.2, 128.8, 127.9, 127.8, 125.8, 122.5, 122.0, 119.2, 117.3, 74.7, 66.7, 29.7; IR (KBr) cm^{-1} 3472, 3361, 3104, 2172, 1736, 1607, 1569, 1416, 739; ESI-HRMS: calcd for $C_{27}H_{19}N_2O_2$ 403.14505, found 403.14410.

4.3. Synthesis of 4df, 4ff, 4gf and 4ag catalyzed by NaOAc

4.3.1. General procedure. The reactions performed with **3** (0.1 mmol, 1.0 equiv), NaOAc (0.1 mmol, 1.0 equiv) and TBAB (0.1 mmol, 1.0 equiv) in 2 mL EtOH. The reaction mixture was refluxed for 12 h. The end of reaction was detected by TLC (ethyl acetate/petroleum ether 1:8). The solvent was removed and flash chromatography on silica gel (ethyl acetate/petroleum ether 1:15) gave **4** as a yellow solid.

*4.3.1.1. 2-Chloro-7-amino-6-phenyl-9-(4-chlorophenyl)-6H-dibenzo[b,d]pyran-8-carbonitirle (**4df**).* Yellow solid; mp 203.3–204.8 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm), 7.64 (d, J=2.4 Hz, 1H), 7.53–7.50 (m, 3H), 7.44–7.32 (m, 2H), 7.29–7.23 (m, 5H), 7.11–7.08 (m, 1H), 6.28 (s, 1H), 4.11 (s, 2H), 2.29 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 152.5, 147.0, 143.1, 138.8, 136.6, 134.3, 129.7, 129.3, 129.0, 128.9, 128.9, 128.9, 128.6, 128.5, 128.1, 128.0, 126.5, 125.3, 123.1, 121.1, 120.3, 116.9, 98.8, 74.9, 20.5; IR (KBr) cm^{-1} 3501, 3208, 2092, 1698, 1593, 1537, 1397, 695; ESI-HRMS: calcd for $C_{27}H_{19}ClN_2NaO$ 445.10828, found 445.10781.

*4.3.1.2. 7-Amino-6-(4-chlorophenyl)-9-phenyl-6H-benzo[c]-chromene-8-carbonitrile (**4ff**).* Yellow solid; mp 198.3–199.5 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.65 (d, J=7.8 Hz, 1H), 7.50–7.39 (m, 5H), 7.33–7.14 (m, 5H), 6.97–6.89 (m, 2H), 6.23 (s, 1H), 4.11 (s, 2H), 2.28 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 153.6, 147.0, 143.0, 139.0, 135.4, 135.0, 134.7, 130.2, 129.5, 129.1, 129.0, 128.9, 128.6, 128.5, 128.5, 128.4, 123.9, 123.2, 121.8, 120.6, 119.0, 117.1, 98.3,

73.8, 29.7, 20.6; IR (KBr) cm^{-1} 3442, 3279, 3100, 2237, 1697, 1603, 1536, 1412, 697; ESI-HRMS: calcd for $C_{27}H_{19}ClN_2NaO$ 445.10809, found 445.10781.

*4.3.1.3. 7-Amino-9-phenyl-6-p-tolyl-6H-benzo[c]chromene-8-carbonitrile (**4gf**).* Yellow solid; mp 205.2–206.7 °C; ^1H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.66 (d, J=7.9 Hz, 1H), 7.52–7.42 (m, 5H), 7.17–7.14 (m, 3H), 7.08–6.98 (m, 2H), 6.96–6.90 (m, 2H), 6.25 (s, 1H), 4.10 (s, 2H), 2.30 (s, 3H), 2.23 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 154.0, 146.6, 143.1, 139.1, 139.0, 135.4, 133.1, 130.0, 129.6, 129.4, 129.1, 128.6, 128.4, 128.3, 128.1, 124.0, 123.0, 121.6, 121.6, 121.5, 119.1, 117.3, 98.1, 74.5, 21.2, 20.6; IR (KBr) cm^{-1} 3387, 3176, 3108, 2217, 1770, 1614, 1541, 1410, 686; ESI-HRMS: calcd for $C_{28}H_{22}N_2NaO$ 425.16271, found 425.16243.

*4.3.1.4. 7-Amino-9-ethyl-10-methyl-6-phenyl-6H-benzo[c]-chromene-8-carbonitrile (**4ag**).* Yellow solid; mp 198.1–199.6 °C; ^1H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.59 (d, J=7.8 Hz, 1H), 7.24–7.20 (m, 5H), 7.13–7.09 (m, 1H), 6.97–6.93 (m, 1H), 6.87 (d, J=8.0 Hz, 1H), 6.19 (s, 1H), 4.01 (s, 2H), 2.97–2.91 (m, 2H), 2.51 (s, 3H), 1.27 (t, J=7.3 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm) 153.9, 147.2, 143.1, 136.2, 135.4, 129.8, 129.0, 128.7, 128.6, 128.0, 124.2, 122.6, 121.5, 120.1, 119.1, 117.4, 97.6, 74.8, 26.6, 17.9, 14.2; IR (KBr) cm^{-1} 3297, 3169, 3112, 2009, 1756, 1651, 1532, 1421, 656; ESI-HRMS: calcd for $C_{23}H_{20}N_2NaO$ 363.14706, found 363.14678.

5. Crystallographic data

Crystallographic Data Crystal data for **3df** $C_{27}H_{19}ClN_3O_3$ (468.90), space group monoclinic, $C2/2$, a=32.1978(16), b=9.3776 (4), c=20.6161(9) Å, U=6210.4(5) $Å^3$, Z=8, specimen 0.215×0.183×0.094 mm^3, T=296(2) K, SIEMENS P4 diffractometer, absorption coefficient 0.149 mm^{-1}, reflections collected 46,321/7116 [R(int)=0.0763], refinement by Full-matrix least-squares on F^2, data/restraints/parameters 7116/1/310, goodness-of-fit on F^2=1.041, final R indices [$I>2\sigma(I)$] $R1$=0.1842, $wR2$=0.4711, R indices (all data) $R1$=0.2453, $wR2$=0.5447, largest diff. peak and hole 3.065 and −0.530 e $Å^{-3}$. Crystallographic data for the structure **3df** have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-761098.

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Supplementary data

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.tet.2010.07.042. These data include MOL files and InChIKeys of the most important compounds described in this article.

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