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ORIGINAL PAPER

A facile synthesis of 2-aryl-4-(indol-3-yl)-4*H*-chromenes using amberlyst-15 as an efficient recyclable heterogeneous catalyst

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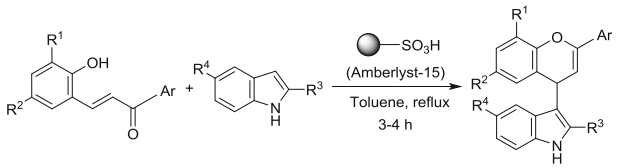
Abstract Starting from 2-hydroxychalcones and indoles, a facile synthesis of 2-aryl-4-(indol-3-yl)-4*H*-chromenes has been achieved by use of amberlyst-15, a sulfonated polystyrene resin, as a recyclable heterogeneous catalyst. The methodology involves a domino sequence of Michael addition, cyclization, and dehydration.

Graphical abstract



Keywords 2-Aryl-4-(indol-3-yl)-4*H*-chromenes · Heterogeneous catalysis · Michael addition · Cyclization

Introduction

Chromenes are often found to be present in the structural motif of a good number of natural products, the important ones of which include some alkaloids, flavonoids, tocopherols, and anthocyanins [1]. Many chromenes exhibit important biological activities like anticancer [2, 3], antibacterial [4], apoptosis inducer [5, 6], potassium channel opener [7], insecticide [8], termiticide [9], etc. Again, some chromene crystals are reported to exhibit photochromism [10]. Such wide range of natural availability coupled with their diverse utility has made these heterocycles popular synthetic targets [11–17]. On the other hand, indole derivatives are well-known for their versatile biological activities [18], some of which include selective PPAR gamma modulator [19], sodium/potassium exchanger inhibitor [20], etc. It is observed that construction of molecules by combination of two or more different biologically active structural units often generates compounds having enriched activities [5, 6]. So, we became interested to undertake the synthesis of molecules containing both chromene and indole moieties. A detailed survey of literature revealed that there are several reports describing synthesis of such molecules [13, 21–24]. However, those synthetic methodologies are found to involve use of expensive reagents, complex starting materials, or non-recyclable catalyst. Herein, we report a facile synthesis of 2-aryl-4-(indol-3-yl)-4*H*-chromenes **1** starting from molecules as simple as 2-hydroxychalcones **2** and indoles **3** and using amberlyst-15, a commercially available sulfonated polystyrene resin, as a recyclable catalyst. The methodology involves a domino sequence of Michael addition, cyclization, and dehydration.

Results and discussion

In this study, our aim was to achieve a simple synthesis of 2-aryl-4-(indol-3-yl)-4*H*-chromenes **1** in three steps, the first one being a Michael addition of indoles **3** with 2-hydroxychalcones **2** and the subsequent ones cyclization followed by dehydration. Chalcones and their derivatives, by virtue of possessing an α,β-unsaturated keto system,

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serve as good Michael acceptors [25]. On the other hand, indoles are well-known for exhibiting electrophilic substitution reactions at their C-3 position and thus serving as a good source of carbon nucleophile of soft nature [26]. Amberlyst-15, known to be useful for Michael addition [25, 27], was employed to catalyze the first step which was performed under refluxing condition in toluene. Here, it was observed with interest that instead of stopping in the Michael addition step, the reaction proceeded further generating our target molecules **1** in good yield (Scheme 1).

It was then our interest to develop the methodology further. The reaction condition was optimized for this purpose using different solvents and catalyst loads (Table 1). Thus, use of only 30 mg of the catalyst for 1 mmol of each of the reactants under refluxing toluene for 3 h was found to be the optimum condition for synthesis of **1h**. This protocol was then successfully applied to sixteen combinations of reactants involving four indoles and seven 2-hydroxychalcones and one related compound (Table 2).

It was observed that the presence of an electron-withdrawing substituent like Cl at either of the phenyl rings of 2-hydroxychalcone improved the yield whereas an electron-releasing substituent like OMe diminished the same. The reaction with 2-hydroxybenzalacetone with indole did not yield any product analogous to **1**. Again, 2-methylindole was found to give better yield than indole itself while the yields were found to be gradually lower in cases of 5-methoxyindole and 5-bromoindole. Attempted synthesis of the compounds analogous to **1** by involving 1-methylindole and 2-phenylindole were, however, unsuccessful.

The plausible mechanism for formation of the indolylchromene derivatives **1** is shown in Scheme 2. The acidic resin first catalyzes the Michael addition to give the adduct **4** which undergoes acid catalyzed cyclization followed by proton capture generating the protonated alcohol **5**. The latter on dehydration followed by deprotonation yields **1**. It is reasonable to expect that the conjugate acid of **2** will be more reactive towards indole addition when that contains electron withdrawing group at either of the phenyl rings, and this was our observation. However, the effect of incorporating a substituent in indole could not be fully rationalized. The overall process restores the resin in its original form, which is used in the next cycle of reactions. It has been observed that the resin can be recovered from the mixture after completion of the reaction and can be used further with no significant reduction of its activity (Figs. 1, 2).

In fine, we report a very simple methodology for rapid synthesis of 2-aryl-4-(indol-3-yl)-4*H*-chromenes **1** having potential biological activities.

Experimental

Melting points were recorded on a Kofler block. Analytical samples were dried in vacuo at room temperature. IR spectra were recorded on a Perkin Elmer FT-IR Spectrophotometer (Spectrum BX II) as KBr pellets. ^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ on a Bruker AV-300 (300 MHz) and Bruker AVANCE IIIHD (400 MHz) spectrometer using TMS as an internal standard. FAB MS was measured with a JEOL JMS-700 spectrometer and HRMS with a Waters Xevo G2QTof HRMS spectrometer. Microanalytical data were recorded on two Perkin-Elmer 2400 Series II C, H, N analyzers. Column chromatography was performed on neutral alumina using petroleum ether (60–80 °C) and petroleum ether-ethyl acetate mixtures as eluents. TLC was done with silica gel G. Amberlyst-15 was manufactured by Fluka Chemika, Switzerland; its specification and SEM picture are given as supplementary material. 2-Hydroxychalcones and related compound used in this study were obtained by simple Claisen-Schmidt condensation of salicylaldehydes and aromatic methyl ketones.

*General procedure for synthesis of 2-aryl-4-(indol-3-yl)-4H-chromenes **1***

A mixture of 2-hydroxychalcone **2** (1 mmol), indole **3** (1 mmol), and 30 mg amberlyst-15 was refluxed in 10 cm^3 dry toluene for 3 h. The resulting mixture was filtered through cotton and washed thoroughly with diethyl ether. The catalyst thus separated was preserved for recovery.

Scheme 1

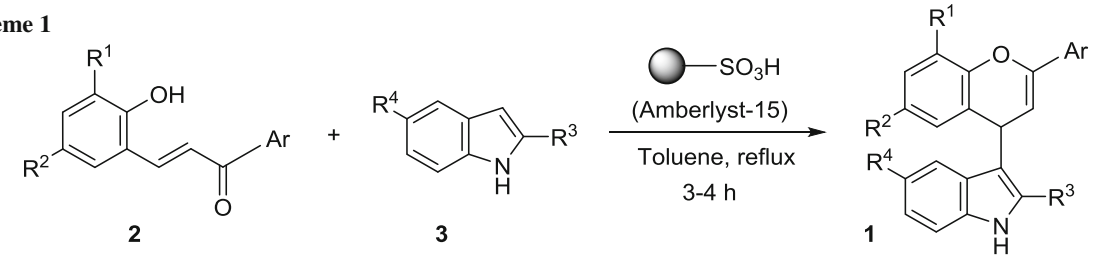


Table 1 Optimization of reaction conditions

Entry	Amount of catalyst/mg	Solvent	Temp.	Time/h	Yield[a]/%
1	No catalyst	Toluene	Reflux	3	13
2	10	Toluene	Reflux	3	56
3	20	Toluene	Reflux	3	66
4	30	Toluene	Reflux	3	76
5	40	Toluene	Reflux	3	76
6	30	Toluene	Reflux	3.5	74
6	30	Toluene	Reflux	4	73
7	30	THF	Reflux	3	43
8	30	Ethanol	Reflux	3	46
9	30	Acetonitrile	Reflux	3	34
11	30	Dioxane	Reflux	3	22
12	30	DMF	Reflux	3	17
13	30	DMF	120 °C	3	23

Reaction was carried out with 1 mmol 2-hydroxychalcone (**2a**) and 1 mmol 2-methylindole (**3b**)

[a] Isolated yields

From the filtrate, solvent was distilled out under reduced pressure and the residue was subjected to a rapid column chromatography over neutral alumina to get **1** in pure state.

Recovery of the catalyst

The catalyst separated from the reaction mixture was washed thoroughly with ethyl acetate and acetone successively until the washings became colorless. It was then dried in a hot air oven at 100 °C for 8 h. The dried catalyst was used further.

*4-(Indol-3-yl)-2-phenyl-4H-chromene (**1a**)*
Dark red solid; m.p.: 104–106 °C (Ref. [24] 100–102 °C).

4-(Indol-3-yl)-2-(4-methylphenyl)-4H-chromene
(**1b**, $C_{24}H_{19}NO$)
Dark red solid; m.p.: 94–96 °C; ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 2.35$ (1H, s, $-CH_3$), 5.16 (1H, d, $J = 3.9$ Hz, chromene H-4), 5.65 (1H, d, $J = 3.9$ Hz, chromene H-3), 6.85–6.98 (m, 1H), 7.02–7.21 (m, 7H), 7.45 (d, 2H, $J = 8.7$ Hz), 7.63 (dd, 2H, $J = 8.2$, 2.4 Hz), 7.89 (d, 1H, $J = 8.1$ Hz), 8.14 (s, 1H, indole N–H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 21.2$, 32.1, 100.2, 111.3, 116.5, 119.4, 119.6, 121.6, 122.1, 123.3, 123.5, 124.6, 126.4, 127.5, 128.9, 129.3, 129.5, 131.7, 136.7, 138.2, 147.8, 151.2 ppm; IR (KBr): $\bar{\nu} = 3{,}406$ (N–H), 2,857, 1,726, 1,465, 1,233, 756 cm^{-1}; FAB MS: *m/z* calcd. for $C_{24}H_{19}NO$ (M^+) 337.28, found 337.30.

*4-(Indol-3-yl)-2-(4-methoxyphenyl)-4H-chromene (**1c**)*
Dark red solid; m.p.: 98–100 °C (Ref. [24] 96–97 °C).

*2-(4-Chlorophenyl)-4-(indol-3-yl)-4H-chromene (**1d**)*
Dark red solid; m.p.: 87–89 °C (Ref. [24] 85–86 °C).

*4-(Indol-3-yl)-2-(thiophen-2-yl)-4H-chromene (**1e**)*
Dark red oil; ^{1}H NMR was found to agree with the one given in Ref. [24].

6-Chloro-4-(indol-3-yl)-2-phenyl-4H-chromene
(**1f**, $C_{23}H_{16}ClNO$)
Dark red solid; m.p.: 76–78 °C; ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 5.14$ (1H, d, $J = 3.9$ Hz, chromene H-4), 5.70 (1H, d, $J = 3.9$ Hz, chromene H-3), 7.03 (1H, d, $J = 2.1$ Hz), 7.10–7.47 (9H, m), 7.66 (1H, d, $J = 7.8$ Hz), 7.77 (2H, d, $J = 6.9$ Hz), 7.98 (1H, *s*, indole N–H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 62.3$, 100.8, 111.5,

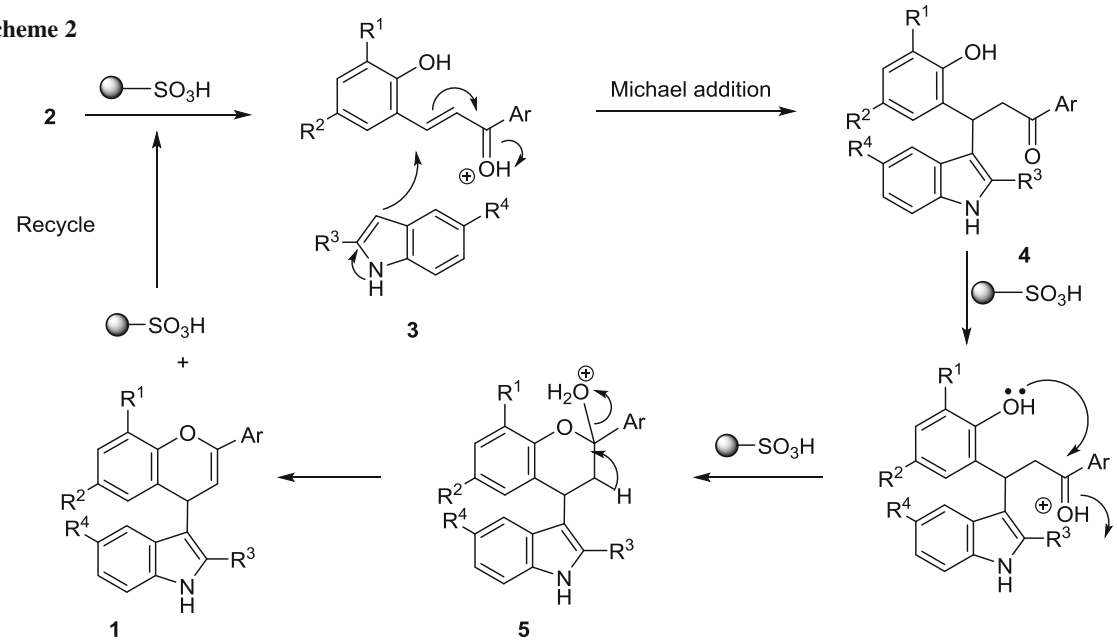
Table 2 Synthesis of 2-aryl-4-(indole-3-yl)-4*H*-chromenes (**1**) from substituted 2-hydroxychalcones and indoles (Scheme 1)

Entry	Prod.	Ar	R^1	R^2	R^3	R^4	Time/h	Yield/%[a]
1	**1a**	C_6H_5	H	H	H	H	3	73
2	**1b**	4-CH_3–C_6H_4	H	H	H	H	3	69
3	**1c**	4-CH_3O–C_6H_4	H	H	H	H	3.5	65
4	**1d**	4-Cl–C_6H_4	H	H	H	H	3	74
5	**1e**	2-Thienyl	H	H	H	H	4	53
6	**1f**	C_6H_5	H	Cl	H	H	3	74
7	**1g**	4-CH_3O–C_6H_4	H	Cl	H	H	3	68
8	**1h**	C_6H_5	H	H	CH_3	H	3	76
9	**1i**	4-CH_3O–C_6H_4	H	H	CH_3	H	3	71
10	**1j**	4-Cl–C_6H_4	H	H	CH_3	H	3	78
11	**1k**	C_6H_5	CH_3O	H	CH_3	H	3.5	69
12	**1l**	C_6H_5	H	Cl	CH_3	H	3	77
13	**1m**	4-CH_3O–C_6H_4	H	Cl	CH_3	H	3	70
14	**1n**	C_6H_5	H	H	H	CH_3O	3.5	65
15	**1o**	4-CH_3–C_6H_4	H	H	H	Br	4	55
16	**1p**	4-Cl–C_6H_4	H	H	H	Br	4	61

Reaction was performed under optimized condition

[a] Isolated yields

Scheme 2



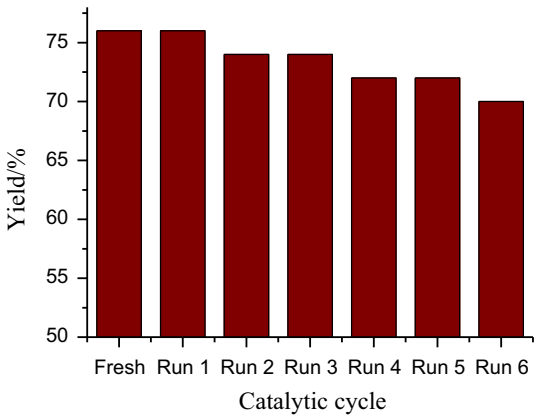


Fig. 1 Plot of isolated yield against catalytic cycle

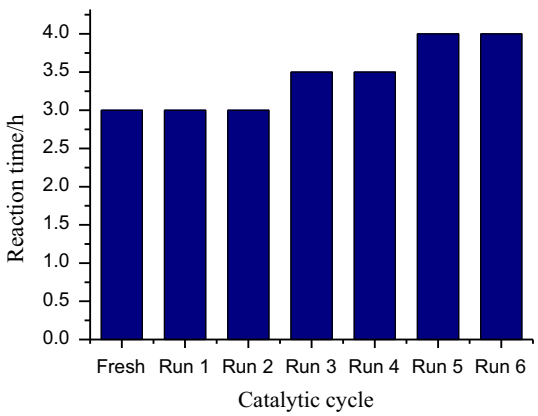


Fig. 2 Plot of reaction time against catalytic cycle

118.0, 119.3, 119.8, 120.6, 122.3, 124.8, 125.2, 126.2, 127.7, 128.1, 128.4, 128.6, 128.8, 129.2, 134.1, 136.8, 147.7, 149.8 ppm; IR (KBr): $\bar{\nu}$ = 3,406 (N–H), 3,057, 1,719, 1,598, 1,485, 1,230, 1,060 cm^{-1}; HRMS: *m/z* calcd. for $C_{23}H_{16}ClNO$ $(M + H)^+$ 358.10, found 358.08.

6-Chloro-4-(indol-3-yl)-2-(4-methoxyphenyl)-4H-chromene (**1g**, $C_{24}H_{18}ClNO_2$)

Dark red solid; m.p.: 90–92 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.86 (3H, s, –OCH_3), 5.09 (1H, d, J = 3.9 Hz, chromene H-4), 5.54 (1H, d, J = 3.9 Hz, chromene H-3), 6.88 (2H, d, J = 8.4 Hz), 6.92–7.25 (m, 6H), 7.36 (1H, d, J = 8.1 Hz), 7.59–7.72 (3H, m), 8.06 (1H, s, indole N–H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ = 32.1, 55.2, 99.4, 111.2, 113.7, 116.5, 119.4, 119.6, 121.8, 122.0, 122.1, 123.3, 123.5, 126.1, 126.4, 127.2, 127.4, 129.5, 136.7, 147.6, 151.2, 159.8 ppm; IR (KBr): $\bar{\nu}$ = 3,423 (N–H), 2,924, 1,639, 1,501, 1,238, 1,172 cm^{-1}; HRMS: *m/z* calcd. for $C_{24}H_{18}ClNO_2$ $(M + H)^+$ 388.10, found 388.09.

4-(2-Methylindol-3-yl)-2-phenyl-4H-chromene (***1h***)

Pale brown solid; m.p.: 149–151 °C (Ref. [24] 146–147 °C).

2-(4-Methoxyphenyl)-4-(2-methylindol-3-yl)-4H-chromene (**1i**, $C_{25}H_{21}NO_2$)

Pale brown solid; m.p.: 70–72 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.39 (3H, s, –CH_3), 3.85 (3H, s, –OCH_3), 5.18 (1H, d, J = 3.6 Hz, chromene H-4), 5.45 (1H, d,

$J = 3.6$ Hz, chromene H-3), 6.86–6.97 (5H, m), 7.05–7.17 (4H, m), 7.45 (1H, d, $J = 8.0$ Hz), 7.65 (2H, dd, $J = 7.0$, 1.8 Hz), 7.81 (1H, s, indole N–H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 11.9$, 30.9, 55.3, 99.3, 110.2, 113.7, 116.1, 116.3, 118.6, 119.4, 120.9, 123.3, 123.5, 126.0, 127.2, 127.4, 127.9, 129.4, 131.4, 135.2, 147.5, 151.3, 159.8 ppm; IR (KBr): $\bar{\nu} = 3{,}404$ (N–H), 2,858, 2,354, 1,731, 1,465, 1,241 cm^{-1}; FAB MS: *m/z* calcd. for $C_{25}H_{21}NO_2$ (M^+) 367.17, found 367.2.

2-(4-Chlorophenyl)-4-(2-methylindol-3-yl)-4H-chromene (**1j**, $C_{24}H_{18}ClNO$)

Dark brown solid; m.p.: 106–108 °C; ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 2.40$ (3H, s, $-CH_3$), 5.18 (1H, d, $J = 3.6$ Hz, chromene H-4), 5.55 (1H, d, $J = 3.9$ Hz, chromene H-3), 6.87–6.98 (2H, m), 7.05–7.22 (4H, m), 7.33–7.43 (4H, m), 7.65 (2H, d, $J = 7.2$ Hz), 7.83 (1H, s, indole N–H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 11.9$, 31.1, 101.6, 110.4, 116.0, 116.4, 118.7, 119.6, 121.2, 123.5, 123.6, 124.8, 127.6, 127.9, 128.4, 129.6, 131.6, 134.5, 135.2, 147.8, 151.3 ppm; IR (KBr): $\bar{\nu} = 3{,}413$ (N–H), 3,024, 1,666, 1,582, 1,458, 1,326, 1,230, 1,181 cm^{-1}; HRMS: *m/z* calcd. for $C_{24}H_{18}ClNO$ $(M + H)^+$ 372.13, found 372.14.

8-Methoxy-4-(2-methylindol-3-yl)-2-phenyl-4H-chromene (**1k**, $C_{25}H_{21}NO_2$)

Dark red solid; m.p.: 66–68 °C; ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.40$ (3H, s, $-CH_3$), 3.86 (3H, s, $-OCH_3$), 5.17 (1H, d, $J = 3.9$ Hz, chromene H-4), 5.44 (1H, d, $J = 3.9$ Hz, chromene H-3), 6.86–6.98 (5H, m), 7.05–7.17 (4H, m), 7.45 (1H, d, $J = 8.4$ Hz), 7.65 (2H, d, $J = 8.1$ Hz), 7.79 (1H, s, indole N–H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 11.9$, 30.9, 55.3, 99.2, 110.2, 113.6, 116.0, 116.3, 118.6, 119.3, 120.9, 123.3, 123.4, 126.0, 127.1, 127.3, 127.8, 129.4, 131.4, 135.2, 147.4, 151.2, 159.7 ppm; IR (KBr): $\bar{\nu} = 3{,}413$ (N–H), 2,918, 1,589, 1,468, 1,308, 1,248, 753 cm^{-1}; FAB MS: *m/z* calcd. for $C_{25}H_{21}NO_2$ (M^+) 367.17, found 367.3.

6-Chloro-4-(2-methylindol-3-yl)-2-phenyl-4H-chromene (**1l**, $C_{24}H_{18}ClNO$)

Dark red solid; m.p.: 82–84 °C; ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 2.42$ (3H, s, $-CH_3$), 5.14 (1H, d, $J = 3.3$ Hz, chromene H-4), 5.54 (1H, d, $J = 3.3$ Hz, chromene H-3), 6.91 (s, 1H), 6.97 (1H, t, $J = 7.3$ Hz), 7.04–7.12 (3H, m), 7.29–7.44 (5H, m), 7.70 (2H, d, $J = 7.5$ Hz), 7.86 (1H, s, indole N–H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 11.9$, 29.7, 31.1, 100.5, 110.3, 115.4, 117.8, 118.5, 119.6, 121.2, 124.7, 125.0, 127.6, 128.1, 128.3, 128.5, 129.0, 131.5, 134.0, 135.2, 147.7, 149.9 ppm; IR (KBr): $\bar{\nu} = 3{,}425$ (N–H), 2,879, 2,347, 1,598, 1,472, 1,248 cm^{-1}; FAB MS: *m/z* calcd. for $C_{24}H_{18}ClNO$ (M^+) 371.16, found 371.2.

6-Chloro-2-(4-methoxyphenyl)-4-(2-methylindol-3-yl)-4H-chromene (**1m**, $C_{25}H_{20}ClNO_2$)

Pale brown solid; m.p.: 142–144 °C; ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 2.42$ (3H, s, $-CH_3$), 3.83 (3H, s, $-OCH_3$), 5.11 (1H, d, $J = 3.3$ Hz, chromene H-4), 5.41 (1H, d, $J = 3.3$ Hz, chromene H-3), 6.85 (d, 3H, $J = 8.4$ Hz), 6.89–7.29 (m, 6H), 7.43 (d, 1H, $J = 7.8$ Hz), 7.63 (d, 1H, $J = 8.7$ Hz),7.84 (1H, s, indole N–H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 11.9$, 26.9, 55.5, 99.3, 110.2, 113.7, 116.1, 116.3, 118.6, 119.4, 120.9, 123.3, 123.5, 126.0, 127.2, 127.4, 127.9, 129.4, 131.4, 135.2, 147.5, 151.3, 159.8 ppm; IR (KBr): $\bar{\nu} = 3{,}453$ (N–H), 2,865, 2,347, 1,822, 1,466, 1,088 cm^{-1}; HRMS: *m/z* calcd. for $C_{25}H_{20}ClNO_2$ $(M + H)^+$ 402.1283, found 402.1296.

4-(5-Methoxyindol-3-yl)-2-phenyl-4H-chromene (**1n**, $C_{24}H_{19}NO_2$)

Dark red oil; ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 3.66$ (3H, s, $-OCH_3$), 5.15 (1H, d, $J = 3.9$ Hz, chromene H-4), 5.70 (1H, d, $J = 3.9$ Hz, chromene H-3), 6.85 (dd, 1H, $J = 8.7$, 2.1 Hz), 6.97 (t, 2H, $J = 6.9$ Hz), 7.06–7.74 (m, 7H), 7.75–7.77 (m, 3H), 7.98 (1H, s, indole N–H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 32.2$, 55.8, 101.0, 101.2, 111.9, 112.3, 116.5, 121.3, 122.8, 123.4, 124.7, 126.8, 127.5, 128.3, 128.6, 129.5, 131.8, 134.4, 147.9, 151.2, 153.9 ppm; FAB MS: *m/z* calcd. for $C_{24}H_{19}NO_2$ (M^+) 353.14, found 353.3.

4-(5-Bromoindol-3-yl)-2-(4-methylphenyl)-4H-chromene (**1o**, $C_{24}H_{18}BrNO$)

Dark red solid; m.p.: 64–66 °C; ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 2.39$ (3H, s, $-CH_3$), 5.14 (1H, d, $J = 3.9$ Hz, chromene H-4), 5.61 (1H, d, $J = 3.9$ Hz, chromene H-3), 6.97 (t, 1H, $J = 7.8$ Hz), 7.05–7.29 (m, 7H), 7.64 (d, 2H, $J = 8.1$ Hz), 7.81 (s, 1H, indole H-4), 8.07 (1H, s, indole N–H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 21.2$, 31.8, 99.8, 102.2, 112.5, 112.8, 116.7, 121.5, 121.8, 123.1, 123.4, 124.7, 125.0, 125.4, 128.1, 129.3, 131.5, 135.2, 138.4, 148.1, 151.2, 162.4 ppm; IR (KBr): $\bar{\nu} = 3{,}400$ (N–H), 2,928, 1,479, 1,317, 1,247, 743 cm^{-1}; FAB MS: *m/z* calcd. for $C_{24}H_{18}BrNO$ (M^+) 414.16 and 416.16, found 414.2 and 416.2.

4-(5-Bromoindol-3-yl)-2-(4-chlorophenyl)-4H-chromene (***1p***)

Dark red solid; m.p.: 72–74 °C (Ref. [24] 75–77 °C).

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