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An efficient and fast synthesis of 4-aryl-3,4-dihydrocoumarins by $(CF_3SO_3)_3Y$ catalysis under microwave irradiation

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Abstract—A new and efficient synthesis of eleven 4-aryl-3,4-dihydrocoumarins, in which six are new compounds, was performed using $(CF_3SO_3)_3Y$ as catalyst under microwave irradiation. The target compounds were obtained in good yields (68–80%) and remarkable time (7–20 min) when compared to the literature reports (1–40 h).

4-Aryl-3,4-dihydrocoumarins (neoflavonones) are natural products that share structural similarities with flavonoids and isoflavonoids.[1] The biological properties of compounds having 4-aryl-3,4-dihydrocoumarin feature have been little investigated, despite the important activities of some, such as aldose reductase inhibition, antiherpetic, and a moderate estrogenic activity, which has been recently described.[2,3] The 4-aryl-3,4-dihydrocoumarins synthesis was registered by Talapatra et al.[4] two decades ago.

7-Hydroxy-4-(4-methoxyphenyl)3,4-dihydrocoumarin was synthesized by the condensation reaction of resorcinol with cinnamic acid for 2 h under reflux, in the presence of PPA and xylene in 56% yield. However, the reaction using phloroglucinol under the same experimental, or comparatively drastic, conditions did not work.[4]

The 4-aryl-3,4-dihydrocoumarin synthesis has received more attention, in order to reach chromones, terpenoids and dihydrocoumarins. Youn et al. had showed Ru(III) as catalyst in arene and alkene substrate cyclization reactions in 42% yield for 12 h.[5]

Jia et al. had synthesized a series of 4-aryl-3,4-dihydrocoumarins using electrophilic metalation of aromatic C–H bonds by Pd(II) complexes to result in σ-aryl-Pd complexes; $Pd(OAc)_2$ 1% and TFA/CH_2Cl_2 system at room temperature were applied for 10 h in 85–90% yields. This procedure has established that the use of TFA as solvent facilitates the highly cationic $[Pd(II)–O_2CCF_3]^+$ species generation to form σ-aryl-Pd complexes through electrophilic substitution reactions of aromatic C–H bonds.[6–8]

In contrast to literature reports, Li et al. has recently discovered that the hydroarylation of cinnamic acids in TFA does not need the presence of palladium as catalyst, this was revealed by the lack of difference in the qualitative rates of product formation with or without $Pd(OAc)_2$. Having failed to validate the catalytic role of palladium, the attention was returned to the investigation of TFA-mediated hydroarylation using TFA/CH_2Cl_2 system, providing 4-aryl-dihydrocoumarins in 43–90% yields and 16–40 h of time reactions.[9]

Considering our interest in the natural compounds class, the long time reaction and controversial catalyst used in the 4-aryl-dihydrocoumarin synthesis, this work describes a new and efficient synthesis using the $(CF_3SO_3)_3Y$ as catalyst in intermolecular hydroarylation reaction, on solvent-free conditions under microwave irradiation.

The synthetic approach started from substituted cinnamic acids, obtained by Doebner–Knoevenagel condensation reactions between the respective benzaldehydes and malonic acid in the presence of pyridine and piperidine in 89–92% yields, as previously described.[10]

Keywords: 4-Aryl-3,4-dihydrocoumarins; Microwave irradiation; Yttrium trifluoromethanesulphonate.
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At a later stage, the intermolecular hydroarylation reaction was performed using the cinnamic acids and resorcinol or phloroglucionol, in the presence of Lewis acid under microwave irradiation.

In order to find the best reaction conditions, a systematic screening was realized using $ZnCl_2$, a trivial Lewis acid, and $(CF_3SO_3)_3Y$, a sophisticated Lewis acid, which was recently shown to have high performances in cyclotrimerization reactions; they were added to resorcinol ($R_3 = H$) and 4-methoxy-cinnamic acid in condensation reactions (Scheme 1) to result in **5a**.[11] The reactions were performed at different mw irradiation time and catalyst perceptual molar amounts as shown in Table 1. Furthermore, the reaction was evaluated by TLC observation without catalyst presence, indicating no apparent reaction.

The increase of $ZnCl_2$ catalytic amount showed a reduction on the yields (30–25%), while the increase of the irradiation time did not have any significant yield change. In fact, increasing the time for 20 min, a resin similar to the black product of polymerization was observed. The results showed that $ZnCl_2$ was not efficient for this reaction system.

Since then, we have focused on $(CF_3SO_3)_3Y$ Lewis acid, initially on the time reaction of 5 min a 70% yield was obtained, which was a significant increase when comparing to the use of $ZnCl_2$ in similar conditions. The catalytic amount increase had not significantly changed (72%), but adding 2 min to the time reaction (7 min in total) has slightly improved (75%) the obtained results. If the time reaction is around 20 min, several co-products will be formed (similar to the resin obtained when using $ZnCl_2$). The time irradiation was established at maximum of 3 min, followed by a 2 min cooling interval between the irradiations. According to the literature, this method was designed to avoid reactants overheating, since the unmodified domestic microwave oven lacks the special attributes of commercial reactors in terms of temperature control.[12,13]

Table 1. Time reactions and Lewis acid amounts for the synthesis of 7-hydroxy-4-(4-methoxyphenyl)-3,4-dihydrocoumarin (**5a**)

Entry	Catalyst (mol %)	Time	Yields (%)
1	—	10 min	No[a]
2	$ZnCl_2$[b] (40)	5 min	30
3	$ZnCl_2$ (60)	5 min	25
4	$ZnCl_2$ (40)	10 min	30
5	$(CF_3SO_3)_3Y$ (20)	5 min	70
6	$(CF_3SO_3)_3Y$ (40)	5 min	72
7	$(CF_3SO_3)_3Y$ (20)	7 min	75
8	$(CF_3SO_3)_3Y$ (20)	40 h[c]	70

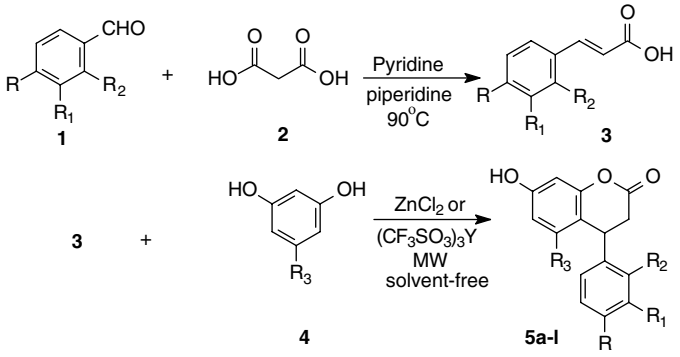
[a] No product observed.
[b] $ZnCl_2$ was dried in bunsen burner.
[c] Reflux/$CHCl_3$.

After the general screening to choose the best catalytic conditions, the synthesis of eleven dihydrocoumarins was realized, where six were new compounds (**5b–c**, **5e**, **5h–i** and **5l**) as described in the note (Table 2).[14] The reaction was also done using resorcinol and 4-methoxy-cinnamic acid condensation with $(CF_3SO_3)_3Y$ in 40 h of $CHCl_3$ refluxing, and it resulted in 70% yield of **5a** (Table 1). Compound **5d** was also performed in conventional conditions which provided the target compound in similar yield (68%), but after 35 h of $CHCl_3$ refluxing.

Unlike we had expected the use of phloroglucinol, with more electron-donor groups than the resorcinol,

Table 2. Time reactions and yields for **5a–l** obtained using the $(CF_3SO_3)_3Y$ as catalyst and MW irradiation

Compound	Time (min)	Yield (%)	Compound	Time (min)	Yield (%)
5a	7	75	**5g**	20	75
5b	15	70	**5h**	20	70
5c	15	65	**5i**	20	80
5d	7	67	**5k**	20	68
5e	15	65	**5l**	20	65
5f	15	68			



5a R = OCH_3, $R_1 = R_2 = R_3 = H$
5b R = H, $R_1 = OCH_3$, $R_2 = R_3 = H$
5c R = $R_1 = H$, $R_2 = OCH_3$, $R_3 = H$
5d R = OH, $R_1 = R_2 = R_3 = H$
5e R = OCH_3, R_1 = OH, $R_2 = R_3 = H$
5f R = OH, $R_1 = OCH_3$, $R_2 = R_3 = H$
5g R = OCH_3, $R_1 = R_2 = R_3$ = OH
5h R = H, $R_1 = OCH_3$, R_2 = H, R_3 = OH
5i R = $R_1 = H$, $R_2 = OCH_3$, R_3 = OH
5k R = OH, $R_1 = R_2 = H$, R_3 = OH
5l R = OH, $R_1 = OCH_3$, R_2 = H, R_3 =OH

Scheme 1.

presented a lower reactivity since it had taken 20 min to all condensation reactions under microwave irradiation.

Thus, as indicated in Table 2, the yields achieved by $(CF_3SO_3)_3Y$ catalyzed reactions and microwave irradiation were good (65–80%), and performed in remarkable time when compared to refluxing or to any different reaction condition of the literature.[9] The reactions were regioselectives and all compounds were fully characterized by spectroscopic routine analysis as IR, ^1H and ^{13}C NMR and MS.

In conclusion, we have described a new, fast, effortless and efficient protocol for the preparation of 4-aryl-3,4-dihydrocoumarins using $(CF_3SO_3)_3Y$ as catalyst under microwave irradiation, in which the target compounds were obtained in good yields and remarkable time reactions.

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References and notes

1. Harbone, J. B. *The Flavonoids—Advances in Research since 1986*; Chapman & Hall: London, 1994; pp 239–257.
2. Kumar, A.; Singh, B. K.; Tyagi, R.; Jain, S. K.; Sharma, S. K.; Prasad, A. K.; Raj, H. G.; Rastogi, R. C.; Watterson, A. C.; Parmar, V. S. *Bioorg. Med. Chem.* **2005**, *13*, 4300–4305.
3. Roelens, F.; Huvaere, K.; Dhooge, W.; Cleemput, M. V.; Comhaire, F.; Keukeleire, D. D. *Eur. J. Med. Chem.* **2005**, *40*, 1042–1151.
4. Talapatra, B.; Deb, T.; Talapatra, S. *Indian J. Chem.* **1986**, *25B*, 1122–1125.
5. Youn, S. W.; Pastine, S. J.; Sames, D. *Org. Lett.* **2004**, *6*, 581–584.
6. Jia, C.; Piao, D.; Kitamura, T.; Fujiwara, Y. *J. Org. Chem.* **2000**, *65*, 7516–7522.
7. Jia, C.; Kitamatura, T.; Fujiwara, Y. *Acc. Chem. Res.* **2001**, *34*, 633–639.
8. Jia, C.; Lu, W.; Oyamada, J.; Kitamura, T.; Matsuda, K.; Irie, M.; Fujiwara, Y. *J. Am. Chem. Soc.* **2000**, *122*, 7252–7263.
9. Li, K.; Foresee, L. N.; Tunge, J. A. *J. Org. Chem.* **2005**, *70*, 2881–2883.
10. Santos, A. C. S.; Echevarria, A. *Magn. Reson. Chem.* **2001**, *39*, 182–186.
11. De la Hoz, A.; Díaz-Ortiz, A.; Elguero, J.; Martínez, L. J.; Moreno, A.; Sánchez-Migallón, A. *Tetrahedron* **2001**, *57*, 4397–4403.
12. Varma, R. S.; Dahiya, R. *J. Org. Chem.* **1998**, *63*, 8038–8041.
13. Sagrera, G. J.; Seoane, G. A. *J. Braz. Chem. Soc.* **2005**, *16*, 851–856.
14. General procedure for 4-aryl-3,4-dihydrocoumarin (**5a–l**) synthesis: the solutions of cinnamic acids (0.84 mmol), phenols (0.84 mmol) and $(CF_3SO_3)_3Y$ (0.17 mmol) in CH_2Cl_2 (3 mL) were dried, and the mixtures were later put in the microwave oven (Consul Pratice-Brastemp S.A/ Model MU31AO, a domestic oven). The reaction mixtures were irradiated for 3 min for 2 (**5a** and **d**), 5 (**5b–c**) and 6 (**5g–l**) successive periods, with 2 min cooling intervals. The time reaction was monitored by TLC (EtOAc–hexane, 7:3). After the irradiation, the reaction mixtures were washed with water (40 mL), and the products were extracted with $CHCl_3$ (4×10 mL). This procedure does not need subsequent purification. 7-Hydroxy-4-(4-methoxyphenyl)-3,4-dihydrocoumarin (**5a**): orange solid; mp 152–153 °C (lit.[4] 150 °C); IR (KBr, cm^{-1}): 1028; 1148; 1243; 1450; 1618; 1735; 2838; 2926; 3003; 3335; ^1H NMR (DMSO-d_6, 200 MHz): δ 2.97 (m; 1H; $J = 7.38$ and 17.20 Hz); 3.04 (m; 1H; $J = 6.90$ and 16.70 Hz); 3.70 (s; 3H); 4.29 (t; 1H; $J = 6.16$ Hz); 6.52 (s; 1H); 6.54 (d; 1H; $J = 2.22$ Hz); 6.81 (d; 1H; $J = 8.1$ Hz); 6.87 (d; 1H; $J = 8.36$ Hz); 7.04 (d; 2H; $J = 8.36$ Hz); ^{13}C NMR (DMSO-d_6, 50.3 MHz): δ 36.95; 38.01; 55.05; 103.38; 111.72; 114.18; 116.60; 128.37; 128.39; 133.67; 151.99; 157.63; 158.56; 167.91; MS *m/z* (% rel.): 270 ($M^{+\cdot}$, 100); 242 (25); 227 (40); 197 (47); 162 (15); 134 (15); 108 (97); 91 (5); 63 (8); 51 (7). 7-Hydroxy-4-(3-methoxyphenyl)-3,4-dihydrocoumarin (**5b**): red oil; IR (KBr, cm^{-1}): 1030; 1150; 1252; 1344; 1451; 1511; 1617; 1736; 2837; 2928; 3338; ^1H NMR (DMSO-d_6, 200 MHz): δ 2.99 (d; 2H; $J = 5.14$ Hz); 4.27 (d; 2H; $J = 5.14$ Hz); 6.48 (ls; 2H); 6.85 (d; 2H; $J = 6.85$ Hz); 7.02 (d; 2H; $J = 6.76$ Hz); 9.74 (s; 1H); ^{13}C NMR (DMSO-d_6, 50.3 MHz): δ 36.89; 37.92; 55.02; 103.30; 106.18; 111.64; 114.16; 116.55; 128.35; 133.65; 151.94; 157.55; 158.22; 167.83; MS *m/z* (% rel.): 270 ($M^{+\cdot}$, 100); 242 (25); 227 (50); 197 (35); 184 (10); 77 (8); 63 (5); 51 (4); Calcd for $C_{16}H_{14}O_4$: C, 71.09; H, 5.23. Found: C, 71.11; H, 5.24. 7-Hydroxy-4-(2-methoxyphenyl)-3,4-dihydrocoumarin (**5c**): orange oil; IR (KBr, cm^{-1}): 1030; 1151; 1246; 1412; 1461; 1487; 1604; 1625; 1744; 2837; 2952; 3471; ^1H NMR (DMSO-d_6, 200 MHz): δ 2.74 (d; 1H; $J = 15.88$ Hz); 3.05 (d; 1H; $J = 15.52$ Hz and 5.06); 4.44 (d; 1H; $J = 6.5$ Hz); 6.1 (d; 1H; $J = 1.08$ Hz); 6.4 (d; 1H; $J = 1.08$ Hz); 6.73 (d; 1H; $J = 8.3$ Hz); 6.78 (d; 1H; $J = 6.48$ Hz); 6.81 (d; 1H; $J = 1.44$ Hz); 6.92 (d; 1H; $J = 8.83$ Hz); 7.15 (d; 1H; $J = 7.22$ Hz); 9.09 (s; 1H); ^{13}C NMR (DMSO-d_6, 50.3 MHz): δ 34.22; 35.13; 55.32; 103.27; 106.33; 111.91; 115.00; 120.64; 128.65; 129.35; 158.55; 157.67; 167.83; MS *m/z* (% rel.): 270 ($M^{+\cdot}$, 100); 242 (15); 227 (15); 197 (65); 181 (7); 77 (15); 63 (7); 51 (12); Calcd for $C_{16}H_{14}O_4$: C, 71.09; H, 5.23. Found: C, 71.10; H, 5.26. 7-hydroxy-4-(4-hydroxyphenyl)-3,4-dihydrocoumarin (**5d**): yellow oil; IR (KBr, cm^{-1}): 1036; 1347; 1457; 1512; 1606; 1742; 3378; ^1H NMR (DMSO-d_6, 200 MHz): δ 2.86 (m; 1H; $J = 5.24$ and 15.74 Hz); 3.03 (m; 1H; $J = 6.06$ and 15.72 Hz); 4.20 (t; 1H; $J = 6.08$ Hz); 6.25 (d; 1H; $J = 2.22$ Hz); 6.53 (t; 2H; $J = 2.28$ and 8.28 Hz); 6.72 (d; 1H; $J = 8.84$ Hz); 6.84 (d; 1H; $J = 8.56$ Hz); 6.95 (d; 2H; $J = 8.56$ Hz); ^{13}C NMR (DMSO-d_6, 50.3 MHz): δ 38.56; 40.29; 104.51; 107.67; 112.82; 116.55; 129.53; 130.90; 153.70; 157.64; 158.97; 170.31; MS *m/z* (% rel.): 256 ($M^{+\cdot}$, 100); 228 (25); 197 (17); 163 (10); 91 (6); 77(10); 63 (8); 51 (5). 7-Hydroxy-4-(3-hydroxy-4-methoxyphenyl)-3,4-dihydrocoumarin (**5e**): red oil; IR (KBr, cm^{-1}): 1026; 1269; 1368; 1452; 1512; 1622; 1743; 2845; 2972; 3381; ^1H NMR (DMSO-d_6, 200 MHz): δ 2.97 (m; 1H; $J = 4.52$ and 13.56 Hz); 3.03 (m; 1H; $J = 6.40$ and 15.82 Hz); 4.16 (t; 1H; $J = 6.04$ Hz); 6.24 (d; 1H; $J = 1.88$ Hz); 6.51 (d; 3H; $J = 1.50$ Hz); 6.83 (d; 2H; $J = 7.90$ Hz); ^{13}C NMR (DMSO-d_6, 50.3 MHz): δ 40.47; 40.81; 56.33; 103.43; 107.22; 112.44; 116.11; 129.45; 138.21; 146.98; 147.19; 156.56 ($2 \times C$); 174.45; MS *m/z* (% rel.): 286 ($M^{+\cdot}$, 100); 253 (35); 243 (25); 227 (27); 176 (20); 124 (35); 91 (5); 77 (7); 63 (5); 51 (7); Calcd for $C_{16}H_{14}O_5$: C, 67.12; H, 4.94. Found: C, 67.09; H, 4.92.

7-Hydroxy-4-(4-hydroxy-3-methoxyphenyl)-3,4-dihydrocoumarin (**5f**) red oil; IR (KBr, cm^{-1}): 1033; 1267; 1376; 1461; 1515; 1618; 1747; 2886; 2923; 3383; ^1H NMR (DMSO-d_6, 200 MHz): δ 2.99 (m; 1H; $J = 6.0$ and 21.38 Hz); 3.21(m; 1H; $J = 6.60$ and 19.80 Hz); 4.20 (d; 1H; $J = 6.30$ Hz); 6.15 (s; 1H); 6.40 (d; 1H; $J = 8.16$ Hz); 6.49 (d; 1H; $J = 7.86$ Hz); 6.52 (d; 1H; $J = 8.18$ Hz); 6.73 (t; 2H; $J = 8.18$ and 6.28 Hz); ^{13}C NMR (DMSO-d_6, 50.3 MHz): δ 36.95; 38.37; 55.63; 103.27; 106.24; 111.67; 115.49; 116.67; 119.49; 129.01; 132.56; 145.57; 147.79; 157.52; 158.49; 168.04; MS *m*/*z* (% rel.): 286 ($M^{+\cdot}$, 100); 243 (25); 227 (20); 213 (18); 176 (12); 77 (8); 63 (5); 51 (5). 5,7-Dihydroxy-4-(4-methoxyphenyl)-3,4-dihydrocoumarin (**5g**): orange oil: IR (KBr, cm^{-1}): 1057; 1138; 1247; 1337; 1463; 1512; 1614; 1747; 2839; 2934; 3382; ^1H NMR (DMSO-d_6, 200 MHz): δ 2.75 (m; 1H; $J = 6.16$ Hz); 3.12 (m; 1H; $J = 6.72$ and 15.86 Hz); 4.35 (t; 1H; $J = 6.10$ Hz); 5.99 (s; 1H); 6.20 (s; 1H); 6.80 (d; 2H; $J = 7.92$ Hz); 6.94 (d; 2H; $J = 8.54$ Hz); ^{13}C NMR (DMSO-d_6, 50.3 MHz): δ 33.01; 37.37; 55.08; 94.78; 98.81; 103.48; 114.06; 127.77; 134.35; 153.00; 155.43; 157.91; 159.07; 168.07; MS *m*/*z* (% rel.): 286 ($M^{+\cdot}$, 100); 243 (50); 213 (25); 178 (15); 150 (13); 108 (47); 91 (3); 69 (9). 5,7-Dihydroxy-4-(3-methoxyphenyl)-3,4-dihydrocoumarin (**5h**): orange solid; mp 110–112 °C; IR (KBr, cm^{-1}): 1059; 1338; 1461; 1513; 1614; 1730; 3341; ^1H NMR (DMSO-d_6, 200 MHz): δ 2.72 (m; 1H; $J = 15.82$ Hz); 3.13 (m; 1H; $J = 6.0$ and 15.82 Hz); 4.22 (t; 1H; $J = 6.0$ Hz) 5.97 (s; 1H); 6.12 (s; 1H; $J = 1.92$ Hz); 6.61 (d; 2H; $J = 8.22$ Hz); 6.82 (d; 2H; $J = 8.52$ Hz); ^{13}C NMR (DMSO-d_6, 50.3 MHz): δ 33.01; 37.49; 54.61; 94.75; 98.78; 103.69; 115.37; 127.71; 132.59; 153.00; 155.40; 156.13; 157.82; MS *m*/*z* (% rel.): 272 ($M^{+\cdot}$, 100); 257 (10); 229 (95); 213 (30); 179 (65); 150 (25); 69 (15); 51 (5); Calcd for $C_{16}H_{14}O_5$: C, 67.12; H, 4.94. Found: C, 67.13; H, 4.92. 5,7-Dihydroxy-4-(2-methoxyphenyl)-3,4-dihydrocoumarin (**5i**): white solid; mp 125–127 °C; IR (KBr, cm^{-1}): 1064; 1139; 1245; 1460; 1492; 1627; 1766; 2853; 2925; 3379; ^1H NMR (DMSO-d_6, 200 MHz): δ 2.72 (m; 1H; $J = 8.86$ and 16.32 Hz); 3.10 (m; 1H; $J = 7.46$ and 16.0 Hz); 3.78 (s; 3H); 4.6 (t; 1H; $J = 8.86$ Hz and 16.32 Hz); 6.19 (s; 1H); 6.56 (m; 1H; $J = 3.3$ Hz); 6.70 (d; 1H; $J = 7.10$ Hz); 6.97 (d; 1H;$J = 5.32$ Hz); 7.20 (d; 2H; $J = 7.8$ Hz) 9.8 (s; 1H); ^{13}C NMR (DMSO-d_6, 50.3 MHz): δ 31.40; 38.20; 55.60; 94.50; 99.55; 111.60; 120.54; 128.54; 130.54; 157.64; 158.40; 159.34; MS *m*/*z* (% rel.): 286 (25); 270 (7); 256 (5); 241 (27); 227 (7); 213 (20); 91 (4); 51 (3); Calcd for $C_{16}H_{14}O_5$: C, 67.12; H, 4.94. Found: C, 67.09; H, 4.91. 5,7-Dihydroxy-4-(4-hydroxyphenyl)-3,4-dihydrocoumarin (**5k**): orange oil; IR (KBr, cm^{-1}): 1059; 1134; 1461; 1513; 1614; 1730; 2983; 3341; ^1H NMR (DMSO-d_6, 200 MHz): δ 2.73 (m; 1H; $J = 15.82$ Hz); 3.11 (m; 1H; $J = 6.00$ and 15.48 Hz); 5.97 (s; 1H); 6.13 (d; 1H; $J = 1.90$ Hz); 6.61 (d; 2H; $J = 8.22$ Hz); 6.81 (d; 2H; $J = 8.52$ Hz); 9.24 (s; 1H); 9.51 (s; 1H); 9.69 (s; 1H); ^{13}C NMR (DMSO-d_6, 50.3 MHz): δ 33.01; 37.49; 94.75; 98.78; 103.68; 115.37; 127.71; 132.59; 153.00; 155.40; 156.13; 157.82; 168.16; MS *m*/*z* (% rel.): 272 (100); 257 (15); 244 (17); 229 (95); 213 (27); 69 (13); 51 (7). 5,7-Dihydroxy-4-(4-hydroxy-3-methoxyphenyl)-3,4-dihydrocoumarin (**5l**): orange solid; mp 145–147 °C; IR (KBr, cm^{-1}): 1059; 1137; 1262; 1467; 1515; 1620; 1753; 2851; 2925; 3408; ^1H NMR (DMSO-d_6, 200 MHz): δ 2.75 (m; 1H; $J = 15.98$ Hz); 3.09 (m; 1H; $J = 8.57$ Hz and $J = 15.60$ Hz); 3.64 (s; 3H); 4.28 (d; 1H; $J = 5.44$ Hz); 5.96 (s; 1H); 6.11 (d; 1H; $J = 2.18$ Hz); 6.25 (d; 1H; $J = 8.00$ Hz); 6.57 (d; $J = 7.98$ Hz); 6.70 (s; 1H); 8.92 (s; 1H); 9.51 (s; 1H); 9.70 (s; 1H); ^{13}C NMR (DMSO-d_6, 50.3 MHz): δ 33.34; 37.46; 55.60; 94.72; 98.78; 103.57; 108.49; 111.37; 118.40; 133.32; 147.67; 153.03; 155.40; 157.80; 158.98; 168.20; MS *m*/*z* (% rel.): 302 (100); 284 (3); 259 (28); 217 (10); 179 (25); 124 (47); 69 (10); 51 (7); Calcd for $C_{16}H_{14}O_5$: C, 63.56; H, 4.68. Found: C, 63.56; H, 4.63.