Facile iron(III) chloride hexahydrate catalyzed synthesis of coumarins

Saisuree Prateeptongkum,*[a] Nongnaphat Duangdee,[b] and Panumart Thongyoo[a]

[a]*Department of Chemistry, Faculty of Science & Technology, Thammasat University, 99 Moo 18 Paholyothin Road, Klong Luang, Rangsit, Prathumthani 12121, Thailand*
[b]*Drug Discovery and Development Center, Thammasat University, 99 Moo 18 Paholyothin Road, Klong Luang, Rangsit, Prathumthani 12121, Thailand*
E-mail: saisuree@tu.ac.th

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Abstract
A practical and inexpensive synthesis of coumarins, from phenols and β-keto esters, via the Pechmann reaction catalyzed by 10 mol% of $FeCl_3 \cdot 6H_2O$ is described. The reaction was applied to transform phenols and β-keto esters into the corresponding coumarins in moderate to excellent yields.

Keywords: Pechmann reaction, coumarin, hydrated Fe(III) chloride, phenols, β-keto esters

Introduction

Coumarins are one of the important structural units and widely found in nature.[1-4] They show diverse biological and pharmacological activities ranging from antimicrobial, anti-arrhythmic, antitumor, antifungal, anti-HIV, anti-osteoporosis to anti-inflammatory.[5-12] Apart from their pharmaceutical applications,[13-14] coumarins have been used as additives in foods, perfumes and cosmetics as well as in the preparation of optical brighteners, laser dyes, fluorescent labels and nonlinear optical chromophores.[15-19]

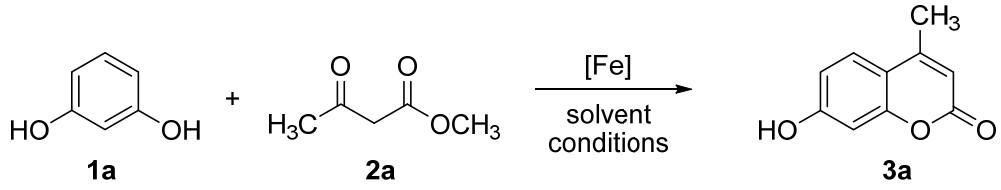
The Pechmann reaction[20] is known as one of the most valuable methods for the synthesis of coumarins since it proceeds from simple starting materials, a phenol and a β-keto ester, together with an acid catalyst. Various protocols have been developed by using different catalysts including sulfuric acid,[20] trifluoroacetic acid,[21] phosphorus pentaoxide,[22] aluminium chloride,[23-24] indium(III) chloride,[25] titanium(IV) chloride,[26] silica gel supported zirconyl chloride octahydrate,[27] samarium(III) nitrate hexahydrate,[28] bismuth(III) nitrate pentahydrate,[29] ionic liquids[30] and many more.[31-33] However, the development of practical, efficient and environmentally benign synthetic protocols for the synthesis of coumarins is greatly desirable.

Among the transition metal catalysts, iron is in many ways ideal, owing to its ready availability, low price and environmentally friendly character. In this respect, iron-catalyzed reactions for a variety of transformations have gained an increasing interest in the literature.[34-36] A few examples of iron-catalyzed synthesis of 4-substituted coumarins through the Pechmann condensation have been demonstrated very recently[37-38] by employing anhydrous $FeCl_3$ as the active catalyst under microwave and ultrasonic irradiation as well as conventional heating[37] and in an ionic liquid medium.[38] We envisioned that the use of an Fe(III) hydrate as a catalyst instead of anhydrous $FeCl_3$ would be an advantage, as it is cheap and easily available. There appear to be no reports of the use of such an iron hydrate in the Pechmann reaction. Herein, we report that iron(III) chloride hexahydrate can be used as an effective catalyst for the synthesis of coumarin derivatives by Pechmann condensation of phenols and β-keto esters.

Results and Discussion

Initially, the reaction between resorcinol (**1a**) and methyl acetoacetate (**2a**) in the presence of iron salt catalyst was selected as a model system.

Table 1. Optimization of the Pechmann reaction conditions[a]

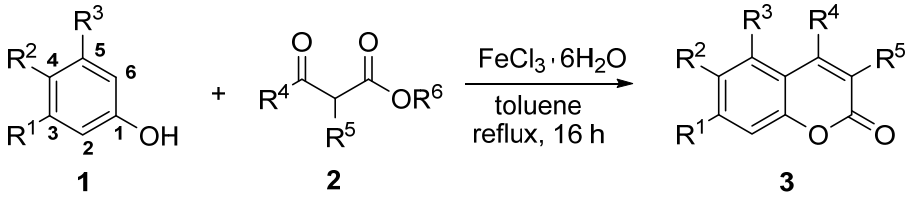


Entry	Catalyst (mol%)	Solvent	Condition	Yield (%)[b]
1	$FeCl_3·6H_2O$ (10)	toluene	rt, 16 h	30
2	$FeCl_3·6H_2O$ (10)	toluene	reflux, 4.5 h	76
3	$FeCl_3·6H_2O$ (10)	toluene	reflux, 16 h	92
4	$FeCl_3·6H_2O$ (5)	toluene	reflux, 16 h	55
5	$FeCl_3·6H_2O$ (20)	toluene	reflux, 16 h	63
6	$FeCl_3·6H_2O$ (10)	ethanol	reflux, 16 h	40
7	$FeSO_4·7H_2O$ (20)	toluene	reflux, 16 h	20
8	$NH_4Fe(SO_4)_2·12H_2O$ (10)	toluene	reflux, 16 h	79

[a] 3 mmol of resorcinol and 3 mmol of methyl acetoacetate in 10 mL of solvent.
[b] Isolated yield.

Various reaction conditions in the presence of different catalytic amounts of $FeCl_3 \cdot 6H_2O$ in toluene at room temperature and under reflux were optimized (Table 1, entries 1-5). It can be clearly seen from Table 1 that a high yield was achieved with the use of 10 mol% $FeCl_3 \cdot 6H_2O$ in toluene under reflux for 16 h without the need of an inert atmosphere (Table 1, entry 3). However, a low yield was observed using ethanol as a solvent (Table 1, entry 6). A brief survey of other iron salts, such as $FeSO_4 \cdot 7H_2O$ and $NH_4Fe(SO_4)_2 \cdot 12H_2O$ reveal that $FeCl_3 \cdot 6H_2O$ was the most active catalyst for the model reaction though $NH_4Fe(SO_4)_2 \cdot 12H_2O$ showed significant activity (Table 1, entries 7-8).

Table 2. Synthesis of coumarins via the Pechmann reaction catalyzed by $FeCl_3 \bullet 6H_2O$[a]



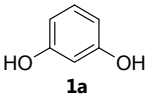
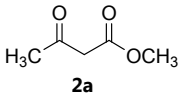
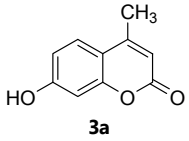
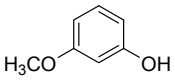
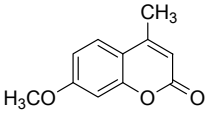
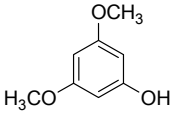
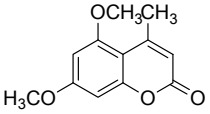
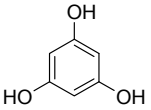
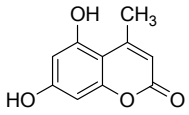
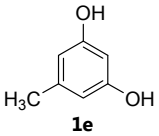
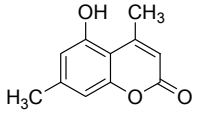
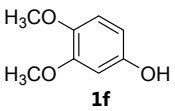
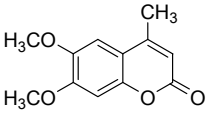
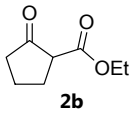
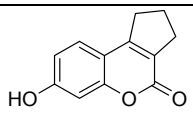
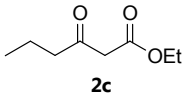
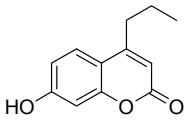
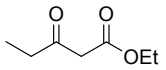
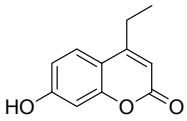
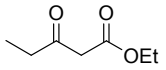
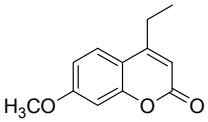
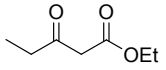
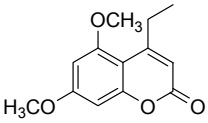
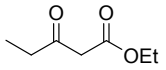
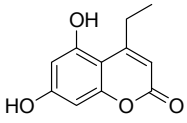
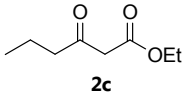
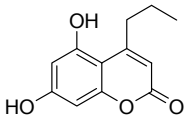
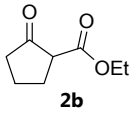
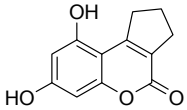
Entry	Phenol	β-Ketoester	Product	Yield (%)[b]
1	 **1a**	 **2a**	 **3a**	92
2	 **1b**	**2a**	 **3b**	83
3	 **1c**	**2a**	 **3c**	54
4	 **1d**	**2a**	 **3d**	75
5	 **1e**	**2a**	 **3e**	46
6	 **1f**	**2a**	 **3f**	44

Table 2. (Continued)

Entry	Phenol	β-Ketoester	Product	Yield (%)[b]
7	**1a**	 **2b**	 **3g**	54
8	**1a**	 **2c**	 **3h**	56
9	**1a**	 **2d**	 **3i**	62
10	**1b**	 **2d**	 **3j**	34
11	**1c**	 **2d**	 **3k**	20
12	**1d**	 **2d**	 **3l**	60
13	**1d**	 **2c**	 **3m**	40
14	**1d**	 **2b**	 **3n**	28

[a] 3 mmol of phenol, 3 mmol of methyl acetoacetate and 10 mol% of $FeCl_3 \cdot 6H_2O$ in 10 mL of toluene, 16 h under reflux.
[b] Isolated yield.

Next, the effect of substituents on the reactivity of the phenol were investigated by the reaction of a variety of phenols and methyl acetoacetate (**2a**) (Table 2, entries 1-6). Phenols with a strong electron-donating group (R^1) at the *meta* position yielded the desired products in high yields (Table 2, entries 1-2). These good yields are the result of the presence of the increased electron density at position 6 where electrophilic substitution takes place. 3,5-Disubstituted

phenols **1c**-**1e** with electron-donating groups gave the corresponding coumarins in lower yields, possibly because of the steric effect of the substituents at position 5 (Table 2, entries 3-5). In addition, 3,4-dimethoxyphenol (**1f**) showed low activity, leading to **3f** in 44% yield (Table 2, entry 6). It was assumed that an electron-donating substituent at position 4 could decrease electron density at position 6.

Finally, the scope and limitations of the reaction were examined by employing various phenols and β-keto esters (Table 2, entries 7-14). Apart from the substituent effects of the phenols, steric effects from substituents (R^4, R^5) of β-keto esters may play an important role in the reaction as seen more sterically hindered β-keto esters affording lower yields of the corresponding products (Table 2, entries 7-9, 12-14).

Conclusions

We have developed a general and practical iron-catalyzed synthetic method for coumarin derivatives via the Pechmann reaction. A variety of phenols and β-keto esters were converted into the corresponding coumarins in moderate to excellent yields. Notably, the reaction proceeds in the presence of a simple, commercially available and inexpensive iron catalyst.

Experimental Section

General. Melting points (^oC) were measured with a Gallenkamp melting point apparatus and are uncorrected. However, the melting point of **3l** was determined by polarized light microscopy (Olympus BH-2) using a Mettler FP52 microfurnace and FP5 temperature controller. ^1H and ^{13}C NMR spectra were recorded on a Bruker AV400 spectrometer. Chemical shifts (δ) are given in ppm and refer to TMS or the residual undeuterated solvent as the internal standard. The following abbreviations are used: s = singlet, d = doublet, t = triplet, q = quartet, quint = quintet, sext = sextet, m = multiplet, dd = double doublet, br.s = broad singlet. ESI mass spectra were recorded on a Thermo Finnigan LCQ Advantage Mass Spectrometer. High Resolution Mass Spectrometry was performed with a MicroTOF$_{LC}$, Bruker Daltonics. FTIR spectra were obtained with a Perkin Elmer FT-IR Spectrum GX. Flash chromatography was performed with Fluka silica gel 60 (70-230 mesh) in common glass columns. All chemicals were obtained from commercial suppliers, and were used without further purification.

General procedure for the synthesis of coumarins 3a-3n

To a mixture of phenol (3 mmol) and β-keto ester (3 mmol) in toluene (10 mL) was added iron(III) chloride hexahydrate (0.08 g, 10 mol%) at room temperature, and the mixture was heated to reflux for 16 h. After cooling to room temperature, the mixture was quenched with water (10 mL) and the aqueous phase was extracted with EtOAc (3x15 mL). The organic phases

were combined, dried over anhydrous Na_2SO_4, concentrated by rotary evaporator and the residue purified by column chromatography on silica gel (eluent: hexane/EtOAc or hexane/CH_2Cl_2/Me_2CO) to give the coumarin product.

7-Hydroxy-4-methyl-2*H*-2-chromenone (3a). White solid; yield 92%, mp 188-190 ^oC (from EtOH-H_2O) (lit[37] mp 184-186 ^oC). IR (nujol): ν_{max} 3502, 2923, 2846, 1669, 1607, 1456, 1378, 1277, 1076 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ 10.50 (s, 1H), 7.58 (d, *J* 8.7 Hz, 1H), 6.80 (dd, *J* 8.7, 2.3 Hz, 1H), 6.70 (d, *J* 2.3 Hz, 1H), 6.11 (d, *J* 1.0 Hz, 1H), 2.37 (d, *J* 1.0 Hz, 3H). ^{13}C NMR (100 MHz, DMSO-d_6): δ 161.63 (C), 160.71 (C), 155.33 (C), 153.90 (C), 127.00 (CH), 113.32 (CH), 112.50 (C), 110.72 (CH), 102.67 (CH), 18.51 (CH_3). MS (ESI^+), *m/z* (%) 177.7 ($M+H^+$, 100).

7-Methoxy-4-methyl-2*H*-chromen-2-one (3b). White solid; yield 83%, mp 157-158 ^oC (from EtOH-H_2O) (lit[39] mp 160-161 ^oC). IR (nujol): ν_{max} 2923, 2854, 1732, 1608, 1457, 1376, 1287, 1267, 1215, 1154, 1072, 1026, 856 cm^{-1}. ^1H-NMR (400 MHz, $CDCl_3$): δ 7.52 (d, *J* 8.7 Hz, 1H), 6.89 (d, *J* 8.7, 2.5 Hz, 1H), 6.84 (d, *J* 2.5 Hz, 1H), 6.16 (d, *J* 0.8 Hz, 1H), 3.90 (s, 3H), 2.42 (d, *J* 0.8 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.71 (*C*), 161.17 (*C*), 155.39 (*C*), 152.39 (*C*), 125.49 (*C*H), 113.62 (*C*), 112.25 (*C*H), 112.02 (*C*H), 100.92 (*C*H), 55.71 (CH_3), 18.59 (CH_3); MS (ESI^+), *m/z* (%) 191.7 ($M+H^+$, 100).

5,7-Dimethoxy-4-methyl-2*H*-chromen-2-one (3c). White solid; yield 76%, mp 170-172 ^oC (from EtOH-H_2O) (lit[37] mp 170-172 ^oC). IR (nujol): ν_{max} 2924, 2854, 1723, 1607, 1457, 1385, 1353, 1112, 1081 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ 6.44 (d, *J* 2.3 Hz, 1H), 6.29 (d, *J* 2.3 Hz, 1H), 5.95 (s, 1H), 3.86 (s, 3H), 3.85 (s, 3H), 2.53 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.80 (C), 161.08 (C), 159.15 (C), 157.02 (C), 154.45 (C), 111.42 (CH), 104.93 (C), 95.48 (CH), 93.42 (CH), 55.73 (CH_3), 55.69 (CH_3), 24.17 (CH_3); MS (ESI^+), *m/z* (%) 221.9 ($M+H^+$, 100).

5,7-Dihydroxy-4-methyl-2*H*-chromen-2-one (3d). White solid; yield 75%, mp 291-294 ^oC (from EtOH-H_2O) (lit[37] mp 293-295 ^oC); IR (nujol): ν_{max} 3429, 2924, 2854, 1670, 1622, 1558, 1457, 1377, 1301, 1162, 825 cm^{-1}. ^1H-NMR (400 MHz, DMSO-d_6): δ 10.52 (s, 1H), 10.29 (s, 1H), 6.26 (d, *J* 2.3 Hz, 1H), 6.17 (d, *J* 2.3 Hz, 1H), 5.85 (s, 1H), 2.49 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 161.00 (*C*), 160.00 (*C*), 157.87 (*C*), 156.45 (*C*), 154.88 (*C*), 108.79 (*C*H), 102.06 (*C*), 99.06 (*C*H), 94.48 (*C*H), 23.32 (CH_3); MS (ESI^+) *m/z* (%) 193.8 ($M+H^+$, 100).

5-Hydroxy-4,7-dimethyl-2*H*-chromen-2-one (3e). Beige colored solid; yield 46%, mp 255-257 ^oC (from EtOH-H_2O) (lit[28] mp 257-258 ^oC); IR (nujol): ν_{max} 3395, 2923, 1734, 1608, 1457, 1377, 1286, 856 cm^{-1}. ^1H-NMR (400 MHz, DMSO-d_6): δ 10.52 (s, 1H), 6.63 (s, 1H), 6.58 (s, 1H), 6.05 (s, 1H), 2.55 (s, 3H), 2.28 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6): δ 159.68 (*C*), 156.43 (*C*), 154.78 (*C*), 154.46 (*C*), 142.61 (*C*), 111.89 (*C*H), 111.76 (*C*H), 107.58 (*C*H), 106.47 (*C*), 23.30 (CH_3), 21.00 (CH_3); MS (ESI^+), *m/z* (%) 191.8 ($M+H^+$, 100).

6,7-Dimethoxy-4-methyl-2*H*-chromen-2-one (3f). Beige colored solid; yield 44%, mp 128-129 ^oC (from EtOH-H_2O) (lit[40] mp 130-131 ^oC, lit[41] mp 136-137 ^oC). IR (nujol): ν_{max} 2924, 2845. 1719, 1616, 1515, 1458, 1376, 1280, 1162 cm^{-1}. ^1H-NMR (400 MHz, $CDCl_3$): δ 6.94 (s, 1H), 6.85 (s, 1H), 6.17 (s, 1H), 3.95 (s, 3H), 3.94 (s, 3H), 2.41 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 161.56 (*C*), 153.03 (*C*), 152.36 (*C*), 149.69 (*C*), 146.44 (*C*), 112.72 (*C*), 112.58 (*C*H), 105.61

(*C*H), 100.38 (*C*H), 56.69 (*C*H_3), 56.50 (*C*H_3), 18.98 (*C*H_3). MS (ESI$^+$), *m*/*z* (%) 221.9 (M+H$^+$, 100); HRMS (MALDI-TOF): calcd for $C_{12}H_{13}O_4$ [M+H]$^+$: 221.0808; found: 221.0811.

2,3-Dihydro-7-hydroxycyclopenta[*c*]chromen-4(1*H*)-one (3g). Beige colored solid; yield 54%, mp 241-243 ^{o}C (from EtOH-H_2O) (lit[42] mp 248-250 ^{o}C); IR (nujol) ν_{max} 3193, 2923, 1675, 1621, 1457, 1377, 1307, 1149, 1075, 851, 721 cm^{-1}. ^{1}H-NMR (400 MHz, DMSO-d_6): δ 10.39 (s, 1H), 7.42 (d, *J* 8.5 Hz, 1H)**,** 6.79 (dd, *J* 8.5, 2.2 Hz, 1H), 6.75 (d, *J* 2.2 Hz, 1H), 3.02 (t, *J* 7.5 Hz, 2H), 2.72 (t, *J* 7.5 Hz, 2H), 2.09 (quint, *J* 7.5 Hz, 2H). ^{13}C NMR (100 MHz, DMSO-d_6): δ 160.40 (*C*), 159.22 (*C*), 156.57 (*C*), 155.27 (*C*), 126.32 (*C*H), 122.29 (*C*), 112.71 (*C*H), 110.61 (*C*), 102.04 (*C*H), 31.50 (*C*H_2), 29.84 (*C*H_2), 21.96 (*C*H_2). MS (ESI$^+$), *m*/*z* (%) 203.9 (M+H$^+$, 100); HRMS (MALDI-TOF): calcd for $C_{12}H_{11}O_3$ [M+H]$^+$: 203.0703; found: 203.0698.

7-Hydroxy-4-propyl-2*H*-chromen-2-one (3h). Beige colored solid; yield 56%, mp 131-133 ^{o}C (from EtOH-H_2O) (lit[37] mp 129-131 ^{o}C, lit[43] mp 132-134 ^{o}C). IR (nujol) ν_{max} 3193, 2926, 1696, 1616, 1563, 1457, 1376, 1140, 994, 850 cm^{-1}. ^{1}H-NMR (400 MHz, DMSO-d_6): δ 10.52 (s, 1H), 7.65 (d, *J* 8.7 Hz, 1H)**,** 6.80 (dd, *J* 8.7, 2.3 Hz, 1H), 7.71 (d, *J* 2.3 Hz, 1H)**,** 6.08 (s, 1H), 2.71 (t, *J* 7.5 Hz, 2H), 1.63 (sext, *J* 7.5 Hz, 2H), 0.97 (t, *J* 7.5 Hz, 3H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 161.01 (*C*), 160.38 (*C*), 156.89 (*C*), 155.11 (*C*), 126.34 (*C*H), 112.90 (*C*H), 111.21 (*C*), 109.32 (*C*H), 102.37 (*C*H), 32.83 (*C*H_2), 21.34 (*C*H_2), 13.65 (*C*H_3). MS (ESI$^+$), *m*/*z* (%) 205.9 (M+H$^+$, 100).

4-Ethyl-7-hydroxy-2*H*-chromen-2-one (3i). White solid; yield 62%, mp 170-173 ^{o}C (from EtOH-H_2O) (lit[43] mp 175-177 ^{o}C). IR (nujol): ν_{max} 3230, 2923, 1678, 1623, 1600, 1456, 1376, 1231, 1159, 1080, 850 cm^{-1}. ^{1}H-NMR (400 MHz, DMSO-d_6): δ 10.51 (s, 1H), 7.64 (d, *J* 8.7 Hz, 1H)**,** 6.81 (dd, *J* 8.7, 2.3 Hz, 1H), 6.72 (d, *J* 2.3 Hz, 1H), 6.08 (s, 1H), 2.77 (q, *J* 7.4 Hz, 2H), 1.22 (t, *J* 7.4 Hz, 3H). ^{13}C NMR (100 MHz, DMSO-d_6): δ 160.94 (*C*), 160.43 (*C*), 158.27 (*C*), 154.95 (*C*), 126.05 (*C*H), 112.84 (*C*H), 111.10 (*C*), 108.33 (*C*H), 102.31 (*C*H), 23.94 (*C*H_2), 12.30 (*C*H_3). MS (ESI$^+$), *m*/*z* (%) 191.8 (M+H$^+$, 100).

4-Ethyl-7-methoxy-2*H*-chromen-2-one (3j). Beige colored solid; yield 34%, mp 115-118 ^{o}C (from EtOH-H_2O) (lit[44] mp 92-93 ^{o}C, lit[45] mp 100-101 ^{o}C). IR (nujol): ν_{max} 2925, 2846, 1727, 1622, 1457, 1377, 1293, 1153, 1081, 1028, 858, 721 cm^{-1}. ^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.53 (d, *J* 8.8 Hz, 1H)**,** 6.86 (dd, *J* 8.8, 2.4 Hz, 1H), 6.83 (d, *J* 2.4 Hz, 1H), 6.15 (s, 1H), 3.87 (s, 3H), 2.78 (q, *J* 7.4 Hz, 2H), 1.32 (t, *J* 7.4 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 162.71 (*C*), 161.73 (*C*)**,** 157.70 (*C*), 155.69 (*C*), 125.23 (*C*H), 113.08 (*C*), 112.43 (*C*H), 110.21 (*C*H), 101.26 (*C*H), 55.87 (*C*H_3), 24.89 (*C*H_2), 12.39 (*C*H_3). MS (ESI$^+$), *m*/*z* (%) 205.7 (M+H$^+$, 100); HRMS (MALDI-TOF): calcd for $C_{12}H_{13}O_3$ [M+H]$^+$: 205.0859; found: 205.0868.

4-Ethyl-5,7-dimethoxy-2*H*-chromen-2-one (3k). Light yellow solid; yield 20%, mp 146-148 ^{o}C (from EtOH-H_2O) (lit[46] mp 144-145 ^{o}C); IR (nujol): ν_{max} 2924, 2846, 1713, 1620, 1600, 1457, 1377, 1238, 1160, 1115 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.46 (d, *J* 2.4 Hz, 1H), 6.31 (d, *J* 2.4 Hz, 1H), 6.01 (s, 1H), 3.87 (s, 3H), 3.85 (s, 3H), 2.95 (q, *J* 7.2 Hz, 2H), 1.22 (t, *J* 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): *δ* 162.64 (*C*), 161.42 (*C*), 159.84 (*C*), 158.79 (*C*), 157.23 (*C*), 109.72 (*C*H), 104.36 (*C*), 95.60 (*C*H), 93.62 (*C*H), 55.75 (*C*H_3), 55.67 (*C*H_3), 29.36 (*C*H_2), 13.53

(CH_3); MS (ESI^+), *m/z* (%) 235.8 ($M+H^+$, 100); HRMS (MALDI-TOF): calcd for $C_{13}H_{15}O_4$ $[M+H]^+$: 235.0965; found: 235.0975.

4-Ethyl-5,7-dihydroxy-2*H*-chromen-2-one (3l). White solid; yield 60%, mp 248 °C (dec) (from EtOH-H_2O) (lit[47] mp 241-243 °C). IR (nujol): ν_{max} 3277, 2924, 2846, 1698, 1654, 1559, 1542, 1457, 1377, 1277, 1157, 1101, 1031, 825 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ 10.57 (s, 1H), 10.28 (s, 1H), 6.28 (d, *J* 2.3 Hz, 1H), 6.19 (d, *J* 2.3 Hz, 1H), 5.84 (s, 1H), 2.92 (q, *J* 7.3 Hz, 2H), 1.17 (t, *J* 7.3 Hz, 3H). ^{13}C NMR (100 MHz, DMSO-d_6): δ 160.92 (*C*), 160.33 (*C*), 160.30 (*C*), 157.43 (*C*), 156.74 (*C*), 107.28 (*C*H), 101.35 (*C*), 99.25 (*C*H), 94.71 (*C*H), 28.40 (CH_2), 13.89 (CH_3); MS (ESI^+), *m/z* (%) 207.9 ($M+H^+$, 100).

5,7-Dihydroxy-4-propyl-2*H*-chromen-2-one (3m). Light yellow solid; yield 40%, mp 239-240 °C (from EtOH-H_2O) (lit[37] mp 241-243 °C); IR (nujol): ν_{max} 3216, 2925, 2846, 1664, 1616, 1553, 1561, 1459, 1377, 1270, 1154, 1098, 826 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ 10.57 (s, 1H), 10.28 (s, 1H), 6.27 (d, *J* 2.3 Hz, 1H), 6.18 (d, *J* 2.3 Hz, 1H), 5.83 (s, 1H), 2.85 (t, *J* 7.4 Hz, 2H), 1.59 (sext, *J* 7.4 Hz, 2H), 0.95 (t, *J* 7.4 Hz, 3H). ^{13}C NMR (100 MHz, DMSO-d_6): δ 160.90 (*C*), 160.16 (*C*), 158.49 (*C*), 157.41 (*C*), 156.83 (*C*), 108.28 (*C*H), 101.37 (*C*), 99.26 (*C*H), 94.73 (*C*H), 37.22 (CH_2), 22.52 (CH_2), 13.80 (CH_3); MS (ESI^+), *m/z* (%) 221.8 ($M+H^+$, 100).

2,3-Dihydro-7,9-dihydroxycyclopenta[*c*]chromen-4(1*H*)-one (3n). Light yellow solid; yield 28%, mp 250 °C (decomposed) (from EtOH-H_2O) (lit[47] mp 216-218 °C). IR (nujol): ν_{max} 3199, 2924, 2846, 1681, 1625, 1557, 1463, 1377, 1286, 1153, 1113, 1082, 840, 739 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ 10.34 (br.s, 1H), 10.17 (br.s, 1H), 6.24 (d, *J* 2.2 Hz, 1H), 6.19 (d, *J* 2.2 Hz, 1H), 3.21 (t, *J* 7.6 Hz, 2H), 2.60 (t, *J* 7.6 Hz, 2H), 1.99 (pent, *J* 7.6 Hz, 2H). ^{13}C NMR (100 MHz, DMSO-d_6): δ 160.58 (*C*), 159.33 (*C*), 156.50 (*C*), 156.38 (*C*), 156.23 (*C*), 120.04 (*C*), 101.30 (*C*), 98.52 (*C*H), 94.11 (*C*H), 35.55 (CH_2), 28.89 (CH_2), 22.23 (CH_2). MS (ESI^+), *m/z* (%) 218.4 (M^+, 100).

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