Tetrahedron 64 (2008) 9646–9653

Contents lists available at ScienceDirect

Tetrahedron

journal homepage: www.elsevier.com/locate/tet

Convenient synthesis and unusual reactivity of 2-oxo-2*H*,5*H*-pyrano-[3,2-*c*]chromenes

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ARTICLE INFO

Article history:
Received 21 December 2007
Received in revised form 25 June 2008
Accepted 10 July 2008
Available online 15 July 2008

Keywords:
Chromenes
Rearrangement
Condensation
Microwave

ABSTRACT

The reaction of 4-oxo-4*H*-chromen-3-carbaldehydes with coumarin-4-acetic acids under the Perkin conditions follows an interesting pathway that involves aldol reaction and subsequent intramolecular lactonization to afford 2-oxo-2*H*,5*H*-pyrano[3,2-*c*]chromene skeleton. In contrast to chromone-3-carbaldehydes, the same reaction with chromone-2-carbaldehydes yielded only the aldol condensation product. The reaction was performed under thermal and microwave conditions. The reactivity of 2-oxo-2*H*,5*H*-pyrano[3,2-*c*]chromenes in water, alcohol and acetic acid was described.

1. Introduction

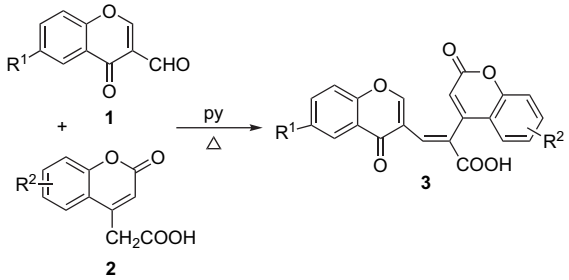
Chromone and coumarin derivatives are versatile molecules because their reactivity towards nucleophiles provides an useful route to preparation of variety of rearranged products and new heterocyclic systems. Many of them exhibit a broad spectrum of biological properties such as antitumour,[1] antimicrobial[2] and antiviral[3] activities. In addition, several chromene derivatives have been identified in angiogenesis,[4] protein tyrosine phosphatase 1B[5] inhibition and also as selective estrogen receptor modulators.[6]

4-Oxo-4*H*-chromen-3-carbaldehyde (chromone-3-carbaldehyde) has been extensively studied in the synthesis of various heterocycles[7] since the introduction of its convenient synthesis by a Vilsmeier–Haack reaction.[8] Chromone-3-carbaldehydes can give access to compounds when the chromone ring is retained[9] or 2-hydroxybenzoyl derivatives resulting from the opening of the pyran-4-one ring.[10]

Recently we have reported studies on the reaction of chromonecarbaldehydes with active methylene compounds.[9a,11] Here we describe the reaction of chromones **1** with different 2-oxo-2*H*-chromen-4-acetic acids (coumarin-4-acetic acids) **2**. This work is an extension of our previous work on aldol reaction of aryl- or heteroarylacetic acids.[12] The aim of this study was to determine the reaction conditions for coupling two chromene (4-oxo- and 2-oxo-) moieties **1**, **2** in one skeleton under different conditions than the Doebner reaction. Considering that chromones and coumarins have found many applications in medicine,[1–6] synthesis of new types of chromene derivatives is therefore of high interest.

2. Results and discussion

The reaction between 4-oxo-4*H*-chromen-3-carbaldehyde **1** and coumarin-4-acetic acids **2** was already described by Karale and co-workers[13] to give aldol condensation product **3** by heating a pyridine solution of equimolar quantities of both reagents at reflux for 6 h (Scheme 1). As we have experience[12] with aldol reactions of aryl- or heteroarylacetic acids under the conditions of Perkin synthesis, we decided to perform the reaction of equimolar quantities of aldehydes **1** and acids **2** in acetic anhydride in the



Scheme 1.

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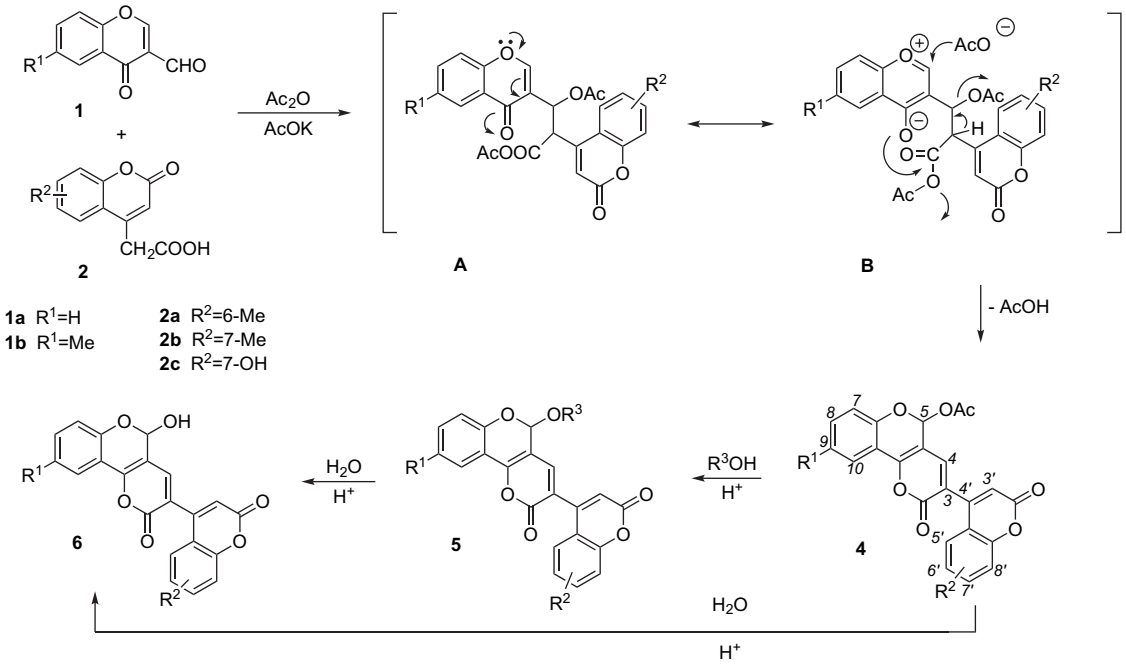
doi:10.1016/j.tet.2008.07.032



1a R^1=H
1b R^1=Me

2a R^2=6-Me
2b R^2=7-Me
2c R^2=7-OH

6a R^1=H, R^2=6'-Me
6b R^1=H, R^2=7'-Me
6c R^1=9-Me, R^2=7'-Me
6d R^1=9-Me, R^2=7'-OAc

5a R^1=H, R^2=6'-Me, R^3=Me
5b R^1=H, R^2=6'-Me, R^3=Et
5c R^1=H, R^2=6'-Me, R^3=Pr
5d R^1=H, R^2=6'-Me, R^3=1-MeHept
5e R^1=H, R^2=7'-Me, R^3=Me
5f R^1=H, R^2=7'-Me, R^3=Et
5g R^1=H, R^2=7'-Me, R^3=Pr
5h R^1=H, R^2=7'-Me, R^3=allyl
5i R^1=H, R^2=7'-Me, R^3=Bu
5j R^1=H, R^2=7'-Me, R^3=Pent
5k R^1=H, R^2=7'-Me, R^3=Hex
5l R^1=H, R^2=7-Me, R^3=Hept
5m R^1=H, R^2=7'-Me, R^3=1-MeHept
5n R^1=9-Me, R^2=6'-Me, R^3=Et
5o R^1=9-Me, R^2=7'-Me, R^3=Et
5p R^1=9-Me, R^2=7'-AcO, R^3=Et

4a R^1=H, R^2=6'-Me
4b R^1=H, R^2=7'-Me
4c R^1=9-Me, R^2=6'-Me
4d R^1=9-Me, R^2=7'-Me
4e R^1=9-Me, R^2=7'AcO

Scheme 2.

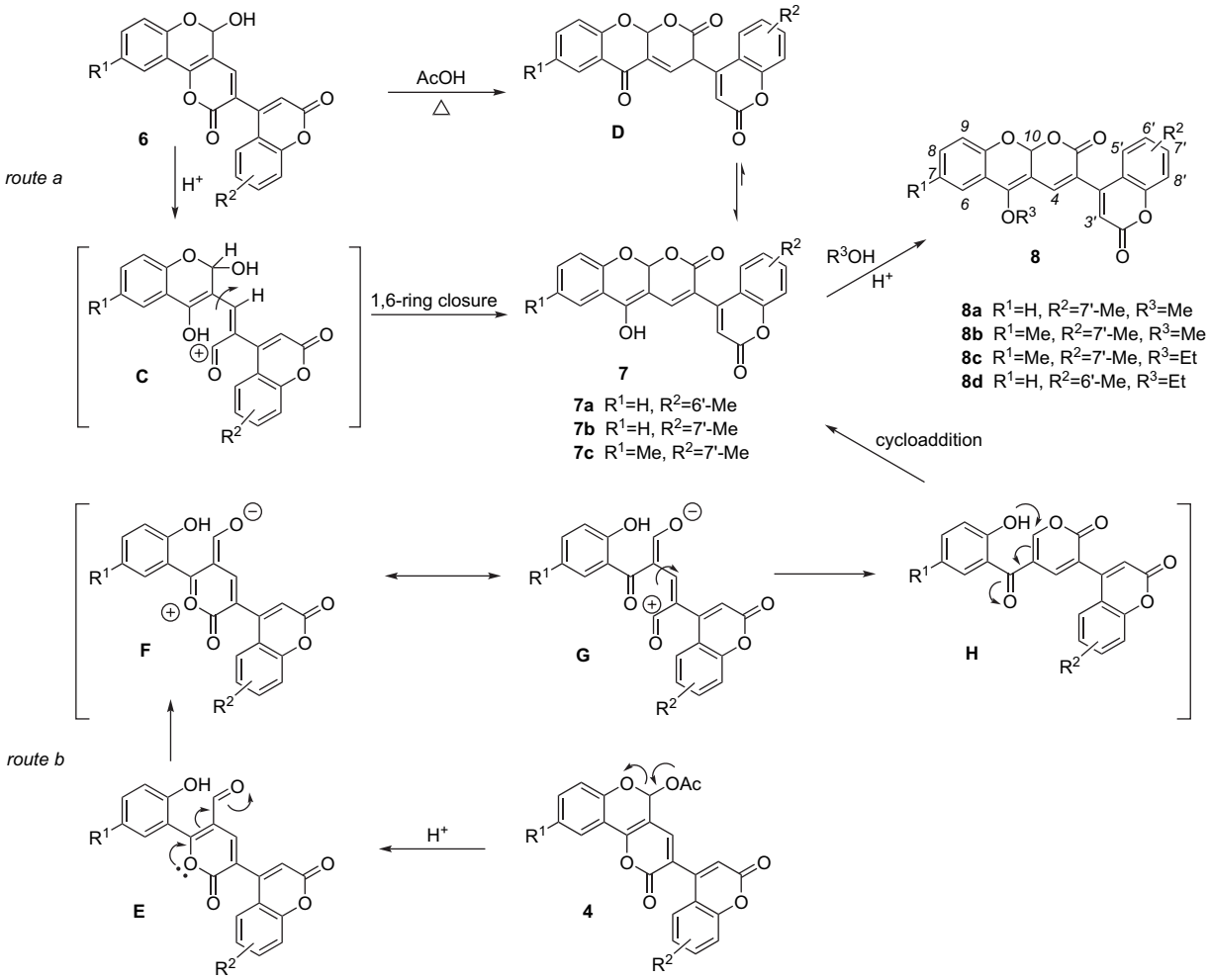
presence of potassium acetate. Surprisingly, 3-(2-oxo-2*H*-chromen-4-yl)-2-oxo-2*H*,5*H*-pyrano[3,2-*c*]chromen-5-yl acetates **4** (Scheme 2) were isolated as the only products in high yields (69–81%) after 2 h of heating at 90–100 °C. No traces of other products were found in the reaction mixtures. The isolation of acetates **4** from reaction mixtures was simple because they are formed as the first precipitates. Prolonged reaction time or increase in reaction temperature leads to a mixture of various products. Compounds **4** were also isolated when the same reaction was carried out in a microwave oven. No aldol condensation products **3** were obtained in that case. The yields and purity of acetates **4** were comparable under both experimental conditions, but the duration under microwave irradiation was considerably shorter (10 min instead of 2 h).

The formation of 3-(2-oxo-2*H*-chromen-4-yl)-2-oxo-2*H*,5*H*-pyrano[3,2-*c*]chromen-5-yl acetates **4** probably involves reaction of aldehydes **1** with the mixed anhydride of acetic and coumarin-4-acetic acids **2** yielding aldol reaction intermediate **A**, which can exist in an equilibrium with its pyrylium salt **B**. The next step is intramolecular nucleophilic attack of enolate anion at C-4 to the C=O bond of the mixed anhydride functionality of **B** with concomitant attack of acetate anion at C-2 position of reactive pyrylium ring followed by stabilization through deacetylation. The 2-oxo-2*H*-chromene moiety from **2** stays in this case unchanged (Scheme 2).

Compounds **4** are reactive species. The acetyloxy group at C-5 is easily interchangeable with alkoxy or hydroxy group under acidic conditions. Treatment of compounds **4** with various alcohols or water in the presence of a catalytic amount of *p*-toluenesulfonic acid at 60–100 °C afforded compounds **5** or **6**, respectively, in 72–92% yields (Scheme 2). Lower yields of **5** were isolated when a secondary alcohol (e.g., octane-2-ol) was used for the substitution. The products **5** can also be obtained in high yields after irradiation of the reaction mixtures in microwave oven at 400 W for 10 min.

5-Substituted 3-(2-oxo-2*H*-chromen-4-yl)-2-oxo-2*H*,5*H*-pyrano[3,2-*c*]chromenes **4**–**6** rearrange readily in acidic media (e.g., by acetic acid) to afford 5-hydroxy-3-(2-oxo-2*H*-chromen-4-yl)pyrano[2,3-*b*]chromen-2(10a*H*)-ones **7** (Scheme 3). The reaction is very fast. The conversion of starting compounds **4**–**6** to derivatives **7** in the reaction mixture was about 60% within 5 min of heating. Prolonged heating of the reaction mixture at 60 °C (30 min) led to nearly quantitative yields of compounds **7** (90–95%). In order to prove the structure of compounds **7** we carried out alkylation of **7** with alcohols in the presence of *p*-TsOH to give 5-alkoxy-3-(2-oxo-2*H*-chromen-4-yl)pyrano[2,3-*b*]chromen-2(10a*H*)-ones **8**.

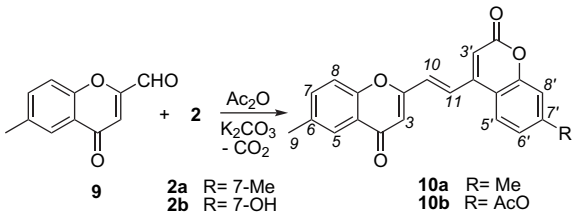
Formation of **7** can be explained by a series of reaction steps. The first step of the rearrangement of compounds **4** or **5** in acetic acid is presumably formation of hydroxyderivative **6**. The 2-oxo-2*H*,5*H*-pyrane ring of **6** is susceptible to influence of acids and/or temperature and ring opening takes place (structure **C**) as the first step of the rearrangement (Scheme 3, route a). The next step of the reaction is rotation of a part of the molecule around a single bond followed by 1,6-ring closure resulting in formation of 3-(2-oxo-2*H*-chromen-4-yl)-3,10a-dihydropyrano[2,3-*b*]chromen-2,5-diones **D**, mostly in their enolic forms **7**. An alternative route of the formation of compounds **7** involves acid and/or temperature ring opening of the 2*H*-chromene ring of **4** or **5** resulting in the formation of 2-(2-hydroxyphenyl)-6-oxo-6*H*-pyran-3-carbaldehyde **E** (Scheme 3, route b). This step is followed by 6-oxo-6*H*-pyran ring opening (structures **F** and **G**), rotation of a part of the molecule around a single



Scheme 3.

bond forming structure **H** and subsequent intramolecular cycloaddition of **H** to enol **7**. The exact reaction pathway is under investigation.

The reaction of 4-oxo-4*H*-chromen-2-carbaldehydes **9** with coumarin-4-acetic acids **2** under Perkin conditions was also studied in order to find if chromone-2-carbaldehydes give the products of aldol condensation. The reaction was carried out in acetic anhydride in the presence of potassium carbonate and afforded 2-[2-(2-oxo-2*H*-chromen-4-yl)ethenyl]-4*H*-chromen-4-ones **10** in 90% yield (Scheme 4). These compounds are obtained as condensation products that readily decarboxylate. Coumarin-4-acetic acids **2** themselves are thermolabile and decarboxylate particularly easily in basic media.[14]



Scheme 4.

As mentioned above, the synthesis of new types of chromene derivatives is of interest because many of them exhibit a broad spectrum of biological activities. The series of obtained derivatives **4**–**8** are under anti-neoplastic activities evaluation. Compound (**5h**) has already showed cytostatic activity (GI_{50}: 10^{-6}–10^{-8} M) determined on the 60 human tumour cell lines panel assay in NCI USA.[15]

3. Conclusions

Chromone-3-carbaldehydes **1** react with coumarin-4-acetic acids **2** under Perkin conditions by thermal or microwave acceleration to yield 3-(2-oxo-2*H*-chromen-4-yl)-2-oxo-2*H*,5*H*-pyrano[3,2-*c*]chromen-5-yl acetates **4** that are reactive towards different alcohols or water. We have observed that compounds **4** readily rearrange to 5-hydroxy-3-(2-oxo-2*H*-chromen-4-yl)pyrano[2,3-*b*]chromen-2(10a*H*)-iones **7** in acidic media at elevated temperature. The prepared heterocyclic compounds are under anti-neoplastic activities evaluation.

4. Experimental section

4.1. General

Melting points (uncorrected) were measured on a Kofler hot stage. The ^{1}H NMR/^{13}C NMR spectra were recorded on a 300 MHz/75 MHz Varian Gemini 200 spectrometer in $CDCl_3$ or DMSO-d_6 with tetramethylsilane as internal standard. IR spectra were recorded on

a FT-IR-ATR REACT IR 1000 spectrometer in solid state and on a Specord 75 spectrometer in Nujol. Elemental analyses were performed on a Carlo Erba Strumentazione 1106 apparatus. All microwave assisted reactions were carried out in a Lavis-1000 multi Quant microwave oven. The apparatus has been adapted for laboratory application with an external reflux condenser.

4.2. Starting materials

Chemicals were purchased from the major chemical suppliers as highest purity grade. Substituted chromone-3-carbaldehydes **1**,[8] coumarin-4-acetic acids **2**[16] and 6-methylchromone-2-carbaldehyde **9**[17] were prepared according to the literature procedures.

*4.2.1. 3-(2-Oxo-2H-chromen-4-yl)-2-oxo-2H,5H-pyrano[3,2-c]-chromen-5-yl acetates (**4a**–**e**)*

Method A. 6-R^1-Chromone-3-carbaldehyde **1** (2.26 mmol), R^2-coumarin-4-acetic acid **2** (2.26 mmol) and potassium acetate (8 mg, 0.2 mmol) were dissolved, under stirring, in freshly distilled acetic anhydride (4 mL) and heated at 90–100 °C for 2 h. The formed solid product was filtered off, washed with diethyl ether and recrystallized from toluene or ethyl acetate–aceticanhydride mixture (3:1).

Method B. The mixture of 6-R^1-chromone-3-carbaldehyde **1** (2.26 mmol), R^2-coumarin-4-acetic acid **2** (2.26 mmol) and potassium acetate (8 mg, 0.2 mmol) in acetic anhydride (4 mL) was irradiated in a microwave oven at 400 W for 10 min. The solid product was filtered off, washed with diethyl ether and recrystallized from toluene.

*4.2.1.1. 3-(6-Methyl-2-oxo-2H-chromen-4-yl)-2-oxo-2H,5H-pyrano-[3,2-c]chromen-5-yl acetate (**4a**).* Method A, work-up as described above gave 69% of **4a**; method B, work-up as described above gave 75% of **4a** as yellow powder: mp 244–247 °C [Found: C, 69.36; H, 3.82. $C_{24}H_{16}O_7$ (416.39) requires: C, 69.23; H, 3.87%.]; ν_{max} (Nujol) 1730, 1720, 1700, 1620, 1610, 1560 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 2.07 (3H, s, $(CH_3)_{Ac}$), 2.37 (3H, s, CH_3), 6.09 (1H, s, H-5), 6.47 (1H, s, H-3′), 7.12 (1H, dd, *J* 8.1, 0.9 Hz, H-7), 7.16–7.21 (2H, m, H-5′,9), 7.28 (1H, d, *J* 8.4 Hz, H-8′), 7.36 (1H, dd, *J* 8.4, 1.8 Hz, H-7′), 7.46–7.52 (1H, m, H-8), 7.48 (1H, s, H-4), 7.91 (1H, dd, *J* 8.0, 1.8 Hz, H-10). δ_C (75 MHz, DMSO-d_6) 20.3, 20.8, 89.3, 105.4, 114.0, 116.6, 117.4, 117.5, 120.6, 120.7, 122.9, 123.5, 126.7, 133.2, 133.6, 133.8, 143.1, 149.4, 151.2, 151.9, 153.2, 158.3, 159.7, 168.5.

*4.2.1.2. 3-(7-Methyl-2-oxo-2H-chromen-4-yl)-2-oxo-2H,5H-pyrano-[3,2-c]chromen-5-yl acetate (**4b**).* Method A, work-up as described above gave 80% of **4b**; method B, work-up as described above gave 74% of **4b** as yellow powder: mp 205–206 °C [Found: C, 69.26; H, 3.82. $C_{24}H_{16}O_7$ (416.39) requires: C, 69.23; H, 3.87%.]; ν_{max} (Nujol) 1730, 1715, 1700, 1620, 1610, 1560 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 2.07 (3H, s, $(CH_3)_{Ac}$), 2.46 (3H, s, CH_3), 6.43 (1H, s, H-3′), 7.08 (1H, dd, *J* 8.1, 1.5 Hz, H-6′), 7.17 (1H, dd, *J* 8.4, 1.2 Hz, H-7), 7.20 (1H, d, *J* 1.5 Hz, H-8′), 7.22–7.27 (1H, m, H-9), 7.29 (1H, d, *J* 8.1 Hz, H-5′), 7.37 (1H, s, H-5), 7.50–7.56 (1H, m, H-8), 7.58 (1H, s, H-4), 7.95 (1H, dd, *J* 7.8, 1.8 Hz, H-10); δ_C (75 MHz, DMSO-d_6) 20.7, 20.9, 88.9, 113.9, 115.1, 115.3, 116.6, 117.4, 120.6, 122.7, 123.5, 125.3, 125.4, 126.8, 131.2, 133.6, 143.1, 143.3, 149.3, 151.9, 153.1, 158.2, 159.7, 168.9.

*4.2.1.3. 9-Methyl-3-(6-methyl-2-oxo-2H-chromen-4-yl)-2-oxo-2H, 5H-pyrano[3,2-c]chromen-5-yl acetate (**4c**).* Method A, work-up as described above gave 81% of **4c** as yellow powder: mp 204–206 °C (decomp.) [Found: C, 70.38; H, 3.62. $C_{25}H_{18}O_7$ (430.42) requires: C, 70.59; H, 3.77%.]; ν_{max} (Nujol) 1740, 1720, 1700, 1620, 1610, 1560 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 2.07 (3H, s, $(CH_3)_{Ac}$), 2.38 (3H, s, $(CH_3)_{C\text{-}6'}$), 2.41 (3H, s, $(CH_3)_{C\text{-}9}$), 6.49 (1H, s, H-3′), 7.07 (1H, d, *J* 8.2 Hz, H-7), 7.17 (1H, d, *J* 1.9 Hz, H-5′), 7.29 (1H, d, *J* 8.1 Hz, H-8′), 7.32 (1H, dd, *J* 8.1, 1.9 Hz, H-7′), 7.33 (1H, dd, *J* 8.2, 2.1 Hz, H-8), 7.34 (1H, s, H-5), 7.58 (1H, s, H-4), 7.78 (1H, d, *J* 2.1 Hz, H-10).

*4.2.1.4. 9-Methyl-3-(7-methyl-2-oxo-2H-chromen-4-yl)-2-oxo-2H, 5H-pyrano[3,2-c]chromen-5-yl acetate (**4d**).* Method A, work-up as described above gave 81% of **4d** as yellow powder: mp 206–208 °C (decomp.) [Found: C, 70.29; H, 3.54. $C_{25}H_{18}O_7$ (430.42) requires: C, 70.59; H, 3.77%.]; ν_{max} (Nujol) 1730, 1720, 1700, 1620, 1610, 1560 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 2.06 (3H, s, $(CH_3)_{Ac}$), 2.41 (3H, s, $(CH_3)_{C\text{-}9}$), 2.46 (3H, s, $(CH_3)_{C\text{-}7'}$), 6.44 (1H, s, H-3′), 7.05–7.10 (2H, m, H-5′,7), 7.20 (1H, d, *J* 1.5 Hz, H-8′), 7.29 (1H, dd, *J* 8.1, 1.5 Hz, H-6′), 7.32–7.35 (2H, m, H-5,8), 7.57 (1H, s, H-4), 7.76 (1H, d, *J* 1.8 Hz, H-10).

*4.2.1.5. 3-(7-Acetyloxy-2-oxo-2H-chromen-4-yl)-9-methyl-2-oxo-2H, 5H-pyrano[3,2-c]chromen-5-yl acetate (**4e**).* Method A, work-up as described above gave 78% of **4e** as yellow powder: mp 190–192 °C [Found: C, 65.76; H, 3.78. $C_{26}H_{18}O_9$ (474.42) requires: C, 65.82; H, 3.82%.]; ν_{max} (Nujol) 1740, 1720, 1700, 1620, 1610, 1560 cm^{-1}; δ_H (300 MHz, DMSO-d_6) 2.00 (3H, s, $(CH_3)_{C\text{-}9}$), 2.32 (3H, s, $(CH_3)_{Ac\text{-}5}$), 2.38 (3H, s, $(CH_3)_{Ac\text{-}7'}$), 6.61 (1H, s, H-3′), 7.14 (1H, d, *J* 8.7 Hz, H-7), 7.16 (1H, dd, *J* 8.7, 2.2 Hz, H-8), 7.36 (1H, d, *J* 2.2 Hz, H-10), 7.40 (1H, dd, *J* 8.5, 1.4 Hz, H-6′), 7.44 (1H, s, H-5), 7.66 (1H, d, *J* 1.4 Hz, H-8′), 7.73 (1H, d, *J* 8.5 Hz, H-5′), 8.02 (1H, s, H-4).

*4.2.2. 5-Alkoxy-3-(2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]-chromen-2-ones (**5a**–**p**)*

Method A. 2-Oxo-2*H*,5*H*-pyrano[3,2-*c*]chromen-5-yl acetate **4** (0.72 mmol) was dissolved in an appropriate alcohol (7 mL), *p*-toluenesulfonic acid (14 mg, 0.08 mmol) was added to the solution and the mixture was heated at 90 °C for 2 h (for alcohols with lower boiling points, refluxed for 2 h). After cooling, the yellow precipitate was filtered off, washed with diethyl ether, dried and recrystallized from above used alcohol.

Method B. The mixture of the same composition as in the method A was irradiated in a microwave oven at 400 W for 10 min. After cooling, yellow precipitate was filtered off, washed with diethyl ether, dried and recrystallized from appropriate alcohol.

*4.2.2.1. 5-Methoxy-3-(6-methyl-2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]chromen-2-one (**5a**).* Method A, work-up as described above gave 66% of **5a** as yellow powder: mp 226–228 °C (methanol) [Found: C, 71.02; H, 4.02. $C_{23}H_{16}O_6$ (388.38) requires: C, 71.13; H, 4.15%.]; ν_{max} (Nujol) 1740, 1720, 1610, 1600, 1560 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 2.37 (3H, s, $(CH_3)_{C\text{-}6'}$), 3.60 (3H, s, CH_3), 5.99 (1H, s, H-5), 6.43 (1H, s, H-3′), 7.14–7.17 (2H, m, H-5′,9), 7.21 (1H, dd, *J* 7.8, 1.2 Hz, H-7), 7.28 (1H, d, *J* 8.4 Hz, H-8′), 7.36 (1H, dd, *J* 8.4, 1.5 Hz, H-7′), 7.47–7.53 (1H, m, H-8), 7.48 (1H, s, H-4), 7.92 (1H, dd, *J* 7.5, 1.5 Hz, H-10).

*4.2.2.2. 5-Ethoxy-3-(6-methyl-2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]chromen-2-one (**5b**).* Method A, work-up as described above gave 93% of **5b** as yellow powder: mp 238–239 °C (ethanol) [Found: C, 71.56; H, 4.40. $C_{24}H_{18}O_6$ (402.41) requires: C, 71.64; H, 4.47%.]; ν_{max} (Nujol) 1740, 1720, 1620, 1610, 1560 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 1.24 (3H, t, CH_3), 2.37 (3H, s, CH_3), 3.74–4.09 (2H, q, CH_2), 6.09 (1H, s, H-5), 6.47 (1H, s, H-3′), 7.12 (1H, dd, *J* 8.1, 0.9 Hz, H-7), 7.16–7.21 (2H, m, H-5′,9), 7.28 (1H, d, *J* 8.4 Hz, H-8′), 7.36 (1H, dd, *J* 8.4, 1.8 Hz, H-7′), 7.46–7.52 (1H, m, H-8), 7.48 (1H, s, H-4), 7.91 (1H, dd, *J* 8.0, 1.8 Hz, H-10); δ_C (75 MHz, DMSO-d_6/$CDCl_3$) 15.0, 20.2, 63.9, 96.3, 107.6, 114.6, 116.4, 117.6, 117.7, 120.7, 120.7, 122.7, 122.7, 126.6, 133.2, 133.3, 133.8, 143.2, 143.3, 149.6, 151.3, 152.6, 158.5, 159.7.

*4.2.2.3. 3-(6-Methyl-2-oxo-2H-chromen-4-yl)-5-propyloxy-2H,5H-pyrano[3,2-c]chromen-2-one (**5c**).* Method A, work-up as described

above gave 57% of **5c**; method B, work-up as described above gave 56% of **5c** as yellow powder: mp 206–208 °C (propanol) [Found: C, 71.88; H, 4.69. $C_{25}H_{20}O_6$ (416.43) requires: C, 71.64; H, 4.47%.]; ν_{max} (Nujol) 1740, 1720, 1640, 1620, 1550 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 0.90 (3H, t, CH_3), 1.57 (2H, m, CH_2), 2.37 (3H, s, $(CH_3)_{C\text{-}6'}$), 3.65–3.97 (2H, m, OCH_2), 6.08 (1H, s, H-5), 6.47 (1H, s, H-3′), 7.12 (1H, dd, *J* 8.1, 1.2 Hz, H-7), 7.16–7.21 (2H, m, H-5′,9), 7.28 (1H, d, *J* 8.4 Hz, H-8′), 7.37 (1H, dd, *J* 8.4, 1.8 Hz, H-7′), 7.46–7.52 (1H, m, H-8), 7.48 (1H, s, H-4), 7.92 (1H, dd, *J* 7.5, 1.5 Hz, H-10); δ_C (75 MHz, DMSO-d_6/$CDCl_3$) 15.4, 20.7, 23.4, 69.9, 96.4, 107.7, 114.6, 116.5, 116.6, 117.6, 117.8, 120.7, 122.7, 122.8, 126.7, 133.2, 133.3, 133.8, 143.2, 143.2, 149.6, 151.3, 152.7, 158.6, 159.7.

*4.2.2.4. 3-(6-Methyl-2-oxo-2H-chromen-4-yl)-5-(1-methylheptyloxy)-2H,5H-pyrano[3,2-c]chromen-2-one (**5d**).* Method A, work-up as described above gave 33% of **5d** as yellow powder: mp 165–167 °C (octane-2-ol) [Found: C, 73.88; H, 6.39. $C_{30}H_{30}O_6$ (486.56) requires: C, 74.06; H, 6.21%.]; ν_{max} (Nujol) 1740, 1720, 1640, 1620, 1560 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 0.81–0.88 (3H, m, CH_3), 1.14–1.34 (11H, m, $(CH_2)_4$, CH_3), 1.38–1.49 (2H, m, $CHCH_2$), 2.45 (3H, s, $(CH_3)_{C\text{-}6'}$), 3.99–4.18 (1H, m, OCH), 6.13 (1H, s, H-5), 6.44 (1H, s, H-3′), 7.06–7.11 (2H, m, H-5′,7), 7.14–7.22 (2H, m, H-8′,9), 7.33 (1H, d, *J* 7.8 Hz, H-7′), 7.42–7.51 (1H, m, H-8), 7.47 (1H, s, H-4), 7.90 (1H, dd, *J* 7.8, 1.8 Hz, H-10).

*4.2.2.5. 5-Methoxy-3-(7-methyl-2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]chromen-2-one (**5e**).* Method A, work-up as described above gave 73% of **5e** as yellow powder: mp 214–215 °C (methanol) [Found: C, 70.89; H, 4.12. $C_{23}H_{16}O_6$ (388.38) requires: C, 71.13; H, 4.15%.]; ν_{max} (Nujol) 1730, 1710, 1620, 1600, 1550 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 2.46 (3H, s, $(CH_3)_{C\text{-}7'}$), 3.59 (3H, s, CH_3), 5.98 (1H, s, H-5), 6.43 (1H, s, H-3′), 7.08 (1H, dd, *J* 8.1, 1.2 Hz, H-6′), 7.13–7.20 (2H, m, H-7,9), 7.22 (1H, d, *J* 1.4 Hz, H-8′), 7.30 (1H, d, *J* 8.1 Hz, H-5′), 7.46–7.52 (1H, m, H-8), 7.47 (1H, s, H-4), 7.91 (1H, dd, *J* 7.8, 1.8 Hz, H-10).

*4.2.2.6. 5-Ethoxy-3-(7-methyl-2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]chromen-2-one (**5f**).* Method A, work-up as described above gave 93% of **5f**; method B, work-up as described above gave 85% of **5f** as yellow powder: mp 231–233 °C (ethanol) [Found: C, 71.69; H, 4.32. $C_{24}H_{18}O_6$ (402.41) requires: C, 71.64; H, 4.47%.]; ν_{max} (Nujol) 1730, 1715, 1620, 1610, 1550 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 1.24 (3H, t, CH_3), 2.45 (3H, s, $(CH_3)_{C\text{-}7'}$), 3.74–3.84 (2H, q, CH_2), 6.08 (1H, s, H-5), 6.43 (1H, s, H-3′), 7.07 (1H, dd, *J* 8.1, 1.5 Hz, H-6′), 7.12 (1H, dd, *J* 8.1, 0.9 Hz, H-7), 7.15–7.21 (1H, m, H-9), 7.19 (1H, d, *J* 1.5 Hz, H-8′), 7.31 (1H, d, *J* 8.1 Hz, H-5′), 7.45–7.51 (1H, m, H-8), 7.47 (1H, s, H-4), 7.90 (1H, dd, *J* 7.8, 1.8 Hz, H-10); δ_C (75 MHz, DMSO-d_6/$CDCl_3$) 15.0, 20.7, 63.8, 96.2, 107.5, 114.6, 115.3, 115.4, 117.6, 119.4, 120.5, 122.6, 122.6, 125.4, 126.7, 133.2, 133.2, 142.1, 143.2, 149.4, 152.3, 153.2, 158.4, 159.6.

*4.2.2.7. 3-(7-Methyl-2-oxo-2H-chromen-4-yl)-5-propyloxy-2H,5H-pyrano[3,2-c]chromen-2-one (**5g**).* Method A, work-up as described above gave 83% of **5g**; method B, work-up as described above gave 75% of **5g** as yellow powder: mp 221–222 °C (propanol) [Found: C, 71.92; H, 4.72. $C_{25}H_{20}O_6$ (416.43) requires: C, 72.11; H, 4.84%.]; ν_{max} (Nujol) 1730, 1710, 1620, 1610, 1550 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 1.24 (3H, t, CH_3), 1.56–1.68 (2H, m, CH_2), 2.46 (3H, s, $(CH_3)_{C\text{-}7'}$), 3.64–3.72 (2H, m, OCH_2), 6.07 (1H, s, H-5), 6.43 (1H, s, H-3′), 7.07 (1H, dd, *J* 8.4, 1.8 Hz, H-6′), 7.11 (1H, dd, *J* 8.1, 0.6 Hz, H-7), 7.15–7.20 (1H, m, H-9), 7.19 (1H, d, *J* 1.8 Hz, H-8′), 7.32 (1H, d, *J* 8.4 Hz, H-5′), 7.45–7.51 (1H, m, H-8), 7.47 (1H, s, H-4), 7.90 (1H, dd, *J* 7.8, 1.5 Hz, H-10).

*4.2.2.8. 5-Allyloxy-3-(7-methyl-2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]chromen-2-one (**5h**).* Method A, work-up as described above gave 50% of **5h** as yellow powder: mp 209–211 °C (allylalcohol) [Found: C, 72.42; H, 4.49. $C_{25}H_{18}O_6$ (414.41) requires: C, 72.46; H, 4.38%.]; ν_{max} (Nujol) 1720, 1700, 1630, 1620, 1560 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 2.46 (3H, s, CH_3), 4.26–4.42 (2H, m, CH_2), 5.27–5.33 (2H, m, $=CH_2$), 5.90 (1H, m, =CH), 6.12 (1H, s, H-5), 6.43 (1H, s, H-3′), 7.08 (1H, dd, *J* 7.8, 1.2 Hz, H-6′), 7.13 (1H, dd, *J* 8.1, 0.9 Hz, H-7), 7.17–7.22 (1H, m, H-9), 7.19 (1H, d, *J* 1.2 Hz, H-8′), 7.31 (1H, d, *J* 7.8 Hz, H-5′), 7.46–7.52 (1H, m, H-8), 7.47 (1H, s, H-4), 7.91 (1H, dd, *J* 7.8, 1.5 Hz, H-10).

*4.2.2.9. 5-Butyloxy-3-(7-methyl-2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]chromen-2-one (**5i**).* Method A, work-up as described above gave 56% of **5i** as yellow powder: mp 187–189 °C (butanol) [Found: C, 72.48; H, 4.89. $C_{26}H_{22}O_6$ (430.46) requires: C, 72.55; H, 5.15%.]; ν_{max} (Nujol) 1730, 1710, 1620, 1610, 1540 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 0.89 (3H, t, CH_3), 1.26–1.38 (2H, m, CH_2), 1.53–1.62 (2H, m, CH_2), 2.46 (3H, s, CH_3), 3.68–3.75 (2H, m, OCH_2), 6.06 (1H, s, H-5), 6.43 (1H, s, H-3′), 7.06–7.13 (2H, m, H-6′,7), 7.13–7.20 (1H, m, H-9), 7.19 (1H, s, H-8′), 7.32 (1H, d, *J* 8.1 Hz, H-5′), 7.45–7.51 (1H, m, H-8), 7.47 (1H, s, H-4), 7.90 (1H, dd, *J* 7.8, 1.5 Hz, H-10).

*4.2.2.10. 3-(7-Methyl-2-oxo-2H-chromen-4-yl)-5-pentyloxy-2H,5H-pyrano[3,2-c]chromen-2-one (**5j**).* Method A, work-up as described above gave 73% of **5j** as yellow powder: mp 225–227 °C (pentanol) [Found: C, 72.88; H, 5.31. $C_{27}H_{24}O_6$ (444.48) requires: C, 72.96; H, 5.44%.]; ν_{max} (Nujol) 1730, 1715, 1620, 1610, 1550 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 0.86 (3H, t, CH_3), 1.24–1.31 (4H, m, $(CH_2)_2$), 1.55–1.64 (2H, m, CH_2), 2.46 (3H, s, CH_3), 3.67–3.99 (2H, m, OCH_2), 6.06 (1H, s, H-5), 6.44 (1H, s, H-3′), 7.06–7.13 (2H, m, H-6′,7), 7.15–7.21 (1H, m, H-9), 7.19 (1H, s, H-8′), 7.32 (1H, d, *J* 8.1 Hz, H-5′), 7.45–7.51 (1H, m, H-8), 7.47 (1H, s, H-4), 7.90 (1H, dd, *J* 7.8, 1.5 Hz, H-10).

*4.2.2.11. 5-Hexyloxy-3-(7-methyl-2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]chromen-2-one (**5k**).* Method A, work-up as described above gave 76% of **5k** as yellow powder: mp 232–234 °C (hexanol) [Found: C, 73.16; H, 5.49. $C_{28}H_{26}O_6$ (458.51) requires: C, 73.36; H, 5.72%.]; ν_{max} (Nujol) 1730, 1720, 1640, 1620, 1560 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 0.82–0.86 (3H, m, CH_3), 1.22–1.29 (6H, m, $(CH_2)_3$), 1.53–1.62 (2H, m, CH_2), 2.46 (3H, s, CH_3), 3.67–4.00 (2H, m, OCH_2), 6.06 (1H, s, H-5), 6.43 (1H, s, H-3′), 7.06–7.15 (2H, m, H-6′,7), 7.18–7.19 (2H, m, H-8′,9), 7.32 (1H, d, *J* 8.1 Hz, H-5′), 7.45–7.54 (1H, m, H-8), 7.47 (1H, s, H-4), 7.90 (1H, d, *J* 7.5 Hz, H-10).

*4.2.2.12. 5-Heptyloxy-3-(7-methyl-2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]chromen-2-one (**5l**).* Method A, work-up as described above gave 70% of **5l** as yellow powder: mp 199–201 °C (heptanol) [Found: C, 73.92; H, 5.79. $C_{29}H_{28}O_6$ (472.54) requires: C, 73.71; H, 5.97%.]; ν_{max} (Nujol) 1740, 1720, 1620, 1610, 1560 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 0.85 (3H, t, CH_3), 1.21–1.29 (8H, m, $(CH_2)_4$), 1.54–1.63 (2H, m, CH_2), 2.46 (3H, s, CH_3), 3.67–3.74 (2H, m, OCH_2), 6.06 (1H, s, H-5), 6.43 (1H, s, H-3′), 7.06–7.13 (2H, m, H-6′,7), 7.15–7.20 (2H, m, H-8′,9), 7.32 (1H, d, H-5′), 7.45–7.51 (1H, m, H-8), 7.47 (1H, s, H-4), 7.90 (1H, dd, *J* 7.8, 1.8 Hz, H-10); δ_C (75 MHz, DMSO-d_6) 13.8, 20.9, 21.8, 25.3, 28.2, 28.8, 31.1, 68.1, 96.4, 107.5, 114.4, 115.2, 115.2, 117.6, 118.4, 120.5, 122.5, 122.6, 125.3, 126.7, 133.1, 133.1, 142.1, 149.5, 152.5, 153.1, 158.4, 159.6.

*4.2.2.13. 3-(7-Methyl-2-oxo-2H-chromen-4-yl)-5-(1-methylheptyloxy)-2H,5H-pyrano[3,2-c]chromen-2-one (**5m**).* Method A, work-up as described above gave 50% of **5m** as yellow powder: mp 159–161 °C (octane-2-ol) [Found: C, 74.26; H, 6.41. $C_{30}H_{30}O_6$ (486.56) requires: C, 74.06; H, 6.21%.]; ν_{max} (Nujol) 1730, 1720, 1620, 1610, 1600 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 0.80–0.89 (3H, m, CH_3), 1.13–1.31 (11H, m, $(CH_2)_4$, CH_3), 1.41–1.49 (2H, m, CH_2), 2.37 (3H, s, CH_3), 4.09–4.19 (1H, m, OCH), 6.13 (1H, s, H-5), 6.47 (1H, s, H-3′), 7.08 (1H, dd, *J* 8.3, 0.9 Hz, H-7), 7.15–7.21 (2H, m, H-8′,9), 7.27 (1H, d, *J* 8.7 Hz,

H-5′), 7.36 (1H, dd, *J* 8.7, 1.8 Hz, H-6′), 7.41 (1H, s, H-4), 7.44–7.50 (1H, m, H-8), 7.91 (1H, dd, *J* 7.7, 1.5 Hz, H-10).

*4.2.2.14. 5-Ethoxy-9-methyl-3-(6-methyl-2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]chromen-2-one (**5n**).* Method A, work-up as described above gave 92% of **5n** as yellow powder: mp 234–236 °C (ethanol) [Found: C, 72.05; H, 4.69. $C_{25}H_{20}O_6$ (416.43) requires: C, 72.11; H, 4.84%.]; ν_{max} (Nujol) 1740, 1715, 1620, 1610, 1560 cm^{-1}; δ_H (300 MHz, DMSO-d_6) 1.12 (3H, t, CH_3), 2.33 (3H, s, $(CH_3)_{C\text{-}6'}$), 2.37 (3H, s, $(CH_3)_{C\text{-}9}$), 3.76 (1H, m, CH), 3.88 (1H, m, CH), 6.28 (1H, s, H-5), 6.59 (1H, s, H-3′), 7.12 (1H, d, *J* 8.2 Hz, H-7), 7.13 (1H, d, *J* 8.5 Hz, H-8′), 7.38 (1H, dd, *J* 8.5, 1.6 Hz, H-7′), 7.45 (1H, d, *J* 1.6 Hz, H-5′), 7.48 (1H, dd, *J* 8.2, 2.2 Hz, H-8), 7.61 (1H, d, *J* 2.2 Hz, H-10), 7.93 (1H, s, H-4); δ_C (75 MHz, DMSO-d_6) 14.9, 20.1, 20.3, 63.8, 96.1, 107.6, 114.8, 114.4, 116.8, 117.5, 120.5, 120.8, 122.5, 126.6, 132.1, 133.1, 133.7, 134.1, 143.2, 143.3, 149.6, 150.5, 152.1, 158.6, 159.9.

*4.2.2.15. 5-Ethoxy-9-methyl-3-(7-methyl-2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]chromen-2-one (**5o**).* Method A, work-up as described above gave 91% of **5o** as yellow powder: mp 241–243 °C (ethanol) [Found: C, 72.24; H, 4.66. $C_{25}H_{20}O_6$ (416.43) requires: C, 72.11; H, 4.84%.]; ν_{max} (Nujol) 1730, 1720, 1620, 1610, 1550 cm^{-1}; δ_H (300 MHz, DMSO-d_6) 1.11 (3H, t, CH_3), 2.36 (3H, s, $(CH_3)_{C\text{-}9}$), 2.43 (3H, s, $(CH_3)_{C\text{-}7'}$), 3.77 (1H, m, CH_2), 3.87 (1H, m, CH_2), 6.27 (1H, s, H-5), 6.54 (1H, s, H-3′), 7.11 (1H, d, *J* 8.2 Hz, H-7), 7.17 (1H, dd, *J* 7.9, 2.2 Hz, H-6′), 7.31 (1H, d, *J* 2.2 Hz, H-8′), 7.37 (1H, dd, *J* 8.2, 1.6 Hz, H-8), 7.52 (1H, d, *J* 7.9 Hz, H-5′), 7.59 (1H, d, *J* 1.6 Hz, H-10), 7.93 (1H, s, H-4); δ_C (75 MHz, DMSO-d_6) 15.0, 19.9, 20.7, 63.7, 96.1, 107.6, 114.3, 115.3, 115.4, 117.6, 120.3, 120.4, 122.5, 125.4, 126.8, 131.8, 133.9, 134.0, 143.1, 143.3, 149.6, 150.2, 153.2, 159.8, 160.9.

*4.2.2.16. 3-(7-Acetyloxy-2-oxo-2H-chromen-4-yl)-5-ethoxy-9-methyl-2H,5H-pyrano[3,2-c]chromen-2-one (**5p**).* Method A, work-up as described above gave 85% of **5p** as yellow powder: mp 208–210 °C (ethanol) [Found: C, 67.75; H, 4.27. $C_{26}H_{20}O_8$ (460.44) requires: C, 67.82; H, 4.38%.]; ν_{max} (Nujol) 1740, 1720, 1700, 1620, 1615, 1550 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 1.22 (3H, t, CH_3), 2.34 (3H, s, $(CH_3)_{C\text{-}9}$), 2.38 (3H, s, $(CH_3)_{Ac\text{-}7'}$), 3.79 (1H, m, CH_2), 3.99 (1H, m, CH_2), 6.05 (1H, s, H-5), 6.47 (1H, s, H-3′), 7.01 (1H, d, *J* 8.5 Hz, H-7), 7.04 (1H, dd, *J* 8.5, 2.2 Hz, H-8), 7.17 (1H, d, *J* 2.2 Hz, H-10), 7.29 (1H, dd, *J* 8.8, 1.9 Hz, H-6′), 7.46 (1H, d, *J* 8.8 Hz, H-5′), 7.49 (1H, s, H-4), 7.70 (1H, d, *J* 1.9 Hz, H-8′).

*4.2.3. 5-Hydroxy-3-(2-oxo-2H-chromen-4-yl)-2H,5H-pyrano-[3,2-c]chromen-2-ones (**6a–d**)*

2-Oxo-2*H*,5*H*-pyrano[3,2-*c*]chromen-5-yl acetate **4** (0.72 mmol) was dissolved in water (15 mL), *p*-toluenesulfonic acid (14 mg, 0.08 mmol) was added to the solution and the mixture was heated to reflux for 2 h. After cooling, the yellow precipitate was filtered off, washed with diethyl ether, dried and recrystallized from dioxane–water mixture.

*4.2.3.1. 5-Hydroxy-3-(6-methyl-2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]chromen-2-one (**6a**).* Work-up as described above gave 70% of **6a** as yellow solid: mp 222–224 °C [Found: C, 70.50, H, 3.57. $C_{22}H_{14}O_6$ (374.40) requires: C, 70.59, H, 3.77%.]; ν_{max} (solid) 3350, 1740, 1715, 1620, 1610, 1560 cm^{-1}; δ_H (300 MHz, DMSO-d_6) 2.33 (3H, s, CH_3), 6.45 (1H, d, *J* 6.2 Hz, H-5), 6.57 (1H, s, H-3′), 7.16 (1H, d, *J* 8.2 Hz, H-7), 7.37 (1H, dd, *J* 8.2, 7.7 Hz, H-8), 7.41 (1H, d, *J* 1.8 Hz, H-5′), 7.45–7.56 (3H, m, H-7′,8′,9), 7.78 (1H, d, *J* 7.7 Hz, H-10), 7.83 (1H, d, *J* 6.2 Hz, OH), 7.90 (1H, s, H-4); δ_C (75 MHz, DMSO-d_6) 20.3, 91.1, 109.0, 114.3, 116.4, 116.6, 117.6, 117.7, 120.4, 122.2, 122.5, 126.5, 133.1, 133.2, 133.8, 143.6, 149.8, 151.3, 152.3, 153.1, 158.7, 159.7.

*4.2.3.2. 5-Hydroxy-3-(7-methyl-2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]chromen-2-one (**6b**).* Work-up as described above gave 68% of **6b** as yellow solid: mp 210–211 °C [Found: C, 70.49; H, 3.51. $C_{22}H_{14}O_6$ (374.40) requires: C, 70.59; H, 3.77%.]; ν_{max} (solid) 3350, 1740, 1720, 1620, 1610, 1555 cm^{-1}; δ_H (300 MHz, DMSO-d_6) 2.43 (3H, s, CH_3), 6.43 (1H, d, *J* 6.3 Hz, H-5), 6.52 (1H, s, H-3′), 7.16 (1H, dd, *J* 8.2, 1.6 Hz, H-6′), 7.17 (1H, dd, *J* 6.8, 1.6 Hz, H-7), 7.21 (1H, ddd, *J* 7.9, 7.7, 1.6 Hz, H-9), 7.32 (1H, d, *J* 1.6 Hz, H-8′), 7.48 (1H, d, *J* 8.2 Hz, H-5′), 7.52 (1H, ddd, *J* 7.9, 6.8, 1.6 Hz, H-8), 7.78 (1H, dd, *J* 7.7, 1.6 Hz, H-10), 7.83 (1H, d, *J* 6.3 Hz, OH), 7.91 (1H, s, H-4); δ_C (75 MHz, DMSO-d_6) 21.0, 91.0, 109.0, 114.3, 115.3, 115.5, 116.8, 117.7, 120.3, 122.2, 122.5, 125.5, 126.7, 133.1, 133.3, 143.5, 149.6, 152.4, 153.1, 153.3, 158.6, 159.7.

*4.2.3.3. 5-Hydroxy-9-methyl-3-(7-methyl-2-oxo-2H-chromen-4-yl)-2H,5H-pyrano[3,2-c]chromen-2-one (**6c**).* Work-up as described above gave 72% of **6c** as yellow solid: mp 232–234 °C [Found: C, 70.95; H, 4.03. $C_{23}H_{16}O_6$ (388.40) requires: C, 71.13; H, 4.15%]; ν_{max} (solid) 3350, 1740, 1720, 1620, 1615, 1555 cm^{-1}; δ_H (300 MHz, DMSO-d_6) 2.35 (3H, s, $(CH_3)_{C\text{-}9}$), 2.43 (3H, s, $(CH_3)_{C\text{-}7'}$), 6.41 (1H, d, *J* 6.1 Hz, H-5), 6.52 (1H, s, H-3′), 7.06 (1H, d, *J* 8.4 Hz, H-5′), 7.18 (1H, dd, *J* 7.9, 1.6 Hz, H-8), 7.28–7.34 (2H, m, H-6′,8′), 7.45 (1H, d, *J* 7.9 Hz, H-7), 7.57 (1H, d, *J* 1.6 Hz, H-10), 7.73 (d, 1H, *J* 6.1 Hz, OH), 7.90 (1H, s, H-4).

*4.2.3.4. 3-(7-Acetyloxy-2-oxo-2H-chromen-4-yl)-5-hydroxy-9-methyl-2H,5H-pyrano[3,2-c]chromen-2-one (**6d**).* Work-up as described above gave 65% of **6d** as yellow solid: mp 247–249 °C (decomp.) [Found: C, 66.57; H, 3.65. $C_{24}H_{16}O_8$ (432.38) requires: C, 66.67; H, 3.73%.]; ν_{max} (solid) 3348, 1740, 1715, 1700, 1620, 1610, 1560 cm^{-1}; δ_H (300 MHz, DMSO-d_6) 2.31 (3H, s, $(CH_3)_{Ac}$), 2.36 (3H, s, $(CH_3)_{C\text{-}9}$), 6.48 (1H, d, *J* 5.5 Hz, H-5), 6.59 (1H, s, H-3′), 7.05 (1H, d, *J* 8.3 Hz, H-7), 7.14 (1H, dd, *J* 8.7, 2.3 Hz, H-6′), 7.34 (1H, dd, *J* 8.3, 2.2 Hz, H-8), 7.37 (1H, d, *J* 2.2 Hz, H-10), 7.59 (1H, d, *J* 2.3 Hz, H-8′), 7.66 (1H, d, *J* 8.7 Hz, H-5′), 7.78 (1H, d, *J* 5.5 Hz, OH), 7.93 (1H, s, H-4).

*4.2.4. 5-Hydroxy-3-(2-oxo-2H-chromen-4-yl)pyrano[2,3-b]chromen-2(10aH)-ones (**7a–c**)*

Compound **4** or **5** (0.72 mmol) was dissolved in acetic acid (10 mL) and stirred at 60 °C for 30 min. After cooling, the yellow precipitate was filtered off, dried and recrystallized from acetic acid.

*4.2.4.1. 5-Hydroxy-3-(6-methyl-2-oxo-2H-chromen-4-yl)pyrano-[2,3-b]chromen-2(10aH)-one (**7a**).* Work-up as described above gave 75% of **7a** as yellow solid: mp 245–247 °C (decomp.) [Found: C, 70.38; H, 3.72. $C_{22}H_{14}O_6$ (374.40) requires: C, 70.59; H, 3.77%.]; ν_{max} (solid) 3388, 1740, 1720, 1620, 1610, 1560 cm^{-1}; δ_H (300 MHz, DMSO-d_6) OH not seen, 2.43 (3H, s, CH_3), 6.57 (1H, s, H-3′), 7.15 (1H, dd, *J* 7.4, 1.3 Hz, H-9), 7.20 (1H, ddd, *J* 7.9, 7.5, 1.3 Hz, H-7), 7.26 (1H, d, *J* 7.5 Hz, H-8′), 7.35 (1H, d, *J* 1.5 Hz, H-5′), 7.38 (1H, s, H-10), 7.49 (1H, dd, *J* 7.59, 1.5 Hz, H-7′), 7.53 (1H, ddd, *J* 7.4, 7.5, 1.5 Hz, H-8), 7.78 (1H, dd, *J* 7.9, 1.5 Hz, H-6), 7.90 (1H, s, H-4); δ_C (75 MHz, DMSO-d_6) 20.1, 96.1, 109.0, 114.3, 116.3, 116.5, 117.6, 120.3, 122.0, 122.4, 126.4, 132.9, 133.1, 133.7, 143.1, 143.4, 149.6, 151.2, 152.6, 152.9, 158.6, 159.6.

*4.2.4.2. 5-Hydroxy-3-(7-methyl-2-oxo-2H-chromen-4-yl)pyrano-[2,3-b]chromen-2(10aH)-one (**7b**).* Work-up as described above gave 75% of **7b** as yellow solid: mp 219–221 °C [Found: C, 70.62; H, 3.54. $C_{22}H_{14}O_6$ (374.40) requires: C, 70.59; H, 3.77%.]; ν_{max} (solid) 3346, 1730, 1720, 1645, 1610, 1550 cm^{-1}; δ_H (300 MHz, DMSO-d_6) OH not seen, 2.30 (3H, s, CH_3), 6.68 (1H, s, H-3′), 7.34–7.37 (2H, m, H-7,9), 7.52 (1H, d, *J* 0.8 Hz, H-10), 7.54–7.69 (2H, m, H-5′,8′), 7.85 (1H, ddd, *J* 8.1, 7.8, 1.6 Hz, H-8), 8.02–8.12 (1H, m, H-6′), 8.13 (1H, d, *J* 0.8 Hz, H-4), 8.26 (1H, dd, *J* 8.8, 1.6 Hz, H-6); δ_C (75 MHz, DMSO-d_6) 21.1, 96.1, 107.5, 114.4, 115.3, 116.6, 117.6, 120.5, 122.4, 122.6, 125.4, 126.6, 133.0, 133.2, 142.2, 143.5, 149.4, 149.5, 152.8, 153.1, 158.4, 159.6.

*4.2.4.3. 5-Hydroxy-3-(7-methyl-2-oxo-2H-chromen-4-yl)pyrano-[2,3-b]chromen-2(10aH)-one (**7c**).* Work-up as described above gave 76% of **7c** as yellow solid: mp 206–208 °C [Found: C, 71.02; H, 4.14. $C_{23}H_{16}O_6$ (388.38) requires: C, 71.13; H, 4.15%.]; ν_{max} (solid) 3358, 1725, 1720, 1620, 1610, 1550 cm^{-1}; δ_H (300 MHz, DMSO-d_6) OH not seen, 2.36 (s, 3H, $(CH_3)_{C\text{-}7'}$), 2.43 (s, 3H, $(CH_3)_{C\text{-}7}$), 6.52 (s, 1H, H-3′), 7.05 (d, ^3J 8.4 Hz, 1H, H-9), 7.16 (dd, ^3J 8.1 Hz, ^4J 1.0 Hz, 1H, H-6′), 7.29 (dd, ^3J 8.4 Hz, ^4J 1.3 Hz, 1H, H-8), 7.31 (1H, s, H-10), 7.32 (d, ^4J 1.0 Hz, 1H, H-8′), 7.47 (d, ^3J 8.1 Hz, 1H, H-5′), 7.57 (d, ^4J 1.3 Hz, 1H, H-6), 7.90 (s, 1H, H-4).

*4.2.5. 5-Alkoxy-3-(2-oxo-2H-chromen-4-yl)pyrano[2,3-b]-chromen-2(10aH)-ones (**8a**–**d**)*

Compound **7** (0.72 mmol) was dissolved in the appropriate alcohol (15 mL), a few drops (5) of DMF and *p*-toluenesulfonic acid (14 mg, 0.08 mmol) were added to the solution and the mixture was heated to reflux for 2 h. After cooling, the yellow precipitate was filtered off, dried and recrystallized from appropriate alcohol.

*4.2.5.1. 5-Methoxy-3-(7-methyl-2-oxo-2H-chromen-4-yl)pyrano-[2,3-b]chromen-2(10aH)-one (**8a**).* Work-up as described above gave 92% of **8a** as yellow solid: mp 247–249 °C (decomp.) (methanol) [Found: C, 71.12; H, 3.98. $C_{23}H_{16}O_6$ (388.38) requires: C, 71.13; H, 4.15%.]; ν_{max} (solid) 1720, 1717, 1644, 1605, 1555 cm^{-1}; δ_H (300 MHz, DMSO-d_6) 2.44 (3H, s, CH_3), 3.49 (3H, s, OCH_3), 6.21 (1H, s, H-10), 6.54 (1H, s, H-3′), 7.16 (1H, dd, *J* 8.1, 1.7 Hz, H-9), 7.25 (dd, 1H, *J* 8.3, 1.0 Hz, H-6′), 7.27 (1H, ddd, *J* 8.1, 7.9, 1.7 Hz, H-7), 7.32 (1H, d, *J* 1.0 Hz, H-8′), 7.51 (1H, d, *J* 8.3 Hz, H-5′), 7.57 (1H, ddd, *J* 8.1, 7.8, 1.7 Hz, H-8), 7.79 (1H, dd, *J* 7.9, 1.7 Hz, H-6), 7.95 (1H, s, H-4); δ_C (75 MHz, DMSO-d_6) 21.0, 55.3, 97.2, 107.4, 114.6, 115.4, 116.7, 117.7, 117.8, 120.6, 122.6, 122.8, 125.4, 126.8, 133.3, 143.2, 143.3, 149.6, 152.5, 152.7, 153.2, 158.5, 159.7.

*4.2.5.2. 5-Methoxy-7-methyl-3-(7-methyl-2-oxo-2H-chromen-4-yl)-pyrano[2,3-b]chromen-2(10aH)-one (**8b**).* Work-up as described above gave 96% of **8b** as yellow solid: mp 237–239 °C (methanol) [Found: C, 71.55; H, 4.47. $C_{24}H_{18}O_6$ (402.40) requires: C, 71.64; H, 4.51%.]; ν_{max} (solid) 1730, 1720, 1650, 1610, 1560 cm^{-1}; δ_H (300 MHz, DMSO-d_6) 2.36 (3H, s, $(CH_3)_{C\text{-}7'}$), 2.43 (3H, s, $(CH_3)_{C\text{-}7}$), 3.47 (3H, s, OCH_3), 6.17 (1H, s, H-10), 6.54 (1H, s, H-3′), 7.14 (1H, d, *J* 8.3 Hz, H-9), 7.16 (1H, dd, *J* 8.1, 1.1 Hz, H-6′), 7.31 (1H, d, *J* 1.1 Hz, H-8′), 7.37 (1H, dd, *J* 8.3, 1.8 Hz, H-8), 7.50 (1H, d, *J* 8.1 Hz, H-5′), 7.59 (1H, d, *J* 1.8 Hz, H-6), 7.94 (1H, s, H-4).

*4.2.5.3. 5-Ethoxy-7-methyl-3-(7-methyl-2-oxo-2H-chromen-4-yl)-pyrano[2,3-b]chromen-2(10aH)-one (**8c**).* Work-up as described above gave 80% of **8c** as yellow solid: mp 235–236 °C (ethanol) [Found: C, 72.04; H, 4.73. $C_{25}H_{20}O_6$ (416.43) requires: C, 72.12; H, 4.84%.]; ν_{max} (solid) 1720, 1715, 1660, 1615, 1560 cm^{-1}; δ_H (300 MHz, DMSO-d_6) 1.12 (3H, t, CH_3), 2.35 (3H, s, $(CH_3)_{C\text{-}7'}$), 2.43 (3H, s, $(CH_3)_{C\text{-}7}$), 3.81 (2H, q, CH_2), 6.30 (1H, s, H-10), 6.54 (1H, s, H-3′), 7.12 (1H, d, *J* 8.4 Hz, H-9), 7.16 (1H, dd, *J* 8.1, 1.1 Hz, H-6′), 7.31 (1H, d, *J* 1.1 Hz, H-8′), 7.36 (1H, dd, *J* 8.4, 1.5 Hz, H-8), 7.52 (1H, d, *J* 8.1 Hz, H-5′), 7.59 (1H, d, *J* 1.5 Hz, H-6), 7.93 (1H, s, H-4).

*4.2.5.4. 5-Ethoxy-3-(6-methyl-2-oxo-2H-chromen-4-yl)pyrano[2,3-b]-chromen-2(10aH)-one (**8d**).* Work-up as described above gave 90% of **8d** as yellow solid: mp 230–232 °C (decomp.) (ethanol) [Found: C, 71.83; H, 4.49. $C_{24}H_{18}O_6$ (402.2) requires: C, 71.64; H, 4.51%.]; ν_{max} (solid) 1720, 1715, 1650, 1610, 1555 cm^{-1}; δ_H (300 MHz, DMSO-d_6) 1.13 (3H, t, CH_3), 2.33 (3H, s, $(CH_3)_{C\text{-}6'}$), 3.84 (2H, q, CH_2), 6.32 (1H, s, H-10), 6.59 (1H, s, H-3′), 7.23 (1H, dd, *J* 8.1, 0.9 Hz, H-9), 7.25 (1H, ddd, *J* 7.8, 7.6, 0.9 Hz, H-7), 7.37 (1H, dd, *J* 7.1, 1.9 Hz, H-7′), 7.46 (1H, d, *J* 1.9 Hz, H-5′), 7.48 (1H, d, *J* 7.1 Hz, H-8′), 7.56 (1H, ddd, *J* 8.1, 7.6, 1.4 Hz, H-8), 7.8 (1H, dd, *J* 7.8, 1.4 Hz, H-6), 7.93 (1H, s, H-4).

*4.2.6. 2-[2-(2-Oxo-2H-chromen-4-yl)ethenyl]-4H-chromen-4-ones (**10a**,**b**)*

Method A. 6-Methyl-4-oxo-4*H*-chromen-2-carbaldehyde **9** (425 mg, 2.26 mmol) and 7-R^2-coumarin-4-acetic acid **2** (2.26 mmol) were dissolved in acetic anhydride (4 mL), K_2CO_3 (11 mg, 0.08 mmol) was added and the mixture has been stirred at 40–50 °C for 2 h. The yellow precipitate was filtered off, dried and recrystallized from chloroform.

Method B. 6-Methyl-4-oxo-4*H*-chromen-2-carbaldehyde **9** (425 mg, 2.26 mmol) and 7-R^2-coumarin-4-acetic acid **2** (2.26 mmol) were dissolved in anhydrous acetic anhydride (4 mL), K_2CO_3 (11 mg, 0.08 mmol) was added and the mixture was irradiated in a microwave oven at 400 W for 4 min. After cooling, the yellow precipitate was filtered off, dried and recrystallized from chloroform.

*4.2.6.1. 6-Methyl-2-[2-(7-methyl-2-oxo-2H-chromen-4-yl)ethenyl]-4H-chromen-4-one (**10a**).* Method A, work-up as described above gave 90% of **10a**; method B, work-up as described above gave 85% of **10a** as yellow solid: mp 297–298 °C [Found: C, 76.54; H, 4.54. $C_{22}H_{16}O_4$ (344.40) requires: C, 76.73; H, 4.68%.]; ν_{max} (solid) 1740, 1720, 1645, 1610, 1560 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 2.41 (3H, s, $(CH_3)_{C\text{-}6}$), 2.49 (3H, s, $(CH_3)_{C\text{-}7'}$), 6.43 (1H, s, H-3′), 6.56 (1H, s, H-3), 6.96 (1H, d, *J* 15.7 Hz, H-9), 7.18 (1H, d, *J* 8.7 Hz, H-8), 7.22 (1H, d, *J* 1.0 Hz, H-8′), 7.48 (1H, dd, *J* 8.8, 1.0 Hz, H-6′), 7.55 (1H, dd, *J* 8.7, 1.0 Hz, H-7), 7.67 (1H, d, *J* 8.8 Hz, H-5′), 7.83 (1H, d, *J* 15.7 Hz, H-9′), 8.01 (1H, d, *J* 1.3 Hz, H-5).

*4.2.6.2. 2-[2-(7-Acetyloxy-2-oxo-2H-chromen-4-yl)ethenyl]-6-methyl-4H-chromen-4-one (**10b**).* Method A, work-up as described above gave 90% of **10b**; method B, work-up as described above gave 85% of **10b** as yellow solid: mp 253–256 °C [Found: C, 71.02; H, 4.13. $C_{23}H_{16}O_6$ (388.40) requires: C, 71.13; H, 4.15%.]; ν_{max} (solid) 1740, 1720, 1700, 1650, 1610, 1560 cm^{-1}; δ_H (300 MHz, DMSO-d_6) 2.35 (3H, s, $(CH_3)_{Ac}$), 2.44 (3H, s, $(CH_3)_{C\text{-}6}$), 6.63 (1H, s, H-3′), 6.88 (1H, s, H-3), 7.26 (1H, dd, *J* 8.8, 2.2 Hz, H-6′), 7.35 (1H, d, *J* 2.2 Hz, H-8′), 7.55 (1H, d, *J* 15.9 Hz, H-9), 7.69 (1H, d, *J* 8.2 Hz, H-8), 7.71 (1H, dd, *J* 8.2, 1.9 Hz, H-7), 7.82 (1H, d, *J* 1.9 Hz, H-5), 8.01 (1H, d, *J* 15.9 Hz, H-9′), 8.19 (1H, d, *J* 8.8 Hz, H-5′).

Acknowledgements

This work was supported by Science and Technology Assistance Agency under the contract No. APVT-20-031904, LPP-0153-06, Slovak Grant Agency (Grants No. 1/0639/08, 1/4467/07) and for dissemination and networking also Cost Action CM0602/329/06.

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