Reliable Synthesis of 9-Aryl-Substituted 2,6,7-Trihydroxyxanthen-3-ones

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Dedicated to Prof. Reinhard W. Hoffmann on the occasion of his 75th birthday

Abstract: 2,6,7-Trihydroxyxanthen-3-ones are reliably prepared by a one-pot protocol using alkali peroxosulfates in the key step. NMR spectra in deuterated sodium hydroxide confirm the anticipated structures and allow the determination of the dye contents by an internal standard.

Key words: heterocycles, oxidations, condensation, dye, xanthenones

Hydroxylated 9-substituted xanthenones represent an important class of dyes. Although these compounds exhibit splendid absorption and fluorescence characteristics they show limited photochemical stability. The most prominent examples as dyes are 6-hydroxy derivatives, for example, fluorescein or eosin.¹ Beside the application in inks, the xanthenone-based dyes are employed for analytical purposes. Combined with specific crown ethers a fluorimetric determination of Hg²⁺ in fish or Pb²⁺ in living cells was demonstrated.^{2,3} Early transition metal cations, for example, Zr⁴⁺ as well as cations of main group elements like tin can be detected photometrically by 9-arylsubstituted 2,6,7-trihydroxyxanthen-3-one derivatives.⁴ The specific binding of these particular heterocycles to histones - DNA binding proteins - or specific amino acids renders them useful for molecular biological studies.^{5,6} In contrast to the 6-hydroxyxanthen-3-ones the 2,6,7-trihydroxy congeners exhibit an extremely low solubility.

Since usually only small quantities are required for photometric investigations, all reported preparations of 9-aryl-2,6,7-trihydroxyxanthen-3-ones follow the protocol of Liebermann and Lindenbaum.⁷ After a two-fold Friedel– Crafts alkylation of 1,2,4-triacetoxybenzene (1),⁸ the acetates are cleaved under acidic alcoholic conditions. In the original protocol, the oxidation of **3** occurs under aerobic conditions over an extended period of time. Since the transformation is accompanied by a series of decomposition reactions, the desired compound **4** is only collected in low yield, typically in the range of $4-20\%^9$ (Scheme 1). Due to the low solubility, **4** is only characterized by photometric data and elemental analysis. In general, structural elucidations are missing.

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Scheme 1 One-pot sequence to 9- aryl-2,6,7-trihydroxyxanthen-3-ones

9-(3-Pyridyl)-2,6,7-trihydroxyxanthen-3-one (4d) was described by Fogl and Vrbsky.¹⁰ Following precisely their protocol yields not the desired compound 4a, but a complex mixture of higher molecular by-products.¹¹ Since 4a has a technical relevance for the photometric determination of heavy metal cations we reinvestigated the preparation of this particular class of compounds. For accomplishing the transformation a single trihydroxy benzene moiety of 3 has to be oxidized to the corresponding *p*-benzoquinone, which subsequently undergoes a cyclocondensation reaction to the xanthenone fragment.

Thus, typical oxidation conditions for hydroquinones to quinones have been tested. A wide variety of reagents accomplish this transformation including stoichiometric amounts of chromium trioxide,¹² sodium hypochlorite,¹³ iron(III) chloride,¹⁴ and silver oxide¹⁵ as oxidants. Alternatively, the oxidation can be performed using nitrogen



Scheme 2 Screening of reaction conditions for the technically relevant derivative 4a

oxides/O₂,¹⁶ alumina supported copper sulfate/O₂,¹⁷ and VO(acac)₂/O₂,¹⁸ or electrochemical methods.¹⁹ However, we focused on oxidants which result in easily removable reagent waste. In particular, the by-product has to be either volatile or a salt which can be removed by washing. Consequently, quinones like DDQ or chloranil were not considered. Furthermore, reagents based on transition metals in high oxidation states have to be strictly avoided because of the potential interference in the latter application. The screening for suitable reaction conditions was performed on the transformation to **4** (Ar = 3-pyridyl) since this particular compound was technically required (Scheme 2).

The method at ambient conditions as reported by Fogl and Vrbsky¹⁰ results in no dye formation in the absence of light, whereas sunlight allows the formation of traceable amounts of 4a in a complex tarry mixture (Table 1, entries 1, 2). Employing hydrogen peroxide (30 wt% in water) leads to very small amounts of 4a (entry 3). Prolonged reaction times and elevated temperatures did not significantly improve the situation. However, organic peroxides were envisioned to be the reagents of choice but under various conditions at ambient conditions almost no formation of the desired 2,6,7-trihydroxyxanthen-3-one occurred. Elevated reaction temperatures afforded 4a with a moderate dye content (Table 1, entries 4, 5). Therefore, peroxodisulfates, which represent stronger oxidants, were applied. The most common reagent, potassium peroxodisulfate provides even at ambient temperature a tremendously increased yield with a dye content of about 45% (entry 6). Elevated temperatures rendered ameliorated results in yield as well as dye content (entry 7). Best results were obtained when the oxidant was added in small portions over a range of about 50 minutes. Additional reflux of 40 minutes completes the conversion providing a strongly colored slurry. The subsequent time for precipitation by slow cooling is crucial for a good yield of **4a**, because filterable crystals are formed. This protocol can be scaled up to a multimolar range. By switching to a higher boiling primary alcohol as solvent yield and product quality are significantly increased (Table 1, entry 9). When the corresponding sodium salt of the peroxide is used as reagent, the yield is slightly decreased, whereas the dye content increases because of the better solubility of the byproducts based on sodium sulfates. The strongly colored washings indicate that the sodium cations solubilize 4a to some extent by complex formation. Ammonium peroxo-

 Table 1
 Variation of the Oxidative Conditions to 4a

Entry	Method and conditions	Yield (%)	Dye content (%)
1	air, r.t., 30 d, darkness	_	_
2	air, r.t., 30 d, sunlight	traces	n.d.
3	H ₂ O ₂ , r.t., 24 h	3	n.d.
4	C ₄ H ₉ OOC ₄ H ₉ , r.t., 24 h	traces	n.d.
5	C ₄ H ₉ OOC ₄ H ₉ , 80 °C, 3 h	9	42
6	K ₂ S ₂ O ₈ , r.t., 24 h	34	45
7	K ₂ S ₂ O ₈ , 80 °C, 1.5 h	58	76
8	K ₂ S ₂ O ₈ , 97 °C, 1.5 h (propan-1-ol as solvent)	83	81
9	Na ₂ S ₂ O ₈ , 97 °C, 1.5 h (propan-1-ol as solvent)	79	89
10	anodic treatment ^b	7	n.d. ^c
11	(NH ₄) ₂ S ₂ O ₈ , 80 °C, 1.5 h	9	41

^a Consistent data by ¹H NMR assessment and microanalysis.
 ^b Platinum electrodes in an undivided cell, 2F, current density: 20 mA/

 cm^2 .

^c Very complex mixture.

sulfate gives at various reaction conditions the desired compound **4a** surprisingly only in low yield and with modest dye content (entry 11). With our experience in anodic treatment of phenols,^{20–24} we considered the electrochemical conversion as ideal because no reagent waste is produced. Unfortunately, the conversion in an undivided standard electrolysis cell²⁵ at platinum electrodes rendered a very complex reaction mixture (Table 1, entry 10).

Assessment of the dye content was carried out by combustion analysis.²⁶ This particular method is time-consuming and often not available, but required for UV/Vis characterization of a novel compound. We used alternatively NMR spectroscopy. In 5 wt% NaOD in D₂O compounds like 4a exhibit sufficient solubility to acquire NMR data. As internal standard sodium 3-trimethylsilyl-2,2,3,3- $[d_4]$ propionate was employed. If the NMR measurements are performed immediately after preparation of the sample the resulting dye content is in complete accordance to the combustion analysis or photometric determination. Due to slow degradation of the 2,6,7-trihydroxyxanthen-3-one system by hydroxide ions a continuously decreasing dye content is observed.²⁷ The significant advantages of this approach are the quick procedure and the additional structural information on the studied compounds.

Microscopic investigations on the crude **4a** reveal that the crystals of the desired compound are tightly bound to crystals of K_2SO_4 and KHSO₄, respectively. Extensive washings with water do not enhance the dye content significantly. Aqueous treatment of crude **4a** at elevated temperatures for a prolonged time in a Soxhlet apparatus can increase the dye content only unsatisfactorily. Since the

Entry	Aryl	Product	Yield (%)	Dye content
1	$\langle \rangle$	4b	59	98
2	F	4c	71	80
3	ci-	4d	74	97
4	Br	4e	81	92
5	Br	4f	97	87
6	0 ₂ N-	4g	65	81
7	но	4h	76	81
8	ноос	_4i	59	96
9	N	4j	53	75
10	Br OH	4k	86	92
11	СІ	41	73	86
12		4m	80	98
13		4n	96	98
14	ČČ	40	74	98

Table 2Scope of the Transformation

^a Consistent data by ¹H NMR assessment and microanalysis.

by-product from the preparation of **4a** mostly consists of KHSO₄ treatment with 0.1 equivalent of NaOH in water provides a purified residue with a dye content of 95%. If necessary, this seems to be the best way for purification of 9-aryl-substituted 2,6,7-trihydroxyxanthen-3-ones with an acceptable loss of about 15–22% of the dye material.

Various aromatic and heteroaromatic aldehydes were subjected to the same reaction conditions (Table 1, entry 7)



(%)^a





Scheme 3 Mesomeric structures of 4h

that have been identified for **4a**. Table 2 displays the generality of this protocol.

Conversion of benzaldehyde results in the compound known as Fluorone Black with excellent quality (Table 2, entry 1).²⁸ Substituents on the phenyl group such as halogens, nitro, hydroxy or carboxy moieties allow reliable transformations (entries 2-8). The 4-pyridylcarbaldehyde renders lower yield and dye content since 4j exhibits a similar affinity to the potassium salts as the structurally related 4a (entry 9). Halogen-substituted salicylaldehydes are also successful reaction partners in this transformation providing almost pure dye material in the crude precipitate (entries 10–12). Polycyclic aldehydes undergo the same reaction sequence, which is demonstrated by both the naphthyl derivatives (entries 13, 14). 9-Anthranylcarbaldehyde can be converted in the same manner, but the resulting product turned out to be completely insoluble, thereby preventing any unequivocal characterization.

The acquisition of NMR spectra in deuterated sodium hydroxide solution allows not only the assessment of the dye content but also the structural confirmation of the formed molecules **4**. Since no detailed NMR reference data were available for the 9-aryl-substituted 2,6,7-trihydroxyxan-then-3-ones we used HMQC and HMBC experiments to assign most of the NMR signals unequivocally. A complete set of data is given for **4a**. Especially, the ¹³C NMR signals of all 9-aryl-substituted 2,6,7-trihydroxyxanthen-3-ones **4** appear in well defined and narrow ranges for the chemical shifts and can therefore be used as model compounds of similar structures (Figure 1).

Significant variation in the 13 C NMR chemical shifts is found in position 9 where the different aryl substituents are attached and the adjacent positions 8a/9a (Table 3). The unusual different shifts for **4h** indicate the partial quinoide nature of the aryl moiety in position 9 (Scheme 3).

In conclusion, 9-aryl-substituted 2,6,7-trihydroxyxanthen-3-ones are reliably and easily synthesized when alkali peroxosulfates are employed. This method is applicable to a broad variety aromatic aldehydes and feasible on a

Table 3 ¹³C NMR Shift Ranges for 4

Entry	Position at xanthen-3one	Range of shifts (ppm)
1	C-1/C-8	104.40–104.83
2	C-2/C-7	162.09–162.93
3	C-3/C-6	176.98–177.79
4	C-4/C-5	107.13–108.78
5	C-4a/C-10a	154.13–154.91
6	C-8a/C-9a	115.50–117.57
7	C-9	(134.38) ^a 142.13–149.18

^a Data for 4h.

multimolar scale. The structural confirmation and assessment of the dye content can quickly be performed by NMR spectroscopy using $NaOD/D_2O$ and an internal standard.

All reagents used were analytical grades. Solvents were dried if necessary by standard methods. NMR spectra were recorded at 25 °C on a Bruker DPX 300 or DPX 400 spectrometer using sodium 3-trimethylsilyl-2,2,3,3- $[d_4]$ propionate as an internal standard. Chemical shifts (δ) are reported in parts per million (ppm) relative to internal standard and/or HDO signal of the deuterated solvent (15% NaOD in D₂O). ¹⁹F NMR shift refers to external calibration. Highresolution mass spectra were obtained on a FT-ICR APEX IV (Bruker, Karlsruhe, Germany) employing ESI techniques. Stock solutions of samples (1 mM) in 10% NaOH were prepared and diluted with MeOH to 50 μ M. UV/Vis spectra were recorded on a UV 2010 (Shimadzu, Japan) using 50 µM solutions in 10% NaOH as solvent. Microanalyses were determined on a Vario EL III (Elementaranalysensysteme, Hanau, Germany). The appearance of the products is described according to common color charts. Despite the crystalline nature of the products, defined melting points or decomposition points could not be determined <250 °C.

9-Aryl-2,6,7-trihydroxyxanthen-3-ones 4; General procedure

A round-bottomed flask equipped with a condenser and a mechanical stirrer was charged with 1,2,4-triacetoxybenzene (1; 5.00 g, 20 mmol) in 50% EtOH (75 mL). Concd H₂SO₄ (3 mL) was added and the white suspension was heated to reflux, resulting in a clear, honey-colored solution. To this boiling mixture was added dropwise the aldehyde 2 (10 mmol) within 2 min. The stirred mixture was kept at reflux for another 60 min. Subsequently, K₂S₂O₈ (2.70 g, 10 mmol) was added at 80 °C within a period of 50 min in small portions. The mixture turned from a brown solution into a viscous and dark colored suspension. The contents were brought to reflux for another 20 min and then poured onto ice water (1 L). The strongly colored fine crystals were collected by filtration under suction and thoroughly washed with distilled H₂O (ca. 100 mL). In order to minimize the salt content of the crude material, the filter cake had to be pressed during the filtration step and subsequent washings. The residue was dried under high vacuum (10^{-3} mbar) at 60 °C.

9-(3-Pyridyl)-2,6,7-trihydroxyxanthen-3-one (4a)

Crude material: 2.43 g; auburn-colored crystals; dye content: 76%; yield (corrected): 1.85 g (58%).

¹H NMR (400 MHz, NaOD/D₂O): δ = 5.64 (s, 2 H, H-4, H-5), 6.17 (s, 2 H, H-1, H-8), 7.11 (br, 1 H, H-16), 7.27 (br, 1 H, H-15), 7.88 (s, 1 H, H-12), 8.31 (s, 1 H, H-14).

¹³C NMR (100 MHz, NaOD/D₂O): δ = 104.80 (C-1, C-8), 107.24 (C-4, C-5), 116.34 (C-9a, C-8a), 126.45 (C-15), 134.32 (C-11), 141.22 (C-16), 142.13 (C-9), 150.82 (C-14), 151.11 (C-12), 154.13 (C-4a, C-10a), 162.50 (C-2, C-7), 177.31 (C-3, C-6).

HMBC NMR (100 MHz/400 MHz, NaOD/D₂O): δ (¹³C)/ δ (¹H) = 104.80 (C-1, C-8)/5.64 (H-4, H-5), 107.24 (C-4, C-5)/6.17 (H-1, H-8), 116.34 (C-9a, C-8a)/6.17 (H-1, H-8), 126.45 (C-15)/7.88 (H-12), 8.31 (H-14), 134.32 (C-11)/6.17 (H-1, H-8), 7.88 (H-12), 8.31 (H-14), 141.22 (C-16)/7.88 (H-12), 8.31 (H-14), 142.13 (C-9)/5.64 (H-4, H-5), 6.17 (H-1, H-8), 7.88 (H-12), 150.82 (C-14)/7.11 (H-16) 7.88 (H-12), 151.11 (C-12)/7.11 (H-16), 8.31 (H-14), 154.13 (C-4a, C-10a)/5.64 (H-4, H-5), 6.17 (H-1, H-8), 162.50 (C-2, C-7)/5.64 (H-4, H-5), 6.17 (H-1, H-8), 177.31 (C-3, C-6)/5.64 (H-4, H-5), 6.17 (H-1, H-8), 177.31 (C-3, C-6)/5.64 (H-4, H-5), 6.17 (H-1, H-8).

HRMS: m/z calcd for $C_{18}H_{10}NO_5 [M - H]^-$: 320.0564; found: 320.0559.

UV/Vis: $\lambda_{max} = 556.5 \text{ nm}$; $\epsilon (1/M^{-1} \text{ cm}) = 2.55 \cdot 10^4$.

9-Phenyl-2,6,7-trihydroxyxanthen-3-one (4b)

Crude material: 1.94 g; cadmium-red crystals; dye content: 98%; yield (corrected): 1.90 g (59%).

¹H NMR (300 MHz, NaOD/D₂O): δ = 6.08 (s, 2 H, H-4, H-5), 6.57 (s, 2 H, H-1, H-8), 7.19 (br, 1 H, H-14), 7.30 (br, 2 H, H-13, H-15), 7.53 (br, 2 H, H-12, H-16).

¹³C NMR (75 MHz, NaOD/D₂O): δ = 104.64 (C-1, C-8), 108.06 (C-4, C-5), 116.62 (C-9a, C-8a), 131.00 (C-12, C-16), 132.07 (C-13, C-15), 138.22 (C-14), 148.00 (C-9, C-11), 154.91 (C-4a, C-10a), 162.52 (C-2, C-7), 177.50 (C-3, C-6).

HRMS: m/z calcd for $C_{19}H_{11}O_5$ [M - H]⁻: 319.0612; found: 319.0615.

UV/Vis: $\lambda_{\text{max}} = 545.5 \text{ nm}, \epsilon (1/M^{-1} \text{ cm}): 3.24 \cdot 10^4.$

9-(4-Fluorophenyl)-2,6,7-trihydroxyxanthen-3-one (4c)

Crude material: 3.00 g; cadmium-red crystals; dye content: 80%; yield (corrected): 2.40 g (71%).

¹H NMR (300 MHz, NaOD/D₂O): δ = 5.87 (s, 2 H, H-4, H-5), 6.33 (s, 2 H, H-1, H-8), 6.93 (br, 2 H, H-13, H-15), 7.08 (br, 2 H, H-12, H-16).

 ^{13}C NMR (75 MHz, NaOD/D2O): δ = 104.40 (C-1, C-8), 107.64 (C-4, C-5), 116.26 (C-9a, C-8a), 117.45 (C-13, C-15), 133.62 (C-12, C-16), 133.73 (C-11), 146.42 (C-9), 154.25 (C-4a, C-10a), 162.12, 162.92 (C-2, C-7), 166.15 (C-14), 177.04 (C-3, C-6).

¹⁹F NMR (282 MHz, NaOD/D₂O): δ = -114.55.

HRMS: m/z calcd for $C_{19}H_{10}FO_5$ [M - H]⁻: 337.0518; found: 337.0511.

UV/Vis: $\lambda_{max} = 547.0 \text{ nm}$, $\epsilon (1/M^{-1} \text{ cm})$: $5.55 \cdot 10^4$.

9-(4-Chlorophenyl)-2,6,7-trihydroxyxanthen-3-one (4d)

Crude material: 2.72 g; cadmium-red crystals; dye content: 97%; yield (corrected): 2.64 g (74%).

¹H NMR (400 MHz, NaOD/D₂O): δ = 6.00 (s, 2 H, H-4, H-5), 6.49 (s, 2 H, H-1, H-8), 7.18 (br, 2 H, H-13, H-15), 7.49 (br, 2 H, H-12, H-16).

¹³C NMR (100 MHz, NaOD/D₂O): δ = 104.68 (C-1, C-8), 107.77 (C-4, C-5), 116.39 (C-9a, C-8a), 130.94 (C-12, C-16), 133.60 (C-13, C-15), 136.49, 136.51 (C-14, C-11), 146.26 (C-9), 154.56 (C-4a, C-10a), 162.48 (C-2, C-7), 177.42 (C-3, C-6).

HRMS: m/z calcd for $C_{19}H_{10}ClO_5$ [M – H]⁻: 353.0222; found: 353.0216.

UV/Vis: $\lambda_{max} = 550.0 \text{ nm}$, $\epsilon (1/M^{-1} \text{ cm})$: 4.57·10⁴.

9-(4-Bromophenyl)-2,6,7-trihydroxyxanthen-3-one (4e)

Crude material: 3.52 g; deep red crystals; dye content: 92%; yield (corrected): 3.24 g (81%).

¹H NMR (400 MHz, NaOD/D₂O): δ = 5.85 (s, 2 H, H-4, H-5), 6.36 (s, 2 H, H-1, H-8), 6.97 (d, *J* = 6.8 Hz, 2 H, H-12, H-16), 7.52 (d, *J* = 6.8 Hz, 2 H, H-13, H-15).

¹³C NMR (100 MHz, NaOD/D₂O): δ = 104.72 (C-1, C-8), 107.85 (C-4, C-5), 116.45 (C-9a, C-8a), 124.51 (C-14), 133.92, 134.05 (C-12, C-16), 137.09 (C-13, C-15), 146.42 (C-9, C-11), 154.78 (C-4a, C-10a), 162.57 (C-2, C-7), 177.53 (C-3, C-6).

HRMS: m/z calcd for $C_{19}H_{10}BrO_5$: $[M - H]^-$: 396.9717; found: 396.9714.

UV/Vis: $\lambda_{max} = 552.5$ nm, $\epsilon (1/M^{-1} \text{ cm})$: $6.50 \cdot 10^4$.

9-(2-Bromophenyl)-2,6,7-trihydroxyxanthen-3-one (4f)

Crude material: 4.47 g; burnt umber crystals; dye content: 87%; yield (corrected): 3.89 g (97%).

¹H NMR (400 MHz, NaOD/D₂O): δ = 5.65 (s, 2 H, H-4, H-5), 6.39 (s, 2 H, H-1, H-8), 6.97 (d, *J* = 6.9 Hz, 1 H, H-16), 7.22 (m, 1 H, H-15), 7.32 (m, 1 H, H-14), 7.59 (d, *J* = 7.9 Hz, 1 H, H-13).

¹³C NMR (100 MHz, NaOD/D₂O): δ = 104.82 (C-1, C-8), 107.48 (C-4, C-5), 116.45 (C-9a, C-8a), 124.75 (C-12), 130.40 (C-15), 132.80 (C-16), 133.62 (C-14), 135.20 (C-13), 139.16 (C-11), 145.96 (C-9), 154.84 (C-4a, C-10a), 162.82 (C-2, C-7), 177.79 (C-3, C-6).

HRMS: m/z calcd for $C_{19}H_{10}BrO_5$ [M – H]⁻: 396.9717; found: 396.9712.

UV/Vis: $\lambda_{\text{max}} = 556.5 \text{ nm}, \epsilon (1/M^{-1} \text{ cm}): 4.68 \cdot 10^4$.

9-(4-Nitrophenyl)-2,6,7-trihydroxyxanthen-3-one (4g)

Crude material: 2.94 g; dark red crystals; dye content: 81%; yield (corrected): 2.38 g (65%).

¹H NMR (400 MHz, NaOD/D₂O): δ = 5.89 (s, 2 H, H-4, H-5), 6.47 (s, 2 H, H-1, H-8), 7.35 (br, 2 H, H-12, H-16), 8.27 (br, 2 H, H-13, H-15).

¹³C NMR (100 MHz, NaOD/D₂O): δ = 104.83, 104.84 (C-1, C-8), 107.42, 107.43 (C-4, C-5), 115.97, 115.99 (C-9a, C-8a), 126.20 (C-13, C-15), 133.25, 133.28 (C-12, C-13), 144.47, 145.41 (C-9, C-11), 149.74 (C-14), 154.50, 154.51 (C-4a, C-10a), 162.65, 162.66 (C-2, C-7), 177.58 (C-3, C-6).

HRMS: m/z calcd for $C_{19}H_{10}NO_7$ [M – H]⁻: 364.0463; found: 364.0472.

UV/Vis: $\lambda_{max} = 552.5$ nm, $\epsilon (1/M^{-1} \text{ cm})$: $5.23 \cdot 10^4$.

9-(4-Hydroxyphenyl)-2,6,7-trihydroxyxanthen-3-one (4h)

Crude material: 3.14 g; auburn crystals; dye content: 81%; yield (corrected): 2.54 g (76%).

¹H NMR (400 MHz, NaOD/D₂O): δ = 6.44 (s, 2 H, H-4, H-5), 6.59 (s, 2 H, H-1, H-8), 6.78 (d, *J* = 8.4 Hz, 2 H, H-13, H-15), 7.15 (d, *J* = 8.4 Hz, 2 H, H-12, H-16).

¹³C NMR (100 MHz, NaOD/D₂O): δ = 104.65 (C-1, C-8), 109.01 (C-4, C-5), 116.71 (C-9a, C-8a), 120.81 (C-13, C-15), 123.47 (C-11), 134.38 (C-9), 150.38 (C-12, C-16), 154.82 (C-4a, C-10a), 162.16 (C-2, C-7), 169.72 (C-14), 176.98 (C-3, C-6).

HRMS: m/z calcd for $C_{19}H_{11}O_6$ [M – H]⁻: 335.0561; found: 335.0559.

UV/Vis: $\lambda_{\text{max}} = 549.5 \text{ nm}, \epsilon (1/M^{-1} \text{ cm}): 1.20 \cdot 10^4.$

9-(4-Carboxyphenyl)-2,6,7-trihydroxyxanthen-3-one (4i)

Crude material: 3.11 g; deep red crystals; dye content: 96%; yield (corrected): 2.15 g (59%).

¹H NMR (400 MHz, NaOD/D₂O): δ = 5.61 (s, 2 H, H-4, H-5), 6.11 (s, 2 H, H-1, H-8), 6.70 (d, *J* = 8.0 Hz, 2 H, H-12, H-16), 7.60 (d, *J* = 8.0 Hz, 2 H, H-13, H-15).

¹³C NMR (100 MHz, NaOD/D₂O): δ = 104.61 (C-1, C-8), 107.65 (C-4, C-5), 116.03 (C-9a, C-8a), 131.05 (C-12, C-16), 131.96 (C-13, C-15), 138.14 (C-14), 140.85 (C-11), 146.57 (C-9), 154.24 (C-4a, C-10a), 162.31 (C-2, C-7), 177.22 (C-17), 177.47 (C-3, C-6).

HRMS: m/z calcd for $C_{20}H_{11}O_7$ [M – H]⁻: 363.0510; found: 363.0495.

UV/Vis: $\lambda_{max} = 548.0 \text{ nm}, \epsilon (1/M^{-1} \text{ cm}): 5.28 \cdot 10^4$.

9-(4-Pyridyl)-2,6,7-trihydroxyxanthen-3-one (4j)

Crude material: 2.26 g; black crystals; dye content: 75%; yield (corrected): 1.69 g (53%).

¹H NMR (400 MHz, NaOD/D₂O): δ = 5.72 (s, 2 H, H-4, H-5), 6.28 (s, 2 H, H-1, H-8), 6.90 (d, *J* = 4.4 Hz, 2 H, H-12, H-16,), 8.42 (d, *J* = 4.4 Hz, 2 H, H-13, H-15).

¹³C NMR (100 MHz, NaOD/D₂O): δ = 104.81 (C-1, C-8), 107.13 (C-4, C-5), 115.50 (C-9a, C-8a), 127.51 (C-12, C-16), 143.02 (C-9), 147.60 (C-11), 151.33 (C-13, C-15), 154.39 (C-4a, C-10a), 162.68 (C-2, C-7), 177.58 (C-3, C-6).

HRMS: m/z calcd for $C_{18}H_{10}NO_5~[M-H]^-:$ 320.0564; found: 320.0551.

UV/Vis: $\lambda_{max} = 556.5 \text{ nm}, \epsilon (1/M^{-1} \text{ cm}): 4.47 \cdot 10^4.$

9-(5-Bromo-2-hydroxyphenyl)-2,6,7-trihydroxyxanthen-3-one (4k)

Crude material: 3.87 g; dark red crystals; dye content: 92%; yield (corrected): 3.56 g (86%).

¹H NMR (400 MHz, NaOD/D₂O): $\delta = 6.09$ (s, 2 H, H-4, H-5), 6.50 (s, 2 H, H-1, H-8), 6.53 (d, J = 8.8 Hz, 1 H, H-15), 6.96 (d, J = 2.7 Hz, 1 H, H-12), 7.23 (dd, J = 8.8, 2.7 Hz, 1 H, H-14).

 13 C NMR (100 MHz, NaOD/D₂O): δ = 104.37 (C-1, C-8), 105.90 (C-13), 108.74 (C-4, C-5), 117.52 (C-9a, C-8a), 124.11 (C-15), 130.38 (C-11), 134.64 (C-12), 134.75 (C-14), 149.00 (C-9), 154.77 (C-4a, C-10a), 162.09 (C-2, C-7), 166.50 (C-16), 177.37 (C-3, C-6).

HRMS: m/z calcd for $C_{19}H_{10}BrO_6$: $[M - H]^-$: 412.9666, found: 412.9663.

UV/Vis: $\lambda_{max} = 526.5 \text{ nm}$, $\epsilon (1/M^{-1} \text{ cm})$: 5.94·10⁴.

9-(5-Chloro-2-hydroxyphenyl)-2,6,7-trihydroxyxanthen-3-one (4l)

Crude material: 3.15 g; raw umber crystals; dye content: 86%; yield (corrected): 2.71 g (73%).

¹H NMR (400 MHz, NaOD/D₂O): $\delta = 6.14$ (s, 2 H, H-4, H-5), 6.55 (s, 2 H, H-1, H-8), 6.63 (d, J = 8.8 Hz, 1 H, H-15), 6.89 (d, J = 2.9 Hz, 1 H, H-12), 7.16 (dd, J = 8.8, 2.9 Hz, 1 H, H-14).

 ^{13}C NMR (100 MHz, NaOD/D₂O): δ = 104.41 (C-1, C-8), 108.78 (C-4, C-5), 117.57 (C-9a, C-8a), 119.13 (C-15), 123.44 (C-11), 129.61 (C-13), 131.87 (C-12, C-14), 149.18 (C-9), 154.82 (C-4a, C-10a), 162.11 (C-2, C-7), 166.03 (C-16), 177.38 (C-3, C-6).

HRMS: m/z calcd for $C_{19}H_{10}ClO_6$ [M - H]⁻: 369.0717; found: 369.0170.

UV/Vis: $\lambda_{max} = 521.5$ nm, $\epsilon (1/M^{-1} \text{ cm})$: 2.51·10³.

9-(3,5-Dichloro-2-hydroxyphenyl)-2,6,7-trihydroxyxanthen-3one (4m)

Crude material: 2.15 g; cadmium-red crystals; dye content: 98%; yield (corrected): 2.11 g (80%).

¹H NMR (400 MHz, NaOD/D₂O): δ = 5.99 (s, 2 H, H-4, H-5), 6.46 (s, 2 H, H-1, H-8), 6.72 (d, *J* = 2.7 Hz, 1 H, H-12,), 7.27 (d, *J* = 2.7 Hz, 1 H, H-14).

¹³C NMR (100 MHz, NaOD/D₂O): δ = 104.36 (C-1, C-8), 108.47 (C-4, C-5), 117.41 (C-9a, C-8a), 118.01 (C-15), 126.81 (C-11), 130.13 (C-12), 130.49 (C-13), 130.99 (C-14), 148.15 (C-9), 154.77 (C-4a, C-10a), 161.69 (C-16), 162.16 (C-2, C-7), 177.44 (C-3, C-6).

HRMS: m/z calcd for $C_{19}H_9Cl_2O_6$ [M – H]⁻: 402.9782; found: 402.9779.

UV/Vis: $\lambda_{max} = 528.5 \text{ nm}, \epsilon (1/M^{-1} \text{ cm}): 5.17 \cdot 10^4.$

9-(Naphthyl)-2,6,7-trihydroxyxanthen-3-one (4n)

Crude material: 3.62 g; scarlet-red crystals; dye content: 98%; yield (corrected): 3.54 g (96%).

¹H NMR (400 MHz, NaOD/D₂O): δ = 5.51 (s, 2 H, H-4, H-5), 6.40 (s, 2 H, H-4, H-5), 7.01 (br, 2 H, H-16, H-17), 7.09 (br, 1 H, H-12), 7.23 (br, 1 H, H-18), 7.42 (br, 1 H, H-13), 7.74 (d, *J* = 7.8 Hz, 1 H, H-14), 7.79 (d, *J* = 7.8 Hz, 1 H, H-15).

¹³C NMR (100 MHz, NaOD/D₂O): δ = 104.50 (C-1, C-8), 107.83 (C-4, C-5), 117.53 (C-9a, C-8a), 128.00 (C-12), 128.20 (C-18), 128.95 (C-13), 129.22 (C-16), 129.90 (C-17), 130.89 (C-14, C-15), 133.45 (C-18a), 135.40 (C-14a), 135.99 (C-11), 146.05 (C-9), 154.61 (C-4a, C-10a), 162.53 (C-2, C-7), 177.65 (C-3, C-6).

HRMS: m/z calcd for $C_{23}H_{13}O_5$ [M – H]⁻: 369.0768; found: 369.0777.

UV/Vis: $\lambda_{max} = 550.0 \text{ nm}, \epsilon (1/M^{-1} \text{ cm}): 6.20 \cdot 10^4.$

9-(Naphth-2-yl)-2,6,7-trihydroxyxanthen-3-one (40)

Crude material: 2.80 g; raw umber crystals; dye content: 98%; yield (corrected): 2.74 g (74%).

¹H NMR (400 MHz, NaOD/D₂O): δ = 6.03 (s, 2 H, H-4, H-5), 6.54 (s, 2 H, H-1, H-8), 7.34 (br, 1 H, H-12), 7.46 (br, 2 H, H-15, H-16), 7.72 (br, 1 H, H-13), 7.80 (br, 1 H, H-14), 7.88 (br, 1 H, H-17), 7.95 (br, 1 H, H-18).

¹³C NMR (100 MHz, NaOD/D₂O): δ = 104.71 (C-1, C-8), 108.14 (C-4, C-5), 116.70 (C-9a, C-8a), 129.43 (C-12, C-15), 130.19 (C-16, C-18), 131.04 (C-14), 134.93 (C-13, C-17), 135.70 (C-13a, C-17a), 147.48 (C-9, C-11), 154.74 (C-4a, C-10a), 162.39 (C-2, C-7), 177.36 (C-3, C-6).

HRMS: m/z calcd for $C_{23}H_{13}O_5$ [M – H]⁻: 369.0768; found: 369.0778.

UV/Vis: $\lambda_{max} = 549.0 \text{ nm}, \epsilon (1/M^{-1} \text{ cm}): 6.80 \cdot 10^4$.

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