Tetrahedron 65 (2009) 4099–4105

Contents lists available at ScienceDirect

Tetrahedron

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

Synthesis of polyketide-type phenols by domino 'Michael/retro-Michael/Aldol' reactions of 3-formylchromones with silyl enol ethers derived from ethyl 3,5-dioxohexanoate

Muhammad Adeel [a], Muhammad Nawaz [a], Alexander Villinger [a], Helmut Reinke [a], Christine Fischer [b], Peter Langer [a,b,*]

[a] Institut für Chemie, Universität Rostock, Albert-Einstein-Str. 3a, 18059 Rostock, Germany
[b] Leibniz-Institut für Katalyse e. V. an der Universität Rostock, Albert-Einstein-Str. 29a, 18059 Rostock, Germany

ARTICLE INFO

Article history:
Received 6 January 2009
Received in revised form 21 March 2009
Accepted 23 March 2009
Available online 1 April 2009

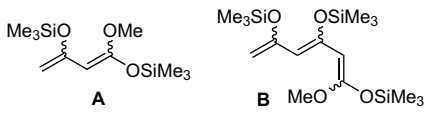
ABSTRACT

Highly functionalized polyketide-type phenols were prepared by domino 'Michael/retro-Michael/aldol' reactions of 3-formylchromones with 1-ethoxy-1,3,5-tris(trimethylsilyloxy)-1,3,5-hexatriene and its synthetic precursor, ethyl 3,5-bis(trimethylsilyloxy)-2,4-hexadienoate.

© 2009 Elsevier Ltd. All rights reserved.

1. Introduction

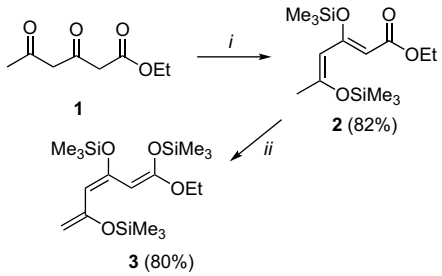
In recent years, several one-pot cyclization reactions of 1,3-bis(silyloxy)-1,3-butadienes, such as **A**,[1] have been reported (Scheme 1). This includes, for example, cyclizations with oxalyl chloride to give butenolides,[2] formal [3+3] cyclocondensations to give salicylates,[3] syntheses of 2-alkylidenetetrahydrofurans,[4] reactions with iminium salts,[5] and domino reactions with benzopyrylium triflates.[6] In contrast, reactions of 1,3,5-tris(silyloxy)-1,3,5-hexatrienes, such as **B**, have only scarcely been reported to date. Trienes **B** contain three rather than only two masked carbonyl groups. Chan and co-workers studied their reaction with acid chlorides to give polyketides, which spontaneously underwent an intramolecular aldol reaction to give hydroxylated arenes.[7] The cyclization of **B** with oxalyl chloride has also been reported.[8] Recently, we developed a new synthesis of 4-(2-hydroxybenzoyl)phenols by domino reaction of 1,3-bis(silyloxy)-1,3-butadienes with 3-formylchromones.[9] Herein, we report for the first time the application of this methodology to 1-ethoxy-1,3,5-tris(trimethylsilyloxy)-1,3,5-hexatriene and its synthetic precursor, ethyl 3,5-bis(trimethylsilyloxy)-2,4-hexadienoate. The domino reactions reported herein provide a convenient access to highly functionalized polyketide-type phenols, which are not readily available by other methods.



Scheme 1. Structure of 1,3-bis(silyloxy)-1,3-butadiene **A** and 1,3,5-tris(silyloxy)-1,3,5-hexatriene **B**.

2. Results and discussion

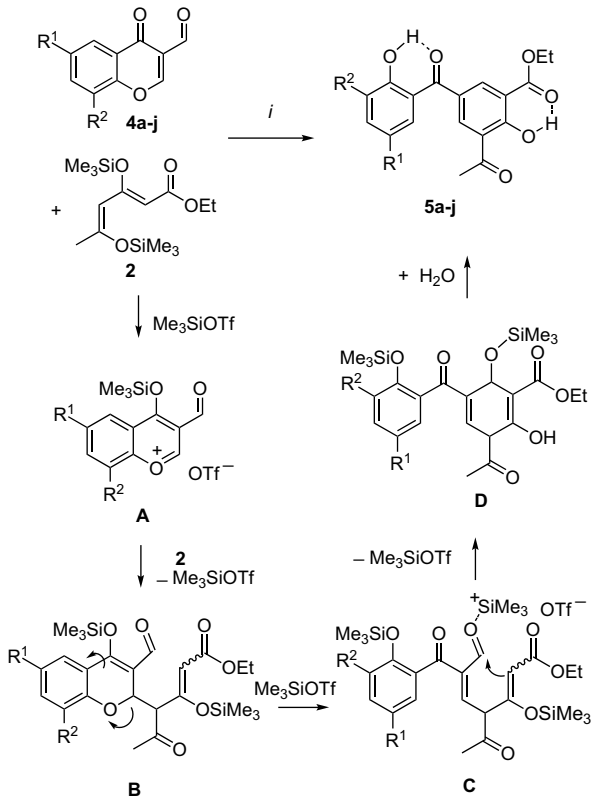
1,3,5-Tris(silyloxy)-1,3,5-hexatriene **3** was prepared, following the procedure reported for the synthesis of the methoxy derivative,[7] in two steps (Scheme 1). The silylation of ethyl 3,5-dioxohexanoate (**1**) gave ethyl 3,5-bis(trimethylsilyloxy)-2,4-hexadienoate (**2**). Deprotonation of the latter with LDA and subsequent addition of Me_3SiCl gave **3** in 80% overall yield (Scheme 2). The reaction of 1,3-bis(trimethylsilyloxy)-1,3-butadiene **2** with 3-formylchromones **4a–j** afforded the functionalized 4-(2-hydroxybenzoyl)phenols **5a–j** (Scheme 3, Table 1). The formation of the



Scheme 2. Synthesis of **3**: (i) Me_3SiCl (3.6 equiv), NEt_3 (3 equiv), C_6H_6, 20 °C, 72 h; (ii) (1) LDA (1.5 equiv), THF, −78 °C, 1 h; (2) Me_3SiCl (2.5 equiv), 20 °C, −78→20 °C.

* Corresponding author. Tel.: +49 381 4986410; fax: +49 381 4986412.
E-mail address: peter.langer@uni-rostock.de (P. Langer).

0040-4020/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tet.2009.03.070



Scheme 3. Synthesis of **5a–j**. Reagents and conditions: (i) (1) **4a–j** (1.0 equiv), Me_3SiOTf (0.3 equiv), 20 °C, 10 min; (2) **2** (1.3 equiv), CH_2Cl_2, 0→20 °C, 12 h; (3) HCl (10%).

Table 1
Synthesis of **5a–j**

4,5	R^1	R^2	Yield[a] (%)	δ[b] (O–H)
a	H	H	79	11.67, 12.62
b	Me	H	88	11.47, 12.62
c	Et	H	63	11.48, 12.64
d	*i*Pr	H	52	11.47, 12.65
e	NO_2	H	43	12.28, 12.70
f	Br	H	54	11.55, 12.66
g	Br	Br	56	12.10, 12.68
h	Cl	H	76	11.54, 12.65
i	Cl	Cl	80	11.93, 12.67
j	F	H	79	11.36, 12.63

[a] Yields of isolated products.
[b] Chemical shifts (^{1}H NMR, $CDCl_3$).

products can be explained by a domino 'Michael/retro-Michael/aldol' reaction: the reaction of **4a–j** with Me_3SiOTf gave pyrylium triflate **A**. The conjugate addition of the diene onto **A** afforded intermediate **B**, which underwent a retro-Michael reaction to give intermediate **C**. An aldol reaction of the latter gave intermediate **D**, which underwent an elimination of silanolate and aromatization (before or during the aqueous work-up) to give the final product. The best yields were obtained for products **5a**,**b**,**h–j**, which are derived from the chlorinated and fluorinated chromones **4h–j**, from parent formylchromone **4a** and from **4b**.

The structures of all products were established by spectroscopic methods. The structures of **5e**, **5h**, and **5j** were independently confirmed by X-ray crystal structure analyses (Figs. 1 and 2).[10] All products possess two low field signals (^{1}H NMR, $CDCl_3$) for the protons involved in intramolecular hydrogen bonds O–H···O.[11] The chemical shifts of the hydroxyl proton derived from the chromone moiety are found in the range of δ=11.36–12.10 ppm and strongly depend on the substitution pattern (Table 1). The most extreme downfield shift is observed for derivative **5e** (δ=12.28), due to the electron-withdrawing effect of the nitro group. Extreme low field

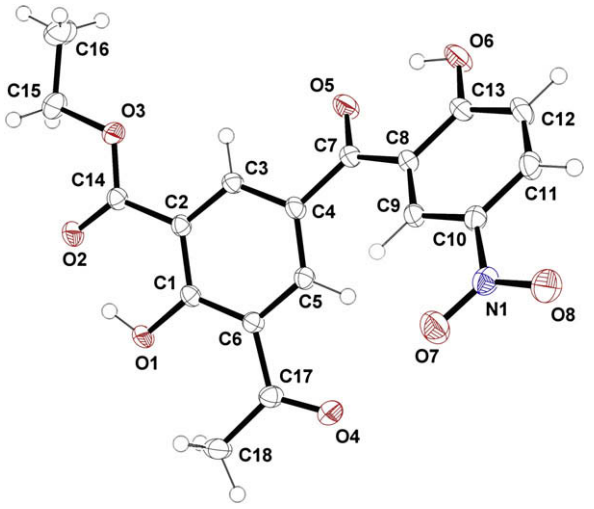


Figure 1. Ortep plot of **5e**.

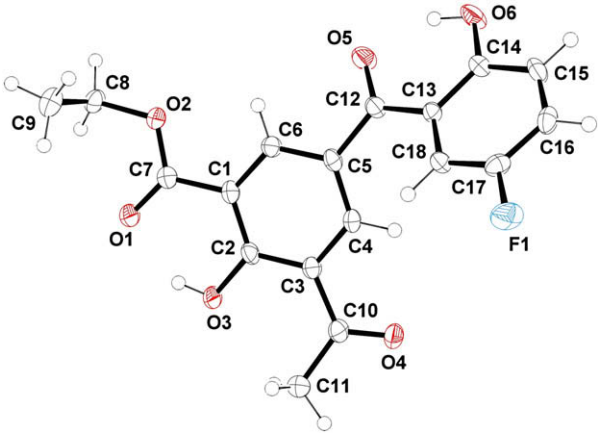
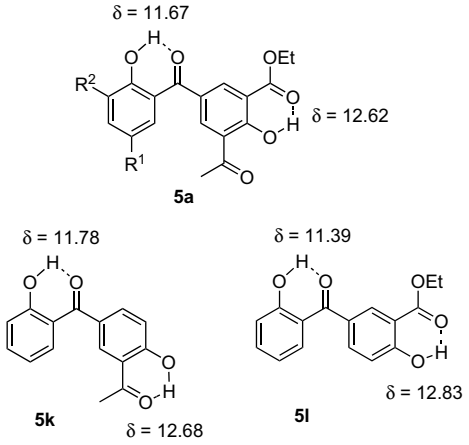


Figure 2. Ortep plot of **5j**.

shifts are observed also for compounds **5g** and **5i** containing two halogen atoms.

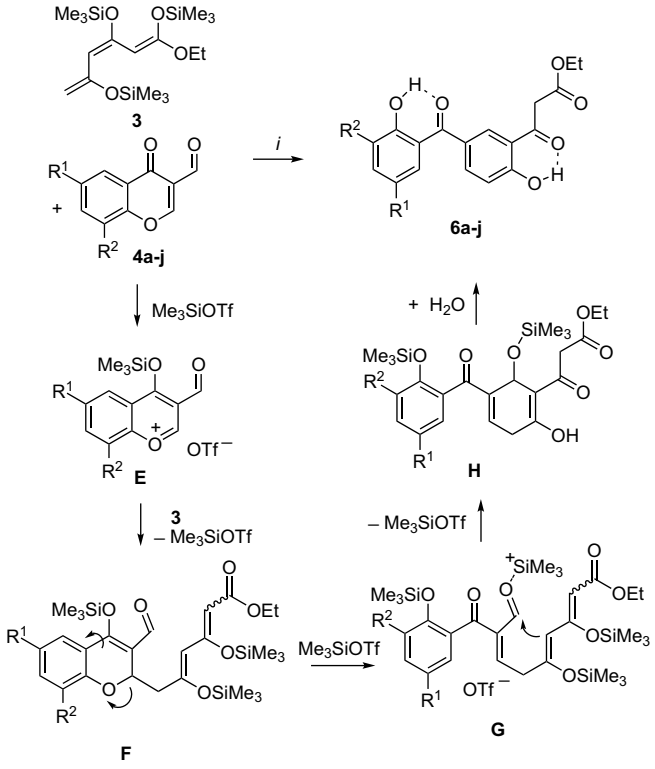
The signals of the hydroxyl protons of the second phenol moiety (which is derived from the diene **2**) are located in a rather narrow chemical shift range (δ=12.62–12.70 ppm). This can be explained by the fact that the substitution pattern of this phenol moiety is the same for all derivatives **5a–j**. The chemical shifts of the hydroxyl protons appear in the same range as earlier reported[9] for derivatives **5k** and **5l** (Scheme 4). It is worth to be noted that the



Scheme 4. Chemical shifts (^{1}H NMR) of OH protons of **5a**, **5k**, and **5l**.

hydroxyl proton may participate in a hydrogen bond either to the acetyl or the ester oxygen atom. In the solid state structures of **5e**, **5h**, and **5j**, the hydrogen bonds involve the ester group. However, the solution structures might be different. The comparison of the chemical shifts of the low field signals of **5a–j** with those of derivatives **5k** and **5l**, containing an acetyl and an ester group, do not allow to clearly distinguish the solution structure. However, the ester group is expected to be a better hydrogen bond acceptor than the keto group, which is in accordance with the structures observed in the solid state.

The cyclization of 3-formylchromones **4a–j** with 1,3,5-tris(silyloxy)-1,3,5-hexatriene **3** afforded the 4-(2-hydroxybenzoyl)-phenols **6a–j**, which represent regioisomers of **5a–j** (Scheme 5, Table 2). The cyclizations involve, as expected, the terminal carbon atom of the triene. The formation of phenols **6a–j**, which can be regarded as masked polyketides, can be explained by the mechanism depicted in Scheme 5. All products exist in their keto tautomeric form. The yields of **6a–j** are generally lower than the yields of **5a–j**. This can be explained by the unstable nature of triene **3**, which results in some decomposition and hydrolysis under the reaction conditions. In fact, a small amount of 3,5-dioxoester **1** was isolated as side-product in all reactions. Similar to products **5a** and **5i**, relatively good yields are obtained for **6a** and **6i**, which are derived from parent formylchromone **4a** and from dichlorinated formylchromone **4i**, respectively. Besides, the trends of the yields of products **5** and **6** are quite different from each other.



Scheme 5. Synthesis of **6a–j**. Reagents and conditions: (i) (1) **4a–j** (1.0 equiv), Me_3SiOTf (0.3 equiv), 20 °C, 10 min; (2) **3** (1.1 equiv), CH_2Cl_2, 0→20 °C, 12 h; (3) HCl (10%).

Table 2
Synthesis of **6a–j**

4,6	R^1	R^2	Yield[a] (%)	δ[b] (O–H)
a	H	H	43	11.63, 12.14
b	Me	H	36	11.60, 12.29
c	Et	H	45	11.60, 12.30
d	*i*Pr	H	47	11.59, 12.30
e	NO_2	H	30	12.30, 12.30
f	Br	H	31	11.56, 12.24
g	Br	Br	33	12.13, 12.27
h	Cl	H	37	11.63, 12.33
i	Cl	Cl	59	12.13, 12.27
j	F	H	34	11.39, 12.23

[a] Yields of isolated products.
[b] Chemical shifts (^{1}H NMR, $CDCl_3$).

Two low field signals, assigned to hydroxyl protons, are observed also for products **6a–j** (Table 2). The signals assigned to the chromone-derived hydroxyl protons are in the range of δ=11.39–12.20 ppm and again depend on the substitution pattern. In contrast, the signals of the other hydroxyl protons are found in a rather narrow range.

In conclusion, we have reported the synthesis of highly functionalized polyketide-type phenols by domino 'Michael/retro-Michael/aldol' reactions of 3-formylchromones with 1-ethoxy-1,3,5-tris(trimethylsilyloxy)-1,3,5-hexatriene and its synthetic precursor, ethyl 3,5-bis(trimethylsilyloxy)-2,4-hexadienoate. The products are not readily available by other methods.

3. Experimental section

3.1. General comments

All solvents were dried by standard methods and all reactions were carried out under an inert atmosphere. For ^{1}H and ^{13}C NMR spectra the deuterated solvents indicated were used. Mass spectrometric data (MS) were obtained by electron ionization (EI, 70 eV), chemical ionization (CI, H_2O) or electrospray ionization (ESI). For preparative scale chromatography, silica gel (60–200 mesh) was used. Melting points are uncorrected. Compounds **2a–c** are commercially available.

*3.1.1. Ethyl 3,5-bis(trimethylsiloxy)hexa-2,4-dienoate (**2**)*

To a stirred benzene solution (95 mL) of **1** (5.36 g, 31.16 mmol) was added triethylamine (13 mL, 93.6 mmol). After stirring for 2 h TMSCl (14.18 mL, 112.32 mmol) was added. After stirring for 72 h, the solvent was removed in vacuo and to the residue was added Hexane (50 mL) to give a suspension. The latter was filtered under argon atmosphere. The filtrate was distilled in vacuo to give **2** as yellow oil (8.10 g, 82%). ^{1}H NMR (250 MHz, $CDCl_3$): δ=0.14–0.21 (br s, 18H, CH_3), 1.16 (t, 3H, J=7.1 Hz, CH_3), 2.01 (s, 3H, CH_3), 4.01 (q, 2H, J=6.8 Hz, OCH_2), 5.71 (s, 1H, CH), 6.67 (s, 1H, CH); ^{13}C NMR (62.90 MHz, $CDCl_3$): δ=0.02–1.17 (6C, CH_3), 14.3 (CH_3), 21.57 (CH_3), 60.9 (OCH_2), 96.6, 103.5 (CH), 160.6, 165.0 (*C*OSi$(CH_3)_3$), 167.3 (C=O).

*3.1.2. 1,3,5-Tris (trimethylsiloxy)-1-ethoxyhexa-1,3,5-triene (**3**)*

Starting with LDA (38 mmol, 1.5 equiv), **2** (8 g, 25.30 mmol), TMSCl (8.0 mL, 63.25 mmol), and THF (45 mL), **3** was isolated as a yellow oil (7.80 g, 80%). ^{1}H NMR (250 MHz, $CDCl_3$): δ=0.11–0.43 (br s, 27H, CH_3), 1.14 (t, 3H, J=7.2 Hz, CH_3), 4.11 (q, 2H, J=7.0 Hz, OCH_2), 4.20 (s, 1H, CH), 4.51 (d, 1H, J=2 Hz, CH), 4.82 (s, 1H, CH), 5.57 (d, 1H, J=2 Hz, CH); ^{13}C NMR (62.90 MHz, $CDCl_3$): δ=0.05–1.23 (9C, CH_3), 14.0 (CH_3), 62.9 (OCH_2), 78.4 (CH), 92.1 (CH_2), 105.4 (CH), 153.0, 155.0, 158.7 (*C*OSi$(CH_3)_3$).

3.2. General procedure for the synthesis of 5a–j

To 3-formylchromones **4a–j** (1.0 equiv) was added Me_3SiOTf (0.3 equiv) at 20 °C. After stirring for 10 min CH_2Cl_2 (8 mL/mmol) was added, the solution was cooled to 0 °C, and the ethyl 3,5-bis(trimethylsiloxy)hexa-2,4-dienoate **2** (1.1 equiv) was added. The mixture was stirred for 12 h at 20 °C and was subsequently poured into an aqueous solution of hydrochloric acid (10%). The organic and the aqueous layer were separated and the latter was extracted with CH_2Cl_2 (3×80 mL). The combined organic layers were washed

with brine, dried (Na_2SO_4), filtered, and the filtrate was concentrated in vacuo. The residue was purified by column chromatography (silica gel, *n*-heptane/EtOAc=10:1).

3.2.1. Ethyl 3-acetyl-2-hydroxy-5-(2-hydroxybenzoyl)-benzoate (**5a**)

Starting with 3-formylchromone **4a** (261 mg, 1.5 mmol), 3,5-bis(silyl enol ether) **2** (521 mg, 1.65 mmol), and Me_3SiOTf (0.08 mL, 0.45 mmol), **5a** was isolated as a yellowish crystalline solid (390 mg, 79%), mp=111–113 °C; ^1H NMR (250 MHz, $CDCl_3$): δ=1.35 (t, 3H, J=6.6 Hz, CH_3), 2.66 (s, 3H, CH_3), 4.35 (q, 2H, J=7.8 Hz, OCH_2), 6.80 (t, 1H, J=8.5 Hz, ArH), 6.98 (d, 1H, J=9.6 Hz, ArH), 7.42–7.48 (m, 2H, ArH), 8.26 (d, 1H, J=2.8 Hz, ArH), 8.37 (d, 1H, J=3.4 Hz, ArH), 11.67 (s, 1H, OH), 12.62 (s, 1H, OH); ^{13}C NMR (62.90 MHz, $CDCl_3$): δ=14.1, 30.6 (CH_3), 62.3 (OCH_2), 115.6 (C), 118.6 (CH), 118.7 (C), 118.9 (CH), 125.3, 128.4 (C), 132.7, 136.5, 136.6, 137.3 (CH), 163.0 (C–OH), 164.2 (C=O), 168.3 (C–OH), 198.3, 199.0 (C=O); IR (neat): ν=3066 (w), 2985 (w), 2850 (w), 1737 (w), 1677 (s), 1624 (s), 1586 (s), 1483 (m), 1454 (m), 1174 (s), 760 (s) cm^{-1}; GC–MS (EI, 70 eV) m/z (%): 328 (M^+, 86), 282 (100), 254 (47), 239 (49), 211 (20), 121 (67); HRMS (EI) calcd for $C_{18}H_{16}O_6$ [M^+]: 328.09414, found: 328.093983.

3.2.2. Ethyl 3-acetyl-2-hydroxy-5-(2-hydroxy-5-methylbenzoyl)benzoate (**5b**)

Starting with 6-methyl-3-formylchromone **4b** (282 mg, 1.5 mmol), 3,5-bis(silyl enol ether) **2** (521 mg, 1.65 mmol), and Me_3SiOTf (0.08 mL, 0.45 mmol), **5b** was isolated as a yellow crystalline solid (450 mg, 88%), mp=124–126 °C. ^1H NMR (250 MHz, $CDCl_3$): δ=1.35 (t, 3H, J=7.7 Hz, CH_3), 2.19 (s, 3H, CH_3), 2.66 (s, 3H, CH_3), 4.35 (q, 2H, J=9.0 Hz, CH_2), 6.89 (d, 1H, J=7.7 Hz, ArH), 7.19–7.28 (m, 2H, ArH), 8.26 (d, 1H, J=2.2 Hz, ArH), 8.36 (d, 1H, J=2.3 Hz, ArH), 11.47 (s, 1H, OH), 12.62 (s, 1H, OH); ^{13}C NMR (62.90 MHz, $CDCl_3$): δ=14.1, 20.4, 30.6 (CH_3), 62.3 (OCH_2), 115.6 (C), 118.3 (CH), 118.4, 125.2, 128.1, 128.5 (C), 132.3, 136.9, 137.3, 137.6 (CH), 161.0 (C–OH), 164.2 (C=O), 168.3 (C–OH), 198.2, 199.1 (C=O); IR (neat): ν=2983 (w), 2992 (w), 2855 (w), 1737 (w), 1682 (s), 1662 (s), 1628 (s), 1583 (s), 1480 (m), 1455 (m), 1170 (s), 784 (s) cm^{-1}; GC–MS (EI, 70 eV) m/z (%): 342 (M^+, 77), 296 (100), 281 (18), 253 (41), 225 (17), 134 (48); HRMS (EI) calcd for $C_{19}H_{18}O_6$ [M^+]: 342.10979, found: 342.109773.

3.2.3. Ethyl 3-acetyl-5-(5-ethyl-2-hydroxybenzoyl)-2-hydroxybenzoate (**5c**)

Starting with 6-ethyl-3-formylchromone **4c** (303 mg, 1.5 mmol), 3,5-bis(silyl enol ether) **2** (521 mg, 1.65 mmol), and Me_3SiOTf (0.08 mL, 0.45 mmol), **5c** was isolated as yellowish oil (337 mg, 63%). ^1H NMR (250 MHz, $CDCl_3$): δ=1.12 (t, 3H, J=6.8 Hz, $3CH_3$), 1.35 (t, 3H, J=7.4 Hz, CH_3), 2.456 (q, 2H, J=8.1 Hz, CH_2), 2.66 (s, 3H, CH_3), 4.35 (q, 2H, J=7.4 Hz, OCH_2), 6.92 (d, 1H, J=7.4 Hz, ArH), 7.28–7.32 (m, 2H, ArH), 8.30 (d, 1H, J=3.3 Hz, ArH), 8.39 (d, 1H, J=1.6 Hz, ArH), 11.48 (s, 1H, OH), 12.64 (s, 1H, OH); ^{13}C NMR (62.90 MHz, $CDCl_3$): δ=14.1, 15.7 (CH_3), 27.9 (CH_2), 30.5 (CH_3), 62.3 (OCH_2), 115.5 (C), 118.4 (CH), 125.3, 128.4, 128.5 (C), 131.2 (CH), 134.6 (C), 136.5, 136.8, 137.5 (CH), 161.1 (C–OH), 164.2 (C=O), 168.2 (C–OH), 198.1, 199.1 (C=O); IR (neat): ν=2993 (w), 2966 (w), 2929 (w), 1737 (w), 1626 (m), 1584 (s), 1479 (m), 1322 (m), 1245 (s), 1169 (s), 1020 (s), 789 (s) cm^{-1}; GC–MS (EI, 70 eV) m/z (%): 356 (M^+, 74), 310 (100), 282 (22), 267 (37), 239 (15), 148 (49); HRMS (EI) calcd for $C_{20}H_{20}O_6$ [M^+]: 356.12544, found: 356.125099.

3.2.4. Ethyl 3-acetyl-2-hydroxy-5-(2-hydroxy-5-isopropylbenzoyl)benzoate (**5d**)

Starting with 6-isopropyl-3-formylchromone **4d** (324 mg, 1.5 mmol), 3,5-bis(silyl enol ether) **2** (521 mg, 1.65 mmol), and Me_3SiOTf (0.08 mL, 0.45 mmol), **5d** was isolated as a yellowish oil (329 mg, 59%). ^1H NMR (250 MHz, $CDCl_3$): δ=1.11 (d, 6H, J=7.0 Hz, $2CH_3$), 1.31 (t, 3H, J=7.2 Hz, CH_3), 2.66 (s, 3H, CH_3), 2.78 (m,1H, CH), 4.34 (q, 2H, J=7.6 Hz, OCH_2), 6.92 (d, 1H, J=8.6 Hz, ArH), 7.30–7.36 (m, 2H, ArH), 8.32 (d, 1H, J=2.5 Hz, ArH), 8.40 (d, 1H, J=2.5 Hz, ArH), 11.47 (s, 1H, OH), 12.65 (s, 1H, OH); ^{13}C NMR (62.90 MHz, $CDCl_3$): δ=14.1 (CH_3), 23.9 (2C, CH_3), 30.4 (CH_3), 33.14 (CH), 62.3 (OCH_2), 115.6 (C), 118.3 (CH), 125.3, 128.3, 128.4 (C), 129.8, 135.2, 136.9, 137.6 (CH), 139.2 (C), 161.1 (C–OH), 164.3 (C=O), 168.2 (C–OH), 198.0, 199.1 (C=O); IR (neat): ν=3067 (w), 2960 (w), 2928 (w), 2871 (w), 1731 (w), 1674 (s), 1628 (s), 1584 (s), 1480 (m), 1453 (m), 1176 (s), 788 (s) cm^{-1}; GC–MS (EI, 70 eV) m/z (%): 370 (M^+, 81), 324 (100), 309 (90), 281 (26), 162 (26), 147 (93); HRMS (EI) calcd for $C_{21}H_{22}O_6$ [M^+]: 370.14109, found: 370.140795.

3.2.5. Ethyl 3-acetyl-5-(5-nitro-2-hydroxybenzoyl)-2-hydroxybenzoate (**5e**)

Starting with 6-nitro-3-formylchromone **4e** (138 mg, 0.63 mmol), 3,5-bis(silyl enol ether) **2** (218 mg, 0.69 mmol), and Me_3SiOTf (0.03 mL, 0.18 mmol), **5e** was isolated as a crystalline solid (100 mg, 43%), mp=107–109 °C. ^1H NMR (250 MHz, $CDCl_3$): δ=1.36 (t, 3H, J=7.0 Hz, CH_3), 2.68 (s, 3H, CH_3), 4.40 (q, 2H, J=8.1 Hz, CH_2), 7.11 (d, 1H, J=8.9 Hz, ArH), 8.31–8.35 (m, 2H, ArH), 8.40 (d, 1H, J=2.1 Hz, ArH), 8.45 (d, 1H, J=2.6 Hz, ArH), 12.28 (s, 1H, OH), 12.70 (s, 1H, OH); ^{13}C NMR (62.90 MHz, $CDCl_3$): δ=14.1, 30.7 (CH_3), 62.6 (OCH_2), 115.8, 117.6 (C), 119.7 (CH), 126.1, 126.9 (C), 128.7, 131.0, 136.4, 137.4 (CH), 139.58 (C), 164.9 (C–OH), 167.7 (C=O), 168.2 (C–OH), 197.2, 198.4 (C=O); IR (neat): ν=3074 (w), 2990 (w), 2914 (m), 1731 (m), 1667 (s), 1620 (s), 1446 (s), 1331 (s), 1175 (s), 749 (s) cm^{-1}; GC–MS (EI, 70 eV): m/z (%): 373 (M^+, 35), 327 (82), 312 (100), 299 (43), 189 (16), 166 (20), 135 (41); HRMS (EI) calcd for $C_{18}H_{15}NO_8$ [M^+]: 373.07922, found: 373.078896.

3.2.6. Ethyl 3-acetyl-5-(5-bromo-2-hydroxybenzoyl)-2-hydroxybenzoate (**5f**)

Starting with 6-bromo-3-formylchromone **4f** (253 mg, 1.0 mmol), 3,5-bis(silyl enol ether) **2** (348 mg, 1.1 mmol), and Me_3SiOTf (0.05 mL, 0.3 mmol), **5f** was isolated as a crystalline solid (219 mg, 54%), mp=118–120 °C. ^1H NMR (250 MHz, $CDCl_3$): δ=1.37 (t, 3H, J=7.1 Hz, CH_3), 2.68 (s, 3H, CH_3), 4.40 (q, 2H, J=7.1 Hz, OCH_2), 6.91 (d, 1H, J=8.4 Hz, ArH), 7.51–7.57 (m, 2H, ArH), 8.27 (d, 1H, J=2.6 Hz, ArH), 8.36 (d, 1H, J=3.6 Hz, ArH), 11.55 (s, 1H, OH), 12.66 (s, 1H, OH); ^{13}C NMR (62.90 MHz, $CDCl_3$): δ=14.1, 30.6 (CH_3), 62.4 (OCH_2), 110.5, 115.7, 120.0 (C), 120.7 (CH), 125.6, 127.7 (C), 134.6, 136.6, 137.3, 139.1 (CH), 161.9 (C–OH), 164.5 (C=O), 168.2 (C–OH), 197.2, 198.8 (C=O); IR (neat): ν=3072 (w), 2942 (w), 2929 (w), 1731 (w), 1673 (s), 1627 (s), 1586 (s), 1462 (m), 1446 (s), 1407 (s), 1316 (s), 1174 (s) cm^{-1}; GC–MS (EI, 70 eV) m/z (%): 408 (M^+, ^{81}Br, 48), 406 (M^+, ^{79}Br, 46), 362 (98), 360 (100), 345 (22), 334 (28), 332 (24), 317 (30), 201 (43); HRMS (EI) calcd for $C_{18}H_{15}BrO_6$ [M^+, ^{79}Br]: 406.00465, found 406.003581.

3.2.7. Ethyl 3-acetyl-5-(3,5-dibromo-2-hydroxybenzoyl)-2-hydroxybenzoate (**5g**)

Starting with 6,8-dibromo-3-formylchromone **4g** (331 mg, 1.0 mmol), 3,5-bis(silyl enol ether) **2** (348 mg, 1.1 mmol), and Me_3SiOTf (0.05 mL, 0.3 mmol), **5g** was isolated as a crystalline solid (219 mg, 56%), mp=139–141 °C. ^1H NMR (250 MHz, $CDCl_3$): δ=1.37 (t, 3H, J=7.1 Hz, CH_3), 2.67 (s, 3H, CH_3), 4.40 (q, 2H, J=7.1 Hz, OCH_2), 7.55 (d, 1H, J=2 Hz, ArH), 7.83 (d, 1H, J=2.3 Hz, ArH), 8.27 (d, 1H, J=2.3 Hz, ArH), 8.36 (d, 1H, J=2 Hz, ArH), 12.10 (s, 1H, OH), 12.68 (s, 1H, OH); ^{13}C NMR (62.90 MHz, $CDCl_3$): δ=14.1, 30.6 (CH_3), 62.5 (OCH_2), 110.5, 113.5, 115.7, 120.5, 125.8, 127.2 (C), 133.8, 136.6, 137.4, 141.4 (CH), 158.4 (C–OH), 164.8 (C=O), 168.2 (C–OH), 196.8, 198.5 (C=O); IR (neat): ν=3079 (w), 3062 (w), 2994 (w), 1731 (w), 1669 (s), 1622 (s), 1587 (s), 1434 (m), 1414 (s), 1247 (s), 1159 (s), 787 (s) cm^{-1}; GC–MS (EI, 70 eV) m/z (%): 488 (M^+, [2×^{81}Br], 12), 486 (M^+, [$^{81}Br^{79}Br$], 25), 484 (M^+, [2×^{79}Br],12), 442 (48), 440 (100), 412

(23), 279 (18), 189 (36). HRMS (EI) calcd for $C_{18}H_{14}Br_2O_6$ [M^+, $2\times^{79}Br$]: 483.91516, found: 483.915551.

3.2.8. Ethyl 3-acetyl-5-(5-chloro-2-hydroxybenzoyl)-2-hydroxybenzoate (**5h**)

Starting with 6-chloro-3-formylchromone **4h** (208 mg, 1.0 mmol), 3,5-bis(silyl enol ether) **2** (348 mg, 1.1 mmol), and Me_3SiOTf (0.05 mL, 0.3 mmol), **5h** was isolated as a crystalline solid (279 mg, 76%), mp=124–125 °C. ^1H NMR (250 MHz, $CDCl_3$): δ=1.37 (t, 3H, J=7.2 Hz, CH_3), 2.68 (s, 3H, CH_3), 4.40 (q, 2H, J=8.4 Hz, CH_2), 6.96 (d, 1H, J=9.8 Hz, ArH), 7.39–7.42 (m, 2H, ArH), 8.27 (d, 1H, J=2.4 Hz, ArH), 8.36 (d, 1H, J=2.4 Hz, ArH), 11.54 (s, 1H, OH), 12.65 (s, 1H, OH); ^{13}C NMR (75.46 MHz, $CDCl_3$): δ=14.1, 30.7 (CH_3), 62.5 (OCH_2), 115.3, 119.4 (C), 120.3 (CH), 123.7, 127.8, 127.9 (C), 131.5, 136.4, 136.5, 137.2 (CH), 161.5 (C–OH), 164.5 (C=O), 168.2 (C–OH), 197.3, 198.3 (C=O); IR (neat): ν=3077 (w), 3005 (w), 2938 (w), 1738 (w), 1672 (s), 1622 (s), 1587 (s), 1455 (s), 1409 (s), 1318 (s), 1175 (s), 780 (s) cm^{-1}; GC–MS (EI, 70 eV): m/z (%): 364 (M^+, ^{37}Cl, 17), 362 (M^+, ^{35}Cl, 54), 316 (100), 301 (26), 273 (28), 245 (13), 189 (16), 155 (31); HRMS (EI) calcd for $C_{18}H_{15}ClO_6$ [M^+, ^{35}Cl]: 362.05517, found: 362.054803.

3.2.9. Ethyl 3-acetyl-5-(3,5-dichloro-2-hydroxybenzoyl)-2-hydroxybenzoate (**5i**)

Starting with 6,8-dichloro-3-formylchromone **4i** (243 mg, 1.0 mmol), 3,5-bis(silyl enol ether) **2** (348 mg, 1.1 mmol), and Me_3SiOTf (0.05 mL, 0.3 mmol), **5i** was isolated as a light yellow solid (320 mg, 80%), mp=145–146 °C. ^1H NMR (300 MHz, $CDCl_3$): δ=1.34 (t, 3H, J=7.02 Hz, CH_3), 2.66 (s, 3H, CH_3), 4.37 (q, 2H, J=7.3 Hz, OCH_2), 7.35 (d, 1H, J=2.3 Hz, ArH), 7.53 (d, 1H, J=2.7 Hz, ArH), 8.26 (d, 1H, J=1.95 Hz, ArH), 8.36 (d, 1H, J=2.7 Hz, ArH), 11.93 (s, 1H, OH), 12.67 (s, 1H, OH); ^{13}C NMR (75.46 MHz, $CDCl_3$): δ=14.1, 30.6 (CH_3), 62.5 (OCH_2), 110.5, 113.5, 115.7, 120.5, 125.8, 127.2 (C), 133.8, 136.6, 137.4, 141.4 (CH), 158.4 (C–OH), 164.8 (C=O), 168.2 (C–OH), 196.8, 198.5 (C=O); IR (neat): ν=3070 (w), 2996 (w), 2979 (w), 1671 (s), 1626 (s), 1590 (s), 1448 (m), 1418 (s), 1249 (s), 1163 (s), 789 (s) cm^{-1}; MS (EI, 70 eV) m/z (%): 400 (M^+, [$2\times^{37}Cl$], 3), 398 (M^+, [$^{37}Cl^{35}Cl$], 21), 396 (M^+, [$2\times^{35}Cl$],33), 353 (14), 350 (100), 337 (11), 279 (6), 189 (8). HRMS (EI) calcd for $C_{18}H_{14}Cl_2O_6$ [M^+, $2\times^{35}Cl$]: 396.01620, found: 396.015936.

3.2.10. Ethyl 3-acetyl-5-(5-fluoro-2-hydroxybenzoyl)-2-hydroxybenzoate (**5j**)

Starting with 6-fluoro-3-formylchromone **4j** (192 mg, 1.0 mmol), 3,5-bis(silyl enol ether) **2** (348 mg, 1.1 mmol), and Me_3SiOTf (0.05 mL, 0.3 mmol), **5j** was isolated as a crystalline solid (270 mg, 79%), mp=111–112 °C. ^1H NMR (250 MHz, $CDCl_3$): δ=1.36 (t, 3H, J=6.5 Hz, CH_3), 2.66 (s, 3H, CH_3), 4.36 (q, 2H, J=9.1 Hz, CH_2), 6.95–7.00 (m, 1H, ArH), 7.10–7.24 (m, 2H, ArH), 8.26 (d, 1H, J=2.5 Hz, ArH), 8.35 (d, 1H, J=2.5 Hz, ArH), 11.36 (s, 1H, OH), 12.63 (s, 1H, OH); ^{13}C NMR (62.90 MHz, $CDCl_3$): δ=14.1, 30.7 (CH_3), 62.4 (OCH_2), 115.6 (C), 117.2, 119.9, 123.9 (CH), 125.6, 127.9 (C), 136.4, 137.2 (CH), 152.7, 156.5 (C), 159.1 (C–OH), 164.4 (C=O), 168.3 (C–OH), 197.3, 198.7 (C=O); IR (neat): ν=3078 (w), 3008 (w), 2928 (w), 1737 (w), 1668 (s), 1591 (s), 1468 (s), 1420 (s), 1318 (s), 1241 (s), 783 (s) cm^{-1}; GC–MS (EI, 70 eV) m/z (%): 346 (M^+, 56), 300 (100), 272 (32), 257 (37), 229 (16), 189 (13); HRMS (EI) calcd for $C_{18}H_{15}FO_6$ [M^+]: 346.08471, found: 346.0084999.

3.3. General procedure for the synthesis of 6a–j

To 3-formylchromones **4a–j** (1.0 equiv) was added Me_3SiOTf (0.3 equiv) at 20 °C. After stirring for 10 min CH_2Cl_2 (8 mL/mmol) was added, the solution was cooled to 0 °C, and the 1,3,5-tris (trimethylsiloxy)-1-ethoxyhexa-1,3,5-triene **3** (1.1 equiv) was added. The mixture was stirred for 12 h at 20 °C and was subsequently poured into an aqueous solution of hydrochloric acid (10%). The organic and the aqueous layer were separated and the latter was extracted with CH_2Cl_2 (3×80 mL). The combined organic layers were washed with brine, dried (Na_2SO_4), filtered, and the filtrate was concentrated in vacuo. The residue was purified by column chromatography (silica gel, n-heptane/EtOAc=10:1).

3.3.1. Ethyl 3-(2-hydroxy-5-(2-hydroxybenzoyl)phenyl)-3-oxopropanoate (**6a**)

Starting with 3-formylchromone **4a** (261 mg, 1.5 mmol), 1,3,5-tris(silyl enol ether) **3** (641 mg, 1.65 mmol), and Me_3SiOTf (0.08 mL, 0.45 mmol), **6a** was isolated as a highly viscous oil (210 mg, 43%). ^1H NMR (300 MHz, $CDCl_3$): δ=1.13 (t, 3H, J=6.78 Hz, CH_3), 3.91 (s, 2H, CH_2), 4.08 (q, 2H, J=7.56 Hz, CH_2), 6.7 (m, 1H, ArH), 6.9 (t, 1H, J=7.98 Hz, ArH), 7.38 (m, 2H, ArH), 7.76 (d, 1H, J=2.0 Hz, ArH), 7.79 (d, J=2.67 Hz, 1H, ArH), 8.00 (d, J=3.72 Hz, 1H, ArH), 11.63 (s, 1H, OH), 12.14 (s, 1H, OH); ^{13}C NMR (62.89 MHz, $CDCl_3$): δ=14.0 (CH_3), 45.7 (CH_2), 61.9 (OCH_2), 118.4, 118.6, 118.81, 118.85 (CH), 129.03, 132.73, 132.97 (CH), 132.97, 136.39, 137.84 (C), 163.04, 165.70 (COH), 166.41, 166.43, 198.5 (C=O); IR (neat): ν=3042 (w), 2980 (w), 2872 (w), 1734 (s), 1681 (s), 1584 (s), 1479 (s), 1352 (s), 1290 (s), 1183 (s), 794 (s) cm^{-1}; ESI^+-MS (ESI-TOF/MS) m/z (%): 351.08 [M+Na]$^+$ calcd for $C_{18}H_{16}O_6$ [M^+], found: 328.09469.

3.3.2. Ethyl 3-(2-hydroxy-5-(2-hydroxy-5-methylbenzoyl)phenyl)-3-oxopropanoate (**6b**)

Starting with 6-methyl-3-formylchromone **4b** (282 mg, 1.5 mmol), 1,3,5-tris(silyl enol ether) **3** (641 mg, 1.65 mmol), and Me_3SiOTf (0.08 mL, 0.45 mmol), **6b** was isolated as a yellow solid (186 mg, 36%), mp=81–84 °C; ^1H NMR (250 MHz, $CDCl_3$): δ=1.31 (t, 3H, J=7.1 Hz, CH_3), 2.32 (s, 3H, CH_3), 4.07 (s, 2H, CH_2), 4.25 (q, 2H, J=7.1 Hz, CH_2), 7.06 (d, 1H, J=9.0 Hz, ArH), 7.13 (d, 1H, J=9.0 Hz, ArH), 7.36 (m, 2H, ArH), 7.89 (dd, 1H, J=2.0, 8.7 Hz, ArH), 8.16 (d, 1H, J=2.0 Hz, ArH), 11.60 (s, 1H, OH), 12.29 (s, 1H, OH); ^{13}C NMR (75.46 MHz, $CDCl_3$): δ=14.0, 20.4 (CH_3), 45.7 (CH_2), 61.9 (OCH_2), 118.3 (CH), 118.4, 118.5 (C), 118.7 (CH), 128.0, 129.2 (C), 132.4, 132.9 (CH), 136.7, 137.8 (CH), 161.0, 165.6 (COH), 166.4, 198.3, 198.5 (C=O); IR (neat): ν=2970 (w), 2930 (w), 2859 (w), 1726 (s), 1630 (s), 1587 (s), 1479 (s), 1324 (s), 1207 (s), 1170 (s), 785 (s) cm^{-1}; GC–MS (EI, 70 eV) m/z (%): 342 (M^+, 86), 296 (100), 281 (23), 268 (31), 253 (48), 225 (19), 189 (12), 134 (45); HRMS (EI) calcd for $C_{19}H_{18}O_6$ [M^+]: 342.10979, found: 342.109866.

3.3.3. Ethyl 3-(5-(5-ethyl-2-hydroxybenzoyl)-2-hydroxyphenyl)-3-oxopropanoate (**6c**)

Starting with 6-ethyl-3-formylchromone **4c** (303 mg, 1.5 mmol), 1,3,5-tris(silyl enol ether) **3** (641 mg, 1.65 mmol), and Me_3SiOTf (0.08 mL, 0.45 mmol), **6c** was isolated as a yellowish brown solid (240 mg, 45%), mp=55–58 °C. ^1H NMR (250 MHz, $CDCl_3$): δ=1.22 (t, 3H, J=7.5 Hz CH_3), 1.30 (t, 3H, J=7.1 Hz, CH_3), 2.456 (q, 2H, J=8.1 Hz, CH_2), 4.05 (s, 2H, CH_2), 4.12 (q, 2H, J=6.0 Hz, OCH_2), 7.03 (d, 1H, J=8.3 Hz, ArH), 7.13 (d, 1H, J=8.7 Hz, ArH), 7.39–7.7.43 (m, 2H, ArH), 7.90 (dd, 1H, J=1.9, 8.7 Hz, ArH), 8.16 (d, 1H, J=1.95 Hz, ArH), 11.60 (s, 1H, OH), 12.30 (s, 1H, OH); ^{13}C NMR (62.90 MHz, $CDCl_3$): δ=14.0, 15.7 (CH_3), 27.9, 45.6 (CH_2), 61.9 (OCH_2), 118.4 (CH), 118.4, 118.5 (C), 118.7 (CH), 129.2 (C), 131.3, 132.9 (CH), 134.6 (C), 136.3, 137.8 (CH), 161.1, 165.6 (COH), 166.4, 198.1, 198.5 (C=O); IR (neat): ν=2963 (m), 2930 (m), 1735 (m), 1680 (w), 1628 (s), 1583 (s), 1479 (s), 1352 (m), 1285 (s), 1201 (s), 832 (m) cm^{-1}; GC–MS (EI, 70 eV): m/z (%): 356 (M^+, 30), 310 (75), 267 (17), 241 (12), 148 (100), 133 (62), 84 (23); HRMS (EI) calcd for $C_{20}H_{20}O_6$ [M^+]: 356.12544, found: 356.125284.

3.3.4. Ethyl 3-(2-hydroxy-5-(2-hydroxy-5-isopropylbenzoyl)-phenyl)-3-oxopropanoate (**6d**)

Starting with 6-isopropyl-3-formylchromone **4d** (324 mg, 1.5 mmol), 1,3,5-tris(silyl enol ether) **3** (641 mg, 1.65 mmol), and

Me_3SiOTf (0.08 mL, 0.45 mmol), **6d** was isolated as a yellow solid (260 mg, 47%), mp=60–63 °C; ^1H NMR (250 MHz, $CDCl_3$): δ=1.22–1.32 (m, 9H, $3CH_3$), 2.88 (m,1H, CH), 4.07 (s, 2H, CH_2), 4.25 (q, 2H, J=7.2 Hz, OCH_2), 7.04 (d, 1H, J=8.6 Hz, ArH), 7.14 (d, 1H, J=8.6 Hz, ArH), 7.40–7.48 (m, 2H, ArH), 7.90 (dd, 1H, J=2.0, 8.8 Hz, ArH), 8.17 (d, 1H, J=2.1 Hz, ArH), 11.59 (s, 1H, OH), 12.30 (s, 1H, OH); ^{13}C NMR (75.46 MHz, $CDCl_3$): δ=14.1, 23.9, 24.0 (CH_3), 33.1 (CH), 45.7 (CH_2), 61.9 (OCH_2), 118.3 (C), 118.4 (CH), 118.5 (C), 118.7 (CH), 129.2 (C), 129.9, 132.9, 134.9, 137.8 (CH), 139.2 (C), 161.1, 165.6 (COH), 166.3, 198.5, 198.5 (C=O); IR (neat): ν=3058 (w), 2956 (m), 2924 (m), 1744 (s), 1681 (w), 1653 (m), 1628 (s), 1583 (s), 1480 (s), 1343 (m), 1207 (s), 1181 (s), 832 (s) cm^{-1}; GC–MS (EI, 70 eV) m/z (%): 370 (M^+, 77), 324 (53), 309 (78), 283 (17), 267 (23), 162 (46), 147 (100), 44 (37); HRMS (EI) calcd for $C_{21}H_{22}O_6$ [M^+]: 370.14109, found: 370.140462.

3.3.5. Ethyl 3-(2-hydroxy-5-(2-hydroxy-5-nitrobenzoyl)phenyl)-3-oxopropanoate (6e)

Starting with 6-nitro-3-formylchromone **4e** (328 mg, 1.5 mmol), 1,3,5-tris(silyl enol ether) **3** (641 mg, 1.65 mmol), and Me_3SiOTf (0.08 mL, 0.45 mmol), **6e** was isolated as a yellow solid (160 mg, 29%), mp=130–133 °C. ^1H NMR (300 MHz, $CDCl_3$): δ=1.19 (t, 3H, J=7.1 Hz, CH_3), 3.96 (s, 2H, CH_2), 4.25 (q, 2H, J=7.1 Hz, OCH_2), 7.10 (m, 2H, ArH), 7.36 (m, 2H, ArH), 7.84 (dd, 1H, J=2.1, 8.7 Hz, ArH), 8.14 (d, J=2.0 Hz, 1H, ArH), 8.30 (m, 1H, ArH), 12.30 (br, 2H, OH); ^{13}C NMR (75.47 MHz, $CDCl_3$): δ=14.0 (CH_3), 45.9 (CH_2), 62.1 (OCH_2), 117.6, 118.7 (C), 119.5, 119.7, 128.8, 129.4, 130.8, 133.5 (CH), 137.5, 139.5 (C), 166.1, 166.5 (COH), 167.7, 197.3, 198.3 (C=O); IR (neat): ν=3088 (w), 2969 (w), 2849 (w), 1726 (s), 1628 (s), 1593 (s), 1519 (m), 1470 (s), 1338 (s), 1209 (s), 742 (s) cm^{-1}; GC–MS (EI, 70 eV) m/z (%): 373 (M^+, 37), 327 (100), 310 (23), 286 (64), 258 (40), 166 (40), 147 (25), 120 (60); HRMS (EI) calcd for $C_{18}H_{15}NO_8$ [M^+]: 373.07922, found: 373.078728.

3.3.6. Ethyl 3-(5-(5-bromo-2-hydroxybenzoyl)-2-hydroxyphenyl)-3-oxopropanoate (6f)

Starting with 6-bromo-3-formylchromone **4f** (379 mg, 1.5 mmol), 1,3,5-tris(silyl enol ether) **3** (641 mg, 1.65 mmol), and Me_3SiOTf (0.08 mL, 0.45 mmol), **6f** was isolated as a yellow solid (190 mg, 31%), mp=117–120 °C. ^1H NMR (250 MHz, $CDCl_3$): δ=1.21 (t, 3H, J=6.9 Hz, CH_3), 2.68 (s, 2H, CH_2), 4.23 (q, 2H, J=7.1 Hz, OCH_2), 6.91 (d, 1H, J=8.85 ArH), 7.06 (d, 1H, J=8.75 Hz, ArH), 7.51 (m, 1H, ArH), 7.79 (d, 1H, J=1.75 Hz, ArH), 7.83 (d, J=1.75 Hz, 1H, ArH), 8.06 (d, J=1.8 Hz, 1H, ArH), 11.56 (s, 1H, OH), 12.24 (s, 1H, OH); ^{13}C NMR (75.46 MHz, $CDCl_3$): δ=14.0 (CH_3), 45.7 (CH_2), 62.0 (OCH_2), 110.4, 118.6 (C), 119.1 (CH), 120.1 (C), 120.6 (CH), 128.3 (C), 133.0, 134.5, 137.3, 138.9 (CH), 161.8, 166.0 (COH), 166.3, 197.2, 198.5 (C=O); IR (neat): ν=3073 (w), 3002 (w), 2966 (m), 1728 (s), 1680 (s), 1643 (s), 1626 (m), 1447 (s), 1462 (s), 1422 (s), 786 (s) cm^{-1}; GC–MS (EI, 70 eV) m/z (%): 408 (M^+, ^{81}Br, 47), 406 (M^+, ^{79}Br, 47), 362 (78), 360 (75), 291 (28), 200 (100), 147 (30), 120 (41), 92 (14); HRMS (EI) calcd for $C_{18}H_{15}BrO_6$ [M^+, ^{79}Br]: 406.00465, found: 406.004404.

3.3.7. Ethyl 3-(5-(3,5-dibromo-2-hydroxybenzoyl)-2-hydroxyphenyl)-3-oxopropanoate (6g)

Starting with 6,8-dibromo-3-formylchromone **4g** (331 mg, 1.0 mmol), 1,3,5-tris(silyl enol ether) **3** (427 mg, 1.1 mmol), and Me_3SiOTf (0.05 mL, 0.3 mmol), **6g** was isolated as a light brown solid (159 mg, 33%), mp=101–103 °C; ^1H NMR (250 MHz, $CDCl_3$): δ=1.21 (t, 3H, J=6.9 Hz, CH_3), 3.97 (s, 2H, CH_2), 4.14 (q, 2H, J=7.1 Hz, OCH_2), 7.06 (d, 1H, J=8.7 Hz, ArH), 7.58 (d, 1H, J=2.3 Hz, ArH), 7.78–7.84 (m, 2H, ArH), 8.07 (d, J=2.0 Hz, 1H, ArH), 12.13 (s, 1H, OH), 12.27 (s, 1H, OH); ^{13}C NMR (75.46 MHz, $CDCl_3$): δ=14.0 (CH_3), 45.7 (CH_2), 62.1 (OCH_2), 110.4, 113.5, 118.7 (C), 119.2 (CH), 120.6, 128.3 (C), 133.3, 133.8, 137.6, 141.3 (CH), 158.4, 166.2 (COH), 166.3, 197.0, 198.4 (C=O); IR (neat): ν=3067 (w), 3002 (w), 2974 (m), 2919 (m), 1735 (s), 1694 (w), 1651 (s), 1626 (s), 1583 (s), 1214 (s), 1159 (s), 771 (s) cm^{-1}; GC–MS (EI, 70 eV) m/z (%): 488 (M^+, [2×^{81}Br], 13), 486 (M^+, [$^{81}Br^{79}Br$], 27), 484 (M^+, [2×^{79}Br], 13), 442 (23), 440 (47), 399 (29), 371 (34), 278 (100), 147 (32), 120 (40). HRMS (EI) calcd for $C_{18}H_{14}Br_2O_6$ [M^+, 2×^{79}Br]: 483.91516, found: 483.915113.

3.3.8. Ethyl 3-(5-(5-chloro-2-hydroxybenzoyl)-2-hydroxyphenyl)-3-oxopropanoate (6h)

Starting with 6,8-dibromo-3-formylchromone **4h** (312 mg, 1.5 mmol), 1,3,5-tris(silyl enol ether) **3** (641 mg, 1.65 mmol), and Me_3SiOTf (0.08 mL, 0.45 mmol), **6h** was isolated as a reddish brown solid (203 mg, 37%), mp=98–99 °C; ^1H NMR (250 MHz, $CDCl_3$): δ=1.30 (t, 3H, J=7.1 Hz, CH_3), 4.07 (s, 2H, CH_2), 4.25 (q, 2H, J=7.1 Hz, OCH_2), 7.07 (d, 1H, J=9.0 Hz, ArH), 7.16 (d, 1H, J=8.7 Hz, ArH), 7.48–7.52 (m, 1H, ArH), 7.56 (d, 1H, J=2.5 Hz, ArH), 7.90 (dd, 1H, J=2.0, 8.7 Hz, ArH), 8.16 (d, 1H, J=1.95 Hz, ArH), 11.63 (s, 1H, OH), 12.33 (s, 1H, OH); ^{13}C NMR (75.46 MHz, $CDCl_3$): δ=14.1 (CH_3), 45.7 (CH_2), 62.0 (OCH_2), 118.6 (C), 119.1 (CH), 119.4 (C), 120.3 (CH), 123.6, 128.3 (C), 131.5, 133.0, 136.2, 137.6 (CH), 161.4, 164.5 (COH), 166.3, 197.5, 198.4 (C=O); IR (neat): ν=3074 (w), 2978 (m), 2932 (w), 1728 (m), 1668 (s), 1626 (s), 1587 (s), 1459 (s), 1274 (s), 1173 (s), 1095 (s), 834 (m) cm^{-1}; GC–MS (EI, 70 eV): m/z (%): 364 (M^+, ^{37}Cl, 20), 362 (M^+, ^{35}Cl, 47), 316 (100), 301 (25), 273 (34), 245 (15), 207 (14), 155 (35), 44 (29); HRMS (EI) calcd for $C_{18}H_{15}O_6Cl$ [M^+, ^{35}Cl]: 362.05517, found: 362.054802.

3.3.9. Ethyl 3-(5-(3,5-dichloro-2-hydroxybenzoyl)-2-hydroxyphenyl)-3-oxopropanoate (6i)

Starting with 6,8-dichloro-3-formylchromone **4i** (240 mg, 1 mmol), 1,3,5-tris(silyl enol ether) **3** (430 mg, 1.1 mmol), and Me_3SiOTf (0.05 mL, 0.3 mmol), **6i** was isolated as a light yellow solid (230 mg, 59%), mp=124–125 °C. ^1H NMR (250 MHz, $CDCl_3$): δ=1.21 (t, 3H, J=6.9 Hz, CH_3), 3.97 (s, 2H, CH_2), 4.14 (q, 2H, J=7.1 Hz, OCH_2), 7.06 (d, 1H, J=8.7 Hz, ArH), 7.58 (d, 1H, J=2.3 Hz, ArH), 7.78–7.84 (m, 2H, ArH), 8.07 (d, J=2.0 Hz, 1H, ArH), 12.13 (s, 1H, OH), 12.27 (s, 1H, OH); ^{13}C NMR (75.46 MHz, $CDCl_3$): δ=14.0 (CH_3), 45.7 (CH_2), 62.1 (OCH_2), 110.4, 113.5, 118.7 (C), 119.2 (CH), 120.6, 128.3 (C), 133.3, 133.8, 137.6, 141.3 (CH), 158.4, 166.2 (COH), 166.3, 197.0, 198.4 (C=O); IR (neat): ν=3068 (w), 2976 (w), 2938 (m), 2869 (m), 1735 (s), 1656 (w), 1628 (s), 1588 (s), 1576 (s), 1214 (s), 1161 (s), 771 (s) cm^{-1}; MS (EI, 70 eV) m/z (%): 400 (M^+, [2×^{37}Cl], 3), 398 (M^+, [$^{37}Cl^{35}Cl$], 22), 396 (M^+, [2×^{35}Cl], 34), 353 (6), 350 (51), 309 (40), 190 (67), 188 (100). HRMS (EI) calcd for $C_{18}H_{14}Cl_2O_6$ [M^+, 2×^{35}Cl]: 396.01620, found: 396.015918.

3.3.10. Ethyl 3-(5-(5-fluoro-2-hydroxybenzoyl)-2-hydroxyphenyl)-3-oxopropanoate (6j)

Starting with 6,8-dibromo-3-formylchromone **4j** (288 mg, 1.5 mmol), 1,3,5-tris(silyl enol ether) **3** (641 mg, 1.65 mmol), and Me_3SiOTf (0.08 mL, 0.45 mmol), **6j** was isolated as a light yellow solid (179 mg, 34%), mp=72–74 °C; ^1H NMR (250 MHz, $CDCl_3$): δ=1.22 (t, 3H, J=7.1 Hz, CH_3), 3.97 (s, 2H, CH_2), 4.22 (q, 2H, J=7.1 Hz, OCH_2), 6.96–6.99 (m, 1H, ArH), 7.08 (d, 1H, J=8.75 Hz, ArH), 7.20 (m, 1H, ArH), 7.81 (d, 1H, J=2.0 Hz, ArH), 7.85 (d, 1H, J=2.1 Hz, ArH), 8.06 (d, 1H, J=2.0 Hz, ArH), 11.39 (s, 1H, OH), 12.23 (s, 1H, OH); ^{13}C NMR (75.46 MHz, $CDCl_3$): δ=14.1 (CH_3), 45.7 (CH_2), 62.0 (OCH_2), 118.6 (C), 119.1 (CH), 119.4 (C), 120.3 (CH), 123.6, 128.3 (C), 131.5, 133.0, 136.2, 137.6 (CH), 161.4, 164.5 (COH), 166.3, 197.5, 198.4 (C=O); IR (neat): ν=3069 (w), 2998 (w), 2974 (w), 1726 (s), 1655 (s), 1634 (s), 1622 (m), 1470 (s), 1598 (s), 1469 (s), 987 (s) cm^{-1}; GC–MS (EI, 70 eV) m/z (%): 346 (M^+, 50), 326 (18), 300 (44), 259 (50), 231 (70), 139 (100), 120 (31), HRMS (EI) calcd for $C_{18}H_{15}FO_6$ [M^+]: 346.08472, found: 346.084658.

Acknowledgements

Financial support by the State of Mecklenburg-Vorpommern is gratefully acknowledged.

References and notes

1. For a review of 1,3-bis(silyloxy)-1,3-butadienes, see: Langer, P. *Synthesis* **2002**, 441.
2. Review: Langer, P. *Synlett* **2006**, 3369.
3. Review: Feist, H.; Langer, P. *Synthesis* **2007**, 327.
4. Review: Bellur, E.; Feist, H.; Langer, P. *Tetrahedron* **2007**, *63*, 10865.
5. Review: Langer, P. *Eur. J. Org. Chem.* **2007**, 2233.
6. Review: Langer, P. *Synlett* **2007**, 1016.
7. (a) Chan, T.-H.; Stössel, D. *J. Org. Chem.* **1988**, *53*, 4901; (b) Chan, T.-H.; Stössel, D. *J. Org. Chem.* **1986**, *51*, 2423.
8. Freifeld, I.; Bose, G.; Eckardt, T.; Langer, P. *Eur. J. Org. Chem.* **2007**, 351.
9. Appel, B.; Rotzoll, S.; Reinke, H.; Langer, P. *Eur. J. Org. Chem.* **2006**, 3638.
10. CCDC-716902 and CCDC-716903 contain all crystallographic details of this publication and is available free of charge at www.ccdc.cam.ac.uk/conts/retrieving.html or can be ordered from the following address: Cambridge Crystallographic Data Centre, 12 Union Road, GB-Cambridge CB21EZ, UK; fax: +44 1223 336 033; or deposit@ccdc.cam.ac.uk.
11. For a recent review on the strength of hydrogen bonds, see: Gilli, P.; Pretto, L.; Bertolasi, V.; Gilli, G. *Acc. Chem. Res.* **2009**, *42*, 33.