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Ytterbium triflate-catalyzed conjugate addition of β-ketoesters to activated 1,4-naphthoquinones

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ABSTRACT

An efficient procedure for the conjugate addition of various β-ketoesters to activated 1,4-naphthoquinones using a catalytic amount of $Yb(OTf)_3$ was developed. The tri-, tetra-, and pentacyclic adducts were obtained in very good to excellent yield. Cyclic β-ketoesters added smoothly to activated quinones when compared to their acyclic counterparts.

1. Introduction

Quinones are important compounds, which are widely distributed in nature and undergo a number of biochemical transformations. From a biological point of view, quinones are significant in many natural products. As a result of their importance, a large number of reactions have been investigated with quinones. One class of reactions which has primordial importance for the functionalization of quinones are nucleophilic addition reactions. In this perspective, the addition of thiols, amines, alkoxides, and azides is well studied.[1] The alkylation of quinones makes use of radical additions, organotin[2] and organosilicon[3] reagents, while acetonyl chains are added using pyridinium ylide chemistry.[4] Until now, carbon nucleophiles such as β-ketoesters have been added to the quinone moiety under basic conditions[5] or using free radical reactions with $Mn(OAc)_2$.[6] However, as is experienced, quinones often behave better under acidic conditions, resulting in less formation of disturbing side products. Therefore, it was felt necessary to investigate the addition reaction of β-ketoesters under acidic conditions. To our knowledge, this is the first report on addition of β-ketoesters to quinones under Lewis acidic mediated conditions.

2. Results and discussion

The accepting quinone of choice is 2-(methoxycarbonyl)-1,4-naphthoquinone **1**, a quinone which is activated toward nucleophilic additions by the presence of an electron-withdrawing ester moiety. Initially, a blank reaction was carried out between 2-(methoxycarbonyl)cyclohexanone **5** and 2-(methoxycarbonyl)-1,4-naphthoquinone **1** in ethanol for 2 h without any catalyst at room temperature. The products were not identified and a complex mixture was obtained. It was reasoned that the addition of Lewis acids such as scandium(III) triflate, bismuth(III) triflate, or ytterbium(III) triflate would assist in the addition of β-ketoesters in two ways. On the one hand, these Lewis acids catalyze the enolization of the β-ketoesters, making the nucleophiles more reactive. On the other hand, the Lewis acids will complex with the accepting quinone, making the acceptor more reactive (Scheme 1).

Therefore, the reaction of 2-(methoxycarbonyl)-1,4-naphthoquinone **1** with different β-ketoesters was investigated in the presence of different Lewis catalysts. The reactions were performed in ethanol at 0 °C. All reactions resulted in the addition—ring closure product, with ytterbium(III) triflate outperforming bismuth(III) triflate and scandium(III) triflate. Because of ytterbium(III) triflate's cost-effectiveness (compared to scandium(III) triflate) in combination with its stability toward water,[7] it became the Lewis acid of choice for further experimentation.

Thus, reactions were conducted between cyclic β-ketoesters **4** and **5**, and 2-(methoxycarbonyl)-1,4-naphthoquinone **1** in ethanol at 0 °C using 5 mol % of $Yb(OTf)_3$ (Scheme 2) affording the tetracyclic compounds **6** and **7** in 89% and 84% yield, respectively. Additionally, it was found that the reaction behaved better in acetonitrile with yields of 95% and 88% for compounds **6** and **7**, respectively. In an effort to extend the feasibility of this methodology, subsequently the naphthoquinone ester **1** was reacted with other β-ketoesters such as 2-(methoxycarbonyl)-1-indanone **8** and 2-(methoxycarbonyl)-1-tetralone **9**. The pentacyclic compounds **10** and **11** were obtained in excellent yields of 95% and 92%, respectively. However, these bulky esters need more time to complete the reaction, when compared to acyclic β-ketoesters.

In order to further extend the scope of this reaction to acyclic β-ketoesters, methyl acetoacetate **12a** was reacted with quinone **1** under similar experimental conditions in EtOH. The corresponding

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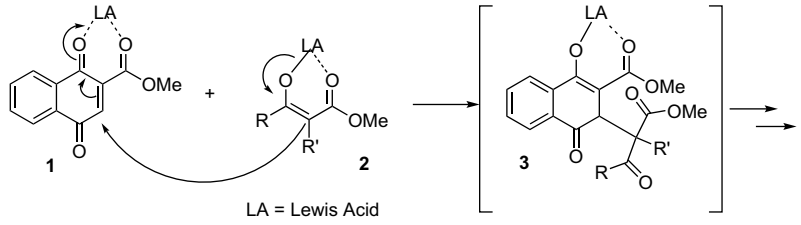
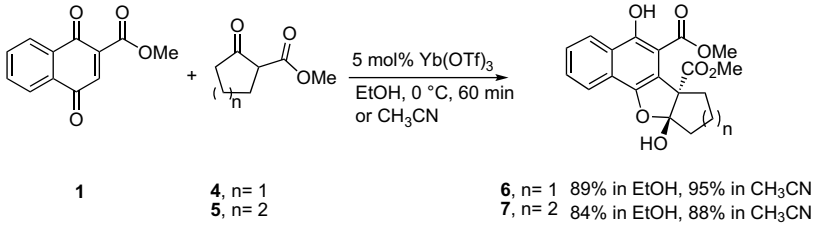
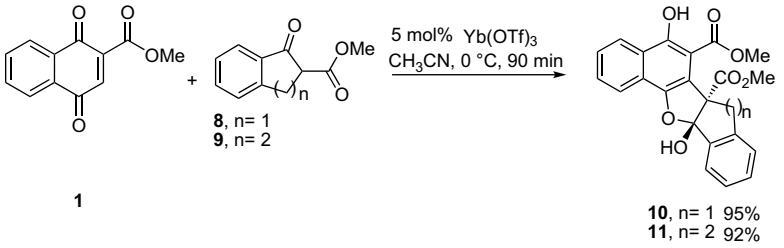


Scheme 1.





Scheme 2.

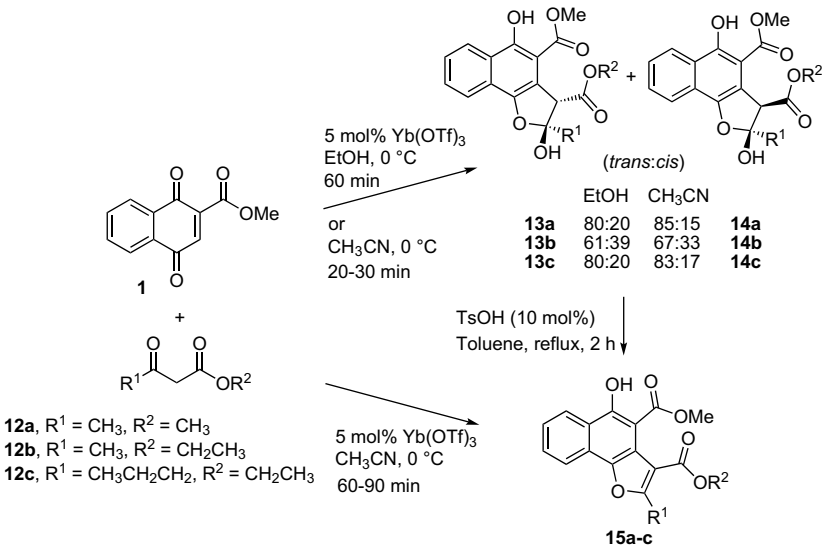
hydroxy adducts **13a** and **14a** were obtained as a brown solid in 61% yield as an inseperable mixture of cis and trans isomers (trans/cis 80:20) (Table 1). However, in contrast to the reaction products of cyclic β-ketoesters (**6**, **7**, **10**, and **11**), these hydroxy compounds **13** and **14** can be easily converted into their corresponding dehydrated naphthofurans **15** using 10 mol % of *p*-toluenesulfonic acid in toluene under reflux. Likewise, the reactions were also performed using other β-ketoesters such as ethyl acetoacetate **12b** and ethyl butyrylacetate **12c** with 2-(methoxycarbonyl)-1,4-naphthoquinone **1** and the corresponding hydroxy compounds **13b** and **14b** (87%, trans/cis 60:40) and **13c** and **14c** (44%, trans/cis 80:20) were obtained as solids (Table 1, entries 4 and 7; Scheme 3).

Reaction times and solvents played an important role in determining the fate of the product in case of acyclic substrates. The reaction in chlorinated solvents such as CH_2Cl_2 yielded the dehydrated compound **15a** in 62% after 4 h. Shifting from EtOH to acetonitrile changed the outcome of the reaction. Using 5 mol % of $Yb(OTf)_3$, a reaction between 2-(methoxycarbonyl)-1,4-naphthoquinone **1** and methyl acetoacetate **12a** was carried out in CH_3CN at 0 °C. After 60 min, addition of water followed by a simple filtration, afforded a brown colored solid, which was identified as the corresponding dehydrated tricyclic naphthofuran **15a** by spectroscopic analysis. The formation of dehydrated compound **15a** in a single step by a simple filtration led us to focus attention in this direction as the dehydrated compound **15a** is originating from the corresponding hydroxy compounds **13a** and **14a**. Next, in an attempt to stop the reaction before the dehydration step, 5 mol % of $Yb(OTf)_3$ was used in a reaction between 2-(methoxycarbonyl)-1,4-naphthoquinone **1** and methyl acetoacetate **12a** in CH_3CN for only 30 min resulting in the formation of tricyclic compounds **13a** and **14a** in 91% yield with a little increase in selectivity (trans/cis 85:15, entry 2). Acetonitrile as a solvent for this reaction has several advantages in comparison to EtOH such as (i) improved product yield as well as selectivity, (ii) choice of the product outcome is possible, and (iii) improved product purification techniques. For instance, the reaction between 2-(methoxycarbonyl)-1,4-naphthoquinone **1** and methyl acetoacetate **12a** in ethanol at 0 °C for 60 min provided the corresponding hydroxy adducts **13a** and **14a** in 61% yield. Whereas, the reaction between same substrates in CH_3CN for 30 min provided the hydroxy adducts **13a** and **14a** in 91% yield and the dehydrated adduct **15a** in 88% yield after 60 min. The generality of this transformation has been successfully verified by reacting 2-(methoxycarbonyl)-1,4-naphthoquinone **1** with other acyclic β-ketoesters (**12b**–**c**) in the presence of 5 mol % of $Yb(OTf)_3$ resulting in the corresponding hydroxy adducts (**13b** and **14b**, 95%; **13c** and **14c**, 82%) as well as the dehydrated adducts (**15b**, 82%; **15c**, 72%) in

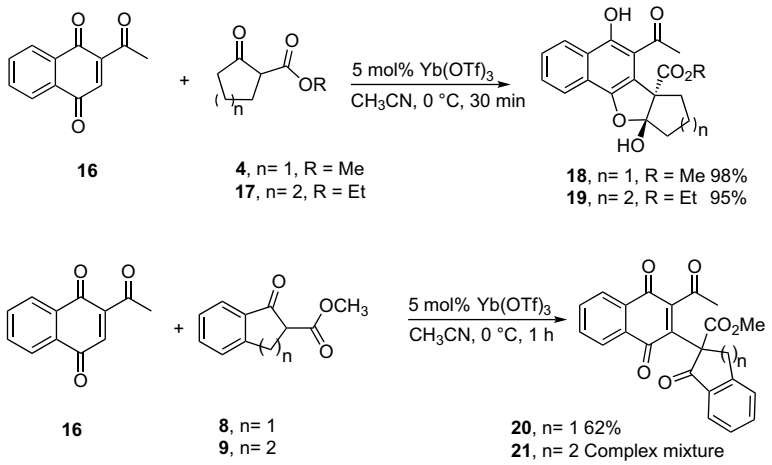
Table 1
$Yb(OTf)_3$-catalyzed conjugate addition of β-ketoesters **12** to 2-(methoxycarbonyl)-1,4-naphthoquinone **1**

Entry	Solvent	β-Ketoester	Time (min)	Hydroxy compounds **13**, **14** (yield %, *trans*/*cis*)[a]	Dehydrated compound **15** (yield %)
1	EtOH	**12a**	60	**13a**, **14a** (61%, 80:20)	
2	CH_3CN	**12a**	30	**13a**, **14a** (91%, 85:15)	
3	CH_3CN	**12a**	60		**15a** (88%)
4	EtOH	**12b**	60	**13b**, **14b** (87%, 61:39)	
5	CH_3CN	**12b**	30	**13b**, **14b** (95%, 67:33)	
6	CH_3CN	**12b**	60		**15b** (82%)
7	EtOH	**12c**	60	**13c**, **14c** (44%, 80:20)	
8	CH_3CN	**12c**	45	**13c**, **14c** (82%, 83:17)	
9	CH_3CN	**12c**	90		**15c** (72%)

[a] trans/cis ratio was determined by ^1H NMR.



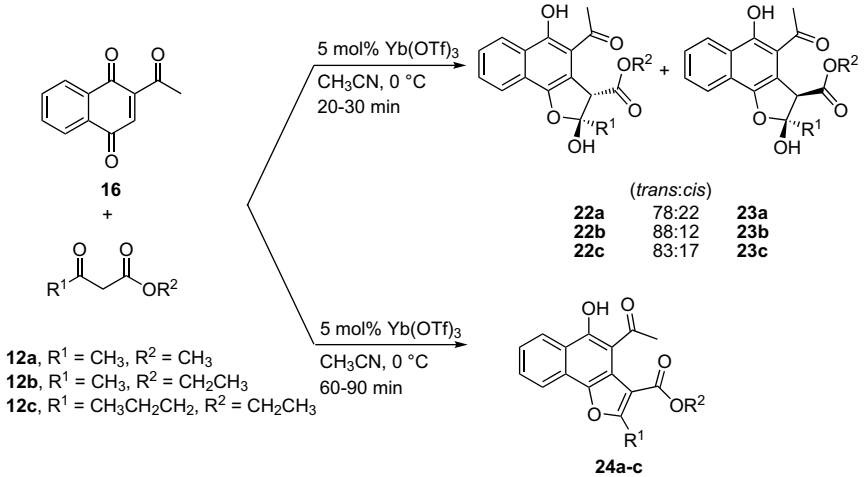
Scheme 3.



Scheme 4.

different reactions with different intervals of time (Table 1, entries 5, 6, 8, and 9). The choice of the β-ketoester influenced the trans/cis selectivity of the hydroxy product. Thus, β-ketoesters such as **12a** and **12c** gave the corresponding hydroxy products **13a**, **14a** (85:15) and **13c**, **14c** (83:17) with highest trans/cis selectivity. However, the lower trans/cis selectivity in case of **12b** was not clearly understood.

In order to determine the versatile catalytic activity of the $Yb(OTf)_3$, next the naphthoquinone moiety was varied. To this end,



Scheme 5.

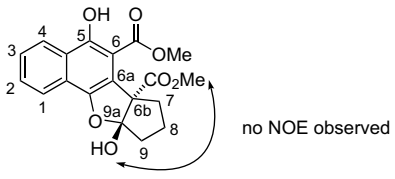
Table 2
Yb(OTf)$_3$-catalyzed conjugate addition of β-ketoesters **12a–c** to 2-acetyl-1,4-naphthoquinone **15**

Entry	Solvent	β-Ketoester	Time (min)	Hydroxy compounds **22**, **23** (yield %, *trans*/*cis*)[a]	Dehydrated compound **24** (yield %)
1	CH_3CN	**12a**	30	**22a**, **23a** (85%, 78:22)	
2	CH_3CN	**12a**	90		**24a** (82%)
3	EtOH	**12b**	60	**22b**, **23b** (93%, 92:8)	
4	CH_3CN	**12b**	30	**22b**, **23b** (87%, 88:12)	
5	CH_3CN	**12b**	90		**24b** (75%)
6	CH_3CN	**6c**	30	**22c**, **23c** (68%, 83:17)	
7	CH_3CN	**6c**	90		**24c** (75%)

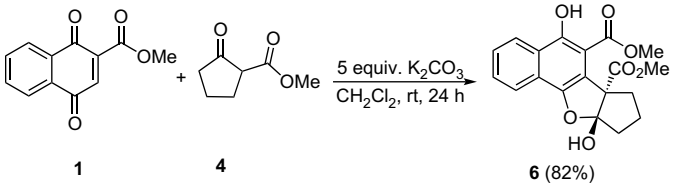
[a] trans/cis ratio was determined by ^{1}H NMR.

2-acetyl-1,4-naphthoquinone **16** was chosen as the substrate to react in the same way with β-ketoesters. The cyclic β-ketoesters 2-methoxycarbonyl-1-cyclopentanone **4** and 2-ethoxycarbonyl-1-cyclohexanone **17** were successfully reacted with 2-acetyl-1,4-naphthoquinone **16** using 5 mol % of Yb(OTf)$_3$ to obtain the corresponding tetracyclic compounds **18** and **19**, respectively, in excellent yield (Scheme 4). A similar reaction with more bulkier cyclic β-ketoester such as 2-(methoxycarbonyl)-1-indanone **8** either in EtOH or in CH_3CN afforded only the addition product, instead of a ring closure product. Increasing the reaction time in order to obtain the corresponding ring closure product led to a complex reaction mixture. Reaction of 2-(methoxycarbonyl)-1-tetralone **9** with 2-acetyl-1,4-naphthoquinone **16** provided a complex mixture of products.

Subsequently, acyclic β-ketoesters **12a–c** were reacted with 2-acetyl-1,4-naphthoquinone **16** (Scheme 5, Table 2).



Scheme 6.



Scheme 7.

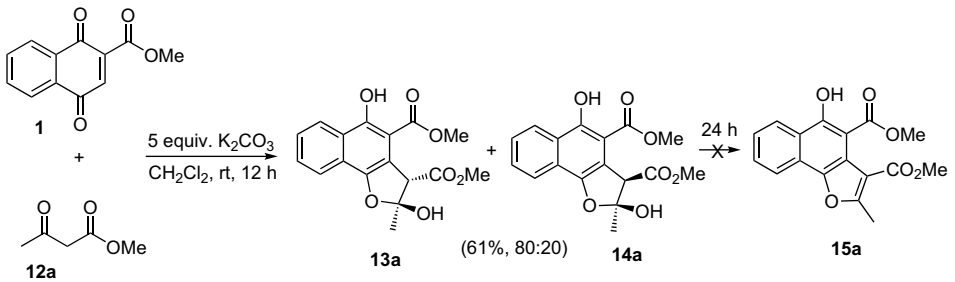
Using 5 mol % of Yb(OTf)$_3$, the reaction between methyl acetoacetate **12a** and 2-acetylnaphthoquinone **16** for 30 min at 0 °C smoothly afforded the corresponding tricyclic hydroxy compounds **22a**, **23a** in 85% yield with a trans/cis selectivity of 78:22. Similarly, β-ketoesters **12b** and **12c** afforded the corresponding hydroxy adducts **22b**, **23b** (87%) and **22c**, **23c** (68%). No significant effect of solvent was observed concerning yields as well as trans/cis selectivity of the corresponding hydroxy adducts (Table 2, entries 3 and 4). In case of 2-acetylnaphthoquinone **16**, the highest trans/cis selectivity was observed with β-ketoester **12b**, in contrast to reaction with activated quinone **1** where β-ketoester **12c** had the highest trans/cis selectivity. In the same way, β-ketoesters **12a–c** reacts with quinone compound **16** for 60 min to afford the corresponding dehydrated compounds **24a–c** in moderate to very good yield (Table 2, entries 2, 5, and 7).

In the case of all cyclic β-ketoesters **4**, **5**, **8**, **9**, and **17**, trans compounds were observed exclusively, whereas for acyclic β-ketoesters **12a–c**, an inseperable mixture of cis and trans compounds was obtained. The trans-configuration of **6**, **7**, **10**, **11**, **18**, and **19** was confirmed by NOESY experiments, for example, on compound **6**, in which no Overhauser effect was observed between the 9a-hydroxy and 6b-methoxycarbonyl substituents (Scheme 6). Furthermore, the exclusive formation of a single trans diastereomer can be explained by the continuous ring opening and ring closure of the unstable hemiacetal equilibrating into the more stable trans-configuration.

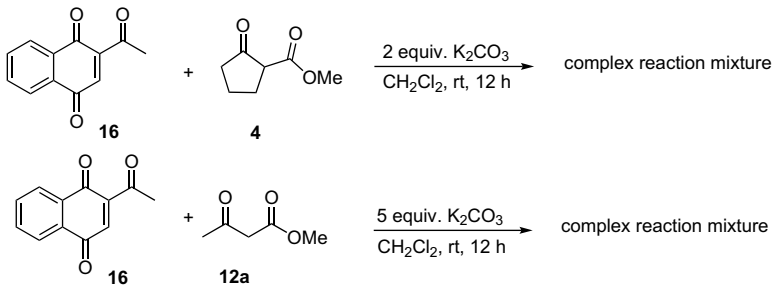
Subsequently, the Yb(OTf)$_3$-catalyzed reactions were compared with addition reactions in basic conditions using potassium carbonate. The reaction between 2-methoxycarbonyl-1,4-naphthoquinone **1** and cyclic β-ketoester 2-methoxycarbonyl-1-cyclopentanone **4** with 5 equiv of potassium carbonate resulted in the formation of tetracyclic adduct **6** in 82% yield. However, the reaction needed much longer reaction times (24 h vs 60 min) in order to go to completion (Scheme 7).

The reaction between activated quinone **1** and methyl acetoacetate **12a** reveals the true benefit of the Lewis acidic conditions. The reaction with methyl acetoacetate **12a** using potassium carbonate results in the formation of hydroxy compounds **13a** and **14a**, which were impossible to convert into the dehydrated compound **15a** even after prolonged reaction times (Scheme 8).

The reaction with 2-acetyl-1,4-naphthoquinone **16** is even more beneficial in acidic conditions as only complex reaction mixtures are obtained with potassium carbonate, whereas the reaction with catalytic ytterbium(III) triflate cleanly results in hydroxy compounds **22a–c** and **23a–c** and dehydrated compounds **24a–c** (Scheme 9). In short, the benefits of the ytterbium(III) triflate method in comparison with the potassium carbonate are (1) the possibility to use catalytic amounts of ytterbium(III) triflate, (2) shorter reaction rates (1 h vs 1 day), (3) the possibility to get dehydrated naphthofuran compounds **15**, (4) the easy work-up procedures, and (5) the possibility to use 2-acetyl-1,4-naphthoquinone **16**.



Scheme 8.



Scheme 9.

3. Conclusions

In conclusion, a novel protocol was developed for the conjugate addition of β-ketoesters to activated 1,4-naphthoquinones such as 2-methoxycarbonyl-1,4-naphthoquinone **1** and 2-acetyl-1,4-naphthoquinone **16** in Lewis acid mediated conditions using catalytic amounts of $Yb(OTf)_3$. The present methodology is the first of its kind that uses Lewis acid for the nucleophilic addition of carbon nucleophiles to activated quinones. The tri-, tetra-, and pentacyclic adducts were obtained in very good to excellent yield by the reaction of various β-ketoesters with activated naphthoquinones. Cyclic β-ketoesters added smoothly to 2-methoxycarbonyl-1,4-naphthoquinone **1**, providing the corresponding hydroxy compounds exclusively in trans-configuration. The benefits of the Lewis acidic conditions in comparison with basic conditions using potassium carbonate are stated. Further work is in progress to explore the possibility of addition of other carbon nucleophiles to activated quinones.

4. Experimental

4.1. General

^1H NMR (300 MHz) and ^{13}C NMR (75 MHz) peak assignments were performed with the aid of the DEPT technique, 2D COSY spectra, and HETCOR spectra. Mass spectra were recorded using a direct inlet system (70 eV) with a VL detector (ES, 4000 V). Elemental analyses were executed with a Perkin–Elmer Series II CHNS/O Analyzer 2400. The reported melting points are uncorrected. Flash chromatography was carried out using silica gel (particle size 0.035–0.07 mm, pore diameter ca. 6 nm). Solvent systems were determined via initial TLC analysis (Merck, silica gel $60F_{254}$). Dry solvents tetrahydrofuran (THF) and diethyl ether were freshly distilled over sodium benzophenone ketyl. Other solvents were used as received from the supplier.

4.2. General procedure for the $Yb(OTf)_3$-catalyzed conjugate addition of β-ketoesters to 2-(methoxycarbonyl)-1,4-naphthoquinone 1 in EtOH

The synthesis of hydroxy compounds **13a** and **14a** was taken as example.

To a stirred solution of 2-(methoxycarbonyl)-1,4-naphthoquinone **1** (1 mmol) in abs EtOH (4 ml) at 0 °C was added ytterbium(III) triflate (0.05 mmol). After 10 min, methyl acetoacetate **12a** (1 mmol) was added and the reaction mixture was stirred for 1 h. After evaporation of the solvent, water (20 ml) was added to the residue and the aqueous solution was extracted with ethyl acetate (3×10 ml). The combined organic extracts were dried over $MgSO_4$ and the solvent was evaporated in vacuo. The residue was purified by column chromatography (petroleum ether/ethyl acetate 1:1, R_f 0.46) to provide 61% of a mixture of *trans* and *cis* hydroxy compounds **13a** and **14a** (80:20, 0.61 mmol).

4.3. General procedure for the $Yb(OTf)_3$-catalyzed conjugate addition of β-ketoesters to activated quinones 1 or 16

The synthesis of compounds **13a**, **14a**, and **15a** is outlined as an example.

To a stirred solution of activated quinone **1** (1 mmol) in CH_3CN (5 ml) at 0 °C was added ytterbium(III) triflate (0.05 mmol) followed by methyl acetoacetate **12a** (1 mmol). After 30 min (TLC monitoring), water (20 ml) was added to the reaction mixture and stirring was continued for 10 min to form a brown precipitate. The precipitate was filtered, washed with water (2×10 ml), and dried in vacuo to provide 91% of a mixture of *trans* and *cis* hydroxy compounds **13a** and **14a** (85:15, 0.91 mmol). Adopting the same procedure, but prolonging the reaction time (60 min) resulted in the formation of the dehydrated compound **15a** in 88% yield (0.88 mmol).

4.3.1. trans-Methyl 5,9a-dihydroxy-6b-methoxycarbonyl-7,8,9,9a-tetrahydro-10-oxa-pentaleno[2,1-a]naphthalene-6-carboxylate ***6***

Yield: 95%. Yellow solid (mp: 191–192 °C). ^1H NMR ($CDCl_3$): δ 1.48–1.66 (1H, m, CH_2), 1.79–1.90 (1H, m, CH_2), 1.92–2.02 (1H, m, CH_2), 2.09–2.23 (1H, m, CH_2), 2.34–2.44 (1H, m, CH_2), 3.01–3.14 (1H, m, CH_2), 3.50 (1H, s, OH), 3.70 (3H, s, CO*OMe*), 3.87 (3H, s, CO*OMe*), 7.52–7.59 (1H, m, CH_{ar}), 7.62–7.69 (1H, m, CH_{ar}), 7.94 (1H, d, J=7.7 Hz, CH_{ar}), 8.40 (1H, d, J=7.7 Hz, CH_{ar}), 11.96 (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 22.67 (CH_2), 37.42 (CH_2), 39.25 (CH_2), 51.63 (CO*OMe*), 52.65 (CO*OMe*), 68.07 (C_{quat}), 101.66 (C_{quat}), 117.71 (C_{quat}), 120.55 (C_{quat}), 121.86 (CH_{ar}), 124.05 (C_{quat}), 124.58 (CH_{ar}), 125.36 (C_{quat}), 126.61 (CH_{ar}), 129.79 (CH_{ar}), 147.18 (C_{quat}), 157.56 (C_{quat}), 170.60 (*CO*OMe), 172.52 (*CO*OMe). IR (KBr) ν_{max}: 1703, 1660. MS (ES^-) m/z (%): 357 ($M-H^+$, 100). Anal. Calcd for $C_{19}H_{18}O_7$: C, 63.68; H, 5.06. Found: C, 63.34; H, 4.96.

4.3.2. trans-Methyl 5,10a-dihydroxy-6b-methoxycarbonyl-8,9,10,10a-tetrahydro-7H-benzo[b]naphtho[2,1-d]furan-6-carboxylate **7**

Yield: 88%. Pale brown solid (mp: 132–133 °C). ^1H NMR ($CDCl_3$): δ 1.34–1.51 (1H, m, CH_2), 1.58–1.72 (1H, m, CH_2), 1.75–1.99 (3H, m, CH_2), 2.17–2.31 (1H, m, CH_2), 2.38–2.49 (1H, m, CH_2), 2.76–2.87 (1H, m, CH_2), 3.71 (3H, s, COOMe), 3.75 (1H, s, OH), 3.91 (3H, s, COOMe), 7.51–7.61 (1H, m, CH_{ar}), 7.62–7.69 (1H, m, CH_{ar}), 7.99 (1H, d, J=7.7 Hz, CH_{ar}), 8.41 (1H, d, J=8.5 Hz, CH_{ar}), 12.00 and 12.17 (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 20.41 (CH_2), 20.99 (CH_2), 31.72 (CH_2), 34.29 (CH_2), 51.71 (CO*OMe*), 52.19 (CO*OMe*), 61.74 (C_{quat}), 77.33 (C_{quat}), 102.04 (C_{quat}), 108.81 (C_{quat}), 120.61 (C_{quat}), 121.85 (CH_{ar}), 124.61 (CH_{ar}), 125.16 (C_{quat}), 125.33 (C_{quat}), 126.64 (CH_{ar}), 129.80 (CH_{ar}), 145.47 (C_{quat}), 157.58 (C_{quat}), 170.68 (*CO*OMe), 172.89 (*CO*OMe). IR (KBr) ν_{max}: 1730, 1660. MS (ES^+) m/z (%): 371 ($M-H^+$, 100). Anal. Calcd for $C_{20}H_{20}O_7$: C, 64.51; H, 5.41. Found: C, 64.37; H, 4.89.

4.3.3. trans-Methyl 5,11b-dihydroxy-6b-methoxycarbonyl-7,11b-dihydro-12-oxa-benzo[4,5]pentaleno[2,1-a]naphthalene-6-carboxylate ***10***

Yield: 95%. Yellow solid (mp: 226–227 °C). ^{1}H NMR ($CDCl_3$): δ 3.19 and 3.25 (1H, s, CH_2), 3.74 (3H, s, COOMe), 3.80 (1H, s, OH), 3.97 (3H, s, COOMe), 4.36 and 4.42 (1H, s, CH_2), 7.24 (1H, d, J=7.7 Hz, CH_{ar}), 7.34–7.40 (2H, m, CH_{ar}), 7.49–7.72 (3H, m, CH_{ar}), 7.94 (1H, d, J=7.7 Hz, CH_{ar}), 8.38 (1H, d, J=8.3 Hz, CH_{ar}), 11.94 (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 43.00 (CH_2), 51.83 (COO*Me*), 52.93 (COO*Me*), 68.68 (C_{quat}), 101.53 (C_{quat}), 118.19 (C_{quat}), 120.24 (C_{quat}), 122.05 (C_{quat}), 123.88 (CH_{ar}), 124.55 (CH_{ar}), 125.25 (CH_{ar}), 125.47 (C_{quat}), 125.49 (C_{quat}), 126.75 (CH_{ar}), 127.85 (CH_{ar}), 129.86 (CH_{ar}), 130.70 (CH_{ar}), 139.24 (C_{quat}), 141.68 (C_{quat}), 146.67 (C_{quat}), 157.76 (C_{quat}), 170.52 (*CO*OMe), 172.00 (*CO*OMe). IR (KBr) ν_{max}: 1716, 1659. MS (ES^-) m/z (%): 405 ($M-H^+$, 60). Anal. Calcd for $C_{23}H_{18}O_7$: C, 67.98; H, 4.46. Found: C, 67.46; H, 3.90.

4.3.4. trans-Methyl 5,12b-dihydroxy-6b-methoxycarbonyl-7,8,12b,13-tetrahydrodihydro-dibenzo[a-l]fluorene-6-carboxylate ***11***

Yield: 92%. Brown solid (mp: 183–184 °C). ^{1}H NMR ($CDCl_3$): δ 2.06–2.16 (1H, m, CH_2), 2.56–2.66 (1H, m, CH_2), 2.78–3.03 (2H, m, CH_2), 3.62 (3H, s, CO*OMe*), 3.69 (3H, s, CO*OMe*), 4.64 (1H, s, OH), 7.16 (1H, d, J=7.4 Hz, CH_{ar}), 7.23–7.31 (1H, m, CH_{ar}), 7.44 (1H, dd, J=6.9, 7.4 Hz, CH_{ar}), 7.59 (1H, dd, J=6.9, 7.4 Hz, CH_{ar}), 7.71 (1H, dd, J=6.9, 7.4 Hz, CH_{ar}), 7.95–8.02 (2H, m, CH_{ar}), 8.06 (1H, d, J=8.3 Hz, CH_{ar}), 12.15 (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 26.28 (CH_2), 32.85 (CH_2), 51.78 (COO*Me*), 52.59 (COO*Me*), 96.99 (C_{quat}), 106.69 (C_{quat}), 116.95 (C_{quat}), 122.11 (CH_{ar}), 124.61 (CH_{ar}), 124.96 (C_{quat}), 125.95 (CH_{ar}), 126.73 (CH_{ar}), 126.93 (CH_{ar}), 127.36 (C_{quat}), 127.43 (CH_{ar}), 129.22 (CH_{ar}), 129.94 (CH_{ar}), 131.02 (C_{quat}), 133.96 (C_{quat}), 134.61 (C_{quat}), 139.71 (C_{quat}), 158.09 (C_{quat}), 170.63 (*CO*OMe), 172.86 (*CO*OMe). IR (KBr) ν_{max}: 1732, 1660. MS (ES^+) m/z (%): 403 ($M-OH^-$, 100). Anal. Calcd for $C_{24}H_{20}O_7$: C, 68.57; H, 4.80. Found: C, 68.67; H, 5.13.

4.3.5. cis and trans Methyl 2,5-dihydroxy-3-methoxycarbonyl-2-methyl-2,3-dihydronaphtho[1,2-b]furan-4-carboxylate ***13a***, ***14a***

Yield: 91%. Brown solid, mixture of cis and trans isomers, major (M) 85% and minor (m) 15%. ^{1}H NMR ($CDCl_3$): δ 1.79 (m) and 1.89 (M) (3H, s, Me), 3.15 (m) and 3.58 (M) (1H, s, OH), 3.72 (m) and 3.78 (M) (3H, s, COOMe), 3.90 and 3.91 (3H, s, COOMe), 4.55 (m) and 4.64 (M) (1H, s, CH), 7.52–7.69 (2H, m, CH_{ar}), 7.93 (1H, d, J=8.3 Hz, CH_{ar}), 8.40 (1H, d, J=8.5 Hz, CH_{ar}), 11.73 (M) and 11.76 (m) (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 23.98 (m) and 27.55 (M) (Me), 51.89 (M) and 51.99 (m) (CO*OMe*), 52.36 (m) and 52.52 (M) (CO*OMe*), 61.13 (M) and 62.24 (m) (CH), 102.53 (C_{quat}), 108.67 (m) and 109.19 (M) (C_{quat}), 112.46 (m) and 113.30 (M) (C_{quat}), 121.74 and 121.79 (CH_{ar}), 124.31 (C_{quat}), 124.60 (CH_{ar}), 125.62 (C_{quat}), 126.58 and 126.73 (CH_{ar}), 129.65 and 129.73 (CH_{ar}), 146.81 (M) and 146.93 (m) (C_{quat}), 156.92 (M) and 156.99 (m) (C_{quat}), 170.61 (M) and 170.71 (m) (C=O), 171.12 (C=O). IR (KBr) ν_{max}: 3411, 1730, 1656. MS (ES^+) m/z (%): 315 ($M-OH^-$, 100). Anal. Calcd for $C_{17}H_{16}O_7$: C, 61.44; H, 4.85. Found: C, 61.04; H, 5.09.

4.3.6. cis and trans Methyl 2,5-dihydroxy-3-ethoxycarbonyl-2-methyl-2,3-dihydronaphtho[1,2-b]furan-4-carboxylate ***13b***, ***14b***

Yield: 95%. Pale brown crystals, mixture of cis and trans isomers, major (M) 67% and minor (m) 33%. ^{1}H NMR ($CDCl_3$): δ 1.25 (m) and 1.29 (M) (3H, t, J=7.1 Hz, OCH_2CH_3), 1.78 (m) and 1.88 (M) (3H, s, Me), 3.52 (m) and 3.74 (M) (1H, s, OH), 3.87 (m) and 3.89 (M) (3H, s, OMe), 4.19 (m) and 4.20 (M) (2H, q, J=7.1 Hz, OCH_2CH_3), 4.49 (m) and 4.60 (M) (1H, s, CH), 7.52–7.65 (2H, m, CH_{ar}), 7.91 (1H, d, J=7.9 Hz, CH_{ar}), 8.38 (1H, d, J=8.5 Hz, CH_{ar}), 11.71 (M) and 11.75 (m) (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 14.38 (OCH_2CH_3), 23.92 (m) and 27.48 (M) (Me), 51.91 (M) and 51.60 (m) (OMe), 60.99 (M) and 62.19 (m) (CH), 61.14 (m) and 61.37 (M) (OCH_2CH_3), 102.44 (C_{quat}), 108.59 (M) and 109.09 (m) (C_{quat}), 112.45 (M) and 113.26 (m) (C_{quat}), 121.18 (C_{quat}), 121.64 (CH_{ar}), 124.42 (CH_{ar}), 125.44 (C_{quat}), 126.39 (m) and 126.53 (M) (CH_{ar}), 129.46 (m) and 129.55 (M) (CH_{ar}), 146.67 (M) and 146.78 (m) (C_{quat}), 156.70 (M) and 156.78 (m) (C_{quat}), 170.47 (m) and 170.55 (M) (C=O), 170.55 (M) and 170.62 (m) (C=O). IR (KBr) ν_{max}: 3411, 1730, 1664. MS (ES^-) m/z (%): 345 ($M-H^+$, 100). Anal. Calcd for $C_{19}H_{20}O_7$: C, 63.33; H, 5.59. Found: C, 63.51; H, 5.64.

4.3.7. cis and trans Methyl 2,5-dihydroxy-3-ethoxycarbonyl-2-propyl-2,3-dihydronaphtho[1,2-b]furan-4-carboxylate ***13c***, ***14c***

Yield: 82%. Pale brown crystals, mixture of cis and trans isomers, major (M) 83% and minor (m) 17%. ^{1}H NMR ($CDCl_3$): δ 1.01 (3H, t, J=7.4 Hz, OCH_2CH_3), 1.30 (3H, s, Me), 1.58–1.71 (2H, m, CH_2), 2.03–2.13 (2H, m, CH_2), 3.16 (m) and 3.59 (M) (1H, s, OH), 3.90 (3H, s, COOMe), 4.12–4.34 (2H, m, OCH_2CH_3), 4.52 (m) and 4.62 (M) (1H, s, CH), 7.51–7.59 (1H, m, CH_{ar}), 7.60–7.69 (1H, m, CH_{ar}), 7.94 (1H, d, J=8.0 Hz, CH_{ar}), 8.40 (1H, d, J=8.3 Hz, CH_{ar}), 11.74 (M) and 11.78 (m) (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 14.21 and 14.38 (OCH_2CH_3), 16.41 (m) and 16.57 (M) (CH_3), 42.67 (CH_2), 51.90 (CH_2), 59.68 ($COOCH_3$), 61.22 (m) and 61.45 (M) (OCH_2CH_3), 102.67 (C_{quat}), 110.27 (M) and 110.47 (m) (C_{quat}), 112.55 (C_{quat}), 121.85 (CH_{ar}), 124.29 (C_{quat}), 124.58 (CH_{ar}), 125.63 (C_{quat}), 126.50 (C_{quat}), 126.67 (CH_{ar}), 129.66 (CH_{ar}), 146.98 (C_{quat}), 156.86 (C_{quat}), 170.72 (C=O), 170.83 (C=O). IR (KBr) ν_{max}: 3400, 1730, 1664. MS (ES^-) m/z (%): 373 ($M-H^+$, 100). Anal. Calcd for $C_{20}H_{22}O_7$: C, 64.16; H, 5.92. Found: C, 63.69; H, 5.46.

4.3.8. Methyl 5-hydroxy-3-methoxycarbonyl-2-methylnaphtho-[1,2-b]furan-4-carboxylate ***15a***

Yield: 88%. Brown solid (mp: 125–126 °C). ^{1}H NMR ($CDCl_3$): δ 2.65 (3H, s, Me), 3.91 (3H, s, COOMe), 3.93 (3H, s, COOMe), 7.49–7.57 (1H, m, CH_{ar}), 7.67–7.75 (1H, m, CH_{ar}), 8.15 (1H, d, J=8.3 Hz, CH_{ar}), 8.44 (1H, d, J=8.3 Hz, CH_{ar}), 11.59 (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 13.59 (Me), 52.03 and 52.10 (COOMe), 99.83 (C_{quat}), 113.34 (C_{quat}), 117.62 (C_{quat}), 119.77 (CH_{ar}), 122.79 (C_{quat}), 124.19 (C_{quat}), 124.98 (CH_{ar}), 125.50 (CH_{ar}), 130.21 (CH_{ar}), 143.51 (C_{quat}), 157.85 (C_{quat}), 158.14 (C_{quat}), 166.15 (*CO*OMe), 170.84 (*CO*OMe). IR (KBr) ν_{max}: 3317, 1711, 1657. MS (ES^-) m/z (%): 315 ($M+H^+$, 100). Anal. Calcd for $C_{17}H_{14}O_6$: C, 64.97; H, 4.49. Found: C, 64.73; H, 5.75.

4.3.9. Methyl 5-hydroxy-3-ethoxycarbonyl-2-methylnaphtho[1,2-b]-furan-4-carboxylate ***15b***

Yield: 82%. Light-brown crystals (mp: 85 °C). ^{1}H NMR ($CDCl_3$): δ 1.38 (3H, t, J=7.1 Hz, OCH_2CH_3), 2.66 (3H, s, Me), 3.92 (3H, s, OMe), 4.37 (2H, q, J=7.1 Hz, OCH_2CH_3), 7.50–7.55 (1H, m, CH_{ar}), 7.67–7.72 (1H, m, CH_{ar}), 8.12–8.15 (1H, m, CH_{ar}), 8.41–8.44 (1H, m, CH_{ar}), 11.56 (1H, br s, ArOH). ^{13}C NMR ($CDCl_3$): δ 13.60 (OCH_2CH_3), 14.41 (Me), 51.95 (OMe), 61.01 (OCH_2CH_3), 99.94 (C_{quat}), 113.59 (C_{quat}), 117.71 (C_{quat}), 119.76 (CH_{ar}), 121.64 (CH_{ar}), 124.42 (CH_{ar}), 125.44 (C_{quat}), 126.39 (m) and 126.53 (M) (CH_{ar}), 129.46 (m) and 129.55 (M) (CH_{ar}), 146.67 (M) and 146.78 (m) (C_{quat}), 156.70 (M) and 156.78 (m) (C_{quat}), 170.47 (m) and 170.55 (M) (C=O), 170.55 (M) and 170.62 (m) (C=O). IR (KBr) ν_{max}: 1715, 1658, 1638. MS (ES^-) m/z (%): 329 ($M+H^+$, 100). Anal. Calcd for $C_{18}H_{16}O_6$: C, 65.85; H, 4.91. Found: C, 65.91; H, 4.83.

4.3.10. Methyl 5-hydroxy-3-ethoxycarbonyl-2-propylnaphtho-[1,2-b]furan-4-carboxylate ***15c***

Yield: 72%. Colorless crystals (mp: 99–100 °C). ^{1}H NMR ($CDCl_3$): δ 1.02 (3H, t, J=7.4 Hz, CH_2CH_3), 1.38 (3H, t, J=7.2 Hz, OCH_2CH_3), 1.85 (2H, sextet, J=7.4 Hz, $CH_2CH_2CH_3$), 2.96 (3H, t, J=7.4 Hz, $CH_2CH_2CH_3$), 3.93 (3H, s, CO*OMe*), 4.36 (2H, dd, J=7.2, 7.4 Hz, OCH_2CH_3), 7.49–7.57 (1H, m, CH_{ar}), 7.66–7.74 (1H, m, CH_{ar}), 8.16 (1H, d, J=8.4 Hz, CH_{ar}), 8.44 (1H, d, J=8.4 Hz, CH_{ar}), 11.63 (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 13.86 (OCH_2CH_3), 14.42 (Me), 21.87 (CH_2), 29.54 (CH_2), 51.94 (CO*OMe*), 60.96 ($COOCH_2CH_3$), 99.88 (C_{quat}), 113.49 (C_{quat}), 117.58 (C_{quat}), 119.85 (CH_{ar}), 122.81 (C_{quat}), 124.29 (C_{quat}), 124.98 (CH_{ar}), 125.45 (CH_{ar}), 130.15 (CH_{ar}), 143.54

(C_{quat}), 158.17 (C_{quat}), 161.21 (C_{quat}), 165.77 (C=O), 170.91 (C=O). IR (KBr) ν_{max}: 1711, 1656. MS (ES^-) *m/z* (%): 357 ($M+H^+$, 100). Anal. Calcd for $C_{20}H_{20}O_6$: C, 67.41; H, 5.66. Found: C, 67.39; H, 5.16.

4.3.11. *trans*-Methyl 6-acetyl-5,9a-dihydroxy-7,8,9,9a-tetrahydro-10-oxa-pentaleno[2,1-a]naphthalene-6b-carboxylate **18**

Yield: 98%. Yellow solid (mp: 197–198 °C). ^1H NMR ($CDCl_3$): δ 1.63–1.81 (1H, m, CH_2), 1.88–2.01 (1H, m, CH_2), 2.08–2.28 (2H, m, CH_2), 2.36–2.43 (1H, m, CH_2), 2.44 (3H, s, CO*Me*), 3.12–3.24 (1H, m, CH_2), 3.36 (1H, s, OH), 3.77 (3H, s, COO*Me*), 7.53–7.61 (1H, m, CH_{ar}), 7.69–7.72 (1H, m, CH_{ar}), 7.93 (1H, d, *J*=8.3 Hz, CH_{ar}), 8.48 (1H, d, *J*=8.3 Hz, CH_{ar}). ^{13}C NMR ($CDCl_3$): δ 23.02 (CH_2), 29.92 (CO*Me*), 38.39 (CH_2), 38.47 (CH_2), 53.13 (COO*Me*), 68.04 (C_{quat}), 110.49 (C_{quat}), 116.44 (C_{quat}), 120.85 (C_{quat}), 121.89 (CH_{ar}), 124.73 (C_{quat}), 125.30 (CH_{ar}), 126.37 (C_{quat}), 126.96 (CH_{ar}), 130.61 (CH_{ar}), 147.01 (C_{quat}), 161.24 (C_{quat}), 173.42 (*C*OOMe), 203.18 (*C*OMe). IR (KBr) ν_{max}: 1735, 1630. MS (ES^-) *m/z* (%): 341 ($M-H^+$, 100). Anal. Calcd for $C_{19}H_{18}O_6$: C, 66.66; H, 5.30. Found: C, 66.33; H, 5.01.

4.3.12. *trans*-Ethyl 6-acetyl-5,10a-dihydroxy-8,9,10,10a-tetrahydro-7H-benzo[b]naphtha[2,1-d]furan-6b-carboxylate **19**

Yield: 95%. Light-brown crystals (mp: 153 °C). ^1H NMR ($CDCl_3$): δ 1.27 (3H, t, *J*=7.1 Hz, OCH_2CH_3), 1.56–1.74 (3H, m, Me), 1.85–2.01 (3H, m, Me), 2.38–2.45 (1H, m, CH), 2.50 (3H, s, CO*Me*), 2.87–2.93 (1H, m, CH), 3.81 (1H, s, OH), 4.25 (2H, q, *J*=7.1 Hz, OCH_2CH_3), 7.54–7.59 (1H, m, CH_{ar}), 7.64–7.69 (1H, m, CH_{ar}), 7.98 (1H, d, *J*=7.7 Hz, CH_{ar}), 8.45 (1H, d, *J*=8.5 Hz, CH_{ar}), 12.24 (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 14.05 (OCH_2CH_3), 20.83 (CH_2), 21.02 (CH_2), 31.03 (CO*Me*), 31.42 (CH), 35.61 (CH), 61.94 (OCH_2CH_3), 65.95 (C_{quat}), 108.86 (C_{quat}), 112.35 (C_{quat}), 120.03 (C_{quat}), 121.88 (CH_{ar}), 125.01 (CH_{ar}), 125.56 (C_{quat}), 126.12 (C_{quat}), 126.92 (CH_{ar}), 130.20 (CH_{ar}), 145.18 (C_{quat}), 158.90 (C_{quat}), 172.78 (*C*OOEt), 203.72 (*C*OMe). IR (KBr) ν_{max}: 3400, 1706, 1682. MS (ES^+) *m/z* (%): 353 ($M-OH^-$, 100). Anal. Calcd for $C_{21}H_{22}O_6$: C, 68.10; H, 5.99. Found: C, 67.84; H, 6.13.

4.3.13. Methyl 2-(3-acetyl-1,4-dioxo-1,4-dihydronaphthalen-2-yl)-1-oxo-indan-2-carboxylate **20**

Yield: 62%. Light-brown powder (mp: 124 °C). ^1H NMR ($CDCl_3$): δ 2.56 (3H, s, COMe), 3.30 (1H, d, *J*=17.1 Hz, CH), 3.65 (1H, s, COO*Me*), 4.27 (1H, d, *J*=17.1 Hz, CH), 7.41–7.48 (1H, m, CH_{ar}), 7.53–7.56 (1H, m, CH_{ar}), 7.67–7.72 (1H, m, CH_{ar}), 7.76–7.83 (3H, m, CH_{ar}), 8.03–8.12 (2H, m, CH_{ar}). ^{13}C NMR ($CDCl_3$): δ 32.04 (CH_2), 40.65 (CO*Me*), 53.75 (COO*Me*), 64.18 (C_{quat}), 121.83 (C_{quat}), 124.98 (CH_{ar}), 125.13 (C_{quat}), 126.35 (CH_{ar}), 126.47 (CH_{ar}), 127.00 (CH_{ar}), 128.01 (CH_{ar}), 131.57 (C_{quat}), 132.57 (C_{quat}), 134.60 (CH_{ar}), 134.73 (CH_{ar}), 136.06 (CH_{ar}), 146.06 (C_{quat}), 148.80 (C_{quat}), 152.54 (C_{quat}), 168.48 (COO*Me*), 193.27 (C=O), 197.30 (C=O), 198.62 (C=O), 202.93 (COMe). IR (KBr) ν_{max}: 3334, 2997, 1732, 1711, 1677, 1661. MS (ES^+) *m/z* (%): 389 ($M+H^+$, 100). Anal. Calcd for $C_{23}H_{16}O_6$: C, 71.13; H, 4.15. Found: C, 71.54; H, 4.52.

4.3.14. *cis* and *trans* Methyl 4-acetyl-2,5-dihydroxy-2-methyl-2,3-dihydronaphtho[1,2-b]furan-3-carboxylate **22a**, **23a**

Yield: 85%. Light-brown crystals, mixture of cis and trans isomers, major (M) 78% and minor (m) 22%. ^1H NMR ($CDCl_3$): δ 1.82 (m) and 1.91 (M) (3H, s, Me), 2.55 (3H, s, CO*Me*), 3.27 (m) and 3.95 (M) (1H, s, OH), 3.74 (m) and 3.78 (M) (3H, s, OMe), 4.56 (m) and 4.61 (M) (1H, s, CH), 7.53–7.61 (1H, m, CH_{ar}), 7.63–7.71 (1H, m, CH_{ar}), 7.94 (1H, d, *J*=8.3 Hz, CH_{ar}), 8.46 (1H, d, *J*=8.3 Hz, CH_{ar}), 11.71 (M) and 11.75 (m) (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 14.12 and 14.21 (OCH_2CH_3), 23.84 (m) and 27.19 (M) (Me), 29.90 and 30.21 (CO*Me*), 60.38 (M) and 62.35 (m) (CH), 61.94 and 62.15 (OCH_2CH_3), 108.72 and 108.98 (C_{quat}), 110.86 and 111.16 (C_{quat}), 111.41 and 112.21 (C_{quat}), 121.82 and 121.92 (CH_{ar}), 124.80 (C_{quat}), 125.18 and 125.27 (CH_{ar}), 126.43 and 126.47 (C_{quat}), 126.87 and 127.07 (CH_{ar}), 130.35 and 130.41 (CH_{ar}), 146.95 and 147.09 (C_{quat}), 158.95 and 159.97 (C_{quat}), 170.31 and 170.54 (*C*OOMe), 202.92 and 203.00 (*C*OMe). IR (KBr) ν_{max}: 1716, 1614. MS (ES^-) *m/z* (%): 315 ($M-H^+$, 100). Anal. Calcd for $C_{17}H_{16}O_6$: C, 64.55; H, 5.10. Found: C, 64.19; H, 5.13.

4.3.15. Ethyl 4-acetyl-2,5-dihydroxy-2-methyl-2,3-dihydronaphtho[1,2-b]furan-3-carboxylate **22b**, **23b**

Yield: 93%. Light-brown crystals (mp: 154–155 °C), mixture of cis and trans isomers, major (M) 92% and minor (m) 8%. ^1H NMR ($CDCl_3$): δ 1.28 (3H, t, *J*=7.1 Hz, OCH_2CH_3), 1.84 (m) and 1.90 (M) (3H, s, Me), 2.59 (3H, s, CO*Me*), 4.10 (M) and 4.13 (m) (1H, s, OH), 4.25 (2H, q, *J*=7.1 Hz, OCH_2CH_3), 4.53 (m) and 4.58 (M) (1H, s, CH), 7.54–7.60 (1H, m, CH_{ar}), 7.64–7.67 (1H, m, CH_{ar}), 7.94 (1H, d, *J*=8.0 Hz, CH_{ar}), 8.46 (1H, d, *J*=8.0 Hz, CH_{ar}), 11.71 (M) and 11.75 (m) (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 14.12 and 14.21 (OCH_2CH_3), 23.84 (m) and 27.19 (M) (Me), 29.90 and 30.21 ($COCH_3$), 60.38 (M) and 62.35 (m) (CH), 61.94 and 62.15 (OCH_2CH_3), 108.72 and 108.98 (C_{quat}), 110.86 and 111.16 (C_{quat}), 111.41 and 112.21 (C_{quat}), 121.82 and 121.92 (CH_{ar}), 124.80 (C_{quat}), 125.18 and 125.27 (CH_{ar}), 126.43 and 126.47 (C_{quat}), 126.87 and 127.07 (CH_{ar}), 130.35 and 130.41 (CH_{ar}), 146.95 and 147.09 (C_{quat}), 158.95 and 159.97 (C_{quat}), 170.31 and 170.54 (*C*OOMe), 202.92 and 203.00 (*C*OMe). IR (KBr) ν_{max}: 1718, 1614. MS (ES^+) *m/z* (%): 331 ($M+H^+$, 100). Anal. Calcd for $C_{18}H_{18}O_6$: C, 65.45; H, 5.49. Found: C, 65.31; H, 5.04.

4.3.16. Ethyl 4-acetyl-2,5-dihydroxy-2-propyl-2,3-dihydronaphtho[1,2-b]furan-3-carboxylate **22c**, **23c**

Yield: 68%. Orange crystals, mixture of cis and trans isomers, major (M) 83% and minor (m) 17%. ^1H NMR ($CDCl_3$): δ 1.02 (3H, t, *J*=7.3 Hz, $CH_2CH_2CH_3$), 1.28 (3H, t, *J*=7.3 Hz, OCH_2CH_3), 1.60–1.74 (2H, m, CH_2), 2.05–2.14 (2H, m, CH_2), 2.58 (M) and 2.62 (m) (3H, s, CO*Me*), 3.21 (m) and 3.95 (M) (1H, s, OH), 4.17–4.29 (2H, m, OCH_2CH_3), 4.52 (m) and 4.60 (M) (1H, s, CH), 7.52–7.61 (1H, m, CH_{ar}), 7.63–7.71 (1H, m, CH_{ar}), 7.93 (1H, d, *J*=8.2 Hz, CH_{ar}), 8.46 (1H, d, *J*=8.2 Hz, CH_{ar}). ^{13}C NMR ($CDCl_3$): δ 14.16 ($CH_2CH_2CH_3$), 14.22 (OCH_2CH_3), 16.62 ($CH_2CH_2CH_3$), 29.98 (CO*Me*), 42.38 ($CH_2CH_2CH_3$), 59.31 (CH), 62.13 (OCH_2CH_3), 110.46 (C_{quat}), 111.17 (C_{quat}), 111.31 (C_{quat}), 121.95 (CH_{ar}), 124.73 (C_{quat}), 125.21 (CH_{ar}), 126.43 (C_{quat}), 127.05 (CH_{ar}), 130.37 (CH_{ar}), 147.07 (C_{quat}), 159.07 (C_{quat}), 170.74 ($COOCH_2CH_3$), 202.97 (*C*OMe). IR (KBr) ν_{max}: 1718, 1614. MS (ES^+) *m/z* (%): 359 ($M+H^+$, 20), 341 ($M-OH^-$, 100). Anal. Calcd for $C_{20}H_{22}O_6$: C, 67.03; H, 6.19. Found: C, 66.95; H, 6.16.

4.3.17. Methyl 4-acetyl-5-hydroxy-2-methylnaphtho[1,2-b]furan-3-carboxylate **24a**

Yield: 82%. Brown solid (mp: 116 °C). ^1H NMR ($CDCl_3$): δ 2.40 (3H, s, Me), 2.79 (3H, s, CO*Me*), 3.90 (3H, s, COO*Me*), 7.49–7.58 (1H, m, CH_{ar}), 7.67–7.76 (1H, m, CH_{ar}), 8.14 (1H, d, *J*=8.3 Hz, CH_{ar}), 8.46 (1H, d, *J*=8.3 Hz, CH_{ar}), 12.46 (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 14.48 (Me), 29.55 (CO*Me*), 51.61 (COO*Me*), 110.03 (C_{quat}), 112.08 (C_{quat}), 117.82 (C_{quat}), 119.77 (CH_{ar}), 123.37 (C_{quat}), 124.31 (C_{quat}), 125.44 (CH_{ar}), 125.79 (CH_{ar}), 130.47 (CH_{ar}), 143.82 (C_{quat}), 156.81 (C_{quat}), 161.65 (C_{quat}), 165.07 (*C*OOMe), 203.41 (*C*OMe). IR (KBr) ν_{max}: 1698, 1674. MS (ES^+) *m/z* (%): 299 ($M+H^+$, 100). Anal. Calcd for $C_{17}H_{14}O_5$: C, 68.45; H, 4.73. Found: C, 68.59; H, 4.49.

4.3.18. Ethyl 4-acetyl-5-hydroxy-2-methylnaphtho[1,2-b]furan-3-carboxylate **24b**

Yield: 75%. Light-brown crystals (mp: 110 °C). ^1H NMR ($CDCl_3$): δ 1.38 (3H, t, *J*=7.1 Hz, OCH_2CH_3), 2.42 (3H, s, Me), 2.80 (3H, s, CO*Me*), 4.36 (2H, q, *J*=7.1 Hz, OCH_2CH_3), 7.50–7.56 (1H, m, CH_{ar}), 7.68–7.74 (1H, m, CH_{ar}), 8.14 (1H, d, *J*=8.3 Hz, CH_{ar}), 8.45 (1H, d, *J*=8.3 Hz, CH_{ar}), 12.43 (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 14.27 (OCH_2CH_3), 14.53 (Me), 29.80 (Me), 61.00 (OCH_2CH_3), 110.21 (C_{quat}), 112.31 (C_{quat}), 118.18 (C_{quat}), 119.76 (CH_{ar}), 123.34 (C_{quat}), 124.29 (C_{quat}), 125.40 (CH_{ar}), 125.74 (CH_{ar}), 130.41 (CH_{ar}), 143.68 (C_{quat}), 156.64 (C_{quat}), 161.45 (C_{quat}), 164.75 ($COOCH_2CH_3$), 203.50 (COMe).

IR (KBr) ν_{max}: 1714, 1633. MS (ES^+) m/z (%): 313 ($M+H^+$, 100). Anal. Calcd for $C_{18}H_{16}O_5$: C, 69.22; H, 5.16. Found: C, 68.97; H, 4.91.

4.3.19. Ethyl 4-acetyl-5-dihydroxy-2-propylnaphtho[1,2-b]furan-3-carboxylate ***24c***

Yield: 75%. Brown solid (mp: 110–111 °C). ^1H NMR ($CDCl_3$): δ 1.05 (3H, t, J=7.3 Hz, $CH_2CH_2CH_3$), 1.38 (3H, t, J=7.3 Hz, OCH_2CH_3), 1.88 (2H, sextet, J=7.3 Hz, $CH_2CH_2CH_3$), 2.42 (3H, s, CO*Me*), 3.14 (2H, t, J=7.3 Hz, $CH_2CH_2CH_3$), 4.36 (2H, q, J=7.3 Hz, OCH_2CH_3), 7.50–7.57 (1H, m, CH_{ar}), 7.67–7.75 (1H, m, CH_{ar}), 8.14–8.17 (1H, m, CH_{ar}), 8.44–8.48 (1H, m, CH_{ar}), 12.43 (1H, s, ArOH). ^{13}C NMR ($CDCl_3$): δ 13.97 ($CH_2CH_2CH_3$), 14.24 (OCH_2CH_3), 21.92 ($CH_2CH_2CH_3$), 29.76 (CO*Me*), 30.08 ($CH_2CH_2CH_3$), 60.97 (OCH_2CH_3), 110.24 (C_{quat}), 112.06 (C_{quat}), 118.15 (C_{quat}), 119.83 (CH_{ar}), 123.37 (C_{quat}), 124.37 (C_{quat}), 125.42 (CH_{ar}), 125.74 (CH_{ar}), 130.38 (CH_{ar}), 143.74 (C_{quat}), 156.72 (C_{quat}), 164.78 (C_{quat}), 165.04 ($COOCH_2CH_3$), 203.48 (*CO*Me). IR (KBr) ν_{max}: 1715, 1638. MS (ES^+) m/z (%): 341 ($M+H^+$, 100). Anal. Calcd for $C_{20}H_{20}O_5$: C, 70.57; H, 5.92. Found: C, 70.77; H, 5.82.

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References and notes

1. Finley, K. T. In *Quinones as Synthons*; Patai, S., Rappoport, Z., Eds.; The Chemistry of Quinonoid Compounds; John Wiley & Sons: Chichester, New York, Brisbane, Toronto, Singapore, 1988; Vol. 2, Part 1, Chapter 11, pp. 654–658.
2. Naruta, Y. *J. Am. Chem. Soc.* **1980**, *102*, 3774.
3. Hosomi, A.; Sakurai, H. *Tetrahedron Lett.* **1977**, 4041.
4. (a) Aldersley, M. F.; Dean, F. M.; Nayyirmazhir, R. *J. Chem. Soc., Perkin Trans. 1* **1983**, 1753; (b) Aldersley, M. F.; Dean, F. M.; Mann, B. E. *J. Chem. Soc., Perkin Trans. 1* **1986**, 2217; (c) Aldersley, M. F.; Dean, F. M.; Hanzah, A. S. *Tetrahedron Lett.* **1986**, *27*, 255; (d) Aldersley, M. F.; Chishti, S. H.; Dean, F. M.; Douglas, M. E.; Ennis, D. S. *J. Chem. Soc., Perkin Trans. 1* **1990**, 2163; (e) Kesteleyn, B.; Nguyen Van, T.; De Kimpe, N. *Tetrahedron* **1999**, *55*, 2091.
5. (a) Lee, H.-J.; Park, S.-Y.; Kim, J. S.; Song, H. M.; Suh, M.-E.; Lee, C.-O. *Bioorg. Med. Chem.* **2003**, *11*, 4791; (b) Lee, H.-J.; Suh, M.-E.; Lee, C.-O. *Bioorg. Med. Chem.* **2003**, *11*, 1511; (c) Makosza, M.; Nizamov, S. *Tetrahedron* **2001**, *57*, 9615; (d) Makovetskii, V. P.; Grubyi, V. P. *Ukr. Khim. Zh. (Russ. Ed.)* **1989**, *55*, 436; (e) Gorelik, M. V.; Arinich, L. V.; Kotlyarevskii, O. V.; Feskova, E. A. *Zh. Vses. Khim. Ova.* **1985**, *30*, 576; (f) Gorelik, M. V.; Arinich, L. V.; Kotlyarevskii, O. V.; Feskova, E. A. *Zh. Org. Khim.* **1986**, *22*, 147; (g) Okamoto, M.; Ohta, S.; Terada, S. *Yakugaku Zasshi* **1979**, *12*, 1219; (h) Reynolds, G. A.; VanAllan, J. A.; Adel, R. E. *J. Org. Chem.* **1965**, *30*, 3819; (i) Widmer, E.; Meyer, J. W.; Walser, A.; Hardegger, E. *Helv. Chim. Acta* **1965**, *48*, 538.
6. (a) Tseng, C.-M.; Wu, Y.-L.; Chuang, C.-P. *Tetrahedron* **2004**, *60*, 12249; (b) Tseng, C.-C.; Wu, Y.-L.; Chuang, C.-P. *Tetrahedron* **2002**, *58*, 7625; (c) Tsai, A.-I.; Wu, Y.-L.; Chuang, C.-P. *Tetrahedron* **2001**, *57*, 7829; (d) Wang, S.-F.; Chuang, C.-P.; Lee, J.-H. *Heterocycles* **1999**, *50*, 489; (e) Chuang, C.-P.; Wang, S.-F. *Tetrahedron* **1998**, *54*, 10043; (f) Chuang, C.-P.; Wang, S.-F. *J. Chin. Chem. Soc. (Taipei)* **1997**, *44*, 271; (g) Yamashita, Y.; Katsuki, T. *Synlett* **1996**, 829; (h) Murphy, W. S.; Neville, D.; Ferguson, G. *Tetrahedron Lett.* **1996**, *37*, 7615; (i) Chuang, C.-P.; Wang, S.-F. *Tetrahedron Lett.* **1994**, *35*, 4365.
7. De, S. K.; Gibbs, R. A. *Tetrahedron Lett.* **2005**, *46*, 1647.