Pergamon

Tetrahedron 57 (2001) 4429–4436

TETRAHEDRON

Efficient preparation of 3-substituted-furan-2(5*H*)-ones and their direct vinylogous aldol addition

Marco Bella,[a,b,*] Giovanni Piancatelli[a,*] and Antonella Squarcia[a]

[a]*Dipartimento di Chimica, Università 'La Sapienza', Piazzale Aldo Moro 5, Box No. 34-Roma 62, 00185 Rome, Italy*
[b]*Centro CNR di Studio per la Chimica delle Sostanze Organiche Naturali, Piazzale Aldo Moro 5, Box No. 34-Roma 62, 00185 Rome, Italy*

Received 25 October 2000; revised 1 March 2001; accepted 15 March 2001

Abstract—The deprotonation of 3-substituted-furan-2(5*H*)-ones **1**, obtained via the hydrolysis of 3-substituted-2,5-dihydro-2,5-dimethoxyfurans, affords in the reaction with both aromatic and aliphatic aldehydes regioselectively the unsaturated 3-substituted 5-(1′-hydroxy)-γ-butyrolactones, such as **4**, **5**, **6**, **7**, **8**, **9** and **10**. The use of Lewis acids allows modulation of the diastereoisomeric ratios. The subsequent reduction, carried out with nickel boride, gives rise to the formation of the corresponding saturated 5-(1′-hydroxy)-γ-butyrolactones, such as **11**, **12** and **13**.

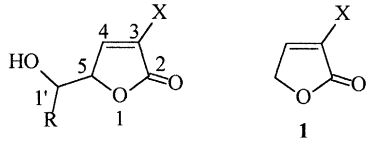
1. Introduction

Unsaturated and saturated 5-(1′-hydroxy)-γ-butyrolactones comprise a very important class of organic compounds both existing in natural products and in synthetic bioactive molecules.[1]

Owing to the growing interest in these substances, both syntheses involving *de novo* construction of the lactone ring or the functionalization of butenolides are continously published in the literature; particularly, there is the monumental work of Casiraghi and Rassu exploiting the condensation of trimethylsilyloxyfuran (synthetic equivalent of the anion of furan-2(5*H*)-one) with chiral aldehydes to obtain a large number of useful intermediates in organic synthesis.[2]

In strict contrast, only a few authors report the *direct* addition of aldehydes to the readily available metal enolates of furan-2(5*H*)-ones. This is probably due to the relatively low-yielding and time-consuming synthesis of these systems, but mainly due to the formation of both the C5 and C3 functionalized products in the reaction with electrophiles. To date, it is known that enolate formation of furan-2(5*H*)-one and its condensation with aliphatic aldehydes gives predominantly (3:1) the C3 functionalized products as major regioisomer together with the C5 functionalized product (as a 1:1 *syn*/*anti* mixture of diastereoisomers).[3] This methodology was employed only once in the literature in the key step for the preparation of melondrinol,[4] affording the desired product in low yield, presumably due to the formation of regioisomers. Employing aromatic aldehydes, the reaction is reported to be regioselective.[5] The anions of particular butenolides, suitably substituted as methyl tetronate, 4-methoxyfuran-2(5*H*)-one, undergo prevalently functionalization on the C5 with electrophiles.[6]

Herein we describe a method for the easy synthesis of 3-substituted-furan-2(5*H*)-ones **1** (Fig. 1) in which the phenylselenyl group and halogen atoms act as 'protective groups' for the C3 position that allow specific functionalization at the C5 position and could then be easily removed having performed the aldol addition. Butenolides with halogen substituents on the double bond have been developed as cytostatics[7] and are present in some naturally occurring rubrolides.[8] Furthermore, the preparation of 4-halo- and *pseudo*-halofuran-2(5*H*)-ones is described[9] as well as their functionalization with aromatic and vinylic moieties (Suzuki and Stille coupling),[10] but there is a paucity of general methods which allows us to obtain the corresponding 3-furan-2(5*H*)-ones.[11,12]



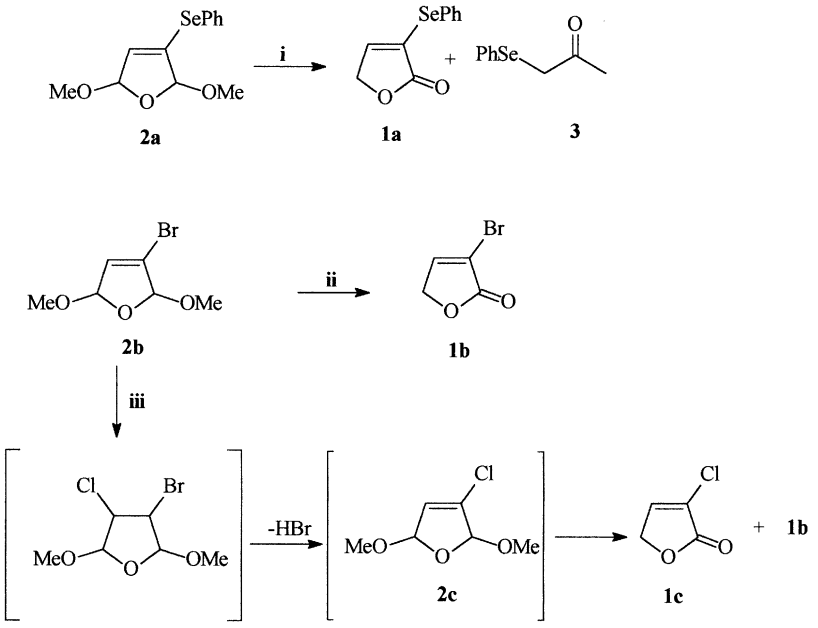
1

a, X=SePh
b, X=Br
c, X=Cl

Figure 1.

Keywords: regioselective aldol reaction; furanones.
* Corresponding authors. Tel.: +39-6-4991-3861; fax: +39-6-490631; e-mail: Giovanni.Piancatelli@uniroma1.it

0040–4020/01/$ - see front matter
PII: S0040-4020(01)00331-3

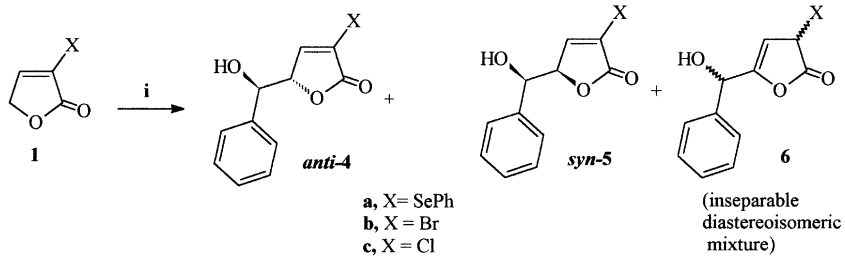


Scheme 1. i: 1 M HCl_{aq}, acetone, 2 h, rt, 66%; **ii**: 63% HBr_{aq}, acetone, 2 h, rt, 80%; **iii**: 37% HCl_{aq}, acetone, 2 h, rt, **1c**=70%, **1b**=12%.

2. Results and discussion

3-Phenylselenylfuran-2(5*H*)-one **1a** was prepared as previously described[13] (acetone, 1 M HCl, 66%) from 3-phenylselenyl-2,5-dihydro-2,5-dimethoxyfuran **2a**; we prefer the use of acetone instead of CH_3CN because despite the lower yield (66% instead of 81%) the only by-product is the easily separable 1-phenylselenylacetone **3**.[14]

Compound **1b** was obtained as a single product in the

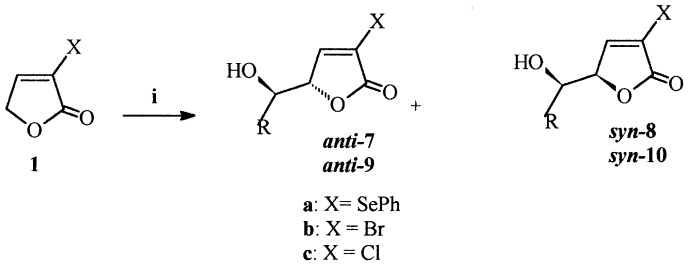


Scheme 2. i: LHMDS, 1.5 equiv., THF, 1 h, −78°C, then Lewis acid, PhCHO, 15 min.

Table 1. Vinylogous aldol condensation of 3-substituted-furan-2(5*H*)-ones **1** with benzaldehyde

Entry	Starting materials	Lewis acid	**5** *syn*: **4** *anti* ratio	Temp. of addition of the aldehyde (°C)	Yield (%)	
					4, **5**	**6**
1	**1a**	None	1:2	−78	40	–
2	**1a**	$BF_3{\cdot}Et_2O$[a]	6:1	−78	83	–
3	**1a**	$Zn(OTf)_2$[c]	1:4	−78	70	–
4	**1a**	$Sn(OTf)_2$[c]	1:3.5	−78	70	–
5	**1a**	$BF_3{\cdot}Et_2O$[a,b]	1:1	−78	95	–
6	**1a**	$Zn(OTf)_2$[b,c]	1:6	−78	70	–
7	**1b**	None	–	−78	–	30
8	**1b**	$BF_3{\cdot}Et_2O$[a]	>20:1	−78	65	15
9	**1b**	$BF_3{\cdot}Et_2O$[a]	>20:1	20	70	4
10	**1c**	None	–	−78	–	20
11	**1c**	$BF_3{\cdot}Et_2O$[a]	>20:1	−78	65	15
12	**1c**	$BF_3{\cdot}Et_2O$[a]	3:1	20	70	–

[a] 20 equiv. of $BF_3{\cdot}Et_2O$ were employed.
[c] 1.5 equiv. were used.
[b] Toluene instead of THF was employed as solvent.



Scheme 3. i: LHMDS, 1.5 equiv., THF, −78°C 1 h, then $BF_3{\cdot}Et_2O$, 20 equiv., RCHO: $CH_3CH{=}CHCHO$ and $C_{12}H_{25}CHO$, 15 min.

Table 2. Vinylogous aldol condensation of furan-2(5*H*)-ones **1** with crotonaldehyde and tridecyl aldehyde

Entry	Starting materials	Products	Aldehyde	*Anti*/*syn* ratio	Yield (%)
1	**1a**	**7a**, **8a**	Crotonaldehyde	1:1	90
2	**1a**	**9a**, **10a**	n-$C_{12}H_{25}CHO$	1:1	90
3	**1b**	**7b**, **8b**	Crotonaldehyde	1:1	90
4	**1b**	**9b**, **10b**	n-$C_{12}H_{25}CHO$	1:2	70
5	**1c**	**7c**, **8c**	Crotonaldehyde	1:1	85
6	**1c**	**9c**, **10c**	n-$C_{12}H_{25}CHO$	1:1	85

reaction of **2b** with concentrated HBr (acetone, 63% HBr_{aq}, rt, 80%). Using concentrated HCl (acetone, 37% HCl_{aq}, rt), surprisingly we isolated instead 3-chlorofuran-2(5*H*)-one **1c** (70%) and only in low yields (12%) the desired 3-bromofuran-2(5*H*)-one **1b**. This may be due to the formation of **2c** as key intermediate, through an addition of HCl/elimination of HBr, prior to lactonization (Scheme 1).

Noteworthy, even if the transformation of the 3-substituted-2,5-dihydro-2,5-dimethoxyfurans into the 3-substituted-furan-2(5*H*)-ones has been occasionally reported,[15] these are the only examples in which a single regioisomer is obtained in such a reaction.

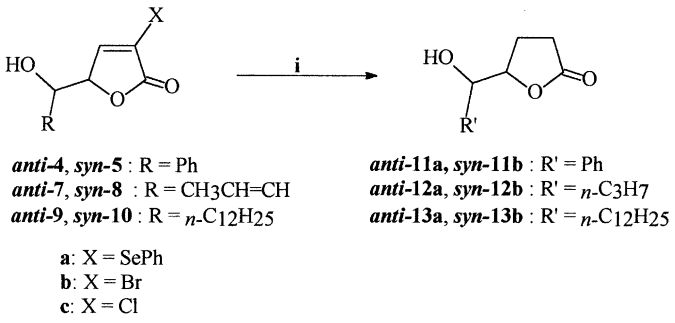
The reaction of compound **1a** with aromatic aldehydes (LHMDS, THF, then Lewis acids, PhCHO; Scheme 2 and Table 1), gave only the C5 functionalization products *anti*-**4a**, and *syn*-**5a**; no traces of dialkylated products were detected even if the reaction was performed with an excess of base.[16] Lewis acids made it possible both to increase yields and to modulate the diastereoselectivity (from 1:6 *anti*/*syn* ratio up to 6:1; Table 1, entries 2, 6).

In contrast, halogenated compounds **1b** and **1c** in the reaction without Lewis acids gave only the isomeric 5-(1′-hydroxy)-furan-2(3*H*)-ones **6b** and **6c** as an inseparable 3:1 mixture of diastereoisomers (20–30%, Table 1, entries 7, 10). The presence of $BF_3{\cdot}Et_2O$ as Lewis acid in the reaction medium made it possible to isolate the desired isomers *anti*-**4b**, **4c** and *syn*-**5b**, **5c**. The enolate of the 3-phenylselenylfuran-2(5*H*)-one **1a** is unstable at rt as the lithiated furan-2(5*H*)-one,[5] while the enolates derived from 3-bromo- and 3-chlorofuran-2(5*H*)-ones **1b** and **1c** could be warmed up to rt without significant decomposition. Adding benzaldehyde to the lithium enolates of **1b** and **1c** in the presence of $BF_3{\cdot}Et_2O$ both at rt and at −78°C, the products were the expected compounds **4b**, **4c** and **5b**, **5c**, showing an excellent diastereoselectivity with a >20:1 *syn*/*anti* ratio (Table 1, entries 8, 9, 11).

With the long-chain aliphatic aldehyde tridecanal as electrophile in order to mimic the structure of the natural

Table 3. Reduction of unsaturated 3-substituted-5-(1′-hydroxy)-γ-butyrolactones to 5-(1′-hydroxy)-γ-butyrolactones **11**, **12**, **13**

Entry	Starting material	Products	Yield (%)
1	**4a**, **5a**	**11a**, **11b**	90
2	**4b**, **5b**	**11a**, **11b**	90
3	**4c**, **5c**	**11a**, **11b**	85
4	**7a**, **8a**	**12a**, **12b**	70
5	**7b**, **8b**	**12a**, **12b**	70
6	**7c**, **8c**	**12a**, **12b**	70
7	**9a**, **10a**	**13a**, **13b**	80
8	**9b**, **10b**	**13a**, **13b**	70
9	**9c**, **10c**	**13a**, **13b**	90



Scheme 4. i: $NiCl_2$, $NaBH_4$, THF/MeOH, 10 min, 0°C.

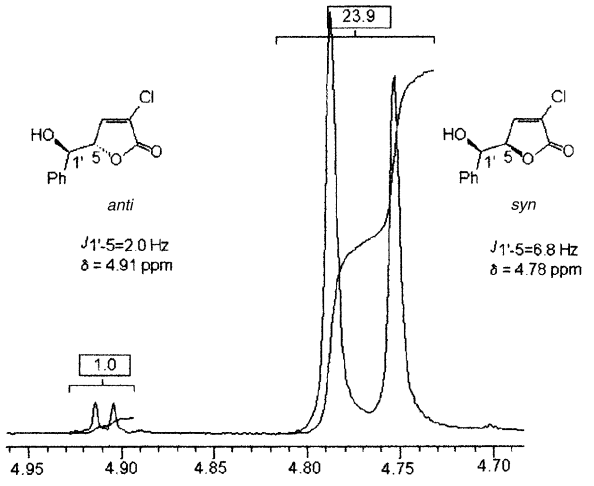


Figure 2. >20:1 *syn/anti* mixture of 3-chloro-5-(1′hydroxy)-furan-2(5*H*)-ones: resonance of proton on the C1′ after D_2O addition.

substance muricatacin,[17] we obtained a mixture of only the C5 functionalized compounds with little or no diastereoisomeric excesses albeit in good yields (Scheme 3 and Table 2, entries 2, 4, 6). Employing crotonaldehyde (the recently isolated sapinofuranones show a similar structural moiety),[18] only the desired 1,2 functionalization products are formed with no detectable trace of 1,4-conjugate addition compounds (Table 2, entries 1, 3, 5).

The removal of the double bond and the phenylselenyl group was accomplished by reaction with $NiCl_2/NaBH_4$ (Scheme 4 and Table 3, entries 1, 4, 7). Although it is already reported that this reagent combination removes the phenylselenyl group and the conjugate double bonds separately,[19] the one pot procedure applied on all compounds including halogenated ones (entries 2, 3, 5, 6, 8, 9) gave rise to the desired γ-butyrolactones in good yields. In addition, the side chain double bond of compounds **7a**, **8a**, **7b**, **8b** and **7c**, **8c** was also hydrogenated in this procedure (entries 4, 5, 6).

Relative *syn/anti* stereochemistry was assigned on the analysis of ^{1}H-NMR spectra; the *syn* diastereoisomers have a larger value of the coupling constant $J_{5-1'}$ between the protons on the C5 and the C1′ and a lower chemical shift of the protons on the C1 and C3 if compared with the corresponding *anti* isomers (Fig. 2).[20] A confirmation of our assignments is also the chemical correlation of the compound *syn*-**5b** with the known *syn*-**14** (Scheme 5).[21]

3. Conclusions

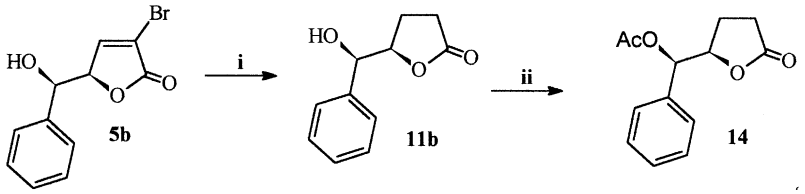
Our synthesis of 1′-hydroxysubstituted-γ-butyrolactones *via* direct vinylogous aldol condensation of furan-2(5*H*)-ones is an alternative methodology with respect to the Lewis acid-mediated silyloxyfuran condensation with aldehydes. The diastereoselectivity could be effectively modulated employing Lewis acids and selecting the experimental conditions; we also describe a new regioselective method for the preparation of halogenated furan-2(5*H*)-ones **1b** and **1c**. Work is in progress in our group to apply this reactivity to other electrophiles in light of the greater nucleophilicity of our lithium enolates compared to the silyl enol ethers generally used up to now.

4. Experimental

4.1. General experimental

^{1}H-NMR and ^{13}C-NMR spectra were recorded on a Varian Gemini 200 spectrometer with $CDCl_3$ as the solvent and as the internal standard. Coupling constants are quoted in Hertz (Hz). IR spectra were obtained with a Shimazu IR 435 grating infrared spectrophotometer. Melting points were determined on a Mettler FP apparatus and are uncorrected. Yields are given for isolated products after column chromatography showing a single spot on the TLC plate and no detectable impurities in the ^{1}H-NMR spectrum. Compounds **2a**,[22] **2b**[23] were prepared according to literature; spectra of compounds **12a**, **12b**,[24] and **13a**, **13b**[25] are in agreement with those previously reported. LHMDS (1 M solution in hexane), benzaldehyde, tridecanal, crotonaldehyde, boron trifluoride etherate, zinc(II) triflate, and tin(II) triflate were used as purchased (Aldrich). THF and toluene were dried over sodium wire and distilled prior to use. Hexane, acetone, ethyl acetate, methanol, diethyl ether, acetic anhydride, pyridine, 63% HBr and 37% HCl solution are analytical grade reagents purchased from Carlo Erba. Silica gel (230–400 mesh) was purchased from Merck.

4.1.1. 3-Phenylselenylfuran-2(5*H*)-one 1a. To a solution of 3-phenylselenyl-2,5-dihydro-2,5-dimethoxyfuran **2a** (1.00 g, 3.51 mmol) in acetone (30 mL) placed in an open-air round-bottomed flask with vigorous stirring, 1 M HCl solution (1 mL) was added dropwise. The colour of the solution changed from colourless to light yellow then again to colourless. The reaction mixture was stirred until no starting material was detectable on TLC (2 h). The reaction mixture was diluted with ethyl acetate, washed once with water, the organic layer was dried over anhydrous Na_2SO_4 and solvent evaporated *in vacuo* to give an oil that was purified *via* flash chromatography on silica gel (15 g, eluant hexane/ethyl acetate 9:1, then hexane/ethyl acetate 2:1) to give 553 mg of compound **1a** (2.32 mmol, 66%) as pale



Scheme 5. i: $NiCl_2$, $NaBH_4$, THF/MeOH, 10 min, rt, 90%; **ii**: Ac_2O, Py, 24 h, rt, 85%.

yellow solid [mp=55–58°C (ether/hexane). Lit.[14]: 57–58°C], and 80 mg of compound **3**[26] (10%) as an oil.

4.1.2. 3-Bromofuran-2(5*H*)-one 1b. The same experimental procedure for the preparation of **1a**, starting from **2b** (1.00 g, 4.78 mmol) gave **1b** (3.83 mmol, 624 mg, 80%) employing 63% HBr solution (7 mL). White solid, mp=54–58°C (ether/hexane). Lit.[11a]: 56–58°C. ^{1}H-NMR, δ ($CDCl_3$): 4.86 (2H, d, J=2 Hz, CH_2CH=); 7.62 (1H, t, J=2 Hz, CH=C). ^{13}C-NMR, δ ($CDCl_3$): 71.90 (*C*H_2CH=); 113.70 (CH=*C*); 149.59 (*C*H=C); 169.39 (*C*O).

4.1.3. 3-Chlorofuran-2(5*H*)-one 1c. The same experimental procedure for the preparation of **1a** starting from **2b** (1.00 g 4.78 mmol) gave **1c** as a white solid (3.35 mmol, 360 mg, 70%) and **1b** (0.57 mmol, 93 mg, 12%) employing 37% HCl solution (7 mL). Mp=23–26°C (ether/hexane). Lit.[11b]: 25–27°C. ^{1}H-NMR, δ ($CDCl_3$): 4.89 (2H, d, J=2 Hz, CH_2CH=); 7.41 (1H, t, J=2 Hz, CH=C). ^{13}C-NMR, δ ($CDCl_3$): 70.24 (*C*H_2CH=); 125.25 (CH=*C*); 144.99 (*C*H=C); 168.79 (*C*O).

4.2. General procedure for the direct aldol condensation of 1 with aldehydes

To a cooled (−78°C) solution of **1a** (0.31 mmol) in dry THF (2 mL) under argon, LHMDS (0.32 mL, 1 M solution in THF, 1.05 equiv.) was added dropwise. The reaction mixture was stirred at this temperature for 45 min. A THF (1 mL) solution of Lewis acid (see Table 1) was added also at −78°C under argon and after 10 min a THF (1 mL) solution of aldehyde (1.5 equiv.). After 5 min, NH_4Cl (2 M solution, 5 mL) was added dropwise and the mixture diluted with ethyl acetate (10 mL). The organic layer was washed with brine (3 mL), dried (Na_2SO_4) and solvent evaporated *in vacuo* to give an oil. This was purified by flash chromatography on silica gel (3 g, eluant hexane/ethyl acetate 9:1 then hexane/ethyl acetate 6:1) to give pure compounds as depicted in Table 1.

4.2.1. *anti*-(1′*R, 5*S**)-1′-Hydroxybenzyl-3-phenylselenylfuran-2(5*H*)-one 4a.** Dense pale yellow oil: [Found: C, 58.90; H, 4.13. $C_{17}H_{14}O_3Se$ requires C, 58.96; H, 4.08%]. ^{1}H-NMR, δ ($CDCl_3$): 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 4.97 (1H, d, J=4.4 Hz, C*H*OH); 5.03 (1H, dd, J_1=4.4 Hz, J_2=1.8 Hz, C*H*CH=); 6.73 (1H, d, J=1.8 Hz, CHC*H*=); 7.2–7.5 (8H, m, Ph); 7.5–7.6 (2H, m, Ph). ^{13}C-NMR, δ ($CDCl_3$): 73.91 (*C*HOH); 87.28 (*C*HCH=); 126.0, 126.7, 127.0, 127.5, 127.7, 128.3, 128.7, 130.0 (2 Ph); 135.56 (CH=*C*); 148.65 (*C*H=C); 171.28 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3350; 3110; 1756; 1630; 1210. HRMS (FAB) 346.01076 ($C_{17}H_{14}O_3Se$ requires 346.01081).

4.2.2. *syn*-(1′*R, 5*R**)-1′-Hydroxybenzyl-3-phenylselenylfuran-2(5*H*)-one 5a.** Dense pale yellow oil: [Found: C, 58.98; H, 4.03. $C_{17}H_{14}O_3Se$ requires C, 58.96; H, 4.08%]. ^{1}H-NMR, δ ($CDCl_3$): 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 4.69 (1H, d, J=6.4 Hz, C*H*OH); 5.01 (1H, dd, J_1=6.4 Hz, J_2=1.8 Hz, C*H*CH=); 6.52 (1H, d, J=1.8 Hz, CHC*H*=); 7.2–7.5 (8H, m, Ph); 7.5–7.6 (2H, m, Ph). ^{13}C-NMR, δ ($CDCl_3$): 75.67 (*C*HOH); 87.45 (*C*HCH=); 126.0, 126.5, 127.1, 128.2, 128.8, 129.3, 129.8, 130.0 (2 Ph); 135.73 (CH=*C*); 146.99 (*C*H=); 171.28 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3350; 3110; 1756; 1630; 1210. HRMS (FAB) 346.0100 ($C_{17}H_{14}O_3Se$ requires 346.0108).

4.2.3. *syn*-(1′*R, 5*R**)-3-Bromo-1′-hydroxybenzylfuran-2(5*H*)-one 5b.** White solid, mp=100–102°C (ether/hexane): [Found: C, 49.32; H, 3.16. $C_{11}H_9O_3Br$ requires C, 49.26; H, 3.38%]. ^{1}H-NMR, δ ($CDCl_3$): 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 4.76 (1H, d, J=6.8 Hz, C*H*OH); 5.11 (1H, dd, J_1=6.8 Hz, J_2=1.8 Hz, C*H*CH=); 7.24 (1H, d, J=1.8 Hz, CHC*H*=); 7.4 (5H, m, Ph). ^{13}C-NMR, δ ($CDCl_3$): 73.12 (*C*HOH); 86.12 (*C*HCH=); 114.47; 126.83; 128.98; 129.27 (Ph); 137.40 (CH=*C*); 149.92 (*C*H=C); 168.17 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3615; 3100; 1775; 1625; 1200. HRMS (FAB) 267.97355 ($C_{11}H_9O_3Br$ requires 267.97350).

4.2.4. 3-Bromo-1′-hydroxybenzylfuran-2(3*H*)-one 6b. Inseparable 3:1 mixture of diastereoisomers. Colourless oil: [Found: C, 49.36; H, 3.51. $C_{11}H_9O_3Br$ requires C, 49.26; H, 3.38%]. ^{1}H-NMR, δ ($CDCl_3$): (major diastereoisomer) 2.5 (1H, br, disappears after D_2O addition, CHO*H*); 5.10 (2H, s,); 7.4 (6H, m). ^{13}C-NMR, δ ($CDCl_3$): (major diasteroisomer) 73.11; 85.90; 114.40; 126.16; 128.82; 129.00; 137.86; 149.50; 168.16 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3640; 3010; 1770; 1645; 1210. HRMS (FAB) 267.97353 ($C_{11}H_9O_3Br$ requires 267.97350).

4.2.5. *anti*-(1′*R, 5*S**)-3-Chloro-1′-hydroxybenzylfuran-2(5*H*)-one 4c.** Dense pale yellow oil: [Found: C, 58.95; H, 4.23. $C_{11}H_9O_3Cl$ requires C, 58.81; H, 4.04%]. ^{1}H-NMR, δ ($CDCl_3$): 2.5 (1H, br, disappears after D_2O addition, CHO*H*); 4.90 (1H, d, J=2 Hz, C*H*OH); 5.10 (1H, dd, J_1=2 Hz, J_2=1.8 Hz, C*H*CH=); 7.37 (1H, d, J=1.8 Hz, CHC*H*=); 7.4 (5H, m, Ph). ^{13}C-NMR, δ ($CDCl_3$):): 75.37 (*C*HOH); 84.30 (*C*HCH=); 126.09; 127.80; 128.98; 129.27 (Ph); 140.36 (CH=*C*); 145.81 (*C*H=C); 170.01 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3615; 3120; 1770; 1635; 1090. HRMS (FAB) 224.02406 ($C_{11}H_9O_3Cl$ requires 224.02402).

4.2.6. *syn*-(1′*R, 5*R**)-3-Chloro-1′-hydroxybenzylfuran-2(5*H*)-one 5c.** White solid, mp=87–89°C (ether/hexane): [Found: C, 58.79; H, 4.13. $C_{11}H_9O_3Cl$ requires C, 58.81; H, 4.04%]. ^{1}H-NMR, δ ($CDCl_3$): 2.5 (1H, br, disappears after D_2O addition, CHO*H*); 4.74 (1H, d, J=6.8 Hz, C*H*OH); 5.13 (1H, dd, J_1=6.8 Hz, J_2=1.8 Hz, C*H*CH=); 7.05 (1H, d, J=1.8 Hz, CHC*H*=); 7.4 (5H, m, Ph). ^{13}C-NMR, δ ($CDCl_3$): 73.12 (*C*HOH); 84.36 (*C*HCH=); 126.09; 126.80; 128.98; 129.27 (Ph); 137.36 (CH=*C*); 144.81 (*C*H=C); 167.50 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3615; 3120; 1770; 1635; 1090. HRMS (FAB) 224.02406 ($C_{11}H_9O_3Cl$ requires 224.02402).

4.2.7. 3-Chloro-1′-hydroxybenzylfuran-2(3*H*)-one 6c. Inseparable 3:1 mixture of diastereoisomers. Colourless oil: [Found: C, 58.72; H, 4.20. $C_{11}H_9O_3Cl$ requires C, 58.81; H, 4.04%]. ^{1}H-NMR, δ ($CDCl_3$): (minor diastereoisomer): 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 5.07 (1H, s, C*H*OH); 5.13 (1H, d, J=1.8 Hz, C*H*CH=); 7.21 (1H, d J=1.8 Hz, CH=C); 7.4 (5H, m, Ph); (major diasteroisomer): 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 5.09 (1H, s, C*H*OH); 5.11 (1H, d,

J=1.8 Hz, C*H*CH=); 7.21 (1H, d, J=1.8 Hz, C*H*=C); 7.4 (5H, m, Ph). ^{13}C-NMR, δ ($CDCl_3$): (major diasteroisomer): 75.37 (*C*HOH); 84.26 (*C*HCH=); 126.09; 126.80; 128.98; 129.27 (Ph); 137.36 (CH=*C*); 144.84 (*C*H=C); 167.50 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3620; 3115; 1777; 1650; 1110. HRMS (FAB) 224.02416 ($C_{11}H_9O_3Cl$ requires 224.02402).

4.2.8. *anti*-(1′*R, 5*S**)-1′-Hydroxycrotyl-3-phenylselenylfuran-2(5*H*)-one 7a and *syn*-(1′*R**, 5*R**)-1′-hydroxycrotyl-3-phenylselenylfuran-2(5*H*)-one 8a.** Inseparable mixture 1:1 of diastereoisomers. Dense pale yellow oil: [Found: C, 54.28; H, 4.68. $C_{14}H_{14}O_3Se$ requires C, 54.38; H, 4.56%]. ^{1}H-NMR, δ ($CDCl_3$), *syn*/*anti* mixture: 1.70 (6H, m, 2CH_3); 3.0 (2H, br, disappears after D_2O addition, CHO*H*); 4.0–4.1 (1H, m, C*H*OH); 4.2–4.3 (1H, m, C*H*OH); 4.85 (1H, dd, J_1=2 Hz, J_2=2.4 Hz, C*H*C=); 4.88 (1H, dd, J_1=1.4Hz, J_2=1.6 Hz, C*H*C=); 5.35–5.40 (1H, m, CH=C*H*Me); 5.4–5.5 (1H, m, CH=C*H*Me); 5.7–5.8 (1H, m, C*H*=CHMe); 5.8–5.9 (1H, m, C*H*=CHMe); 6.75 (1H, d, J=1.8 Hz, C*H*=CSePh); 6.84 (1H, d, J=1.8 Hz, C*H*=C-SePh); 7.4 (5H, m. Ph); 7.65–7.70 (5H, m, Ph). ^{13}C-NMR, δ ($CDCl_3$), *syn*/*anti* mixture: 18.37 (2*C*H_3); 72.98 (*C*HOH); 73.95 (*C*HOH); 86.61 (*C*HC=); 86.79 (*C*HC=); 127.73; 127.97; 129.30; 129.54; 129.65; 129.72; 129.75; 130.37; 130.39; 130.42; 131.43; 132.04; 135.78 (CH=*C*SePh); 135.86 (CH=*C*SePh); 146.79 (*C*H=CSePh); 146.90 (*C*H=CSePh); 171.35 (*C*O); 171.56 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3520; 3100; 1756; 1650; 1630; 1200. HRMS (FAB) 310.01088 ($C_{14}H_{14}O_3Se$ requires 310.01081).

4.2.9. *anti*-(1′*R, 5*S**)-1′-Hydroxytridecyl-3-phenylselenylfuran-2(5*H*)-one 9a and *syn*-(1′*R**, 5*R**)-1′-hydroxytridecyl-3-phenylselenylfuran-2(5*H*)-one 10a.** Inseparable mixture 1:1 of diastereoisomers. Dense pale yellow oil: [Found: C, 63.26; H, 7.36. $C_{23}H_{32}O_3Se$ requires C, 63.28; H, 7.39%]. ^{1}H-NMR, δ ($CDCl_3$): (*anti*) 0.86 (3H, t, J=6.6 Hz, CH_3CH$_2$); 1.24 (22H, bs, $CH_3(CH_2)_{11}$); 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 3.7–3.8 (1H, m, C*H*OH); 4.85 (1H, dd, J_2=1.8 Hz, J_3=5.2 Hz, C*H*CH=); 6.88 (1H, d, J_1=1.8 Hz, CHC*H*=); 7.3–7.5 (3H, m, Ph); 7.5–7.7 (2H, m, Ph). ^{1}H-NMR, δ ($CDCl_3$): (*syn*) 0.86 (3H, t, J=6.6 Hz, CH_3CH$_2$); 1.24 (22H, s, $CH_3(CH_2)_{11}$); 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 3.6–3.7 (1H, m, C*H*OH); 4.82 (1H, dd, J_1=1.8 Hz, J_2=7.0 Hz, C*H*CH=); 6.77 (1H, d, J=1.8 Hz, CHC*H*=); 7.3–7.5 (3H, m, Ph); 7.5–7.7 (2H, m, Ph). ^{13}C-NMR, δ ($CDCl_3$), *syn*/*anti* mixture: 14.62 (2 peaks, *C*H_3); 23.18; 25.98; 26.03; 29.71; 29.85; 29.92; 30.00; 30.07; 30.15; 32.40; 33.4 (11 peaks, *C*H_2); 72.13 (*C*HOH); 72.29 (*C*HOH); 87.16 (*C*HCH=); 87.23 (*C*HCH=); 126.14; 126.19; 129.69; 129.82; 129.90; 130.41; 135.78; 135.83; 136.11; 136.96; 147.32 (*C*H=C-SePh); 147.41 (*C*H=CSePh); 171.64 (*C*O); 171.69 (*C*O). IR ν ($CHCl_3$)/cm^{-1}, *syn*/*anti* mixture: 3100; 2930; 1754; 1625; 1150. HRMS (FAB) 436.15160 ($C_{23}H_{32}O_3Se$ requires 436.15167).

4.2.10. *anti*-(1′*R, 5*S**)-3-Bromo-1′-hydroxycrotylfuran-2(5*H*)-one 7b.** Dense colourless oil: [Found: C, 41.36; H, 3.79. $C_8H_9O_3Br$ requires C, 41.38; H, 3.91%]. ^{1}H-NMR, δ ($CDCl_3$): 1.7–1.8 (3H, m, CH_3); 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 4.39 (1H, t, J=5.4, C*H*OH); 4.91 (1H, dd, J_1=1.8 Hz, J_2=4.6 Hz, C*H*CH=); 5.4–5.5 (1H, m, CH=C*H*Me), 5.8–6.0 (1H, m, C*H*=CHMe), 7.57 (1H, d, J=1.8 Hz, C*H*=CBr). ^{13}C-NMR, δ ($CDCl_3$): 18.00 (*C*H_3); 73.15 (*C*HOH); 85.32 (*C*HCH=); 114.19 (CH=*C*HMe); 126.98 (*C*H=CHMe); 132.34 (CH=*C*Br); 150.37 (C*H*=CBr); 168.47 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3815; 3150; 2900; 1811; 1650; 1625; 1100. HRMS (FAB) 231.97355 ($C_8H_9O_3Br$ requires 231.97350).

4.2.11. *syn*-(1′*R, 5*R**)-3-Bromo-1′-hydroxycrotylfuran-2(5*H*)-one 8b.** Dense colourless oil: [Found: C, 41.18; H, 3.75. $C_8H_9O_3Br$ requires C, 41.38; H, 3.91%]. ^{1}H-NMR, δ ($CDCl_3$): 1.73 (3H, dd, J_1=1 Hz, J_2=6.6 Hz, CH_3); 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 4.25 (1H, t, J=6.6 Hz, C*H*OH); 4.93 (1H, dd, J_1=1.8 Hz, J_2=5.8 Hz, C*H*CH=); 5.4–5.5 (1H, m, CH=C*H*Me); 5.8–6.0 (1H, m, C*H*=CHMe); 7.51 (1H, d, J=1.8 Hz, C*H*=CBr). ^{13}C-NMR, δ ($CDCl_3$): 18.00 (*C*H_3); 72.03 (*C*HOH); 85.26 (*C*HCH=); 114.12 (CH=*C*HMe); 127.18 (*C*H=CHMe); 131.36 (CH=*C*Br); 150.21 (C*H*=CBr); 168.66 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3815; 3150; 2900; 1811; 1650; 1625; 1100. HRMS (FAB) 231.97352 ($C_8H_9O_3Br$ requires 231.97350).

4.2.12. *anti*-(1′*R, 5*S**)-3-Bromo-1′-hydroxytridecylfuran-2(5*H*)-one 9b.** White solid, mp=68–70°C (ether/hexane): [Found: C, 56.89; H, 7.46. $C_{17}H_{27}O_3Br$ requires C, 56.97; H, 7.60%]. ^{1}H-NMR, δ ($CDCl_3$): 0.87 (3H, t, J=6.8 Hz, CH_3CH$_2$); 1.25 (22H, bs, $CH_3(CH_2)_{11}$); 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 3.8–3.9 (1H, m, C*H*OH); 4.88 (1H, dd, J_1=1.8 Hz, J_2=4.5 Hz, C*H*CH=); 7.61 (1H, d, J=1.8 Hz, CHC*H*=). ^{13}C-NMR, δ ($CDCl_3$): 13.15 (*C*H_3); 21.69; 24.42; 28.25; 28.36; 28.53; 28.60; 28.64; 28.67; 30.92; 32.02; 34.32 (11 *C*H_2); 70.37 (*C*HOH); 84.29 (*C*HCH=); 113.05 (CH=*C*Br); 148.99 (*C*H=CBr); 167.19 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3150; 2930; 1772; 1630; 1150. HRMS (FAB) 358.11438 ($C_{17}H_{27}O_3Br$ requires 358.11436).

4.2.13. *syn*-(1′*R, 5*R**)-3-Bromo-1′-hydroxytridecylfuran-2(5*H*)-one 10b.** White solid, mp=70–73°C (ether/hexane): [Found: C, 56.79; H, 7.56. $C_{17}H_{27}O_3Br$ requires C, 56.97; H, 7.60%]. ^{1}H-NMR, δ ($CDCl_3$): 0.87 (3H, t, J=6.8 Hz, CH_3CH$_2$); 1.25 (22H, bs, $CH_3(CH_2)_{11}$); 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 3.7–3.9 (1H, m, C*H*OH); 4.92 (1H, dd, J_1=1.8 Hz, J_2=4.8 Hz, C*H*CH=); 7.52 (1H, d, J_2=1.8 Hz, CHC*H*=). ^{13}C-NMR, δ ($CDCl_3$): 14.22 (*C*H_3); 22.87; 25.53; 29.46; 29.50; 29.59; 29.66; 29.73; 29.76; 29.80; 32.05; 33.17 (11 *C*H_2); 71.95 (*C*HOH); 85.69 (*C*HCH=); 114.10 (CH=*C*Br); 150.44 (*C*H=CBr); 168.44 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3150; 2930; 1772; 1630; 1150. HRMS (FAB) 358.11426 ($C_{17}H_{27}O_3Br$ requires 358.11436).

4.2.14. *anti*-(1′*R, 5*S**)-3-Chloro-1′-hydroxycrotylfuran-2(5*H*)-one 7c.** Dense colourless oil: [Found: C, 51.13; H, 4.95. $C_8H_9O_3Cl$ requires C, 51.06; H, 4.82%]. ^{1}H-NMR, δ ($CDCl_3$): 1.75–1.80 (3H, m, CH_3); 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 4.3–4.4 (1H, m, C*H*OH); 4.94 (1H, dd, J_1=1.8 Hz, J_2=4.6 Hz, C*H*CH=); 5.4– 5.5 (1H, m, CH=C*H*Me); 5.8–6.0 (1H, m, C*H*=CHMe); 7.39 (1H, d, J=1.8 Hz, C*H*=CCl). ^{13}C-NMR, δ ($CDCl_3$): 17.98 (*C*H_3); 73.37 (*C*HOH); 83.50 (*C*HCH=); 126.10 (CH=*C*HMe); 126.95 (*C*H=CHMe); 132.45 (CH=*C*Cl); 145.22 (C*H*=CCl); 167.65 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3815;

3120; 2920, 1816; 1635; 1650; 1090. HRMS (FAB) 188.02409 ($C_8H_9O_3Cl$ requires 188.02402).

4.2.15. *syn*-(1′*R, 5*R**)-3-Chloro-1′-hydroxycrotylfuran-2(5*H*)-one *8c*.** Dense colourless oil: [Found: C, 51.3; H, 4.9. $C_8H_9O_3Cl$ requires C, 51.06; H, 4.82%]. ^{1}H-NMR, δ ($CDCl_3$): 1.7–1.8 (3H, m, C*H*$_3$); 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 4.40–4.45 (1H, m, C*H*OH); 4.97 (1H, dd, J_1=1.8 Hz, J_2=5.7 Hz, C*H*CH=); 5.4–5.5 (1H, m, CH=C*H*Me); 5.9–6.0 (1H, m, C*H*=CHMe); 7.31 (1H, d, J=1.8 Hz, C*H*=CCl). ^{13}C-NMR, δ ($CDCl_3$): 17.83 (*C*H$_3$); 72.22 (*C*HOH); 83.44 (*C*HCH=); 125.95 (CH=*C*HMe); 127.17 (*C*H=CHMe); 131.36 (CH=*C*Cl); 145.65 (C*H*=CCl); 168.44 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3815; 3120; 2920, 1816; 1635; 1650; 1090. HRMS (FAB) 188.02410 ($C_8H_9O_3Cl$ requires 188.02402).

4.2.16. *anti*-(1′*R, 5*S**)-3-Chloro-1′-hydroxytridecylfuran-2(5*H*)-one 9c and *syn*-(1′*R**, 5*R**)-3-chloro-1′-hydroxytridecylfuran-2(5*H*)-one 10c.** Inseparable mixture (*syn*/*anti* 1:1) of diastereoisomers. White solid, mp=61–64°C: [Found: C, 64.79; H, 8.59. $C_{17}H_{27}O_3Cl$ requires C, 64.93; H, 8.67%]. ^{1}H-NMR, δ ($CDCl_3$): (*anti*) 0.87 (3H, t, J=6.2 Hz, C*H*$_3$CH$_2$); 1.25 (22H, bs, CH$_3$(C*H*$_2$)$_{11}$); 3.5 (1H, br, disappears after D_2O addition, CHO*H*); 3.8–3.9 (1H, m, C*H*OH); 4.97 (1H, dd, J_1=1.8 Hz, J_2=4.4 Hz, C*H*CH=); 7.43 (1H, d, J=1.8 Hz, CHC*H*=). ^{1}H-NMR, δ ($CDCl_3$) (*syn*) 0.87 (3H, t, J=6.2 Hz, C*H*$_3$CH$_2$); 1.25 (22H, s, CH$_3$(C*H*$_2$)$_{11}$); 3.5 (1H, br, disappears after D_2O addition, CHO*H*); 3.7–3.8 (1H, m, C*H*OH); 4.93 (1H, dd, J_1=1.8 Hz, J_2=4.7 Hz, C*H*CH=); 7.34 (1H, d, J_2=1.8 Hz, CHC*H*=). ^{13}C-NMR, δ ($CDCl_3$): (*syn*/*anti* mixture): 14.22 (2 peaks, *C*H$_3$); 22.78; 25.58; 29.45; 29.48; 29.57; 29.56; 29.72; 29.75; 29.72; 32.03; 33.12 (22 peaks, *C*H$_2$); 71.51 (*C*HOH); 71.75 (*C*HOH); 83.83 (*C*HCH=); 83.76 (*C*HCH=); 125.67 (CH=*C*Cl); 125.84 (CH=*C*Cl); 135.42 (*C*H=CCl); 145.78 (*C*H=CCl); 167.92 (*C*O); 167.94 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: (*syn*/*anti* mixture): 3120; 2930; 1775; 1630; 1170. HRMS (FAB) 314.16495 ($C_{17}H_{27}O_3Cl$ requires 314.16487).

4.3. General procedure for reductive deselenylation/dehalogenation

To a 1:1 THF/MeOH solution (5 mL) of the unsaturated 3-substituted-5-(1′-hydroxy)-γ-butyrolactones (0.47 mmol), $NiCl_2$ (1.41 mmol, 3 equiv.) and $NaBH_4$ (4.23 mmol, 9 equiv.) were added at 0°C. After 5 min the mixture was diluted with ethyl acetate (50 mL) and filtered over celite to give, after evaporation of the solvent, the corresponding saturated butyrolactones **11**, **12** and **13** (see Table 3).

4.3.1. *syn*-(1′*R, 5*R**)-1′-Hydroxybenzyl-γ-butyrolactone 11b.** Dense colourless oil: [Found: C, 68.89; H, 6.43. $C_{11}H_{12}O_3$ requires C, 68.72; H, 6.30%]. ^{1}H-NMR, δ ($CDCl_3$) (only discerned signals): 2.1–2.4 (2H, m, C*H*$_2$CH$_2$CO); 2.4–2.5 (2H, m, CH$_2$C*H*$_2$CO); 3.0 (1H, br, disappears after D_2O addition, CHO*H*); 4.6–4.7 (1H, m, C*H*CHOH); 5.09 (1H, d, J=2.8 Hz, C*H*OH); 7.3–7.4 (5H, m, Ph). ^{13}C-NMR, δ ($CDCl_3$): 24.10 (*C*H$_2$CH$_2$CO); 28.82 (*C*H$_2$CH$_2$CO); 76.82 (*C*HCHOH); 83.62 (*C*HOH); 126.17; 127.07; 128.87; 138.46 (Ph); 177.31 (*C*O). IR ν ($CHCl_3$)/cm^{-1}: 3615; 2900; 1772; 1200. HRMS (FAB) 192.07857 ($C_{11}H_{12}O_3$ requires 192.07864).

4.3.2. *syn*-(1′*R, 5*R**)-1′-Acetoxybenzyl-γ-butyrolactone 14.** Compound **11b** (40 mg, 0.21 mmol) in acetic anhydride (1 mL) and pyridine (0.1 mL) was stirred at rt for 24 h. The resulting solution was then diluted with ethyl acetate (10 mL) and washed with a $CuSO_4$ saturated solution (3×10 ml), the solvent was then evacuated *in vacuo* to give 41 mg of product **14** as a viscous oil (85%). The ^{1}H-NMR of the product was identical to the one reported in literature.[21]

14: ^{1}H-NMR, δ ($CDCl_3$): 2.0 (2H, m, C*H*$_2$CH$_2$CO); 2.12 (3H, s, C*H*$_3$CO); 2.4–2.5 (2H, m, CH$_2$C*H*$_2$CO); 4.79 (1H, q, J=6.6 Hz, C*H*CHOAc); 5.80 (1H, d, J=6.6 Hz, C*H*OAc); 7.3–7.4 (5H, m, Ph). ^{13}C-NMR, δ ($CDCl_3$): 21.02 (*C*H$_2$CH$_2$CO); 24.13 (*C*H$_3$CO); 28.06 (CH$_2$*C*H$_2$CO); 76.36 (*C*HCHOAc); 80.51 (*C*HOAc); 127.32; 128.78; 128.98; 135.41 (Ph); 169.69 (*C*O); 176.37 (*C*O).

Acknowledgements

We wish to thank MURST COFIN 98 for financial support.

References

1. (a) Fadnavis, N. W.; Kumara Vadivel, S.; Sharfuddin, M. *Tetrahedron: Asymmetry* **1999**, *10*, 3675–3680. (b) Saiah, M. W.; Bessodes, M.; Antonakis, K. *Tetrahedron Lett.* **1993**, *34*, 1597–1598. (c) Numata, A.; Hokimoto, K.; Takemura, T.; Katsuno, T.; Yamamoto, K. *Chem. Pharm. Bull.* **1984**, *32*, 2815–2820.
2. (a) Rassu, G.; Zanardi, F.; Battistini, L.; Casiraghi, G. *Synlett* **1999**, *9*, 1333–1350. For a general review on the vinylogous aldol reaction see: (b) Casiraghi, G.; Zanardi, F.; Appendino, G.; Rassu, G. *Chem. Rev.* **2000**, *100*, 1929–1972.
3. Brown, D. W.; Campbell, M. M.; Taylor, A. P.; Zhang, A. *Tetrahedron Lett.* **1987**, *28*, 985–988.
4. Pohmakotr, M.; Tuchinda, P.; Premkairson, P.; Limpongpan, A.; Reutrakul, V. *Heterocycles* **1999**, *51*, 795–802.
5. Pohmakotr, M.; Tuchinda, P.; Premkairson, P.; Reutrakul, V. *Tetrahedron* **1998**, *54*, 11297–11304.
6. (a) Honda, T.; Kondoh, H.; Okumaya, A.; Hayakawa, T.; Tsubuki, M.; Nagase, H. *Heterocycles* **1992**, *33*, 67–72. (b) Pelter, A.; Al-Bayati, R. I.; Ayoub, M. T. J.; Lewis, W.; Pardasani, P.; Hänsel, R. *J. Chem. Soc., Perkin Trans. I* **1987**, 717–742.
7. (a) Semonský, M.; Zikán, V.; Kacáč, B.; JelÍnek, V. *Collect. Czech. Chem. Commun.* **1970**, *35*, 96–106. (b) Zikán, V.; Vrba, L.; Kacáč, B.; Semonský, M. *Collect. Czech. Chem. Commun.* **1972**, *38*, 1091–1094.
8. Ortega, M. J.; ZubÍa, E.; Ocaña, M. J.; Naranjo, S.; Salva, J. *Tetrahedron* **2000**, *56*, 3963–3967 and references cited therein.
9. Hollingworth, G. J.; Knight, J. R.; Sweeney, J. B. *Synth. Commun.* **1994**, *24*, 755–758.
10. (a) Lattmann, E.; Hoffmann, H. M. R. *Synthesis* **1996**, *1*, 155–163. (b) Boukouvalas, J.; Lachance, N.; Ouellet, M.; Trudeau, M. *Tetrahedron Lett.* **1998**, *39*, 7665–7668.

11. Even if compound **1b** is known since 1894 but its correct spectral data are only recently unambiguously reported: (a) Brecker, L.; Kreiser, W.; Ernest, L.; Hopf, H. *Collect. Czech. Chem. Commun.* **1999**, *64*, 1154–1158. Preparation of **1c**: (b) Kayser, M. M.; Morand, P. *Can. J. Chem.* **1980**, *58*, 2484–2490.
12. Preparation and coupling of a substituted 3-bromofuran-2(5*H*)-one with stannyl derivatives: Rossi, R.; Bellina, F.; Biagetti, M.; Mannina, L. *Tetrahedron Lett.* **1998**, *38*, 7799–7802.
13. Bella, M.; Piancatelli, G.; Squarcia, A.; Trolli, C. *Tetrahedron Lett.* **2000**, *41*, 3669–3672.
14. Bella, M.; Piancatelli, G.; Pigro, C. *Tetrahedron* **1999**, *55*, 12387–12398.
15. (a) Abdel-Rahman, H.; Adams, J. P.; Boyes, A. L.; Kelly, M. J.; Mansfiel, D. J.; Procopiu, P. A.; Roberts, S. M.; Slee, D. H.; Watson, N. S. *J. Chem. Commun.* **1993**, 1839–1841. (b) Hughes, M. J.; Thomas, E. J. *J. Chem. Soc., Perkin Trans. I* **1993**, 1493–1505. (c) Feringa, B. L.; Danneberg, W. *Synth. Comm.* **1983**, *13*, 509–514. (d) Ley, S. V.; Mahon, M. *Tetrahedron Lett.* **1981**, *15*, 4747–4750.
16. See Ref. 6b.
17. Rieser, M. J.; Kozlowsky, J. F.; Wood, K. V.; McLaughin, J. L. *Tetrahedron Lett.* **1991**, *32*, 1137–1140.
18. Evidente, A.; Sparapano, L.; Fierro, O.; Bruno, G. *J. Nat. Prod.* **1999**, *62*, 253–256.
19. Removal of phenylselenyl group: (a) Back, T. G.; Birss, V. I.; Edwards, M.; Krishna, M. V. *J. Org. Chem.* **1988**, *53*, 3815–3822. For the reduction of double bonds in butenolides see: (b) Jefford, C. W.; Jaggi, D.; Boukouvalas, J. *Tetrahedron* **1987**, *35*, 4037–4040.
20. Bigi, F.; Casnati, G.; Sartori, G.; Araldi, G. *Gazz. Chim. Ital.* **1989**, 413–419.
21. Citterio, A.; Sebastiano, R.; Nicolini, M. *Tetrahedron* **1993**, *49*, 7743–7760.
22. D'Onofrio, F.; Margarita, R.; Parlanti, L.; Pernazza, D.; Piancatelli, G. *Tetrahedron* **1997**, *53*, 15843–15852.
23. McDonald, E.; Suksamaran, A.; Wylie, R. D. *J. Chem. Soc. Perkin Trans. 1* **1979**, 1893–1900.
24. See Ref. 17.
25. See Ref. 17.
26. Ryu, I.; Muraoka, H.; Kambe, N.; Komatsu, M.; Sonoda, N. *J. Org. Chem.* **1996**, *61*, 6396–6403.