Synthesis of 2-(2-phenylethenyl) substituted 4,5-dihydrofurans by regioselective addition of 1,3-dicarbonyl compounds to dienes promoted by cerium(IV) ammonium nitrate

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Abstract
Radical addition of 1,3-dicarbonyl compounds to conjugated dienes in the presence of cerium(IV) ammonium nitrate in THF produced 4,5-dihydrofurans in good to excellent yields. All radical additions occurred on the terminal double bond as regioselective. Two different dihydrofurans were obtained from the reaction of 1-phenyl-1,3-butanedione with 1-phenyl-1,3-butadiene and 3-methyl-1-phenyl-1,3-butadiene. All compounds were characterised by IR, 1H, 13C-NMR and HRMS spectra.

Keywords: Cerium(IV) ammonium nitrate, oxidative addition, dihydrofuran, conjugated diene.

Introduction
It is well known that Mn(OAc)31-14 and (NH4)2Ce(NO2)6 (CAN)15-24 are widely used as radical oxidants in the synthesis of poly functional organic compounds forming C-C bond between basic compounds. These radical oxidants enable formation of dihydrofurans obtained from reaction of 1,3-dicarbonyls, 3-oxopropanenitriles, β-ketoesters and their derivatives with alkenes easily prepared by basic methods.

Our research group has focused the synthesis of dihydrofuran derivatives by the radical addition of various activated methyl ketones to unsaturated units such as alkenes, alkynes, dienes, and acrylamides. Recently, we have prepared 2,3-dihydro-4H-furo[3,2-c]chromen-4-ones and 2,3-dihyronaphtho[2,3-b]furan-4,9-diones by the cyclization of 4-hydroxycoumarin and 2-hydroxy-1,4-naphthoquinone, respectively.25, 26 Also, we carried out the reactions of fluorinated-1,3-dicarbonyl compounds with dienes27 and conjugated alkenes,28-31 resulting in fluoroacetylated and fluoroalkylated 4,5-dihydrofurans. Moreover, we reported reactions of 1,3-dicarbonyl compounds with alkynes32 and various substituted alkenes.33-36 Very recently, we have prepared 4,5-dihydrofuran-carbonitriles by the treatment of 3-oxopropanenitriles with...
alkenes, unsaturated amides and esters using Mn(OAc)$_3$. In these reactions, Mn(OAc)$_3$ was frequently used as radical oxidant in the presence of HOAc. However, recently we performed an optimization study on the radical addition of 3-oxopropanenitriles to alkenes using CAN in ethereal solvents, resulting CAN / THF system formed dihydrofurans in high yields on mild condition. In the present study, we applied the previous method to reactions of 1,3-dicarbonyl compounds with conjugated dienes promoted CAN / THF and obtained 2-(2-phenylethenyl) substituted 4,5-dihydrofurans as regioselectively in excellent yields.

**Results and Discussion**

Conjugated dienes 1-phenyl-1,3-butadiene 2a and 3-methyl-1-phenyl-1,3-butadiene 2b were synthesized from the reaction of methyl-triphenylphosphonium bromide and suitable carbonyl compounds in the presence of NaH/THF. 1,1-Diphenyl-1,3-butadiene 2c was prepared from water elimination of alcohol obtained from Grignard reaction of benzophenone and allylmagnesium bromide.

Radical addition of dimedone 1a and 1,3-cyclohexanediene 1b to 1-phenyl-1,3-butadiene 2a gave 2-(2-phenylethenyl) dihydrofuran 3a (85%) and 3b (80%) in excellent yields, respectively (Table 1). Also, treatment of 5-phenyl-1,3-cyclohexanediene 1c with 2a produced dihydrofuran 3c in 78% yield as diastereomeric mixture (determined by $^1$H NMR spectrum, dr = 50:50) of. Moreover, the reaction of 2,4-pentanedione 1d and ethyl 3-oxobutanoate 1e with 2a occur 3d (65%) and 3e (63%) in good yields, respectively. However, two different cyclic products 3f and 3g were obtained from the reaction of 1-phenyl-1,3-butanedione 1f and 2a since 1f have two different enol forms. These products 3f and 3g were differentiated by the chemical shift of the carbonyl carbons in their $^{13}$C NMR spectra which show 195 ppm for 3f and 193.4 ppm for 3g. Also, $^1$H NMR spectrum of compound 3g show that protons H4 resonate with methyl group on the C-2 carbon ($^3$J 1.6 Hz) as long range coupling, but same coupling is not observed in the spectrum of 3f.

Treatments of 1a and 1d with 1,1-diphenyl-1,3-butadiene 2c gave dihydrofuran 3h (91%) (obtained in 78% yield by Mn(OAc)$_3$) and 3i (84%) in excellent yields, respectively (Entries, 7 and 8). Upon comparing the addition reactions of both compounds 2a and 2c, it is observed that diene 2c produced dihydrofuran in higher yield. This occurrence can be explained with the stability of intermediate radical formed in 1,3-dicarbonyl. Since 2c has two phenyl groups, radical group of it is more stable compared to that of 2a’s.

It was reported in the literature that radical reaction of dimedone 1a with 1-phenyl-3-methyl-1,3-butadiene 2b produced 3j by using PbI(OAc)$_2$ (69%) and CAN / MeOH (40%) as radical oxidants. But in this work, dihydrofuran 3j was obtained in 92 % yield using CAN/THF system. Also, 2-(2-phenylethenyl) substituted dihydrofuran 3k (88%) and diastereomeric mixture (dr = 50:50) of 3l (82%) were obtained in excellent yields (entries 4 and 5). Similarly, while it was reported that synthesis of compounds 3m and 3n through CAN/MeOH in 45% and 40% yields,
respectively. We obtained these compounds in very good yields (75% and 71%, respectively) by using THF as solvent.

The reaction of 1f with 2b gave two different cyclic products 3o and 3p in moderate yields. These compounds were differentiated by the chemical shift of carbonyl groups in their $^{13}$C NMR spectra as mentioned above.

Table 1. Radical addition of 1,3-dicarbonyl compounds (1a-f) to conjugated dienes (2a-c)

<table>
<thead>
<tr>
<th>Entry</th>
<th>R$^1$</th>
<th>R$^2$</th>
<th>R$^3$</th>
<th>R$^4$</th>
<th>Products and yields$^a$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-CH$_2$C(CH$_3$)$_2$CH$_2$-</td>
<td>1a</td>
<td>H</td>
<td>H</td>
<td>2a 3a (85)</td>
</tr>
<tr>
<td>2</td>
<td>-CH$_2$CH$_2$CH$_2$-</td>
<td>1b</td>
<td>H</td>
<td>H</td>
<td>2a 3b (80)</td>
</tr>
<tr>
<td>3</td>
<td>-CH$_2$CHPhCH$_2$-</td>
<td>1c</td>
<td>H</td>
<td>H</td>
<td>2a 3e (78)</td>
</tr>
<tr>
<td>4</td>
<td>-CH$_3$    -CH$_3$</td>
<td>1d</td>
<td>H</td>
<td>H</td>
<td>2a 3d (65)</td>
</tr>
<tr>
<td>5</td>
<td>-OCH$_2$CH$_3$ -CH$_3$</td>
<td>1e</td>
<td>H</td>
<td>H</td>
<td>2a 3e (63)</td>
</tr>
<tr>
<td>6</td>
<td>-CH$_3$    -Ph</td>
<td>1f</td>
<td>H</td>
<td>H</td>
<td>2a 3f (27)$^b$ 3g (39)$^c$</td>
</tr>
<tr>
<td>7</td>
<td>-CH$_2$C(CH$_3$)$_2$CH$_2$-</td>
<td>1a</td>
<td>H</td>
<td>Ph</td>
<td>2c 3h (91)</td>
</tr>
<tr>
<td>8</td>
<td>CH$_3$     CH$_3$</td>
<td>1d</td>
<td>H</td>
<td>Ph</td>
<td>2c 3i (84)</td>
</tr>
<tr>
<td>9</td>
<td>-CH$_2$C(CH$_3$)$_2$CH$_2$-</td>
<td>1a</td>
<td>CH$_3$</td>
<td>H</td>
<td>2b 3j (92)</td>
</tr>
<tr>
<td>10</td>
<td>-CH$_2$CH$_2$CH$_2$-</td>
<td>1b</td>
<td>CH$_3$</td>
<td>H</td>
<td>2b 3k (88)</td>
</tr>
<tr>
<td>11</td>
<td>-CH$_2$CHPhCH$_2$-</td>
<td>1c</td>
<td>CH$_3$</td>
<td>H</td>
<td>2b 3l (82)</td>
</tr>
<tr>
<td>12</td>
<td>-CH$_3$    -CH$_3$</td>
<td>1d</td>
<td>CH$_3$</td>
<td>H</td>
<td>2b 3m (75)</td>
</tr>
<tr>
<td>13</td>
<td>-OCH$_2$CH$_3$ -CH$_3$</td>
<td>1e</td>
<td>CH$_3$</td>
<td>H</td>
<td>2b 3n (71)</td>
</tr>
<tr>
<td>14</td>
<td>-CH$_3$    -Ph</td>
<td>1f</td>
<td>CH$_3$</td>
<td>H</td>
<td>2b 3o (40)$^b$ 3p (38)$^c$</td>
</tr>
</tbody>
</table>

$^a$Yields of isolated products based on the dienes. $^b$ For the compounds 3f and 3o, R$^1$ = CH$_3$, R$^2$ = Ph c: For the compounds 3g and 3p, R$^1$ = Ph, R$^2$ = CH$_3$. 
The mechanism proposed for the radical addition of conjugated dienes 2a-c with 1,3-dicarbonyls 1a-f is presented in Scheme 1. According to this mechanism, while Ce^{+4} is reduced to Ce^{+3} a radical cation B is formed. Then, addition of the radical to the terminal double bond of the diene forms an allylic radical intermediate C. Radical C is oxidized to the carbocation D by CAN, followed by cyclization of D to give 5-(2-phenylvinyl)-4,5-dihydrofuran E. Intermediates F and H which is the another enol form of F were obtained from the radical addition of 1-phenyl-1,3-butanedione 1f to diene 2b. Intramolecular cyclization of these intermediates gave dihydrofurans G and I, respectively. All radical additions to the dienes occurred on the terminal double bond of the dienes as regioselectively, other adduct products were not observed.

Scheme 1. Mechanism proposed for the formation of dihydrofurans.

Conclusions

Cerium(IV) amonium nitrate promoted radical addition of 1,3-dicarbonyl compounds to 1,3-butadiene derivatives was investigated, resulting in formation of various 2-phenylvinyl-4,5-dihydrofurans. Previous methodology that was optimized using alkenes was applied here to radical addition of 1,3-dicarbonyls to dienes. Upon doing a literature review and comparing the results, it is deduced that, in the radical addition of dienes to 1,3-dicarbonyls promoted CAN/THF system can be used in a highly effective way.
Experimental Section

**General.** Melting points were determined on an electrothermal capillary melting point apparatus. IR spectra (ATR) were obtained with a Bruker Tensor-27 400-4000 cm⁻¹ range with 2 cm⁻¹ resolution. ¹H NMR, ¹³C NMR, spectra were recorded on a Bruker Avance DPX-400 MHz and Varian Oxford NMR300 High performance Digital FT-NMR spectrophotometers. High Resolution Mass Time-of-Flight (TOF) was measured on an Agilent 1200/6210 LC/MS spectrophotometer. The mass spectra were measured on a Waters-2695-Alliance-Micromass-ZQ instrument in m/z (rel.%). Elemental analyses were performed on a VarioEL III CHNS instrument. [Mn(OAc)₃].2H₂O was prepared by electrochemically method according to the literature ⁴. Thin layer chromatography (TLC) was performed on Merck aluminum-packed silica gel plates. Purification of the products was performed by column chromatography on silica gel (Merck silica gel 60, 40-63 mm).

**General procedure for the synthesis of 4,5-dihydrofurans (3a-p).** To a soln. of 1,3-dicarbonyls (1 mmol) and diene (1.5 mmol) in THF (10 mL) under N₂ in an oil bath, a mixture of CAN (2.5 mmol) and NaHCO₃ (2.5 mmol) was added at 30°C. Then, the temp. was slowly increased to 40°C. The reaction was completed when the orange colour of CAN had disappeared (10 min) or when the diene spot on TLC had completely vanished. H₂O was added to the soln. and the mixture was extracted with CHCl₃ (3x20 mL). The combined organic phase was dried (Na₂SO₄) and concentrated and the crude product purified by column chromatography on silica gel (230 – 400 mesh) or preparative TLC (20x20 cm plates, 2 mm thickness, n-hexane/EtOAc (5:1).

6,6-Dimethyl-2-[(E)-2-phenylvinyl]-3,5,6,7-tetrahydro-1-benzofuran-4(2H)-one (3a). Light yellow oil, yield 85%, 228 mg, IR (ATR, cm⁻¹): 3058, 2961, 1695 (C=O), 1625 (C=C), 1020, 756, 696. ¹H NMR (400MHz, CDCl₃), δH 1.09 (6H, s, 2xCH₃), 2.22 (2H, s, H5), 2.30 (2H, s, H7), 2.70 (1H, dd, J 14.4 and 7.6 Hz, H3), 3.07 (1H, dd, J 14.4 and 10.4 Hz, H3), 5.37 (1H, dt, J 10.4 and 7.6 Hz, H2), 6.22 (1H, dd, J 16.0 and 7.6 Hz, Holef.), 6.62 (1H, d, J 16.0 Hz, Holef.), 7.25 (1H, t, J 7.2 Hz), 7.30 (2H, t, J 7.2 Hz), 7.36 (2H, d, J 7.6 Hz). ¹³C NMR (100MHz, CDCl₃), δC 28.9 (CH₃), 28.95 (CH₃), 32.3, 34.3, 38.0, 51.2 (C3), 86.4 (C2), 111.7 (C3a), 127.0, 127.4 (2xCH), 128.5 (2xCH), 128.9, 133.2, 136.0, 176.2 (C7a), 194.5 (C=O). m/z (ESI⁺) = 269 (MH⁺, 100%). HRMS (ESI⁺): m/z (M+H)⁺ C₁₈H₂₀O₂: 269.15361 found: 269.15461. Anal. Calcd for C₁₈H₂₀O₂ (268.35): C, 80.56; H, 7.51%. Found: C, 80.42; H, 7.73%.

2-[(E)-2-Phenylvinyl]-3,5,6,7-tetrahydro-1-benzofuran-4(2H)-one (3b). Yellow solid, yield 80%, 192 mg, mp 67-69 °C, IR (ATR, cm⁻¹): 2948, 2866, 1623 (C=O), 1600 (C=C), 1227, 968, 756, 691. ¹H NMR (400MHz, CDCl₃), δH 2.05 (2H, f, J 6.4 Hz, H6), 2.36 (2H, t, J 3.2 Hz, H5), 2.46 (2H, tt, J 6.4 and 5JH₇-H₃ = 1.6 Hz, H7), 2.7 (1H, ddd, J 14.4, 8.0 and 5JH₃-H₇ = 1.6 Hz, H3), 3.1 (1H, ddt, J 14.4, 10.4 and 5JH₃'H₇ = 1.6 Hz, H3), 5.30 (1H, ddd, J 10.4 7.6 and 7.2 Hz, H2), 6.20 (1H, dd, J 16.0 and 7.2 Hz, Holef.), 6.60 (1H, d, J 16.0 Hz, Holef.), 7.20 (1H, tt, J 7.6 and 2.4 Hz), 7.30 (2H, t, J 7.6 Hz), 7.40 (2H, d, J 8.4 Hz). ¹³C NMR (100MHz, CDCl₃), δC 21.9 (CH₂),
24.2 (CH₂), 32.5, 36.7 (C₃), 86.2 (C₂), 127.0, 127.4 (2xCH), 128.5 (2xCH), 128.9, 133.3, 136.0, 177.3 (C₇a), 195.6 (C=O). m/z (ESI⁺) = 241 (MH⁺, 100%). HRMS (ESI⁺): m/z (M+H⁺) C₁₆H₁₆O₂: 241.12231 found: 241.12334. Anal. Calcd for C₁₆H₁₆O₂ (240.29): C, 79.97; H, 6.71%. Found: C, 80.35; H, 6.52%.

6-Phenyl-2-[(E)-2-phenylvinyl]-3,5,6,7-tetrahydro-1-benzofuran-4(2H)-one (3c). Pale yellow solid, yield 78%, 246 mg, mp 64-66 °C, IR (ATR, cm⁻¹): 3029, 2954, 2937, 1623 (C=O), 1600 (C=C), 1203, 748, 688. ¹H NMR (300MHz, CDCl₃), δH 2.56-2.70 (5H, m, H₅, H₆, H₇), 3.07 (1H, m, H₃), 3.38 (1H, m, H₃), 5.35 (1H, m, H₂), 6.20 (1H, dd, J 15.9 and 7.5 Hz, H_olef.), 6.60 (1H, d, J 15.9 Hz, H_olef.), 7.16-7.34 (10H, m). ¹³C NMR (75MHz, CDCl₃), δC 31.8 (CH₂), 32.2 (CH₂), 40.5, 44.0 (C₃), 86.6 (C₂), 113.1 (C₃a), 127.0, 127.05, 127.1 (2xCH), 127.4 (2xCH), 128.6 (2xCH), 128.9, 129.0, 133.3, 135.9, 142.8, 176.6 (C₇a), 194.2 (C=O). m/z (ESI+) = 317 (MH⁺, 100%). HRMS (ESI⁺): m/z (M+H⁺) C₂₂H₂₀O₂: 317.15361 found: 317.15315. Anal. Calcd for C₂₂H₂₀O₂ (316.39): C, 83.51; H, 6.37%. Found: C, 83.85; H, 6.30%.

1-{2-Methyl-5-[(E)-2-phenylvinyl]-4,5-dihydrofuran-3-yl}ethanone (3d). Yellow oil, yield 65%, 148 mg, IR (ATR, cm⁻¹): 3027, 2925, 1698 (C=O), 1592 (C=C), 1221, 979, 749, 693. ¹H NMR (300MHz, CDCl₃), δH 2.21 (3H, s, CH₃), 2.25 (3H, t, J 1.5 Hz, CH₃), 2.81 (1H, ddq, J 14.1, 8.1 and 1.5 Hz, H₄), 3.17 (1H, ddq, J 14.1, 10.5 and 1.5 Hz, H₄), 5.20 (1H, ddd, J 10.2, 8.1 and 7.2 Hz, H₅), 6.23 (1H, dd, J 15.9 and 7.5 Hz, H_olef.), 6.60 (1H, d, J 15.9 Hz, H_olef.), 7.25 (1H, t, J 8.4 Hz), 7.31 (2H, t, J 6.9 Hz), 7.4 (2H, d, J 8.4 Hz). ¹³C NMR (75MHz, CDCl₃), δC 15.3 (CH₃), 29.7 (CH₃), 36.9 (C₄), 83.0 (C₅), 102.0 (C₃), 126.9, 127.8 (2xCH), 128.5 (2xCH), 128.9, 132.8, 136.1, 167.8 (C₂), 194.8 (C=O). m/z (ESI⁺) = 229 (MH⁺, 100%). HRMS (ESI⁺): m/z (M+H⁺) C₁₅H₁₆O₂: 229.12284. Anal. Calcd for C₁₅H₁₆O₂ (228.28): C, 78.92; H, 7.06%. Found: C, 79.05; H, 7.18%.

Ethyl 2-methyl-5-[(E)-2-phenylvinyl]-4,5-dihydrofuran-3-carboxylate(3e). Pale yellow oil, yield 63%, 163 mg, IR (ATR, cm⁻¹): 2962, 1692 (C=O), 1644 (C=C), 1078, 786, 692. ¹H NMR (300 MHz, CDCl₃), δH 1.27 (3H, t, J 9.2 Hz, -OCH₂CH₃), 2.20 (3H, t, J 1.5 Hz, CH₃), 2.75 (1H, ddq, J 14.1, 8.1 and 1.5 Hz, H₄), 3.12 (1H, ddq, J 14.1, 10.5 and 1.5 Hz, H₄), 4.2 (2H, q, J 7.2 Hz, -OC₂H₅), 5.20 (1H, ddd, J 10.5, 7.8 and 6.9 Hz, H₅), 6.25 (1H, dd, J 15.9 and 7.2 Hz, H_olef.), 6.60 (1H, d, J 15.9 Hz, H_olef.), 7.25 (1H, t, J 6.6 Hz), 7.31 (2H, t, J 6.6 Hz), 7.4 (2H, d, J 8.4 Hz). ¹³C NMR (75MHz, CDCl₃), δC 14.4 (CH₃), 14.7 (CH₃), 36.2 (C₂), 59.7, 82.8 (C₅), 102.0 (C₃), 126.9, 128.1 (2xCH), 128.3, 128.8 (2xCH), 132.5, 136.3, 166.3 (C₂), 167.8 (C=O). m/z (ESI⁺) = 259 (MH⁺, 100%). HRMS (ESI⁺): m/z (M+H⁺) C₁₆H₁₈O₃: 259.13231. Anal. Calcd for C₁₆H₁₈O₃ (258.31): C, 74.39; H, 7.02%. Found: C, 74.55; H, 6.75%.

1-{2-Phenyl-5-[(E)-2-phenylvinyl]-4,5-dihydrofuran-3-yl}ethane (3f). Yellow oil, yield 27%, 78 mg, IR (ATR, cm⁻¹): 2925, 1717 (C=O), 1677 (C=C), 1595, 750, 693. ¹H NMR (300 MHz, CDCl₃), δH 1.94 (3H, s, CH₃), 3.0 (1H, dd, J 15.0 and 8.4 Hz, H₄), 3.32 (1H, dd, J 15.0 and 10.2 Hz, H₄), 5.30 (1H, ddq, J 10.0, 8.4 and 7.2 Hz, H₅), 6.30 (1H, dd, J 15.9 and 7.2 Hz, H_olef.), 6.65 (1H, d, J 15.9 Hz, H_olef.), 7.22-7.30 (3H, t, J 6.6 Hz), 7.31-7.42 (5H, m), 7.30 (2H, dd, J 7.8 and 1.5 Hz). ¹³C NMR (75MHz, CDCl₃), δC 29.1(CH₃), 37.6 (C₄), 83.2 (C₅), 114.9 (C₃), 127.0, 127.7, 128.0 (2xCH), 128.4 (2xCH), 128.6 (2xCH), 128.9 (2xCH), 129.5, 130.9, 133.1,
136.2, 168.7 (C2), 195.0 (C=O). \( m/z \) (ESI\(^{+}\)) = 291 (MH\(^{+}\), 100%). HRMS (ESI\(^{+}\)): \( m/z \) (M+H\(^{+}\)\) C\(_{20}\)H19O2: 291.13796 found: 291.14053. Anal. Calcd for C\(_{20}\)H18O2 (290.35): C, 82.73; H, 6.25%. Found: C, 82.60; H, 6.47%.

{2-Methyl-5-[(E)-2-phenylvinyl]-4,5-dihydropuran-3-yl}(phenyl)methanone (3g). Yellow oil, yield 39%, 113 mg, IR (ATR, cm\(^{-1}\)): 3059, 1717 (C=O), 1700 (C=C), 1600 (C=C), 1597, 1219, 749, 692. \(^{1}\)H NMR (300MHz, CDCl\(_3\)), \( \delta \)H 1.94 (3H, t, \( J \) 1.5Hz, CH\(_3\)), 3.02 (1H, ddq, \( J \) 14.7, 8.4 and \( J \) 1.5Hz, H4), 3.34 (1H, ddq, \( J \) 14.7, 10.2 and \( J \) 1.5Hz, H4), 5.30 (1H, ddd, \( J \) 10.0, 8.4 and 7.8 Hz, H5), 6.34 (1H, dd, \( J \) 15.6 and 7.2 Hz, H\(_{\text{olefin}}\)), 6.68 (1H, d, J 15.6 Hz, H\(_{\text{olefin}}\)), 7.28-7.36 (3H, m), 7.41-7.50 (5H, m), 7.60-7.63 (2H, m). \(^{13}\)C NMR (75MHz, CDCl\(_3\)), \( \delta \)C 15.8 (CH\(_3\)), 37.6 (C4), 83.2 (C5), 112.7 (C3), 127.0, 127.7, 128.0 (2xCH), 128.4 (2xCH), 128.5 (2xCH), 128.9 (2xCH), 131.3, 130.0, 136.2, 141.1, 168.9 (C2), 193.4 (C=O). \( m/z \) (ESI\(^{+}\)) = 291 (MH\(^{+}\), 100%). HRMS (ESI\(^{+}\)): \( m/z \) (M+H\(^{+}\)+ C\(_{20}\)H19O2: 291.13796 found: 291.14061. Anal. Calcd for C\(_{20}\)H18O2 (290.35): C, 82.73; H, 6.25%. Found: C, 82.87; H, 6.15%.

2-(2,2-Diphenylvinyl)-6,6-dimethyl-3,5,6,7-tetrahydro-1-benzofuran-4(2H)-one (3h). Pale yellow solid, yield 91%, 313 mg, mp 113-115 °C, IR (ATR, cm\(^{-1}\)): 2916, 1690 (C=O), 1686 (C=C), 1073, 742, 693. \(^{1}\)H NMR (400MHz, CDCl\(_3\)), \( \delta \)H 1.08 (3H, s, CH\(_3\)), 1.12 (3H, s, CH\(_3\)), 2.23 (2H, s, H5), 2.95 (2H, t, \( J \) 2.0 Hz, H7), 2.73 (1H, dd, \( J \) 14.4 and 7.6 Hz, H3), 3.01 (1H, dd, \( J \) 14.4 and 10.4 Hz, H3), 5.27 (1H, td, \( J \) 10.0 and 7.6 Hz, H2), 6.14 (1H, d, J 9.2 Hz), 7.21 (2H, dd, \( J \) 8.4 and 2.0 Hz), 7.23-7.30 (3H, m), 7.36-7.41 (3H, m). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)), \( \delta \)C 29.0 (2xCH\(_3\)), 33.2, 34.3, 38.2, 51.2 (C3), 83.8 (C2), 111.8 (C3a), 126.5, 128.0 (2xCH), 128.2 (2xCH), 128.4 (2xCH), 128.6, 130.1, 138.8, 141.3, 146.3, 176.4 (C7a), 195.0 (C=O). \( m/z \) (ESI\(^{+}\)) 345 (MH\(^{+}\), %100). HRMS (ESI\(^{+}\)): \( m/z \) (M+H\(^{+}\)+ C\(_{24}\)H24O2: 345.18491 found: 345.18699.

1-[5-(2,2-Diphenylvinyl)-2-methyl-4,5-dihydropuran-3-yl]ethanone (3i). Yellow oil, yield 84%, 255 mg, IR (ATR, cm\(^{-1}\)): 3048, 2944, 1628 (C=O), 1602 (C=C), 1249, 1180, 728, 692. \(^{1}\)H NMR (400MHz, CDCl\(_3\)), \( \delta \)H 2.19 (3H, s, CH\(_3\)), 2.22 (3H, s, CH\(_3\)), 2.86 (1H, ddq, \( J \) 14.0, 8.0 and 1.6 Hz, H4), 3.09 (1H, ddq, \( J \) 14.4, 10.0 and 1.6 Hz, H4), 5.10 (1H, ddd, \( J \) 10.4, 9.2 and 8.0 Hz, H5), 6.16 (1H, d, J 9.2 Hz), 7.20 (2H, dd, \( J \) 8.4 and 2.0 Hz), 7.25-7.29 (5H, m), 7.35-7.40 (3H, m). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)), \( \delta \)C 15.4 (CH\(_3\)), 29.7 (CH\(_3\)), 37.8 (C4), 80.3 (C5), 112.4 (C3), 126.9, 128.0 (2xCH), 128.5 (2xCH), 128.6, 130.1, 138.8, 141.3, 146.3, 176.4 (C7a), 195.0 (C=O). \( m/z \) (ESI\(^{+}\)) 345 (MH\(^{+}\), %100). HRMS (ESI\(^{+}\)): \( m/z \) (M+H\(^{+}\)+ C\(_{21}\)H20O2: 305.15361 found: 305.15616. Anal. Calcd for C\(_{21}\)H20O2 (304.38): C, 82.86; H, 6.62%. Found: C, 81.34; H, 6.55%.

2,6,6-Trimethyl-2-[(E)-2-phenylvinyl]-3,5,6,7-tetrahydro-1-benzofuran-4(2H)-one (3j). Colourless oil, yield 92%, 259 mg, \(^{1}\)H NMR (300MHz, CDCl\(_3\)), \( \delta \)H 1.07 (3H, s, CH\(_3\)), 1.08 (3H, s, CH\(_3\)), 1.57 (3H, s, CH\(_3\)), 2.21 (2H, s, H5), 2.29 (2H, s, H7), 2.72 (1H, d, J 14.4 Hz, H3), 2.90 (1H, d, J 14.4 Hz, H3), 6.27 (1H, d, J 15.9 Hz, H\(_{\text{olefin}}\)), 6.53 (1H, d, J 15.9 Hz, H\(_{\text{olefin}}\)), 7.20 (1H, t, J 6.9 Hz), 7.28 (2H, d, J 7.5 Hz), 7.35 (2H, d, J 6.9 Hz). HRMS (ESI\(^{+}\)): \( m/z \) (M+H\(^{+}\)+ C\(_{19}\)H\(_{22}\)O\(_2\): 283.16926 found: 283.17136.
2-Methyl-2-\[(E)-2-phenylvinyl]-3,5,6,7-tetrahydro-1-benzofuran-4(2H)-one (3k). Oil, yield 88%, 224 mg, IR (ATR, cm\(^{-1}\)): 3026, 2943, 2866, 1620 (C=O), 1595 (C=C), 1244, 998, 749, 692. \(^1\)H NMR (300MHz, CDCl\(_3\)), \(\delta_{H} 1.58\) (3H, s, CH\(_3\)), 2.02 (2H, f, J 6.6 Hz, H6), 2.34 (1H, t, J 6.9 Hz, H5), 2.44 (2H, td, J 6.9 and 1.5 Hz, H7), 2.71 (1H, td, J 14.4 and 1.8 Hz, H3), 2.90 (1H, td, J 14.4 and 1.8 Hz, H3), 6.29 (1H, d, J 15.9 Hz, H olef.), 6.55 (1H, t, J 15.9 Hz, H olef.), 7.24 (1H, tt, J 6.6 and 1.5 Hz), 7.29 (2H, t, J 6.9 Hz), 7.35 (2H, dd, J 6.9 and 1.8 Hz). \(^13\)C NMR (75 MHz, CDCl\(_3\)), \(\delta_{C} 21.9\) (CH\(_3\)), 24.4, 27.1, 36.6, 38.6 (C3), 91.5 (C 3a), 112.4 (C2), 126.9, 128.2 (2xCH), 128.7 (2xCH), 128.8, 132.1, 136.3, 176.4 (C7a), 196.0 (C=O). m/z (ESI\(^{+}\)) 255 (MH\(^{+}\), %100). HRMS (ESI \(^{+}\))\(m/z\) (M+H)\(^{+}\) C\(_{17}\)H\(_{18}\)O\(_2\): 255.13795 found: 255.13822. Anal. Calcd for C\(_{17}\)H\(_{18}\)O\(_2\) (254.32): C, 80.28; H, 7.13%. Found: C, 80.36; H, 7.43%.

2-Methyl-6-phenyl-2-\[(E)-2-phenylvinyl]-3,5,6,7-tetrahydro-1-benzofuran-4(2H)-one (3l). Colourless solid, yield 82%, 271 mg, mp 158-160 °C, IR (ATR, cm\(^{-1}\)): 2977, 1649 (C=O), 1623 (C=C), 1218, 1028, 750, 690. \(^1\)H NMR (300MHz, CDCl\(_3\)), \(\delta_{H} 1.65\) (3H, s, CH\(_3\)), 2.65 (2H, dd, J 9.0 and 2.4 Hz, H5), 2.68-2.73 (2H, m, H7), 2.80 (1H, ddd, J 14.4, 4.2 and 1.5 Hz, H3), 2.98 (1H, ddd, J 14.4, 4.2 and 1.5 Hz, H3), 3.46 (1H, m, H6), 6.32 (1H, d, J 15.9 Hz, H olef.), 6.55 (1H, t, J 15.9 Hz, H olef.), 7.25-7.40 (10H, m). \(^13\)C NMR (75 MHz, CDCl\(_3\)), \(\delta_{C} 27.1\) (CH\(_3\)), 31.9, 38.5, 40.6, 44.0 (C2), 92.2 (C3a), 112.6, 126.9, 127.0 ( 2xCH), 127.3 (2xCH), 128.9(2xCH), 129.0, 132.0, 136.2, 142.9, 175.5 (C7a), 194.5 (C=O). m/z (ESI\(^{+}\)) 331 (MH\(^{+}\), %100). HRMS (ESI \(^{+}\))\(m/z\) (M+H)\(^{+}\) C\(_{23}\)H\(_{22}\)O\(_2\): 331.16926 found: 331.16895. Anal. Calcd for C\(_{23}\)H\(_{22}\)O\(_2\) (330.41): C, 83.60; H, 6.71%. Found: C, 83.91; H, 6.88%.

1-{2,5-Dimethyl-5-\[(E)-2-phenylvinyl]-4,5-dihydrofuran-3-yl}ethanone (3m). Yellow oil, yield 75%, 181 mg, \(^1\)H NMR (300MHz, CDCl\(_3\)), \(\delta_{H} 1.57\) (3H, s, CH\(_3\)), 2.27 (3H, t, J 1.5 Hz, CH\(_3\)), 2.86 (1H, dq, J 14.1 and 1.5 Hz, H3), 3.02 (1H, dq, J 14.1 and 1.5 Hz, H3), 6.30 (1H, d, J 16.2 Hz, H olef.), 6.55 (1H, d, J 16.2 Hz, H olef.), 7.27 (1H, tt, J 6.9 and 1.5 Hz), 7.31(2H, t, J 6.9 Hz), 7.38 (2H, dd, J 6.9 and 1.8 Hz). HRMS (ESI\(^{+}\))\(m/z\) (M+H)\(^{+}\) C\(_{16}\)H\(_{18}\)O\(_2\): 243.13796 found: 243.13702.

Ethyl 2,5-dimethyl-5-\[(E)-2-phenylvinyl]-4,5-dihydrofuran-3-carboxylate (3n). Pale yellow oil, yield 71%, 193 mg, \(^1\)H NMR (300MHz, CDCl\(_3\)), \(\delta_{H} 1.27\) (3H, t, J 7.2 Hz, -OCH\(_2\)C\(_{3}\)), 1.55 (3H, s, CH\(_3\)), 2.24 (3H, t, J 1.5 Hz, CH\(_3\)), 2.80 (1H, dq, J 14.4 and 1.5 Hz, H3), 3.02 (1H, dq, J 14.4 and 1.5 Hz, H3), 6.30 (1H, d, J 16.2 Hz, H olef.), 6.55 (1H, d, J 16.2 Hz, H olef.), 7.27 (1H, tt, J 6.9 and 1.5 Hz), 7.31(2H, t, J 6.9 Hz), 7.38 (2H, dd, J 6.9 and 1.8 Hz). HRMS (ESI\(^{+}\))\(m/z\) (M+H)\(^{+}\) C\(_{17}\)H\(_{20}\)O\(_3\): 273.14852 found: 273.14841.

1-{5-Methyl-2-phenyl-5-\[(E)-2-phenylvinyl]-4,5-dihydrofuran-3-yl}ethanone (3o). Yellow oil, yield 40%, 122 mg, IR (ATR, cm\(^{-1}\)): 3018, 1716 (C=O), 1600 (C=O), 1587 (C=C), 1241, 749, 693. \(^1\)H NMR (300MHz, CDCl\(_3\)), \(\delta_{H} 1.59\) (3H, s, CH\(_3\)), 1.88 (3H, s, CH\(_3\)), 2.96 (1H, d, J 14.4 Hz, H3), 3.20 (1H, d, J 14.4 Hz, H3), 6.30 (1H, d, J 16.2 Hz, H olef.), 6.55 (1H, d, J 16.2 Hz, H olef.), 7.25 (2H, t, J 6.9 Hz), 7.31-7.39 (5H, m), 7.56 (3H, m). \(^13\)C NMR (75 MHz, CDCl\(_3\)), \(\delta_{C} 15.9\) (CH\(_3\)), 27.0 (CH\(_3\)), 43.6 (C4), 87.6 (C5), 114.6 (C3), 126.8, 127.9, 127.9 (2xCH), 128.1 (2xCH), 128.4 (2xCH), 128.8 (2xCH), 129.4, 131.1, 132.6, 136.5, 141.2, 168.0 (C2), 195.1
(C=O). \(m/z\) (ESI\(^+\)) 305 (MH\(^+\), %100). HRMS (ESI\(^+\)): \(m/z\) (M+H\(^+\)) \(C_{21}H_{20}O_2\): 305.15361 found: 305.15495. Anal. Calcd for \(C_{21}H_{20}O_2\) (304.38): C, 82.86; H, 6.62%. Found: C, 83.06; H, 6.84%.

{2,5-Dimethyl-5-[(E)-2-phenylvinyl]-4,5-dihydrofuran-3-yl}(phenyl)methanone (3p). Yellow oil, yield 38%, 116 mg, IR (ATR, cm\(^{-1}\)): 3027, 2974, 2927, 1650 (C=O), 1593 (C=C), 1239, 746, 693. \(^1\)H NMR (400MHz, CDCl\(_3\)), \(\delta_H\) 1.62 (3H, s, CH\(_3\)), 1.89 (3H, t, \(J\ =\ 1.6\) Hz, CH\(_3\)), 3.0 (1H, dq, \(J\ =\ 14.4\) and 1.6 Hz, H\(_3\)), 3.20 (1H, dq, \(J\ =\ 14.4\) and 1.6 Hz, H\(_3\)), 6.35 (1H, d, \(J\ =\ 16.0\) Hz, H\(_{olef.}\)), 6.60 (1H, d, \(J\ =\ 16.0\) Hz, H\(_{olef.}\)), 7.32 (2H, t, \(J\ =\ 7.6\) Hz), 7.39-7.42 (5H, m), 7.56 (3H, m). \(^13\)C NMR (100 MHz, CDCl\(_3\)), \(\delta_C\) 15.7 (CH\(_3\)), 27.1 (CH\(_3\)), 43.4 (C4), 87.4 (C5), 112.0 (C3), 126.6, 127.7, 127.9 (2xCH), 128.1 (2xCH), 128.3 (2xCH), 128.6 (2xCH), 132.1, 132.4, 136.2, 141.0, 167.7 (C2), 193.2 (C=O). \(m/z\) (ESI\(^+\)) 305 (MH\(^+\), %100). HRMS (ESI\(^+\)): \(m/z\) (M+H\(^+\)) \(C_{21}H_{20}O_2\): 305.15361 found: 305.15534. Anal. Calcd for \(C_{21}H_{20}O_2\) (304.38): C, 82.86; H, 6.62%. Found: C, 83.12; H, 6.41%.

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**References**

1. Garzino, F.; Méou, A.; Brun, P. *Tetrahedron Lett.* **2000**, *41*, 9803-9807. [http://dx.doi.org/10.1016/S0040-4039(00)01729-9](http://dx.doi.org/10.1016/S0040-4039(00)01729-9)
7. Snider, B. B. *Chem. Rev.* **1996**, *96*, 339-363. [http://dx.doi.org/10.1021/cr950026m](http://dx.doi.org/10.1021/cr950026m)
8. Wang, G.-W.; Dong, Y.-W.; Wu, P.; Yuan, T.-T.; Shen, Y.-B. *J. Org. Chem.* **2008**, *73*, 7088-7095. [http://dx.doi.org/10.1021/jo800870z](http://dx.doi.org/10.1021/jo800870z)
   [http://dx.doi.org/10.2174/157017907780598871](http://dx.doi.org/10.2174/157017907780598871)
   [http://dx.doi.org/10.1016/j.tet.2013.02.009](http://dx.doi.org/10.1016/j.tet.2013.02.009)
   [http://dx.doi.org/10.1016/j.tetlet.2013.01.056](http://dx.doi.org/10.1016/j.tetlet.2013.01.056)
   [http://dx.doi.org/10.1002/hlca.201300229](http://dx.doi.org/10.1002/hlca.201300229)
   [http://dx.doi.org/10.1016/j.tet.2014.01.013](http://dx.doi.org/10.1016/j.tet.2014.01.013)
   [http://dx.doi.org/10.1016/S0040-4020(00)00839-5](http://dx.doi.org/10.1016/S0040-4020(00)00839-5)
   [http://dx.doi.org/10.1016/S0040-4020(01)00700-1](http://dx.doi.org/10.1016/S0040-4020(01)00700-1)
   [http://dx.doi.org/10.1016/S0040-4020(02)00864-5](http://dx.doi.org/10.1016/S0040-4020(02)00864-5)
   [http://dx.doi.org/10.1016/S0040-4020(03)00486-1](http://dx.doi.org/10.1016/S0040-4020(03)00486-1)
   [http://dx.doi.org/10.3987/COM-02-9690](http://dx.doi.org/10.3987/COM-02-9690)
   [http://dx.doi.org/10.1021/cr068408n](http://dx.doi.org/10.1021/cr068408n)
   [http://dx.doi.org/10.1016/j.tetlet.2006.02.051](http://dx.doi.org/10.1016/j.tetlet.2006.02.051)
   [http://dx.doi.org/10.3987/COM-00-S(1)14](http://dx.doi.org/10.3987/COM-00-S(1)14)
   [http://dx.doi.org/10.1021/jo8010232](http://dx.doi.org/10.1021/jo8010232)
   [http://dx.doi.org/10.1080/00397910701845456](http://dx.doi.org/10.1080/00397910701845456)
   [http://dx.doi.org/10.1039/C3RA48015A](http://dx.doi.org/10.1039/C3RA48015A)
   [http://dx.doi.org/10.1002/hlca.201100105](http://dx.doi.org/10.1002/hlca.201100105)
   [Link](http://dx.doi.org/10.1016/j.jfluchem.2005.02.002)

   [Link](http://dx.doi.org/10.1016/j.jfluchem.2011.06.023)

   [Link](http://www.arkat-usa.org/get-file/47725/)

   [Link](http://dx.doi.org/10.1080/00397910500501516)

   [Link](http://journals.tubitak.gov.tr/chem/issues/kim-08-32-4/kim-32-4-2-0708-25.pdf)

   [Link](http://dx.doi.org/10.3998/ark.5550190.0015.500)

   [Link](http://dx.doi.org/10.1002/hlca.201100397)

   [Link](http://dx.doi.org/10.1002/hlca.201200098)

   [Link](http://dx.doi.org/10.1016/j.tet.2005.07.019)

   [Link](http://journals.tubitak.gov.tr/chem/issues/kim-08-32-4/kim-32-4-2-0708-25.pdf)

   [Link](http://dx.doi.org/10.1002/jccs.201400173)

   [Link](http://dx.doi.org/10.1016/j.tet.2007.04.088)

   [Link](http://dx.doi.org/10.3998/ark.5550190.0012.230)

   [Link](http://dx.doi.org/10.1002/hlca.201000440)

   [Link](http://dx.doi.org/10.2174/157017806776114621)

   [Link](http://dx.doi.org/10.1021/ol049085p)

   [Link](http://dx.doi.org/10.1002/poc.531)

   [Link](http://dx.doi.org/10.1016/S0040-4039(03)01644-7)

http://dx.doi.org/10.1021/jo0625406