Synthesis of Dihydropyrans and Dihydrofurans *via* Radical Cyclization of Unsaturated Alcohols and 1,3-Dicarbonyl Compounds

by **Hakan Aslan***[a]), **Deniz E. Akpınar**[a]), **Atilla Öktemer**[a]), **Mehtap Yakut**[a]), and **Oğuzhan Alagöz**[b])

[a]) Department of Chemistry, Faculty of Science, Ankara University, TR-06100 Tandogan, Ankara (phone: +90-312-2126720; fax: +90-312-2232395; e-mail: hakaslan@gmail.com)

[b]) Department of Chemical Engineering, Faculty of Engineering, Afyon Kocatepe University, TR-03200 Afyonkarahisar

The oxidative cyclization reactions of 1,3-dicarbonyl compounds **1a**–**1c** and α,β-unsaturated alcohols **2a**–**2f** with $Mn(OAc)_3$ were performed, leading to dihydrofurans. Treatment of **1a** and **1b** with 2-methylbut-3-en-2-ol (**2a**) gave dihydrofurans **3aa** and **3ba**, and dihydropyrans **4aa** and **4ba**, as unexpected products. While the reaction of 2-methylbut-3-yn-2-ol (**2b**) with acetylacetone (**1b**) yielded a bifuran, ethyl acetoacetate (**1a**) led to a mixture of furan, bifuran, and salicylate derivatives. Besides, surprisingly, styryl-substituted dihydrofurans were obtained from the reactions of 1,3-dicarbonyl compounds and (3*E*)-2,4-diphenylbut-3-en-2-ol. The reaction mechanisms were proposed for the formation of the different products, considering intermediates in these reaction mixtures.

Introduction. – Dihydrofurans form the basic structure of many natural compounds, and they possess a wide range of biological activities [1]. These compounds are synthesized easily by cyclization of a 1,3-dicarbonyl compound with an unsaturated system mediated by transition metal salts (Mn^{3+}, Ce^{4+}, Ag^{+}, *etc.*). Among these metal salts, $Mn(OAc)_3$ [2] and $[(NH_4)_2Ce(NO_3)6]$ [3] are widely used in organic synthesis for the formation of C–C bonds.

Radical cyclizations of unsaturated alcohols and 1,3-dicarbonyl compounds in $Mn(OAc)_3$- and $[(NH_4)_2Ce(NO_3)_6]$-mediated reactions were rarely studied, mainly based on natural product synthesis [4]. The aim of this study on radical cyclizations of unsaturated alcohols and 1,3-dicarbonyl compounds was the synthesis of dihydrofurans which commonly have biological activity. Further, dihydropyrans, bifuran, styryl ((*E*)-2-phenylethenyl)-substituted dihydrofurans, and salicylate derivatives were obtained from the same reactions.

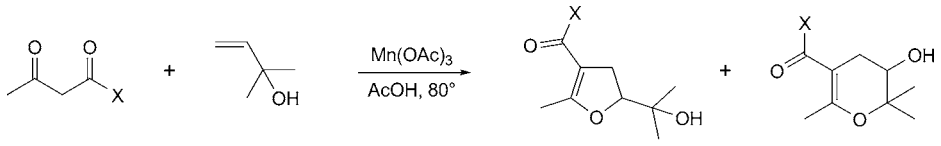
Dihydropyrans also widely occur in natural products with various biological activities [5], and, therefore, numerous methods have been reported for the synthesis of functionalized pyran ring systems [6]. Frequently used methods are hetero *Diels–Alder* cycloadditions [7], ring-expansion reactions [8], intramolecular ring-opening reactions [9], dioxanone *Claisen* rearrangements [10], and S_N2 reactions [11]. In this study, we synthesized dihydropyrans *via* cyclization of unsaturated alcohols and 1,3-dicarbonyl compounds by treatment with $Mn(OAc)_3$ as a new approach to these molecules.

Results and Discussion. – *Reaction of 2-Methylbut-3-en-2-ol* (**2a**) *with* **1a** *and* **1b** *in the Presence of* $Mn(OAc)_3$*, Synthesis of Dihydrofurans and Dihydropyrans.* We initially

examined the reactions of ethyl acetoacetate (**1a**) and acetylacetone (**1b**) with 2-methylbut-3-en-2-ol (**2a**), which furnished 2,3-dihydrofurans, **3aa** and **3ba**, and dihydropyrans, **4aa** and **4ba** (*Table 1*). The reaction mechanism for the formation of these compounds are proposed in *Scheme 1*. The interaction of the Mn^{III}–enolate complex and **2a** affords the C-radical **A**, which is subsequently oxidized with $Mn(OAc)_3$ to give the corresponding carbocation **B**, as usually observed in similar reactions of 1,3-dicarbonyl compounds or 3-oxopropanenitriles with alkenes [12]. Cyclization of **B** gives dihydrofuran **3** *via* pathway *i* or affords oxirane cation **C** *via* pathway *ii*. Similarly, **3** can be produced *via* pathway *iii*. *Via* pathway *iv*, ring opening of the oxirane leads to the more stable carbocation **D**, and dihydropyran **4** forms after the cyclization.

Compounds **3** and **4** were distinguished by ^{1}H- and ^{13}C-NMR spectroscopy [13]. The CH_2(4) and H–C(5) of dihydrofuran resonated at lower field than those of

Table 1. *Radical Cyclization of* **1a** *and* **1b** *with* **2a**

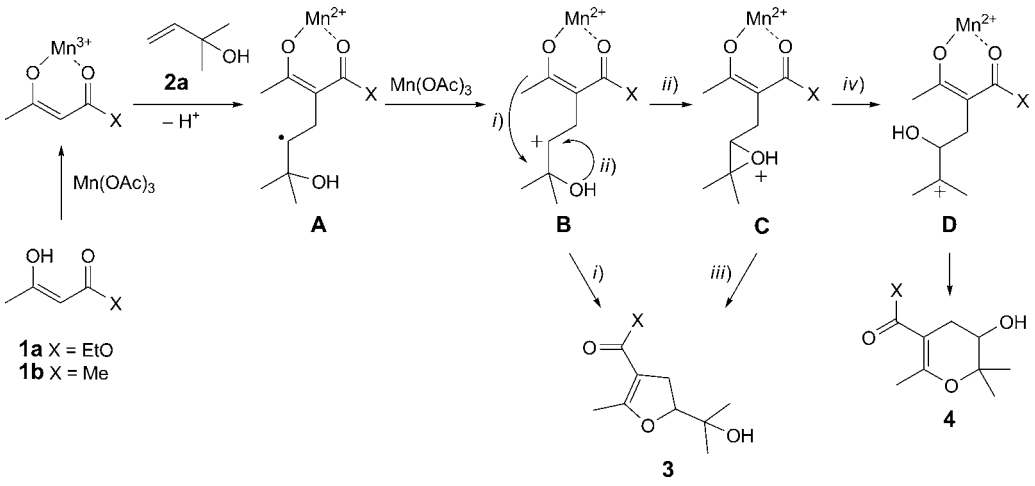


1a, 1b **2a** **3aa, 3ba** **4aa, 4ba**

Entry	1,3-Dicarbonyl compounds	X	**1**/**2a**/$Mn(OAc)_3$[a])	Products	Yield [%]
1	**1a**	EtO	2 : 2 : 4.4	**3aa**[b])	35
				4aa	20
2	**1b**	Me	2.5 : 2 : 5.5	**3ba**	26
				4ba	14

[a]) Molar ratio. [b]) **3aa** was synthesized by another method [14].

Scheme 1. *Proposed Mechanism for the Formation of Dihydrofurans and Dihydropyrans*



dihydropyran in the ^{1}H-NMR spectra. Similarly, the C(5) of dihydrofuran resonated at lower field than C(6) of dihydropyran in the ^{13}C-NMR spectra.

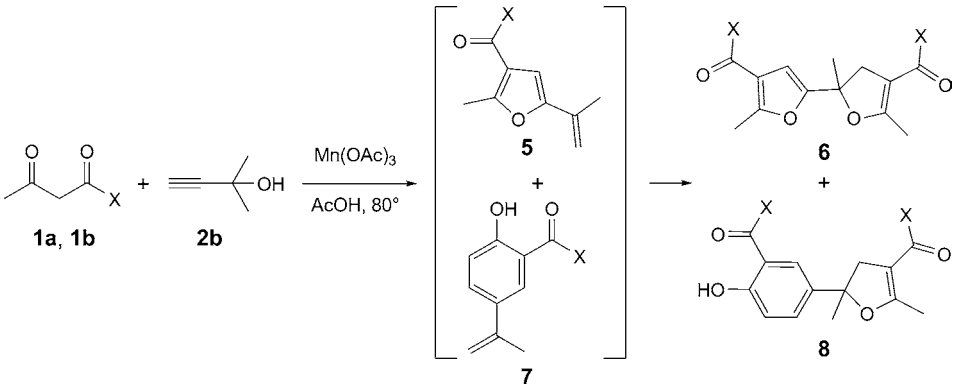
Of the compounds obtained, CH_2(4) of **4aa** and **3aa** resonate at 2.35–2.59 and 2.76–2.84 ppm, respectively. Apart from that, H–C(5) of **4aa** and **3aa** resonates at 3.64 and 4.44 ppm, respectively. In the ^{13}C-NMR spectrum, the signal of C(6) of **4aa** appears at 78.2 ppm, and C(5) of **3aa** resonates at 88.5 ppm.

Reaction of 2-Methylbut-3-yn-2-ol (**2b**) *with* **1a** and **1b** *in the Presence of Mn(OAc)$_3$, Synthesis of Furan, Bifurans, and Salicylate Derivatives.* The Mn(OAc)$_3$-mediated reaction of **2b** with **1a** and **1b** gave bifurans **6ab** and **6bb**, respectively, in low yields (*Table 2*). The mechanism proposed for the formation of compounds **6** (*Path i*) is outlined in *Scheme 2*. First, the C-radical **E** is formed from **2b** and the Mn^{III}–enolate complex. Oxidation of **E** may generate carbocation **F**, and furan **G** is formed by subsequent cyclization of **F**. The dehydration of **G** leads to an alkene intermediate of type **5**, which, in the case of **5ab**, was isolated from the reaction mixture of **1a** and **2b** by terminating the reaction at the half of the reaction time. Finally, bifuran **6** is formed by the reaction of the 1,3-dicarbonyl compound and **5** with 2 equiv. of Mn(OAc)$_3$.

The reaction of 2-methylbut-1-en-3-yne, the dehydrated product of **2b**, with **1a** and Mn(OAc)$_3$/Cu(OAc)$_2$ gave ethyl 5-ethynyl-2,5-dimethyl-4,5-dihydrofuran-3-carboxylate (**11**; 51%) and bifuran-dicarboxylate **6ab** (6%) reported by *Melikyan et al.* in 1982 (*Scheme 3*) [15]. In our study, inability to obtain **11** from the performed reactions established that dehydration step occurs after the first intramolecular cyclization. In addition, the isolation of the intermediate product **5ab** from the reaction of **1a** and **2b** with Mn(OAc)$_3$ supported our proposed mechanism.

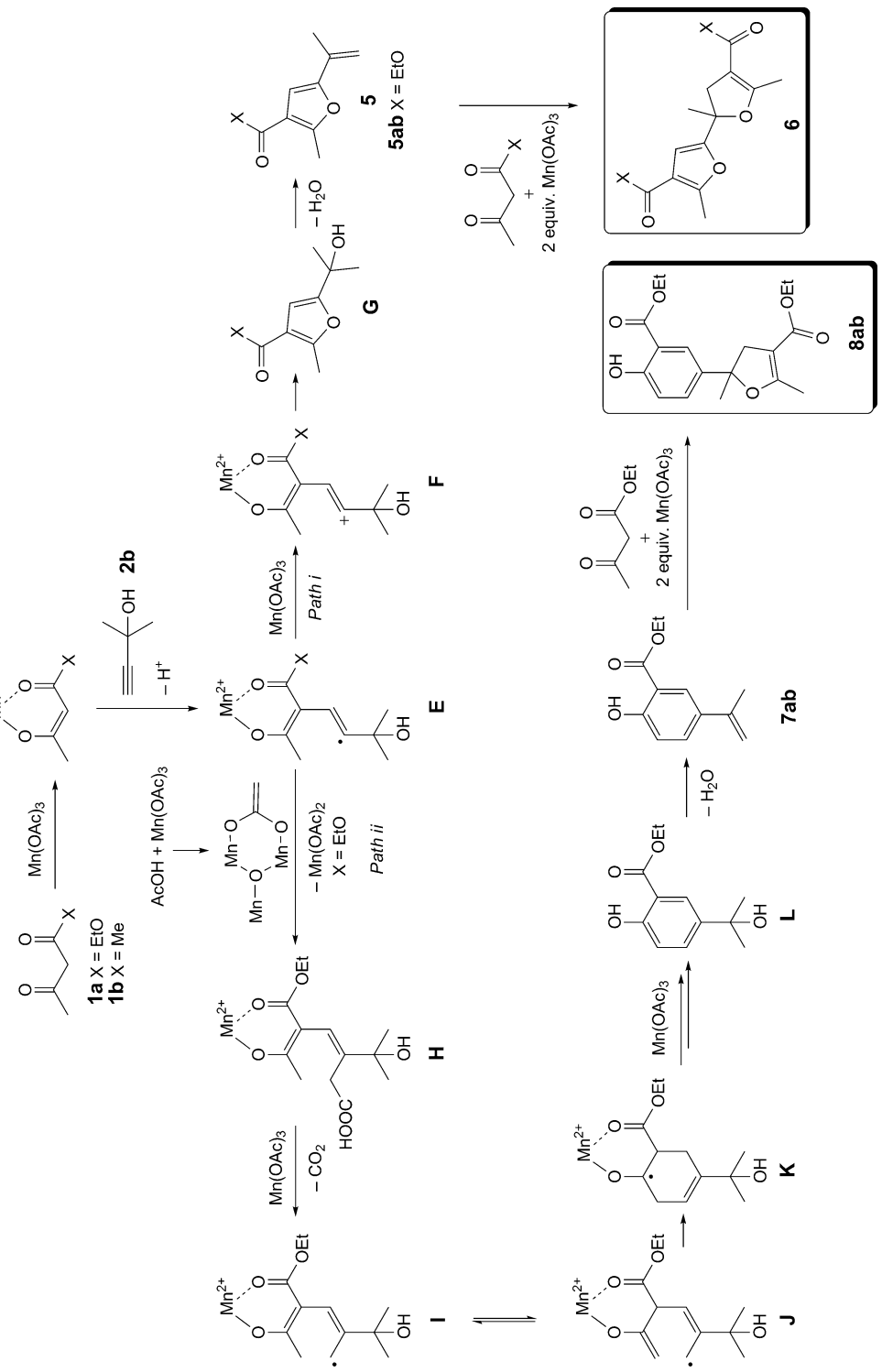
The Mn(OAc)$_3$-mediated reaction of **1a** with 2-methylbut-3-yn-2-ol (**2b**) gave also small amounts of salicylate derivatives **7ab** and **8ab** (*Table 2*). The mechanism proposed for the formation of salicylate derivatives (*Path ii*) is depicted in *Scheme 2*.

Table 2. *Radical Cyclization of* **1a** *and* **1b** *with* **2b**

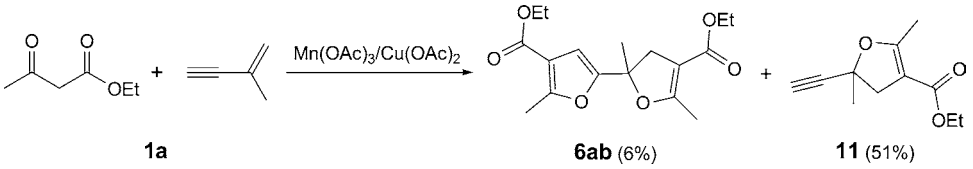


Entry	1,3-Dicarbonyl compounds	X	Intermediates	Products	Yield [%]
1	**1a**	EtO	**5ab**	**6ab**	13
			7ab	**8ab**	3
2	**1b**	Me	–	**6bb**	16

Scheme 2. *Proposed Mechanism for the Formation of Bifurans and Salicylate Derivatives*



Scheme 3. *Reaction of 2-Methylbut-1-en-3-yne, Dehydrated Form of* **2b**, *with* **1a**



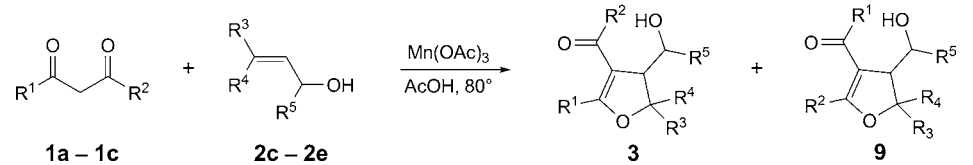
1a **6ab** (6%) **11** (51%)

The interaction of **E** and acetic acid–enolate–Mn^{III} complex affords acid intermediate product **H**, which may be decarboxylated with $Mn(OAc)_3$ to give C-radical **I**. Cyclization of **J**, which is another enol form of **I**, gives cyclic C-radical **K**, followed by aromatization of **K** in the presence of $Mn(OAc)_3$ leading to product **L**. Dehydration of **L** gives the alkene intermediate **7ab**, which was isolated from the reaction mixture by terminating the reaction at the half of the reaction time. Then, **8ab** is formed by radical cyclization of **7ab** and **1a** mediated by $Mn(OAc)_3$. Decarboxylation [16] and aromatization [17] steps *via* reaction with $Mn(OAc)_3$ are known.

In the NMR spectra of **7ab** and **8ab**, the signals in the range of 6.9–7.8 ppm (^{1}H-NMR) and 112–161 ppm (^{13}C-NMR) establish the presence of an aromatic structure.

Reaction of **2c**–**2e** *with* **1a**–**1c** *in the Presence of Mn(OAc)$_3$, Synthesis of Dihydrofurans.* From the reactions of 1,3-dicarbonyl compounds with allylic alcohols mediated by $Mn(OAc)_3$, dihydrofurans were obtained in moderate yields (*Table 3*). The value of the coupling constant $^3J(4,5)$ in tetrasubstituted 4,5-dihydrofurans obtained from the reactions of 1,2-disubstituted alkene is in the range of 4.0–6.8. Therefore, these compounds are *cis*-isomers [18].

Table 3. *Radical Cyclization of* **1a**–**1c** *with* **2c**–**2e**



1a – 1c **2c – 2e** **3** **9**

Entry	**1**	R^1	R^2	**2**	R^3	R^4	R^5	**1/2**/$Mn(OAc)_3$[a])	Products	Yield [%]
1	**1a**	Me	EtO	**2c**	Me	Me	H	2.5 : 3 : 5	**3ac**	42
2	**1b**	Me	Me	**2c**	Me	Me	H	2 : 4 : 5	**3bc**	20
3	**1c**	Me	Ph	**2c**	Me	Me	H	2 : 2 : 4.4	**3cc**	14
									9cc	7
4	**1a**	Me	EtO	**2d**	Ph	H	H	2 : 1 : 3	**3ad**	35
5	**1b**	Me	Me	**2d**	Ph	H	H	2 : 1 : 3	**3bd**	38
6	**1c**	Me	Ph	**2d**	Ph	H	H	3 : 1 : 3	**3cd**	18
									9cd	16
7	**1a**	Me	EtO	**2e**	Ph	H	Me	2.5 : 5 : 5	**3ae**	25
8	**1b**	Me	Me	**2e**	Ph	H	Me	3 : 1 : 3	**3be**	25

[a]) Molar ratio.

The ^{1}H-NMR spectrum of **3be** in $CDCl_3$ was examined; it was observed that H_b and H_c (*cf. Fig.*) did not couple. It is assumed that this results from a rigid structure as a consequence of the C=O and OH groups forming a H-bond, and positioning H_b and H_c at nearly 90° angle. In (D_6)acetone or in $CDCl_3$, the ^{1}H-NMR spectra revealed that these H-atoms were coupled or not (see also the COSY spectrum of **3be** in (D_6)acetone and $CDCl_3$ in the *Figure*).

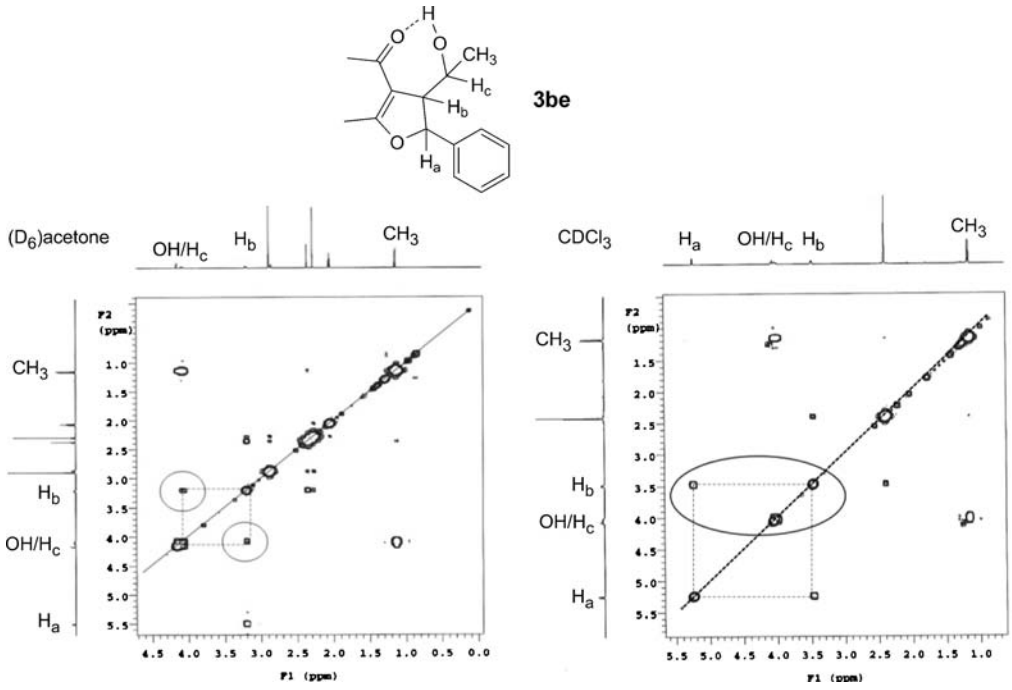


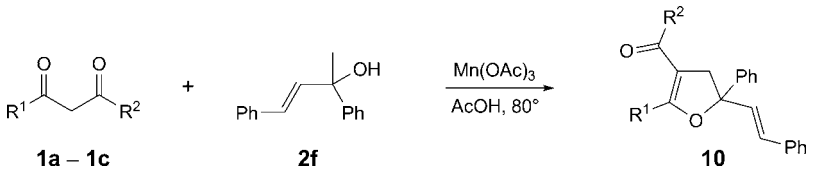
Figure. *Structure and COSY Spectra of* **3be** *in (D_6)acetone and $CDCl_3$*

*Reaction of (3*E*)-2,4-Diphenylbut-3-en-2-ol* (**2f**) *with* **1a**–**1c** *in the Presence of Mn(OAc)$_3$, Synthesis of Styryl-Substituted Dihydrofurans.* Unexpectedly, the reaction of **2f** with **1a**–**1c** did not give any $HOCH_2$-substituted dihydrofurans, but styryl-substituted dihydrofurans were obtained as the sole products (*Table 4*). A plausible mechanism for the formation of these products is proposed in *Scheme 4*. According to this mechanism, a diene is formed *in situ* from **2f**, and it reacts with the Mn^{III}–enolate complex to produce C-radical **M**, which is then oxidized to the carbocation **N** by $Mn(OAc)_3$, and intramolecular cyclization of **N** affords **10**.

In ^{1}H-NMR spectra of **10af** and **10bf**, the diastereotopic H-atoms at C(4), resonated at 3.30–3.44 ppm (^2J(H,H) = 14.4–14.8). Besides, the Me at C(2) gave rise to a *triplet* (^5J(H,H) = 1.6) through coupling with CH_2(4).

Conclusions. – In this study, the free-radical cyclizations of 1,3-dicarbonyl compounds and unsaturated alcohols mediated by $Mn(OAc)_3$ were investigated.

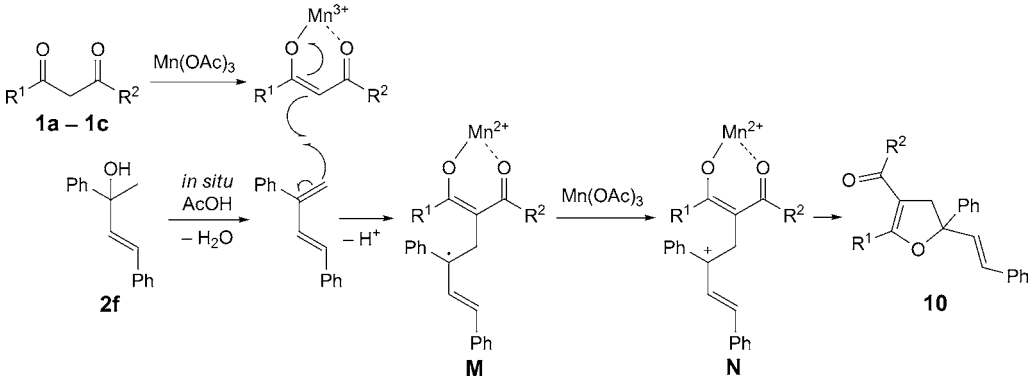
Table 4. *Radical Cyclization of* **1a**–**1c** *with* **2f**



Entry	1,3-Dicarbonyl compounds	R^1	R^2	**1**/**2**/$Mn(OAc)_3$[a])	Products	Yield [%]
1	**1a**	Me	EtO	1 : 1.25 : 2.5	**10af**	61
2	**1b**	Me	Me	1.25 : 1 : 2.5	**10bf**	57
3	**1c**	Ph	Me	2 : 1 : 2.5	**10cf**	35

[a]) Molar ratio.

Scheme 4. *Proposed Mechanism for the Formation of Styryl-Substituted Dihydrofurans*



It is well-known that dihydrofurans and furans can be synthesized *via* the $Mn(OAc)_3$-mediated reactions of 1,3-dicarbonyl compounds, and alkenes and alkynes. Using of unsaturated alcohols instead of alkenes/alkynes in these reactions led to the formation of dihydropyrans, bifurans, and salicylate derivatives in low yields besides dihydrofurans and furans. The cyclization of some unsaturated alcohols and 1,3-dicarbonyl compounds with $Mn(OAc)_3$ offers a new aproach for the dihydropyran formation.

The mechanism for the formation of salicylate derivatives include oxidative addition, formation of AcOH–enolate–Mn^{III} complex, radical coupling, decarboxylation, cyclization, and aromatization steps. This is the first example including almost all reaction types of $Mn(OAc)_3$-mediated reactions.

Finally, synthesized dihydrofuran and dihydropyran derivatives were evaluated for their antimicrobial activities against *Gram*-positive (*e.g.*, *Bacillus megaterium* M22) and *Gram* negative bacteria (*e.g.*, *Escherichia coli* ATCC 25922). The antibacterial activities were determined by the disc-diffusion method and minimum inhibition concentration (*MIC*) against *Gram*-positive and *Gram*-negative bacteria. All the

bacteria were studied against to antibiotics such as ampicillin and penicillin to compare with our products' zone diameters. Antibiogram test of our new compounds showed better results than some known antibiotics.

We are grateful to Prof. *Elif Loğoğlu*, Laboratory of Biochemistry, Faculty of Science, Gazi University, Turkey, for antimicrobial activity test.

Experimental Part

General. 1,3-Dicarbonyl compounds **1a**–**1c** and unsaturated alcohols **2a**–**2d** are commercially available, and they were used in highest purity. *(3*E*)-4-Phenylbut-3-en-2-ol* (**2e**) was prepared by the reduction of benzylideneacetone with $NaBH_4$ as described in [19]. *(3*E*)-2,4-Diphenylbut-3-en-2-ol* (**2f**) was prepared by the reaction of PhMgBr and benzylideneacetone in Et_2O as described in [20]. TLC: *Merck* Al-packed silica gel (SiO_2) plates. Prep. TLC: SiO_2 $PF_{254-366\,nm}$ (*Merck*). Column chromatography (CC): SiO_2 (*Merck 60*, 40–60 mm). M.p.: Electrothermal cap. melting-point apparatus. IR Spectra: *PerkinElmer Spectrum 100* FT-IR in the 400–4000-cm^{-1} range with 4-cm^{-1} resolution; in KBr or $CHCl_3$; $\tilde{\nu}$ in cm^{-1}. ^{1}H- and ^{13}C-NMR spectra: *Varian Mercury-400* high performance digital FT-NMR spectrophotometer; δ in ppm rel. to Me_4Si as internal standard, J in Hz. MS: *Waters 2695 Alliance Micromass ZQ* LC/ESI-MS spectrometer and *Agilent Technologies 6890 N* Network GC/MS System; in m/z (rel. %). Elemental analyses: *Leco CHNS-932* instrument; in %.

Synthesis of **2e** [19]. In a round-bottomed 250-ml flask equipped with a condenser and magnetic stirrer, benzylideneacetone (5.00 g, 34.25 mmol) was dissolved in EtOH (80 ml). Then, $NaBH_4$ (1.30 g; 34.25 mmol) was added. The mixture was stirred at r.t. for 5 min, and the reaction progress was monitored by TLC. After completion of the reaction, the mixture was filtered through a pad of *Celite*, and the filtrate was concentrated under reduced pressure. The product was purified by CC (hexane/AcOEt 3:1): 4.28 g (84%) of **2e**; m.p. 31° ([19]: 30–31°).

Synthesis of **2f** [20]. A soln. of benzylideneacetone 2.92 g, (20 mmol) in Et_2O (10 ml) was added dropwise to a soln. of PhMgBr at 0° in dried Et_2O (20 ml). The mixture was heated at reflux for 2 h and then hydrolyzed with sat. aq. NH_4Cl soln. in an ice-salt bath, and the soln. was extracted with Et_2O (3 × 20 ml). The combined org. layers were washed with H_2O and brine, and dried (Na_2SO_4). The product was purified by CC (hexane/AcOEt 3:1): 2.33 g (52%) of **2f**; m.p. 56–58° ([20]: 58°).

General Procedure for the Reactions of 1,3-Dicarbonyl Compounds with Unsaturated Alcohols. A soln. of $Mn(OAc)_3 \cdot H_2O$ in glacial AcOH was heated under N_2 at 80° until it dissolved. Then, a soln. of 1,3-dicarbonyl compound and unsaturated alcohol in glacial AcOH (5 ml) was added to the mixture. The reaction was complete when the dark brown color of the soln. disappeared. H_2O was added to the mixture, which was extracted with $CHCl_3$ (3 × 20 ml). The combined org. layers were neutralized with sat. aq. $NaHCO_3$ soln., washed with H_2O, dried (Na_2SO_4), and evaporated to give an oil. Products were purified by CC (SiO_2) or prep. TLC (SiO_2), eluating with hexane/AcOEt mixtures.

Ethyl 4,5-Dihydro-5-(1-hydroxy-1-methylethyl)-2-methylfuran-3-carboxylate (**3aa**). Colorless oil. IR (KBr): 3473 (OH), 2982–2940 (CH), 1732 (C=O), 1648 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.18 (*s*, 3 H); 1.25 (*s*, 3 H); 1.28 (*t*, J = 7.2, 3 H); 2.20 (*t*, J = 1.6, 3 H); 2.76 (*ddq*, J = 14.4, 9.6, 1.6, H); 2.84 (*ddd*, J = 14.4, 10.8, 1.6, H); 4.16 (*q*, J = 7.2, 2 H); 4.44 (*dd*, J = 10.4, 9.2, 1 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 14.2; 14.6; 23.8; 25.6; 31.0; 59.8; 72.0; 88.5; 102.8; 166.3 (C=O); 167.8 (C(2)). MS: 214 (60, M^+), 181 (88, $[M - Me - H_2O]^+$), 169 (53, $[M - C_2H_5O]^+$), 156 (100, $[M - C_3H_6O]^+$), 127 (9, $[M - C_5H_{11}O]^+$), 59 (77, $C_3H_7O^+$), 43 (88, $C_2H_3O^+$), 29 (23, $C_2H_5^+$).

*Ethyl 3,4-Dihydro-3-hydroxy-2,2,6-trimethyl-2*H*-pyran-5-carboxylate* (**4aa**). White solid. M.p. 61°. IR (KBr): 3464 (OH), 2977–2941 (CH), 1684 (C=O), 1610 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.25 (*s*, 3 H); 1.28 (*s*, 3 H); 1.28 (*t*, J = 7.2, 1 H); 1.80 (*s*, 1 H); 2.24 (*d*, J = 1.6, 3 H); 2.35 (*ddd*, J = 17.2, 5.6, 1.2, 1 H); 2.59 (*ddd*, J = 17.2, 5.2, 1.6, 1 H); 3.62–3.67 (*m*, 1 H); 4.15 (*q*, J = 7.2, 2 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 14.6; 20.6; 22.0; 24.9; 28.8; 60.0; 69.2; 78.2; 97.7; 163.4 (C(2)); 168.5 (C=O). MS: 214 (34, M^+), 169 (25, $[M - C_2H_5O]^+$), 143 (100, $[M - C_4H_7O]^+$), 97 (100, $C_6H_9O^+$), 72 (42, $C_4H_8O^+$), 43 (50, $C_2H_3O^+$), 29 (9, $C_2H_5^+$). Anal. calc. for $C_{11}H_{18}O_4$ (214.2582): C 61.66, H 8.47; found: C 61.48, H 8.25.

1-[4,5-Dihydro-5-(1-hydroxy-1-methylethyl)-2-methylfuran-3-yl]ethanone (**3ba**). Colorless oil. IR (KBr): 3418 (OH), 2981–2939 (CH), 1738 (C=O), 1606 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.19 (*s*, 3 H); 1.27 (*s*, 3 H); 2.0 (*s*, 1 H); 2.22 (*s*, 3 H); 2.24 (*t*, *J* = 1.2, 3 H); 2.81–2.93 (*m*, 2 H); 4.46 (*dd*, *J* = 9.2, 8.8, 1 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 15.2; 24.0; 25.7; 29.7; 31. 71.9; 88.6; 113.1; 167.7 (C(2)); 194.8 (C=O). MS: 184 (8, M^+), 151 (13, $[M - Me - H_2O]^+$), 111 (66, $[M - C_4H_9O]^+$), 59 (37, $C_3H_7O^+$), 43 (100, $C_2H_3O^+$). Anal. calc. for $C_{10}H_{16}O_3$ (184.2322): C 65.19, H 8.75; found: C 64.95, H 8.58.

*1-(3,4-Dihydro-3-hydroxy-2,2,6-trimethyl-2*H*-pyran-5-yl)ethanone* (**4ba**). White solid. M.p. 92–93°. IR (KBr): 3348 (OH), 2992–2932 (CH), 1660 (C=O), 1558 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.27 (*s*, 3 H); 1.29 (*s*, 3 H); 1.84 (*d*, *J* = 6.8, 1 H); 2.22 (*t*, *J* = 1.6, 3 H); 2.23 (*s*, 3 H); 2.39 (*ddd*, *J* = 16.4, 6.0, 1.2, 1 H); 2.64 (*ddd*, *J* = 16.0, 5.2, 1.2, 1 H); 3.7 (*q*, *J* = 6.0, 1 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 21.5; 21.8; 25.0; 29.9; 30.0; 69.3; 78.1; 106.5; 163.2 (C(2)); 198.9 (C=O). MS: 184 (14, M^+), 151 (7, $[M - Me - H_2O]^+$), 113 (44, $[M - C_4H_7O]^+$), 72 (37, $C_4H_8O^+$), 43 (100, $C_2H_3O^+$). Anal. calc. for $C_{10}H_{16}O_3$ (184.2322): C 65.19, H 8.75; found: C 64.98, H 8.62.

Ethyl 2-Methyl-5-(1-methylethenyl)furan-3-carboxylate (**5ab**). Colorless oil. ^{1}H-NMR (400 MHz, $CDCl_3$): 1.35 (*t*, *J* = 7.2, 3 H); 2.00 (*s*, 3 H); 2.59 (*s*, 3 H); 4.29 (*q*, *J* = 7.2, 2 H); 4.96 (*s*, 1 H); 5.47 (*s*, 1 H); 6.50 (*s*, 1 H).

Diethyl 2,3-Dihydro-2,5,5′-trimethyl-2,2′-bifuran-4,4′-dicarboxylate (**6ab**). Colorless oil. IR (KBr): 2981–2936 (CH), 1704 (C=O), 1651 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.29 (*t*, *J* = 7.2, 3 H); 1.34 (*t*, *J* = 7.2, 3 H); 1.69 (*s*, 3 H); 2.20 (*d*, *J* = 1.6, 3 H); 2.58 (*s*, 3 H); 2.83 (*dd*, *J* = 14.8, 1.6, 1 H); 3.30 (*dd*, *J* = 14.4, 1.6, 1 H); 4.14–4.31 (*m*, 4 H); 6.58 (*s*, 1 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 14.1; 14.5; 14.7; 14.9; 21.0; 40.9; 59.8; 60.4; 78.3; 101.5; 107.5; 114.3; 153.7; 164.1; 166.3; 167.6; 172.5. MS: 322 (28, M^+), 276 (100, $[M - C_2H_6O]^+$), 231 (18, $[M - C_7H_7]^+$), 202 (41, $[M - C_9H_{12}]^+$), 43 (30, $C_3H_7^+$).

1,1′-(2,3-Dihydro-2,5,5′-Trimethyl-2,2′-bifuran-4,4′-diyl)bis[ethanone] (**6bb**). Pale-yellow oil. IR (KBr): 2989–2938 (CH), 1768–1714 (C=O), 1681–1600 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.72 (*s*, 3 H); 2.24 (*t*, *J* = 1.2, 3 H); 2.25 (*s*, 3 H); 2.41 (*s*, 3 H); 2.60 (*s*, 3 H); 2.91 (*dd*, *J* = 14.4, 1.6, 1 H); 3.37 (*dd*, *J* = 14.0, 1.2, 1 H); 6.6 (*s*, 1 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 14.8; 15.5; 25.8; 29.4; 29.7; 41.6; 83.4; 107.3; 112.0; 122.2; 153.5 (C(2′)); 159.1 (C(5)); 166.3 (C(5′)); 194.3 (C=O); 194.9 (C=O). MS: 262 (100, M^+), 219 (22, $[M - MeCO]^+$), 177 (33, $[M - C_5H_9O]^+$), 43 (83, $MeCO^+$). Anal. calc. for $C_{15}H_{18}O_4$ (262.301): C 68.68, H 6.92; found: C 68.91, H 7.05.

Ethyl 2-Hydroxy-5-(1-methylethenyl)benzoate (**7ab**). Colorless oil. ^{1}H-NMR (400 MHz, $CDCl_3$): 1.43 (*t*, *J* = 7.2, 3 H); 2.14 (*d*, *J* = 0.8, 3 H); 4.43 (*q*, *J* = 7.2, 2 H); 5.04 (*t*, *J* = 1.2, 1 H); 5.30 (*s*, 1 H); 6.95 (*d*, *J* = 8.4, 1 H); 7.61 (*dd*, *J* = 8.4, 2.4, 1 H); 7.92 (*d*, *J* = 2.4, 1 H); 10.85 (*s*, 1 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 14.7; 22.1; 61.7; 111.6; 112.3; 117.6; 126.8; 132.6; 133.0; 142.0; 161.3; 170.5. LC/MS: 207 (100, $[M + H]^+$).

Ethyl 5-[3-(Ethoxycarbonyl)-4-hydroxyphenyl]-4,5-dihydro-2,5-dimethylfuran-3-carboxylate (**8ab**). Colorless oil. ^{1}H-NMR (400 MHz, $CDCl_3$): 1.27 (*t*, *J* = 7.2, 3 H); 1.44 (*t*, *J* = 7.2, 3 H); 1.67 (*s*, 3 H); 2.29 (*t*, *J* = 1.6, 3 H); 3.03 (*dd*, *J* = 14.4, 1.2, 1 H); 3.09 (*dd*, *J* = 14.4, 1.6, 1 H); 4.16 (*q*, *J* = 7.2, 2 H); 4.43 (*q*, *J* = 7.2, 2 H); 6.98 (*d*, *J* = 8.4, 1 H); 7.47 (*dd*, *J* = 8.8, 2.4, 1 H); 7.81 (*d*, *J* = 2.4, 1 H); 10.84 (*s*, 1 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 14.5; 14.6; 14.7; 29. 6; 44.5; 59.8; 61.8; 88.1; 101.6; 112.3; 118.0; 125.6; 132.3; 137.3; 161.1; 166.4; 166.6; 170.3. MS: 334 (7, M^+), 288 (14, $[M - C_2H_6O]^+$), 242 (100, $[M - C_4H_{12}O_2]^+$), 214 (18, $[M - C_5H_{12}O_3]^+$), 172 (20, $[M - C_6H_{12}O_4]^+$), 43 (22, $MeCO^+$).

Ethyl 4,5-Dihydro-4-(hydroxymethyl)-2,5,5-trimethylfuran-3-carboxylate (**3ac**). Colorless oil. IR (KBr): 3491 (OH), 2982–2939 (CH), 1739 (C=O), 1635 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.31 (*t*, *J* = 7.2, 3 H); 1.37 (*s*, 3 H); 1.39 (*s*, 3 H); 2.18 (*d*, *J* = 1.6, 3 H); 2.96 (*t*, *J* = 4.8, 1 H); 3.64 (*s*, 1 H); 3.73 (*d*, *J* = 5.6, 2 H); 4.21 (*q*, *J* = 7.2, 2 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 14.6; 15.5; 22.0; 29.3; 53.6; 60.2; 62.7; 88.3; 104.0; 168.0 (C=O); 169.1 (C(2)). MS: 214 (5, M^+), 183 (100, $[M - MeO]^+$), 110 (53, $[M - C_4H_8O_3]^+$), 43 (53, $C_3H_7^+$). Anal. calc. for $C_{11}H_{18}O_4$ (214.2582): C 61.66, H 8.47; found: C 61.78, H 8.61.

1-[4,5-Dihydro-4-(hydroxymethyl)-2,5,5-trimethylfuran-3-yl]ethanone (**3bc**). Colorless oil. IR (KBr): 3472 (OH), 2977–2936 (CH), 1741 (C=O), 1602 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.34 (*s*, 3 H); 1.38 (*s*, 3 H); 2.25 (*d*, *J* = 0.8, 3 H); 2.36 (*s*, 3 H); 3.02 (*ddd*, *J* = 8.0, 3.6, 0.8, 1 H); 3.62 (*dd*, *J* = 10.4, 8.0, 1 H); 3.69 (*d*, *J* = 10.4, 1 H); 4.57 (*s*, 1 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 16.9; 22.1; 29.0; 29.7; 54.3; 63.3; 88.4; 117.9; 169.3 (C(2)); 196.6 (C=O). MS: 184 (4, M^+), 151 (4, $[M - Me - H_2O]^+$), 111 (54, $[M - C_4H_9O]^+$), (100, $MeCO^+$). Anal. calc. for $C_{10}H_{16}O_3$ (184.2322): C 65.19, H 8.75; found: C 65.32, H 8.82.

[4,5-Dihydro-4-(hydroxymethyl)-2,5,5-trimethylfuran-3-yl](phenyl)methanone (**3cc**). Pale-yellow oil. IR (KBr): 3464 (OH), 3062 (arom. H), 2981–2939 (CH), 1721 (C=O), 1600 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.40 (*s*, 3 H); 1.49 (*s*, 3 H); 1.61 (*s*, 3 H); 3.18 (*dd*, *J* = 8.0, 4.0, 1 H); 3.73 (*dd*, *J* = 10.4, 8.0, 1 H); 3.80 (*dd*, *J* = 10.4, 3.2, 1 H); 4.72 (*s*, 1 H); 7.57–7.35 (*m*, 5 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 16.8; 22.1; 28.9; 55.2; 63.5; 88.6; 116.8; 128.4; 128.7; 131.8; 141.1; 170.9 (C(2)); 196.4 (C=O). MS: 246 (3, M^+), 216 (17, $[M - CH_2O]^+$), 215 (17, $[M - MeO]^+$), 105 (100, $C_6H_5CO^+$), 77 (26, $C_6H_5^+$), 28 (37, CO^+). Anal. calc. for $C_{15}H_{18}O_3$ (246.3016): C 73.15, H 7.37; found: C 73.25, H 7.42.

1-[4,5-Dihydro-4-(hydroxymethyl)-5,5-dimethyl-2-phenylfuran-3-yl]ethanone (**9cc**). Pale-yellow oil. IR (KBr): 3427 (OH), 3062 (arom. H), 2978–2934 (CH), 1718 (C=O), 1614–1587 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.43 (*s*, 3 H); 1.51 (*s*, 3 H); 1.93 (*s*, 3 H); 3.18 (*dd*, *J* = 8.4, 4.0, 1 H); 3.75 (*dd*, *J* = 10.8, 8.4, 1 H); 3.82 (*d*, *J* = 9.6, 1 H); 4.70 (*s*, 1 H); 7.53–7.46 (*m*, 5 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 22.0; 28.7; 29.0; 55.3; 63.7; 89.1; 119.0; 128.8; 129.4; 131.3; 131.4; 169.4 (C(2)); 198.5 (C=O). MS: 246 (4, M^+), 216 (33, $[M - CH_2O]^+$), 215 (73, $[M - MeO]^+$), 173 (38, $[M - C_4H_9O]^+$), 105 (54, $C_6H_5CO^+$), 77 (33, $C_6H_5^+$), 43 (100, $MeCO^+$), 27 (57, $C_2H_3^+$). Anal. calc. for $C_{15}H_{18}O_3$ (246.3016): C 73.15, H 7.37; found: C 73.32, H 7.48.

Ethyl 4,5-Dihydro-4-(hydroxymethyl)-2-methyl-5-phenylfuran-3-carboxylate (**3ad**). Colorless oil. IR (KBr): 3455 (OH), 3065–3034 (arom. H), 2982–2939 (CH), 1738 (C=O), 1695–1645 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.30 (*t*, *J* = 7.2, 3 H); 2.32 (*d*, *J* = 1.2, 3 H); 3.11 (*s*, 1 H); 3.35 (*q*, *J* = 5.6, 1 H); 3.79 (*dd*, *J* = 10.0, 4.4, 1 H); 3.85 (*dd*, *J* = 10.8, 5.6, 1 H); 4.16–4.24 (*m*, 2 H); 5.32 (*d*, *J* = 6.4, 1 H); 7.39–7.30 (*m*, 5 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 14.6; 15.0; 54.1; 60.3; 65.3; 86.4; 103.2; 125.7; 128.5; 129.0; 141.1; 167.0 (C(2)); 170.2 (C=O). MS: 262 (4, M^+), 231 (100, $[M - MeO]^+$), 158 (43, $[M - C_4H_8O_3]^+$), 77 (12, $C_6H_5^+$), 43 (49, $C_3H_7^+$). Anal. calc. for $C_{15}H_{18}O_4$ (262.301): C 68.68, H 6.92; found: C 68.55, H 6.78.

1-[4,5-Dihydro-4-(hydroxymethyl)-2-methyl-5-phenylfuran-3-yl]ethanone (**3bd**). Colorless oil. IR (KBr): 3413 (OH), 3064–3032 (arom. H), 2983–2939 (CH), 1741 (C=O), 1617 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 2.36 (*s*, 3 H); 2.37 (*d*, *J* = 1.2, 3 H); 3.41 (*q*, *J* = 5.6, 1 H); 3.74 (*dd*, *J* = 10.4, 4.8, 1 H); 3.80 (*dd*, *J* = 10.4, 6.8, 1 H); 5.24 (*d*, *J* = 6.8, 1 H); 7.39–7.28 (*m*, 5 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 16.3; 29.7; 54.6; 65.7; 86.3; 116.2; 125.7; 128.7; 129.0; 140.6; 167.0 (C(2)); 195.7 (C=O). MS: 232 (8, M^+), 202 (38, $[M - CH_2O]^+$), 201 (100, $[M - MeO]^+$), 141 (21, $[M - C_7H_7]^+$), 77 (11, $C_6H_5^+$), 43 (100, $MeCO^+$). Anal. calc. for $C_{14}H_{16}O_3$ (232.275): C 72.39, H 6.94; found: C 72.27, H 6.78.

[4,5-Dihydro-4-(hydroxymethyl)-2-methyl-5-phenylfuran-3-yl](phenyl)methanone (**3cd**). Pale-yellow oil. IR (KBr): 3423 (OH), 3063–3033 (arom. H), 2926–2881 (CH), 1721 (C=O), 1604–1571 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.78 (*d*, *J* = 1.2, 3 H); 3.59 (*q*, *J* = 6.0, 1 H); 3.85 (*d*, *J* = 6.4, 2 H); 3.97 (*s*, 1 H); 5.33 (*d*, *J* = 6.0, 1 H); 7.59–7.34 (*m*, 10 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 16.3; 55.2; 65.6; 86.4; 115.1; 125.8; 128.4; 128.7; 129.1; 131.9; 140.5; 140.7; 170.6 (C(2)); 195.3 (C=O). LC/MS: 295 (100, $[M + H]^+$). Anal. calc. for $C_{19}H_{18}O_3$ (294.3444): C 77.53, H 6.16; found: C 77.44, H 5.97.

1-[4,5-Dihydro-4-(hydroxymethyl)-2,5-diphenylfuran-3-yl]ethanone (**9cd**). Pale-yellow oil. IR (KBr): 3421 (OH), 3063–3033 (arom. H), 2931–2878 (CH), 1740 (C=O), 1622–1590 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.97 (*s*, 3 H); 3.59 (*td*, *J* = 6.8, 4.4, 1 H); 3.87 (*dd*, *J* = 10.4, 4.4, 1 H); 3.95 (*dd*, *J* = 10.4, 7.6, 1 H); 5.34 (*d*, *J* = 6.8, 1 H); 7.59–7.36 (*m*, 10 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 29.2; 55.3; 66.5; 86.4; 117.6; 125.7; 128.8; 128.9; 129.1; 129.5; 130.9; 131.4; 140.5; 169.7 (C(2)); 197.4 (C=O). LC/MS: 295 (100, $[M + H]^+$). Anal. calc. for $C_{19}H_{18}O_3$ (294.3444): C 77.53, H 6.16; found: C 77.47, H 6.02.

Ethyl 4,5-Dihydro-4-(1-hydroxyethyl)-2-methyl-5-phenylfuran-3-carboxylate (**3ae**). Colorless oil. IR (KBr): 3450 (OH), 3033 (arom. H), 2977–2932 (CH), 1695 (C=O), 1652 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.21 (*d*, *J* = 6.8, 3 H); 1.30 (*t*, *J* = 7.2, 3 H); 2.34 (*d*, *J* = 1.2, 3 H); 3.14 (*s*, 1 H); 3.34 (*m*, 1 H); 4.12 (*qd*, *J* = 5.6, 2.0, 1 H); 4.16–4.24 (*m*, 2 H); 5.37 (*d*, *J* = 5.2, 1 H); 7.38–7.27 (*m*, 5 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 14.6; 15.0; 19.6; 58.1; 60.3; 68.0; 84.8; 102.1; 125.7; 128.5; 129.0; 141.7; 167.0 (C(2)); 170.4 (C=O). MS: 276 (5, M^+), 261 (4, $[M - Me]^+$), 232 (100, $[M - C_3H_7]^+$), 231 (100, $[M - C_3H_8]^+$), 77 (12, $C_6H_5^+$), 43 (62, $MeCO^+$). Anal. calc. for $C_{16}H_{20}O_4$ (276.3276): C 69.54, H 7.30; found: C 69.39, H 7.49.

1-[4,5-Dihydro-4-(1-hydroxyethyl)-2-methyl-5-phenylfuran-3-yl]ethanone (**3be**). Colorless oil. ^{1}H-NMR (400 MHz, $CDCl_3$): 1.16 (*d*, *J* = 6.0, 3 H); 2.39 (*s*, 3 H); 2.40 (*s*, 3 H); 3.47 (*d*, *J* = 5.6, 1 H); 4.01 (*td*, *J* = 6.4, 1.2, 1 H); 4.07 (*d*, *J* = 7.2, OH); 5.25 (*d*, *J* = 5.6, 1 H); 7.39–7.26 (*m*, 5 H). ^{1}H-NMR (400 MHz, $CDCl_3 + D_2O$): 1.15 (*d*, *J* = 6.8, 3 H); 2.39 (*s*, 3 H); 2.40 (*s*, 3 H); 3.47 (*dq*, *J* = 6.0, 1.2, 1 H); 4.00 (*qd*, *J* = 6.0, 2.0, 1 H); 5.25 (*d*, *J* = 5.6, 1 H); 7.39–7.25 (*m*, 5 H). ^{1}H-NMR (400 MHz, (D_6)acetone):

1.14 (*d*, *J* = 6.4, 3 H); 2.28 (*s*, 3 H); 2.36 (*d*, *J* = 1.2, 3 H); 3.19 – 3.21 (*m*, 1 H); 4.07 – 4.11 (*m*, 1 H); 4.15 (*d*, *J* = 5.2, 1 H); 5.51 (*d*, *J* = 4.8, 1 H); 7.40 – 7.29 (*m*, 5 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 16.3; 19.2; 29.7; 58.6; 68.5; 85.5; 114.7; 125.6; 128.7; 129.1; 141.1; 170.4; 195.7. LC/MS: 247.3 (100, $[M+H]^+$). Anal. calc. for $C_{15}H_{18}O_3$ (246.3016): C 73.15, H 7.37; found: C 72.87, H 7.53.

*Ethyl 4,5-Dihydro-2-methyl-5-phenyl-5-[(*E*)-2-phenylethenyl]furan-3-carboxylate* (**10af**). Yellow oil. IR (KBr): 3084 (C=C–H), 3059 – 3028 (arom. H), 2938 – 2905 (CH), 1697 (C=O), 1654 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.27 (*t*, *J* = 7.2, 3 H); 2.35 (*t*, *J* = 1.6, 3 H); 3.30 (*dd*, *J* = 14.4, 1.6, 1 H); 3.39 (*dd*, *J* = 14.8, 1.6, 1 H); 4.16 (*q*, *J* = 7.2, 2 H); 6.45 (*d*, *J* = 16.0, 1 H); 6.51 (*d*, *J* = 16.0, 1 H); 7.45 – 7.21 (*m*, 10 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 14.5; 14.7; 43.2; 59.8; 90.3; 101.8; 125.5; 127.0; 127.8; 128.2; 128.7; 128.8; 129.2; 132.6; 136.4; 144.2; 166.2; 166.6. MS: 334 (7, M^+), 291 (46, $[M-C_3H_7]^+$), 261 (40, $[M-C_3H_5O_2]^+$), 218 (100, $[M-C_9H_8]^+$), 91 (12, $C_7H_7^+$), 43 (28, $C_3H_7^+$). Anal. calc. for $C_{22}H_{22}O_3$ (334.4083): C 79.02, H 6.63; found: C 78.87, H 6.71.

*1-{4,5-Dihydro-2-methyl-5-phenyl-5-[(*E*)-2-phenylethenyl]furan-3-yl}ethanone* (**10bf**). Yellow oil. IR (KBr): 3083 (C=C–H), 3059 – 3027 (arom. H), 2922 (CH), 1714 (C=O), 1600 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 2.20 (*s*, 3 H); 2.37 (*t*, *J* = 1.6, 3 H); 3.35 (*dq*, *J* = 14.4, 1.6, 1 H); 3.44 (*dq*, *J* = 14.8, 1.6, 1 H); 6.45 (*d*, *J* = 16.0, 1 H); 6.50 (*d*, *J* = 16.0, 1 H); 7.19 – 7.44 (*m*, 10 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 15.5; 29.7; 43.9; 90.4; 112.2; 125.5; 127.0; 128.0; 128.3; 128.8; 128.9; 129.4; 132.5; 136.3; 144.0; 166.3 (C(2)); 194.6 (C=O). LC/MS: 305 (50, $[M+H]^+$), 287 (100). Anal. calc. for $C_{21}H_{20}O_2$ (304.3823): C 82.86, H 6.62; found: C 82.75, H 6.68.

*1-{4,5-Dihydro-2,5-diphenyl-5-[(*E*)-2-phenylethenyl]furan-3-yl}ethanone* (**10cf**). Yellow oil. IR (KBr): 3083 (C=C–H), 3060 – 3029 (arom. H), 2975 – 2927 (CH), 1717 (C=O), 1634 – 1627 (C=C). ^{1}H-NMR (400 MHz, $CDCl_3$): 1.95 (*s*, 3 H); 3.57 (*d*, *J* = 15.6, 1 H); 3.66 (*d*, *J* = 15.2, 1 H); 6.53 (*d*, *J* = 16.0, 1 H); 6.59 (*d*, *J* = 16.0, 1 H); 7.22 – 7.53 (*m*, 13 H); 7.64 – 7.66 (*m*, 2 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 29.1; 44.3; 90.6; 114.7; 125.6; 127.1; 128.0; 128.3; 128.7; 128.85; 128.88; 129.6; 131.0; 131.2; 132.5; 136.4; 144.0; 165.0 (C(2)); 194.8 (C=O). LC/MS: 367 (100, $[M+H]^+$). Anal. calc. for $C_{26}H_{22}O_2$ (366.4517): C 85.22, H 6.05; found: C 84.99, H 5.91.

REFERENCES

[1] F. M. Dean, 'Advances in Heterocyclic Chemistry', Academic Press, New York, 1982, Vol. 30, p. 167; F. M. Dean, M. V. Sargent, 'Comprehensive Heterocyclic Chemistry', Pergamon, New York, 1984, Vol. 4, Part 3, p. 531; C. Zdero, F. Bohlmann, R. M. King, H. Robinson, *Phytochemistry* **1986**, *25*, 509; M. Miski, J. Jakupovic, *Phytochemistry* **1990**, *29*, 1995; C. E. Heltzel, A. A. L. Gunatilaka, T. E. Glass, D. G. I. Kingston, G. Hoffmann, R. K. Johnson *J. Nat. Prod.* **1993**, *56*, 1500; H.-L. Elbe, F. Kunisch, D. Bielefeldt, R. Tiemann, K. Stenzel, S. Dutzmann, M. Kugler, H. Schrage, US Patent 6,107,336, Aug. 22, 2000; E. Loğoğlu, M. Yılmaz, H. Katircioğlu, M. Yakut, S. Mercan, *Med. Chem. Res.* **2010**, *19*, 490.

[2] J. M. Mellor, S. Mohammed, *Tetrahedron* **1993**, *49*, 7547; G. G. Melikyan, *Synthesis* **1993**, 833; J. Iqbal, B. Bhatia, N. K. Nayyar, *Chem. Rev.* **1994**, *94*, 519; H. Nishino, V. Hguyen, S. Yoshinaga, K. Kurosawa, *J. Org. Chem.* **1996**, *61*, 8264; A. S. Demir, M. Emrullahoğlu, *Curr. Org. Synth.* **2007**, *4*, 223.

[3] Y. R. Lee, B. S. Kim, D. H. Kim, *Tetrahedron* **2000**, *56*, 8845; V. Nair, P. M. Treesa, D. Maliakal, N. P. Rath, *Tetrahedron* **2001**, *57*, 7705; C.-H. Tseng, Y.-L. Wu, C.-P. Chuang, *Tetrahedron* **2002**, *58*, 7625; Y.-J. Liao, Y.-L. Wu, C.-P. Chuang, *Tetrahedron* **2003**, *59*, 3511; K. Kobayashi, K. Nagase, O. Morikawa, H. Konishi, *Heterocycles* **2003**, *60*, 939; Y.-L. Wu, C.-P. Chuang, *Tetrahedron* **2004**, *60*, 1841; V. Nair, A. Deepthi, *Chem. Rev.* **2007**, *107*, 1862; K. Bahrami, M. M. Khodaei, F. Naali, *J. Org. Chem.* **2008**, *73*, 6835.

[4] G. Appendino, G. Cravotto, G. B. Giovenzana, G. Palmisano, *J. Nat. Prod.* **1999**, *62*, 1627; G. Bar, A. F. Parsons, C. B. Thomas, *Tetrahedron Lett.* **2000**, *41*, 7751.

[5] A. Agtarap, J. W. Chamberlin, M. Pinkerton, L. Steinrauf, *J. Am. Chem. Soc.* **1967**, *89*, 5737; M. Dobler, 'Ionophors and Their Structures', Wiley-Interscience, New York, 1981; D. Faulkner, *J. Nat. Prod. Rep.* **2000**, *17*, 7.

[6] S. J. Danishefsky, S. DeNinno, P. Lartey, *J. Am. Chem. Soc.* **1987**, *109*, 2082; B. M. Trost, C. J. Li, *J. Am. Chem. Soc.* **1994**, *116*, 10819; S. R. Angle, N. A. El-Said, *J. Am. Chem. Soc.* **1999**, *121*, 10211; I. Larrosa, P. Romeo, F. Urpı, *Tetrahedron* **2008**, *64*, 2683.
[7] Z. Lian, Y. Wei, M. Shi, *Tetrahedron* **2012**, *68*, 2401; K. C. Majumdar, A. Taher, R. K. Nandi, *Tetrahedron* **2012**, *68*, 5693; A. K. Ghosh, R. Guo-Bao, *J. Org. Chem.* **2012**, *77*, 2559; A. Pałasz, T. Pałasz, *Tetrahedron* **2011**, *67*, 1422; S. Maiti, S. K. Panja, C. Bandyopadhyay, *Tetrahedron* **2010**, *66*, 7625.
[8] B. Guo, G. Schwarzwalder, J. T. Njardarson, *Angew. Chem., Int. Ed.* **2012**, *51*, 5675; T. H. Al-Tel, *Eur. J. Med. Chem.* **2010**, *45*, 4615; C.-W. Li, K. Pati, G.-Y. Lin, S. M. A. Sohel, H.-H. Hung, R.-S. Liu, *Angew. Chem., Int. Ed.* **2010**, *49*, 9891; K. J. Quinn, N. A. Biddick, B. A. DeChristopher, *Tetrahedron Lett.* **2006**, *47*, 7281.
[9] R. S. Perali, S. Kalapati, *Tetrahedron* **2012**, *68*, 3725; W. Li, W. Yuan, S. Pindi, M. Shi, G. Li, *Org. Lett.* **2010**, *12*, 920; C. M. Sousa, P. J. Coelho, G. Vermeersch, J. Berthet, S. Delbaere, *J. Photochem. Photobiol., A* **2010**, *216*, 73; I. Yavari, M. Bayat, *Tetrahedron* **2003**, *59*, 2001.
[10] S. D. Burke, D. M. Armistead, F. J. Schoenen, *Tetrahedron* **1986**, *42*, 2787; S. D. Burke, D. M. Armistead, F. J. Schoenen, *J. Org. Chem.* **1984**, *49*, 4320.
[11] A. Aponick, B. Biannic, *Org. Lett.* **2011**, *13*, 1330; M. A. Virolleaud, V. Sridharan, D. Mailhol, D. Bonne, C. Bressy, G. Chouraqui, L. Commeiras, Y. Coquerel, J. Rodriguez, *Tetrahedron* **2009**, *65*, 9756; K. Lee, H. Kim, J. Hong, *Org. Lett.* **2009**, *11*, 5202; H. Hioki, M. Motosue, Y. Mizutani, A. Noda, T. Shimoda, M. Kubo, K. Harada, Y. Fukuyama, M. Kodama, *Org. Lett.* **2009**, *11*, 579; R. F. de la Pradilla, M. Tortosa, N. Lwoff, M. A. del Águila, A. Viso, *J. Org. Chem.* **2008**, *73*, 6716.
[12] B. B. Snider, *Tetrahedron* **2009**, *65*, 10738; M. Yilmaz, *Tetrahedron* **2011**, *67* 8255; E. V. Burgaz, M. Yilmaz, A. T. Pekel, A. Öktemer, *Tetrahedron* **2007**, *63*, 7229; E. V. Burgaz Yilmaz, M. Yilmaz, A. Öktemer, *Arkivoc* **2011**, *(ii)*, 363.
[13] E. Perez-Sacau, R. G. Díaz-Penate, A. Estevez-Braun, A. G. Ravelo, J. M. Garcia-Castellano, L. Pardo, M. Campillo, *J. Med. Chem.* **2007**, *50*, 696; J.-R. Weng, C.-N. Lin, L.-T. Tsao, J.-P. Wang, *Chem. – Eur. J.* **2003**, *9*, 5520; I. Butenschön, K. Möller, W. Hansel, *J. Med. Chem.* **2001**, *44*, 1249.
[14] S. Temnikowa, *J. Gen. Chem. USSR (Eng. Transl.)* **1963**, *33*, 3436; R. McCrindle, K. H. Overton, R. A. Raphael, *J. Chem. Soc.* **1962**, 4798.
[15] G. G. Melikyan, D. A. Mkrtchyan, S. O. Badanyan, *Chem. Heterocycl. Compd.* **1982**, *18*, 14.
[16] J. M. Anderson, J. K. Kochi, *J. Am. Chem. Soc.* **1970**, *92*, 2450.
[17] B. B. Snider, J. J. Patricia, *J. Org. Chem.* **1989**, *54*, 38; S. A. Kates, M. A. Dombroski, B. B. Snider *J. Org. Chem.* **1990**, *55*, 2427.
[18] M. K. Deliömeroğlu, C. Dengiz, R. Çalışkan, M. Balci, *Tetrahedron* **2012**, *68*, 5838; V. Nair, J. Mathew, K. V. Radhakrishnan, *J. Chem. Soc., Perkin Trans. 1* **1996**, *12*, 1487; J. Qian, W. Cao, H. Zhang, J. Chen, S. Zhu, *J. Fluorine Chem.* **2007**, *128*, 207; A. Wu, D. Cremer, *Int. J. Mol. Sci.* **2003**, *4*, 158.
[19] F. Mohanazadeh, M. Hosini, M. Tajbakhsh, *Monatsh. Chem.* **2005**, *136*, 2041.
[20] B. G. Kelly, D. G. Gilheany, *Tetrahedron Lett.* **2002**, *43*, 887.

Received June 5, 2013