ADVANCED SYNTHESIS OF DIHYDROFURANS: EFFECT OF FORMIC ACID ON THE Mn(III)-BASED OXIDATION

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GRAPHICAL ABSTRACT

Abstract: The Mn(III)-based oxidation of a tertiary alkylamine, such as nitrilotris(ethane-2,1-diyl) tris(3-oxobutanoate) (1) with 1,1-diphenylethenene (2a), effectively proceeded in an acetic acid–formic acid mixed solvent to give nitrilotris(ethane-2,1-diyl) tris(2-methyl-5,5-diphenyl-4,5-dihydrofuran-3-carboxylate) (3). Other typical Mn(III)-based reactions of various β-diketo esters 4a–e, 2,4-pentanedione (6a), malonic acid (6b), and diethyl malonate (6c) with 1,1-diarylenes 2a–d were also investigated in a similar acetic acid–formic acid mixed solvent and the reaction rate was accelerated and the product yield increased.

Keywords: Alkylamine; 4,5-dihydrofurans; formic acid; manganese(III) acetate; oxidation

INTRODUCTION

Heiba and Dessau developed the efficient synthesis of dihydrofurans using manganese(III) acetate in 1974 [Eq. (1)].[1] Since then, many researchers[2,3] reported similar reactions, and the Mn(III)-based oxidative radical cyclization using β-dicarbonyl compounds has been rapidly developing.[4] Dihydrofuran derivatives constitute the basic skeleton of many naturally occurring compounds and therefore are important from the viewpoint of building blocks in the total synthesis. On the other hand, the Mn(III)-mediated formation of the dihydrofuran ring is essential
for the synthesis of functional macrocycles. Based on this background, we embarked on synthesizing nitrogen-anchor tripod-type tris(dihydrofuran)s. During the reaction, we found that formic acid as an additive played an important role in the production of the dihydrofurans. We now describe the characteristic reaction involving formic acid.

RESULTS AND DISCUSSION

Nitrilotris(ethane-2,1-diyl) tris(3-oxobutanoate) (1) was prepared by the condensation of 2,2',2''-nitrilotris(ethanol) with diketene and examined the Mn(III)-based oxidation with 1,1-diphenylethenes (2a) under various conditions (Scheme 1). The reaction of 1 (0.3 mmol) with 2a (1.0 mmol) in the presence of manganese(III) acetate (1.8 mmol) was carried out in acetic acid ($pK_a = 4.76$) at 100 °C under an argon atmosphere to produce the desired tris(4,5-dihydrofuran-3-carboxylate) 3 in a poor yield (Table 1, entry 1). The reaction was then optimized (entries 2–8), and the best yield of 3 was achieved for the reaction at 70 °C using the molar ratio of 1/2a/Mn(OAc)$_3$ = 1:3.3:10 (entry 7). However, the result was not acceptable from the viewpoint of the synthesis of 3. Probably, an undesirable reaction, such as the oxidative dealkylation of 1, occurred under the conditions at the same time. To prevent any undesirable reaction, we next investigated the corresponding ammonium salt which might be inactive for the undesirable oxidative dealkylation. The reaction was carried out by adding various acids, such as 2 M HCl ($pK_a = -8.0$), p-toluenesulfonic acid ($pK_a = -2.8$), methanesulfonic acid (MsOH) ($pK_a = -1.2$), trifluoroacetic acid (TFA) ($pK_a = 0$), 10-camphorsulfonic acid (CSA) ($pK_a = 1.2$), $H_3PO_4$ ($pK_a = 2.16$), benzoic acid ($pK_a = 4.19$), 4-nitrobenzoic acid ($pK_a = 3.41$), acrylic acid ($pK_a = 4.25$), and formic acid ($pK_a = 3.75$) in addition to water (entries 9–22). Surprisingly, the reaction rate dramatically changed, and especially the addition of TFA and formic acid was remarkable (entries 14–18). As a result, the use of a 4:1 v/v mixture of acetic acid and formic acid led to a shorter reaction time and the production of 3 in 49% maximum yield (entry 17).

We were interested in the phenomena by which the addition of formic acid accelerated the reaction and then scrutinized the typical Mn(III)-based oxidative
When the typical reaction of methyl 3-oxobutanoate (4a) with 2a using a stoichiometric amount of manganese(III) acetate was conducted in acetic acid at 100 °C under an argon atmosphere, formic acid was added (Scheme 2; Table 2, entries 1–5). As a result, as the amount of formic acid

![Scheme 2 Mn(III)-based oxidation of 3-oxobutanoates 4a–e with 1,1-diarylethenes 2a–d.](image)

dihydrofuranation under similar conditions.[1–3] The reaction of 1 (0.3 mmol) was carried out in acetic acid under an argon atmosphere.

### Table 1. Mn(III)-based reaction of nitrilotris(ethane-2,1-diy)tris(3-oxobutanoate) (1) with 1,1-diphenylethene (2a) in the absence or presence of various acids*  

| Entry | Mn(OAc) \_ 3 (equiv) | Temp. (°C) | AcOH (mL) | Additive | Time (min) | 3 yield (%) |
|-------|-----------------------|------------|-----------|----------|------------|-------------|
| 1     | 1:3.3:6               | 100        | 50        |          | 8          | 20          |
| 2     | 1:3.3:8               | 100        | 50        |          | 10         | 20          |
| 3     | 1:3.3:10              | 100        | 50        |          | 10         | 19          |
| 4     | 1:3.3:10              | 100        | 100       |          | 10         | 16          |
| 5     | 1:3.3:10              | 100        | 25        |          | 8          | 20          |
| 6     | 1:3.3:10              | Reflux     | 50        |          | 5          | 19          |
| 7     | 1:3.3:10              | 70         | 50        |          | 45         | 34          |
| 8     | 1:3.3:10              | rt         | 50        |          | 1 day      | 6           |
| 9     | 1:3.3:10              | 70         | 49        | H₂O      | 1          | 13 —        |
| 10    | 1:3.3:10              | 70         | 49        | 2 M HCl  | 1          | 5 —         |
| 11    | 1:3.3:10              | 70         | 50        | p-TsOH   | 1 eq.      | 4          | 16          |
| 12    | 1:3.3:10              | 70         | 49        | MSO₄     | 1          | 8          | 13          |
| 13    | 1:3.3:10              | 70         | 50        | CSA      | 1 eq.      | 5          | 26          |
| 14    | 1:3.3:10              | 70         | 49        | TFA      | 1          | 30         | 46          |
| 15    | 1:3.3:10              | 70         | 49        | HCO₂H    | 1          | 12         | 41          |
| 16    | 1:3.3:10              | 70         | 45        | HCO₂H    | 5          | 11         | 47          |
| 17    | 1:3.3:10              | 70         | 40        | HCO₂H    | 10         | 7          | 49          |
| 18    | 1:3.3:10              | 70         | 35        | HCO₂H    | 15         | 5          | 44          |
| 19    | 1:3.3:10              | 70         | 40        | H₃PO₄    | 10         | 3          | Trace       |
| 20    | 1:3.3:10              | 70         | 50        | C₆H₅CO₂H | 1 eq.      | 7          | 30          |
| 21    | 1:3.3:10              | 70         | 50        | 4-        | 1 eq.      | 3          | 28          |

*The reaction of 1 (0.3 mmol) was carried out in acetic acid under an argon atmosphere.

The ethene 2a was recovered and tris(dihydrofuran) 3 was not detected.

One equivalent of the corresponding acid was added for 1.
increased, the reaction time decreased. Although the reaction time was the shortest using formic acid alone as the solvent (entry 6), the yield of the product, dihydrofuranecarboxylate 5aa, decreased, and the best yield was achieved using a 2:3 v/v mixture of acetic acid and formic acid (entry 4). The reaction using other combinations of \( \beta \)-keto esters 4b–e and 1,1-diarylthienes 2b–d was also examined and a similar

### Table 2. Mn(III)-based dihydrofuranation using various \( \beta \)-diketo esters 4a–e

| Entry | 4/R | 2/Ar | AcOH (mL) | HCO\(_2\)H (mL) | Time (s) | 5 yield (%) |
|-------|-----|------|-----------|----------------|----------|-------------|
| 1     | 4a: Me | 2a: Ph | 5         | 0              | 60       | 5aa (69)    |
| 2     | 4a: Me | 2a: Ph | 4         | 1              | 30       | 5aa (71)    |
| 3     | 4a: Me | 2a: Ph | 3         | 2              | 30       | 5aa (74)    |
| 4     | 4a: Me | 2a: Ph | 2         | 3              | 20       | 5aa (75)    |
| 5     | 4a: Me | 2a: Ph | 1         | 4              | 10       | 5aa (65)    |
| 6     | 4a: Me | 2a: Ph | 0         | 5              | 5        | 5aa (39)    |
| 7     | 4b: Et | 2a: Ph | 5         | 0              | 180      | 5ba (77)    |
| 8     | 4b: Et | 2a: Ph | 4         | 1              | 60       | 5ba (73)    |
| 9     | 4b: Et | 2a: Ph | 3         | 2              | 60       | 5ba (71)    |
| 10    | 4b: Et | 2a: Ph | 2         | 3              | 60       | 5ba (82)    |
| 11    | 4b: Et | 2a: Ph | 1         | 4              | 20       | 5ba (65)    |
| 12    | 4b: Et | 2a: Ph | 0         | 5              | 10       | 5ba (46)    |
| 13\(c\) | 4b: Et | 2a: Ph | 2         | 3              | 60       | 5ba (8)     |
| 14\(d\) | 4b: Et | 2a: Ph | 2         | 3              | 60       | 5ba (0)     |
| 15    | 4b: Et | 2b: 4-FC\(_6\)H\(_4\) | 5 | 0 | 90 | 5bb (55) |
| 16    | 4b: Et | 2b: 4-FC\(_6\)H\(_4\) | 2 | 3 | 20 | 5bb (69) |
| 17    | 4b: Et | 2c: 4-Cl\(_6\)H\(_4\) | 5 | 0 | 120 | 5bc (52) |
| 18    | 4b: Et | 2c: 4-Cl\(_6\)H\(_4\) | 2 | 3 | 20 | 5bc (73) |
| 19    | 4b: Et | 2d: 4-Me\(_6\)H\(_4\) | 5 | 0 | 90 | 5bd (76) |
| 20    | 4b: Et | 2d: 4-Me\(_6\)H\(_4\) | 2 | 3 | 15 | 5bd (66) |
| 21    | 4c: Pr | 2a: Ph | 5 | 0 | 180 | 5ca (67) |
| 22    | 4c: Pr | 2a: Ph | 4 | 1 | 60 | 5ca (67) |
| 23    | 4c: Pr | 2a: Ph | 3 | 2 | 60 | 5ca (82) |
| 24    | 4c: Pr | 2a: Ph | 2 | 3 | 30 | 5ca (71) |
| 25    | 4c: Pr | 2a: Ph | 1 | 4 | 10 | 5ca (61) |
| 26    | 4c: Pr | 2a: Ph | 0 | 5 | 10 | 5ca (49) |
| 27    | 4d: i-Pr | 2a: Ph | 5 | 0 | 120 | 5da (64) |
| 28    | 4d: i-Pr | 2a: Ph | 4 | 1 | 30 | 5da (59) |
| 29    | 4d: i-Pr | 2a: Ph | 3 | 2 | 20 | 5da (84) |
| 30    | 4d: i-Pr | 2a: Ph | 2 | 3 | 20 | 5da (83) |
| 31    | 4d: i-Pr | 2a: Ph | 1 | 4 | 10 | 5da (68) |
| 32    | 4d: i-Pr | 2a: Ph | 0 | 5 | 10 | 5da (42) |
| 33    | 4e: Bu | 2a: Ph | 5 | 0 | 120 | 5ea (62) |
| 34    | 4e: Bu | 2a: Ph | 4 | 1 | 60 | 5ea (83) |
| 35    | 4e: Bu | 2a: Ph | 3 | 2 | 60 | 5ea (74) |
| 36    | 4e: Bu | 2a: Ph | 2 | 3 | 30 | 5ea (71) |
| 37    | 4e: Bu | 2a: Ph | 1 | 4 | 20 | 5ea (69) |
| 38    | 4e: Bu | 2a: Ph | 0 | 5 | 10 | 5ea (55) |

\(a\) The reaction of butanoate 4 (0.1 mmol) using the molar ratio of 4:2:Mn(OAc)\(_3\) = 1:1:2 was carried out at 100 °C under an argon atmosphere.

\(b\) Isolated yield based on 4.

\(c\) The reaction was carried out using Mn(OAc)\(_3\) (0.1 mmol) in the presence of Mn(OAc)\(_2\) (0.1 mmol) (4b/2a/Mn(OAc)\(_2\)/Mn(OAc)\(_3\) = 1:1:1:1).

\(d\) The reaction was carried out using Mn(OAc)\(_2\) (0.2 mmol) instead of Mn(OAc)\(_3\) (4b/2a/Mn(OAc)\(_2\) = 1:1:2).
tendency was observed except for the yield of 5bd (R=Et, Ar = 4-MeC₆H₄) (entry 20). In addition, the presence of manganese(II) acetate inhibited the production of the dihydrofuran 5ba (entries 13 and 14).

With acceptable results in hand, we examined other typical Mn(III)-based reactions using 2,4-pentanediione (6a), malonic acid (6b), and diethyl malonate (6c) to produce 3-acetyl-2-methyl-4,5-dihydrofuran 7 [Eq. (2) in Scheme 3] [2] spirodi-γ-lactone 8 [Eq. (3)] [8] and 2-oxo-2,5-dihydrofuran-3-carboxylate 9 [Eq. (4)] [9] respectively.

In all cases, the presence of formic acid led to an extremely short reaction time (Table 3). The reaction of the malonate 6c with the alkene 2a deserves comment. When the reaction was quenched before the complete consumption of Mn(III), the addition product 9 and the substitution product 10 were obtained (entry 5). It is not surprising, as already reported, that the product 10, as an intermediate of 9, was converted into 9 when the oxidation was completed (entry 6). [9] However, it seemed that the reaction afforded 10 as an only isolable product because the existence of formic acid remarkably promoted the oxidation and complicated the reaction (entry 7).

The mechanism for the formation of dihydrofurans, such as 5, is generally accepted that the acetato ligand-bridged oxo-centered manganese(III) complex undergoes a ligand-exchange reaction with the 3-oxobutanoates to generate the manganese(III)-enolate complex, of which the production is the rate-determining step [4g], followed by single-electron transfer (SET) oxidation from the alkenes through the oxobutanoato ligand, giving the carbon adduct radicals. The radicals are further oxidized by Mn(III) according to the normal electron-transfer-type mechanism and subsequently cyclized to produce the dihydrofurans 5. When formic acid was added to the reaction mixture, the ligand exchange from the bridged acetate on the manganese(III) complex into formate should readily occur as being more acidic (pKₐ = 3.75) than acetic acid (pKₐ = 4.76) and the 3-oxobutanoates (pKₐ = 11 for 4b) (A in Scheme 4). [10] Kochi reported that the manganese(III)–strong acid complexes in the oxidative decarboxylation produced both ion-pair and cationic manganese(III) species such as B, which increased the reactivity, [11] so that the formation of the manganese(III)–oxobutanoate complex C should be accelerated.

Scheme 3 Mn(III)-based oxidation of 1,3-dicarbonyl compounds 6a–c with 1,1-diphenylethene (2a).
This was observed as considerably shorter reaction times in our experiment. Again the formato–manganese(III)–oxobutanoate complex C led to another cationic manganese(III) species D that underwent SET oxidation to form adduct radicals E. The radicals E were converted into dihydrofurans 5 during a similar SET oxidation using a typical transition-metal oxidant. Formic acid itself is a reductant \( \text{CO}_2 (g) + 2\text{H}^+ + 2\text{e}^- = \text{HCO}_2\text{H (aq.)}, E^\circ (25 ^\circ C) = -0.199 \text{V},^{[10]} \) so that the oxidant Mn(OAc)\(_3\) itself is reduced by the formic acid. In fact, Mn(OAc)\(_3\) was completely consumed within 2.2 min using acetic acid–formic acid (2:3, v/v) at 100 °C in the absence of the 1,3-dicarbonyl compound and alkene. However, it seems that the oxidative radical reaction as shown in Scheme 4 predominantly proceeded in the mixed solvent system, because all the reaction times became extremely shorter in the presence of the 1,3-dicarbonyl compound and alkene (Tables 1–3).

In summary, it was found that the use of an acetic acid–formic acid mixed solvent effectively accelerated the Mn(III)-based oxidation of the tertiary alkylamine 1 with 1,1-diphenylethene (2a) and nitrioltris(ethane-2,1-diyl)tris(2-methyl-5,5-diphenyl-4,5-dihydrofuran-3-carboxylate) (3) was produced in a synthetically acceptable yield.

### Table 3. Mn(III)-based reaction of other β-dicarbonyl compounds 6a–c with 1,1-diphenylethene (2a)

| Entry | 6/R | 6/2a/Mn(OAc)\(_3\) | Temp. (°C) | AcOH (mL) | HCO\(_2\)H (mL) | Time (min) | Product yield (%) |
|-------|-----|---------------------|------------|-----------|----------------|------------|-------------------|
| 1     | 6a/Me | 1:1:2 | 100 | 5 | 0 | 1 | 7 (77) |
| 2     | 6a/Me | 1:1:2 | 100 | 4 | 1 | 0.5 | 7 (91) |
| 3     | 6b/OH | 1:2:4 | Reflux | 5 | 0 | 2 | 8 (74) |
| 4     | 6b/OH | 1:2:4 | Reflux | 4 | 1 | 1.5 | 8 (78) |
| 5     | 6c/OEt | 1:1:2 | Reflux | 5 | 0 | 3\(^\ddagger\) | 9 (45), 10 (31) |
| 6     | 6c/OEt | 1:1:2 | Reflux | 5 | 0 | 40 | 9 (80) |
| 7     | 6c/OEt | 1:1:2 | Reflux | 2 | 3 | 1 | 10 (30) |

\(^\ddagger\)The reaction of 6 (0.1 mmol) was carried out in acetic acid under an argon atmosphere.

\(^\ddagger\)Molar ratio.

\(^\ddagger\)Isolated yield based on 6.

\(^\ddagger\)The reaction was quenched before the complete consumption of Mn(III).

This was observed as considerably shorter reaction times in our experiment. Again the formato–manganese(III)–oxobutanoate complex C led to another cationic manganese(III) species D that underwent SET oxidation to form adduct radicals E. The radicals E were converted into dihydrofurans 5 during a similar SET oxidation using a typical transition-metal oxidant. Formic acid itself is a reductant \( \text{CO}_2 (g) + 2\text{H}^+ + 2\text{e}^- = \text{HCO}_2\text{H (aq.)}, E^\circ (25 ^\circ C) = -0.199 \text{V},^{[10]} \) so that the oxidant Mn(OAc)\(_3\) itself is reduced by the formic acid. In fact, Mn(OAc)\(_3\) was completely consumed within 2.2 min using acetic acid–formic acid (2:3, v/v) at 100 °C in the absence of the 1,3-dicarbonyl compound and alkene. However, it seems that the oxidative radical reaction as shown in Scheme 4 predominantly proceeded in the mixed solvent system, because all the reaction times became extremely shorter in the presence of the 1,3-dicarbonyl compound and alkene (Tables 1–3).

In summary, it was found that the use of an acetic acid–formic acid mixed solvent effectively accelerated the Mn(III)-based oxidation of the tertiary alkylamine 1 with 1,1-diphenylethene (2a) and nitrioltris(ethane-2,1-diyl)tris(2-methyl-5,5-diphenyl-4,5-dihydrofuran-3-carboxylate) (3) was produced in a synthetically acceptable yield.
Acceleration of the reaction and increase in the product yield using a similar acetic acid–formic acid mixed solvent were also observed in other typical Mn(III)-based oxidations of various β-diketo esters 4a–e, 2,4-pentanedione (6a), malonic acid (6b), and diethyl malonate (6c) with 1,1-diarylethenes 2a–d. It was reported that the solvent effects played an important role in the Mn(III)-based oxidative reaction,[3a,12] especially for the acidity of the reaction medium, which enhanced the condensation rate in the reaction using 2-(alkylamino)-1,4-naphthoquinones.[13] However, in the case of the acetic acid–formic acid mixed solvent, we believe that the presence of both ion-pair and cationic manganese(III) species generated in the acid–mixed solvent accelerated the oxidation reaction.

**EXPERIMENTAL**

**Reaction of Nitrilotris(ethane-2,1-diy1)tris(3-oxobutanoate) (1) with 1,1-Diphenylethene (2a) in the Presence of Mn(OAc)$_3$**

A mixture of tris(3-oxobutanoate) 1 (120.8 mg; 0.3 mmol), diphenylethene 2a (179.5 mg; 1 mmol), and Mn(OAc)$_3$·2H$_2$O[14] (801.9 mg; 3 mmol) in glacial acetic acid (40 mL) and formic acid (10 mL) was degassed under reduced pressure for 30 min using an ultrasonicator for exchange with an argon atmosphere. The mixture was then heated at 70 °C until the brown color of Mn(III) disappeared (normally for 7 min). The solvent was removed in vacuo and water (25 mL) was added to the reaction mixture. The aqueous solution was then extracted three times with chloroform (25 mL). The combined extracts were washed with a saturated aqueous solution of sodium hydrogen carbonate, dried over anhydrous sodium sulfate, and then concentrated to dryness. The residue was separated on silica-gel thin-layer chromatography (TLC) developed with AcOEt–hexane (2:8 v/v), giving the product 3 (138.7 mg; 49%) (Table 1, entry 17). The physical data are listed.

**Nitrilotris(ethane-2,1-diy1)tris(2-methyl-5,5-diphenyl-4,5-dihydrofuran-3-carboxylate) (3)**

Light yellow oil; $R_f = 0.2$ (EtOAc–hexane, 2:8); IR (CHCl$_3$) ν 1690 (C=O); $^1$H NMR (CDCl$_3$) δ 7.37–7.21 (10H × 3, m, arom H), 4.13 (2H × 3, t, $J = 6.0$ Hz, -OCH$_2-$ × 3), 3.56 (2H × 3, d, $J = 1.5$ Hz, CH$_2$ × 3), 2.85 (2H × 3, t, $J = 6.0$ Hz, -CH$_2$N- × 3), 2.30 (3H × 3, s, -CH$_3$ × 3); $^{13}$C NMR (CDCl$_3$) δ 166.8 (C=O × 3), 165.5 (=CO- × 3), 145.0 (6C) (arom C), 128.3 (12C), 127.4 (6C), 125.6 (12C) (arom CH), 101.4 (>C= × 3), 91.6 (>C= × 3), 61.9 (-OCH$_2$- × 3), 53.5 (-NCH$_2$- × 3), 43.9 (-CH$_2$- × 3), 14.1 (CH$_3$ × 3); FAB HRMS (acetone/NBA) calcd. for C$_{60}$H$_{58}$NO$_9$ 936.4112 (M+H). Found 936.4141.

**Mn(III)-Based Reaction of 1,3-Dicarbonyl Compounds 4a–e and 6a–c with 1,1-Diarylethenes 2a–d**

To a 30-mL round-bottomed flask, the 1,3-dicarbonyl compound (0.1 mmol), 1,1-diarylethene (0.1 mmol), and a mixture of acetic acid and formic acid mentioned in Tables 2 and 3 were added. After replacing air with argon in the flask, Mn(OAc)$_3$·2H$_2$O (53.6 mg; 0.2 mmol) was added and then the mixture was heated at 100 °C using a preheated oil bath until the brown color of Mn(III) disappeared (the reaction
times are listed in Tables 2 and 3). After the Mn(III) oxidant was completely consumed, the solvent was removed in vacuo and 2 M HCl (20 mL) was added to the residue. The aqueous solution was then extracted three times with chloroform (25 mL). The combined extracts were washed with a saturated aqueous solution of sodium hydrogencarbonate followed by water, dried over anhydrous sodium sulfate, and then concentrated to dryness. The obtained residue was separated by silica gel column chromatography eluting with AcOEt–hexane (2:8 v/v), giving dihydrofurans 5 and 7, spirodi-γ-lactone 8, butenolide 9, and ethenylmalonate 10, as shown in Schemes 2 and 3 and Tables 2 and 3. The physical data of the products are listed here and in the supporting information.

**Methyl 2-Methyl-5,5-diphenyl-4,5-dihydrofuran-3-carboxylate (5aa)**

Light yellow oil; \( R_f = 0.5 \) (EtOAc–hexane, 1:9); IR (CHCl3) \( \nu = 1693 \) (C=O); \(^1\)H NMR (CDCl3) \( \delta = 7.39–7.24 \) (10H, m, arom H), 3.69 (3H, s, O-CH3), 3.60 (2H, br. q, \( J = 1.8 \) Hz, CH2), 2.35 (3H, t, \( J = 1.8 \) Hz, CH3); \(^{13}\)C NMR (CDCl3) \( \delta = 166.6 \) (C=O), 166.2 (CO-), 145.1 (2C) (arom C), 128.3 (4C), 127.5 (2C), 125.6 (4C) (arom CH), 101.5 (>C=), 91.6 (>C<), 50.9 (-OCH3), 44.0 (-CH2-), 14.2 (CH3); FAB HRMS (acetone/NBA) calcd. for C\(_{19}\)H\(_{19}\)O\(_3\) 295.1334 (M+H). Found: 295.1331.

**Propyl 2-Methyl-5,5-diphenyl-4,5-dihydrofuran-3-carboxylate (5ca)**

Light yellow oil; \( R_f = 0.5 \) (EtOAc–hexane, 1:9); IR (CHCl3) \( \nu = 1686 \) (C=O); \(^1\)H NMR (CDCl3) \( \delta = 7.40–7.24 \) (10H, m, arom H), 4.06 (2H, t, \( J = 7.0 \) Hz, -OCH2-), 3.60 (2H, q, \( J = 1.8 \) Hz, CH2), 2.35 (3H, t, \( J = 1.8 \) Hz, CH3), 1.65 (2H, sex, \( J = 7.0 \) Hz, -CH2CH3), 0.95 (3H, t, \( J = 7.0 \) Hz, CH2CH2CH3); \(^{13}\)C NMR (CDCl3) \( \delta = 166.2 \) (C=O), 165.9 (CO-), 145.2 (2C) (arom C), 128.3 (4C), 127.5 (2C), 125.6 (4C) (arom CH), 101.8 (>C=), 91.5 (>C<), 65.2 (-OCH2), 44.1 (-CH2-), 22.2 (-CH2CH3), 14.2 (CH3), 10.6 (-CH2CH3); FAB HRMS (acetone/NBA) calcd. for C\(_{21}\)H\(_{23}\)O\(_3\) 323.1679 (M+H); found 323.1679.

**Butyl 2-Methyl-5,5-diphenyl-4,5-dihydrofuran-3-carboxylate (5ea)**

Light yellow oil; \( R_f = 0.4 \) (EtOAc–hexane, 1:9); IR (CHCl3) \( \nu = 1686 \) (C=O); \(^1\)H NMR (CDCl3) \( \delta = 7.40–7.24 \) (10H, m, arom H), 4.10 (2H, t, \( J = 7.0 \) Hz, -OCH2-), 3.60 (2H, q, \( J = 1.8 \) Hz, CH2), 2.35 (3H, t, \( J = 1.8 \) Hz, CH3), 1.62 (2H, quin, \( J = 7.5 \) Hz, CH2CH2CH2CH3), 1.38 (2H, sex, \( J = 7.5 \) Hz, CH2CH2CH2CH3), 0.93 (3H, t, \( J = 7.5 \) Hz, CH2CH3); \(^{13}\)C NMR (CDCl3) \( \delta = 166.2 \) (C=O), 165.9 (CO-), 145.2 (2C) (arom C), 128.3 (4C), 127.5 (2C), 125.6 (4C) (arom CH), 101.8 (>C=), 91.5 (>C<), 63.5 (-OCH2), 44.1 (-CH2-), 30.8 (-CH2CH2CH2CH3), 19.3 (-CH2CH2CH2CH3), 14.2 (CH3), 13.8 (-CH2CH2CH2CH3); FAB HRMS (acetone/NBA) calcd. for C\(_{22}\)H\(_{25}\)O\(_3\) 337.1828 (M+H); found 337.1828.

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SUPPLEMENTAL MATERIAL

Measurements, materials, IR, $^1$H and $^{13}$C NMR spectra, distortionless enhancement by polarization transfer (DEPT), and fast atom bombardment (FAB) high-resolution mass spectrometry (HRMS) data for known compounds 5ba, 5bb, 5bc, 5bd, 5da, and 7–10, and copies of $^1$H and $^{13}$C NMR, FAB MS and IR spectral charts for all new compounds 3, 5aa, 5ca, and 5ea for this article can be accessed on the publisher’s website.

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