

# Radical cyclizations of conjugated esters and amides with 3-oxopropanenitriles mediated by manganese(III) acetate

E. Vildan Burgaz Yılmaz,<sup>a\*</sup> Mehmet Yılmaz,<sup>b</sup> and Atilla Öktemer<sup>a</sup>

<sup>a</sup>Department of Chemistry, Faculty of Sciences, Ankara University, 06100 Tandogan, Ankara, Turkey

<sup>b</sup>Department of Chemistry, Faculty of Arts and Sciences, Kocaeli University, 41380 Umuttepe, Kocaeli, Turkey

E-mail: [vildanburgaz@yahoo.com](mailto:vildanburgaz@yahoo.com)

DOI: <http://dx.doi.org/10.3998/ark.5550190.0012.230>

---

## Abstract

Radical cyclizations of conjugated esters and amides with 3-oxopropanenitriles in presence of manganese(III) acetate produced ethyl 4-cyano-2,3-dihydrofuran-3-carboxylates and 4-cyano-2,3-dihydrofuran-3-carboxamides in good yields. The radical cyclizations of conjugated amides gave 2,3-dihydrofurans in better yields than that of conjugated esters. Moreover, the reactions of thienyl substituted amides and esters with 3-oxopropanenitriles afforded 2,3-dihydrofurans more efficiently than phenyl substituted ones.

**Keywords:** Manganese(III) acetate, oxidative cyclization, radical addition, 2,3-dihydrofuran, carboxamide, 3-oxopropanenitrile

---

## Introduction

Transition metal salts ( $Mn^{+3}$ ,  $Ce^{+4}$ ,  $Ag^{+}$ ) having single electron transfer ability are widely used in organic reactions for generating C-C bonds.<sup>1</sup> It is well-known that dihydrofurans<sup>2</sup> are synthesized by radical cyclization reactions with alkenes and 1,3-dicarbonyl compounds using manganese(III)acetate<sup>2,3</sup>, cerium(IV) ammonium nitrate<sup>4</sup> and silver(I) nitrate<sup>5</sup>. Also, it is reported that these radical oxidants are widely used in natural product synthesis.<sup>6</sup> The dihydrofuran skeleton is accepted as an important class of organic compound in terms of representing biological activity and resembling natural products.

Recently, some 4,5-dihydrofuran-3-carbonitrile derivatives have been reported to show antibacterial and antifungal activity.<sup>7</sup> Also, it is known that dihydrofurans containing carboxamide groups show fungicidal and microbicide activity.<sup>8</sup>

Recently, we have reported the study of radical cyclizations of 3-oxopropanenitriles with  $\alpha,\beta$ -unsaturated amides<sup>2h</sup> and alkenes<sup>2i-j</sup> mediated by manganese(III) acetate ( $\text{Mn}(\text{OAc})_3$ ). In this study, we describe radical cyclizations of various 3-oxopropanenitriles with conjugated esters and amides using manganese(III) acetate resulting in the formation of 4-cyano-2,3-dihydrofuran-3-carboxylate and 4-cyano-2,3-dihydrofuran-3-carboxamide derivatives.

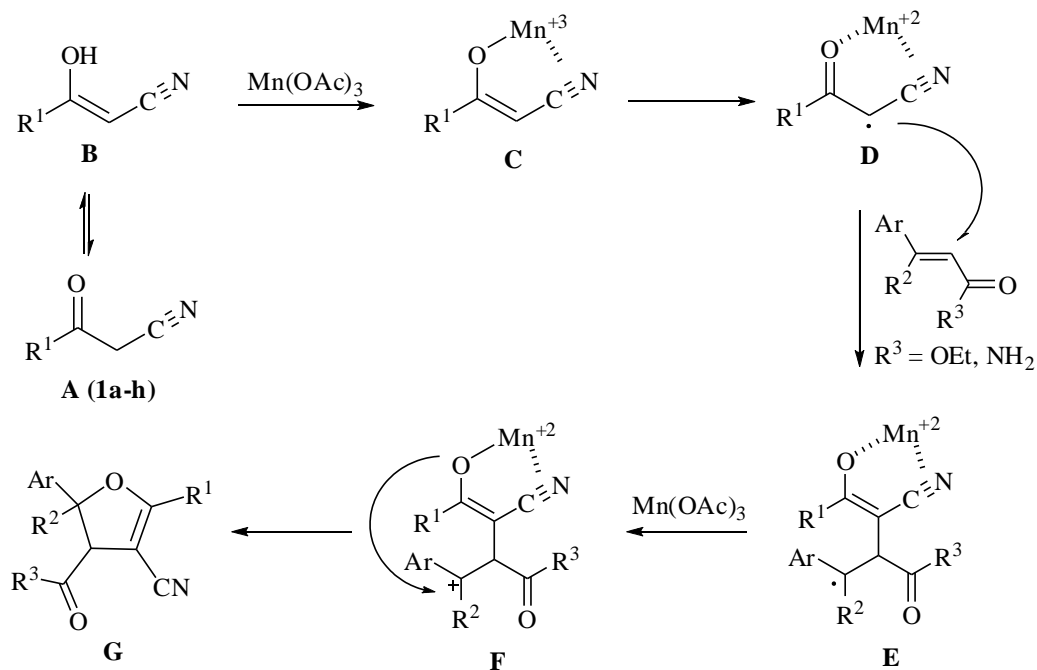
## Results and Discussion

All 3-oxopropanenitriles (except **1e**) were prepared by the reaction of suitable esters with acetonitrile and NaH in PhMe.<sup>9</sup> Ethyl (*2E*)-3-phenylbut-2-enoate **2a**<sup>10</sup>, ethyl 3,3-diphenylacrylate **2c**<sup>10a, d, 11</sup> and ethyl (*2E*)-3-(2-thienyl)but-2-enoate **2e**<sup>12</sup> were synthesized by using suitable carbonyl compounds and ethyl (diethoxyphosphoryl)acetate formed by the reaction of triethyl phosphite and ethyl chloroacetate. (*2E*)-3-Phenylbut-2-enamide **2b**<sup>13</sup>, 3,3-diphenylacrylamide **2d**<sup>14</sup> and (*2E*)-3-(2-thienyl)but-2-enamide **2f** were synthesized from the reaction of ammonia with acyl chloride obtained by the reaction of carboxylic acids with  $\text{SOCl}_2$ . Radical cyclization reactions were performed in 2:1:3 molar ratio (3-oxopropanenitriles: conjugated alkenes:  $\text{Mn}(\text{OAc})_3$ , respectively) under  $\text{N}_2$  atmosphere, at 80 °C, in HOAc. Products were purified by column chromatography or preparative thin layer chromatography (TLC). All new compounds were characterized by IR, <sup>1</sup>H-NMR, <sup>13</sup>C-NMR, MS and micro analysis.

Proposed mechanism for radical cyclization of 3-oxopropanenitriles with conjugated alkenes mediated by  $\text{Mn}(\text{OAc})_3$  is given in scheme 1. According to the mechanism, Mn(III)-enolate complex **C** is formed from the reaction of enol form **B** of 3-oxopropanenitrile with  $\text{Mn}(\text{OAc})_3$  and an  $\alpha$ -carbon radical **D** is occurred while  $\text{Mn}^{+3}$  is reduced to  $\text{Mn}^{+2}$ . The addition of the  $\alpha$ -carbonyl radical to conjugated alkene gives a radical intermediate product **E**. This intermediate product is oxidized to carbocation **F** with  $\text{Mn}(\text{OAc})_3$  and intramolecular cyclization of **F** forms 4-cyano-2,3-dihydrofurans **G**. <sup>1</sup>H NMR spectra of the isolated compounds **3a-w** show a single peak for H-3 protons at between 4.11-4.93 ppm.

However, we reported the chemical shift values of the H-2 protons in similar structures as 5.73-6.56 ppm.<sup>2h</sup> These results support that 2,3-dihydrofurans **G** were formed from the addition of radical intermediate **D** to  $\alpha,\beta$ -unsaturated amides (or esters) regioselectively followed by the cyclization of **F**.

While no product was obtained from the reaction of ethyl (*2E*)-3-phenylbut-2-enoate **2a** with 3-oxopropanenitriles, the reactions of 3-phenyl-3-oxopropanenitrile **1a** and 3-(2-benzofuryl)-3-oxopropanenitrile **1b** with (*2E*)-3-phenylbut-2-enamide **2b** gave 4-cyano-2,3-dihydrofuran-3-carboxamide **3a** and **3b** in low yields respectively (Table 1).



**Scheme 1.** Mechanism for formation of 2,3-dihydrofurans.

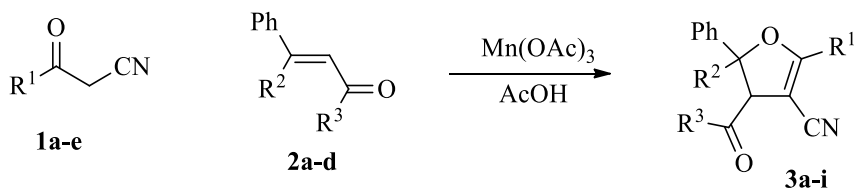
On the other hand, ethyl 4-cyano-2,3-dihydrofuran-3-carboxylate **3c** and **3d** were obtained from the radical cyclization of **1a** and 3-(2-thienyl)-3-oxopropanenitrile **1c** with ethyl 3,3-diphenylacrylate **2c**, respectively. Similarly, **3e** and **3h** were formed by treatment of 3,3-diphenylacrylamide **2d** with the same 3-oxopropanenitriles in moderate yields. Additionally, we obtained similar results in the oxidative cyclizations of **2d** with 3-(4-methoxyphenyl)-3-oxopropanenitrile **1d** and 3-(4-chlorophenyl)-3-oxopropanenitrile **1e**. Moreover, treatment of **1b** with 3,3-diphenylacrylamide **2d** gave **3i** in 40 % yield.

According to these results, the reactions of the two diphenyl substituted alkenes **2c** and **2d** with 3-oxopropanenitriles formed 2,3-dihydrofurans in higher yields than that of the monophenyl substituted alkenes **2a** and **2b**. This can be explained by the stability of the radical intermediate products formed with the addition of an  $\alpha$ -carbon radical to conjugated esters and amides. Since the tertiary radicals obtained from **2c** and **2d** are conjugated with two phenyl groups, stability of these radicals are higher than that of the tertiary radicals of **2a** and **2b**. Therefore, the cyclization of more stable intermediate product forms 2,3-dihydrofuran in a higher yield.

4-Cyano-2,3-dihydrofuran **3j** was obtained in good yield (68%) from the reaction of **1a** with **2e**, while no product was formed in the cyclization of the same 3-oxopropanenitrile with **2a** (table 2). Similarly, the treatment of **1d** and **1e** with **2e** formed 2,3-dihydrofurans **3k** (80%) and **3l** (61%), respectively. 2,5-Dithienyl substituted dihydrofuran **3m** was obtained from the radical cyclization of **1c** with **2e**. While the treatment of 3-(2-furyl)-3-oxopropanenitrile **1f** with **2e** gave **3n** (45%), **3o** (75%) formed with benzofuryl derivative 3-oxopropanenitrile **1b**. Additionally,

ethyl 5-*tert*-butyl-4-cyano-2-methyl-2-(2-thienyl)-2,3-dihydrofuran-3-carboxylate **3p** was produced in the reaction of 4,4-dimethyl-3-oxopropanenitrile **1g** with **2e**.

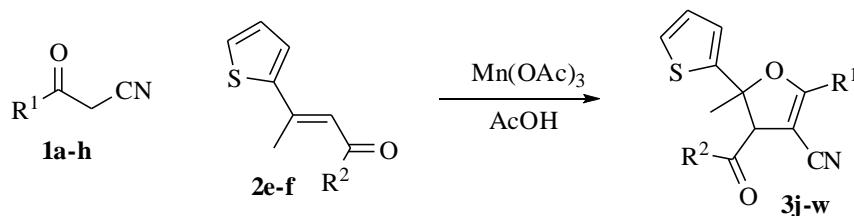
**Table 1.** Oxidative cyclizations of 3-oxopropanenitriles **1a-e** with **2a-d**



Entry	R <sup>1</sup>		R <sup>2</sup>	R <sup>3</sup>		Products and yields <sup>a</sup> (%)
1	Ph	<b>1a</b>	CH <sub>3</sub>	OEt	<b>2a</b>	no product
2	Ph	<b>1a</b>	CH <sub>3</sub>	NH <sub>2</sub>	<b>2b</b>	<b>3a</b> (26)
3	1-benzofuran-2-yl	<b>1b</b>	CH <sub>3</sub>	NH <sub>2</sub>	<b>2b</b>	<b>3b</b> (31)
4	Ph	<b>1a</b>	Ph	OEt	<b>2c</b>	<b>3c</b> (32)
5	2-thienyl	<b>1c</b>	Ph	OEt	<b>2c</b>	<b>3d</b> (20)
6	Ph	<b>1a</b>	Ph	NH <sub>2</sub>	<b>2d</b>	<b>3e</b> (48)
7	4-MeO-C <sub>6</sub> H <sub>4</sub>	<b>1d</b>	Ph	NH <sub>2</sub>	<b>2d</b>	<b>3f</b> (55)
8	4-Cl-C <sub>6</sub> H <sub>4</sub>	<b>1e</b>	Ph	NH <sub>2</sub>	<b>2d</b>	<b>3g</b> (38)
9	2-thienyl	<b>1c</b>	Ph	NH <sub>2</sub>	<b>2d</b>	<b>3h</b> (24)
10	1-benzofuran-2-yl	<b>1b</b>	Ph	NH <sub>2</sub>	<b>2d</b>	<b>3i</b> (40)

<sup>a</sup> Yields of isolated products based on the alkene.

Oxidative cyclizations of (*2E*)-3-(2-thienyl)but-2-enamide **2f** with 3-oxopropanenitriles **1a-f** and **1h** produced 2,3-dihydrofuran carboxamide derivatives **3q-w** in good to excellent yields. Moreover, these products were obtained with higher efficiency than other esters and amides. The best result was obtained by the reactions of **2f** with 3-oxopropanenitriles **1b** and **1d** via Mn(OAc)<sub>3</sub>.

**Table 2.** Oxidative cyclizations of 3-oxopropanenitriles **1a-h** with **2e-f**

Entry	R <sup>1</sup>		R <sup>2</sup>		Products and yields <sup>a</sup> (%)
1	Ph	<b>1a</b>	OEt	<b>2e</b>	<b>3j</b> (68)
2	4-MeO-C <sub>6</sub> H <sub>4</sub>	<b>1d</b>	OEt	<b>2e</b>	<b>3k</b> (80)
3	4-Cl-C <sub>6</sub> H <sub>4</sub>	<b>1e</b>	OEt	<b>2e</b>	<b>3l</b> (61)
4	2-thienyl	<b>1c</b>	OEt	<b>2e</b>	<b>3m</b> (77)
5	2-furyl	<b>1f</b>	OEt	<b>2e</b>	<b>3n</b> (45)
6	1-benzofuran-2-yl	<b>1b</b>	OEt	<b>2e</b>	<b>3o</b> (75)
7	<i>tert</i> -butyl	<b>1g</b>	OEt	<b>2e</b>	<b>3p</b> (48)
8	Ph	<b>1a</b>	NH <sub>2</sub>	<b>2f</b>	<b>3q</b> (77)
9	4-Me-C <sub>6</sub> H <sub>4</sub>	<b>1h</b>	NH <sub>2</sub>	<b>2f</b>	<b>3r</b> (69)
10	4-MeO-C <sub>6</sub> H <sub>4</sub>	<b>1d</b>	NH <sub>2</sub>	<b>2f</b>	<b>3s</b> (91)
11	4-Cl-C <sub>6</sub> H <sub>4</sub>	<b>1e</b>	NH <sub>2</sub>	<b>2f</b>	<b>3t</b> (73)
12	2-thienyl	<b>1c</b>	NH <sub>2</sub>	<b>2f</b>	<b>3u</b> (70)
13	2-furyl	<b>1f</b>	NH <sub>2</sub>	<b>2f</b>	<b>3v</b> (61)
14	1-benzofuran-2-yl	<b>1b</b>	NH <sub>2</sub>	<b>2f</b>	<b>3w</b> (91)

<sup>a</sup> Yields of isolated products based on the alkene.

## Conclusions

In conclusion, Mn(OAc)<sub>3</sub> mediated radical cyclization of conjugated esters and amides with 3-oxopropanenitriles was studied in this work comparatively, resulting in formation of various 2,3-dihydrofuran-3-carboxylates and 2,3-dihydrofuran-3-carboxamides. Similar results were obtained from the reactions of conjugated esters **2a**, **2c**, **2e** and conjugated amides **2b**, **2d**, **2f** with 3-oxopropanenitriles. On the other hand, a noteworthy increase is observed in product yields

when phenyl group of conjugated esters **2a-d** and amides **2e-f** is replaced with thienyl group since carbocation intermediates are stabilized by the lone pair electron of thienyl group.

## Experimental Section

**General.** Melting points were determined on a Gallenkamp capillary melting point apparatus. IR spectra (KBr disc, CHCl<sub>3</sub>) were obtained with a Matson 1000 FT-IR spectrophotometer in the 400–4000 cm<sup>-1</sup> range with 4 cm<sup>-1</sup> resolution. <sup>1</sup>H NMR and <sup>13</sup>C NMR spectra were recorded on a Varian Mercury-400 High performance Digital FT-NMR and Varian Oxford NMR300 spectrometers. The mass spectra were measured on a Waters 2695 Alliance HPLC, Waters micromass 2Q (ESI+) and Waters Xevo TQMS spectrometers. Elemental analyses were performed on a Leco 932 CHNSO instrument. Thin layer chromatography (TLC) was performed on Merck aluminium-packed silica gel plates. Purification of products was performed by column chromatography on silica gel (Merck silica gel 60, 40–60 mm) or preparative TLC on silica gel of Merck (PF254–366 nm). All reagents, 3-(4-chlorophenyl)-3-oxopropanenitrile and 1-benzofuran-2-carboxylic acid were purchased from Sigma–Aldrich.

### General procedure for the synthesis of conjugated esters (**2a**, **2c**) and (**2e**)

To a solution of NaH (120 mmol, 60% dispersion in mineral oil, 4.8 g) in THF (200 mL) a solution of ethyl (diethoxyphosphoryl)acetate (120 mmol, 21 mL) in THF (50 mL) was added dropwise in ice bath. After 30 min, the suitable ketone (100 mmol) was added to the reaction mixture, which was then stirred for 2-3 days in room temperature. After the reaction completed, THF was evaporated under reduced pressure, and the residue was extracted with diethyl ether. The organic layer was dried over sodium sulfate and evaporated. Crude product purified by column chromatography on silica gel using n-hexane: ethyl acetate (5:1) as eluent.

**Ethyl (2E)-3-phenylbut-2-enoate (2a).** Colorless oil, yield 90%, 17.1 g. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 1.36 (3H, t, *J* = 7.2 Hz, CH<sub>3</sub>), 2.62 (3H, d, *J* = 1.2 Hz, CH<sub>3</sub>), 4.25 (2H, q, *J* = 7.2 Hz, CH<sub>2</sub>), 6.17 (1H, m, H<sub>2</sub>), 7.40 (3H, m), 7.51 (2H, m). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 14.6 (CH<sub>3</sub>), 18.2 (CH<sub>3</sub>), 60.2 (CH<sub>2</sub>), 117.4, 126.6, 128.8, 129.3, 142.5, 155.9, 167.2 (CO).

**Ethyl 3,3-diphenylacrylate (2c).** Colorless oil, yield 85%, 21.5 g. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 1.17 (3H, t, *J* = 7.2 Hz, CH<sub>3</sub>), 4.11 (2H, q, *J* = 7.2 Hz, CH<sub>2</sub>), 6.44 (1H, s, H<sub>2</sub>), 7.27-7.45 (10H, m). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 14.3 (CH<sub>3</sub>), 60.4 (CH<sub>2</sub>), 117.7, 128.2, 128.4, 128.6, 128.7, 129.4, 129.7, 139.3, 141.1, 156.9, 166.4 (CO).

**Ethyl (2E)-3-(2-thienyl)but-2-enoate (2e).** Colorless oil, yield 90%, 17.6 g. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 1.34 (3H, t, *J* = 7.2 Hz, CH<sub>3</sub>), 2.63 (3H, d, *J* = 1.2 Hz, CH<sub>3</sub>), 4.22 (2H, q, *J* = 7.2 Hz, CH<sub>2</sub>), 6.22 (1H, d, *J* = 1.2 Hz, H<sub>2</sub>), 7.06 (1H, t, *J* = 4.2 Hz), 7.34 (2H, d, *J* = 4.2 Hz). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 14.6 (CH<sub>3</sub>), 17.5 (CH<sub>3</sub>), 60.2 (CH<sub>2</sub>), 114.5, 127.0, 127.4, 128.2, 145.8, 148.1, 167.0 (CO).

**General procedure for the synthesis of conjugated amides**

Conjugated esters **2a**, **2c** and **2e** were synthesized according to the method explained above. To the conjugated ester (100 mmol), a solution of 5 M NaOH (200 mmol) was added and the mixture was refluxed for 2-3 hours until the phases combined. Water was added to sodium salt and then was hydrolyzed with diluted HCl (25%). Carboxylic acid obtained was filtered and washed with water. Then, fresh distilled thionyl chloride (37 mL, 500 mmol) is added drop by drop in the suspension of carboxylic acid in 200 mL chloroform at room temperature. The mixture was allowed to stand for 12 hours. Without purifying the solution of acyl chloride in chloroform, it is added slowly into a solution of 450 mL ammonia (35 %) containing sodium hydroxide (26 g, 0.2 mole) which was cooled in an ice bath and stirred vigorously. Separated amide was filtered, washed with water and dried. Yield 70%.

**(2E)-3-Phenylbut-2-enamide (2b)**. White solid, mp 116-118 °C<sup>15</sup>. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>),  $\delta_{\text{H}}$  2.66 (3H, s, CH<sub>3</sub>), 5.97 (2H, br, NH<sub>2</sub>), 6.20 (1H, s, H<sub>2</sub>), 7.45-7.56 (5H, m). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>),  $\delta_{\text{C}}$  17.9 (CH<sub>3</sub>), 119.2, 126.4, 128.7, 128.9, 142.7 (C<sub>2</sub>), 152.3 (C<sub>3</sub>), 169.6 (CO).  $m/z$  (ESI<sup>+</sup>) = 162 (MH<sup>+</sup>, 100% ).

**3,3-Diphenylacrylamide (2d)**. White solid, mp 148-150 °C<sup>14b</sup>. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>),  $\delta_{\text{H}}$  5.36 (1H, br, NH), 5.90 (1H, br, NH), 6.51 (1H, s, H<sub>2</sub>), 7.38-7.56 (10H, m). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>),  $\delta_{\text{C}}$  122.0, 128.3, 128.7, 129.0, 129.1, 129.4, 129.5, 138.4, 140.8, 151.2, 169.0 (CO).  $m/z$  (ESI<sup>+</sup>) = 224 (MH<sup>+</sup>, 100% ).

**(2E)-3-(2-Thienyl)but-2-enamide (2f)**. White solid, mp 115-117°C. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>),  $\delta_{\text{H}}$  2.68 (3H, d,  $J = 0.9$  Hz, CH<sub>3</sub>), 5.92 (2H, br, NH<sub>2</sub>), 6.30 (1H, d,  $J = 1.2$  Hz, H<sub>2</sub>), 7.12 (1H, dd,  $J = 4.8$  and  $3.9$  Hz), 7.36 (2H, m). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>),  $\delta_{\text{C}}$  17.3 (CH<sub>3</sub>), 116.2, 126.5, 126.6, 128.1, 145.3, 146.0, 169.0 (CO).  $m/z$  (ESI<sup>+</sup>) = 168 (MH<sup>+</sup>, 100% ).

**General procedure for the synthesis of 4-cyano-2,3-dihydrofurans**

A solution of manganese(III) acetate dihydrate (0.83 g, 3 mmol) in 15 mL of glacial acetic acid was heated under nitrogen atmosphere at 80 °C until it dissolved. After the solution was cooled down to 70 °C, a solution of 3-oxopropanenitrile (2 mmol) and conjugated alkene (1 mmol) in acetic acid was added to this mixture. The reaction was completed when dark brown color of the solution changed to red color (in 30–60 min). Water (20 mL) was added to this solution and extracted with CHCl<sub>3</sub> (3x20 mL). The combined organic phases were neutralized with satd. NaHCO<sub>3</sub> solution, and dried over anhydrous Na<sub>2</sub>SO<sub>4</sub> and evaporated. Crude products were purified by column chromatography on silica gel or preparative TLC (20x20 cm plates, 2 mm thickness) using n-hexane/EtOAc (1:1) as eluent.

**4-Cyano-2-methyl-2,5-diphenyl-2,3-dihydrofuran-3-carboxamide (3a)**. White solid, yield 26%, 80 mg, mp 186-188 °C, IR (KBr disc, cm<sup>-1</sup>): 3428 (NH), 3265 (NH), 2200 (CN), 1683 (C=O), 1623 (C=C), 1261, 764. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>),  $\delta_{\text{H}}$  1.86 (3H, s, CH<sub>3</sub>), 4.11 (1H, s, H<sub>3</sub>), 6.01 (1H, s, NH), 6.06 (1H, s, NH), 7.32-7.57 (8H, m), 8.13 (2H, dt,  $J = 6.4$  and  $1.6$  Hz). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>),  $\delta_{\text{C}}$  25.0 (CH<sub>3</sub>), 62.2 (C<sub>3</sub>), 77.0 (C<sub>2</sub>), 77.3 (C<sub>4</sub>), 77.6, 92.3, 116.9 (CN), 124.0, 127.4, 127.7, 128.4, 129.1, 129.2, 132.6, 145.5, 168.6 (CO), 170.5 (C<sub>5</sub>).  $m/z$  (ESI<sup>+</sup>)

= 305 (MH<sup>+</sup>, 100% ). Anal. Calcd for C<sub>19</sub>H<sub>16</sub>N<sub>2</sub>O<sub>2</sub> (304.34): C, 74.98; H, 5.30; N, 9.20; S, 10.51%, Found: C, 74.88; H, 5.21; N, 9.35; S, 10.72%.

**5-(1-Benzofuran-2-yl)-4-cyano-2-methyl-2-phenyl-2,3-dihydrofuran-3-carboxamide (3b).**

White solid, yield 31%, 105 mg, mp 184-186 °C, IR (KBr disc, cm<sup>-1</sup>): 3400 (NH), 3173 (NH), 2217 (CN), 1679 (C=O), 1639 (C=C), 1216, 752, 702. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 1.89 (3H, s, CH<sub>3</sub>), 4.12 (1H, s, H3), 6.04 (2H, s, NH), 7.32-7.51 (8H, m), 7.62 (1H, d, *J* = 8.8 Hz), 7.70 (1H, d, *J* = 7.6 Hz). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 25.1 (CH<sub>3</sub>), 61.8 (C3), 80.8 (C2), 93.8 (C4), 111.5, 112.4, 115.4 (CN), 122.7, 123.9, 124.4, 127.2, 128.0, 128.4, 129.3, 144.1, 145.1, 156.0, 160.0 (CO), 169.7 (C5). *m/z* (ESI<sup>+</sup>) = 345 (MH<sup>+</sup>, 100% ). Anal. Calcd for C<sub>21</sub>H<sub>16</sub>N<sub>2</sub>O<sub>3</sub> (344.36): C, 73.24; H, 4.68; N, 8.13%, Found: C, 73.10; H, 4.54; N, 8.19%.

**Ethyl 4-cyano-2,2,5-triphenyl-2,3-dihydrofuran-3-carboxylate (3c).**

White solid, yield 32%, 126 mg, mp 102-104 °C, IR (KBr disc, cm<sup>-1</sup>): 2199 (CN), 1737 (C=O), 1617 (C=C), 1213, 759, 688. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 0.91 (3H, t, *J* = 7.2 Hz, CH<sub>3</sub>), 3.76 (2H, dq, *J* = 12.3 and 7.2 Hz, OCH<sub>2</sub>CH<sub>3</sub>), 4.93 (1H, s, H3), 7.26 (5H, m), 7.40-7.55 (6H, m), 7.74 (2H, dd, *J* = 8.1 and 1.2 Hz), 8.16 (2H, dd, *J* = 8.1 and 1.5 Hz). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 13.8 (CH<sub>3</sub>), 60.8 (C3), 62.0 (CH<sub>2</sub>), 80.5 (C2), 95.2 (C4), 116.8 (CN), 126.4, 126.9, 127.8, 128.2, 128.7, 128.9, 129.1, 132.3, 139.9, 142.8, 167.4 (CO), 168.7 (C5). *m/z* (ESI<sup>+</sup>) = 396 (MH<sup>+</sup>, 100% ). Anal. Calcd for C<sub>26</sub>H<sub>21</sub>NO<sub>3</sub> (395.45): C, 78.97; H, 5.35; N, 3.54%, Found: C, 78.89; H, 5.48; N, 3.44%.

**Ethyl 4-cyano-2,2-diphenyl-5-(2-thienyl)-2,3-dihydrofuran-3-carboxylate (3d).**

White solid, yield 20%, 80 mg, mp 129-130 °C, IR (KBr disc, cm<sup>-1</sup>): 2198 (CN), 1734 (C=O), 1612 (C=C), 1186, 759, 696. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 0.80 (3H, t, *J* = 7.2 Hz, CH<sub>3</sub>), 3.65 (2H, dq, *J* = 13.8 and 7.2 Hz, OCH<sub>2</sub>CH<sub>3</sub>), 4.79 (1H, s, H3), 7.10 (1H, dd, *J* = 5.1 and 3.6 Hz), 7.17 (5H, m), 7.30-7.39 (3H, m), 7.51 (1H, dd, *J* = 5.1 and 0.9 Hz), 7.63 (2H, dd, *J* = 8.4 and 1.5 Hz), 7.95 (1H, dd, *J* = 3.6 and 0.9 Hz). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 13.9 (CH<sub>3</sub>), 60.6 (C3), 62.0 (CH<sub>2</sub>), 78.8 (C2), 96.0 (C4), 116.5 (CN), 126.4, 126.9, 128.3, 128.6, 128.7, 128.9, 129.0, 129.7, 131.0, 131.2, 139.8, 142.6, 162.8 (CO), 168.7 (C5). *m/z* (ESI<sup>+</sup>) = 402 (MH<sup>+</sup>, 100% ). Anal. Calcd for C<sub>24</sub>H<sub>19</sub>NO<sub>3</sub>S (401.48): C, 71.80; H, 4.77; N, 3.49; S, 7.99%, Found: C, 71.75; H, 4.97; N, 3.58; S, 8.15%.

**4-Cyano-2,2,5-triphenyl-2,3-dihydrofuran-3-carboxamide (3e).**

Yellow solid, yield 48%, 176 mg, mp 193-195 °C, IR (KBr disc, cm<sup>-1</sup>): 3465 (NH), 3311 (NH), 2204 (CN), 1676 (C=O), 1624 (C=C), 1233, 758, 687. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 4.82 (1H, s, H3), 5.53 (1H, s, NH), 5.67 (1H, s, NH), 7.27 (5H, m), 7.36 (1H, d, *J* = 7.6 Hz), 7.42 (2H, t, *J* = 8.0 Hz), 7.51-7.58 (3H, m), 7.73 (2H, d, *J* = 7.6 Hz), 8.17 (2H, d, *J* = 7.2 Hz). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 61.3 (C3), 80.5 (C2), 96.0 (C4), 116.6 (CN), 126.3, 126.5, 127.3, 127.8, 128.4, 128.6, 128.9, 129.0, 129.3, 132.7, 139.5, 143.1, 168.3 (CO), 170.0 (C5). *m/z* (ESI<sup>+</sup>) = 367 (MH<sup>+</sup>, 100% ). Anal. Calcd for C<sub>24</sub>H<sub>18</sub>N<sub>2</sub>O<sub>2</sub> (366.41): C, 78.67; H, 4.95; N, 7.65%, Found: C, 78.77; H, 4.99; N, 7.59%.

**4-Cyano-5-(4-methoxyphenyl)-2,2-diphenyl-2,3-dihydrofuran-3-carboxamide (3f).**

White solid, yield 55%, 218 mg, mp 222-224 °C, IR (KBr disc, cm<sup>-1</sup>): 3450 (NH), 3291 (NH), 2200 (CN), 1667 (C=O), 1622 (C=C), 1264, 837, 702. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 3.41 (3H, s, CH<sub>3</sub>), 4.34 (1H, s, H3), 6.16 (1H, s, NH), 6.56 (2H, dd, *J* = 8.8 and 2.0 Hz), 6.75 (1H, tt, *J* = 6.0



and 2.4 Hz), 6.79 (2H, td,  $J = 8.0$  and  $2.0$  Hz), 6.85 (1H, tt,  $J = 6.0$  and  $2.4$  Hz), 6.92 (2H, td,  $J = 8.0$  and  $2.0$  Hz), 6.99 (2H, dd,  $J = 8.0$  and  $2.0$  Hz), 7.11 (1H, s, NH), 7.29 (2H, dd,  $J = 7.6$  and  $1.6$  Hz), 7.62 (2H, dd,  $J = 8.8$  and  $2.8$  Hz).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{C}}$  55.4 (CH<sub>3</sub>), 59.3 (C3), 79.6 (C2), 94.8 (C4), 114.1, 117.1 (CN), 120.1, 125.5, 126.1, 127.4, 127.7, 128.1, 128.4, 129.2, 140.1, 143.9, 162.3, 166.6 (CO), 170.1 (C5).  $m/z$  (ESI<sup>+</sup>) = 397 (MH<sup>+</sup>, 100%). Anal. Calcd for C<sub>25</sub>H<sub>20</sub>N<sub>2</sub>O<sub>3</sub> (396.44): C, 75.74; H, 5.08; N, 7.07%, Found: C, 75.64; H, 5.17; N, 7.00%.

**5-(4-Chlorophenyl)-4-cyano-2,2-diphenyl-2,3-dihydrofuran-3-carboxamide (3g).** White solid, yield 38%, 150 mg, mp 192-194 °C, IR (KBr disc,  $\text{cm}^{-1}$ ): 3367 (NH), 3188 (NH), 2210 (CN), 1673 (C=O), 1618 (C=C), 1241, 835, 696.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{H}}$  4.81 (1H, s, H3), 5.52 (1H, s, NH), 5.66 (1H, s, NH), 7.27 (4H, s), 7.36 (2H, tt,  $J = 7.6$  and  $0.4$  Hz), 7.41 (2H, t,  $J = 7.2$  Hz), 7.49 (2H, d,  $J = 8.4$  Hz), 7.70 (2H, d,  $J = 8.0$  Hz), 8.10 (2H, d,  $J = 8.4$  Hz).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{C}}$  61.1 (C3), 81.1 (C2), 96.2 (C4), 116.4 (CN), 125.8, 126.3, 126.4, 128.5 (2xCH), 128.6, 129.0 (2xCH), 129.1 (2xCH), 129.6 (4xCH), 138.9, 139.4, 142.9 (2xCH), 167.1 (CO), 169.8 (C5).  $m/z$  (ESI<sup>+</sup>) = 401 (MH<sup>+</sup>, 100%). Anal. Calcd for C<sub>24</sub>H<sub>17</sub>N<sub>2</sub>O<sub>2</sub> (400.86): C, 76.83; H, 4.46; N, 6.89%, Found: C, 76.75; H, 4.66; N, 6.78%

**4-Cyano-2,2-diphenyl-5-(2-thienyl)-2,3-dihydrofuran-3-carboxamide (3h).** White solid, yield 24%, 90 mg, mp 142-144 °C, IR (KBr disc,  $\text{cm}^{-1}$ ): 3402 (NH), 3300 (NH), 2209 (CN), 1685 (C=O), 1635 (C=C), 1229, 754.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{H}}$  4.83 (1H, s, H3), 5.19 (1H, s, NH), 5.47 (1H, s, NH), 7.24 (1H, dd,  $J = 4.8$  and  $4.4$  Hz), 7.28 (5H, m), 7.37 (1H, d,  $J = 7.2$  Hz), 7.42 (2H, t,  $J = 7.2$  Hz), 7.67 (1H, d,  $J = 4.8$  Hz), 7.74 (2H, d,  $J = 7.6$  Hz), 8.07 (1H, d,  $J = 3.6$  Hz).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{C}}$  55.2 (C3), 80.3 (C4), 88.2 (C2), 116.9 (CN), 126.5, 127.6, 128.5, 128.7, 129.2, 129.3, 129.4, 129.6, 131.0, 132.4, 134.4, 136.0, 162.4 (C5), 171.2 (CO).  $m/z$  (ESI<sup>+</sup>) = 373 (MH<sup>+</sup>, 100%). Anal. Calcd for C<sub>22</sub>H<sub>16</sub>N<sub>2</sub>O<sub>2</sub>S (372.44): C, 70.95; H, 4.33; N, 7.52; S, 8.61%, Found: C, 71.03; H, 4.53; N, 7.46; S, 8.72.

**5-(1-Benzofuran-2-yl)-4-cyano-2,2-diphenyl-2,3-dihydrofuran-3-carboxamide (3i).** White solid, yield 40%, 162 mg, mp 215-217 °C, IR (KBr disc,  $\text{cm}^{-1}$ ): 3442 (NH), 3309 (NH), 2208 (CN), 1673 (C=O), 1628 (C=C), 1257, 739, 697.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{H}}$  4.86 (1H, s, H3), 5.23 (1H, s, NH), 5.50 (1H, s, NH), 7.29-7.32 (5H, m), 7.37 (2H, dd,  $J = 9.6$  and  $7.2$  Hz), 7.44 (2H, t,  $J = 7.6$  Hz), 7.48 (1H, dd,  $J = 7.2$  and  $1.2$  Hz), 7.60 (1H, s), 7.64 (1H, d,  $J = 8.4$  Hz), 7.70 (1H, d,  $J = 8.0$  Hz), 7.75 (2H, d,  $J = 7.6$  Hz).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{C}}$  61.1 (C3), 81.7 (C2), 97.3 (C4), 108.0, 112.1, 112.5, 116.1 (CN), 122.7, 124.4, 126.3, 126.4, 127.2, 128.0, 128.5, 128.7, 128.9, 139.2, 142.6, 144.0, 156.1 (CO), 169.2 (C5).  $m/z$  (ESI<sup>+</sup>) = 407 (MH<sup>+</sup>, 100%). Anal. Calcd for C<sub>26</sub>H<sub>18</sub>N<sub>2</sub>O<sub>3</sub> (406.43): C, 76.83; H, 4.46; N, 6.89%, Found: C, 76.76; H, 4.34; N, 6.98%

**Ethyl 4-cyano-2-methyl-5-phenyl-2-(2-thienyl)-2,3-dihydrofuran-3-carboxylate (3j).** White solid, yield 68%, 230 mg, mp 115-116 °C, IR (KBr disc,  $\text{cm}^{-1}$ ): 2210 (CN), 1720 (C=O), 1621 (C=C), 1254, 770.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{H}}$  1.35 (3H, t,  $J = 7.2$  Hz, CH<sub>3</sub>), 1.86 (3H, s, CH<sub>3</sub>), 4.33 (2H, dq,  $J = 10.8$  and  $7.6$  Hz, OCH<sub>2</sub>CH<sub>3</sub>), 4.38 (1H, s, H3), 6.70 (1H, dd,  $J = 5.2$  and  $3.6$  Hz), 7.14 (1H, dd,  $J = 3.6$  and  $0.8$  Hz), 7.26 (1H, dd,  $J = 5.2$  and  $0.8$  Hz), 7.44-7.51 (3H, m), 8.04 (2H, dd,  $J = 8.0$  and  $1.6$  Hz).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{C}}$  14.5 (CH<sub>3</sub>), 25.3 (CH<sub>3</sub>), 61.3

(C3), 62.2 (CH<sub>2</sub>), 80.2 (C2), 89.6 (C4), 116.8 (CN), 123.8, 125.5, 127.4, 127.6, 127.7, 129.0, 132.2, 148.5, 167.3 (CO), 168.7 (C5). *m/z* (ESI<sup>+</sup>) = 340 (MH<sup>+</sup>, 100%). Anal. Calcd for C<sub>19</sub>H<sub>17</sub>NO<sub>3</sub>S (339.41): C, 67.24; H, 5.05; N, 4.13; S, 9.45%, Found: C, 67.05; H, 5.21; N, 4.32; S, 9.39%.

**Ethyl 4-cyano-5-(4-methoxyphenyl)-2-methyl-2-(2-thienyl)-2,3-dihydrofuran-3-carboxylate (3k).** White solid, yield 80%, 282 mg, mp 94-96 °C, IR (KBr disc, cm<sup>-1</sup>): 2208 (CN), 1742 (C=O), 1619 (C=C), 1260, 834, 695. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 1.40 (3H, t, *J* = 7.2 Hz, CH<sub>3</sub>), 1.89 (3H, s, CH<sub>3</sub>), 3.90 (3H, s, CH<sub>3</sub>), 4.36 (3H, m), 7.01 (2H, d, *J* = 9.3 Hz), 7.05 (1H, dd, *J* = 5.1 and 1.5 Hz), 7.17 (1H, dd, *J* = 3.6 and 1.2 Hz), 7.31 (1H, dd, *J* = 5.4 and 1.5 Hz), 8.06 (2H, d, *J* = 9.0 Hz). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 14.5 (CH<sub>3</sub>), 25.3 (CH<sub>3</sub>), 55.8 (CH<sub>3</sub>), 61.3 (C3), 62.3 (CH<sub>2</sub>), 77.9 (C2), 89.4 (C4), 114.4, 117.4 (CN), 120.2, 123.7, 125.4, 127.4, 129.7, 148.8, 162.7, 167.3 (CO), 169.1 (C5). *m/z* (ESI<sup>+</sup>) = 370 (MH<sup>+</sup>, 100%). Anal. Calcd for C<sub>20</sub>H<sub>19</sub>NO<sub>4</sub>S (369.43): C, 65.02; H, 5.18; N, 3.79; S, 8.68%, Found: C, 64.91; H, 5.08; N, 3.99; S, 8.47%

**Ethyl 5-(4-chlorophenyl)-4-cyano-2-methyl-2-(2-thienyl)-2,3-dihydrofuran-3-carboxylate (3l).** White solid, yield 61%, 228 mg, mp 105-107 °C, IR (KBr disc, cm<sup>-1</sup>): 2210 (CN), 1742 (C=O), 1621 (C=C), 1201, 819, 691. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 1.40 (3H, t, *J* = 7.2 Hz, CH<sub>3</sub>), 1.90 (3H, s, CH<sub>3</sub>), 4.39 (2H, dq, *J* = 13.5 and 7.5 Hz, OCH<sub>2</sub>CH<sub>3</sub>), 4.42 (1H, s, H3), 7.05 (1H, dd, *J* = 5.1 and 3.6 Hz), 7.17 (1H, dd, *J* = 3.6 and 1.2 Hz), 7.33 (1H, dd, *J* = 5.1 and 1.2 Hz), 7.48 (2H, d, *J* = 8.7 Hz), 8.02 (2H, d, *J* = 8.7 Hz). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 14.5 (CH<sub>3</sub>), 25.3 (CH<sub>3</sub>), 61.3 (C3), 62.4 (CH<sub>2</sub>), 80.6 (C2), 89.8 (C4), 116.6 (CN), 123.8, 125.6, 126.1, 127.4, 129.1, 129.4, 138.4, 148.3, 166.2 (CO), 168.7 (C5). *m/z* (ESI<sup>+</sup>) = 374 (MH<sup>+</sup>, 100%). Anal. Calcd for C<sub>19</sub>H<sub>16</sub>ClNO<sub>3</sub>S (373.85): C, 61.04; H, 4.31; Cl, 9.48; N, 3.75; S, 8.58%, Found: C, 61.14; H, 4.50; Cl, 9.27; N, 3.89; S, 8.40%.

**Ethyl 4-cyano-2-methyl-2,5-di-2-thienyl-2,3-dihydrofuran-3-carboxylate (3m).** White solid, yield 77%, 265 mg, mp 110-112 °C, IR (KBr disc, cm<sup>-1</sup>): 2205 (CN), 1725 (C=O), 1611 (C=C), 1175, 715, 700. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 1.45 (3H, t, *J* = 7.2 Hz, CH<sub>3</sub>), 1.95 (3H, s, CH<sub>3</sub>), 4.42 (2H, dq, *J* = 13.5 and 7.2 Hz, OCH<sub>2</sub>CH<sub>3</sub>), 4.45 (1H, s, H3), 7.10 (1H, dd, *J* = 5.1 and 0.9 Hz), 7.23 (1H, dd, *J* = 3.6 and 1.2 Hz), 7.27 (1H, dd, *J* = 3.9 and 1.2 Hz), 7.38 (1H, dd, *J* = 5.1 and 0.9 Hz), 7.67 (1H, dd, *J* = 5.1 and 0.9 Hz), 8.05 (1H, dd, *J* = 3.9 and 0.6 Hz). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 14.6 (CH<sub>3</sub>), 25.3 (CH<sub>3</sub>), 61.1 (C3), 62.5 (CH<sub>2</sub>), 78.4 (C2), 90.6 (C4), 116.7 (CN), 124.0, 125.7, 127.5, 128.6, 129.7, 131.1, 131.4, 148.3, 162.7 (CO), 168.8 (C5). *m/z* (ESI<sup>+</sup>) = 346 (MH<sup>+</sup>, 100%). Anal. Calcd for C<sub>17</sub>H<sub>15</sub>NO<sub>3</sub>S<sub>2</sub> (345.44): C, 59.11; H, 4.38; N, 4.05; S, 18.57%, Found: C, 59.01; H, 4.29; N, 4.15; S, 18.59%.

**Ethyl 3-cyano-5-methyl-5-(2-thienyl)-4,5-dihydro-2,2'-bifuran-4-carboxylate (3n).** White solid, yield 48%, 158 mg, mp 87-89 °C, IR (KBr disc, cm<sup>-1</sup>): 2211 (CN), 1722 (C=O), 1649 (C=C), 1196, 762, 700. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 1.35 (3H, t, *J* = 7.2 Hz, CH<sub>3</sub>), 1.85 (3H, s, CH<sub>3</sub>), 4.30 (2H, m, OCH<sub>2</sub>CH<sub>3</sub>), 4.35 (1H, s, H4), 6.56 (1H, dd, *J* = 3.6 and 1.2 Hz), 6.99 (1H, dd, *J* = 5.1 and 3.6 Hz), 7.10 (1H, d, *J* = 3.6 Hz), 7.13 (1H, dd, *J* = 3.6 and 0.9 Hz), 7.28 (1H, d, *J* = 3.9 Hz), 7.64 (1H, s). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 14.5 (CH<sub>3</sub>), 25.1 (CH<sub>3</sub>), 60.7 (C4),

62.4 (CH<sub>2</sub>), 78.7 (C2), 90.7 (C3), 112.4, 115.6, 115.9 (CN), 124.1, 125.7, 127.4, 143.2, 146.2, 147.9, 158.4 (CO), 168.7 (C2). *m/z* (ESI<sup>+</sup>) = 330 (MH<sup>+</sup>, 100%). Anal. Calcd for C<sub>17</sub>H<sub>15</sub>NO<sub>4</sub>S (329.37): C, 61.99; H, 4.59; N, 4.25; S, 9.74%, Found: C, 61.79; H, 4.50; N, 4.42; S, 9.67%.

**Ethyl 5-(1-benzofuran-2-yl)-4-cyano-2-methyl-2-(2-thienyl)-2,3-dihydrofuran-3-carboxylate (3o).** White solid, yield 77%, 292 mg, mp 122-124 °C, IR (KBr disc, cm<sup>-1</sup>): 2218 (CN), 1743 (C=O), 1654 (C=C), 1175, 752, 713. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 1.39 (3H, t, *J* = 7.2 Hz, CH<sub>3</sub>), 1.93 (3H, s, CH<sub>3</sub>), 4.36 (2H, m, OCH<sub>2</sub>CH<sub>3</sub>), 4.43 (1H, s, H3), 7.03 (1H, dd, *J* = 5.1 and 3.6 Hz), 7.18 (1H, dd, *J* = 3.3 and 1.2 Hz), 7.32-7.34 (2H, m), 7.45 (1H, dd, *J* = 7.8 and 1.2 Hz), 7.48 (1H, s), 7.63 (1H, d, *J* = 8.4 Hz), 7.69 (1H, d, *J* = 7.8 Hz). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 14.5 (CH<sub>3</sub>), 25.2 (CH<sub>3</sub>), 61.0 (C3), 62.5 (CH<sub>2</sub>), 81.5 (C2), 91.0 (C4), 111.6, 112.4, 115.6 (CN), 122.7, 124.1, 124.3, 125.8, 127.3, 127.4, 127.7, 144.3, 147.9, 155.9, 158.6 (CO), 168.5 (C5). *m/z* (ESI<sup>+</sup>) = 380 (MH<sup>+</sup>, 100%). Anal. Calcd for C<sub>21</sub>H<sub>17</sub>NO<sub>4</sub>S (379.43): C, 66.47; H, 4.52; N, 3.69; S, 8.45%, Found: C, 66.26; H, 4.45; N, 3.75; S, 8.24%

**Ethyl 5-tert-butyl-4-cyano-2-methyl-2-(2-thienyl)-2,3-dihydrofuran-3-carboxylate (3p).** Yellow oil, yield 48%, 153 mg, IR (KBr disc, cm<sup>-1</sup>): 2977 (CH), 2213 (CN), 1737 (C=O), 1626 (C=C), 1196, 704. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 1.38 (12H, m), 1.74 (3H, s, CH<sub>3</sub>), 4.19 (1H, s, H3), 4.31 (2H, m), 7.02 (1H, dd, *J* = 5.1 and 3.6 Hz), 7.09 (1H, dd, *J* = 3.6 and 1.2 Hz), 7.29 (1H, dd, *J* = 5.1 and 1.2 Hz). <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 14.5 (CH<sub>3</sub>), 25.1 (CH<sub>3</sub>), 28.1, 35.2 (CH<sub>3</sub>), 61.4 (C3), 62.1 (CH<sub>2</sub>), 79.2 (C2), 88.9 (C4), 116.6 (CN), 123.5, 125.3, 127.3, 148.9, 169.6 (CO), 179.9 (C5). *m/z* (ESI<sup>+</sup>) = 320 (MH<sup>+</sup>, 100%). Anal. Calcd for C<sub>17</sub>H<sub>21</sub>NO<sub>3</sub>S (319.42): C, 63.92; H, 6.63; N, 4.39; S, 10.04%, Found: C, 64.02; H, 6.51; N, 4.51; S, 10.24%.

**4-Cyano-2-methyl-5-phenyl-2-(2-thienyl)-2,3-dihydrofuran-3-carboxamide (3q).** White solid, yield 77%, 240 mg, mp 160-162 °C, IR (KBr disc, cm<sup>-1</sup>): 3415 (NH), 3295 (NH), 2204 (CN), 1672 (C=O), 1620 (C=C), 1257, 772, 719, 687. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 1.93 (3H, s, CH<sub>3</sub>), 4.21 (1H, s, H3), 6.31 (1H, s, NH), 6.77 (1H, s, NH), 6.96 (1H, dd, *J* = 3.6 and 1.2 Hz), 7.13 (1H, dd, *J* = 3.6 and 1.2 Hz), 7.24 (1H, dd, *J* = 5.2 and 1.2 Hz), 7.44 (2H, t, *J* = 7.2 Hz), 7.49 (1H, tt, *J* = 7.2 and 1.6 Hz), 8.02 (2H, dd, *J* = 8.4 and 1.6 Hz). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 24.5 (CH<sub>3</sub>), 62.3 (C3), 80.0 (C2), 90.2 (C4), 117.0 (CN), 124.0, 125.6, 127.4, 127.8 (3xCH), 129.1 (2xCH), 132.5, 148.7, 168.3 (CO), 170.4 (C5). *m/z* (ESI<sup>+</sup>) = 311 (MH<sup>+</sup>, 100%). Anal. Calcd for C<sub>17</sub>H<sub>14</sub>N<sub>2</sub>O<sub>2</sub>S (310.37): C, 65.79; H, 4.55; N, 9.03; S, 10.33%, Found: C, 65.81; H, 4.50; N, 9.13; S, 10.23%.

**4-Cyano-2-methyl-5-(4-methylphenyl)-2-(2-thienyl)-2,3-dihydrofuran-3-carboxamide (3r).** White solid, yield 69%, 220 mg, mp 144-146 °C, IR (KBr disc, cm<sup>-1</sup>): 3428 (NH), 3164 (NH), 2204 (CN), 1670 (C=O), 1619 (C=C), 1243, 823, 710. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>), δ<sub>H</sub> 1.94 (3H, s, CH<sub>3</sub>), 2.42 (3H, s, CH<sub>3</sub>), 4.18 (1H, s, H3), 5.96 (1H, s, NH), 6.16 (1H, s, NH), 6.98 (1H, dd, *J* = 5.2 and 3.6 Hz), 7.12 (1H, dd, *J* = 4.0 and 1.2 Hz), 7.25 (1H, dd, *J* = 5.2 and 0.4 Hz), 7.27 (2H, d, *J* = 8.8 Hz), 7.94 (2H, d, *J* = 8.0 Hz). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>), δ<sub>C</sub> 21.9 (CH<sub>3</sub>), 24.6 (C3), 62.4 (CH<sub>3</sub>), 78.8 (C2), 90.2, 116.9 (CN), 123.8 (C4), 124.6, 125.5, 127.4, 127.8, 129.8, 143.4, 148.8, 168.6 (CO), 169.7 (C5). *m/z* (ESI<sup>+</sup>) = 325 (MH<sup>+</sup>, 100%). Anal. Calcd for C<sub>18</sub>H<sub>16</sub>N<sub>2</sub>O<sub>2</sub>S (324.40): C, 66.64; H, 4.97; N, 8.64; S, 9.88%, Found: C, 66.44; H, 5.08; N, 8.56; S, 9.76%

**4-Cyano-5-(4-methoxyphenyl)-2-methyl-2-(2-thienyl)-2,3-dihydrofuran-3-carboxamide**

**(3s).** White solid, yield 91%, 310 mg, mp 183-185 °C, IR (KBr disc,  $\text{cm}^{-1}$ ): 3395 (NH), 3146 (NH), 2201 (CN), 1689 (C=O), 1665 (C=C), 1269, 806, 771.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{H}}$  1.82 (3H, s,  $\text{CH}_3$ ), 3.78 (3H, s,  $\text{CH}_3$ ), 4.11 (1H, s, H3), 6.91 (2H, d,  $J = 8.8$  Hz), 6.92 (1H, d,  $J = 8.8$  Hz), 7.03 (1H, s, NH), 7.14 (1H, d,  $J = 3.6$  Hz), 7.20 (1H, d,  $J = 5.2$  Hz), 7.66 (1H, s, NH), 7.87 (2H, d,  $J = 8.8$  Hz).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{C}}$  24.8 ( $\text{CH}_3$ ), 55.8 (C3), 61.2 ( $\text{CH}_3$ ), 79.3, 89.8 (C2), 114.4, 117.6 (CN), 120.4 (C4), 123.8, 125.1, 127.2, 129.6, 149.8, 162.6, 167.2 (CO), 170.3 (C5).  $m/z$  ( $\text{ESI}^+$ ) = 341 ( $\text{MH}^+$ , 100%). Anal. Calcd for  $\text{C}_{18}\text{H}_{16}\text{N}_2\text{O}_3\text{S}$  (340.40): C, 63.51; H, 4.74; N, 8.23; S, 9.42%, Found: C, 63.62; H, 4.63; N, 8.12; S, 9.49.

**5-(4-Chlorophenyl)-4-cyano-2-methyl-2-(2-thienyl)-2,3-dihydrofuran-3-carboxamide (3t).**

White solid, yield 73%, 250 mg, mp 163-164 °C, IR (KBr disc,  $\text{cm}^{-1}$ ): 3432 (NH), 3298 (NH), 2207 (CN), 1672 (C=O), 1620 (C=C), 1245, 832, 699.  $^1\text{H}$  NMR (400 MHz, DMSO),  $\delta_{\text{H}}$  1.83 (3H, s,  $\text{CH}_3$ ), 4.20 (1H, s, H3), 7.03 (1H, dd,  $J = 5.2$  and 3.6 Hz), 7.31 (1H, dd,  $J = 3.6$  and 1.2 Hz), 7.48 (1H, dd,  $J = 5.2$  and 1.2 Hz), 7.55 (1H, s, NH), 7.65 (2H, d,  $J = 8.8$  Hz), 7.88 (2H, d,  $J = 8.8$  Hz), 7.92 (1H, s, NH).  $^{13}\text{C}$  NMR (100 MHz, DMSO),  $\delta_{\text{C}}$  24.9 ( $\text{CH}_3$ ), 60.9 (C3), 82.8 (C2), 90.5, 117.1 (CN), 124.9 (C4), 126.2, 126.6, 127.8, 129.3, 130.1, 137.5, 149.2, 165.7 (CO), 169.5 (C5).  $m/z$  ( $\text{ESI}^+$ ) = 345 ( $\text{MH}^+$ , 100%). Anal. Calcd for  $\text{C}_{17}\text{H}_{13}\text{ClN}_2\text{O}_2\text{S}$  (344.82): C, 59.21; H, 3.80; Cl, 10.28; N, 8.12; S, 9.30%, Found: C, 59.29; H, 3.85; Cl, 10.25; N, 8.22; S, 9.20%.

**4-Cyano-2-methyl-2,5-di-2-thienyl-2,3-dihydrofuran-3-carboxamide (3u).**

White solid, yield 70%, 220 mg, mp 175-177 °C, IR (KBr disc,  $\text{cm}^{-1}$ ): 3423 (NH), 3185 (NH), 2201 (CN), 1672 (C=O), 1611 (C=C), 1260, 717.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{H}}$  1.80 (3H, s,  $\text{CH}_3$ ), 4.15 (1H, s, H3), 7.02 (1H, t,  $J = 3.6$  Hz), 7.26 (1H, d,  $J = 4.8$  Hz), 7.29 (1H, t,  $J = 3.6$  Hz), 7.47 (1H, d,  $J = 4.8$  Hz), 7.53 (1H, s, NH), 7.77 (1H, d,  $J = 4.0$  Hz), 7.90 (1H, s, NH), 7.93 (1H, d,  $J = 5.2$  Hz).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{C}}$  24.8 ( $\text{CH}_3$ ), 60.6 (C3), 80.4 (C2), 91.1 (C4), 117.1 (CN), 124.9, 126.3, 127.8, 129.4, 129.6, 131.2, 132.6, 149.2, 162.2 (CO), 169.7 (C5).  $m/z$  ( $\text{ESI}^+$ ) = 317 ( $\text{MH}^+$ , 100%). Anal. Calcd for  $\text{C}_{15}\text{H}_{12}\text{N}_2\text{O}_2\text{S}_2$  (316.40): C, 56.94; H, 3.82; N, 8.85; S, 20.27%, Found: C, 56.83; H, 3.75; N, 8.72; S, 20.35%.

**3-Cyano-5-methyl-5-(2-thienyl)-4,5-dihydro-2,2'-bifuran-4-carboxamide (3v).**

White solid, yield 61%, 185 mg, mp 167-169 °C, IR (KBr disc,  $\text{cm}^{-1}$ ): 3424 (NH), 3298 (NH), 2200 (CN), 1671 (C=O), 1621 (C=C), 1268, 756, 721.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{H}}$  1.94 (3H, s,  $\text{CH}_3$ ), 4.18 (1H, s, H3), 5.93 (1H, s, NH), 5.99 (1H, s, NH), 6.58 (1H, dd,  $J = 3.6$  and 1.6 Hz), 6.99 (1H, dd,  $J = 5.2$  and 3.6 Hz), 7.13 (2H, m), 7.27 (1H, dd,  $J = 5.2$  and 1.2 Hz), 7.65 (1H, dd,  $J = 1.6$  and 0.8 Hz).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{C}}$  24.5 ( $\text{CH}_3$ ), 61.7 (C4), 78.4 (C5), 91.5 (C3), 112.5, 115.7 (CN), 116.1, 124.1, 125.7, 127.4, 143.1, 146.5, 148.2, 159.3 (CO), 169.3 (C2).  $m/z$  ( $\text{ESI}^+$ ) = 301 ( $\text{MH}^+$ , 100%). Anal. Calcd for  $\text{C}_{15}\text{H}_{12}\text{N}_2\text{O}_3\text{S}$  (300.33): C, 59.99; H, 4.03; N, 9.33; S, 10.68%, Found: C, 60.12; H, 4.21; N, 9.20; S, 10.55%.

**5-(1-Benzofuran-2-yl)-4-cyano-2-methyl-2-(2-thienyl)-2,3-dihydrofuran-3-carboxamide**

**(3w).** Yellow solid, yield 91%, 320 mg, mp 192-193 °C, IR (KBr disc,  $\text{cm}^{-1}$ ): 3400 (NH), 3217 (NH), 2214 (CN), 1677 (C=O), 1636 (C=C), 1253, 753, 719.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{H}}$  1.87 (3H, s,  $\text{CH}_3$ ), 4.20 (1H, s, H3), 6.90 (1H, dd,  $J = 5.2$  and 3.6 Hz), 6.95 (1H, s, NH), 7.15

(1H, dd,  $J = 4.0$  and  $1.2$  Hz), 7.20 (1H, dd,  $J = 5.2$  and  $0.8$  Hz), 7.23 (1H, dd,  $J = 7.6$  and  $1.2$  Hz), 7.32 (1H, s), 7.35 (1H, dd,  $J = 8.0$  and  $1.2$  Hz), 7.47 (1H, dd,  $J = 8.0$  and  $1.2$  Hz), 7.59 (1H, dd,  $J = 7.6$  and  $0.8$  Hz), 7.69 (1H, s, NH).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ),  $\delta_{\text{C}}$  24.3 ( $\text{CH}_3$ ), 60.6 (C3), 82.8 (C2), 91.0 (C4), 110.7, 111.7, 115.4 (CN), 122.4, 123.8, 123.9, 125.0, 126.9, 127.0, 127.2, 144.3, 148.5, 155.2, 158.0 (CO), 169.3 (C5).  $m/z$  (ESI $^+$ ) = 351 ( $\text{MH}^+$ , 100%). Anal. Calcd for  $\text{C}_{19}\text{H}_{14}\text{N}_2\text{O}_3\text{S}$  (350.39): C, 65.13; H, 4.03; N, 7.99; S, 9.15%, Found: C, 65.25; H, 4.15; N, 7.95; S, 9.28%

## Acknowledgement

E.V.B.Yilmaz thanks TUBITAK for doctoral fellowship.

## References

- (a) Iqbal, J.; Bhatia, B.; Nayyar, N. K. *Chem. Rev.* **1994**, *94*, 519. (b) Snider, B. B. *Chem. Rev.* **1996**, *96*, 339. (c) Kagan, H. B.; Namy, J. L. *Tetrahedron* **1986**, *42*, 6573. (d) Molander, G. A. *Chem. Rev.* **1992**, *92*, 29.
- (a) Yilmaz, M.; Pekel, A. T. *Synth. Commun.* **2001**, *31*, 3871. (b) Mellor, J. M.; Mohammed, S. *Tetrahedron Lett.* **1991**, *32*, 7111. (c) Nishino, H.; Hguyen, V.; Yoshinaga, S.; Kurosawa, K. *J. Org. Chem.* **1996**, *61*, 8264. (d) Gregory, B.; Parsons, A. F.; Thomas, C. B. *Tetrahedron Lett.* **2000**, *41*, 7751. (e) Yilmaz, M.; Pekel, A. T. *Synth. Commun.* **2001**, *31*, 2189. (f) Yilmaz, M.; Bicer, E.; Pekel, A. T. *Turk. J. Chem.* **2005**, *29*, 579. (g) Yilmaz, M.; Pekel, A. T. *J. Fluorine Chem.* **2005**, *126*, 401. (h) Burgaz, E.V.; Yilmaz, M.; Pekel, A.T. and Oktemer, A. *Tetrahedron* **2007**, *63*, 7229. (i) Yilmaz, M.; Uzunalioglu, N.; Pekel, A. T. *Tetrahedron* **2005**, *61*, 8860. (j) Yilmaz, M.; Uzunalioglu, N.; Pekel, A. T. *Turk. J. Chem.* **2008**, *32*, 411.
- (a) Gregory, B.; Parsons, A. F.; Thomas, C. B. *Tetrahedron* **2001**, *57*, 4719. (b) Alagoz, O.; Yilmaz, M.; Pekel, A. T. *Synth. Commun.* **2006**, *36*, 1005. (c) Kajikawa, S.; Nishino, H.; Kurosawa, K. *Heterocycles* **2001**, *54*, 171. (d) Melikyan, G. G. *Synthesis* **1993**, 833.
- (a) Baciocchi, E.; Ruzziconi, R. *Synth. Commun.* **1988**, *18*, 1841. (b) Nair, V.; Mathew, J.; Radhakrishnan, K. V. *J. Chem. Soc., Perkin Trans.1* **1996**, 1487. (c) Kobayashi, K.; Sakashita, K.; Akamatsu, H.; Tanaka, K.; Uchida, M.; Uneda, T.; Kitamura, T.; Morikawa, O.; Konishi, H. *Heterocycles* **1999**, *51*, 2881. (d) Lee, Y. R.; Kim, B. S.; Kim, D. H. *Tetrahedron* **2000**, *56*, 8845. (e) Nair, V.; Treasa, P. M.; Maliakal, D.; Rath, N. P. *Tetrahedron* **2001**, *57*, 7705. (f) Tseng, C.-H.; Wu, Y.-L.; Chuang, C.-P. *Tetrahedron* **2002**, *58*, 7625. (g) Liao, Y.-J.; Wu, Y.-L.; Chuang, C.-P. *Tetrahedron* **2003**, *59*, 3511. (h) Kobayashi, K.; Nagase, K.; Morikawa, O.; Konishi, H. *Heterocycles* **2003**, *60*, 939. (i) Wu, Y.-L.; Chuang, C.-P. *Tetrahedron* **2004**, *60*, 1841.

5. (a) Lee, Y. G.; Kim, B. S. *Tetrahedron Lett.* **1997**, *38*, 2095. (b) Lee, Y. G.; Kim, B. S.; Kweon, H. *Tetrahedron* **2000**, 3867. (c) Lee, Y. G.; Kim, B. S.; Wang, H-C. *Tetrahedron* **1998**, 12215.
6. (a) Snider, B. B.; Mohan, R.; Kates, S. A. *J. Org. Chem.* **1985**, *50*, 3661. (b) Paquette, L. A.; Schaefer, A. G.; Springer, J. P. *Tetrahedron* **1987**, *43*, 5567. (c) Snider, B. B.; Zhang, Q. *Tetrahedron* **1993**, *49*, 3185. (d) Snider, B. B.; McCarthy, B. A. *Tetrahedron* **1993**, *49*, 9447. (e) Vo, N. H.; Snider, B. B. *J. Org. Chem.* **1994**, *59*, 5419. (f) Snider, B. B.; O'Neil, S. V. *Tetrahedron* **1995**, *51*, 12983. (g) Snider, B. B.; Han, L.; Xie, C. *J. Org. Chem.* **1997**, *62*, 6978. (h) Snider, B. B.; Kiselgof, J. Y.; Foxman, B. M. *J. Org. Chem.* **1998**, *63*, 7945. (i) Yang, D.; Ye, X.; Gu, S.; Ming, X. *J. Am. Chem. Soc.* **1999**, *121*, 5579. (j) Snider, B. B. *Chem. Rev.* **1996**, *96*, 339.
7. Logoglu, E.; Yilmaz, M.; Katircioglu, H.; Yakut, M.; Mercan, S. *Med. Chem. Res.* **2010**, *19*, 490.
8. Elbe, H-L.; Kunisch, F.; Bielefeldt, D.; Tiemann, R.; Stenzel, K.; Dutzmann, S.; Kugler, M.; Schrage, H. U.S. Patent 6 107 336, 2000.
9. Drauz, K.; Kleemann, A.; Wolf-Heuss, E. U.S. Patent 4 728 743, Mar 1, 1988.
10. (a) Pinna, G. A.; Cignarella, G.; Ruiu, S.; Loriga, G.; Murineddu, G.; Villa, S.; Grella, G. E.; Cossu, G. and Fratta, W. *Bioorg. Med. Chem.* **2003**, *11*, 4015. (b) Srikrishna, A.; Kumar, P. P.; Viswajanani, R.; *Tetrahedron. Lett.* **1996**, *37*, 1683. (c) Dunnivant, Hauser; *J. Org. Chem.* 1960, *25*, 503. (d) Pinna, G. A.; Cignarella, G.; Loriga, G.; Murineddu, G.; Mussinu, J.-M.; Ruiu, S. and Fratta, W. *Bioorg. Med. Chem.* **2002**, *10*, 1929.
11. (a) Sabol, J. S.; Gregge, R. J. *Tetrahedron Lett.* **1990**, *31*, 27. (b) Malamas, M. S.; Palka, C. L.; *J. Heterocycl. Chem.* **1996**, *33*, 475.
12. (a) Miller, R. E.; Nord, F. F. *J. Org. Chem.* **1951**, *16*, 728.
13. (b) Miller, R. E.; Nord, F. F. *J. Org. Chem.* **1950**, *15*, 89.
14. (a) Petrova, J.; Momchilova, S.; Vassilev, N. G. *Phosphorus, Sulfur and Silicon* **2000**, 164, 87. (b) Ishikawa, F. *Chem. Pharm. Bull.* **1980**, *28*, 1394.
15. (a) Platzner, K. *Chem. Ber.* **1940**, *73*, 1410. (b) Work, S. D. *J. Am. Chem. Soc.* **1964**, *86*, 872. (c) Ishikawa, F. *Chem. Pharm. Bull.* **1980**, *28*, 1394.
16. Stoermer, R.; Grimm, F.; Laage, E. *Chem. Ber.* **1917**, *50*, 973.