Synthetic Communications: An International Journal for Rapid Communication of Synthetic Organic Chemistry

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/lsyc20

Novel Synthesis of Bis-Iminocoumarins

H. Ammar [a], S. Abid [a], Y. Le Bigot [b] & R. El Gharbi [a]

[a] Laboratoire de Chimie Appliquée: Hétérocycles, Corps Gras et Polymères Faculté des Sciences, Sfax, Tunisia

[b] Laboratoire de Génie Chimique, ENSIACET, Toulouse, France

Available online: 24 Aug 2011

To cite this article: H. Ammar, S. Abid, Y. Le Bigot & R. El Gharbi (2012): Novel Synthesis of Bis-Iminocoumarins, Synthetic Communications: An International Journal for Rapid Communication of Synthetic Organic Chemistry, 42:6, 799-810

To link to this article: http://dx.doi.org/10.1080/00397911.2010.531370

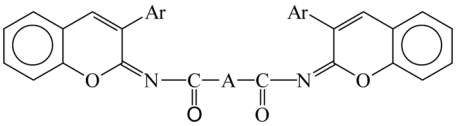
Synthetic Communications®, 42: 799–810, 2012

ISSN: 0039-7911 print/1532-2432 online
DOI: 10.1080/00397911.2010.531370

NOVEL SYNTHESIS OF BIS-IMINOCOUMARINS

H. Ammar,[1] S. Abid,[1] Y. Le Bigot,[2] and R. El Gharbi[1]
[1]*Laboratoire de Chimie Appliquée: Hétérocycles, Corps Gras et Polymères Faculté des Sciences, Sfax, Tunisia*
[2]*Laboratoire de Génie Chimique, ENSIACET, Toulouse, France*

GRAPHICAL ABSTRACT



Abstract *Reaction of 3-aryl iminocoumarins with diacid chlorides as C-electrophilic reagents under mild conditions novel bis-iminocoumarins in good yields. When the reaction was performed with alkylene dibromides by heating them in toluene in the presence of IRA 900 resin, bis-ether compounds were obtained by way opening the pyranic ring. The structures of the product obtained were characterized by Fourier transform infrared, ^{1}H NMR, ^{13}C NMR, and elemental analysis.*

Keywords Bis-iminocoumarins; diacid chlorides; iminocoumarins; Knoevenagel condensation

INTRODUCTION

In recent years, there has been increasing interest in 2H-1-benzopyran-2-imines (also called iminocoumarins) regarding their potential broad-spectrum biological activity,[1–3] their original optical properties,[4–6] and their considerable value in synthetic organic chemistry as starting materials in formation of various polycyclic compounds consisting of benzopyran fragments fused with different heterocyclic rings.[7–10] In the latter context, a number of studies from our laboratory have focused on the reactivity of 3-cyano iminocoumarins toward N-nucleophilic reagents to obtain novel heterocyclic compounds such as benzopyranopyrimidines, benzopyranopyrazoles, benzopyranoisoxazoles, and 3-triazolonyl iminocoumarins, which could exhibit interesting biological activities.[11–14] Iminocoumarins also can be substituted on their imino group by reaction with electrophilic reagents, thus allowing a wide panel of compounds to be prepared.[15–17] We have reported that ethylchloroformate, acid chlorides, organic isocyanates and semicarbazides, as

Received August 5, 2010.
Address correspondence to S. Abid, Laboratoire de Chimie Appliquée: Hétérocycles, Corps Gras et Polymères, Faculté des Sciences de Sfax, 3000, Sfax, Tunisia. E-mail: abidsouhir@yahoo.fr

C-electrophilic reagents, reacted easily with iminocoumarins, leading to novel materials for applications based on their optical properties.[18–22]

As a continuation of this investigation aimed at modifying iminocoumarin properties, we decided to study the synthesis of bifluorophoric molecules incorporating two iminocoumarin nuclei associated by their imidic groups. A literature survey has revealed that this family of iminocoumarinic derivatives has received little attention, whereas the coumarinic analogs occupy an interesting position in the well-known family of coumarin derivatives. Bis-coumarins often possess interesting pharmacological properties such as antimicrobial,[23] anticoagulant,[24] anti-inflammatory,[25] cardiovascular,[26] and antiproliferative activities.[27] Their optical properties are influenced by both the nature of coumarin fluorophore and the chemical structure of the bridge. Thus 3,3′-p-phenylene bis-coumarins are of high interest in the field of fluorescent dyes because they possess molar absorption coefficients much greater than that of corresponding mono-coumarins and their quantum yields are very high,[28] whereas bis-coumarins based on 7-(4-methylcoumarinyl) diesters are not really interesting as fluorescent materials.[29]

Asimov et al.[30] were the first to envisage the synthesis of bifluorophore molecules incorporating an iminocoumarinic fragment, which led to new high-efficiency laser dyes consisting of coumarinic and iminocoumarinic fluorophores linked by thiazolyl heterocycle as a bridge.[30] However, the process and the reaction mechanism were not tackled, and the compound characterization was relatively limited because of the lack of complete spectroscopic assessment. As part of our program directed toward the synthesis of bifluorophore compounds,[31,32] we reported a new synthetic route to a series of bis-iminocoumarins involving the coupling of two 3-aryl iminocoumarin units with aromatic diamines by Schmidt reaction catalyzed by ion-exchange resins.[33]

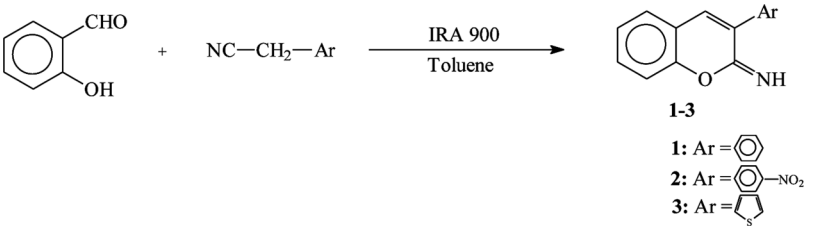
The purpose of this study was the synthesis of new molecules bearing two iminocoumarinic moieties linked by a diacyl bridge because of both their possible use as fluorescent dyes and their potential therapeutical use.

RESULTS AND DISCUSSION

Iminocoumarins **1–3** were prepared using Knoevenagel condensation procedures in one-pot reactions from 2-hydroxybenzaldehyde and arylacetonitriles in the presence of basic resin Amberlite IRA 900 as catalyst. The spontaneous cyclization between the ortho hydroxy group and the side-chain cyano group led to the corresponding iminocoumarin derivatives (Scheme 1) in good yields (recrystallized from toluene). Their structures were assigned by infrared (IR), ^{1}H and ^{13}C NMR, and elemental analysis.

The coupling of compounds **1–3** with diacid chlorides **a–g** led to bis-iminocoumarins following the *N*-nucleophilic attack on acid chloride function (Scheme 2).

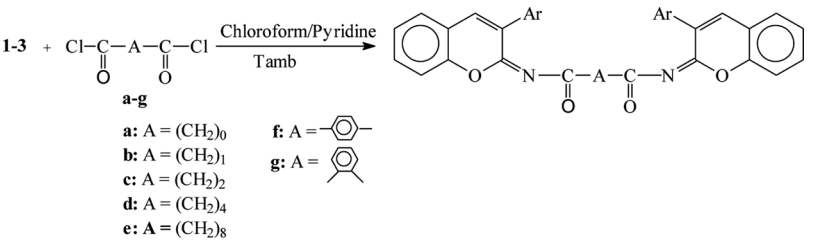
Reaction of **1** + **e** was selected as a model system for a thorough study aimed at optimizing the bis-iminocoumarin yield. Various solvents were tested, ranging in polarity and nucleophilic or electrophilic character from toluene to DMA, but no major trend was observed within this large domain of media because yields varied by only a few percentage points. Iminocoumarin **1** concentration was changed



Scheme 1.

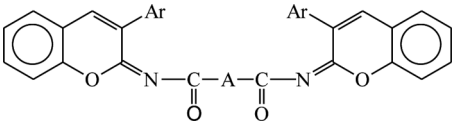
between 0.05 and 0.20 M, and this produced a considerable increase in bis-iminocoumarin yield. With a 0.12 M solution of **1**, the molar concentration of diacid chloride **e** was varied from the stoichiometric value up to a molar excess of 30%. Maximum yield was obtained with 20% excess, suggesting that a small amount of COCl moieties had been hydrolyzed (the corresponding carboxylic acid function is inactive in these systems). All the preliminary runs were conducted in the presence of pyridine used in stoichiometric quantity with respect to the HCl generated in the reaction. Triethylamine was also tested but gave less encouraging results. The role of the reaction temperature was furthermore between 0 and 60 °C. The most adequate temperature was around 25 °C. The reaction time required to attain the optimal conversion was 5 h. With these conditions, yields were reproducibly close to 97%. The application of the optimized conditions to various combinations gave corresponding bis-iminocoumarins with good or moderate yields (Table 1). The expected structures were clearly confirmed by the elemental analyses and the spectroscopic studies.

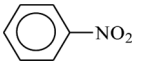
We extended our study to the use of alkylene bromides as C-electrophile reagents, but nucleophilic attack of imidic nitrogen on methylene groups did not take place because detectable bis-iminocoumarins appeared when reacting **1** with p-xylene dibromide, 1,4-dibromobut-2-ene, or 1,4-dibromobutane (Scheme 3). Thus it might be expected that the relatively poor electrophilic character of methylene groups did not allow their interaction with imidic nitrogen. To solve this problem, the reaction was studied in the presence of IRA 900 resin as an appropriate basic entity in the same conditions used for iminocoumarin **1** synthesis, but our attempts failed. The reaction from **h** and **i** furnished novel products **1h** and **1i**, respectively, not containing any benzopyrano fragments instead of the anticipated formation of bis-iminocoumarins as shown in Scheme 3.



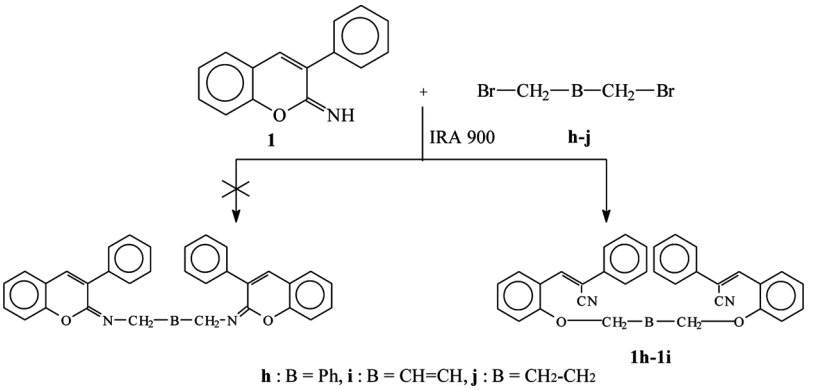
Scheme 2.

Table 1. Synthesis of bis-iminocoumarins

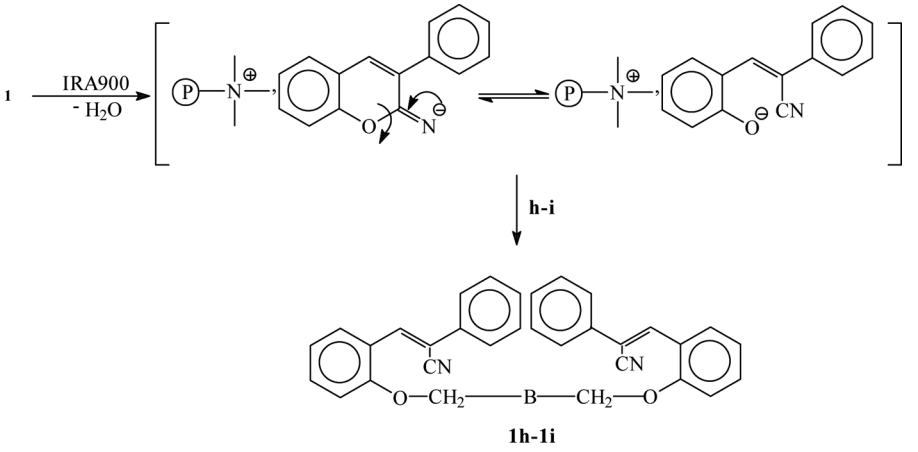


Bis-iminocoumarins	Ar	A	Yields (%)
1a		$(CH_2)_0$	55
1b		$(CH_2)_1$	62
1c		$(CH_2)_2$	70
1d		$(CH_2)_4$	89
1e		$(CH_2)_8$	97
1f		p-Ph	90
1g		o-Ph	86
2b		$(CH_2)_1$	57
2c		$(CH_2)_2$	61
2d		$(CH_2)_4$	80
2e		$(CH_2)_8$	89
2g		o-Ph	80
3c		$(CH_2)_2$	67
3d		$(CH_2)_4$	83
3e		$(CH_2)_8$	92
3f		p-Ph	86

The elemental analysis and the spectral data of these two new compounds were entirely consistent with the structures of **1h** and **1i**. In particular, the Fourier transform infrared (FTIR) spectra showed an absorption band of C≡N function, and in the ^{1}H NMR singlets from -O-CH_2 fragments were observed. As shown in Scheme 4, a mechanism involving two consecutive steps can be postulated to explain the formation of **1h** and **1i**. In the first step, acido-basic interaction of imino group with resin functions takes place after opening the pyranic ring to give phenate ions. In the second stage, an etherification reaction occurs to afford bis-ether compounds **1h** and **1i** by O-nucleophilic attack of phenate ions on methylene groups.



Scheme 3.



1h-1i

Scheme 4.

CONCLUSION

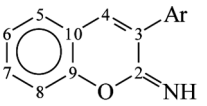
The reaction of 3-aryl iminocoumarins with diacid chlorides appears well suited to the synthesis of bifluorophore compounds bearing two iminocoumarinic moieties. These compounds were easily purified and obtained in good yields. In contrast, when p-xylene dibromide or 1,4-dibromo but-2-ene were used as C-electrophile reagents, an O-alkylation reaction took place, leading to bis-ether formation. Work is in progress to assess the biological activities and the optical properties of these novel materials.

EXPERIMENTAL

2-Hydroxybenzaldehyde, nitriles, diacid chlorides, and dibromide compounds are commercial products. Solvents (toluene, chloroform) were purified by standard techniques and redistilled prior to their use. Catalyst IRA 900 was conditioned and then used. The melting points were determined on an Electrothermal 9100 apparatus. IR spectra were obtained on a Jasco FT-IR 420 instrument using KBr pellets. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker WP 200 spectrometer at 300 MHz and 75.0 MHz, respectively, in $CDCl_3$ or dimethylsulfoxide (DMSO-d_6), with tetramethylsilane (TMS) as internal standard (chemical shifts in ppm). Elemental microanalysis were performed on an EA 1112 analyser from CE Instruments. Mass spectra (MS) were recorded on a DSQII ThermoFisher spectrometer.

Synthesis of Iminocoumarins (1–3)

A mixture of 2-hydroxybenzaldehyde (20 mmol), IRA 900 resin (2 g, 20 mmol OH^-), and toluene (25 mL) was introduced into a 250-mL, three-neck flask equipped with a condenser and stirred for 3 h at 85 °C under a nitrogen atmosphere. After that, nitrile (20 mmol) was added, and the mixture was refluxed for 8 h. After completion of the reaction, the organic phase was separated from the solid catalyst and concentrated under reduced pressure. The solid phase was recrystallized from toluene.



Ar: Ph, p-NO_2Ph, Th

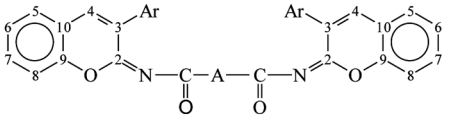
3-Phenyliminocoumarin (1). IR (KBr) (cm^{-1}): $\nu = 1644$ (C=N), 3275 (NH). ^{1}H NMR ($CDCl_3$) (ppm): $\delta = 7.02$–7.21 (m, 2H, H_6, H_8), 7.85 (td, 1H, H_7, $J = 7.9$, 2.2 Hz), 7.92 (dd, 1H, H_5, $J = 8.7$, 2.2 Hz), 7.10–7.35 (m, 5H, H_{Ph}), 8.15 (s, 1H, H_4), 8.60 (br, 1H, NH). ^{13}C NMR ($CDCl_3$) (ppm): $\delta = 156.9$ (C_2), 128.9 (C_3), 138.6 (C_4), 129.2 (C_5), 123.6 (C_6), 132.4 (C_7), 116.1 (C_8), 151.0 (C_9), 119.3 (C_{10}), 125.8, 127.9, 128.2, 129.4 (C_{Ph}). Mp (°C) = 105. Calculated for $C_{15}H_{11}NO$: C, 81.44; H, 4.97; N, 6.33. Found: C, 81.52; H 5.01; N 6.44.

3-(*p*-nitrophenyl)iminocoumarin (2). IR (KBr) (cm^{-1}): $\nu = 1651$ (C=N), 3297 (NH). ^{1}H NMR (DMSO-d_6) (ppm): $\delta = 6.91$–7.20 (m, 2H, H_6, H_8), 7.45 (td, 1H, H_7, $J = 8.7$, 2.1 Hz), 7.58 (dd, 1H, H_5, $J = 8.4$, 2.1 Hz), 7.93 (d, 2H, $H_{2'p\text{-}NO2Ph}$, $J = 8.9$ Hz), 8.32 (d, 2H, $H_{3'p\text{-}NO2Ph}$, $J = 8.9$ Hz), 8.23 (s, 1H, H_4), 8.58 (br, 1H, NH). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 157.7$ (C_2), 127.2 (C_3), 140.8 (C_4), 128.4 (C_5), 124.8 (C_6), 133.7 (C_7), 119.7 (C_8), 153.5 (C_9), 116.6 (C_{10}), 108.0, 120.8, 130.5, 147.6 ($C_{p\text{-}NO2Ph}$). Mp (°C) = 182. Calculated for $C_{15}H_{10}N_2O_3$: C, 67.67; H, 3.76, N, 10.53. Found: C, 67.73, H, 3.81; N, 10.49.

3-(2-Thiophenyl)iminocoumarin (3). IR (KBr) (cm^{-1}): $\nu = 1649$ (C=N), 3276 (NH). ^{1}H NMR (DMSO-d_6) (ppm): $\delta = 7.04$–7.18 (m, 2H, H_6, H_8), 7.72 (td, 1H, H_7, $J = 8.1$, 2.2 Hz), 7.90 (dd, 1H, H_5, $J = 8.5$, 2.2 Hz), 6.98 (dd, 1H, $H_{4'Th}$, $J = 3.7$, 4.9 Hz), 7.29 (dd, 1H, $H_{3'Th}$, $J = 3.7$, 0.9 Hz), 7.45 (dd, 1H, $H_{5'Th}$, $J = 4.9$, 0.9 Hz), 8.12 (s, 1H, H_4), 8.60 (br, 1H, NH). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 158.4$ (C_2), 130.9 (C_3), 137.8 (C_4), 128.0 (C_5), 127.2 (C_6), 136.9 (C_7), 119.8 (C_8), 152.6 (C_9), 115.3 (C_{10}), 123.7, 127.6, 130.4, 137.3 (C_{Th}). Mp (°C) = 80. Calculated for $C_{13}H_9NOS$: C, 68.72, H, 3.96, N, 6.16. Found: C, 68.60; H, 3.87; N, 6.25.

Synthesis of Bis-Iminocoumarins

Diacid chloride (1.8 mmol) was slowly dropped into to a stirred mixture of iminocoumarin (3 mmol) in 25 ml of chloroform, containing 3 mmol of pyridine at 0 °C. The mixture was stirred for 5 h at room temperature. A white solid was precipitated from the reaction mixture and collected by filtration. The solid phase was recrystallized from toluene (compound **1a**– **1e, 2b**–**2e**) or from ethyl acetate (compounds **1f, 1g, 2f, 2g, 3c–3f**).



Ar: Ph, p-NO_2Ph, Th A: $(CH_2)_0$, $(CH_2)_1$, $(CH_2)_2$, $(CH_2)_4$, $(CH_2)_8$, p-Ph, o-Ph

Bis-iminocoumarin (1a). IR (KBr) (cm^{-1}): $\nu = 1633$ (C=N), 1703 (C=O). ^1H NMR ($CDCl_3$) (ppm): $\delta = 7.06$–7.30 (m, 4H, H_6, H_8), 7.46 (td, 2H, H_7, $J = 8.1$, 2.1 Hz), 7.55 (dd, 2H, H_5, $J = 8.7$, 2.1 Hz), 7.62–7.70 (m, 10H, H_{Ph}), 8.26 (s, 2H, H_4). ^{13}C NMR ($CDCl_3$) (ppm): $\delta = 161.4$ (C_2), 127.6 (C_3), 139.8 (C_4), 128.7 (C_5), 124.2 (C_6), 132.4 (C_7), 119.4 (C_8), 154.3 (C_9), 115.5 (C_{10}), 171.5 (C=O), 125.8, 126.1, 127.3, 129.4 (C_{Ph}). Mp (°C) = 185. Calculated for $C_{32}H_{20}N_2O_4$: C, 77.42; H, 4.03; N, 5.64. Found: C, 77.57; H, 3.95, N, 5.74.

Bis-iminocoumarin (1b). IR (KBr) (cm^{-1}): $\nu = 1665$ (C=N), 1713 (C=O). ^1H NMR ($CDCl_3$) (ppm): $\delta = 3.33$ (s, 2H, CH_2), 7.02–7.20 (m, 4H, H_6, H_8), 7.68 (td, 2H, H_7, $J = 7.8$, 2.3 Hz), 7.71 (dd, 2H, H_5, $J = 8.4$, 2.3 Hz), 7.36–7.56 (m, 10H, H_{Ph}), 8.26 (s, 2H, H_4). ^{13}C NMR ($CDCl_3$) (ppm): $\delta = 155.6$ (C_2), 128.3 (C_3), 141.2 (C_4), 128.5 (C_5), 125.7 (C_6), 133.0 (C_7), 117.9 (C_8), 151.5 (C_9), 113.2 (C_{10}), 169.1 (C=O), 125.1, 126.3, 127.8, 129.3 (C_{Ph}), 59.2 (CH_2). Mp (°C) = 130. Calculated for $C_{33}H_{22}N_2O_4$: C, 77.64; H, 4.31; N, 5.49. Found: C, 77.72; H, 4.25; N, 5.60.

Bis-iminocoumarin (1c). IR (KBr) (cm^{-1}): $\nu = 1671$ (C=N), 1712 (C=O). ^1H NMR ($CDCl_3$) (ppm): $\delta = 3.02$ (s, 4H, $2 \times CH_2$), 7.00–7.23 (m, 4H, H_6, H_8), 7.53 (td, 2H, H_7, $J = 8.2$, 2.4 Hz), 7.64 (dd, 2H, H_5, $J = 8.7$, 2.4 Hz), 7.29–7.47 (m, 10H, H_{Ph}), 8.20 (s, 2H, H_4). ^{13}C NMR ($CDCl_3$) (ppm): $\delta = 161.8$ (C_2), 128.5 (C_3), 140.6 (C_4), 128.2 (C_5), 124.9 (C_6), 132.3 (C_7), 119.0 (C_8), 152.4 (C_9), 117.9 (C_{10}), 172.3 (C=O), 125.4, 126.9, 127.8, 128.9 (C_{Ph}), 48.1 (CH_2). Mp (°C) = 210. Calculated for $C_{34}H_{24}N_2O_4$: C, 77.86; H, 4.58; N, 5.34. Found: C, 77.95; H, 4.55; N, 5.27.

Bis-iminocoumarin (1d). IR (KBr) (cm^{-1}): $\nu = 1655$ (C=N), 1710 (C=O). ^1H NMR (DMSO-d_6) (ppm): $\delta = 1.44$ (t, 4H, $2 \times CH_2$, $J = 8.6$ Hz), 1.99 (t, 4H, $2 \times CH_2$, $J = 8.6$ Hz), 6.69–7.09 (m, 4H, H_6, H_8), 7.64 (td, 2H, H_7, $J = 8.2$, 2.5 Hz), 7.71 (dd, 2H, H_5, $J = 8.4$, 2.5 Hz), 7.14–7.44 (m, 10H, H_{Ph}), 8.24 (s, 2H, H_4). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 158.9$ (C_2), 127.9 (C_3), 142.1 (C_4), 127.7 (C_5), 125.3 (C_6), 131.8 (C_7), 118.4 (C_8), 155.0 (C_9), 116.7 (C_{10}), 170.2 (C=O), 125.1, 127.1, 128.6, 129.2 (C_{Ph}), 24.2 (CH_2), 34.5 (CH_2). Mp (°C) = 162. Calculated for $C_{36}H_{28}N_2O_4$: C, 78.26; H, 5.07; N, 5.07. Found: C, 78.32; H, 5.13; N, 5.17.

Bis-iminocoumarin (1e). IR (KBr) (cm^{-1}): $\nu = 1648$ (C=N), 1700 (C=O). ^1H NMR (DMSO-d_6) (ppm): $\delta = 1.20$ (m, 8H, $4 \times CH_2$), 1.44 (m, 4H, $2 \times CH_2$), 2.00 (t, 2H, CH_2, $J = 7.2$ Hz), 2.15 (t, 2H, CH_2, $J = 7.5$ Hz), 7.24–7.44 (m, 14H, H_6, H_8, H_{Ph}), 7.59 (td, 2H, H_7, $J = 8.4$, 1.2 Hz), 7.76 (dd, 2H, H_5, $J = 7.5$, 1.2 Hz), 8.23 (s, 2H, H_4). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 159.4$ (C_2), 128.1 (C_3), 143.1 (C_4), 127.9 (C_5), 124.8 (C_6), 132.1 (C_7), 119.1 (C_8), 154.5 (C_9), 115.8 (C_{10}), 172.0 (C=O), 125.4, 126.8, 127.4, 129.7 (C_{Ph}), 24.1 (CH_2), 28.3 (CH_2), 29.9 (CH_2), 34.1 (CH_2). Mp (°C) = 70. Calculated for $C_{40}H_{36}N_2O_4$: C, 78.94; H, 5.92; N, 4.60. Found: C, 78.85; H, 6.03; N, 4.69.

Bis-iminocoumarin (1f). IR (KBr) (cm^{-1}): $\nu = 1673$ (C=N), 1722 (C=O). ^1H NMR (DMSO-d_6) (ppm): $\delta = 7.00$–7.18 (m, 4H, H_6, H_8), 7.50 (td, 2H, H_7, $J = 8.2$, 1.8 Hz), 7.65 (dd, 2H, H_5, $J = 7.2$, 1.8 Hz), 7.30–7.46 (m, 10H, H_{Ph}), 8.21 (s, 2H, H_4), 7.92 (s, 4H, $H_{p\text{-}Ph}$). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 164.1$ (C_2), 128.2 (C_3), 141.8 (C_4), 127.5 (C_5), 124.9 (C_6), 134.3 (C_7), 119.2 (C_8), 158.3 (C_9), 116.4 (C_{10}), 173.5 (C=O), 125.3, 127.4, 128.3, 129.4 (C_{Ph}), 127.9, 133.4 ($C_{p\text{-}Ph}$).

Mp (°C) = 230. Calculated for $C_{38}H_{24}N_2O_4$: C, 79.72; H, 4.20; N, 4.89. Found: C, 79.63; H, 4.30; N, 4.78.

Bis-iminocoumarin (1g). IR (KBr) (cm^{-1}): $\nu = 1662$ (C=N), 1720 (C=O).^{1}H NMR (DMSO-d_6) (ppm): $\delta = 7.21$–7.49 (m, 14H, H_6, H_8, H_{Ph}), 7.55 (td, 2H, H_7, $J = 9.1$, 2.4 Hz), 7.82 (dd, 2H, H_5, $J = 8.5$, 2.4 Hz), 8.01 (s, 2H, H_4), 7.61–7.73 (m, 4H, $H_{o\text{-}Ph}$). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 168.7$ (C_2), 128.4 (C_3), 140.1 (C_4), 127.7 (C_5), 124.2 (C_6), 134.8 (C_7), 118.9 (C_8), 155.6 (C_9), 115.7 (C_{10}), 172.1 (C=O), 125.5, 127.7, 128.6, 129.7 (C_{Ph}), 130.2, 133.5, 134.9 ($C_{o\text{-}Ph}$). Mp (°C) = 179. Calculated for $C_{38}H_{24}N_2O_4$: C, 79.72; H, 4.20; N, 4.89. Found: C, 79.60; H, 4.31; N, 4.75.

Bis-iminocoumarin (2b). IR (KBr) (cm^{-1}): $\nu = 1652$ (C=N), 1709 (C=O). ^{1}H NMR (DMSO-d_6) (ppm): $\delta = 3.40$ (s, 2H, CH_2), 7.00–7.22 (m, 4H, H_6, H_8), 7.58 (td, 2H, H_7, $J = 9.2$, 2.0 Hz), 7.76 (dd, 2H, H_5, $J = 8.4$, 2.0 Hz), 7.83 (d, 4H, $H_{2'p\text{-}NO2Ph}$, $J = 9.0$ Hz), 8.38 (d, 4H, $H_{3'p\text{-}NO2Ph}$, $J = 9.0$ Hz), 8.30 (s, 2H, H_4). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 159.3$ (C_2), 128.1 (C_3), 142.5 (C_4), 128.3 (C_5), 125.9 (C_6), 134.6 (C_7), 119.6 (C_8), 154.2 (C_9), 116.4 (C_{10}), 172.0 (C=O), 109.5, 122.4, 131.5, 146.9 ($C_{p\text{-}NO2Ph}$), 57.3 (CH_2). Mp (°C) = 145. Calculated for $C_{33}H_{20}N_4O_8$: C, 66.00; H, 3.33; N, 9.33. Found: C, 66.11; H, 3.25; N, 9.44.

Bis-iminocoumarin (2c). IR (KBr) (cm^{-1}): $\nu = 1641$ (C=N), 1716 (C=O). ^{1}H NMR (DMSO-d_6) (ppm): $\delta = 2.96$ (s, 4H, $2 \times CH_2$), 7.09–7.19 (m, 4H, H_6, H_8), 7.63 (td, 2H, H_7, $J = 8.1$, 1.8 Hz), 7.75 (dd, 2H, H_5, $J = 8.4$, 1.8 Hz), 7.42 (d, 4H, $H_{2'p\text{-}NO2Ph}$, $J = 9.0$ Hz), 8.16 (d, 4H, $H_{3'p\text{-}NO2Ph}$, $J = 9.0$ Hz), 8.21(s, 2H, H_4). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 161.3$ (C_2), 128.4 (C_3), 141.9 (C_4), 128.9 (C_5), 125.1 (C_6), 134.0 (C_7), 119.2 (C_8), 152.7 (C_9), 117.5 (C_{10}), 173.1 (C=O), 108.1, 121.6, 133.0, 141.2 ($C_{p\text{-}NO2Ph}$), 48.0 (CH_2). Mp (°C) = 222. Calculated for $C_{34}H_{22}N_4O_8$: C, 66.45; H, 3.58; N, 9.12. Found: C, 66.57; H, 3.75; N, 9.28.

Bis-iminocoumarin (2d). IR (KBr) (cm^{-1}): $\nu = 1650$ (C=N), 1713 (C=O). ^{1}H NMR (DMSO-d_6) (ppm): $\delta = 1.40$ (t, 4H, $2 \times CH_2$, $J = 9.2$ Hz), 2.01 (t, 4H, $2 \times CH_2$, $J = 9.2$ Hz), 6.98–7.19 (m, 4H, H_6, H_8), 7.48 (td, 2H, H_7, $J = 9.2$, 2.0 Hz), 7.69 (dd, 2H, H_5, $J = 8.4$, 2.0 Hz), 7.51 (d, 4H, $H_{2'p\text{-}NO2Ph}$, $J = 7.8$ Hz), 8.11 (d, 4H, $H_{3'p\text{-}NO2Ph}$, $J = 7.8$ Hz), 8.20(s, 2H, H_4). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 155.5$ (C_2), 127.2 (C_3), 142.3 (C_4), 127.5 (C_5), 124.2 (C_6), 133.3 (C_7), 119.2 (C_8), 151.0 (C_9), 115.1 (C_{10}), 173.4 (C=O), 108.2, 120.4, 132.1, 144.9 ($C_{p\text{-}NO2Ph}$), 24.6 (CH_2), 34.7 (CH_2). Mp (°C) = 173. Calculated for $C_{36}H_{26}N_4O_8$: C, 67.29; H, 4.05; N, 8.72. Found: C, 67.40; H, 4.11; N, 8.82.

Bis-iminocoumarin (2e). IR (KBr) (cm^{-1}): $\nu = 1650$ (C=N), 1708 (C=O). ^{1}H NMR (DMSO-d_6) (ppm): $\delta = 1.22$ (m, 8H, $4 \times CH_2$), 1.51 (m, 4H, $2 \times CH_2$), 2.09 (t, 2H, CH_2, J = 7.4 Hz), 2.16 (t, 2H, CH_2, J = 7.2 Hz), 7.01–7.20 (m, 4H, H_6, H_8), 7.55 (td, 2H, H_7, $J = 8.9$, 2.2 Hz), 7.64 (dd, 2H, H_5, $J = 8.3$, 2.2 Hz), 7.72 (d, 4H, $H_{2'p\text{-}NO2Ph}$, $J = 7.8$ Hz), 8.13 (d, 4H, $H_{3'p\text{-}NO2Ph}$, $J = 7.8$ Hz), 8.20 (s, 2H, H_4). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 159.3$ (C_2), 127.0 (C_3), 141.9 (C_4), 127.4 (C_5), 124.7 (C_6), 134.2 (C_7), 118.4 (C_8), 153.4 (C_9), 116.8 (C_{10}), 171.3 (C=O), 109.8, 121.5, 133.5, 145.6 ($C_{p\text{-}NO2Ph}$), 24.3 (CH_2), 29.0 (CH_2), 30.2 (CH_2), 35.2 (CH_2). Calculated for $C_{40}H_{34}N_4O_8$: C, 68.76; H, 4.87; N, 8.02. Found: C, 68.65; H, 5.00; N, 8.10.

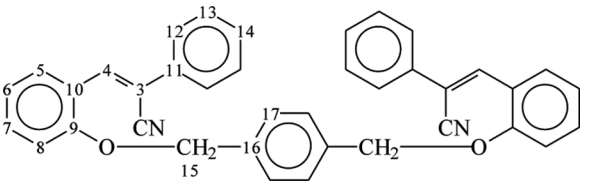
Bis-iminocoumarin (2g). IR (KBr) (cm^{-1}): $\nu = 1654$ (C=N), 1725 (C=O). ^1H NMR (DMSO-d_6) (ppm): $\delta = 7.12$–7.20 (m, 4H, H_6, H_8), 7.51 (td, 2H, H_7, $J = 7.2$, 2.0 Hz), 7.77 (dd, 2H, H_5, $J = 8.1$, 2.0 Hz), 7.66 (d, 4H, $H_{2'p\text{-}NO2Ph}$, $J = 9.3$ Hz), 8.27 (d, 4H, $H_{3'p\text{-}NO2Ph}$, $J = 9.3$ Hz), 8.19 (s, 1H, H_4), 7.54–7.62 (m, 4H, $H_{o\text{-}Ph}$). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 163.4$ (C_2), 128.1 (C_3), 142.5 (C_4), 127.1 (C_5), 124.6 (C_6), 135.8 (C_7), 117.2 (C_8), 153.6 (C_9), 113.9 (C_{10}), 170.9 (C=O), 108.8, 122.1, 130.5, 142.6 ($C_{p\text{-}NO2Ph}$), 131.2, 134.5, 135.2 ($C_{o\text{-}Ph}$). Mp (°C) = 186. Calculated for $C_{38}H_{22}N_4O_8$: C, 68.88; H, 3.32; N, 8.46. Found: C, 68.99; H, 3.21; N, 8.55.

Bis-iminocoumarin (3c). IR (KBr) (cm^{-1}): $\nu = 1664$ (C=N), 1710 (C=O). ^1H NMR (DMSO-d_6) (ppm): $\delta = 2.86$ (s, 4H, $2 \times CH_2$), 7.01–7.21 (m, 4H, H_6, H_8), 7.65 (td, 2H, H_7, $J = 9.1$, 2.0 Hz), 7.94 (dd, 2H, H_5, $J = 8.7$, 2.0 Hz), 6.91 (dd, 2H, $H_{4'Th}$, $J = 4.1$, 5.6 Hz), 7.32 (dd, 2H, $H_{3'Th}$, $J = 4.1$, 1.2 Hz), 7.49 (dd, 2H, $H_{5'Th}$, $J = 5.6$, 1.2 Hz), 8.22 (s, 2H, H_4). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 161.8$ (C_2), 130.8 (C_3), 137.8 (C_4), 128.3 (C_5), 127.2 (C_6), 137.5 (C_7), 119.2 (C_8), 152.6 (C_9), 115.7 (C_{10}), 170.9 (C=O), 123.9, 127.5, 131.9, 138.3 (C_{Th}), 49.9 (CH_2). Mp (°C) = 214. Calculated for $C_{30}H_{20}N_2O_4S_2$: C, 67.16; H, 3.73; N, 5.22. Found: C, 67.25; H, 3.65; N, 5.33.

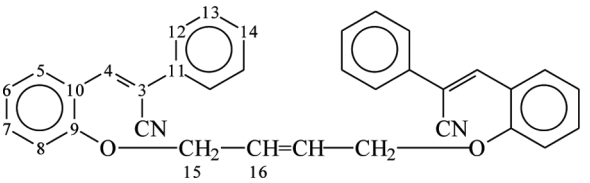
Bis-iminocoumarin (3d). IR (KBr) (cm^{-1}): $\nu = 1647$ (C=N), 1716 (C=O). ^1H NMR (DMSO-d_6) (ppm): $\delta = 1.42$ (t, 4H, $2 \times CH_2$, $J = 7.9$ Hz), 2.08 (t, 4H, $2 \times CH_2$, $J = 7.9$ Hz), 6.94–7.21 (m, 4H, H_6, H_8), 7.61 (td, 2H, H_7, $J = 9.3$, 2.4 Hz), 7.82 (dd, 2H, H_5, $J = 8.7$, 2.4 Hz), 6.83 (dd, 2H, $H_{4'Th}$, $J = 3.7$, 5.7 Hz), 7.32 (dd, 2H, $H_{3'Th}$, $J = 3.7$, 1.1 Hz), 7.52 (dd, 2H, $H_{5'Th}$, $J = 5.7$, 1.1 Hz), 8.19 (s, 2H, H_4). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 162.4$ (C_2), 131.5 (C_3), 147.7 (C_4), 127.4 (C_5), 126.1 (C_6), 130.6 (C_7), 119.8 (C_8), 153.1 (C_9), 117.0 (C_{10}), 172.4 (C=O), 124.3, 127.7, 132.5, 139.0 (C_{Th}), 24.1 (CH_2), 37.2 (CH_2). Mp (°C) = 170. Calculated for $C_{32}H_{24}N_2O_4S_2$: C, 68.08; H, 4.26; N, 4.96. Found: C, 68.24; H, 4.40; N, 5.13.

Bis-iminocoumarin (3e). IR (KBr) (cm^{-1}): $\nu = 1650$ (C=N), 1712 (C=O). ^1H NMR (DMSO-d_6) (ppm): $\delta = 1.28$ (m, 8H, $4 \times CH_2$), 1.63 (m, 4H, $2 \times CH_2$), 2.11 (t, 2H, CH_2 J = 9.4 Hz), 2.27 (t, 2H, CH_2 J = 8.5 Hz), 7.20–7.29 (m, 4H, H_6, H_8), 7.33 (td, 2H, H_7, $J = 9.3$, 2.4 Hz), 7.72 (dd, 2H, H_5, $J = 8.7$, 2.4 Hz), 7.11 (dd, 2H, $H_{4'Th}$, $J = 3.7$, 5.7 Hz), 7.41 (dd, 2H, $H_{3'Th}$, $J = 3.7$, 1.1 Hz), 7.59 (dd, 2H, $H_{5'Th}$, $J = 5.7$, 1.1 Hz), 8.20 (s, 1H, H_4). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 159.4$ (C_2), 133.4 (C_3), 147.8 (C_4), 127.5 (C_5), 126.7 (C_6), 130.9 (C_7), 119.2 (C_8), 151.2 (C_9), 117.4 (C_{10}), 170.2 (C=O), 125.1, 126.4, 132.1, 138.7 (C_{Th}), 24.1 (CH_2), 28.8 (CH_2), 29.5 (CH_2), 34.7 (CH_2). Mp (°C) = 77. Calculated for $C_{36}H_{32}N_2O_4S_2$: C, 69.67; H, 5.16; N, 4.51. Found: C, 69.48; H, 5.10; N, 4.42.

Bis-iminocoumarin (3f). IR (KBr) (cm^{-1}): $\nu = 1670$ (C=N), 1723 (C=O). ^1H NMR (DMSO-d_6) (ppm): $\delta = 7.01$–7.14 (m, 4H, H_6, H_8), 7.36 (td, 2H, H_7, $J = 7.8$, 1.9 Hz), 7.45 (dd, 2H, H_5, $J = 7.3$, 1.9 Hz), 6.86 (dd, 2H, $H_{4'Th}$, $J = 4.2$, 4.8 Hz), 7.36 (dd, 2H, $H_{3'Th}$, $J = 4.2$, 1.3 Hz), 7.58 (dd, 2H, $H_{5'Th}$, $J = 4.8$, 1.3 Hz), 8.22 (s, 2H, H_4), 7.98 (s, 4H, $H_{p\text{-}Ph}$). ^{13}C NMR (DMSO-d_6) (ppm): $\delta = 161.5$ (C_2), 128.9 (C_3), 143.2 (C_4), 127.3 (C_5), 124.2 (C_6), 134.7 (C_7), 119.0 (C_8), 155.1 (C_9), 115.9 (C_{10}), 172.4 (C=O), 125.1, 128.2, 131.5, 139.2 (C_{Th}), 127.6, 134.3 ($C_{p\text{-}Ph}$). Mp (°C) = 222. Calculated for $C_{34}H_{20}N_2O_4S_2$: C, 69.86; H, 3.42; N, 4.79. Found: C, 69.74; H, 3.55; N, 4.60.



Compound (1h). Yield 45%. IR (KBr) (cm^{-1}): $\nu = 1590$ (C=C), 2200 (C≡N). ^1H NMR ($CDCl_3$) (ppm): $\delta = 5.16$ (s, 4H, H_{15}), 6.98 (dd, 2H, H_8, $J = 8.3$, 1.9 Hz), 7.08 (td, 2H, H_{14}, $J = 8.9$, 2.2 Hz), 7.27–7.34 (m, 10H, $H_{6;}H_{12;}H_{13}$), 7.42 (s, 4H, H_{17}), 7.65 (td, 2H, H_7, $J = 8.3$, 1.7 Hz), 8.00 (s, 2H, H_4), 8.17 (dd, 2H, H_5, $J = 7.7$, 1.7 Hz).^{13}C NMR ($CDCl_3$) (ppm): $\delta = 118.0$ (C≡N), 121.4 (C_3), 137.3 (C_4), 131.8 (C_5), 121.3 (C_6), 136.4 (C_7), 112.4 (C_8), 156.9 (C_9), 111.9 (C_{10}), 123.5, 126.0, 128.7, 128.9 ($C_{11\text{-}14}$), 70.3 (C_{15}), 134.6 (C_{16}), 127.5 (C_{17}). Mp (°C) = 183. MS m/z: 544 (4), 324 (45), 220 (100), 104 (80). Calculated for $C_{38}H_{28}N_2O_2$: C, 83.82; H, 5.15; N, 5.15. Found: C, 83.92; H, 5.06; N, 5.26.



Compound (1i). Yield 38%. IR (KBr) (cm^{-1}): $\nu = 1610$ (C=C), 2209 (C≡N). ^1H NMR ($CDCl_3$) (ppm): $\delta = 4.87$ (d, 4H, H_{15}, $J = 7.5$), 6.22 (t, 2H, H_{16}, $J = 7.5$), 7.02 (dd, 2H, H_8, $J = 8.7$, 2.1 Hz), 7.11 (td, 2H, H_{14}, $J = 9.1$, 2.4 Hz), 7.35-7.54 (m, 10H, $H_{6;}H_{12;}H_{13}$), 7.70 (td, 2H, H_7, $J = 8.7$, 1.9 Hz), 8.10 (s, 2H, H_4), 8.15 (dd, 2H, H_5, $J = 7.9$, 1.9 Hz). ^{13}C NMR ($CDCl_3$) (ppm): $\delta = 118.5$ (C≡N), 121.4 (C_3), 137.8 (C_4), 136.9 (C_5), 122.0 (C_6), 134.0 (C_7), 112.6 (C_8), 157.5 (C_9), 112.5 (C_{10}), 125.9, 127.3, 128.5, 129.0 ($C_{11\text{-}14}$), 66.8 (C_{15}), 132.1 (C_{16}). Mp (°C) = 145. MS m/z: 494 (4), 258 (53), 220 (100), 143 (76). Calculated for $C_{34}H_{26}N_2O_2$: C, 82.59; H, 5.26; N, 5.67. Found: C, 82.70; H, 5.14; N, 5.60.

ACKNOWLEDGMENT

The authors acknowledge the Ministry of Higher Education, Scientific Research, and Technology in Tunisia for financial support.

REFERENCES

1. Ukhov, S. V.; Kon'shin, M. E.; Novikova, V. V.; Odegova, T. F. Synthesis and antimicrobial activity of silver salts of substituted 2-iminocoumarin-3-carboxylic acid amides. *Pharm. Chem. J.* **2004**, *38*, 186–187.
2. Burke, B. L.; Marquez, V. E.; Li, Z.-H.; Bolen, J. B.; Stefanova, I.; Horak, I. D. Bicyclic compounds as ring-constrained inhibitors of protein-tyrosine kinase p56lck. *J. Med. Chem.* **1993**, *36*(4), 425–432.

3. Srivastava, S. K.; Tripathi, R. P.; Ramachandran, R. NAD^+-dependent DNA ligase (Rv3014c) from mycobacterium tuberculosis crystal structure of the adenylation domain and identification of novel inhibitors. *J. Biol. Chem.* **2005**, *280*, 30273–30281.
4. Karasev, A. A.; Lukatskaya, L. L.; Rubtsov, M. I.; Zhikol, E. K.; Yarmolenko, S. N.; Ponomarev, O. A. Synthesis, protolytic equilibria, and stability of 2-amino-3-(2-benzimidazolyl)-1-benzopyrylium salts in water–alcohol medium. *Russ. J. Gen. Chem.* **1995**, *65*(2), 1416–1425.
5. Huang, S.-T.; Jian, J.-L.; Peng, H.-Z.; Wang, K.-L.; Lin, C.-M.; Huang, C.-H.; Yang, T. C.-K. The synthesis and optical characterization of novel iminocoumarin derivatives. *Dyes Pigm.* **2010**, *86*, 6–14.
6. Syzova, Z. A.; Doroshenko, A. O.; Lukatskaya, L. L.; Rubtsov, M. I.; Karasyov, A. A. Bichromophoric fluorescent dyes with rigid molecular structure: Fluorescence ability regulation by the photoinduced intramolecular electron transfer. *J. Photochem. Photobiol. A* **2004**, *165*, 59–68.
7. Borisov, A. V.; Gorobets, N. Y.; Yermolayev, S. A.; Zhuravel', I. O.; Kovalenko, S. M.; Desenko, S. M. One-pot microwave-assisted synthesis of a benzopyrano[2,3-c]pyrazol-3(2H)-one library. *J. Comb. Chem.* **2007**, *9*, 909–911.
8. O'Callaghan, C. N.; McMurry, T. B. H.; O'Brien, J. E.; Draper, S. M.; Wilcock, D. J. Formation of polyheterocyclic systems by reaction of 2-imino-4-methyl-2H-1-benzopyran-3-carbonitrile with active methylene compounds. *J. Chem. Soc., Perkin Trans. 1* **1996**, 1067–1071.
9. Bilokin, Y. V.; Kovalenko, S. N.; Bylov, I. E.; Chernykh, V. P. Rearrangements of 2-imino-2H-1-benzopyran-3-carboxamides under action of anthranilic acid as N-nucleophile. *Heterocycl. Commun.* **1998**, *4*, 257–260.
10. Borisov, A. V.; Dzhavakhishvili, S. G.; Zhuravel, I. O., Kovalenko, S. M.; Nikitchenko, V. M. Parallel liquid-phase synthesis of benzopyrano[2,3-d]pyrimidine libraries. *J. Comb. Chem.* **2007**, *9*, 5–8.
11. Turki, H.; Abid, S.; Le Bigot, Y.; Fery-Forgues, S.; El Gharbi, R. Novel synthesis of 2-oxo-2H-benzopyrano[2,3-d]pyrimidines. *Synth. Commun.* **2004**, *34*, 3553–3563.
12. Turki, H.; Genestie, B.; El Gharbi, R.; El Boussiry, S.; Banoub, J. Gas-phase fragmentation study of a novel series of synthetic 2-oxo-2*H*-benzopyrano[2,3-*d*]pyrimidine derivatives using electrospray ionization tandem mass spectroscopy measured with a quadrupole orthogonal time-of-flight hybrid instrument. *Rapid Commun. Mass Spectrom.* **2008**, *23*(2), 267–281.
13. Kammoun, M.; Turki, H.; El Gharbi, R.; Fery-Forgues, S. Reactivity of 3-cyano-N-ethoxycarbonyl-iminocoumarin with hydrazides as N-nucleophiles. *J. Heterocycl. Chem.* **2009**, *46*(1), 28–32.
14. Kammoun, M.; Turki, H.; Fery-Forgues, S.; El Gharbi, R. Convenient synthesis of a new series of 3-triazolonyl iminocoumarins. *Synth. Commun.* **2010**, *40*(6), 888–900.
15. Volmajer, J.; Toplak, R.; Lebanb, I.; Le Marechala, A. M. Synthesis of new iminocoumarins and their transformations into N-chloro and hydrazono compounds. *Tetrahedron* **2005**, *61*, 7012–7021.
16. Gorobets, N. Yu.; Abakumov, V. V.; Borisov, A. V.; Nikitchenko, V. M. Novel aspects of the reaction of 3-(benzimidazol-2-yl)-2-iminocoumarins with aromatic aldehydes. *Chem. Heterocycl. Comp.* **2004**, *40*(3), 334–342.
17. Fadda, A. A.; Zeimaty, M. T.; Gerges, M. M.; Refat, H. M.; Biehl, E. R. Base-catalyzed condensation of malononitrile and 2-hydroxy-1-naphtaldehyde with diffrent ketones. *Heterocycles* **1996**, *43*, 23.
18. Turki, H.; Abid, S.; Fery-Forgues, S.; El Gharbi, R. Optical properties of new fluorescent iminocoumarins: Part 1. *Dyes Pigm.* **2007**, *73*, 311–316.

19. Turki, H.; Abid, S.; Gharbi, R.; Fery-Forgues, S. Optical properties of new fluorescent iminocoumarins, part 2: Solvatochromic study and comparison with the corresponding coumarin. *C. R. Chimie* **2006**, *9*, 1252–1259.
20. Fakhfakh, M.; Turki, H.; Abid, S.; El Gharbi, R.; Fery-Forgues, S. Preparation and optical properties of new fluorescent iminocoumarins: Study of *N*-acyl-derivatives. *J. Photochem. Photobiol. A* **2007**, *185*, 13–18.
21. Fakhfakh, M.; Turki, H.; Fery-Forgues, S.; El Gharbi, R. The synthesis and optical properties of novel fluorescent iminocoumarins and bis-iminocoumarins: Investigations in the series of urea derivatives. *Dyes Pigm.* **2010**, *84*, 108–113.
22. Benmaktouf, L.; Ammar, H.; Le Bigot, Y. Abid, S. Synthesis of new iminocoumarins bearing parabanic moieties. *Synth. Commun.* **2011**, *41*, 1017–1026.
23. Khan, K. M.; Iqbal, S.; Lodhi, M. A.; Maharvi, G. M.; Ullah, Z.; Choudhary, M. I.; Atta-ur-R; Perveen, S. Biscoumarin: New class of urease inhibitors: Economical synthesis and activity. *Bioorgan. Med. Chem.* **2004**, *12*, 1963–1968.
24. Nagashima, R.; Levy, G.; Sarcione, E. J. Comparative pharmacokinetics of coumarin anticoagulants III: Factors affecting the distribution and elimination of bishydroxycoumarin (BHC) in isolated liver perfusion studies. *J. Pharmaceut. Sci.* **1968**, *57*, 1881–1888.
25. Mercep, M.; Malvar, I.; Hrvacic, B.; Markovic, S.; Filipovic-Sucic, A.; Bosnjak, B.; Cempuh-Klonkay, A.; Rupcic, R.; Hutinec, A.; Elenkov, I. J.; Mesic, M. Bis-(coumarin) componds with anti-inflammatory activity. WO patent 2006111858, **2006**.
26. Romeo, A.; Prosdocimi, M. New coumarin derivatives. WO patent 9222545, **1992**.
27. Kostova, I.; Momekov, G. New zirconium(IV) complexes of coumarins with cytotoxic activity. *Eur. J. Med. Chem.* **2006**, *41*, 717–726.
28. Ammar, H.; Fery-Forgues, S.; El Gharbi, R. UV/vis absorption and fluorescence spectroscopic study of novel symmetrical biscoumarin dyes. *Dyes Pigm.* **2003**, *57*, 259–265.
29. Ammar, H.; Abid, S.; Fery-Forgues, S. Synthesis and spectroscopic study of new biscoumarin dyes based on 7-(4-methylcoumarinyl) diesters. *Dyes Pigm.* **2008**, *78*, 1–7.
30. Asimov, M. M.; Nikitchenko, V. M.; Novikov, A. I.; Rubinov, A. N.; Bor, Z.; Gati, L. New high-efficiency biscoumarin laser dyes. *Chem. Physics Lett.* **1988**, *149*(2), 140–144.
31. Ammar, H.; Le Bigot Y.; El Gharbi R. Synthèse des biscoumarines en milieu biphasique solide/liquide 1: Condensation de l'aldéhyde salicilique avec le m-phénylène diacétonitrile. *J. Soc. Chim. Tunisie* **2001**, *4*(9), 915–923.
32. Ammar, H.; Le Bigot, Y.; El Gharbi, R. Synthèse des biscoumarines en milieu biphasique solide/liquide 2: Application de la réaction de Knoevenagel à l'obtention de 3,3′-phénylènebiscoumarines. *J. Soc. Chim. Tunisie* **2001**, *4*(10), 1239–1244.
33. Ammar, H.; Fakhfakh, M.; Le Bigot, Y.; El Gharbi, R. Synthesis of new bis-iminocoumarins by Schmidt reaction catalyzed by ion-exchange resins. *Synth. Commun.* **2003**, *33*(11), 1821–1828.