Novel bithienyl-benzimidazoles: one-pot synthesis and optical and solvatochromic studies

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Abstract: Novel bithienyl-benzimidazoles were synthesised in good to excellent yields, by a one-step reaction via $Na_2S_2O_4$ reduction of *o*-nitroaniline in the presence of formyl-bithiophenes. Using this simple and versatile method, benzimidazoles were directly obtained from several *o*-nitroanilines and aldehydes, *via* a reductive cyclization without purification of any intermediate. Evaluation of the optical and solvatochromic properties of these compounds was carried out.

Keywords: Bithiophenes; Benzimidazoles; UV-visible spectroscopy; Solvatochromism ; Fluorescence

1. Introduction

During the last decades, the design and synthesis of new organic push-pull systems with application on the fields of optoelectronics and photonics has been the target of intense research. It has also been demonstrated that these organic materials have many advantages in comparison to the inorganic ones, such as readily polarizable structure, versatility of synthesis, facile property tuning, well-defined structure, chemical and thermal stability, possibility for additional modification and ease to incorporate into electronic devices.[1] The typical design of these organic push-pull systems consists in to end-cap a suitable conjugated bridge with donor (D) and acceptor (A) substituents.

Benz-X-azoles are a group of heterocyclic compounds which have been applied in numerous aspects of science and technology. As a result of their interesting electronic and optical properties when incorporated in push-pull systems, these heterocycles found application as solvatochromic and fluorescent probes, chemosensors, organic light emitting diodes (OLEDs) and non-linear optical (NLO) chromophores.[2]

In the last decade, our research group has reported experimental and theoretical results regarding the auxiliary donor/acceptor effect of electron deficient benz-X-azole derivatives in push-pull systems.[2a, 2b, 2e, 2f, 2h-j] In this work we describe the synthesis, UV-visible absorption, and fluorescence and solvatochromic studies of a series of heterocyclic chromophores of the benzimidazole type. These new bithienyl-benzimidazoles were synthesised in good to excellent yields, by metal-free one-step reaction

of *o*-nitroanilines in the presence of formyl-bithiophenes, *via* a reductive cyclization, and their optical and solvatochromic properties were evaluated in solvents of different character.

2. Experimental

2.1. General

Reaction progress was monitored by thin layer chromatography (0.25 mm thick precoated silica plates: Merck Fertigplatten Kieselgel 60 F254), while purification was effected by silica gel column chromatography (Merck Kieselgel 60; 230-400 mesh). NMR spectra were obtained on a Varian Unity Plus Spectrometer at an operating frequency of 300 MHz for ^{1}H and 75.4 MHz for ^{13}C NMR using the solvent peak as internal reference. The solvents are indicated in parenthesis before the chemical shift values (δ relative to TMS and given in ppm). Mps were determined on a Gallenkamp apparatus and are uncorrected. Infrared spectra were recorded on a BOMEM MB 104 spectrophotometer. UV-vis absorption spectra (200–800 nm) were obtained using a Shimadzu UV/2501PC spectrophotometer. Fluorescence spectra were collected using a Spex Fluorolog 1680 spectrometer. Mass spectrometry analyses were performed at the "C.A.C.T.I. -Unidad de Espectrometria de Masas" at the University of Vigo, Spain. Formylated bithiophenes **1a-c** were synthesized by us and described elsewhere.[3] All the solvents were of spectrophotometrical grade. *o*-Nitroaniline and other chemicals was purchased from Aldrich and Acros and used as received.

2.2. General procedure for the synthesis of benzimidazoles 3

A solution of formylbitiophenes **1a-c** (0.106 mmol) and *o*-nitroaniline (0.106 mmol) in DMSO (1 mL) was treated with aqueous $Na_2S_2O_4$ (55.4 mg; 0,318 mmol) and was then heated at 100 ºC with stirring for 15 h. The mixture was poured into water (20 mL) and extracted with (3x50 mL) of ethyl acetate. The organic layer was dried with magnesium sulphate and evaporated under reduced pressure to give the crude which were purified by chromatography on silica with increasing amounts of diethyl ether in light petroleum as eluent to give the pure products **3a-c**.

2-(5''-Ethoxy-2',2''-bithienyl)-1H-benzimidazole (**3a**).

Yellow solid (94 %). Mp: 188.9–190.2 ºC. UV-vis (ethanol): λ_{max} nm (ε /M^{-1} cm^{-1}) 377.0 (33,885). IR (KBr) *v* 3078 (NH), 2621 (CH), 1616, 1574, 1506, 1488, 1465, 1420, 1377, 1247, 1225, 1197, 1089, 1046, 933, 744 cm^{-1}. ^{1}H NMR (300 MHz, acetone-d_6) δ 1.43 (t, 3H, J = 7.2 Hz, OCH_2CH_3), 4.23 (q, 2H, J = 7.2 Hz, OCH_2CH_3), 6.31 (d, 1H, J = 4.2 Hz, H-4''), 7.06 (d, 1H, J = 3.9 Hz, H-3''), 7.16 (d, 1H, J = 3.9 Hz, H-3'), 7.20-7.26 (m, 2H, H-5 and H-6), 7.57 (br s, 2H, H-4 and H-7), 7.72 (d, 1H, J = 3.9 Hz, H-4'), 11.90 (s, 1H, NH). ^{13}C NMR (75.4 MHz, acetone-d_6) δ 14.86 (CH_3), 70.21 (OCH_2), 106.41 (C4''), 115.20 (C4 and C7), 123.23 (C5 and C6), 123.44 (C2''), 123.49 (C3''), 123.52 (C3'), 127.70 (C4'),

131.99 (C5'), 132.17 (C3a and C7a), 141.04 (C2'), 147.68 (C2), 166.07 (C5''). MS (EI) m/z (%): 327 (M^++1, 7), 326 (M+, 44), 299 (10), 298 (19), 297 (100), 269 (13), 225 (12). HRMS: (EI) m/z for $C_{17}H_{14}N_2OS_2$; calcd 326.0548; found 326.0546.

2-(5''-N,N-Dimethyl-2',2''-bithienyl)-1H-benzimidazole (**3b**).

Dark red solid (41 %). Mp: 190.1–192.7 °C. UV-vis (ethanol): λ_{max} nm (ε/M^{-1} cm^{-1}) 408.0 (22,033). IR (KBr) *v* 2924 (NH), 2861 (CH), 1728, 1621, 1574, 1510, 1454, 1420, 1272, 1128, 1094, 916, 791, 743 cm^{-1}. ^{1}H NMR (300 MHz, acetone-d_6) δ 3.04 (s, 6H, 2xCH_3), 6.01 (br d, 1H, *J* = 3.6 Hz, H-4''), 7.04 (d, 1H, *J* = 3.6 Hz, H-3''), 7.09 (d, 1H, *J* = 3.9 Hz, H-3'), 7.20–7.25 (m, 2H, H-5 and H-6), 7.54–7.60 (m, 2H, H-4 and H-7), 7.73 (d, 1H, *J* = 4.2 Hz, H-4'). MS (EI) *m/z* (%): 326 (M^++1, 20), 325 (M^+, 100), 310 (53), 277 (7), 269 (9), 225 (11). HRMS: (EI) *m/z* for $C_{17}H_{15}N_3S_2$; calcd 325.0707; found 325.0707.

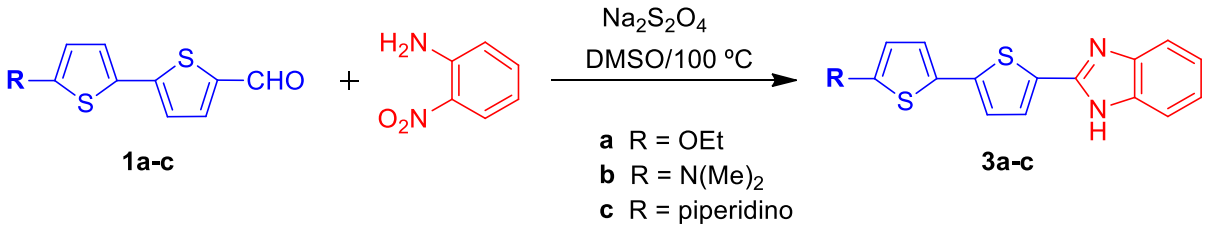
2-(5''-Piperidyl-2',2''-bithienyl)-1H-benzimidazole (**3c**).

Dark red solid (32 %). Mp: 169.8–171.2 °C. UV-vis (ethanol): λ_{max} nm (ε/M^{-1} cm^{-1}) 401.0 (20,150). IR (KBr) *v* 2928 (NH), 2851, 1625, 1574, 1501, 1484, 1445, 1381, 1242, 1124, 1090, 1015, 741 cm^{-1}. ^{1}H NMR (300 MHz, DMSO-d_6) δ 1.61 (m, 6H, *J* = 6.0 Hz, 3xCH_2 piperidino), 3.12 (t, 4H, *J* = 6.0 Hz, 2xCH_2 piperidino), 6.10 (d, 1H, *J* = 4.2 Hz, H-4''), 7.08 (d, 2H, *J* = 3.9 Hz, H-3'' and H-3'), 7.16-7.19 (m, 2H, H-5 and H-6), 7.51 (br s, 2H, H-4 and H-7), 7.66 (d, 1H, *J* = 4.2 Hz, H-4'), 12.87 (s, 1H, N*H*). ^{13}C NMR (75.4 MHz, DMSO-d_6) δ 23.16 (*C*H_2), 24.61 (2x*C*H_2), 51.34 (2x*C*H_2), 104.67 (C4''), 111.30 (C4 and C7), 120.28 (C2''), 121.58 (C3'), 122.14 (C5 and C6), 125.01 (C3''), 127.58 (C4'), 129.34 (C5'), 133.33 (C3a and C7a), 140.23 (C2'), 146.85 (C2), 159.38 (C5''). MS (EI) *m/z* (%): 366 (M^++1, 22), 365 (M^+, 100), 363 (24), 296 (11), 138 (11). HRMS: (EI) *m/z* for $C_{20}H_{19}N_3S_2$; calcd 365.1020; found 365.1021.

3. Results and discussion

3.1. Synthesis

Bithienyl-benzimidazoles **3a-c** were synthesized with different donor groups attached to the bithienyl moiety in order to evaluate the effect of the donor ability of the substituents on the optical properties of the resulting compounds. Therefore, compounds **3a-c** were synthesized by a one-step reaction through the $Na_2S_2O_4$ reduction of *o*-nitroaniline[2j, 4] in the presence of formyl-bithiophenes **1a-c**[3] in DMSO at 100 °C for 15 h (Scheme 1). Thus, the donor-acceptor π-conjugated systems were prepared through metal-free neutral conditions and the synthetic approach involved (*i*) reduction of the *o*-nitroaniline by sodium dithionite, and (*ii*) cyclization of the corresponding diamine using an aldehyde precursor. Under these conditions chromophores **3a-c** were obtained in moderate to excellent yields (32–94 %), and their structures were unambiguously confirmed by their analytical and spectral data (Table 1).



Scheme 1. Synthesis of benzimidazoles **3a-c** by reductive cyclization of *o*-nitroaniline with sodium dithionite in the presence of formyl-bithiophenes **1a-c**.

Table 1. Yields, IR, ^{1}H NMR, UV-vis and fluorescence data of benzimidazoles **3a-c**.

Cpd	R_1	Yield (%)	IR ν (cm^{-1})[a]	δ_H (ppm)	UV-vis[d]		Fluorescence[d]		
					λ_{max} (nm)	ε (M^{-1} cm^{-1})	λ_{emi} (nm)[c]	Stokes' shift (nm)	Φ_F
3a	OEt	94	3078	11.90[b]	374	33,885	460	86	0.93
3b	$N(Me)_2$	41	2924	—	389	22,033	515	126	0.28
3c	piperidino	32	2928	12.87[c]	396	20,150	522	126	0.32

[a] For the NH stretching band for compounds **3a-c** (recorded in KBr).

[b] For the NH of the imidazole moiety in acetone-d_6.

[c] For the NH of the imidazole moiety in DMSO-d_6.

[d] All the UV-vis and fluorescence spectra were recorded in ethanol (10^{-5}– 10^{-6} M solution).

In the ^{1}H NMR spectra of substituted benzimidazoles **3**, signals at about 11.90 and 12.87 ppm were detected for compounds **3a** and **3c**, respectively. These signals were attributed to the NH in the benzimidazole moiety and appeared as a broad singlet. The NH was also identified by IR spectroscopy as a sharp band at about 2924–3078 cm^{-1}.

3.3. Photophysical study of benzimidazoles 3a-c

The UV-vis absorption of 3×10^{-5} M solutions of compounds **3** were measured. Electronic absorption spectra of benzimidazoles **3a-c** in absolute ethanol showed an intense lowest energy charge-transfer absorption band in the UV-visible region (Table 1, Figure 1). The position of this band was strongly influenced by the electronic nature of the electron donor groups (alkoxyl, *N*,*N*-dialkylamino, piperidino) at position 5 of the bithienyl moiety. The high electro-donating character of the substituents lead to a

bathochromic shift in the absorption maxima, as the longest wavelength transition was shifted from 374 nm for **3a** to 396 nm for **3c**.

Fluorescence spectra of 3×10^{-6} M solutions of compounds **3** were measured and emission maxima and fluorescence quantum yields are also reported (Table 1). Emission spectra of compounds **3** were run in degassed absolute ethanol, using 9,10-diphenylanthracene as standard (Φ_F = 0.95 in ethanol). The electronic nature of the donor groups at the bithienyl moiety affected also the position of the emission maxima (λ_{em}), which were shifted from 460 nm for **3a** to 522 nm for **3c**. The compounds were highly emissive, especially **3a** (Φ_F = 0.93), and showed large Stokes' shift (the lowest being 86 nm for **3a** and the highest 126 nm for **3c**). A high Stokes' shift is an interesting characteristic for a fluorescent probe that permits a large spacing between the light inherent to the matrix and the light dispersed by the sample.[5]

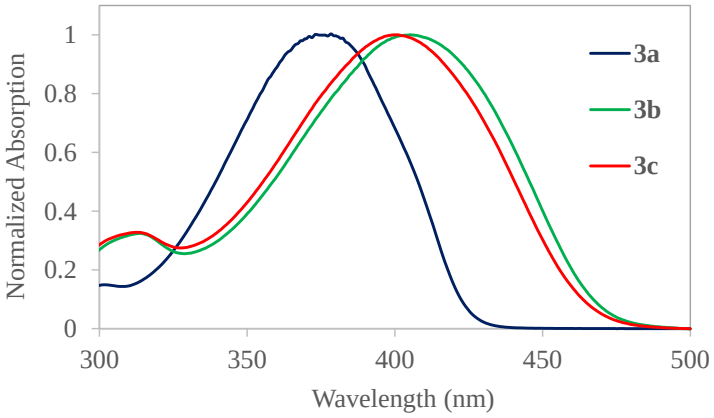


Figure 1. Normalized UV-vis absorption spectra of compounds **3a-c** in dioxane solutions.

3.3. Solvatochromic study

To evaluate the intermolecular forces between the solvents and the solute molecules and in order to determine the best indicator dye, we made a preliminary study of the absorption spectra of compounds **3** in 5 selected solvents of different solvation character (ethanol, dioxane, acetone, chloroform and DMSO). The wavelength maxima λ_{max} and wavenumber maxima ν_{max} of compounds **3** are listed in Table 2 and compared with π^* values for each solvent, determined by Kamlet and Taft.[6] From the results in table 2, it was found that compound **3b** showed the longest shift in wavenumber maxima (ν_{max} = 1953 cm^{-1}), so a full solvatochromic study involving 13 solvents was carried out (Table 3). In general, one may infer that compounds **3a-c** have a positive solvatochromic response, as the highest energy transitions were found with nonpolar solvents and the lower energy transitions were found with more polar solvents such as DMSO. Taking in account the pronounced solvatochromism and the good

correlation with π* values for the 13 solvents investigated, compound **3b** seems to be very adequate to be used as solvent polarity indicating dye.

Table 2. Solvatochromic data [λ_{max} (nm) and ν_{max} (cm^{-1}) of the charge-transfer band] for benzimidazoles **3a-c** in 5 selected solvents with π* values by Kamlet and Taft.[6]

Cpd	**Solvent (π*)**					**$\Delta\nu_{max}$ (cm^{-1})**[a]
	Ethanol (0.54) λ_{max} **(nm)**	**Dioxane (0.55)** λ_{max} **(nm)**	**Acetone (0.71)** λ_{max} **(nm)**	**Chloroform (0.76)** λ_{max} **(nm)**	**DMSO (1.00)** λ_{max} **(nm)**	
3a	374	378	376	379	384	696
3b	389	405	410	416	421	1953
3c	396	400	401	403	408	742

[a] $\Delta\nu_{max} = \nu_{max\ (ethanol)} - \nu_{max\ (DMSO)}$ /cm^{-1}.

Table 3. Solvatochromic data [λ_{max} (nm) and ν_{max} (cm^{-1}) of the charge-transfer band] for benzimidazole **3b** in 13 solvents in comparison with π* values by Kamlet and Taft.[6]

Solvent	**π***[a]	$\lambda_{máx}$ **(nm)**	ν_{max} **(cm^{-1})**
Diethyl ether	0.27	383	26,109
Ethanol	0.54	389	25,707
Toluene	0.54	406	24,630
1,4-Dioxane	0.55	405	24,691
Ethyl acetate	0.55	396	25,252
Tetrahydrofuran	0.58	407	24,570
Methanol	0.60	421	23,753
Acetone	0.71	410	24,390
Acetonitrile	0.75	405	24,691
Chloroform	0.76	416	24,038
Dichloromethane	0.82	418	23,923
DMF	0.88	417	23,981
DMSO	1.00	421	23,752

[a] The correlation coefficient *r* obtained for the linear solvation energy relationship with π* values by Kamlet and Taft was *r* = 0.8889.

4. Conclusions

New bithienyl-benzimidazoles **3a-c** were synthesized in good to excellent yields from easily available formyl-bithiophenes **1a-c** and *o*-nitroaniline by a one-step reduction reaction with $Na_2S_2O_4$ in DMSO. The solvatochromic and optical properties of chromophores **3a-c**, functionalized by groups with different electronic character, were evaluated, and due to their excellent photophysical properties, namely their strongly emissive character, these benzimidazole derivatives could find application as fluorescent markers and probes or as organic components for OLEDs.

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