



1 *Conference Proceedings Paper*

2 **Heterocyclic dicyanovinyl derivatives: synthesis and**  
3 **evaluation of the chemosensory ability in aqueous**  
4 **solution**

5 **R. Cristina M. Ferreira, Susana P. G. Costa and M. Manuela M. Raposo\***

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9 Centro de Química, Universidade do Minho, Campus de Gualtar, 4710-057 Braga,

10 [mfox@quimica.uminho.pt](mailto:mfox@quimica.uminho.pt)

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12 **Abstract:** Two novel dicyanovinyl derivatives **3a-b** were synthesized in moderate to good yields  
13 through a Knoevenagel reaction of the corresponding aldehyde precursors and malononitrile. The  
14 photophysical properties of the new push-pull systems were studied by UV-vis and fluorescence  
15 spectroscopy in acetonitrile. The evaluation of the compounds as colorimetric chemosensors was  
16 carried out by performing spectrophotometric titrations in acetonitrile and acetonitrile/water in the  
17 presence of relevant organic and inorganic anions, and of alkaline, alkaline-earth and transition  
18 metal cations. The benzindole derivative exhibited great selectivity for the cyanide anion over  
19 other anions in acetonitrile/water (8:2) solution showing a distinct color change from colorless to  
20 yellow.

21 **Keywords:** Knoevenagel reaction; benzofuran; benzindole; push-pull dicyanovinyl heterocyclic  
22 compounds; colorimetric sensors; aqueous media.

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24 **1. Introduction**

25 The cyanide anion is well known due to its toxicity to the environment and to mammals, leading  
26 to convulsions, loss of consciousness, and eventual death. It is lethal to humans in concentrations in  
27 the range of 0.5-3.5 mg per Kg of body weight. In addition to being found in many foods and plants,  
28 cyanides are used industrially in the synthesis of organic chemicals, polymers, metallurgy as well as  
29 in gold mining [1].

30 Consequently, selective detection and quantification of cyanide is very important and it has been  
31 the object of increasing investigation. A large number of fluorimetric and/or colorimetric  
32 chemosensors as well as dosimeters, capable of detecting this anion in organic solvents as well as in  
33 aqueous mixtures have been reported during the last decade. Even so, the majority suffer from  
34 several drawbacks such as difficult synthesis, poor selectivity, only work in an organic media and the  
35 use of instrumentation is required [2]. Therefore, the research on versatile and tunable chemosensors  
36 capable of selective and sensitive colorimetric sensing of the cyanide anion, especially in mixed  
37 aqueous solutions, is still a challenge [3].

38 Having in mind the work developed in our research group concerning push-pull dicyanovinyl  
39 derivatives for several optical applications (SHG and TPA NLOphores) [4], we report in this work,  
40 the synthesis, characterization and evaluation of the photophysical properties and the chemosensory

41 ability of novel optical chemosensors based on benzofuran and benzoindole systems functionalized  
42 with the dicyanovinyl group.

## 43 2. Experimental

### 44 2.1. General procedure for the synthesis of dicyanovinyl derivatives 3a-b

45 A solution of aldehyde **2a** or **2b** (0.37 mmol), malononitrile **1** (0.37 mmol) and piperidine (1 drop)  
46 in ethanol (5 mL) was heated at reflux for 5 h. After this time the solvent was evaporated and the  
47 resulting crude products were purified by column chromatography (silica gel, petroleum ether  
48 /dichloromethane (1:1)).

#### 49 2.1.1. 2-((1H-Benzo[g]indol-3-yl)methylene)malononitrile **3a**

50 Compound **3a** was obtained as a light yellow solid (40 mg, 65%). Mp > 300 °C. UV-vis  
51 (acetonitrile):  $\lambda_{\max}$  nm (log  $\epsilon$ ) 374 (4.40).  $^1\text{H}$  NMR (DMSO- $d_6$ ):  $\delta$  = 7.52 (dt, J = 8.0 and 1.2 Hz, 1H, H-7),  
52 7.64 (dt, J = 8.0 and 1.2 Hz, 1H, H-8), 7.74 (d, J = 8.8 Hz, 1H, H-5), 8.0 (d, J = 8.0 Hz, 1H, H-6), 8.11 (d, J  
53 = 8.8 Hz, 1H, H-4), 8.41 (d, J = 8.4 Hz, 1H, H-9), 8.49 (s, 1H, H-2), 8.82 (s, 1H, CH=C), 13.55 (s, 1H, NH)  
54 ppm.  $^{13}\text{C}$  NMR (DMSO- $d_6$ ):  $\delta$  = 70.91 (C-(CN) $_2$ ), 112.38 (C-3a), 115.64 (C $\equiv$ N), 115.71 (C $\equiv$ N), 118.18 (C-  
55 4), 120.76 (C-9), 121.61 (C-9a), 123.28 (C-5), 123.39 (C-3), 125.14 (C-7), 126.57 (C-8), 128.62 (C-6), 129.91  
56 (C-2), 130.70 (C-5a), 131.17 (C-3b), 153.05 (CH=C) ppm.

#### 57 2.1.2. 2-((Benzofuran-2-yl)methylene)malononitrile **3b**

58 Compound **3b** was obtained as a yellow solid (49 mg, 74%). M.p. 170.9-171.5 °C. UV-vis  
59 (acetonitrile):  $\lambda_{\max}$  nm (log  $\epsilon$ ) 361 (4.61).  $^1\text{H}$  NMR (DMSO- $d_6$ ):  $\delta$  = 7.40 (dt, J = 8.0 and 1.2 Hz, 1H, H-5),  
60 7.60 (dt, J = 8.4 and 1.2 Hz, 1H, H-6), 7.70 (dd, J = 8.8 and 0.8 Hz, 1H, H-7), 7.83 (s, 1H, H-3), 7.88 (dd,  
61 J = 8.0 and 1.2 Hz, 1H, H-4), 8.48 (s, 1H, CH=C) ppm.  $^{13}\text{C}$  NMR (DMSO- $d_6$ ):  $\delta$  = 78.67 (C-(CN) $_2$ ), 111.99  
62 (C-7), 113.07 (C $\equiv$ N), 114.35 (C $\equiv$ N), 121.34 (C-3), 123.92 (C-4), 124.70 (C-5), 127.09 (C-3a), 130.25 (C-6),  
63 145.44 (CH=C), 148.98 (C-2), 156.14 (C-7a) ppm.

64

### 65 2.2. Spectrophotometric titrations of compounds 3a-b

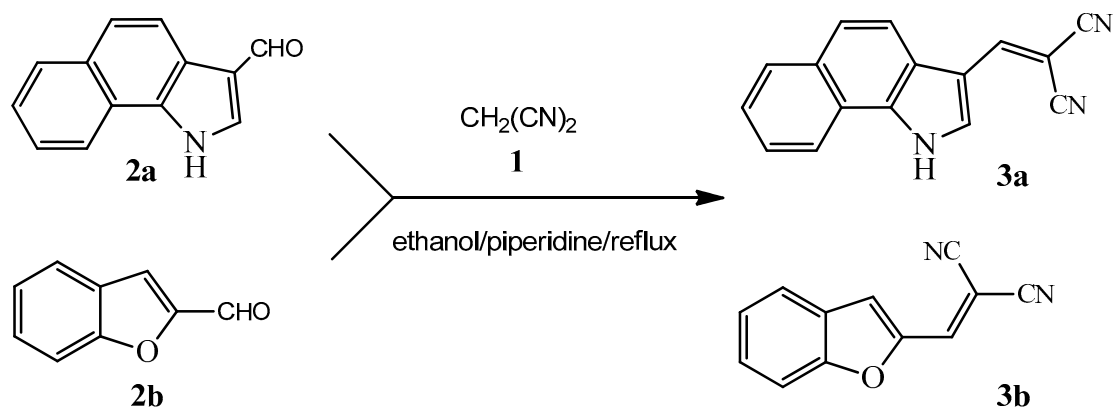
66 UV-visible absorption spectra (250–650 nm) were obtained using a Shimadzu UV/2501PC  
67 spectrophotometer. Fluorescence spectra were collected using a FluoroMax-4 spectrofluorometer.  
68 The relative fluorescence quantum yields were determined by using  $10^{-6}$  M solution of Rhodamine  
69 6G in ethanol as standard ( $\Phi_F = 0.95$ ) [5]. Organic solvents used in the spectroscopic studies were of  
70 spectroscopic grade. Solutions of derivatives **3a-b** (ca.  $1.0 \times 10^{-5}$  M) and of the ions under study (ca.  
71  $1.0 \times 10^{-2}$  and  $1.0 \times 10^{-3}$  M) were prepared in UV-grade acetonitrile or acetonitrile/water (8:2). Titrations  
72 of the compounds **3a-b** in the presence of relevant organic and inorganic anions (AcO $^-$ , F $^-$ , Cl $^-$ , Br $^-$ , CN $^-$ ,  
73 NO $_3^-$ , BzO $^-$ , H $_2$ PO $_4^-$ , HSO $_4^-$ ), and of alkaline, alkaline-earth and transition metal cations (Cu $^{2+}$ , Cd $^{2+}$ ,  
74 Pd $^{2+}$ , Ni $^{2+}$ , Hg $^{2+}$ , Zn $^{2+}$ , Fe $^{2+}$ , Fe $^{3+}$  and Cr $^{3+}$ ) was performed by the sequential addition of the ion stock  
75 solution to the dicyanovinyl solution, in a 10 mm path length quartz cuvette and absorption emission  
76 spectra were measured by excitation at the wavelength of maximum absorption for each compound,  
77 with a 2 nm slit.

## 78 3. Results and discussion

### 79 3.1. Synthesis and characterization

80 Dicyanovinyl **3a-b** were synthesized in moderate to good yields (65-74 %), by a Knoevenagel  
81 reaction between malononitrile **1** and aldehydes **2a-b**. The new compounds were completely  
82 characterized by the usual spectroscopic techniques (Scheme 1, Table 1).

83



84

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**Scheme 1.** Synthesis of dicyanovinyl derivatives **3a-b**.

86 The absorption and emission spectra of compounds **3a-b** were measured in acetonitrile solutions  
87 and showed intense lowest energy charge-transfer absorption bands in the UV-visible region  
88 between 361-374 nm (absorption). Both compounds were very weakly fluorescent, with wavelengths  
89 of maximum emission close to 405-528 nm and with relative fluorescence quantum yields in the  
90 order of 0.005.

91 **Table 1.** Yields, UV-visible absorption and emission data for dicyanovinyls **3a-b** in acetonitrile  
92 solution.

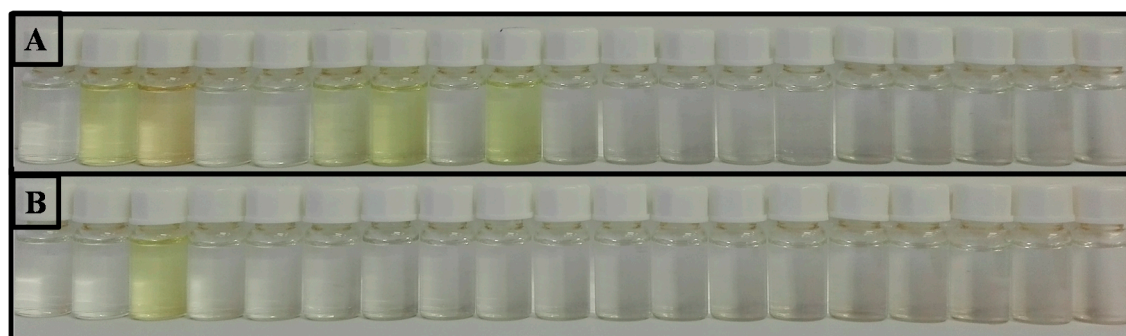
	$\eta(\%)$	Absorption		Emission		
		$\lambda_{\text{max}}$ (nm)	$\log \epsilon$	$\lambda_{\text{em}}$ (nm)	Stokes' shift (nm)	$\Phi_{\text{Flu}}$
<b>3a</b>	65	374	4.40	528	154	0.006
<b>3b</b>	74	361	4.61	405	44	0.005

### 93 3.2. Spectrophotometric titrations of dicyanovinyl derivatives **3a-b** with anions and metallic ions

94 Evaluation of new dicyanovinyl **3a-b** ( $10^{-5}$  M) as colorimetric chemosensors were carried out in  
95 ACN and ACN/H<sub>2</sub>O solutions, in the presence of several ions ( $\text{AcO}^-$ ,  $\text{F}^-$ ,  $\text{Cl}^-$ ,  $\text{Br}^-$ ,  $\text{CN}^-$ ,  $\text{NO}_3^-$ ,  $\text{BzO}^-$ ,  
96  $\text{H}_2\text{PO}_4^-$ ,  $\text{HSO}_4^-$ ,  $\text{Cu}^{2+}$ ,  $\text{Cd}^{2+}$ ,  $\text{Pd}^{2+}$ ,  $\text{Ni}^{2+}$ ,  $\text{Hg}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$  and  $\text{Cr}^{3+}$ ) with biological, environmental and  
97 analytical relevance.

98 Preliminary tests were carried out by addition of up to 50 equiv of each ion to the solutions of  
99 dicyanovinyls **3a-b** in ACN and in aqueous mixture ACN/H<sub>2</sub>O (8:2), revealing that only compound  
100 **3a** exhibited chemosensor ability.

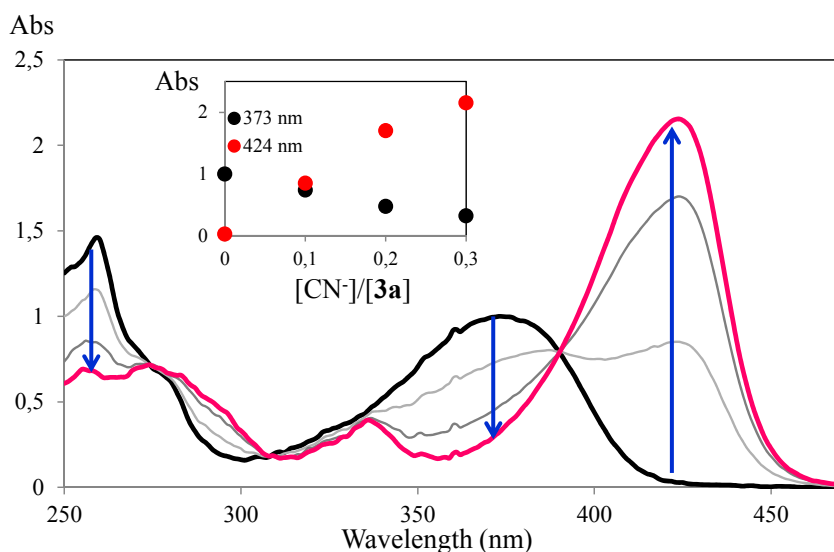
101 It was found that **3a** displayed a marked colour change, from colourless to yellow, upon  
102 interaction with  $\text{AcO}^-$ ,  $\text{F}^-$ ,  $\text{CN}^-$ ,  $\text{BzO}^-$  and  $\text{H}_2\text{PO}_4^-$  in acetonitrile solution. Moreover, **3a** showed  
103 selectivity for the cyanide ion in aqueous mixture displaying the same colour change (Figure 1).



104

105 **Figure 1.** Colour changes of compound **3a** ( $10^{-4}$  M in A: ACN, B: ACN/H<sub>2</sub>O (8:2)) in the presence of 50  
106 equiv. of AcO<sup>-</sup>, CN<sup>-</sup>, HSO<sub>4</sub><sup>-</sup>, NO<sub>3</sub><sup>-</sup>, H<sub>2</sub>PO<sub>4</sub><sup>-</sup>, F<sup>-</sup>, Cl<sup>-</sup>, BzO<sup>-</sup>, Cu<sup>2+</sup>, Pd<sup>2+</sup>, Zn<sup>2+</sup>, Fe<sup>2+</sup>, Hg<sup>2+</sup>, Fe<sup>3+</sup>, Co<sup>2+</sup>, Ca<sup>2+</sup>, Na<sup>+</sup>  
107 and Ni<sup>2+</sup> (in the form of tetrafluoroborate or perchlorate salts).

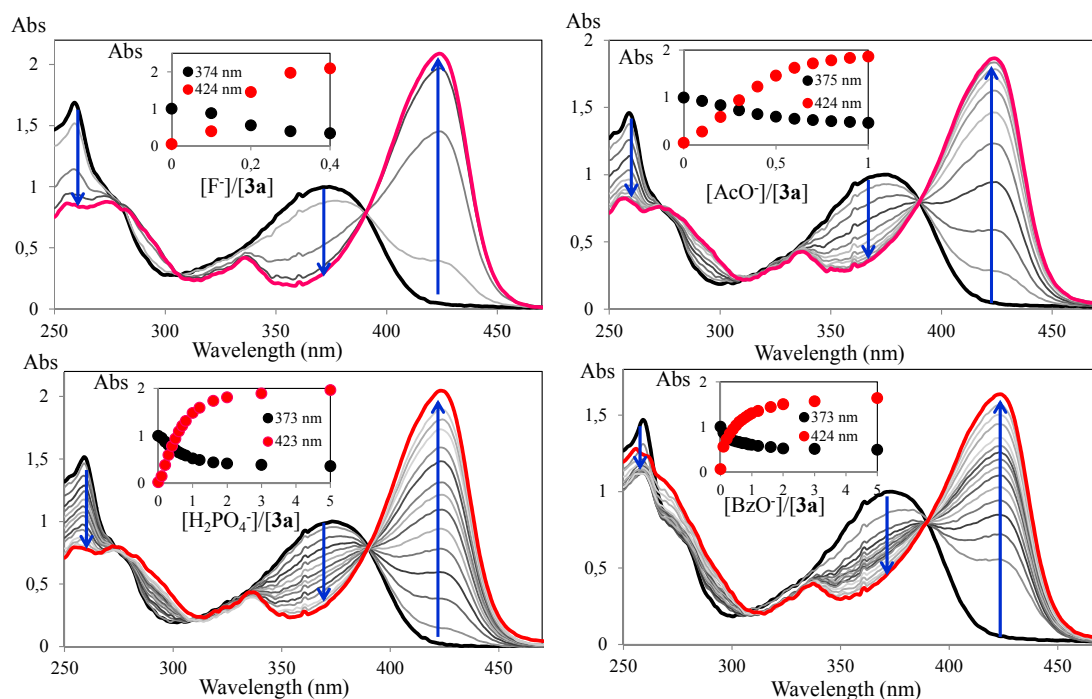
108 Considering these preliminary results, spectrophotometric titration of compound **3a** in ACN  
109 with these selected ions were undertaken. Titration with CN<sup>-</sup> revealed a trend in the UV-Vis spectra,  
110 the intensity of the longest wavelength absorption band at 373 nm decreased progressively upon  
111 addition of the anion, with the simultaneous growth of a new red-shifted absorption band located at  
112 424 nm (Figure 2). It can be seen that a very small amount of cyanide ion (0.3 equiv) caused large  
113 changes in the absorption spectrum and a drastic color change in the solution of compound **3a**.



114

115 **Figure 2.** Spectrophotometric titrations of compound **3a** with addition of increasing amounts of CN<sup>-</sup>  
116 in ACN. The inset represents the normalized absorption ( $[3a] = 1 \times 10^{-5}$  M, T = 298 K).

117 Compound **3a**, in the titration with F<sup>-</sup>, AcO<sup>-</sup>, H<sub>2</sub>PO<sub>4</sub><sup>-</sup> and BzO<sup>-</sup>, revealed the same trend observed  
118 in the titration with cyanide ion (Figure 3). In the titration with F<sup>-</sup> 0.4 equiv were used, 1 equiv was  
119 needed for titration with AcO<sup>-</sup>, and 5 equiv for the titration with H<sub>2</sub>PO<sub>4</sub><sup>-</sup> and BzO<sup>-</sup>. Thus, although  
120 not selective, compound **3a** in acetonitrile was more sensitive to the presence of cyanide ion,  
121 considering that only 0.3 equiv of the cyanide ion were required for the visible colour change.



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**Figure 3.** Spectrophotometric titration of **3a** with addition of increasing amounts of  $F^-$ ,  $AcO^-$ ,  $H_2PO_4^-$  and  $BzO^-$  in ACN. The inset represents the normalized absorption at 373 nm ( $[3a] = 1 \times 10^{-5}$  M,  $T = 298$  K).

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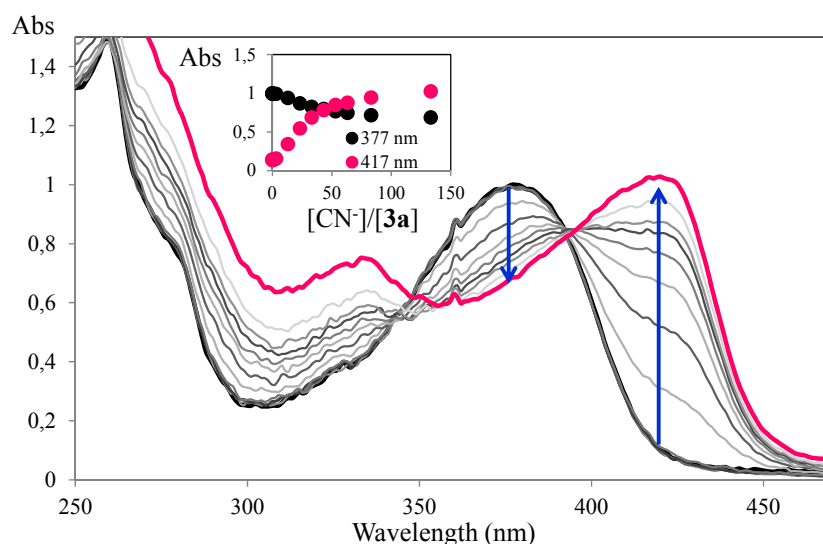
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Spectrophotometric titrations of compound **3a** in ACN/ $H_2O$  (8:2) confirmed the preliminary sensing results, with compound **3a** being selective for the cyanide ion although it required a larger amount of ion to achieve a similar colour change (70 equiv), when compared to the titration in ACN. In Figure 4 it can be seen that there was a gradual decrease in absorption intensity upon addition of the cyanide ion, accompanied by a red-shift with the formation of a new band at 417 nm.



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**Figure 4.** Spectrophotometric titration of compound **3a** with addition of increasing amounts of  $CN^-$  in ACN/ $H_2O$  (8:2). The inset represents the normalized emission ( $[3a] = 1 \times 10^{-5}$  M,  $T = 298$  K).

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135 **4. Conclusions**

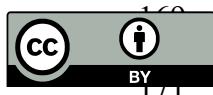
136 The synthesis of new dicyanovinyls **3a-b** was achieved in moderate to good yields by a simple  
137 experimental procedure. The sensory ability was evaluated for several ions by spectrophotometric  
138 titrations in acetonitrile and acetonitrile/water. Compound **3a** was selective for the cyanide ion in  
139 ACN/H<sub>2</sub>O (8:2), which is a very promising result as a colorimetric chemosensor for application in  
140 aqueous media.

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145 Avance III 400 is part of the National NMR Network and was purchased with funds from FCT and  
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