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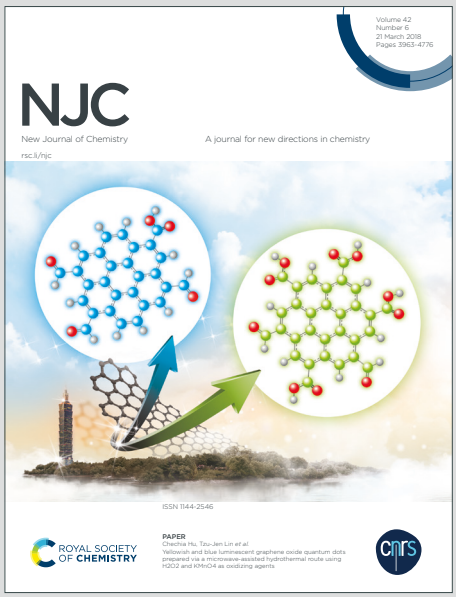

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ARTICLE

Straightforward Synthesis of Photoactive Chalcogen Functionalized Benzimidazo[1,2-*a*]quinolines

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A series of new organochalcogen derivatives of benzimidazo[1,2-*a*]quinolines were synthesized in moderate to excellent yields and in short reaction times from chalcogen benzimidazoles, in a straightforward synthetic procedure, through transition-metal-free cascade reactions involving a sequential intermolecular aromatic nucleophilic substitution (S_NAr), followed by an intramolecular Knoevenagel condensation. Both sulfur and selenium derivatives presented similar photophysical properties, with absorption maxima located in the UV region (~355 nm) related to spin and symmetry allowed electronic p-p* transitions, and fluorescence emission located in the violet-blue region (~440 nm) with relative large Stokes shift (~90 nm). The fluorescence quantum yields were slightly influenced by the chalcogen, with the sulfur derivatives presenting higher values than the selenium analogues, probably due to the intersystem crossing allowed by the selenium atom. Moreover any clear evidence for charge transfer in either compound in the ground and excited states was observed.

Introduction

Heterocyclic compounds containing nitrogen-atoms are found in many bioactive natural products and pharmaceuticals, representing important "privileged structures".[1-4] Substituted benzimidazoles are privileged heterocyclic systems because of their reactivities, notable chemical properties, and biological activities. Additionally, their azino-fused derivatives display a broad spectrum of biological functions such as antiviral, anticancer, antibacterial and antifungal, etc.[5-9] Among fused benzimidazoles, some benzimidazo[1,2-*a*]quinolines have been recently reported to have interesting biological and pharmacological activities, such as antimicrobial,[10] antifungal,[10] antitumor,[11,12] among others (Figure 1).

Despite the importance of these compounds, there are only few reports that merge together a study concerning the structure-activity relationships of substituted benzimidazo[1,2-*a*]quinolines. In fact, this may be due to the difficulty in obtaining these compounds. Consequently, the development of a simple and direct methodology for the synthesis of these privileged structures, in which a variety of substituents at different positions can be introduced, remains a significant challenge in heterocyclic chemistry. The traditional methods for the synthesis of substituted benzimidazo[1,2-*a*]quinolines generally involves an inconvenient multistep synthesis with the use of a metal catalyst as well as ligands and additives.[13-16]

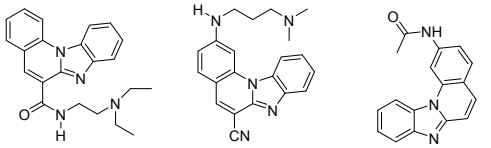

Figure 1. Examples of biologically active benzimidazo[1,2-*a*]quinolines.

Additionally, interest in the chemistry and application of different selenium-containing compounds as potential pharmaceuticals,[17-21] new materials,[22-24] ionic liquids[25-28] and catalysts[29-32] has expanded rapidly during the last years. For instance, the biological and medicinal properties of organochalcogenides have gained increasing interest, which is mainly due to their antioxidant,[33-36] anti-inflammatory,[37-39] anti-HIV[40] activities among others. In the same context, heterocyclic compounds such as substituted benzimidazo[1,2-*a*]quinoline derivatives comprise an interesting class of molecules and they possess interesting electro-optical properties. Their charge transport capability makes them attractive candidates for organic light-emitting diodes (OLEDs).[41,42] Align to this fact, chalcogen derivatives have been

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† *Electronic Supplementary Information (ESI) available: Experimental procedures, characterization data. See DOI: 10.1039/x0xx00000xAddress here.*

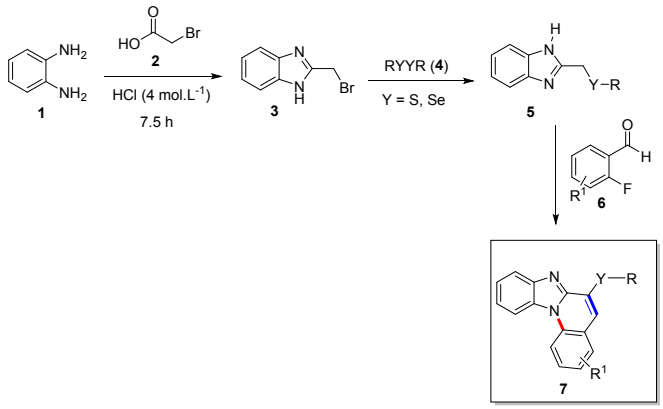
intensively studied in the development of organic materials with technological interest.[43-49]

In this way, taking into account the biological and technological roles of organochalcogen compounds and a broad spectrum of fused benzimidazole properties, the unification of these two moieties might result in the construction of novel compounds with improved activities. With these criteria in mind, and in consonance with our continued interest in the synthesis of organoselenium compounds,[50-53] we designed a selenium-containing precursor **(5)**, for an efficient approach, with the formation of two new bonds, for the synthesis of benzimidazo[1,2-*a*]quinolines containing organochalcogens. To the best of our knowledge, this is the first report of the synthesis of these chalcogen-functionalized fused heterocycles. The cascade process proceeded through an initial intermolecular aromatic nucleophilic substitution (S_NAr) of chalcogen benzimidazoles **5** with substituted 2-fluorobenzaldehydes **6**, followed by the intramolecular Knoevenagel condensation, first described by Yokomatsu and co-workers (Scheme 1).[54] In addition, we also dedicate our efforts to study experimentally the photophysics of these compounds in the ground and excited states by UV-Vis, and fluorescence emissions spectroscopies, aiming to better understand the deactivation channels in these compounds.

Results and discussion

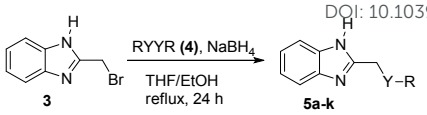
Synthesis

As the starting point of this study, we focused on an efficient way to prepare the precursors, chalcogen 1*H*-benzimidazoles **5a-k** (Table 1). This was conveniently achieved in a short synthetic sequence involving the introduction of the respective organochalcogen moiety in the 2-(bromomethyl)-1*H*-benzo[*d*]imidazole **3** framework, through the reaction with a nucleophilic organyl chalcogenolate. Thus, the nucleophilic organyl chalcogenolates were generated *in situ* from the corresponding diorganyl dichalcogenides **4a-k** by reduction with $NaBH_4$.



Scheme 1. Synthesis of substituted benzimidazo[1,2-*a*]quinolines **7.**

Table 1. Synthesis of chalcogen 1*H*-benzimidazoles **5a-k**.[a]



	Diorganyl dichalcogenides		Product	
Entry	**4**	$(RY)_2$	**5**	Yield (%)[b]
1	**4a**	$(PhSe)_2$	**5a**	81
2	**4b**	$(4\text{-}MePhSe)_2$	**5b**	54
3	**4c**	$(4\text{-}MeOPhSe)_2$	**5c**	44
4	**4d**	$(2\text{-}MeOPhSe)_2$	**5d**	58
5	**4e**	$(4\text{-}ClPhSe)_2$	**5e**	60
6	**4f**	$(3\text{-}CF_3PhSe)_2$	**5f**	58
7	**4g**	$(2,4,6\text{-}MePhSe)_2$	**5g**	52
8	**4h**	$(BuSe)_2$	**5h**	68
9	**4i**	$(PhS)_2$	**5i**	43
10	**4j**	$(4\text{-}MeOPhS)_2$	**5j**	62
11	**4k**	$(3\text{-}CF_3PhS)_2$	**5k**	69

[a] All reactions were performed in the presence of 2-(bromomethyl)-1*H*-benzo[*d*]imidazole **3** (1.0 mmol), diorganyl dichalcogenides **4** (0.5 mmol) and THF/EtOH (3:1) under nitrogen atmosphere. [b] Isolated yields.

The reaction was tolerant to a variety of electron-donating and electron-withdrawing substituents at the aromatic ring of the diaryl diselenides, allowing for the preparation of a series of selanyl-1*H*-benzimidazoles **5a-f** in moderate and good yields (entries 1-6). Even when the sterically hindered dimesityl diselenide **4g** was applied, a good yield was obtained and the product **5g** was obtained in 52 % yield (entry 7). We could also prepare an analogous compound with an aliphatic chain, through the reaction with dibutyl diselenide **4h**, under the standard reaction conditions, leading to the formation of the expected product **5h** in moderate yield (entry 8). The reaction is also efficient with a sulfur nucleophile, which results in the thio-1*H*-benzimidazoles **5i-k** in good yields (entries 9-11). With this variety of chalcogen-1*H*-benzimidazoles **5a-k**, we turned our attention toward the S_NAr/Knoevenagel cyclization domino reaction, using 2-[(phenylselanyl)methyl]-1*H*-benzo[*d*] imidazole **5a** and 2-fluorobenzaldehyde **6a** as model substrates to optimize the reaction conditions (Table 2), in the presence of Cs_2CO_3 in DMF.

Under these reaction conditions, the desired product **7a** was obtained in 76% yield (entry 1) after 8h at 120°C. Increasing the reaction time did not improve the reaction yields (entries 2-3). When the amount of 2-fluorobenzaldehyde **6a** was reduced from 1.2 mmol to 1.0 mmol, a decrease in the yield of product **7a** was observed (entry 4). We next evaluated the effect of the base for this cascade reaction, and in order to accomplish that, five reactions were performed in the presence of different bases, such as Et_3N, DBU, K_2CO_3, K_2HPO_4 and Na_2CO_3 (entries 5-9). However, all tested bases afforded inferior yields when compared to Cs_2CO_3 (entry 9). Different solvents were also investigated in this domino reaction. When the reaction was

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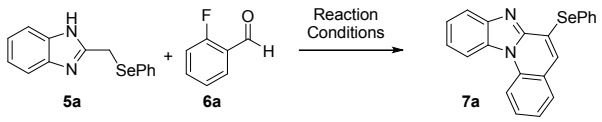
Table 2. Optimization of the metal-free cascade synthesis of organochalcogen derivatives.[a]



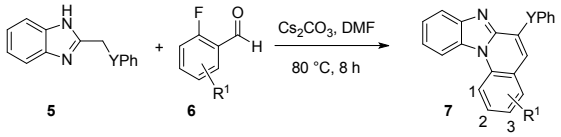
Entry	Base	Solvent	Temp (°C)	Time (h)	Yield (%)[b]
1	Cs_2CO_3	DMF	120	8	76
2	Cs_2CO_3	DMF	120	24	74
3	Cs_2CO_3	DMF	120	48	77
4	Cs_2CO_3	DMF	120	8	66[c]
5	Et_3N	DMF	120	8	nr[d]
6	DBU	DMF	120	8	Trace
7	K_2CO_3	DMF	120	8	69
8	$KHPO_4$	DMF	120	8	nr[d]
9	Na_2CO_3	DMF	120	8	nr[d]
10	Cs_2CO_3	Toluene	120	8	nr[d]
11	Cs_2CO_3	MeCN	80	8	Trace
12	Cs_2CO_3	Ethanol	80	8	nr[d]
13	Cs_2CO_3	1,2-DCE	80	8	Trace
14	Cs_2CO_3	DMSO	120	8	60
15	Cs_2CO_3	DMF	140	8	70
16	Cs_2CO_3	DMF	80	8	77
17	Cs_2CO_3	DMF	80	4	68
18	Cs_2CO_3	DMF	80	8	76[e]

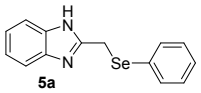
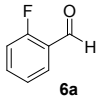
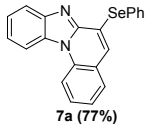
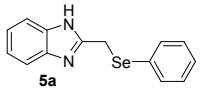
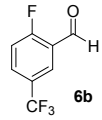
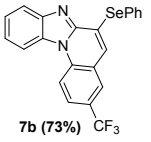
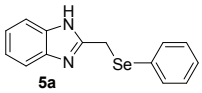
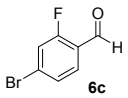
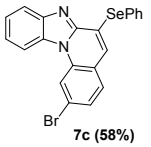
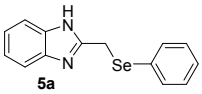
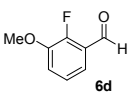
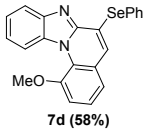
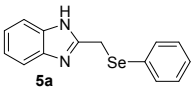
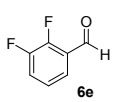
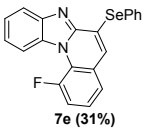
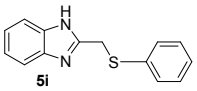
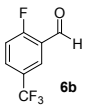
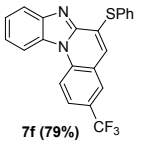
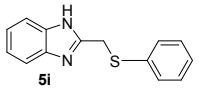
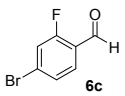
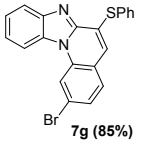
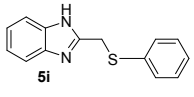
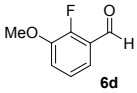
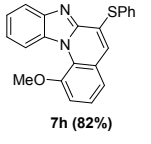
[a]All reactions were carried out in the presence of 2-[(phenylselanyl)methyl]-1*H*-benzo[*d*] imidazole **5a** (1.0 mmol), 2-fluorobenzaldehyde **6a** (1.2 mmol), and base (3.0 mmol) in the indicated time and solvent (5 mL) unless otherwise stated. [b]Isolated yield. [c]2-fluorobenzaldehyde **6a** (1.0 mmol). [d]No reaction. [e]Cs_2CO_3 (4.0 mmol).

carried out with Cs_2CO_3, upon switching the solvent from DMF to toluene, acetonitrile, ethanol or 1,2-dichloroethane, the desired product **7a** was not observed or only traces were formed (entries 10-13). On the other hand, the product was also obtained in DMSO, albeit in moderate yield (entry 14). The domino reaction is affected by the reaction temperature, and after several experiments, we have established 80°C as the ideal reaction temperature. Finally, reducing the reaction time to 4 hours or increasing the amount of the base did not improve the reaction yields (Table 2, entries 17 and 18). Based on these results, the optimal conditions for the domino reaction were with 3.0 eq. of Cs_2CO_3 in DMF at 80°C for 8h.

To explore the scope and limitation of this method, after determining the optimal conditions, we explored first the influence of the substituents on the 2-fluorobenzaldehydes (Table 3). For this purpose, 2-[(phenylselanyl)methyl]-1*H*-benzo[*d*] imidazole **5a** was reacted with a variety of 2-fluorobenzaldehydes **6** bearing an electron-donating or withdrawing substituent on the aromatic ring, affording the corresponding 6-(phenylselanyl)benzimidazo[1,2-*a*]quinolines **7a-d** in good yields (entries 1-4). However, only the 2-fluorobenzaldehyde bearing the electron-withdrawing substituent -F, was a surprisingly poor substrate, furnishing the desired product **7e** with low yield (entry 5). This low yield resulted from the formation of significant amounts of by-products. We also prove the generality of our method, and the reaction between 2-((phenylthio)methyl)-1*H*-benzo[*d*]imidazole **5i** and 2-fluorobenzaldehydes bearing electron-donating or withdrawing substituents worked well under the optimal conditions, leading to the formation of the desired products **7f-h** in excellent yield (entries 6-8).

Table 3. Investigation on the scope of the 2-fluorobenzaldehydes.[a]



Entry	1*H*-benzimidazole	Aldehyde	Product[b]
1	 5a	 6a	 7a (77%)
2	 5a	 6b	 7b (73%)
3	 5a	 6c	 7c (58%)
4	 5a	 6d	 7d (58%)
5	 5a	 6e	 7e (31%)
6	 5i	 6b	 7f (79%)
7	 5i	 6c	 7g (85%)
8	 5i	 6d	 7h (82%)

[a]All reactions were carried out in the presence of **5a** and **5i** (1.0 mmol), aromatic aldehydes **6** (1.2 mmol), and Cs_2CO_3 (3.0 mmol) in DMF (5 mL) at 80 °C. [b]Isolated yield.

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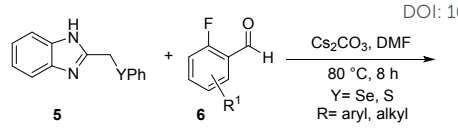
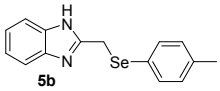
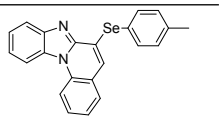
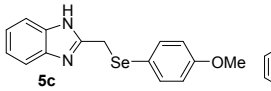
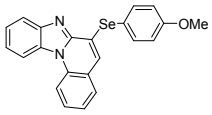
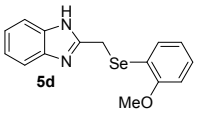
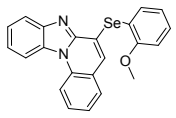
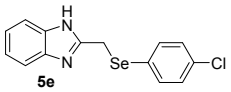
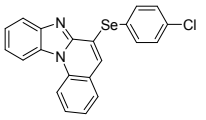
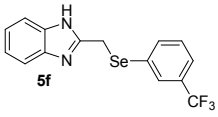
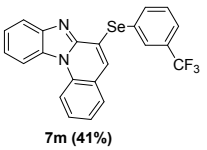
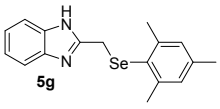
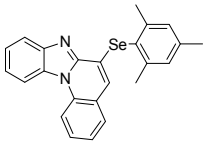
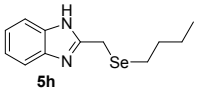
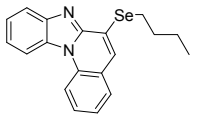
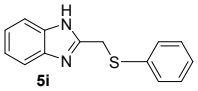
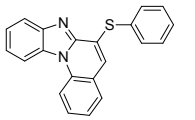
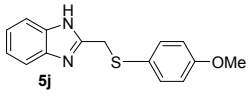
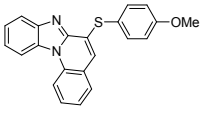
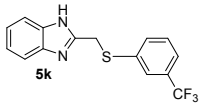
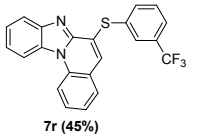
The possibility of performing this domino reaction with other chalcogen 1*H*-benzimidazoles **5b-k** was also investigated, as shown in Table 4. Thus, we examined the reaction of 2-fluorobenzaldehyde **6a** with a variety of selanyl-1*H*-benzimidazoles bearing electron-donating (–CH_3 and –OCH_3) and electron withdrawing (-CF_3 and -Cl) substituents, affording the respective products **7i-r** in moderate and good yields (entries 1-6). Moreover, selanyl-1*H*-benzimidazoles **5h** containing an alkyl chain, also undergoes the desired transformation as show for the formation of the desired product **7o** (entry 7). Due to the success obtained with the preparation of the 6-(phenylselanyl)benzimidazo[1,2-*a*]quinolines, we decided to extend our studies to thio-1*H*-benzimidazoles, bearing a neutral, electron-donating and -withdrawing substituents. By using our standard protocol, the corresponding products **7p-r** were obtained in good yield (entries 8-10) The results revealed some influence of the electronic effect on the chalcogen benzimidazo[1,2-*a*]quinolines **7i-r**. For example, the chalcogen benzimidazo[1,2-*a*]quinolines bearing a neutral substituent **7a** and **7p**, gave higher yields than chalcogen benzimidazo[1,2-*a*]quinolines bearing electron-donating and electron-withdrawing substituents.

Table 4. Investigation on the scope of the chalcogen 1*H*-benzimidazoles **5b-k**.[a]



Entry	1*H*-benzimidazole	Aldehyde	Product[b]
1			
	5b	6a	7i (78%)
2			
	5c	6a	7j (42%)
3			
	5d	6a	7k (48%)
4			
	5e	6a	7l (47%)
5			
	5f	6a	7m (41%)
6			
	5g	6a	7n (78%)
7			
	5h	6a	7o (68%)
8			
	5i	6a	7p (65%)
9			
	5j	6a	7q (42%)
10			
	5k	6a	7r (45%)

[a]All reactions were carried out in the presence of 1*H*-benzimidazoles **5b-k** (1.0 mmol), 2-fluorobenzaldehyde **6a** (1.2 mmol), and Cs_2CO_3 (3.0 mmol) in DMF (5 mL) at 80 °C for 8 h. [b]Isolated yield.

Photophysics

The photophysical investigation of the chalcogen functionalized benzimidazo[1,2-*a*]quinolines is shown in Figure 2. The relevant data obtained from this investigation are summarized in Tables 5 and 6 for sulfur and selenium derivatives, respectively. Figure 2 (a-d) presents the absorption spectra of these compounds taking the chalcogen, the solvent and the substituents into account. In this discussion, compounds **7p** and **7a** were chosen as model for sulfur and selenium derivatives, respectively. It is worth mentioning that the additional compounds presented quite similar photophysical behavior (data not shown, see supporting information). It can be observed for both set of compounds, sulfur and selenium analogues, a structured absorption spectra with maxima located around 355 nm. The presence of vibronic structure on the UV-Vis spectra suggests that these compounds present upper potential energy curve appreciably displaced horizontally, from the lower due to greater equilibrium bond lengths because electronically excited states usually have more antibonding character than electronic ground states.[55] The absorption spectra of compound **7p** (Figure 2a) show a wavenumber spacing of about 1382 cm^{-1}, where values around 1290 cm^{-1} can be found for compound **7a** (Figure 2c), similar to those found for some aromatic hydrocarbons.[56] This result indicates that the sulfur analogues present higher energy values between the vibrational levels than the selenium ones. Additionally, the intensity of the vibronic structure of the absorption spectra indicates, for all studied compounds, that the most probable electronic transition is usually 0→1 and in few examples 0→2, but not at all the pure electronic transition 0→0 (Figure 2b and 2d). This last observation, the less probable transition ascribed as 0→0 indicates that, for these compounds the internuclear distances in the ground and excited states are not equal. Most probable

electronic transitions ascribed as 0→1 or 0→2 indicates that the excited electronic state presents a larger nuclear separation than in the ground state. In addition, it can also be observed that the solvent seems do not influence the absorption maxima location, where an almost absent solvatochromism is observed (Figure 2a and 2c). Similarly, the chalcogen also seems not to play a significant role on the ground state properties of these compounds (Figure 2b and 2d). On the other hand, the substituents presented a more significant influence on the location of the absorption maxima of the sulfur containing compounds than the selenium analogues (Tables 5 and 6).

The photophysical data in the ground state also allowed obtaining the oscillator strength (f_e) and the radiative rate constant for emission (k_e^0) applying the well-known Strickler-Berg equation (Equation 1).[57]

$$f_e = 4.32 \times 10^{-9} \int \varepsilon(\overline{\nu}) d\overline{\nu}, \text{ (Equation 1)}$$

In Equation (1), the integral is the area under the absorption curve, which corresponds to a single electron oscillator. Equally, the radiative rate constant for emission can be related to the extinction coefficient for absorption from Equation (2).[58]

$$k_e^0 \approx 2.88 \times 10^{-9} \overline{\nu}_0^2 \int \varepsilon(\overline{\nu}) d\overline{\nu}, \text{ (Equation 2)}$$

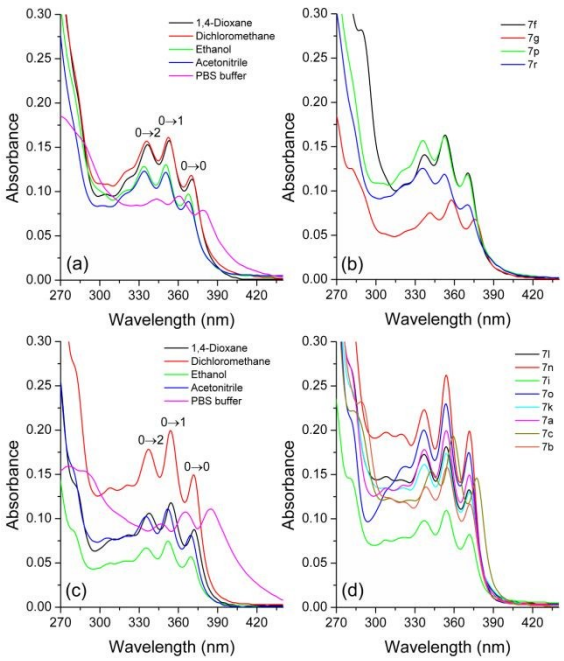


Figure 2. UV-Vis absorption spectra of (a) sulfur derivative **7p** in different organic solvents (10^{-5} M), (b) sulfur containing compounds in dichloromethane (10^{-5} M), (c) selenium derivative **7a** in different organic solvents (10^{-5} M) and (d) selenium containing compounds in dichloromethane (10^{-5} M).

From the Strickler–Berg relation, values for the oscillator strength, f_e ranges 0.087-0.349 (Table 5), which corroborates with electronic dipole-allowed transitions, as expected (f_e~10^{-3}-1).[59] Moreover, the obtained molar absorptivity coefficient ε values for all studied compounds (10^4 $M^{-1}{\cdot}cm^{-1}$), as well as the calculated radiative rate constant (10^8 s^{-1}) indicate spin and symmetry allowed $^1\pi$- π^* electronic transitions, that usually ranges values to e (10^2-10^6 $M^{-1}{\cdot}cm^{-1}$) and k_e^0 (10^5-10^9 s^{-1}). The pure radiative lifetime (t^0) was also obtained as $1/k_e^0$, with similar magnitude (ns) for all compounds, indicating that after radiation absorption the chalcogen functionalized benzimidazo[1,2-*a*]quinolines populate the same excited state.

Table 5. Photophysical data of sulfur functionalized benzimidazo[1,2-*a*]quinolines, where ε is the molar extinction coefficient (x10^4 $M^{-1}{\cdot}cm^{-1}$), λ_{abs} and λ_{em} are the absorption and emission maxima (nm), $\Delta\lambda_{ST}$ is the Stokes shift (nm/cm^{-1}), and ϕ_{FL} is the total quantum yield (%), f_e is the calculated oscillator strength, k_e^0 is the calculated radiative rate constant (10^8 s^{-1}) and τ^0 is the calculated pure radiative lifetime (ns).

#	Solvent	λ_{abs}	ε	λ_{em}	$\Delta\lambda_{ST}$	ϕ_{FL}	f_e	k_e^0	τ^0
	1,4-Dioxane	354	1.87	446	92/5827	1.1	0.276	2.20	4.54
	DCM	353	1.64	450	97/6106	0.9	0.231	1.85	5.40
7f	Ethanol	350	1.45	465	115/7066	0.4	0.281	2.29	4.36
	Acetonitrile	351	1.19	452	101/6366	0.3	0.196	1.59	6.30
	PBS	361	1.30	450	89/5479	4.2	0.279	2.14	4.68
	1,4-Dioxane	358	0.75	445	87/5461	3.4	0.105	0.82	12.20
	DCM	358	0.91	445	87/5461	2.9	0.131	1.03	9.75
7g	Ethanol	356	1.01	450	94/5868	0.8	0.125	0.99	10.11
	Acetonitrile	356	1.17	450	94/5868	0.3	0.167	1.32	7.58
	PBS	366	1.20	455	89/5344	2.1	0.279	2.08	4.81
	1,4-Dioxane	353	1.57	439	86/5550	7.2	0.238	1.91	5.25
	DCM	352	1.63	440	88/5682	5.3	0.267	2.15	4.65
7p	Ethanol	350	1.32	450	100/6349	1.3	0.228	1.86	5.37
	Acetonitrile	350	1.23	440	90/5844	2.1	0.209	1.70	5.87
	PBS	361	0.95	448	87/5379	3.6	0.183	1.41	7.10
	1,4-Dioxane	352	1.22	442	90/5785	4.2	0.242	1.95	5.13
	DCM	352	1.19	440	88/5682	3.9	0.209	1.69	5.93
7r	Ethanol	350	0.74	437	87/5688	2.5	0.142	1.16	8.60
	Acetonitrile	350	0.81	450	100/6349	1.7	0.136	1.11	9.02
	PBS	361	0.47	455	94/5723	2.5	0.099	0.76	13.10

The normalized fluorescence emission spectra of the chalcogen functionalized benzimidazo[1,2-*a*]quinolines are shown in Figure 3. The emission curves were obtained by exciting the compounds at the respective absorption maxima wavelengths (λ_{abs}). The data from fluorescence emission spectroscopy are also summarized in Tables 5 and 6.

Despite the vibronic structure on the UV-Vis spectra, the fluorescence spectroscopy presents broad structureless emission spectra, with maxima located in the violet-blue region with relative large Stokes shift (Figure 3). The absence of the mirror effect in these compounds indicates that the energy spacing between the vibrational levels and the Franck-Condon factors are different in S_0 and S_1.**Error! Bookmark not defined.** Once again, changes on the chalcogen seem do not affect the photophysics of these compounds, since quite

similar emission maxima location was observed for all compounds. Although the emission maxima changes depending on the solvent, any clear tendency was observed, discarding a solvatochromic effect in redshifted emission if compared to other solvents, which can be associated to specific interactions afforded by this solvent with the fluorophore, lowering its excited state energy.[60] The studied compounds, even containing fused aromatic rings, which provide significant structural rigidity, present relatively low fluorescence quantum yield (ϕ_{FL}) values (Tables 5 and 6).

Table 6. Photophysical data of selenium functionalized benzimidazo[1,2-*a*]quinolines, where ε is the molar extinction coefficient (x10^4 $M^{-1}\cdot cm^{-1}$), λ_{abs} and λ_{em} are the absorption and emission maxima (nm), $\Delta\lambda_{ST}$ is the Stokes shift (nm/cm^{-1}), and ϕ_{FL} is the total quantum yield (%), f_e is the calculated oscillator strength, k_e^0 is the calculated radiative rate constant (10^8 s^{-1}) and τ^0 is the calculated pure radiative lifetime (ns).

#	Solvent	λ_{abs}	ε	λ_{em}	$\Delta\lambda_{ST}$	ϕ_{FL}	f_e	k_e^0	τ^0
	1,4-Dioxane	354	1.27	438	84	0.28	0.192	1.53	6.53
	DCM	354	2.03	440	86	0.12	0.301	2.40	4.16
7a	Ethanol	352	0.74	470	118	0.88	0.116	0.93	10.71
	Acetonitrile	352	1.17	450	98	0.16	0.162	1.30	7.67
	PBS	365	1.08	443	78	0.91	0.232	1.75	5.73
	1,4-Dioxane	354	1.10	445	91	0.26	0.180	1.43	6.98
	DCM	354	1.63	445	91	0.17	0.239	1.91	5.23
7b	Ethanol	352	0.92	455	103	0.58	0.123	0.99	10.08
	Acetonitrile	352	1.24	440	88	0.12	0.167	1.35	7.42
	PBS	365	0.95	446	81	0.48	0.195	1.46	6.84
	1,4-Dioxane	360	0.70	444	84	0.37	0.118	0.91	10.96
	DCM	359	1.97	445	86	0.12	0.266	2.07	4.84
7c	Ethanol	357	0.77	445	88	0.28	0.118	0.93	10.77
	Acetonitrile	357	1.23	442	85	0.10	0.168	1.32	7.60
	PBS	370	0.77	453	83	0.85	0.153	1.12	8.95
	1,4-Dioxane	354	1.02	445	91	0.32	0.154	1.23	8.11
	DCM	354	1.11	445	91	0.19	0.167	1.33	7.51
7i	Ethanol	352	1.03	464	112	1.07	0.141	1.14	8.79
	Acetonitrile	352	1.01	447	95	0.17	0.142	1.14	8.74
	PBS	363	0.60	443	80	0.79	0.121	0.92	10.88
	1,4-Dioxane	354	1.54	435	81	0.45	0.226	1.80	5.54
	DCM	354	1.85	440	86	0.23	0.310	2.48	4.04
7k	Ethanol	352	1.13	455	103	0.62	0.166	1.34	7.48
	Acetonitrile	352	1.20	442	90	0.22	0.182	1.47	6.81
	PBS	366	0.77	445	79	0.63	0.183	1.37	7.32
	1,4-Dioxane	354	1.28	440	86	0.40	0.182	1.45	6.88
	DCM	354	1.84	445	91	0.23	0.279	2.23	4.49
7l	Ethanol	352	0.71	455	103	0.45	0.108	0.87	11.44
	Acetonitrile	352	1.03	442	90	0.33	0.144	1.16	8.61
	PBS	362	0.67	440	78	0.53	0.115	0.88	11.36
	1,4-Dioxane	354	1.03	425	71	0.59	0.139	1.11	8.99
	DCM	354	2.67	425	71	0.17	0.349	2.79	3.59
7n	Ethanol	352	1.07	435	83	0.36	0.125	1.01	9.93
	Acetonitrile	352	1.28	420	68	0.15	0.160	1.29	7.73
	PBS	362	1.03	430	68	0.95	0.199	1.52	6.59
	1,4-Dioxane	353	1.16	440	87	0.71	0.182	1.46	6.85
	DCM	354	2.43	425	71	0.46	0.393	3.14	3.19
7o	Ethanol	352	0.69	458	106	3.41	0.097	0.78	12.78
	Acetonitrile	352	1.16	425	73	0.30	0.144	1.16	8.62
	PBS	362	0.52	436	74	0.35	0.087	0.66	15.06

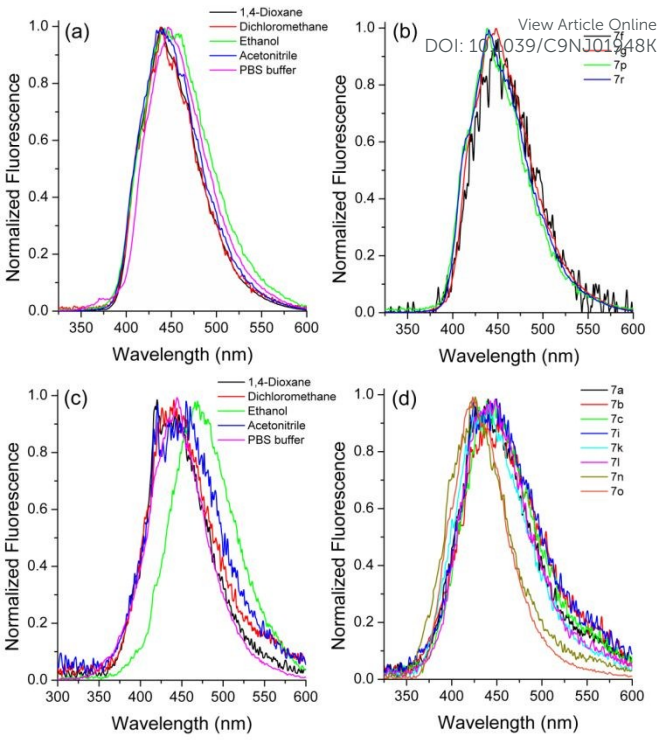


Figure 3. Fluorescence emission spectra of (a) sulfur derivative 7a in different organic solvents (10^{-5} M), (b) sulfur containing compounds in dichloromethane (10^{-5} M), (c) selenium derivative 7p in different organic solvents (10^{-5} M) and (d) selenium containing compounds in dichloromethane (10^{-5} M).

The results from the two sets of compounds (S and Se) may be probably related to triplet state population via intersystem crossing (ISC) after radiation absorption. In this sense, this pathway disfavors the deactivation between states of the same multiplicity or even photoinduced electron transfer (PET) that can take place from the organoyl selenide group to the quinoline moiety. In addition, it can be observed that the sulfur based compounds showed slightly higher ϕ_{FL} values than the selenium analogues. In this context, it is believed that spin-orbit coupling is even more favored for selenium derivatives due to the electronic characteristics of this chalcogen.

In order to exploit the obtained low fluorescence quantum yield values, mainly for the substituted quinolines, an additional experiment based on the selenium oxidation was performed. In this sense, the photophysical behaviour in the excited state of a model compound **7a** bearing a phenyl bonded to the chalcogen, was investigated in presence of an oxidizing agent. It could be observed that right after addition of 20 equiv. of benzoyl peroxide to a solution of **7a** (10^{-5} M) any change was observed in the fluorescence emission spectra (Figure 4). However, an increase in fluorescence intensity was observed over time, starting after 5 minutes and reaching 5 times the initial intensity value after 210 minutes. It is worth mentioning that at this time range (210 minutes) the UV-Vis spectra presented quite the same profile, suggesting that any chemical transformation occurred in the fluorophore. In this way, the observed changes on the fluorescence intensity after addition of benzoyl peroxide can probably be related to

deactivation of fluorescence quenching mechanisms related to the chalcogen atom since the oxidation of selenium and the deactivation of photoinduced electron transfer (PET) process have already been determined in selenium containing BODIPY derivatives.[61-63] Based on these results, the synthesized selenium-quinolines present potential application for peroxide sensing in solution. In order to confirm our hypothesis, a control experiment was performed. Compound **7a** was oxidized with MCPBA, and the product was analyzed by ^{77}Se NMR; we could clearly observe the oxidation product ArSe(O)Ph (data not shown, see supporting information).

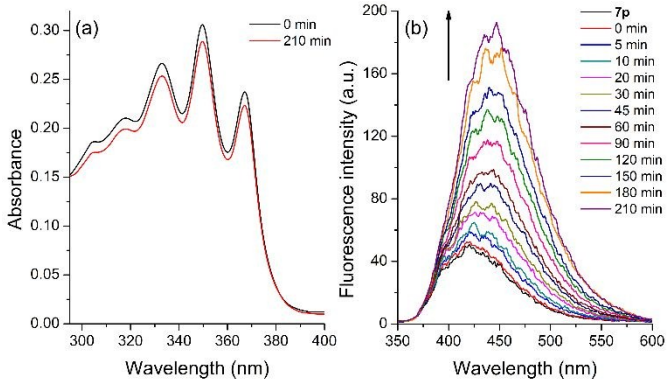


Figure 4. (a) UV-Vis and (b) fluorescence emission spectra of compound **7a** (10^{-5} M) in presence of benzoyl peroxide (10^{-5} M) observed at different time (0-210 minutes).

Conclusions

In summary, we report an efficient way to prepare a wide range of substituted chalcogen-1*H*-benzimidazoles **5a-k**. The products were obtained in good to excellent yields, making them suitable for the synthesis of more complex structures. In this way, we provided a simple and efficient method for the synthesis of wide range of substituted chalcogen-benzimidazo[1,2-*a*]quinolines **7a-s**, without using any transition metal catalysts, through a cascade reaction between the substituted chalcogen-1*H*-benzimidazoles **5a-k** and 2-fluoroarylaldehydes **6** substrates. The corresponding products were obtained in moderate to excellent yields and in a relatively short reaction time. These compounds presented absorption in the UV region related to spin and symmetry allowed electronic π-π* transitions and fluorescence emission located in the violet-blue regions with relative large Stokes shift. The compounds did not show significant solvatochromism in either the ground or the excited state. Moreover, changes on the chalcogen seem not affect the absorption or the emission maxima location. The fluorescence quantum yields were slightly tailored by the chalcogen, with the sulfur derivatives presenting higher values than the selenium analogues, due to quenching mechanisms presented by selenium. These properties were investigated showing that a peroxide oxidation can enhance fluorescence emission and, thus, extend the employment for other analytes sensoring.

Experimental

General procedure for preparation of chalcogen 1*H*-benzimidazoles 5a-k.

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Under an argon atmosphere, sodium borohydride (0.028 g, 0.75 mmol,) was added to a solution of the diorganyl dichalcogenides (**4**) (0.5 mmol) in THF (7.5 mL). EtOH (2.5 mL) was then dropwise added and the clear solution formed was stirred at room temperature for 20 min. After this time a solution of the 2-(bromomethyl)-1H-benzo[d]imidazole **3** (0.211 g, 1.0 mmol) in THF was added dropwise, and the reaction mixture was heated at reflux for 24 h. The solution was washed with $NH_4Cl_{(aq.)}$ (2 x 30 mL) and extracted with CH_2Cl_2 (3 x 20 mL). The combined organic layers were dried over $MgSO_4$, filtered, and concentrated under vacuo. The crude product was purified by silica gel chromatography (eluent: hexane/ethyl acetate).

General procedure for the preparation of 6-(phenylselenyl)benzo[4,5] imidazo[1,2-*a*]quinoline 7a-r.

A mixture of 2-fluorobenzaldehyde **6a** (0.148 g, 1.2 mmol), 2-[(phenylselenyl)methyl]-1*H*-benzo[*d*]imidazole **5a** (0.287 g, 1.0 mmol), and Cs_2CO_3 (0.325g, 3.0 mmol) in DMF (5.0 mL) was stirred at 80 °C for 8 h. After the end of the reaction, the mixture was cooled to room temperature and diluted with water. The resulting mixture was extracted with ethyl acetate. The combined organic layer was washed with water, dried over $MgSO_4$ and the solvent was removed under vacuo. The residue was purified by silica gel chromatography (eluent: hexane/ethyl acetate = 9/1) to afford 6-(phenylselenyl)benzo[4,5]imidazo[1,2-*a*]quinoline **7a** in 77 % yield.

Conflicts of interest

There are no conflicts to declare.

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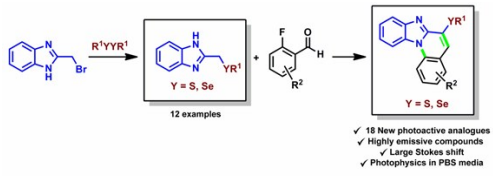

Graphical Abstract