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Novel probes for selective fluorometric sensing of Fe(II) and Fe(III) based on BODIPY dyes

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Abstract: Two novel boron-dipyrromethene (BODIPY) based fluorescence turn-off sensors, which demonstrate high selectivity and sensitivity toward Fe^{2+} and Fe^{3+} ions, have been reported. A simple and high yielded synthesis of fluorescent BODIPY derivatives with malonyl unit for sensitization have been described. This approach provides quick, high yielded, and low-cost preparation of the probes. The two sensors have been comprised of combination of one and two BODIPY fluorophore and a malonyl unit, substituted on meso position of BODIPYs. Synthesized BODIPY derivatives have been characterized via elemental analyses, mass spectrometry, ^{1}H and ^{13}C spectroscopy and their photophysical properties were investigated by UV- Vis absorption and fluorescence emission spectroscopy. The synthesized sensors (**2, 3**) have been used as a fluorescent probe towards the selective and sensitive detection of biologically important Fe^{2+} and Fe^{3+} ions in tetrahydrofuran by fluorescence spectroscopy. The limit of detection (LOD) have been calculated to be for the BODIPY **2**, 14.61 (Fe^{2+}), 1.22 (Fe^{3+}) and for BODIPY **3**, 1.16 (Fe^{2+}) and 1.06 (Fe^{3+}).

Keywords: Borondipyrromethenes, UV-Vis spectroscopy, fluorescence, chemosensor, Fe^{3+}/Fe^{2+}.

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INTRODUCTION

After the recognition of the importance of transition metal ions in a wide range of processes especially in environment and biology, a great deal of attention has been devoted on the advancement of probes to detect transition metal ions (1-3). Within the transition metals, particularly iron, is the most abundant and an essential metal in all organisms and biological systems (4). It has crucial roles in oxygen uptake, oxygen metabolism, electron transfer, and transcriptional regulation and a possible disorder in Fe ion metabolism cause several diseases (5, 6). Thus, detection of Fe ions is useful in a wide range of area, including clinical diagnostics, therapeutic monitoring, and detection of organisms and toxins (7). Numerous research studies have been devoted on the development of Fe^{2+} and/or Fe^{3+} chemosensors (8). Especially within all detection methods, fluorescent chemosensors has received special attention because it enables high sensitivity, noninvasiveness and convenience, low cost and real-time response that depends incremental interaction to analyte (9-11). Even though the are many studies devoted on the preparation of Fe ion probes with different sensing strategies, it is still needed to develop a fluorescence sensor with high selectivity and sensitivity with a decreased response time and convenient instant observation (12).

Within dye based fluorescent probes, 4,4-difluoro-4-bora-3a,4a-diaza-s-indacenes (BODIPYs) have been devised for increasing number of implementation (13). Because BODIPY-based probes exhibit convenient spectral properties like photostability, high fluorescence quantum yield and amenability to alterations in photophysical and photochemical properties via small and facile alteration on molecules (14-16). Recently we have devised fluorescence chemosensors based on methyl malonyl-conjugates of mono- and di- styryl BODIPY dyes for determination of HgB via Fe ion complexation

as an alternative approach to the classical sensing systems of HgB (17). These results have been encouraged us to synthesize new systems based on malonyl unit on meso position of BODIPYs as fluorescence probe by using the advantage of the low cost and rapid process of fluorescence systems. The aim of this study is the synthesis and characterization of novel Fe^{2+} and Fe^{3+} probes especially by using facile synthesis process and determination of their photophyisical properties. Herein we have devised two malonyl edged BODIPY derivatives (**2** and **3**) (Scheme 1). Fe^{2+} and Fe^{3+} have been monitored via fluorescence emission by using their effects on optical properties of BODIPYs (**2** and **3**). Fe^{2+} and Fe^{3+} interact with BODIPYs (**2** and **3**) and cause change in optical characteristics of BODIPYs (**2** and **3**). The degradation in the emission intensities of BODIPYs have been found to be rational to the concentrations of Fe^{2+} and Fe^{3+} and these signals have been used for determination of Fe^{2+} and Fe^{3+} in samples.

EXPERIMENTAL SECTION

Materials

The deuterated solvent ($CDCl_3$) used for NMR spectroscopy, silica gel, trifluoroacetic acid, p-chloroanil, triethylamine, pyridine, boron trifluoride diethyl etherate, n-hexane and dimethylformamide were provided from Merck. The following chemicals were obtained from Sigma Aldrich; ethanol, 2,4-dimethylpyrrole, dichloroethane, methylmalonyl chloride, malonyl dichloride. 4-hydroxybenzaldehyde was purchased from Alfa Aesar. All other chemicals used for the synthesis were reagent grade unless otherwise specified**.** The aqueous solutions of the corresponding metal chlorides (nitrate for Ag^+) were used as the source of metal ions at room temperature.

Equipment

Electronic absorption spectra were recorded with a Shimadzu 2101 UV spectrophotometer in the UV-visible region. Fluorescence excitation and emission spectra were recorded on a Varian Eclipse spectrofluorometer using 1 cm path length cuvettes at room temperature. The fluorescence lifetimes were obtained using Horiba- Jobin-Yvon-SPEX Fluorolog 3-2iHR instrument with Fluoro Hub-B Single Photon Counting Controller at an excitation wavelength of 500 nm and 570 nm. Signal acquisition was performed using a TCSPC module. Mass spectra were acquired in linear modes with average of 50 shots on a Bruker Daltonics Microflex mass spectrometer (Bremen, Germany) equipped with a nitrogen UV-Laser operating at 337 nm. ^1H, and ^{13}C NMR spectra were recorded in $CDCl_3$ solutions on a Varian 500 MHz spectrometer. Analytical thin layer chromatography (TLC) was performed on silica gel plates (Merck, Kieselgel 60 Å, 0.25 mm thickness) with F254 indicator. Column chromatography was performed on silica gel (Merck, Kieselgel 60 Å, 230-400 mesh). Suction column chromatography was performed on silica gel (Merck, Kieselgel 60 Å, 70-230 mesh).

Synthesis

The related BODIPY derivative (**1**) was previously synthesized by a simple one-pot reaction modified according to the procedure reported by Gabe and co-workers (17, 18).

*Synthesis of compound **2***

Compound **1** (50 mg, 0.15 mmol) was dissolved in 15 mL of DCM. Pyridine (15 mg, 0.20 mmol) was added under Ar atmosphere. The mixture was cooled on an ice bath and monomethyl malonyl chloride (24 mg, 0.18 mmol) in 5 mL DCM was added dropwise. The mixture was stirred for 12 h. The reaction mixture was filtered and the solvent was removed. Compound **2** was isolated with column chromatography on silica gel (DCM) (230-400 mesh) (yield: 65%). Spectral data of **2**: Elemental analyses: Calc. (%) for $C_{23}H_{23}BF_2N_2O_4$: C, 62.75; H, 5.27; N, 6.36; found C, 62.68; H, 5.21; N, 6.37. MS (MALDI-TOF) (DIT) m/z Calc.: 440.25; found: 439.16 $[M-H]^+$, 420,16 $[M-H-F]^+$ (Fig. S1). ^1H NMR (500 MHz, $CDCl_3$, 298 K, δ ppm): 7.34 – 7.26 (m, 4H, Ar-CH), 6.00 (s, 2H, -CH), 3.84 (s, 3H, $-OCH_3$), 3.68 (s, 2H, $-CH_2$), 2.56 (s, 6H, $-CH_3$), 1.42 (s, 6H, $-CH_3$) (Fig. S3). ^{13}C NMR (126 MHz, CDCl3, 298 K, δ ppm): 166.49, 164.66, 155.73, 150.90, 143.07, 140.42, 132.88, 131.37, 129.28, 122.34, 121.40, 116.06, 52.83, 41.32, 29.70, 14.54 (Fig. S5).

*Synthesis of compound **3***

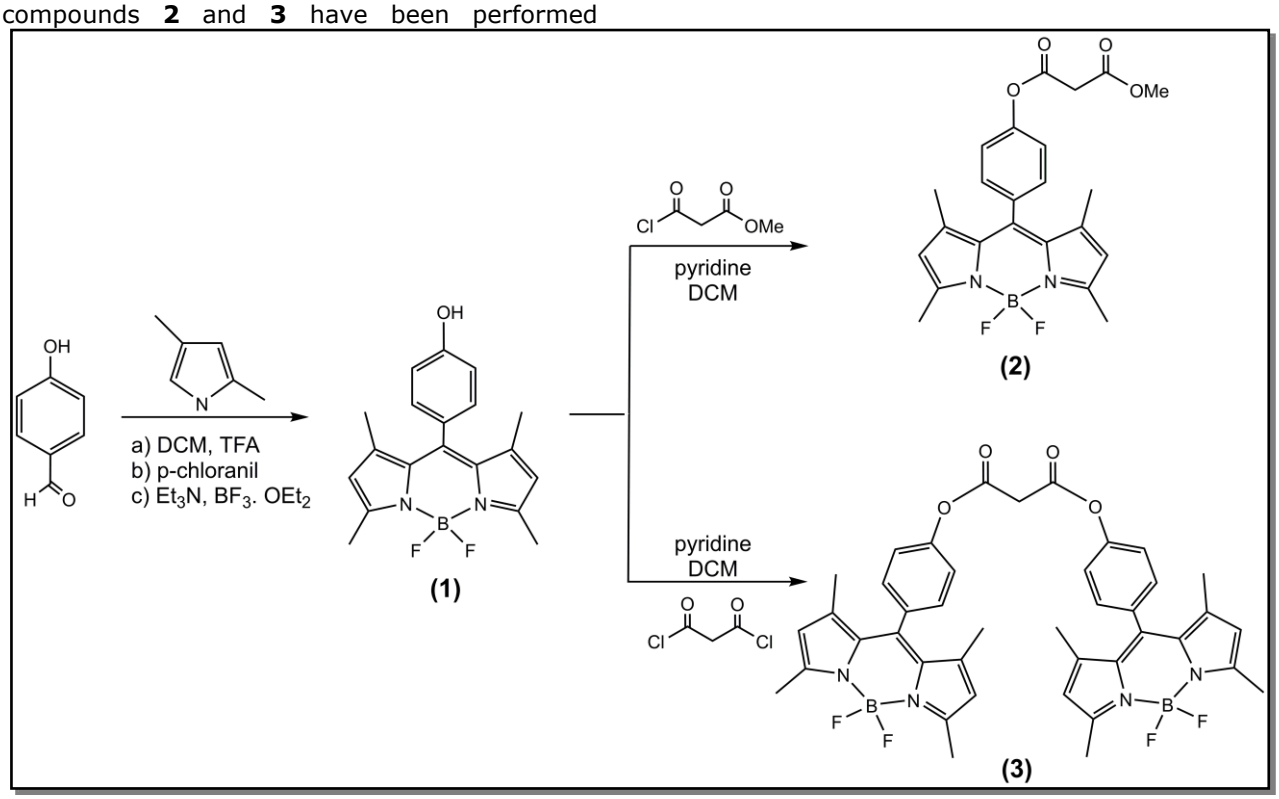
Compound **1** (70 mg, 0.21 mmol) were dissolved in 15 mL of DCM. Pyridine (31 mg, 0.40 mmol) was added under Ar atmosphere. The mixture was cooled on an ice bath and malonyl chloride (14 mg, 0.10 mmol) in 5 mL DCM was added dropwise. The mixture was stirred for 14 h and the reaction mixture was filtered, then the solvent was removed. Compound **3** has been isolated from column chromatography with silica gel (DCM) (230-400 mesh) (yield: 52%). Spectral data of **3**: Elemental analyses: Calc. (%) for $C_{41}H_{38}B_2F_4N_4O_4$: C, 65.80; H, 5.12; N, 7.49 found C, 65.76; H, 5.04; N, 7.52. MS (MALDI-TOF) (DIT) m/z Calc.: 748.39; found: 748.09, $[M]^+$, 727.91 $[M-F]^+$ (Fig. S2). ^1H NMR (500 MHz, $CDCl_3$, 298 K, δ ppm): 7.36 (br, 8H, Ar-CH), 6.01 (s, 4H, -CH), 3.95 (s, 2H, $-CH_2$), 2.57 (s, 12H, $-CH_3$), 1.44 (s, 12H, $-CH_3$) (Fig. S4). ^{13}C NMR (126 MHz, $CDCl_3$, 298 K, δ ppm): 164.24, 155.83, 150.83, 143.01, 140.27, 133.15, 131.38, 129.45, 122.27, 121.43, 53.45, 41.58, 29.69, 14.54 (Fig. S6).

RESULTS AND DISCUSSION

Synthesis and structural characterization

Since BODIPY derivatives are good candidates as fluorescent sensors due to their high molar absorption coefficients and quantum yields, and inertness under several physical conditions, the present work aimed the preparation of malonyl

unit containing BODIPY dyes with a simple synthetic procedure together with high yield as Fe^{2+} and Fe^{3+} probe giving optical signals (19). Malonyl moieties have been used as metal ion binding sites in receptor sub unit. The BODIPY fluorophores have been directly linked to the receptor sub unit that contained one and two chromophores in compound **2** and **3**, respectively. The synthetic pathway is shown in Scheme 1. The one-pot synthesis of compound **1** has been previously described by Gabe and co-workers and involved a condensation of 4-hydroxybenzaldehyde and 2,4-dimethylpyrrole in the presence of trifluoroacetic acid as catalyst in dichloromethane under argon atmosphere followed by oxidization by p-chloranil and complexation with BF_3OEt_2 (17, 18). Acceptable yields have been obtained on a routine basis using substitution reaction between compound **1** with methylmalonyl chloride and malonyl chloride achieved by addition of corresponding BODIPY derivatives (**2** and **3**). Identifications of the compounds **2** and **3** have been performed through elemental analysis, mass spectrometry, ^1H and ^{13}C NMR spectroscopy and the results were consistent with the structures (Fig. S1-S6). The mass spectra of compounds **2** and **3** have been obtained by ESI-TOF-MS and the two spectra revealed the peak groups of molecular ion and molecular ion rupture flour (Fig. S1, S2). The ^1H NMR spectra of compounds **2** and **3** showed sets of signals for benzene protons on BODIPY ~7.3 ppm as overlapped signals of doublets. The *β*- pyrrolic signals of BODIPYs appeared as sharp singlets ~6.0 ppm for each BODIPY derivatives. The -OCH_3 protons in compound **2** observed as sharp singlet at 3.84 ppm and the -CH_2 protons on malonyl units resonated at around 3.68 and around 3.95 ppm for compound **2** and **3**, respectively. The methyl protons of BODIPY units appeared at ca. 2.5 and ca. 1.4 ppm (Fig. S3, S4). In the ^{13}C NMR spectra of the new synthesized compounds (**2** and **3**), the aromatic carbons were observed between 166.0-116.0 ppm and aliphatic carbons 52.0-14.0 ppm region (Fig. S5, S6).



Scheme 1: Synthesis of the BODIPY probes (**2**, **3**).

Photophysical properties

The UV- Vis absorption and fluorescence emission spectra of compound **2** and **3** showed characteristic spectroscopic properties of the BODIPY chromophore with small Stokes' shifts (10 nm) (Table 1). In tetrahydrofuran, strong S_0-S_1 transition with maxima at 473 and 502 nm have been observed, which is characteristic for BODIPY cores. Molar extinction coefficients of both BODIPYs have been calculated to be 8.25 × 10^4 and 18.26 × 10^4 $M^{-1}cm^{-1}$ for compounds **2** and **3** respectively (Fig. S7, S8). The fluorescence emission spectra of **2** and **3** sensors have been observed at 512 nm with an excitation wavelength of 480 nm at room temperature (Figure 1). Absorbance and fluorescence spectra of compounds **2** and **3** have been also investigated in different solvents such as dichloromethane, chloroform, dimethyl sulfoxide, methanol and tetrahydrofuran (Fig. S9-S12). In chloroform, absorption and fluorescence intensities have been observed to degrade. In tetrahydrofuran and dimethyl sulfoxide, both BODIPYs absorption and fluorescence intensities have been found similar, thus we preferred tetrahydrofuran as the solvent because of the ease to work and solubility in water for metal titration studies.

Table 1: Photophysical and Photochemical features of compounds **2** and **3**[a].

Comp.	λ_{ab}, nm	λ_{em}, nm	Δ_{Stokes}, (nm)	ϵ^b, 10^4 M^{-1} cm^{-1}	τ_F (ns)[c]	LOD [d], $\mu g.mL^{-1}$
2	473, 502	512	10	8.25	4.138 (for **2**)	-
					3.601 (for **2+Fe^{2+}**)	14.61 (for Fe^{2+})
					4.132 (for **2+Fe^{3+}**)	1.22 (for Fe^{3+})
3	471, 502	512	10	18.26	3.331 (for **3**)	-
					3.320 (for **3+Fe^{2+}**)	1.16 (for Fe^{2+})
					3.315 (for **3+Fe^{3+}**)	1.06 (for Fe^{3+})

[a]Tetrahydrofuran. [b]Molar extinction coefficients. [c]Lifetime, [d]Limit of Detection.

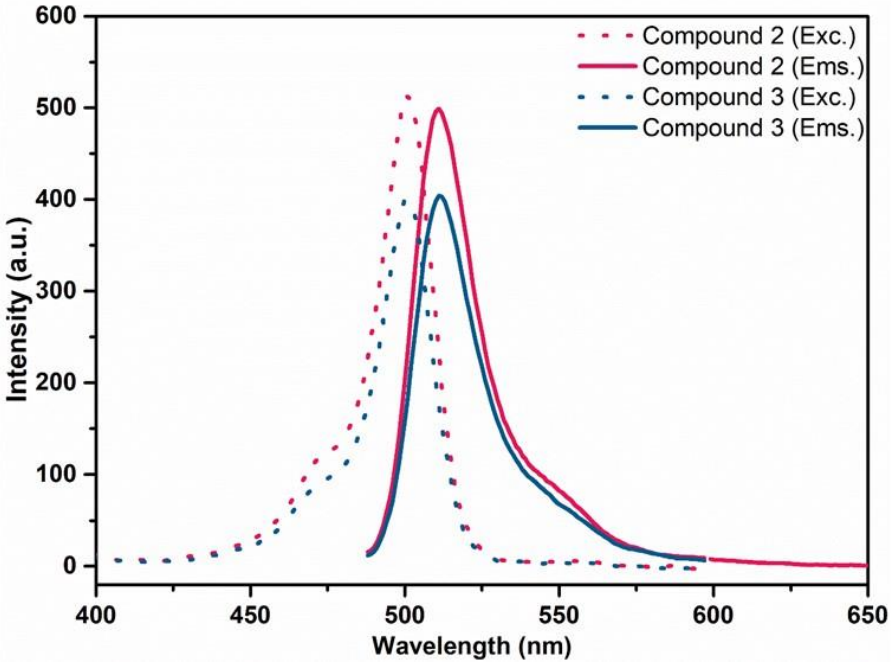


Figure 1: Excitation and Emission spectra of compounds **2** and **3** in tetrahydrofuran (λ_{ex}=480 nm, $5x10^{-7}$ M).

The influence of several analytes (Li^+, Na^+, K^+, Cs^+, Ca^{2+}, Mg^{2+}, Ba^{2+}, Mn^{2+}, Fe^{2+}, Fe^{3+}, Ni^{2+}, Cu^+, Cu^{2+}, Cd^{2+}, Al^{3+}, Cr^{3+}, Hg_2^{2+}, Zn^{2+}, Co^{2+}) on the fluorescence profiles of compounds **2** and **3** have been examined in aqueous solutions, by mixing with the 0.5 and 0.3 μM tetrahydrofuran solutions of BODIPY **2** and **3** respectively, to investigate potential interference. By adding corresponding analytes only Fe^{2+} and Fe^{3+} cause quenching response on the fluorescence intensities of the probe molecules (**2** and **3**). Also, no analytes have been observed, causing interference since no measurable fluorescence decrease have been obtained. The results showed that the fluorescence intensities of BODIPY **2** (0.5 μM) and BODIPY **3** (0.3 μM) solutions have been quenched about 40% and 35% via adding Fe^{2+} and 38% and 32% Fe^{3+} at the concentration of 145 μg. mL^{-1}. As expected, the selectivity of probes against Fe^{2+} and Fe^{3+} have been found to be highly selective (Figure 2).

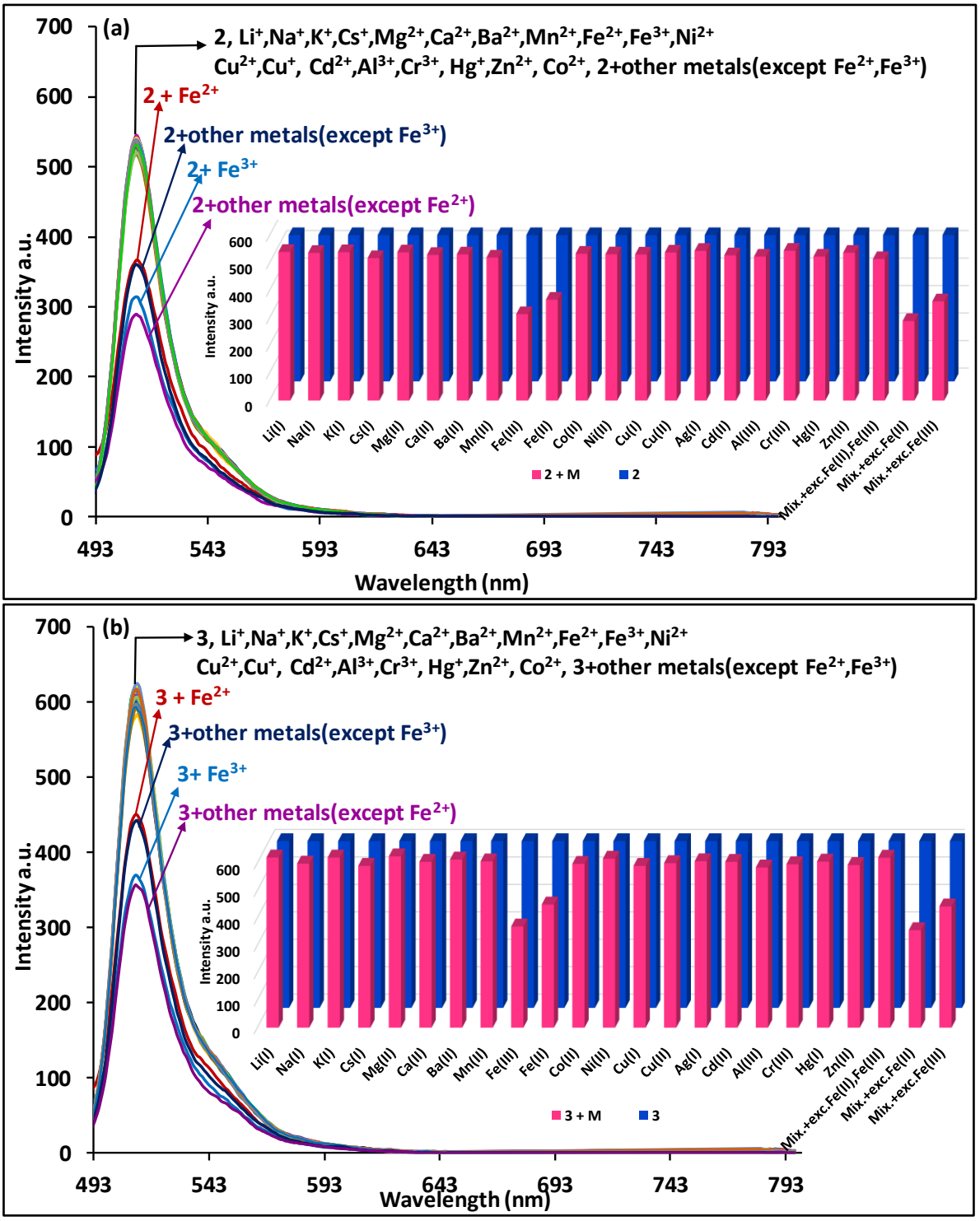


Figure 2: Fluorescence emission spectra of (**a**) **2** (0.5 μM in THF) and (**b**) **3** (0.3 μM in THF) after addition of 0.1 M, 10 μL of different analytes (λ_{ex} = 480 nm).

As mentioned above, the intensities of emission changes explicitly for BODIPY derivatives (**2** and **3**) solely by addition of Fe^{2+} and Fe^{3+} and these changes have been found to be concentration dependent. Thus, for further studies to investigate interaction between BODIPYs (**2** and **3**), the influence of Fe^{2+} and Fe^{3+} ions on fluorescence response Job's plots studies were carried out. As expected, via metal ion coordination to BODIPYs malonyl units, fluorescence intensities decreased, which confirmed the formation of coordination complex between BODIPYs **2** and **3** with Fe^{2+} and Fe^{3+} ions (16, 17, 20-22). Jobs plots have suggested that BODIPYs **2** and **3** formed 2:1 (Ligand: metal) complexes with Fe^{2+} and Fe^{3+} ions (Figure 3). The proposed complex structure between BODIPYs (**2**, **3**) and Fe^{2+} / Fe^{3+} cations have been given in Figure S13.

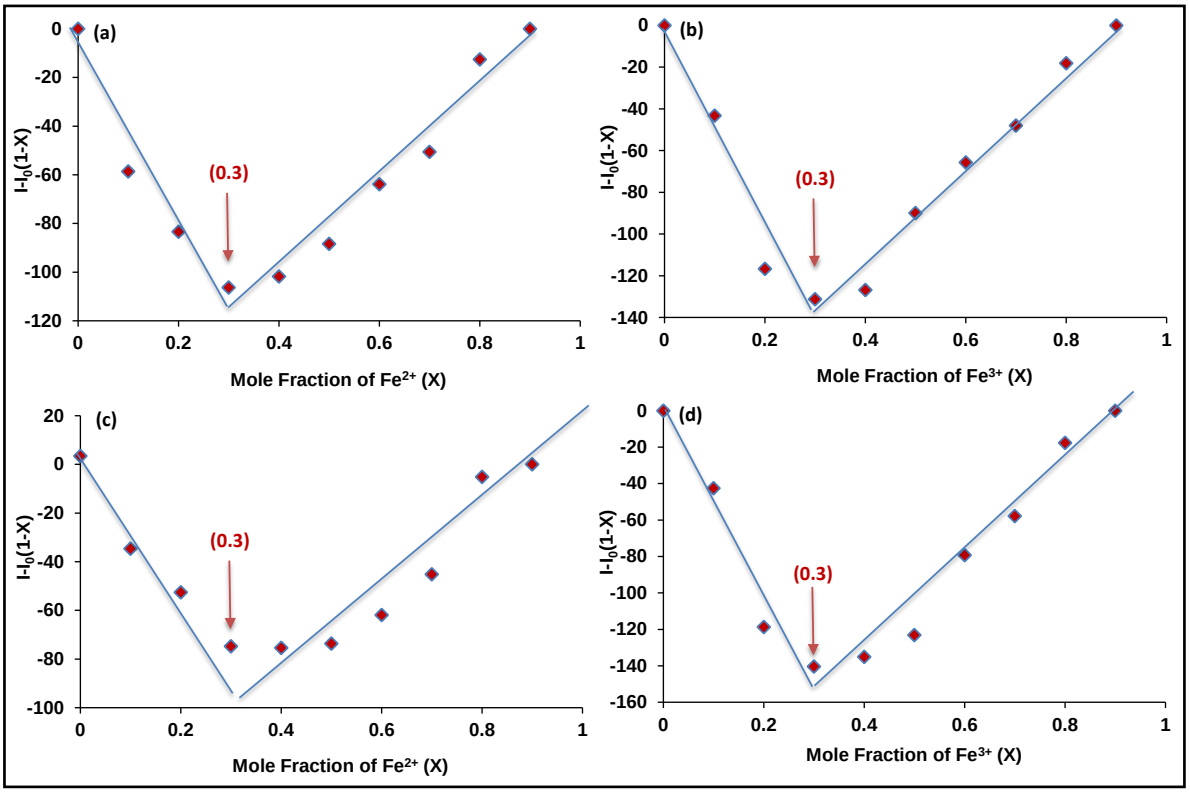


Figure 3: Job's plots of (**a**) Fe^{2+} + 2, (**b**) Fe^{3+} + 2, (**c**) Fe^{2+} + 3, (**d**) Fe^{3+} + 3 in THF.

Figure 4 illustrates the fluorescence responses of both BODIPYs (**2** and **3**) in the presence of regularly increment concentrations of Fe^{2+} and Fe^{3+}. As shown in Figure 4, the emission intensities of compound **2** and **3** have significantly reduced after addition of corresponding analytes and these decreases have been proportional to the Fe^{2+} and Fe^{3+} concentrations. These systematic degradations have been used as analytical signal for Fe^{2+} and Fe^{3+} ions measurements. Also, the limit of detections (LODs) were calculated as 14.61 (Fe^{2+}) and 1.22 (Fe^{3+}) $\mu g.mL^{-1}$ for compound **2** and 1.16 (Fe^{2+}) and 1.06 (Fe^{3+}) $\mu g.mL^{-1}$ for compound **3**.

The fluorescence dynamics of compounds **2** and **3** have been collected as functions of emissive wavelengths λ_{em}. Time resolved fluorescence studies have revealed single exponential decays for BODIPYs (**2** and **3**), **2**+ Fe^{2+}, **3**+ Fe^{2+}, **2**+ Fe^{3+}, **3**+ Fe^{3+} emissions and the lifetimes have been given in Table 1 and Figure 5. The fluorescence lifetimes have been found to be for 4.138 ns (compound **2**), 3.601 ns (**2**+ Fe^{2+}), 4.132 (**2**+ Fe^{3+}), 3.331 (compound **3**), 3.320 (**3**+ Fe^{2+}), 3.315 (**2**+ Fe^{3+}). These measured lifetimes may indicate static quenching due to the formation of complexes in the ground state (23, 24).

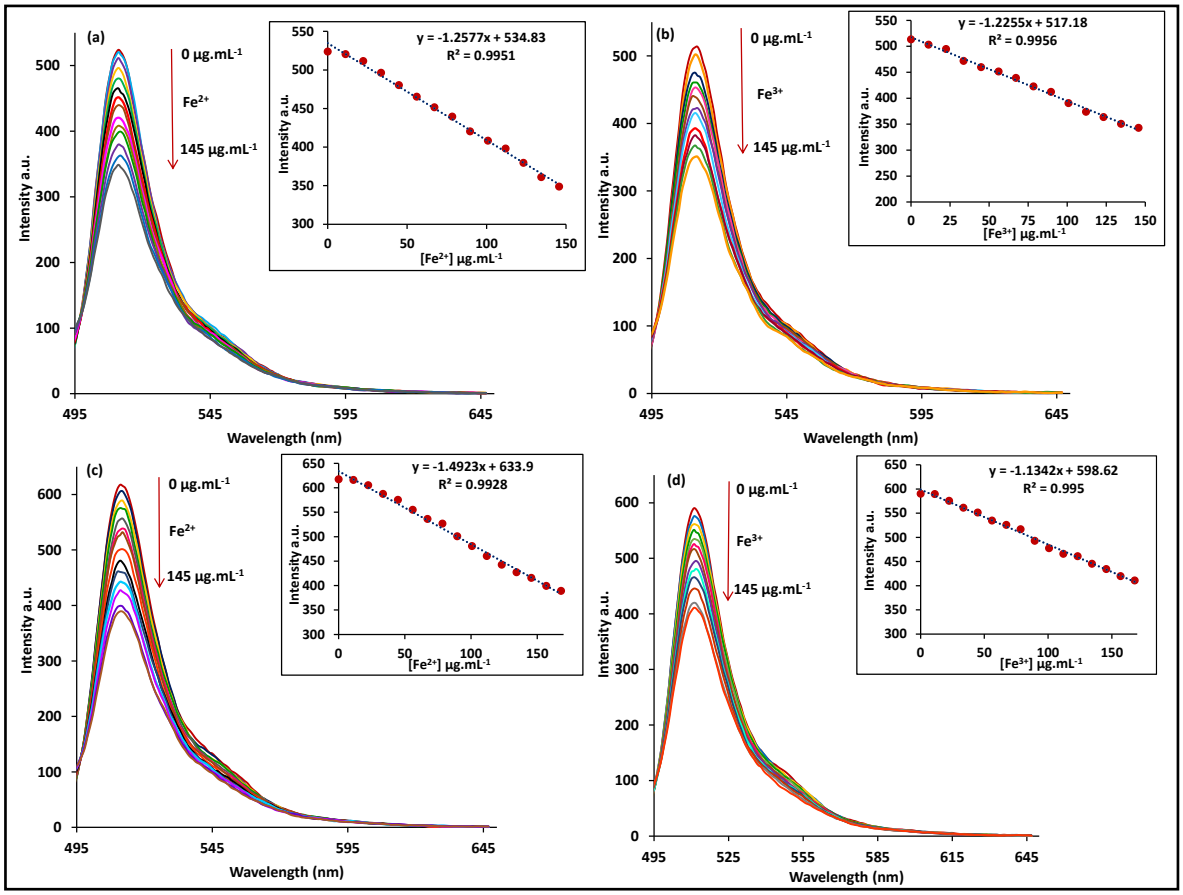


Figure 4: Fluorescence titrations of **2** (0.5 µM in THF) and **3** (0.3 µM in THF) with different amount of (**a**) Fe^{2+}, (**b**) Fe^{3+}, (**c**) Fe^{2+}, (**d**) Fe^{3+}, respectively. Inset: Calibration curve of fluorescence intensity for **2** and **3** (0.5 µM in THF and Fe^{2+}/Fe^{3+} (0-145 µg.mL^{-1}).

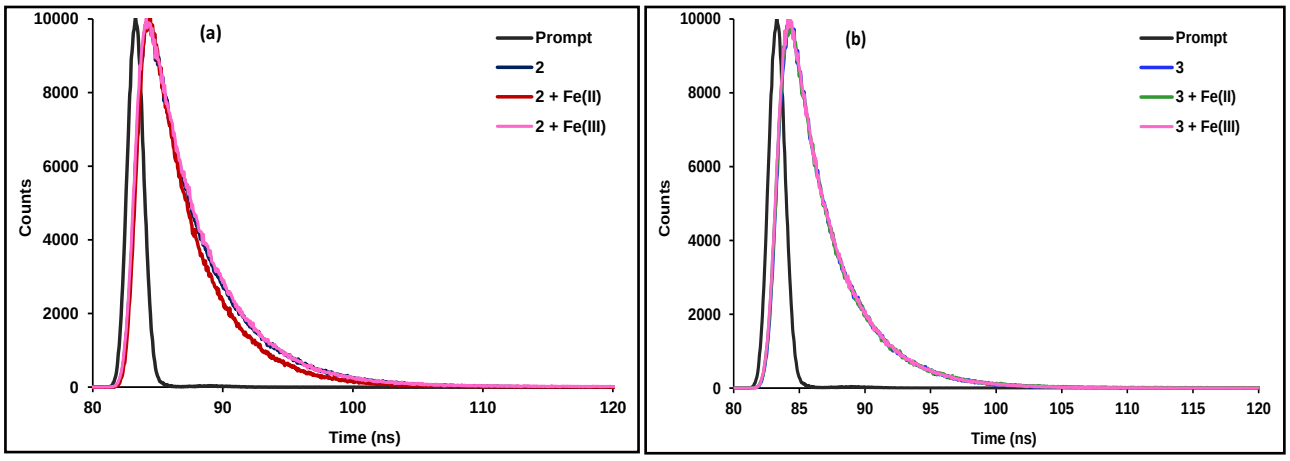


Figure 5: Fluorescence decay profiles of **2**, **2**+Fe^{2+}, **2**+Fe^{3+}, **3**, **3**+Fe^{2+} and **3**+ Fe^{3+} using laser excitation source of 390 nm.

CONCLUSION

In conclusion, two novel fluorescence probes, **2** and **3**, based on BODIPY dyes functionalized with malonyl unit, were synthesized via facile methods with acceptable yields and characterized by various spectroscopic methods. The photophyisical properties of the two compounds have been investigated by UV- Vis absorption and fluorescence emission spectroscopies. A significant decrease in the fluorescence signals have been observed by the addition of Fe^{2+} and Fe^{3+} ions. Two probes were found to be selective for Fe(II) and Fe(III) ions over tested metal ions. According to Job's plot, binding stoichiometry of compounds **2** and **3** were determined as 2:1 (L/M) for Fe^{2+} and Fe^{3+} ions. The results showed that the method is sensitive and has potential for selective detection of trace Fe(II) and Fe(III) ions.

SUPPORTING INFORMATION SUMMARY

Details of photophyisical studies and copies of NMR and mass spectra of the compounds **2** and **3** are described in the supporting information.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1. Hua C-j, Zheng H, Zhang K, Xin M, Gao J-r, Li Y-j. A novel turn off fluorescent sensor for Fe (III) and pH environment based on coumarin derivatives: the fluorescence characteristics and theoretical study. Tetrahedron. 2016;72(51):8365-72.

2. Chen F, Hou F, Huang L, Cheng J, Liu H, Xi P, et al. Development of a novel fluorescent probe for copper ion in near aqueous media. Dyes and Pigments. 2013;98(1):146-52.

3. Wu X, Xu B, Tong H, Wang L. Phosphonate-functionalized polyfluorene film sensors for sensitive detection of iron (III) in both organic and aqueous media. Macromolecules. 2010;43(21):8917-23.

4. Atkinson A, Winge DR. Metal acquisition and availability in the mitochondria. Chemical reviews. 2009;109(10):4708-21.

5. Brugnara C. Iron deficiency and erythropoiesis: new diagnostic approaches. Clinical chemistry. 2003;49(10):1573-8.

6. Zhang X-B, Cheng G, Zhang W-J, Shen G-L, Yu R-Q. A fluorescent chemical sensor for Fe3+ based on blocking of intramolecular proton transfer of a quinazolinone derivative. Talanta. 2007;71(1):171-7.

7. Hirayama T, Nagasawa H. Chemical tools for detecting Fe ions. Journal of clinical biochemistry and nutrition. Journal of clinical biochemistry and nutrition. 2017; 60(1): 39-48.

8. McRae R, Bagchi P, Sumalekshmy S, Fahrni CJ. In situ imaging of metals in cells and tissues. Chemical Reviews. 2009;109(10):4780-827.

9. Chen W-d, Gong W-t, Ye Z-q, Lin Y, Ning G-l. FRET-based ratiometric fluorescent probes for selective Fe 3+ sensing and their applications in mitochondria. Dalton Transactions. 2013;42(28):10093-6.

10. Yang Z, She M, Yin B, Cui J, Zhang Y, Sun W, et al. Three Rhodamine-based "off–on" Chemosensors with high selectivity and sensitivity for Fe3+ imaging in living cells. The Journal of organic chemistry. 2011;77(2):1143-7.

11. Liu M, Hu M, Jiang Q, Lu Z, Huang Y, Tan Y, et al. A novel coumarin derivative as a sensitive probe for tracing intracellular pH changes. RSC Advances. 2015;5(21):15778-83.

12. Zhu X, Zhang Z, Xue Z, Huang C, Shan Y, Liu C, Wang T, et al. Understanding the selective detection of Fe3+ based on graphene quantum dots as fluorescent probes: the K sp of a metal hydroxide-assisted mechanism. Analytical chemistry. 2017; 89(22): 12054-12058.

13. Qin W, Dou W, Leen V, Dehaen W, Van der Auweraer M, Boens N. A ratiometric, fluorescent BODIPY-based probe for transition and heavy metal ions. RSC Advances. 2016;6(10):7806-16.

14. Boens N, Leen V, Dehaen W. Fluorescent indicators based on BODIPY. Chemical Society Reviews. 2012;41(3):1130-72.

15. Loudet A, Burgess K. BODIPY dyes and their derivatives: syntheses and spectroscopic properties. Chemical reviews. 2007;107(11):4891-932.

16. Ulrich G, Ziessel R, Harriman A. The chemistry of fluorescent bodipy dyes: versatility unsurpassed. Angewandte Chemie International Edition. 2008;47(7):1184-201.

17. Okutan E, Tümay SO, Yeşilot S. Colorimetric fluorescent sensors for hemoglobin based on BODIPY dyes. Journal of fluorescence. 2016;26(6):2333-43.

18. Gabe Y, Urano Y, Kikuchi K, Kojima H, Nagano T. Highly sensitive fluorescence probes for nitric oxide based on boron dipyrromethene chromophore rational design of potentially useful bioimaging fluorescence probe. Journal of the American Chemical Society. 2004;126(10):3357-67.

19. Aron AT, Ramos-Torres KM, Cotruvo Jr JA, Chang CJ. Recognition-and reactivity-based fluorescent probes for studying transition metal signaling in living systems. Accounts of chemical research. 2015;48(8):2434-42.

20. Murale DP, Manjare ST, Lee Y-S, Churchill DG. Fluorescence probing of the ferric Fenton reaction via novel chelation. Chemical Communications. 2014;50(3):359-61.

21. Carter KP, Young AM, Palmer AE. Fluorescent sensors for measuring metal ions in living systems. Chemical reviews. 2014;114(8):4564-601.

22. Likussar W, Boltz D. Theory of continuous variations plots and a new method for spectrophotometric determination of extraction and formation constants. Analytical Chemistry. 1971;43(10):1265-72.

23. Bano S, Mohd A, Khan AAP, and Siddiq KS. Complexation and Mechanism of Fluorescence Quenching of Telmisartan with Y(III) and Nd(III). Journal of Chemical Engineering Data. 2010;55:5759–5765.

24. De Costa MDP, Jayasinghe WAPA. Detailed studies on complexation behaviour and mechanism of fluorescence quenching of naphthalene linked hydroxamic acid with transition metal ions by UV-visible and fluorescence spectra. Journal of Photochemistry and Photobiology A: Chemistry. 2004;162(2-3):591-598.