A Benzothiazole-based Ratiometric Fluorescent Probe for Benzoyl Peroxide and Its Applications for Living Cells Imaging

Xiaohua MA,*,** Guoguang WU,**† Yuehua ZHAO,* Zibo YUAN,* Ning XIA,***** Mengnan YANG,* and Lin LIU***†

*School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou, Jiangsu 221116, People’s Republic of China
**Henan Key Laboratory of Biomolecular Recognition and Sensing, College of Chemistry and Chemical Engineering, Shangqiu Normal University, Shangqiu, Henan 476000, People’s Republic of China
***Key Laboratory of New Optoelectronic Functional Materials (Henan Province), College of Chemistry and Chemical Engineering, Anyang Normal University, Anyang, Henan 455000, People’s Republic of China

We present herein a novel ratiometric fluorescent probe (1) for benzoyl peroxide (BPO). Probe 1 was obtained by coupling the recognition unit of arylboronate to a benzothiazole-derived fluorophore. The probe solution is colorless and displays weak blue fluorescence at 460 nm. Upon the addition of BPO, the arylboronate substituent can be removed via oxidation and 1,4-elimination processes. The released fluorophore emits strong yellow-greenish fluorescence at 546 nm. The ratiometric response of the probe is highly selective and sensitive for BPO. The dynamic range was fitted over 1.0 – 75.0 μM with a detection limit of 0.26 μM. In addition, the probe was applied to quantitative detection of BPO in real samples of wheat flour and an antimicrobial agent. Cellular experiments further demonstrated that probe 1 can be effectively utilized for imaging BPO in living cells.

Keywords Fluorescent probe, benzothiazole, benzoyl peroxide, cell imaging

Introduction

Benzoyl peroxide (BPO) is a powerful and very useful oxidizing agent. In a food industry, BPO is a typically used bleaching agent to make flour have an improved appearance.1,2 In the pharmaceutical industry, BPO has been well established as the most common acne medication in dermatology.3–5 In synthetic organic chemistry, BPO acts as an effective radical initiator for promoting the polymerization and aromatic cyclization reactions.6–9 However, the widespread applications of BPO may cause many side effects. For example, excessive addition of BPO in food can induce allergic reactions, leading to the degeneration of carotene and other nutrients. Decomposition products of BPO, including benzoyl oxide free radical (C₆H₅COO•), benzoic acid and biphenyl, may cause cumulative damage to human bodies.10,11 As a result, the use of BPO as a food additive is strictly prohibited in some countries, e.g., France, China. Additionally, the exact medicinal functions and mechanisms of BPO are still insufficiently understood. Therefore, it is highly required to develop effective analytical techniques for monitoring BPO in foods, medicines, as well as in living cells and organisms.

Various traditional analytical methods have been exploited for the detection of BPO, including HPLC techniques,1,2,12 electrochemical assays,13–15 chemiluminescence methods,16–18 Raman19–22 and infrared spectroscopies.23–25 Several colorimetric assays have been reported for monitoring BPO based on various chromogenic agents, such as 2,2′-azino-bis(3-ethylbenzthiazoline-6-sulfonic acid) (ABTS),26 3,3′,5,5′-tetramethylbenzidine (TMB),27 β-carotene,28 and nanomaterials.29,30 These developed methods have provided useful bulk measurements of BPO. However, some problems still remain to be solved, including the use of intricate instruments (i.e. high-performance liquid chromatograph coupled with mass spectrometry, Raman spectrometer, infrared spectrometer), complicated sample handling procedures for chromatographic analysis, low sensitivity for colorimetric analysis, and inability to in vivo tests for all of these above-mentioned methods. The recently developed fluorometric assays based on small probes have proven to be a potent analytical tool to overcome the above-mentioned disadvantages.31–41 Up to now, three BPO fluorescent probes have been developed by incorporating the recognition unit of arylboronate to different fluorophores, including resorufin,42 4-acetamino-2-(benzo[d]thiazol-2-yl)phenol,43 and near-infrared (NIR) scaffold.44 Expanding the chemical toolbox of effective fluorescent BPO probes is still required and also expectable by utilizing various fluorophores in a range of colors. HBT (2-benzothiazol-2-yl)phenol and its derivatives are typical excited-state intramolecular proton transfer (ESIPT) molecules that have been extensively exploited for the development of fluorescent probes with unique spectral properties.
properties, such as a large stokes shift, a high fluorescence quantum yield, and a ratiometric response. Based on a acetamido-substituted HBT fluorophore, Li et al. reported a fluorescent ratiometric probe (A1) for BPO. Nevertheless, the ratiometric spectral response of probe A1 for BPO was located at the blue light region ($\lambda_{\text{max}} = 423$ and 494 nm), which is not favorable for the analysis of real samples, especially for biological imaging. Notably, recent investigations have demonstrated that the introduction of an electron-withdrawing group into the HBT scaffold can lead to a noticeable red-shift in the emission spectra. Based on these considerations, we report a ratiometric fluorescent BPO probe (1) by installing arylboronate to a formylated HBT fluorophore. As expected, the developed probe 1 displayed significant red-shift emission bands ($\lambda_{\text{max}} = 460$ and 546 nm) compared with the previously reported probe A1. Probe 1 is colorless and displays a weak-blue fluorescence at 460 nm due to the inhibition of the ESIPT process. Upon addition of BPO, the probe solution exhibits a strong emission band at 546 nm and a new absorbance band centered at 450 nm. The sensing mechanism involves the BPO-induced oxidation and elimination of the arylboronate moiety, which lead to the release of the highly emissive HBT derived strong emission band at 546 nm and a new absorbance band.

**General procedure for analysis**

A bulk solution of probe 1 and BPO were prepared in ethanol (EtOH). A stock solution of 1 was diluted to the desired concentration with a mixed phosphate aqueous buffer of H2O/EtOH (v/v = 1/1, pH 7.4, 10 mM). Other relevant analytes were prepared in water. All spectral measurements were performed in a mixed solution of phosphate buffer/EtOH (1/1 v/v, pH 7.4, 10 mM) at room temperature. The testing solution was placed in a square quartz cell (path length 1 cm).

**Detection of BPO in real samples**

Real samples of flour (Xinlang pure break flour, Xinxian Xin Liang Grain and Oil Processing Co., Ltd., China) and antimicrobial agent (Oriental cream Piyan Ping 999, China Resource Sanjtu Medical Pharmaceutical Co., Ltd) were purchased from a local market and a local pharmacy, respectively. The real sample (1.0 g) was mixed with a certain amount of BPO (1.0, 5.0, or 10.0 mg). Then, the spiked sample was sonicated in ethanol (10 mL) for 10 min and followed by shaking of the solution for 10 min with a vortex mixer. After being centrifuged, the supernatant was collected and the precipitate was extract one more time according to the same procedures. The supernatant was combined and the volume was adjusted to 100 mL in a volumetric flask using ethanol. The filtered (0.22 μm) sample solution (300 μL), 30 μL of 1 mM 1 stock solution in ethanol, 1170 μL of ethanol, and 1500 μL of phosphate aqueous buffer (pH 7.4, 10 mM) were mixed in a square quartz cell and then and subjected to the fluorescence analysis. The BPO concentration ($c_1$) of the solution in quartz cell was calculated based on the tested fluorescence intensity and the linear equation fitted from the standard solution. The found value of BPO in original real sample was calculated according to the equation $c_1 = \frac{c_2 \times 10 \times 0.1 \times M_{\text{sample}}}{M_{\text{BPO}}/1g}$.

**Materials and instrumentations**

2-Aminobenzenethiol, salicylaldehyde, 4-bromomethylphenylboronic acid pinacol ester, hexamethylenetetramine were purchased from Energy-Chemical (Shanghai, China). Solvent for synthesis was obtained from Dumao Chemical Reagent Co., Ltd. (Tianjin, China). Acetonitrile (HPLC grade) was supplied by Fisher (Fairlawn, NJ, USA). All metal ions (in their chloride form), all anions (as sodium salt), BPO, and ascorbic acid were purchased from Damas-beta Reagent Co. Ltd., (Shanghai, China). Glucose, fructose, saccharose, glycine, VB1, VB6 and VB12, BPO were obtained from Sigma-Aldrich (USA). Unless otherwise stated, all chemicals were of analytical grade. Deionized water obtained from a Milli-Q system was used in all experiments. NMR spectra were recorded on a 400-MHz Bruker NMR spectrometer. Mass spectrometry was performed on a Waters Xevo G2-S QToF™ mass spectrometer (Waters, Milford, MA, USA). The absorbance spectra were obtained on a Cary 60 UV-Vis spectrophotometer (Agilent Technologies, Santa Clara, USA). Fluorescence measurements were recorded on a Varian Cary Eclipse fluorescence spectrophotometer (Agilent Technologies, Santa Clara, USA). HPLC analysis was performed on a Waters Acquity UPLC H-Class system (Milford, MA, USA) equipped with a quaternary solvent delivery system, a column oven, an auto sampler, and a photodiode array detector. The analytes were separated in the gradient mode with a Waters ACQUITY BEH 2.1 × 50 mm C18 1.7 μm column. Flow rate was 0.5 mL/min. Eluent components were water contained water (A) and acetonitrile (B). The mobile-phase gradient was as follows: 0.0 min 50% B → 4.0 min 100% B → 5.0 min 50% B. Detection wavelength was set at 360 nm.

**Scheme 1** Synthesis of probe 1.
Synthesis of probe 1

To a solution of 2 (0.269 g, 1.0 mmol) in acetonitrile (20 mL) was added 4-(bromomethyl)benzeneboronic acid pinacol ester (0.296 mL, 1.0 mmol) and K$_2$CO$_3$ (0.268 g, 2.0 mmol). The mixture was refluxed for 8 h. Then the resulting white precipitate was collected and further purified over silica gel using dichloromethane/methanol (10/1, v/v) as the eluent to afford the desired probe as a white solid (0.369 g, 76%). $^1$H NMR (400 Hz, CDCl$_3$): δ 10.26 (s, 1H), 8.45 (s, 1H), 8.12 (d, $J$ = 7.8 Hz, 1H), 7.91 (d, $J$ = 7.6 Hz, 1H), 7.83 (d, $J$ = 7.2 Hz, 2H), 7.78 (s, 1H), 7.53 (t, $J$ = 7.0 Hz, 1H), 7.43 (d, $J$ = 7.2 Hz, 2H), 7.42 – 7.35 (m, 1H), 5.04 (s, 2H), 2.48 (s, 3H), 1.36 (s, 12H). (see Fig. S1, Supporting Information). HRMS: m/z, calcd for [M+H]$^+$ 486.1910; found 486.1904 (see Fig. S2, Supporting Information) (Scheme 1).

Results and Discussion

Spectral response of probe 1 to BPO

The spectral behaviors of probe 1 in both the presence and absence of BPO were inspected in a phosphate buffer/EtOH (1/1 v/v, pH 7.4, 10 mM). As shown in Fig. 1, the probe 1 solution is colorless with an absorption band at 330 nm, and displays a weak blue fluorescence at 460 nm. Upon the addition of BPO, a new absorption peak at 450 nm appeared, giving a visible yellow color. Meanwhile, a strong yellow-greenish emission was observed ($\lambda_{em} = 546$ nm). All of these yielded spectral features were almost identical to those of compound 2, demonstrating that these spectral responses arise from the transformation of probe 1 to the formylated HBT fluorophore. The significant red-shift in the emission spectra (86 nm) also indicated that compound 1 can act as a ratiometric probe for BPO.

Previous studies on the fluorescence detection of BPO have demonstrated that ethanol as a co-solvent can promote the decomposition of BPO into reactive intermediates, and thus improve the reactivity of BPO. Thus, in the present assays, ethanol was selected as the organic co-solvent. Other experimental parameters were further evaluated, including the reaction time and pH value. To investigate the reaction kinetics, both the time-course absorption variation of probe 1 toward BPO were recorded (Fig. 2). In the presence of BPO, the absorbance value of the probe solution at 450 nm gradually increased and reached a plateau at about 150 min. The free probe solution displayed no spectral changes, indicating that the probe is stable in solution during this time period. Thus, 150 min was set as the reaction time for subsequent experiments.

We then examined the effects of the pH values on fluorescence profiles of probe 1 in the presence and absence of BPO.
The emission feature of free probe 1 was unchanged over the pH range of 3.0 – 10.0, indicating the stable structure of probe 1. With the addition of BPO, the fluorescence intensities of probe 1 varied significantly with the pH values. Under acidic conditions, probe 1 is inactive for the target, and the probe assay also fluoresces weakly under alkaline conditions, which can be ascribed to the inhibited ESIPT process of the released formylated HBT fluorophore via a H-bond interaction between phenolic hydroxyl of HBT fluorophore with OH in the solution medium. Noteworthy, the probe displayed a sensitive fluorescence response towards BPO under near-neutral pH conditions. Considering further applications of the probe for biological monitoring, the physiological pH value of 7.4 was selected for the following experiments.

Sensitivity and selectivity

Under optimized conditions, the spectral response of probe 1 towards different concentrations of BPO was recorded. Upon increment of the BPO concentration, the fluorescence intensity of probe 1 at 460 nm gradually decreased concurrently with the increase in the intensity of a newly appeared emission band at 546 nm (Fig. 4A). A clear isosbestic points at 492 nm can be observed, indicating the generation of a single spectroscopically distinct product. The plot of $I_{546}/I_{492}$ (the ratio of fluorescence intensities at 546 and 492 nm) versus the concentration of BPO displayed a good linear correlation in the range of 1.0 – 75.0 μM (Fig. 4B). The linear equation could be expressed as $I_{546}/I_{492} = 0.1046 \times [\text{BPO}] / \mu\text{M} + 0.4298$. The limit of detection (LOD) was calculated to be 0.26 μM based on the 3σ/S calculation.

To explore the applicability of probe 1 for sensing BPO in complex real samples, the specificity of the probe was inspected.

![Fig. 3](image3.png)

**Fig. 3** pH-dependent fluorescence response of probe 1 (10 μM) toward BPO (100 μM), $\lambda_{ex} = 345$ nm.

![Fig. 4](image4.png)

**Fig. 4** (A) Fluorescence spectra of probe 1 (10 μM) in the presence of various concentrations of BPO (0, 1, 2, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 90, and 100 μM), $\lambda_{ex} = 345$ nm. (B) The fitting curve between $I_{546}/I_{492}$ and the concentration of BPO.

![Fig. 5](image5.png)

**Fig. 5** (A) Fluorescence spectra of probe 1 (10 μM) upon addition of BPO (100 μM) or various interferences (100 μM), including Al³⁺, Ba²⁺, Ca²⁺, Cd²⁺, Fe²⁺, Fe³⁺, K⁺, Li⁺, Mn²⁺, Mg²⁺, Na⁺, Ni²⁺, Pb²⁺, Zn²⁺, AcO⁻, Br⁻, CO₃²⁻, Cl⁻, F⁻, F⁻, NO₂⁻, NO₃⁻, PO₄³⁻, SO₄²⁻, ascorbic acid, glucose, fructose, saccharose, glycine, VB₃, VB₆, VB₁₂. (B) Fluorescence response of probe 1 (10 μM) toward different concentrations of BPO or $\text{H}_2\text{O}_2$, $\lambda_{ex} = 345$ nm.
The probe solution was incubated with different interference species, and the emission spectra were then recorded. Various ions and biological molecules were inspected. As shown in Fig. 5A, all of these investigated interferences do not cause any significant changes of the emission spectra. Moreover, the probe displayed much higher reactivity towards BPO in contrast to H$_2$O$_2$ (Fig. 5B). Benzyl boronic ester (or benzoboric acid) can be used as a kind of typical recognition moiety for several oxidizing substances (i.e. hydrogen peroxide, hypochlorous acid, benzoyl peroxide, peroxynitrite, etc.)$^{42-44,48,55-57}$ The selectivity of the fluorescent probe using benzyl boronic ester (or benzoboric acid) as the recognition site is based on the structure of the probe as well as the solution medium, depending on the target samples for analysis.$^{43}$ This work was aimed to develop an effective fluorescent probe for BPO sensing. For inspecting the selectivity of the proposed probe, the commonly presented ions and biological molecules were tested. Our results indicated that the probe is highly sensitive towards the target.

**Sensing mechanism**

Arylboronate can react with peroxide to produce quantitative yields of phenol. On the basis of this specific reaction, various fluorogenic probes have been developed for the peroxides by exploiting arylboronate as the recognition site. Noticeably, installing arylboronate to certain fluorophore scaffolds can achieve fluorescent probes with much higher reactivity for BPO over other peroxides and oxidants. Probe 1 also features an arylboronate moiety as the reaction site. Thus, the sensing mechanism of probe 1 for BPO can be speculated to that BPO firstly mediated the conversion of arylboronate to phenol within probe 1, which then underwent a 1,6-rearrangement elimination process to remove $p$-quinone-methide and release the highly-emissive formylated HBT fluorophore (Scheme 2). To further confirm this proposed sensing mechanism, HPLC tests were performed to track the reaction between probe 1 and BPO. Various solutions, including probe 1, compound 2, and the reaction mixture of 1 with BPO, were subjected to chromatographic analysis. As shown in Fig. 6, HPLC elution profiles of probe 1 and compound 2 exhibited single chromatographic peaks at 4.41 and 3.54 min, respectively. After reaction with BPO, probe 1 solution displayed a new peak at 3.54 min which corresponded to 2. These chromatographic results convincingly demonstrated the conversion of 1 to 2 in the presence of BPO.

**Detection of BPO in real samples**

BPO is a kind of popular additive for flour and wheat products due to its bleaching and sterilizing capabilities. Moreover, BPO is also a well-established efficacious medication for acne vulgaris. Considering its versatile functions as well as the potential hazardous effects, it is important to detect BPO in the relevant real samples. Two kinds of real samples, wheat flour and antimicrobial agent, were tested in this assay. Sample handling procedures can be seen in the Experimental section. The recoveries for samples spiked with different concentrations of BPO were recorded (Table 1). The recoveries of BPO for these samples ranged from 94.6 to 103.4%. These satisfactory results indicated that the fluorescent assay based on probe 1 is accurate and can be applied for real sample analysis.

### Table 1 Analytical results of the BPO in real samples

| Sample            | Spiked amount/ mg g$^{-1}$ | Found value/ mg g$^{-1}$ | Recovery, % | RSD (n = 3), % |
|-------------------|----------------------------|--------------------------|-------------|----------------|
| Flour sample      |                            |                          |             |                |
| 0                 | ND$^a$                     | ND$^a$                   | ND$^a$      |                |
| 1.0               | 0.95                       | 95.0                     | 5.8         |                |
| 5.0               | 4.97                       | 99.4                     | 6.2         |                |
| 10.0              | 10.4                       | 104.0                    | 4.7         |                |
| Antimicrobial agent |                            |                          |             |                |
| 0                 | ND$^a$                     | ND$^a$                   | ND$^a$      |                |
| 1.0               | 0.92                       | 92.0                     | 7.3         |                |
| 5.0               | 4.85                       | 97.0                     | 5.9         |                |
| 10.0              | 9.83                       | 98.3                     | 3.6         |                |

a. ND, not detected.

**Fluorescence imaging in living cells**

The cytotoxicity of probe 1 was firstly evaluated by the standard MTT assay. Two kinds of cell lines were tested, including A549 cells and Hela cells. The viabilities of all these
inspected cells upon the treatment of probe 1 with concentrations of up to 20 μM were higher than 95% (see Fig. S4, Supporting Information). The results obtained from cytotoxicity experiments indicated that probe 1 is highly biocompatible. We then explored the capability of probe 1 for visualizing exogenous BPO in living A549 cells by using fluorescence microscopy. As shown in Fig. 7, the cells incubated with probe 1 (10 μM) alone displays weak fluorescence in blue channel (Fig. 7B) and is non-emissive in yellow channel (Fig. 7C). On the contrary, treating A549 cells stained with probe 1 (10 μM) by BPO (100 μM) resulted in a bright fluorescence in yellow channel (Fig. 7G). These cell experiments demonstrated that probe 1 is capable of visualizing BPO in living cell.

Conclusions

In summary, we reported a fluorogenic probe for BPO by introducing arylboronate to the formylated HBT fluorophore. Upon the BPO-mediated conversion of arylboronate to phenol and the subsequent release of the highly-emissive fluorophore, a ratiometric fluorescent response was achieved. Fluorescence titration measurements indicated that probe 1 can be utilized to quantitatively monitoring BPO in solution. Recovery tests demonstrated that the fluorescent assay based on probe 1 is accurate in the determination of BPO in real samples. Furthermore, cytotoxicity and imaging experiments indicated that probe 1 is highly biocompatible and capable of visualizing BPO in living cells.

Acknowledgements

We are grateful to the Program for Science and Technology Innovation Talents at the University of Henan Province (18HASTIT005), the Fund Project for Young Scholar sponsored by Henan Province (2016GGJS-122) and the Program for Innovative Research Team of Science and Technology in the University of Henan Province (18IRT-STHN004) for support.

Supporting Information

Procedures for cell cellular experiments, NMR, HRMS and cell cytotoxicity results are available in Supporting Information. This material is available free of charge on the Web at http://www.jsac.or.jp/analsci/.

References

1. Y. Abe-Onishi, C. Yomota, N. Sugimoto, H. Kubota, and K. Tanamoto, J. Chromatogr. A, 2004, 1040, 209.
2. A. I. Saiz, G. D. Manrique, and R. Fritz, J. Agric. Food. Chem., 2001, 49, 98.
3. G. A. Taylor and A. R. Shalita, Am. J. Clin. Dermatol., 2004, 5, 261.
4. E. A. Tanghetti and K. F. Popp, Dermatol. Clin., 2009, 27, 17.
5. K. Okamoto, F. Ikeda, S. Kanayama, A. Nakajima, T. Matsumoto, R. Ishii, M. Umehara, N. Gotoh, N. Hayashi, T. Iyoda, K. Matsuzaki, S. Matsumoto, and M. Kawashima, J. Infect. Chemother., 2016, 22, 426.
6. D. Cheng, T. Chen, X. Xu, and J. Yan, Adv. Synth. Catal., 2018, 360, 901.
7. W. X. Sha, J. T. Yu, Y. Jiang, H. T. Yang, and J. Cheng, Chem. Commun., 2014, 50, 9179.
8. L. Wang, W. X. Sha, Q. Dai, X. M. Feng, W. T. Wu, H. B. Peng, B. Chen, and J. Cheng, Org. Lett., 2014, 16, 2088.
9. K. Yamabe, K. Nakajima, and H. Goto, J. Polym. Sci. Pol. Chem., 2018, 56, 805.
10. S. R. Feldman, J. Tan, Y. Poulin, T. Dirschka, N. Kerrouche, and V. Mannu, J. Am. Acad. Dermatol., 2011, 64, 1085.
11. N. Gaddipati, F. Volpe, and G. Anthony, J. Pharm. Sci., 1983, 72, 1398.
12. Y. C. Chen, P. J. Tsai, Y. B. Huang, and P. C. Wu, Plos One, 2015, 10, e0120171.
13. J. V. B. Kozan, R. P. Silva, S. H. P. Serrano, A. W. O. Lima, and L. Angnes, Biosens. Bioelectron., 2010, 25, 1143.
14. C. Y. Wang and X. Y. Hu, Anal. Lett., 2005, 38, 2175.
15. M. D. P. Sotomayor, I. L. T. Dias, G. D. Neto, and L. T. Kubota, Anal. Chim. Acta, 2003, 494, 199.
16. W. Liu, Z. J. Zhang, and L. Yang, *Food Chem.*, 2006, 95, 693.
17. X. Z. Wang, C. H. Wang, Q. M. Zhang, J. Wang, and T. F. Zheng, *Asian J. Chem.*, 2013, 25, 1942.
18. W. P. Yang, Z. J. Zhang, and X. Hun, *Talanta*, 2004, 62, 661.
19. J. W. Qin, M. S. Kim, K. L. Chao, M. Gonzalez, and B. K. Cho, *Appl. Spectrosc.*, 2017, 71, 2469.
20. X. Wang, W. Huang, C. Zhao, Q. Wang, C. Liu, and G. Yang, *European Food Res. Technol.*, 2017, 243, 2265.
21. X. Wang, W. Huang, Q. Wang, C. Liu, C. Wang, G. Yang, and C. Zhao, *J. Mol. Struct.*, 2017, 1138, 6.
22. X. B. Wang, C. J. Zhao, W. Q. Huang, Q. Y. Cui, C. Liu, and G. Y. Yang, *Spectrosc. Lett.*, 2017, 50, 364.
23. L. Sun, G. Hui, S. Gao, J. Liu, L. Wang, and C. Dai, *Int. J. Food. Prop.*, 2016, 19, 1115.
24. X. X. Guo, W. Hu, Y. Liu, S. Q. Sun, D. C. Gu, H. L. He, C. H. Xu, and X. C. Wang, *Spectrochim. Acta, Part A*, 2016, 154, 123.
25. Z. Y. Zhang, G. Li, L. Lin, X. Y. Cui, and B. J. Zhang, *Spectrosc. Spect. Anal.*, 2012, 32, 2815.
26. K. Ponhong, S. A. Supharoek, W. Sriangkhawut, and K. Grudpan, *J. Food Drug Anal.*, 2015, 23, 652.
27. J. Hu, Y. L. Dong, H. J. Zhang, X. J. Chen, X. G. Chen, H. G. Zhang, and H. L. Chen, *RSC Adv.*, 2013, 3, 26307.
28. S. Supharoek, K. Ponhong, and K. Grudpan, *Talanta*, 2017, 171, 236.
29. Z. L. Jiang, G. Q. Wen, Y. H. Luo, X. H. Zhang, Q. Y. Liu, and A. H. Liang, *Sci. Rep.*, 2014, 4, 5323.
30. T. R. Lin, M. Q. Zhang, F. H. Xu, X. Y. Wang, Z. F. Xu, and L. Q. Guo, *Sens. Actuators, B*, 2018, 261, 379.
31. X. H. Li, X. H. Gao, W. Shi, and H. M. Ma, *Chem. Rev.*, 2014, 114, 590.
32. L. Yuan, W. Y. Lin, K. B. Zheng, L. W. He, and W. M. Huang, *Chem. Soc. Rev.*, 2013, 42, 622.
33. Y. M. Yang, Q. Zhao, W. Feng, and F. Y. Li, *Chem. Rev.*, 2013, 113, 192.
34. W. Chen, W. Shi, Z. Li, H. M. Ma, Y. Liu, J. H. Zhang, and Q. J. Liu, *Anal. Chim. Acta*, 2011, 708, 84.
35. Q. X. Duan, M. Zhang, C. X. Sheng, C. Y. Liu, L. Wu, Z. M. Ma, Q. Zhao, Z. P. Wang, and B. C. Zhu, *Anal. Sci.*, 2017, 33, 1169.
36. T. Yang, F. Zhu, T. X. Zhou, J. Z. Cao, Y. B. Xie, M. Y. Zhang, Y. Wang, D. S. Cao, Q. L. Lin, and L. Zhang, *Anal. Sci.*, 2017, 33, 191.
37. J. Xu, Z. K. Wang, C. Y. Liu, Z. H. Xu, B. C. Zhu, N. Wang, K. Wang, and J. T. Wang, *Anal. Sci.*, 2018, 34, 453.
38. X.-J. Li, J. Ling, C.-L. Han, L.-Q. Chen, Q.-E. Cao, and Z.-T. Ding, *Anal. Sci.*, 2017, 33, 671.
39. H. Wang, J. Chen, Y. Hong, K. Lv, M. Yu, P. Zhang, Y. Long, and P. Yi, *Anal. Sci.*, 2017, 33, 591.
40. Y. Cheng, Y. Zhang, R. Pei, Y. Xie, W. Yao, Y. Guo, and H. Qian, *Anal. Sci.*, 2018, 34, 415.
41. J. Wang, H. Wang, S. Yang, H. Tian, Y. Liu, Y. Hao, J. Zhang, and B. Sun, *Anal. Sci.*, 2018, 34, 329.
42. W. Chen, Z. Li, W. Shi, and H. M. Ma, *Chem. Commun.*, 2012, 48, 2809.
43. L. Q. Wang, Q. G. Zang, W. S. Chen, Y. Q. Hao, Y. N. Liu, and J. Li, *RSC Adv.*, 2013, 3, 8674.
44. X. W. Tian, Z. Li, Y. X. Pang, D. Y. Li, and X. B. Yang, *J. Agric. Food. Chem.*, 2017, 65, 9553.
45. P. Xu, M. Liu, T. Gao, H. Zhang, Z. Li, X. Huang, and W. Zeng, *Tetrahedron Lett.*, 2015, 56, 4007.
46. Y. Jiang, Q. Wu, and X. Chang, *Talanta*, 2014, 121, 122.
47. Z. Huang, S. Ding, D. Yu, F. Huang, and G. Feng, *Chem. Commun.*, 2014, 50, 9185.
48. L. Wu, Y. Wang, M. Weber, L. Liu, A. C. Sedgwick, S. D. Bull, C. Huang, and T. D. James, *Chem. Commun.*, 2018, 54, 9953.
49. T. Honda, Y. Ishida, and T. Arai, *Bull. Chem. Soc. Jpn.*, 2016, 89, 876.
50. H. Zhang, Z. Huang, and G. Feng, *Anal. Chim. Acta*, 2016, 920, 72.
51. K. H. Nguyen, Y. Hao, K. Zeng, S. Fan, F. Li, S. Yuan, X. Ding, M. Xu, and Y.-N. Liu, *Spectrochim. Acta, Part A*, 2018, 199, 189.
52. P. F. Xu, T. Gao, M. H. Liu, H. L. Zhang, and W. B. Zeng, *Analyst*, 2015, 140, 1814.
53. L. Tang, P. He, X. Yan, J. Sun, K. Zhong, S. Hou, and Y. Bian, *Sens. Actuators, B*, 2017, 247, 421.
54. L. W. He, X. L. Yang, K. X. Xu, X. Q. Kong, and W. Y. Lin, *Chem. Sci.*, 2017, 8, 6257.
55. J. Chan, S. C. Dodani, and C. J. Chang, *Nat. Chem.*, 2012, 4, 973.
56. X. Chen, F. Wang, J. Y. Hyun, T. Wei, J. Qiang, X. Ren, I. Shin, and J. Yoon, *Chem. Soc. Rev.*, 2016, 45, 2976.
57. Y.-R. Zhang, Y. Liu, X. Feng, and B.-X. Zhao, *Sens. Actuators, B*, 2017, 240, 18.