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A label-free fluorescent aptasensor for the detection of Aflatoxin B1 in food samples using AIEgens and graphene oxide

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ABSTRACT

The detection of Aflatoxin B1 (AFB1) has attracted extensive attention for food safety is a worldwide public health problem. Herein, a novel, simple and label-free fluorescent aptasensor, based on quaternized tetraphenylethene salt (TPE-Z), graphene oxide (GO) and AFB1 aptamer, has been constructed to detect AFB1. In the presence of AFB1, AFB1 aptamer undergoes a conformational switch from single stranded structure to the AFB1/AFB1 aptamer complex upon target binding, which induces the release of TPE-Z/AFB1 aptamer from the surface of GO. Thus, the fluorescence of TPE-Z/AFB1 aptamer is recovered. The assay can be performed by simply mixing TPE-Z, AFB1 aptamer, the GO and the AFB1 samples with a detection limit of 0.25 ng/mL. It is highly selective against other aflatoxins in foods and its performance has been verified in food samples (corn, milk and rice) with known concentration AFB1.

1. Introduction

Aflatoxins are the secondary metabolites produced by mycotoxins that existed in food and agricultural products, especially in peanut, paddy rice, wheat and corn [1,2]. Among the series of aflatoxins, aflatoxin B1 (AFB1) owns the highest toxicity for binding DNA and RNA, causing haemorrhage and parenchymal cell necrosis [3–5]. In the carcinogens, it has been classified as Group I carcinogens by the International Agency for Research on Cancer (IARC) [6,7]. Thus, the strategy with high specificity and sensitivity is required for the detection of AFB1 in the field of food safety.

There are several reports available for the detection of AFB1 using various analytical instruments include high performance liquid chromatography (HPLC) [8,9], thin-layer chromatography (TLC) [10] and liquid chromatography-tandem mass spectrometry (LC-MS/MS) [11,12]. Although these methods can provide a high accuracy and precision for the detection of AFB1, they usually require equipment and professional personnel as well as time-consuming sample pretreatment [13]. To overcome these limitations and drawbacks, immunoassay methods have been used for AFB1 detection, including enzyme-linked immunosorbent assay (ELISA) [14,15], electrochemical immunoassay [16,17], photo-electrochemical immunoassay [18,19] and colorimetric immunoassay [20]. While, these methods based on antibody are limited by high cost, self-decomposition during storage, non-real-time detection and off-site detection [21]. As an alternative method to antibody for small molecule recognition, aptamer is a single stranded DNA or RNA oligonucleotide that exhibit high affinity and specific for target molecule [22,23]. It exhibits many advantages over antibodies, including high stability, low cost, facile synthesis and easy to modify. As a result, a number of aptasensors have been developed for the detection of AFB1, such as fluorescent [24,25], colorimetric [26], and electrochemical methods [27–29]. Among these, the fluorescent aptasensors have received much attention due to high sensitivity, simple instrumentation and capacity to high-throughput screening. Usually, the fluorescent aptsensor for AFB1 detection need to combine fluorophore and quencher group in nucleic acid probe. Nevertheless, the coexistence of both fluorogen and quencher group suffer from the complex designing of the structure and tedious synthetic procedure [30]. Moreover, the conventional fluorophore such as FAM or Cyanine dye usually displays strong fluorescence in dilute solution and tends to self-quench in aggregating state (aggregation-caused quenching or ACQ). The notorious ACQ effect has limited the label-to-analyte ratio and forces researchers to use very dilute solutions of fluorogens. These issues can be solved by using aggregation-induced emission (AIE) molecules as fluorophore that do not require covalent functionalization with biomolecules, allowing for rapid label-free detection [31]. AIE probes also offer high sensitivity, selectivity, photostability and show no evidence of self-quenching [32–34]. Therefore, AIEgens can be used as a portable

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detection platform with low-cost and specific detection in complex samples [35–37].

In this work, we develop a label-free fluorescent aptasensor for the detection of AFB1 by using AIEgens and GO. A positively charged quaternized tetraphenylethene salt (TPE-Z) prepared according to the previous literature is applied as the label-free fluorophore [30]. GO with good water-solubility is used to quench the fluorescence of TPE-Z via energy-transfer and electron-transfer process [38,39]. In the absence of AFB1, the aggregation complex (TPE-Z/AFB1 aptamer) is absorbed on the surface of GO through the electrostatic interactions, which results in non-emission of TPE-Z/AFB1 aptamer due the quenching effect of GO. Upon the addition of AFB1 to the mixture, AFB1 aptamer undergoes a conformational switch from single stranded structure to the AFB1/AFB1 aptamer complex upon target binding, which induces the release of TPE-Z/AFB1 aptamer from the surface of GO. The release of TPE-Z/AFB1 aptamer from the surface of GO would make GO less efficient to quench the TPE-Z fluorescent signal. The assay can be performed by simply mixing TPE-Z, AFB1 aptamer, the GO and the AFB1 samples with corresponding limit of detection (0.25 ng/mL). The assay is highly selective against other aflatoxins in foods and its performance has been verified in food samples (corn, milk and rice) with known concentration of AFB1.

2. Experimental

2.1. Materials and reagents

Aflatoxin B1 (AFB1), Fumonisin B1 (FB1) and Ochratoxin A (OTA) are purchased from Yuanye Biotechnology Company (Shanghai, China). Graphene Oxide (GO) is purchased from NANO Xian Feng (Nanjing, China). 2-amino-2-(hydroxymethyl)-1,3-propanediol (Tris) is purchased from Sigma. Other chemical reagents are purchased from Shanghai Chemical Reagent Company (Shanghai, China). The water use throughout the experiments is Millipore water (18.2 MΩ) and all reagents are of analytical grade. Food samples (Rice, milk and corn) are purchased from the local supermarket. Tris-HCl buffer (10 mM Tris, 120 mM NaCl, 5 mM KCl, pH 7.0) is used for fluorescent assay.

Oligonucleotides are purchased from Sangon Biotechnology Co., Ltd. (Shanghai, China). The sequences of the oligonucleotides are listed as follows:

AFB1 aptamer: 5′-GTT GGG CAC GTG TTG TCT CTC TGT GTC TCG TGC CCT TCG CTA GGC CCA CA-3′

2.2. Apparatus

All the fluorescence spectra and intensity is recorded by An F-7000 fluorophotometer (Hitachi, Japan). The HPLC data is measured by an Agilent 1260 Infinity.

2.3. Optimization of the concentration of GO

The AFB1 aptamer is dissolved in Tris-HCl buffer and heated to 90 °C for 5 min. After cooling to room temperature, 25 μM TPE-Z is added into this mixture and incubated for 30 min at 37 °C, different concentrations of GO are added to the mixture. After incubating 60 min with 300 rpm shake at 37 °C, the fluorescence intensity is recorded at 480 nm with excitation at 340 nm.

2.4. Sensitivity of the fluorescent chemosensor for AFB1 detection

The AFB1 aptamer is dissolved in Tris-HCl buffer and heated to 90 °C for 5 min. After cooling to room temperature, different concentrations of AFB1 standard solution are added into the reaction buffer containing 10 μM AFB1 aptamers, 25 μM TPE-Z and 40 μg/mL GO. After reaction, the fluorescence intensity is recorded at 480 nm with excitation at 340 nm. Each concentration is measured in three times.

2.5. Specificity of the fluorescent chemosensor for AFB1 detection

The AFB1 aptamer is dissolved in Tris-HCl buffer and heated to 90 °C for 5 min. After cool to room temperature, AFB1, mycotoxins (OTA, FB1) or protein (BSA) is added into the reaction buffer containing 10 μM AFB1 aptamers, 25 μM TPE-Z and 40 μg/mL GO. The final concentration of OTA or FB1 or BSA is 500 ng/mL. While the final concentration of AFB1 in the mixture solution of OTA and AFB1 or the mixture solution of FB1 and AFB1 or the mixture solution of BSA and AFB1 is 50 ng/mL.

2.6. Analysis of AFB1 in food samples (milk, corn and rice)

The extraction of AFB1 from food samples is according to patent (GB5009.22–2016). A 1 g finely pulverized milk, corn or rice powder is extracted with 4 mL methanol-water (70:30, v/v), stirring for 1 h at 30 °C and then centrifugated at 12,000 rpm for 10 min at 4 °C. 1.5 mL supernatant is taken and filtered through a disposable syringe filter (0.45 μm). Then the filtrate diluted into 3 mL Tris-HCl buffer to minimize matrix and methanol influence. Finally, different concentration of AFB1 standard solution is added into the diluted extracts. Eventually, the results of the proposed method are validated using HPLC method.

2.7. The HPLC method for determination of AFB1 in food samples (milk, corn and rice)

A 20 μL sample is analysed using autosampler (Agilent), a fluorescence detector (Agilent) at an excitation wavelength 360 nm and an emission 440 nm, and a HPLC pump (Agilent). The current speed is 1 mL/min at 42 °C through a C^{18} ODS column (4.6 mm × 250 mm × 5 μm) with a guard column (Agilent). The mobile phase is acetonitrile/methanol/water. All these solvents are filtered through a 0.45 μm filter.

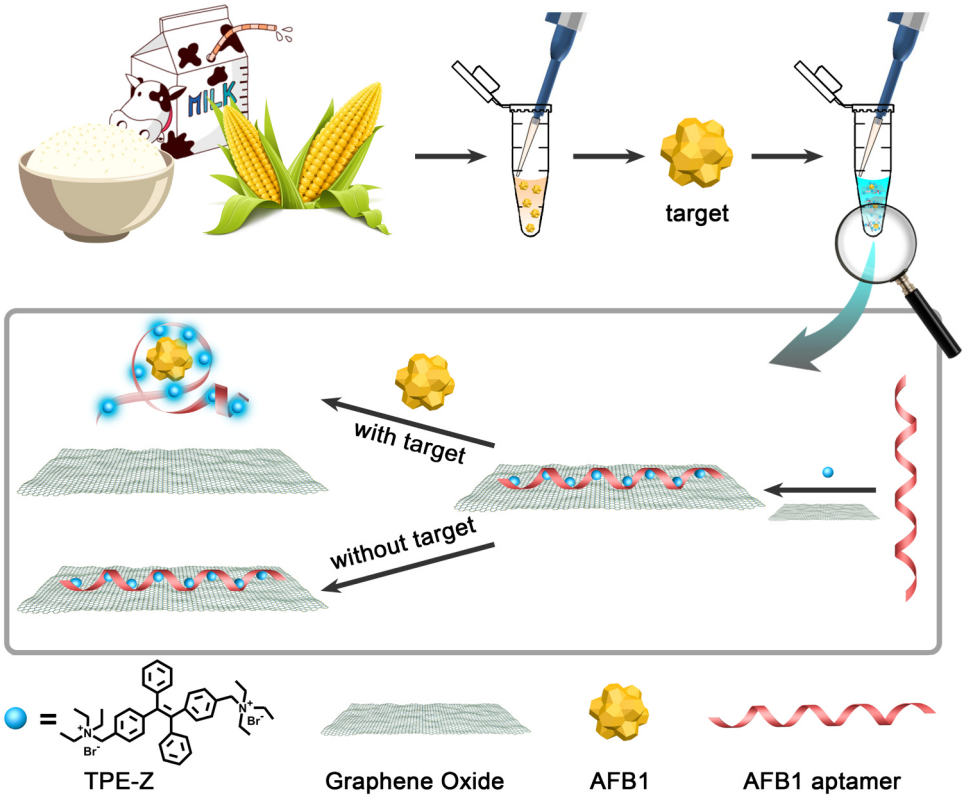
3. Results and discussion

3.1. Design of the label-free fluorescent aptasensor TPE-Z/AFB1 aptamer/GO

Here, we develop a label-free fluorescent aptasensor TPE-Z/AFB1 aptamer/GO for the detection of AFB1 by using AIEgens and GO (Scheme 1). The sensor is almost non-fluorescence in the Tris-HCl buffer solution as a result of electron-transfer process between GO and TPE-Z. Upon the addition of AFB1 to the mixture, AFB1 aptamer undergoes a conformational switch from single stranded structure to the AFB1/AFB1 aptamer complex upon target binding, which induces the release of TPE-Z/AFB1 aptamer from the surface of GO. Thus, the fluorescence of TPE-Z/AFB1 aptamer is recovered. On the other hand, the addition of other aflatoxins cannot induce the structure change of AFB1 aptamer and TPE-Z/AFB1 aptamer remains adsorb on the surface of GO, which results in non-emission of TPE-Z/AFB1 aptamer due to the quenching effect of GO. Therefore, AFB1 can be detected by monitoring the fluorescence intensity change of TPE-Z/AFB1 aptamer.

3.2. Optimization of experiment conditions

The TPE-Z molecules bind to AFB1 aptamer through a non-specific coulomb force between negatively charged AFB1 aptamer and positively charged TPE-Z molecules. Quenched TPE-Z molecules become highly luminescent after binding to DNA via electrostatic and π-π interactions with AFB1 aptamer, which occur due to their high surface charge density. To verify the feasibility of this strategy, we carry out a series of experiments. As shown in Fig. S1, the fluorescence intensity of TPE-Z increases rapidly upon adding AFB1 aptamer. With increasing concentration of AFB1 aptamer, the fluorescence intensity of TPE-Z increases dramatically and then tends to stabilize when the concentration of AFB1 aptamer reaches to 10 μM. Therefore, a



Scheme 1. The schematic diagram of the label-free aptasensor TPE-Z/AFB1 aptamer/GO for AFB1 detection in food samples (corn, milk and rice).

concentration of AFB1 aptamer at 10 μM is chosen for the subsequent experiments.

Introducing GO to the fluorescence detection platform could afford lower background, while, higher concentration of GO might result in lower fluorescence recovery. Thus, the amount of GO adjusts with the complex TPE-Z/AFB1 aptamer is also investigated. Fig. 1A shows the fluorescence signal change of TPE-Z/ aptamer in the presence of different concentration of GO. When the GO suspension is added into the TPE-Z/AFB1 aptamer solution, the fluorescence signal of TPE-Z is rapidly quenched. With the increasing amounts of GO, the fluorescence signal of TPE-Z decreases dramatically and then tends to stabilize when the concentration of GO reaches to 40 μg/mL. The results indicate that 40 μg/mL GO is enough for quenching the fluorescence intensity of the aggregation complex base on TPE-Z and AFB1 aptamer (Fig. 1B). Therefore, the experimental concentration of GO in the assay is 40 μg/mL.

3.3. Sensing property of TPE-Z/AFB1 aptamer/GO to AFB1

To achieve the best sensing platform, the fluorescence experiments are carried out. As illustrate in Fig. 2A, the fluorescence intensity of TPE-Z/AFB1 aptamer enhances more than 14 times in the presence of 150 ng/mL AFB1 compared to the system that without AFB1. In the absence of AFB1, the system shows almost non-fluorescence for the aggregation complex (TPE-Z/AFB1 aptamer) is absorbed on the surface of GO. Upon the addition of AFB1 to the mixture, AFB1 aptamer

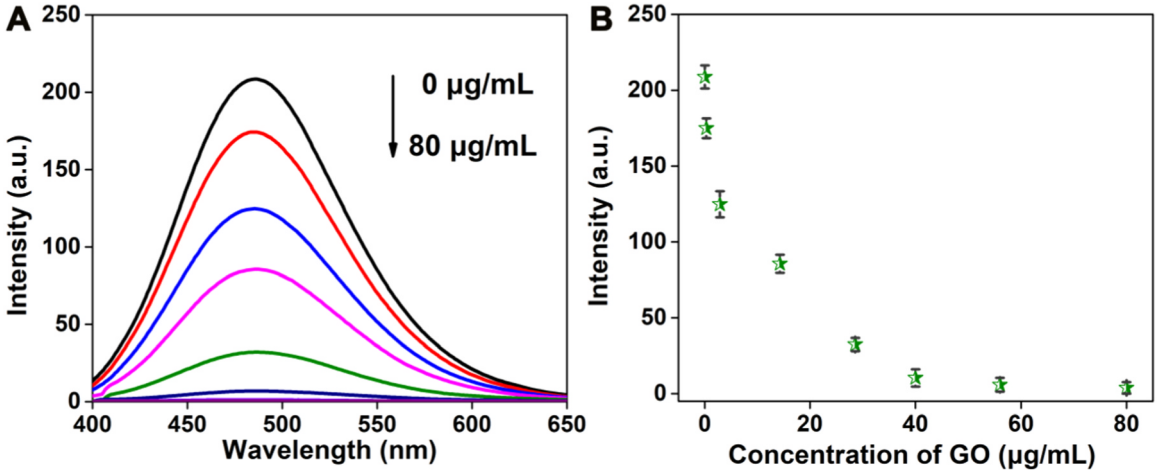


Fig. 1. (A) Fluorescence emission spectra and (B) fluorescence intensity of TPE-Z/AFB1 aptamer with the concentration of GO from o to 80 μg/mL in reaction buffer. Excitation and emission are at λex/λem = 340/480 nm. Conditions are as fllowing: 10 μM AFB1 aptamer and 25 μM TPE-Z in Tris-HCl buffer (10 mM Tris, 120 mM NaCl, 5 mM KCl, pH 7.0).

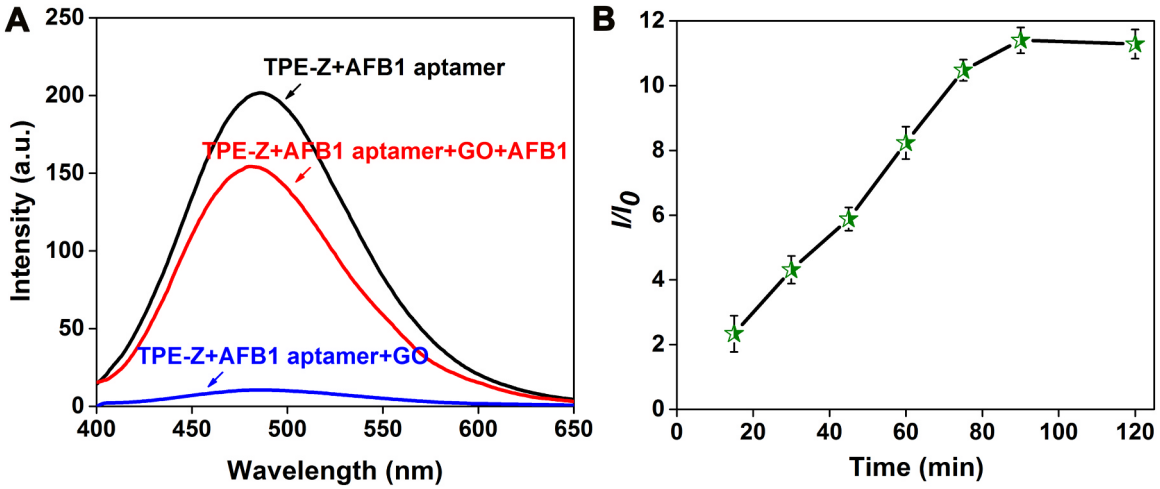


Fig. 2. (A) Fluorescence emission spectra of TPE-Z in the presence of AFB1 aptamer (black), AFB1 aptamer/GO (red), and AFB1 aptamer/GO (blue). (B) The fluorescence intensity ratio of TPE-Z with respect to the reaction time in the presence of AFB1 aptamer, GO and AFB1. Excitation and emission are at λex/λem = 340/480 nm. Conditions are as fllowing: 10 μM AFB1 aptamer, 25 μM TPE-Z, 40 μg/mL GO and 150 ng/mL AFB1 in Tris-HCl buffer (10 mM Tris, 120 mM NaCl, 5 mM KCl, pH 7.0).

undergoes a conformational switch from single stranded structure to the aptamer/target complex upon target binding, which induces the release of TPE-Z/AFB1 aptamer from the surface of GO. Thus, the fluorescence of TPE-Z/AFB1 aptamer is recovered. To achieve the best sensing platform, the buffer and incubation temperature are also optimized (Figs. S2–3). After identifying the label-free fluorescent aptasensor TPE-Z/AFB1 aptamer/GO for AFB1 assay, we investigate the effect of time on the fluorescence intensity change (Fig. S4). As shown in Fig. 2B, the fluorescence intensity significantly increases in the time range of 0–120 min and the signal reach the maximum at 90 min. Therefore, the time point of 90 min is selected for the detection of AFB1 in the following experiments.

3.4. Quantitative detection of AFB1

The sensitivity of a method is a key parameter for determining its applicability. To evaluate the sensitivity for AFB1 assay, different concentrations of AFB1 are added to the mixture of TPE-Z/AFB1 aptamer/GO. As shown in Fig. 3A, the fluorescence intensity of TPE-Z/AFB1 aptamer increases gradually with increasing concentration of AFB1, a good linear relationship is observed in the range of 0–3 ng/mL (Fig. 3B). The detection limit is estimated to be 0.25 ng/mL base on 3σ/S calculation [6] (σ is the standard deviation for the blank solution, and S is the slope of the calibration curve). This LOD meets the AFB1 detection requirement of the European Commission regulations in food [40]. These results imply that the label-free fluorescent aptasensor TPE-Z/AFB1 aptamer/GO can be used as sensitive assay for the detection of AFB1 (Fig. S5).

Notably, compared with other methods base on aptamer for the detection of AFB1, the present label-free fluorescent aptasensor TPE-Z/AFB1 aptamer/GO can be performed by simply mixing TPE-Z, AFB1 aptamer, the GO and the AFB1 samples. It does not require covalent functionalization with biomolecules, allowing for rapid label-free detection (Table 1). The detection limit in this work is superior to other previous report detection methods. Therefore, TPE-Z/AFB1 aptamer/GO has a potential ability to be applied to detect AFB1 in food samples.

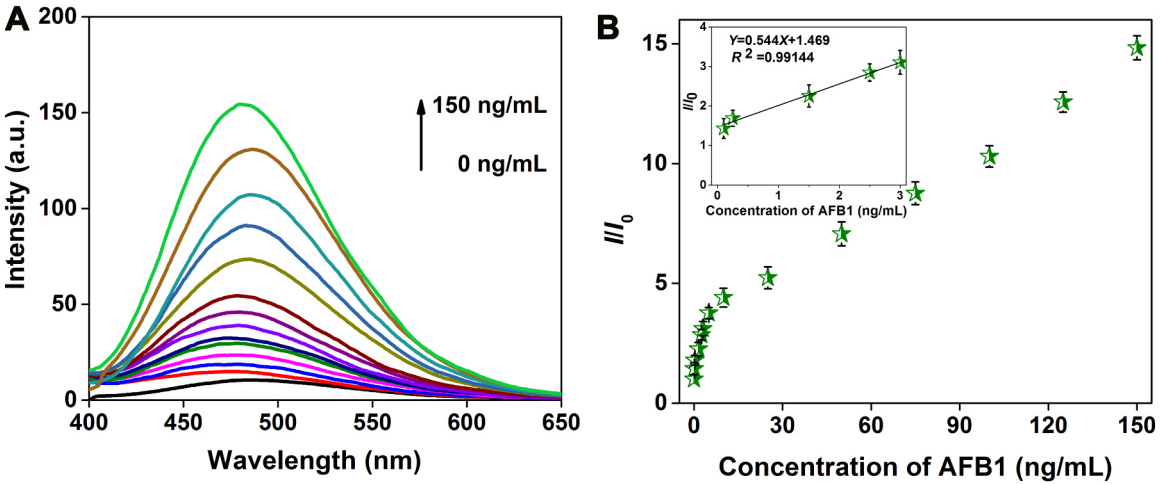


Fig. 3. (A) Fluorescence emission spectra of this sensing system in the response to AFB1 at various concentrations (from bottom to top): 0, 0.1, 0.25, 1.5, 2.5, 3, 5, 10, 25, 50, 75, 100, 125, 150 ng/mL; (B) The linear relationship between the fluorescence enhancement of TPE-Z and the concentration of AFB1. Every data point is the mean of three measurments. The error bars are the standard deviation. Excitation and emission are at λex/λem = 340/480 nm. Conditions are as fllowing: 10 μM AFB1 aptamer, 25 μM TPE-Z and 40 μg/mL GO in Tris-HCl buffer (10 mM Tris, 120 mM NaCl, 5 mM KCl, pH 7.0).

Table 1
Comparison of the developed methods with other aptamer based methods for the detection of AFB1.

Method	Recognition probe	Step	Time (h)	LOD (ng/mL)	Ref.
Chemiluminescence	Dual-labeled	4	> 12	0.1	[41]
Electrochemical	Dual-labeled	4	> 10	0.1	[42]
FRET-based Aptasensor	Dual-labeled	3	< 1	1.6	[6]
QD-aptamer-GO system	Single-labeled	3	< 1	0.3	[28]
DNaseI-based Aptasensor	Single-labeled	3	< 1	0.5	[43]
AIE-aptamer-GO system	Label-free	1	1.5	0.25	Our work

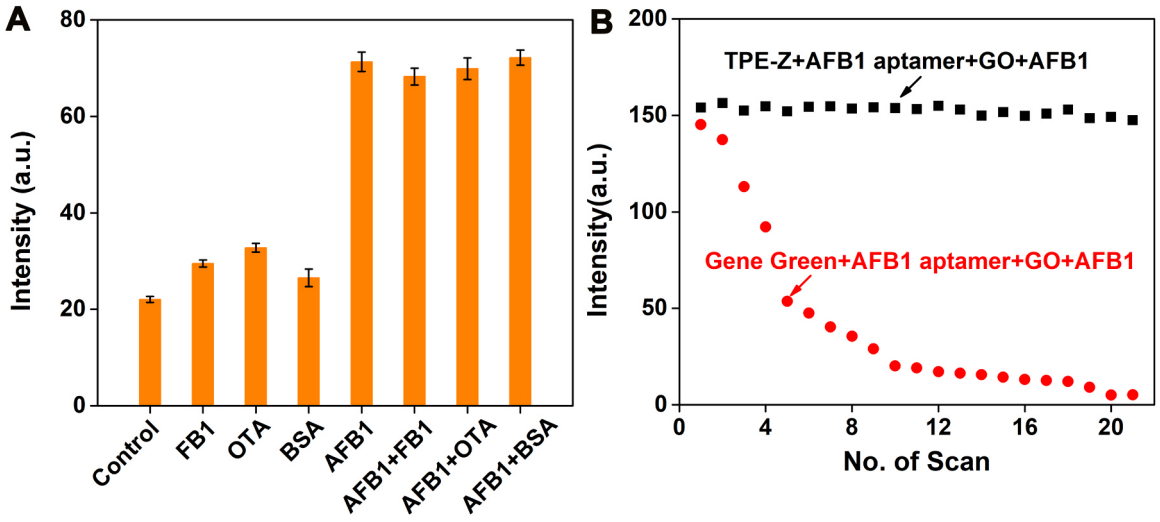


Fig. 4. (A) Selectivity of the designed sensing system for AFB1. (B) The fluorescence intensity of TPE-Z (black square) and Gene Green (red circle) in the presence of AFB1 aptamer, GO and AFB1 with increasing number of scans. Excitation and emission are at λex/λem = 340/480 nm. Conditions are as fllowing: 10 μM AFB1 aptamer, 25 μM TPE-Z, 40 μg/mL GO and 50 ng/mL AFB1 in Tris-HCl buffer (10 mM Tris, 120 mM NaCl, 5 mM KCl, pH 7.0). The concentration of other interferes (FB1, OTA or BSA) are 500 ng/mL.

3.5. Selectivity and photostability

To investigate the selectivity, the sensor is determined by exposing it to the similarity structural mycotoxins (OTA and FB1) or protein (BSA). As shown in Fig. 4A, the fluorescence intensity of TPE-Z/AFB1 aptamer is measured in the presence of OTA, FB1, BSA and AFB1 under the identical conditions. Although the concentration of OTA, FB1 or BSA (500 ng/mL) is 10 times higher than that of AFB1 (50 ng/mL), only AFB1 could cause an obvious fluorescence increase. Adding AFB1 (50 ng/mL) to the mixture of OTA, FB1 or BSA (500 ng/mL), the fluorescence intensity of TPE-Z/AFB1 aptamer almost unchanged compared to only AFB1, though their concentrations are 10 times higher that of AFB1. It indicates that OTA, FB1 or BSA in solution does not interact with TPE-Z/AFB1 aptamer, thus TPE-Z/AFB1 aptamer adsorbs on the surface of GO, and the fluorescence of TPE-Z/AFB1 aptamer is quenched for the fluorescent quenching effect of GO. Only AFB1 can interact with TPE-Z/AFB1 aptamer and form an aptamer/target complex, which induces the release of TPE-Z/AFB1 aptamer from the surface of GO. The fluorescence of TPE-Z/AFB1 aptamer is recovered. Therefore, the label-free fluorescent aptasensor TPE-Z/AFB1 aptamer/GO has demonstrated an excellent selectivity for the detection of AFB1, indicating its potential application for analysis of complex samples.

To further evaluate its value for AFB1 detection, photostability of this method is tested. As shown in Fig. 4B, the signal of TPE-Z remains stable even after 20 scans with a total irradiation time of 10 min. However, the fluorescence signal of commercialized Gene Green almost disappears within 10 scans. The above results suggest that our method indeed has superior photostability and is suitable for AFB1 detection in a long time.

3.6. Mechanism study for AFB1 detection

To investigate the sensing mechanism, UV–vis absorption spectroscopy is performed to characterize the absorption bands of DNA sequence (256 nm) and TPE-Z (320 nm). When we add GO to the solution of TPE-Z/AFB1 aptamer, the absorbance of TPE-Z at 320 nm decrease (red line) and the peak position redshift, suggesting that TPE-Z/AFB1 aptamer is adsorbed on the surface of GO [44] (Fig. 5A). While, introducing AFB1 to the solution of TPE-Z/AFB1 aptamer/GO and incubating for 1.5 h, the absorption of TPE-Z increase and cause a blue shift (blue line) comparing with the absorption solution of TPE-Z/AFB1 aptamer/GO. To further study the sensing mechanism, circular dichroism (CD) spectra are recorded. As shown in Fig. S6, TPE-Z/AFB1 aptamer have a positive band at 277 nm. With the addition of GO into TPE-Z/AFB1 aptaemr complex, the positive band at 277 nm stays still. After the addition of AFB1, there is a negative band at 222 nm, suggesting that the formation of AFB1/TPE-Z/AFB1 aptamer complex changes the structure of TPE-Z/AFB1 aptamer [31,45]. These results illustrate that AFB1 is targeted to TPE-Z/AFB1 aptamer, forming the AFB1/TPE-Z/AFB1 aptamer complex and releasing from the surface of GO.

To better understand the interaction between TPE-Z/AFB1 aptamer, GO and AFB1 in solution, particle size analysis of the label-free fluorescent aptasensor TPE-Z/AFB1 aptamer/GO is measured. As shown in Fig. 5B, the individual particle size of TPE-Z/AFB1 aptamer is 105.71 nm, adding GO to the solution of TPE-Z/AFB1 aptamer, the individual particle size increase to 531.17 nm. This result demonstrates that TPE-Z/AFB1 aptamer is adsorbed on the surface of GO and formed a larger size class. When AFB1 is added to the TPE-Z/AFB1 aptamer/GO solution, the individual particle size is decreased to 91.28 nm. It

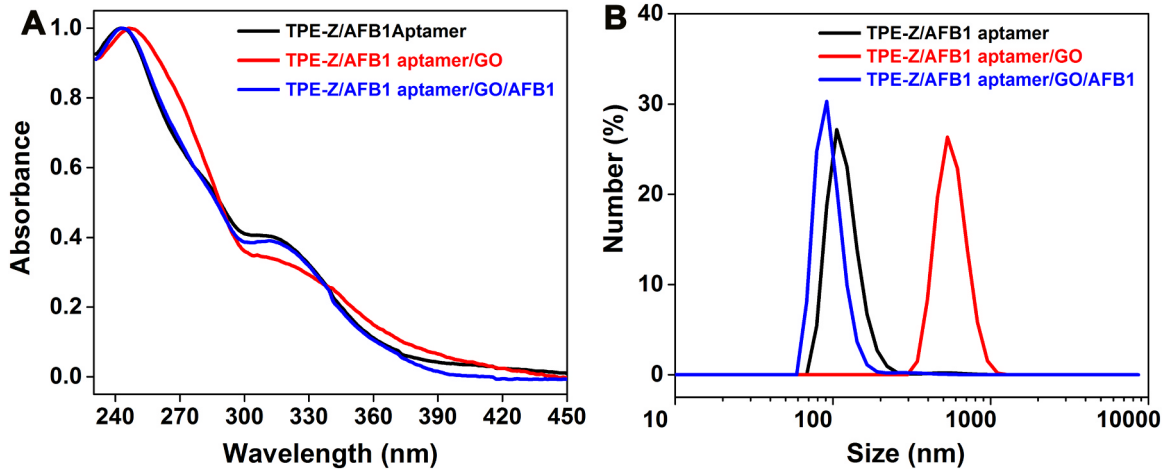


Fig. 5. (A) The UV–vis absorption spectroscopy and (B) particle size analysis of TPE-Z/AFB1 aptamer (black line), TPE-Z/AFB1 aptamer/GO (red line) and TPE-Z/AFB1 aptamer/GO/AFB1 (blue line). Conditions are as fllowing: 10 μM AFB1 aptamer, 25 μM TPE-Z, 40 μg/mL GO and 150 ng/mL AFB1 in Tris-HCl buffer (10 mM Tris, 120 mM NaCl, 5 mM KCl, pH 7.0).

Table 2
Detection of AFB1 in food samples by HPLC and our proposed method.

Sample	Added (ng/mL)	HPLC measured mean[a] ± SD[b] (ng/mL)	Proposed method mean[a] ± SD[b] (ng/mL)	Recovery (%)
Milk	0.00	n[c]	n[c]	/
	1.92	1.685 ± 0.064	1.764 ± 0.041	91.89
	3.84	3.436 ± 0.072	3.508 ± 0.048	91.36
Corn	0.00	n[c]	n[c]	/
	1.92	1.834 ± 0.039	1.799 ± 0.026	93.68
	3.84	3.681 ± 0.043	3.548 ± 0.062	92.39
Rice	0.00	n[c]	n[c]	/
	1.92	1.825 ± 0.027	1.799 ± 0.057	93.72
	3.84	3.761 ± 0.031	3.652 ± 0.061	95.11

[a] The mean of three determinations.
[b] SD = standard deviation.
[c] no AFB1 concentration is detected.

demonstrates that AFB1 is targeted to TPE-Z/AFB1 aptamer, forming the AFB1/TPE-Z/AFB1 aptamer complex and releasing from the surface of GO.

3.7. Detection of AFB1 in food samples

To further demonstrate the application potential of our method for the detection of AFB1 in food samples (milk, corn and rice). The food samples are extracted with methanol-water, centrifuged and filtered through a disposable syringe filter. The supernatants are used for the quantitative analysis. AFB1 is not detected in these food samples (milk, corn and rice) for the concentration of AFB1 is much lower than the detection limit of the label-free fluorescent aptasensor. Therefore the food samples are spiked with standard AFB1 solution at different concentration levels (Fig. S7–9). For comparison, the amount of AFB1 is measured by the commercial HPLC method (Fig. S10). It is found that the average recoveries of AFB1 in the food samples (milk, corn and rice) for the proposed method are in the range of 91.36–95.11% (Table 2). There is no significant difference between the results obtain from the proposed method and the commercial HPLC method. The experimental results verified that the label-free fluorescent aptasensor TPE-Z/AFB1 aptamer/GO can be applied for the quantitative determination of AFB1 in actual food samples (milk, corn and rice).

4. Conclusions

In conclusion, we have developed a novel fluorescent AFB1 detection method in combination AFB1 aptamer, the GO and TPE-Z. It is a label-free and turn-on fluorescent AFB1 detection method involving the principles of AFB1/AFB1 aptamer binding, the fluorescent quench ability of GO and the Aggregation-Induced Emission character of TPE-Z. The introducing GO and TPE-Z, allows creating low background fluorescence signal and photostability, which is a great advantage for the detection of AFB1. In comparison to other aptamer based methods for the detection of AFB1, the method doesn't need to label or modify AFB1 aptamer, reducing the cost and complexity. It can be used to detect AFB1 by simply mixing AFB1 aptamer, the GO, TPE-Z molecules and the AFB1 samples with high sensitivity (0.25 ng/mL) and selectivity. The performance of the method has been demonstrated in food samples (milk, corn and rice) spiked with known concentration of AFB1. Therefore, the label-free fluorescent aptamer sensor TPE-Z/AFB1 aptamer/GO has great potential applications in the field of food safety.

Acknowledgements

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.talanta.2019.01.078.

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