



Bottle-in-bottle reaction device: Portable gas pressure meter for rapid and on-site analysis of oxalate in spinach and tea beverages

Jiayuan Tang^a, Dali Zhuo^a, Xiaoyu Dong^a, Jing Xiao^a, Shu Zhang^a, Xiaoli Xiong^a, Chao Tan^{b,*}, Zhirong Zou^{a,b,*}

^a Key Laboratory of the Evaluation and Monitoring of Southwest Land Resources (Ministry of Education), College of Chemistry and Material Science, Sichuan Normal University, Chengdu, Sichuan, 610068, China

^b Key Lab of Process Analysis and Control of Sichuan Universities, Yibin University, Yibin, Sichuan, 644000, China

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ABSTRACT

A gas pressure meter-based portable/miniatuized analytical kit was established for rapid and on-site detection of oxalate. Potassium permanganate (KMnO₄) and oxalate solution were mixed together in bottle-in-bottle reaction device, a simple oxidation reaction process occurred within 6 min and carbon dioxide (CO₂) was generated, inducing the pressure of the sealed bottle changed, which was measured by a portable gas pressure meter. A detectable range of 0.1–6 μmol mL⁻¹ and a detection limit of 0.064 μmol mL⁻¹ were achieved. The proposed analytical method was further used for the analysis of several real samples (spinach, beverages and water samples), with the recoveries of 89–111%. Considering the interferences from the complicated matrix, calcium chloride (CaCl₂) was served as a precipitant, oxalate (C₂O₄²⁻) was precipitated with Ca²⁺ to form precipitation (CaC₂O₄), CaC₂O₄ was then separated from the matrix by centrifuge/filter, eliminating the interferences. It is a rapid, easy-used and interference-free analytical system/device for oxalate on-site and real time analysis.

1. Introduction

Oxalic acid (H₂C₂O₄) is the simplest binary carboxylic acid and its oxalate form can be found in various plants and foods (Savage, Vanhanen, Mason, & Ross, 2000). The soluble oxalic acid can combine with Ca²⁺ and Mg²⁺ to form insoluble oxalate, which can cause kidney stones (urolithiasis) (Bong, Vanhanen, & Savage, 2017). According to the survey, 80% of the kidney stones are oxalic acid stones (Chen et al., 2023; Jiang et al., 2006), so that the intake of oxalate should be monitored accurately in our daily lives. The daily medium-intensity oxalate intake is 250 mg, while 50–100 g of spinach can cause about 500–1000 mg of oxalic acid salt load and significantly increase the excretion of urine oxalate (Mitchell et al., 2019). Long-term intake of fruit and vegetable juices that containing high level of oxalate, may cause acute kidney injury for normal person (Chaudhari et al., 2022). Therefore, developing a portable and rapid analytical method/device for oxalate monitoring in our daily lives is demanded, especially for urolithiasis patients.

Conventional analytical methods used for oxalate detection, including high-performance liquid chromatography-mass spectrometry

(Perelló, Sanchis, & Grases, 2005), ion chromatography-chemiluminescent method (Maya, Estela, & Cerdà, 2010), visual colorimetric method (Chen et al., 2023), fluorescent methods (Hu et al., 2024; Yang et al., 2024) and electrochemical methods (Arantes et al., 2023; Nagarajan & Sundramoorthy, 2019) etc. It should be pointed out that those methods exhibit good sensitivity and selectivity for oxalate detection, while their limitations also should not be ignored, such as bulky instruments, sophisticated operations and high consumptions etc. There is no doubt that a portable/miniatuized, easy-used and low-cost analytical system/device was needed for on-site and real time analysis of oxalate.

In recent years, the miniaturization of analytical instruments/devices have attracted much attention, smartphone-based analytical system (Jin et al., 2020), colorimetric lateral flow strip (Huang et al., 2023) and miniaturized point discharge atomic emission spectrometry (Yang et al., 2023) etc. were developed for oxalate detection. Yang et al. (2023) developed a cation-modulated Hg²⁺ strategy via chemical vapor generation for oxalate detection in clinical urolithiasis samples by miniaturized point discharge atomic emission spectrometry. Jin et al. (2020) proposed a smartphone-based lab in hydrogel portable kit for on-site

* Corresponding authors.

E-mail addresses: chaotan1112@163.com (C. Tan), zouzhirong@sicnu.edu.cn (Z. Zou).

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monitoring of oxalate in urine sample. Huang et al. (2023) developed an enzyme-based color bar-style lateral flow strip for equipment-free and semi-quantitative detection of urinary oxalate, no any image acquisition or processing equipment was required.

Gas pressure meter is a portable detector for measuring the pressure generated by a gas-generation reaction during chemical and biochemical processes, providing the advantages of portability, low-cost and high sensitivity (signal amplification), it is an ideal candidate for on-site rapid analysis (Liu et al., 2020; Zhang, Lan, & Lu, 2020). Portable pressure meter was initially demonstrated as signal readout for highly sensitive bioanalysis by Yang's group. It is a new strategy for highly sensitive bioanalysis (Zhu et al., 2015). A series of gas pressure meter-based analytical systems were developed for the analysis of microRNA (Shi et al., 2018), ions (Xiao et al., 2024; Zhi, Zhang, Li, Tu, & Lu, 2022), pathogenic bacteria (Li, Xue, Zhang, He, & Fu, 2022) and small molecules (Liu et al., 2017) etc. Li et al. (2022) developed a gas pressure sensor for multiplexed detection of pathogenic bacteria with shape-encoded functional hydrogel pellets. Zhi et al. (2022) developed a portable sensing platform based on an Au nanoparticle-decorated WO₃ hollow nanoflower for sensitive and selective detection of Hg (II) with a pressure, temperature and colorimetric triple-signal readout. Fortunately, to our knowledge, gas pressure meter-based analytical system applied to oxalate rapid detection has not yet reported.

Herein, a rapid and portable instant detection strategy for C₂O₄²⁻ in food samples was developed based on simple KMnO₄ oxidation reaction. Under acidic condition, C₂O₄²⁻ was oxidized to CO₂ by MnO₄⁻. The generated CO₂ caused the changes of gas pressure in sealed vessels. The final pressure values in the vessels were monitored via a gas pressure meter. The pressure changes were proportional to C₂O₄²⁻ concentration in the range of 0.1–6 μmol mL⁻¹ and a detection limit of 0.064 μmol mL⁻¹ was achieved. This system was further utilized for the detection of oxalate in spinach, beverages and water samples, with recoveries of 89%–111%. Besides, this system was integrated in a miniaturized analytical kit for meeting the demand of rapid and on-site detection of oxalate in food samples. It is a potential portable analytical device for oxalate analysis.

2. Experimental

2.1. Reagents and apparatus

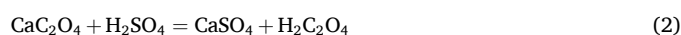
All chemical reagents used here were analytical grade unless other noted. KMnO₄, CaCl₂, MnSO₄·H₂O, H₂C₂O₄·2H₂O, Na₂C₂O₄, H₂SO₄ were obtained from Kelong (Chengdu, China). Lake water was collected from East Lake and river water was collected from Jinjiang River. Tap water and rain water were collected from our campus. Two spinach samples (S1 and S4) and two tea beverage samples (Jasmine tea (T1) and Oolong tea (T4)) were purchased separately from food market and local supermarket. BWJ 4209–2016 was purchased from Weiye Metrology (Beijing China). Deionized water (DIW, 18.25 MΩ·cm) was produced by a water purification system (Chengdu Ultrapure Technology Co., Ltd., Chengdu, China).

Gas pressure meter (PASSTECH, Xiamen, China) was served as a portable detector. Adjustment of pH was made using a digital desktop acidity meter (PHS-3C, Digital Benchtop Acidimeter, Shanghai Pu Chun Measuring Instrument, Co. Ltd., China). Circumferential shaker (Model: SN-HYC-210S, Circumferential shaker, Shanghai ShangPu Instrument Co. Ltd., China) was used for providing the shaking process. Medical freezer centrifuge (TGL-21, Medical freezer centrifuge, Sichuan Shuke Instrument Co. Ltd., China) was used for separating precipitation (CaC₂O₄).

2.2. Sample preparations

(1) Vegetable samples: according to the previous literature (Chai & Lieberman, 2005), the procedures of sample preparation were as follows

(Scheme 1a): **Step I (Cooking):** 20 g chopped spinach were added in a cone-shaped bottle, and then added 200 mL DIW and swamped the spinach sample, the cone-shaped bottle was placed in a constant temperature water bath (100 °C), the cooking time was 12 min, computed from when the steam became visible; **Step II (Precipitation):** chopped spinach in liquid were removed, and the obtained liquid was cooled to room temperature. 50 mL the obtained solution and 1 mL CaCl₂ (3 mol L⁻¹) were added in a centrifuge tube, a white precipitation (CaC₂O₄) was obtained after the solutions were mixed (reaction 1). **Step III (Separation):** this suspension was shake well, transferred 4 mL the suspension solution to a syringe and filtered by a 0.22 μm filter membrane (repeat 6 times, total volume: 24 mL), CaC₂O₄ (on filter) was thus obtained. **Step IV (Dissolution):** the filter membrane (CaC₂O₄ was held on the filter) was then removed to a centrifuge tube, 1 mL H₂SO₄ (3 mol L⁻¹) was added subsequently, and CaC₂O₄ was thus dissolved (reaction 2). In order to obtain a solution with same volume as the original, 23 mL DIW was added. The pH of the solution was adjusted to 2 before analysis.



(2) Water samples and tea beverage samples: four environmental water samples (tap water, rain water, river water and lake water) and two tea beverage samples (Jasmine tea and Oolong tea) were analyzed here. 50 mL sample (containing C₂O₄²⁻) and 1 mL CaCl₂ (3 mol L⁻¹) were added in a centrifuge tube, reacted for a period of time, the CaC₂O₄ precipitation was obtained after centrifugation (9000 r/min for 10 min at room temperature). The filtrate was removed subsequently. 1 mL H₂SO₄ (3 mol L⁻¹) was added to the centrifuge tube and reacted with CaC₂O₄, the precipitation was dissolved. The obtained solution was diluted to 50 mL using a volumetric flask. The solution was adjusted to pH = 2 before analysis. The certified reference water sample (BWJ 4209–2016, 1000 μg mL⁻¹) was diluted to 250 μg mL⁻¹ (2.84 μmol mL⁻¹). Then, the pH of the solution was adjusted to 2 before analysis.

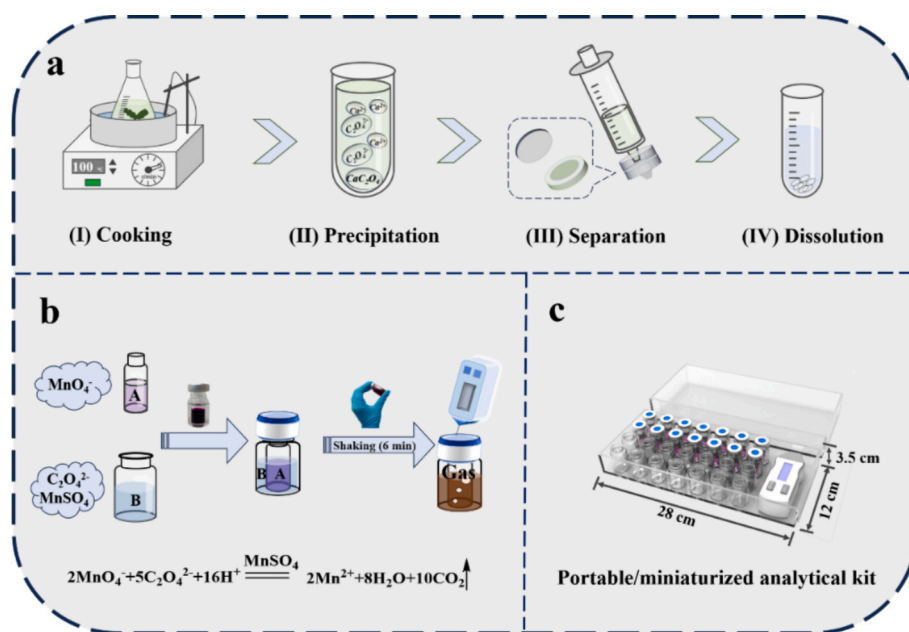
2.3. Analytical procedures

The analytical procedures were presented in Scheme 1b (**Note: all of analytical procedures were processed at room temperature**). **First of all**, 1 mL 0.02 mol L⁻¹ KMnO₄ solution was added into a 1.5 mL bottle (bottle A). 4 mL oxalic acid standard solution or sample (pH = 2) and 0.2 mL of MnSO₄ (20 mmol L⁻¹) were added into an 8 mL bottle (bottle B). **Secondly**, bottle A was placed in the bottle B, and then sealed the bottle B, a “bottle-in-bottle” reaction device was thus obtained (Scheme 1b). This gas-tight reaction device was shaken well of 6 min (hand or use a 200 r/min shaker). Mixing the solutions in bottle A and bottle B evenly, gas-generation reaction occurred and gases were generated in the sealed “bottle-in-bottle” reaction device, causing a significant change in pressure in sealed reaction bottle. **Finally**, the pressure values in “bottle-in-bottle” reaction devices were detected by a gas pressure meter at room temperature. For real samples, the calibration curve and sample analysis were performed at same batch. Detection step is usually completed within 10 min. The concentration of C₂O₄²⁻ in sample was calculated through the established calibration curve between gas pressures and C₂O₄²⁻ concentrations. Furthermore, this analytical method was integrated in a portable analytical kit for meeting the demand of on-site and real-time analysis (Scheme 1c).

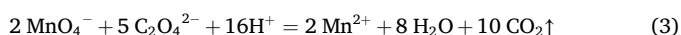
3. Results and discussions

3.1. Detection principle and feasibility discussion

The schematic diagram of this work for C₂O₄²⁻ detection was shown in Scheme 1. The reaction between MnO₄⁻ and C₂O₄²⁻ occurred under acidic condition, CO₂ was generated during the reaction, as shown in reaction 3:



Scheme 1. (a) The procedures of sample preparation for spinach. (b) Analysis of $\text{C}_2\text{O}_4^{2-}$ by portable gas pressure meter. (c) The model of miniaturized analytical kit.



In sealed reaction bottle, significant pressure change was caused by a gas-generation reaction, the pressure change can be readily readout by a gas pressure meter (Liu et al., 2020). In this work, CO_2 was generated after reaction (reaction 3), with increase of $\text{C}_2\text{O}_4^{2-}$ concentrations, pressures in bottles were proportional increased, the analysis of $\text{C}_2\text{O}_4^{2-}$ by a gas pressure meter was thus achieved.

The feasibility of this experiment was also discussed here. The signal responses of 6 conditions were performed in Fig. S1. No obvious signals were observed for those 5 conditions, including (1) $\text{C}_2\text{O}_4^{2-}$ alone; (2) KMnO_4 alone; (3) MnSO_4 alone; (4) $\text{C}_2\text{O}_4^{2-} + \text{KMnO}_4$ and (5) $\text{C}_2\text{O}_4^{2-} + \text{MnSO}_4$, demonstrating no gases were generated during those conditions. A notable signal was observed only when all three reactants were mixed together ((6) $\text{C}_2\text{O}_4^{2-} + \text{KMnO}_4 + \text{MnSO}_4$), indicating the feasibility of this method for the analysis of $\text{C}_2\text{O}_4^{2-}$.

3.2. Optimization of experimental conditions

As above-mentioned, the detection principle of this work was presented as reaction 3, reaction 3 occurred under acidic condition, so that pH was discussed here. As presented in Fig. 1a, with the gradual increase of the pH values, the pressure values were increased and then decreased, an optimized pH was obtained at pH = 2. As a result, pH = 2 was selected for the further experiments. Reaction 3 is a self-catalytic reaction (Lidwell & Bell, 1935), one of the products (Mn^{2+}) can be served as a catalyst to accelerate the reaction rate. In the early stage, the process of reaction is slow. With the increase of Mn^{2+} after reaction, the reaction rate was improved. As a consequence, the addition of MnSO_4 was considered for saving the reaction time. Unfortunately, overuse of MnSO_4 may cause serious pollution for water system (Chang et al., 2022; Hoyland, Knocke, Falkinham, Pruden, & Singh, 2014), so that the concentration of MnSO_4 was optimized. As shown in Fig. 1b, during the same reaction time, the pressure values were increased correspondingly to MnSO_4 concentration, and reached a steady subsequently. 20 mmol L^{-1} MnSO_4 was thus used in the next experiments. Reaction time is another potential parameter that may affect the accuracy of this work. In order to shorten the reaction time and obtain the maximum gas pressure value, reaction time was also optimized (Fig. 1c). As the reaction time increased, the gas pressures were also increased and reached the platform at 6 min, as a result, the optimal reaction time was 6 min.

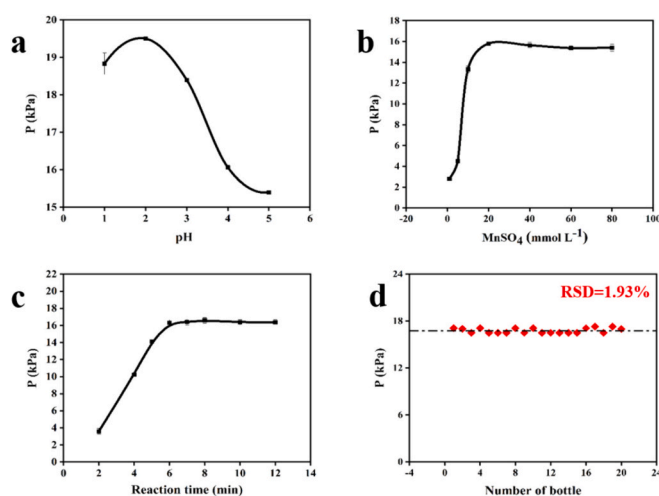


Fig. 1. The optimized conditions for $\text{C}_2\text{O}_4^{2-}$ (4 mL, 5 $\mu\text{mol mL}^{-1}$): (a) pH, (b) MnSO_4 concentration, (c) reaction time, (d) the stability of this work ($n = 20$).

Therefore, the optimal experimental conditions were presented as: pH = 2; concentration of MnSO_4 : 20 mmol L^{-1} and reaction time: 6 min. A good stability of this work was obtained under above-mentioned conditions (Fig. 1d). 20 parallel samples were tested at the same time. An average gas pressure value of 16.8 kPa ($n = 20$, relative standard deviation (RSD) = 1.93%) was obtained.

3.3. Interferences elimination

In this work, oxalate in vegetables and beverages were analyzed based on reaction 3, oxalate was oxidized to CO_2 , in the sealed vessels, the generated gas caused the pressure increased, the pressure changes were detected via a gas pressure meter. Unfortunately, for vegetables and beverage samples, their matrix are complicated. Various organic substrates from the samples (e.g. vitamins and chlorophyll etc.) also can be oxidized to CO_2 by KMnO_4 , which may affect the detection of oxalate by gas pressure meter. Therefore, it is necessary to process a pretreatment for samples. Fortunately, $\text{C}_2\text{O}_4^{2-}$ can be precipitated with Ca^{2+} to

form precipitation (CaC_2O_4), separating from the complicated matrix by centrifugation/filter. The obtained CaC_2O_4 precipitation can be dissolved in H_2SO_4 to obtain a solution containing oxalate again. As a result, the interferences from complicated matrix were efficient eliminated.

The feasibility of the above-mentioned pretreatment was discussed. As shown in Fig. 2a, two conditions were compared: (I) $\text{Na}_2\text{C}_2\text{O}_4$ ($5 \mu\text{mol mL}^{-1}$) reacted with KMnO_4 directly and (II) $\text{Na}_2\text{C}_2\text{O}_4$ reacted with Ca^{2+} and proceed as above-mentioned pretreatment (2.2 Sample preparations), both were monitored by gas pressure meter, and pressure values of 17.4 kPa and 16.1 kPa were obtained, respectively, no significant differences were observed, indicating the feasibility of the pretreatment. According to the relevant reference (Bong et al., 2017), CaCl_2 was selected as the source of Ca^{2+} . The effect of Ca^{2+} concentration was also investigated here (Fig. S2), with the increase of CaCl_2 concentration, the pressure values increased and reached a steady after CaCl_2 concentration was 0.3 mol L^{-1} , so that 0.3 mol L^{-1} was used. Besides, considering the reaction between oxalate and Ca^{2+} (reaction 1) is a reversible reaction, high concentration of Ca^{2+} may help improve the precipitation efficiency of oxalate. Therefore, the effect of multiples of Ca^{2+} concentration (0.3 mol L^{-1}) was further discussed and various multiples (1, 2, 4, 6, 8 and 10 times) were performed. As shown in Fig. 2b, 2-fold (0.6 mol L^{-1}) or higher concentrations of Ca^{2+} exhibit no obvious difference, their precipitation efficiencies were similar (94%–96%). 3 mol L^{-1} (10-fold) Ca^{2+} was selected for samples analysis, because of the contents of oxalate in samples are unknown and high concentration of Ca^{2+} help improve the precipitation efficiency of oxalate.

3.4. Analytical performance and sample analysis

The analytical performance of the portable gas pressure meter-based analytical system was evaluated under the optimized experimental conditions (Fig. 3). The gas pressure values were increased and proportional to $\text{C}_2\text{O}_4^{2-}$ concentrations. A linear range of $0.1\text{--}6 \mu\text{mol mL}^{-1}$ was obtained, its linear correlation coefficient (R^2) was 0.9990. According to the literatures (Chai & Liebman, 2005; Siener, Seidler, Voss, & Hesse, 2017), the oxalate concentrations in vast majority of the samples were within this linear range, meeting the demand for daily analysis. Besides, as above-mentioned, Mn^{2+} can be served as a catalyst to accelerate the reaction rate, the addition of Mn^{2+} can shorten the reaction time. In order to demonstrate the role of Mn^{2+} in this work, various concentrations of Mn^{2+} were added to the $\text{C}_2\text{O}_4^{2-}$ solutions. As shown in Fig. S3, the gas pressure values were almost same, no obvious changes were observed, indicating the role of Mn^{2+} was catalyst. It should be pointed out that the increased of Mn^{2+} amount can be further expanded the linear range of the proposed method under the original optimal reaction time (6 min). A wider linear range ($0.1\text{--}10 \mu\text{mol mL}^{-1}$, $R^2 \geq 0.99$) of $\text{C}_2\text{O}_4^{2-}$ was obtained when 100 mmol L^{-1} Mn^{2+} was used (Fig. S4). The new linear range was 1.7-fold of the original one (Fig. 3,

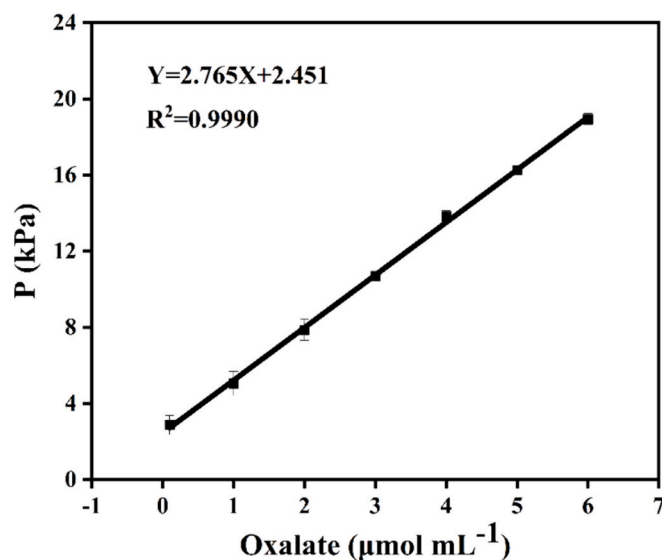


Fig. 3. Linear relationship between pressure values and oxalate concentrations. (Mn^{2+} concentration: 20 mmol L^{-1}).

Mn^{2+} concentration: 20 mmol L^{-1}). The limit of detection (LOD) of this method was $0.064 \mu\text{mol mL}^{-1}$, defined as 3 times the standard deviation of the signal (blank, $n = 11$) divided by the slope of the calibration curve. As a consequence, it also can expand the scope of application for oxalate detection in high concentration samples.

As shown in Table 1, the analytical performance of this method was also compared with other analytical techniques in terms of linear range, LOD and reaction time. Although the LOD of the proposed method was not as low as other methods thanks to the limitation of its detection principle. Fortunately, this method has covered the range of oxalate concentration in real food samples and it is adequate for monitoring the intake of oxalate in our daily lives. Obviously, compared with other reported works, the proposed method takes the advantages of rapidness, wide linear range and portability, it has great potential application for on-site and rapid analysis of $\text{C}_2\text{O}_4^{2-}$ in food samples.

For evaluating the application of this system for on-site detection of oxalate, several real samples (two spinach samples, two beverages, four water samples and a reference water sample) were analyzed based on standard addition method and quality control sample testing (Table 2). The contents of $\text{C}_2\text{O}_4^{2-}$ in water samples were not detected and their spiked samples were agreed with its added values, with recoveries of 89–111%. Two spinach samples and two beverages were analyzed by the proposed method, oxalate in spinach and beverages were detected, and their spiked values were agreed with the analytical results, recoveries ranging from 90% to 109%. A certified reference water sample (BWJ 4209–2016) was also verified here, the analytical result was in

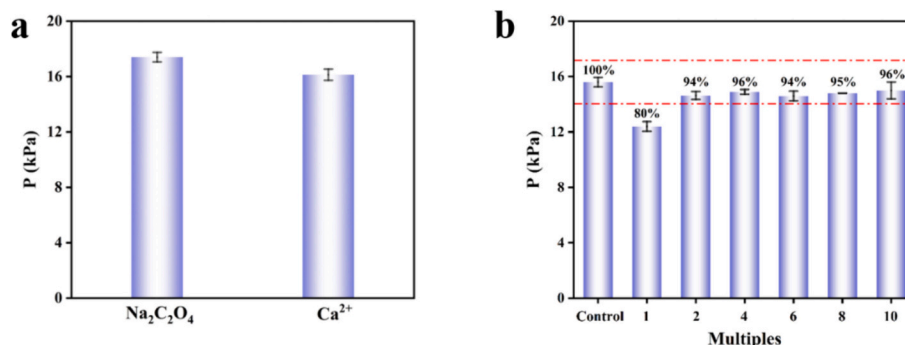


Fig. 2. Evaluation of Ca^{2+} precipitation efficiency. (a) Evaluation of feasibility ($\text{Na}_2\text{C}_2\text{O}_4$ concentration: $5 \mu\text{mol mL}^{-1}$), (b) effect of multiples of CaCl_2 concentration.

Table 1
Analytical figures of merit of this work for $C_2O_4^{2-}$ detection compared with other methods.

Methods	Linear range ($\mu\text{mol mL}^{-1}$)	LOD ($\mu\text{mol mL}^{-1}$)	Detection time (min)	Samples	Refs.
Electrochemical	0.001–0.8	0.001	22	Urine, serums, foods	(Pundir, Chauhan, Rajneesh, & M., & Ravi., 2011)
Electrochemical	0.1–1 and 1–100	0.033	>30	Spinach	(Fakhari, Rafiee, Ahmar, & Bagheri, 2012)
Electrochemical	0.05–3	0.023	>15	Urine	(Akhond, Absalan, Tafakori, & Ershadifar, 2016)
Paper-based colorimetric device	0.01–1	0.01	30	Urine	(Worramongkona et al., 2018)
Colorimetric lateral flow strip	0.3–0.7	<0.3	15	Urine	(Huang et al., 2023)
Colorimetric	0.0078–25	0.91×10^{-3}	15	Urine	(Gan et al., 2019)
Fluorescence	0.0001–1	0.025	6	Urine	(Jiang et al., 2023)
Fluorescence	0.001–0.05	0.69×10^{-3}	18	Urine	(Hu et al., 2024)
Portable gas pressure meter	0.1–10	0.064	6	Spinach, beverages, water samples	This work

Table 2
Analytical results of $C_2O_4^{2-}$ in real samples by portable gas pressure meter.

Samples	$C_2O_4^{2-}$ added/certified ($\mu\text{mol mL}^{-1}$)	Detected ($\mu\text{mol mL}^{-1}$)	Recovery (%)
Tap water (W1)	0	ND	-
(W2)	2	2.23 ± 0.21	111
(W3)	4	3.75 ± 0.10	94
Rain water (W4)	0	ND	-
(W5)	2	2.18 ± 0.13	109
(W6)	4	3.85 ± 0.06	96
Jinjiang river water (W7)	0	ND	-
(W8)	2	1.95 ± 0.02	98
(W9)	4	3.55 ± 0.02	89
East lake water (W10)	0	ND	-
(W11)	2	2.15 ± 0.66	108
(W12)	4	3.89 ± 0.37	97
Jasmine tea (T1)	0	ND	-
(T2)	2	1.87 ± 0.13	94
(T3)	4	3.88 ± 0.48	97
Oolong tea (T4)	0	0.94 ± 0.19	-
(T5)	2	2.95 ± 0.02	100
(T6)	4	4.79 ± 0.13	96
Spinach 1 (S1)	0	5.40 ± 0.01	-
(S2)	2	7.59 ± 0.25	109
(S3)	4	9.41 ± 0.61	100
Spinach 2 (S4)	0	4.76 ± 0.85	-
(S5)	2	6.83 ± 0.56	104
(S6)	4	8.36 ± 0.38	90
BJW 4209–2016	2.84^a	3.02 ± 0.54	106

ND: not detected. ^a diluted from BJW 4209–2016 ($1000 \mu\text{g mL}^{-1}$, $11.36 \mu\text{mol mL}^{-1}$).

accordance with its certified value, further demonstrating its accuracy and applicability.

4. Conclusions

A bottle-in-bottle reaction device was established for the determination of oxalate in foods, $KMnO_4$ and $C_2O_4^{2-}$ in separate bottles were mixed and reacted with each other, CO_2 was generated in sealed reaction bottle after reaction and caused the gas pressure changed, the pressure changes were readily detected by a gas pressure meter. Potential interferences from the complicated matrix were eliminated by a pretreatment process. A detectable linear range of $0.1\text{--}6 \mu\text{mol mL}^{-1}$ was obtained under the optimized conditions. Besides, the detectable range can be further expanded to $10 \mu\text{mol mL}^{-1}$ by using Mn^{2+} (100 mmol L^{-1}) as a catalyst, a limit of detection of $0.064 \mu\text{mol mL}^{-1}$ was obtained. This system was further integrated in a portable analytical kit for meeting the demand of rapid and on-site analysis. It is a potential miniaturized and easy-to-use analytical system/device for real time and on-site analysis of oxalate. Gas pressure meter-based analytical system is an alternative method for food safety testing. Unfortunately, for real samples, their substrates are complicated, a pretreatment (selective adsorption, separation or extraction etc.) was required before analysis. Besides, gas-generation reaction based on specific reaction also can be used for selective and sensitive analysis of analyte in foods.

CRediT authorship contribution statement

Jiayuan Tang: Writing – original draft, Investigation, Data curation, Conceptualization. **Dali Zhuo:** Validation, Investigation. **Xiaoyu Dong:** Validation, Investigation. **Jing Xiao:** Validation, Investigation. **Shu Zhang:** Writing – review & editing, Conceptualization. **Xiaoli Xiong:** Writing – review & editing. **Chao Tan:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Zhirong Zou:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.fochx.2024.101638>.

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