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Catalytic spectrophotometric determination of iodide in pharmaceutical preparations and edible salt

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The catalytic effect of iodide on the oxidation of four dyes: viz. variamine blue (VB), methylene blue (MB), rhodamine B (RB), and malachite green (MG) with different oxidizing agents was investigated for the kinetic spectrophotometric determination of iodide. The above catalyzed reactions were monitored spectrophotometrically by following the change in dye absorbances at 544, 558, 660, or 617 nm for the VB, RB, MB, or MG catalyzed reactions, respectively. Under optimum conditions, iodide can be determined within the concentration levels 0.064–1.27 μg mL^{-1} for VB method, 3.20–9.54 μg mL^{-1} for RB method, 5.00–19.00 μg mL^{-1} for the MB method, and 6.4–19.0 μg mL^{-1} for the MG one, with detection limit reaching 0.004 μg mL^{-1} iodide. The reported methods were highly sensitive, selective, and free from most interference. Applying the proposed procedures, trace amounts of iodide in pharmaceutical and edible salt samples were successfully determined without separation or pretreatment steps. Copyright © 2011 John Wiley & Sons, Ltd.

Keywords: iodide; catalytic spectrophotometry; variamine blue (VB); pharmaceutical preparations; edible salt.

Introduction

Iodine is one of the natural elements required for a human body for proper physical and mental developments. It is necessary for the biosynthesis of the thyroid hormones, triiodothyronine (T_3) and thyroxine (T_4), through the precursor protein, thyroglobulin, and the action of enzyme thyroid peroxidase in the thyroid gland.[1] More than one billion people worldwide are at risk of iodine deficiency disorder (IDD) because they lack access to iodine-containing foods. Iodine supplementation in iodized salt and the use of pharmaceutical preparations containing potassium iodide are used to avoid these symptoms. However, excessive iodine intake can reduce thyroid function, as large amounts of iodine block the thyroid's ability to produce the hormones T_3 and T_4.[2,3] Therefore, it is essential to monitor the concentration of iodine in the diet and pharmaceutical preparations.

Numerous analytical methods, such as spectrophotometry,[4,5] chemiluminescence,[6] electrochemistry,[7–9] atomic absorption spectroscopy (AAS),[10] and chromatography[11–13] could be applied for iodide determination. However, AAS and chromatographic methods require expensive instruments and are time-consuming in sample preparation and long analysis time.

Because of the growing need for highly sensitive analytical methods, catalytic kinetic procedures have become attractive, as the trace determination can be achieved without the need to use expensive or special equipment,[14–17] with higher sensitivity and selectivity compared to the spectrophotometric methods. Several catalytic reactions have been reported for iodide determination, based on its effect on oxidation of organic and inorganic compounds with various oxidizing agents.[18–26] Some of these methods have poor selectivity towards some ions and need elevated temperatures.

For the development of a new indicator reaction, attention should be paid to the following considerations: (1) the reaction time to be analyzed should be as short as possible for high sample output and possibility of incorporation of flow injection analysis (FIA) technique; (2) the catalyzed reaction is preferred to proceed at room temperature for convenient operations; (3) application of non-carcinogenic materials; (4) use of one chromogenic reagent without additional components for an indicator reaction; and finally (5) the indicator reaction preferably has a simple mechanism, without side reactions. The sensitivity could be improved by using a reagent with high molar absorption extinction such as some basic or azo dyes.

In our previous work,[27] a catalytic potentiometric method utilizing dye-PVC electrodes was utilized for iodide determination. The present work aims to introduce novel analytical spectrophotometric procedures for iodide determination based on its catalytic effect in the oxidation of different organic dyes; VB, RB, MB, or MG, which have high molar absorption extinction coefficients. Parallel studies were done on each dye reaction including the effect of reactant concentration, reaction medium, and temperature in order to select the optimum reaction conditions offering the highest sensitivity of the method.

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Experimental

Reagents

All reagents were of analytical grade and bidistilled water was used throughout the experiments. Iodide stock solution (10^{-2} mol L^{-1}) was prepared by dissolving potassium iodide (Analar), previously dried at 105 °C for 2 h, in bidistilled water. Working solutions were prepared daily by appropriate dilution with water and standardized by visual titration method.[28]

Stock dye solutions were prepared by dissolving the appropriate weight of each dye (VB.HCl, $C_{13}H_{14}N_2O.HCl$, BDH; MB: $C_{16}H_{12}ClN_3S$, Merck; RB, $C_{28}H_{31}ClN_2O_3$, Merck Germany; and MG, $C_{23}H_{25}N_2 \cdot C_2HO_4$, BDH) in 100 mL bidistilled water. The exact concentration of each dye solution was estimated by potentiometric titration against standardized sodium tetraphenylborate (NaTPB) using simple coated wire electrode.[29,30]

Hydrogen peroxide solution (10^{-3} mol L^{-1}) was prepared using 30% H_2O_2 (Merck Germany) and standardized by permanganate titration. Other oxidant solutions were prepared by dissolving the appropriate amounts of potassium bromate ($KBrO_3$, BDH), potassium iodate (KIO_3, BDH), potassium periodate (KIO_4, Analar) or potassium persulfate ($K_2S_2O_8$, Analar) in bidistilled water. Acid solutions; H_3PO_4, H_2SO_4, HCl, HNO_3 and acetic acid were prepared by dilution of the analytical grade stock with bidistilled water.

Samples

Edible salt samples

Edible salt samples, collected from local stores, were oven-dried at 120 °C overnight and stored in a desiccator. Sample solutions were prepared by dissolving an accurate weight of the salt in water and making up to 250 mL (note: filtration may be necessary for some sample solutions that contain particulate matter). The samples were analyzed directly using both the proposed catalytic method and the visual titration one.[28]

Pharmaceutical preparations

Betadine sample (antiseptic solution, Povidone-iodine solution, 10% *w*/*v*, Nile Company for Pharmaceutical and Chemical Industries Cairo, Egypt) was purchased from local drug stores. The iodine content was assayed with the proposed catalytic method as well as potentiometric titration with silver nitrate.[31]

Eltroxine tablets (100 μg thyroxine sodium BP, Glaxo Smith Kline Gmbh, Cairo, Egypt) were grounded, and weighed samples were burnt in oxygen atmosphere using the Schoniger's combustion flask method.[32] The combustion products were absorbed in 10 mL hydrazine sulfate solution and completed to 25 mL with water.

Apparatus

Shimadzu UV-1601 Spectrophotometer (Kyoto, Japan) with 1-cm quartz cells was used for spectrophotometric measurements. The catalyzed reactions were carried out in double-jacket thermostated glass cells connected with Haake thermosetting circulating water bath with temperature stability of 25 ± 0.5 °C.

General procedures

VB procedure

Aliquots of iodide solution were transferred to the reaction cell containing 2 mL of 7.4×10^{-5} mol L^{-1} VB solution, 0.5 mL of 1 mol L^{-1} H_3PO_4, and the volume was completed to 8 mL with H_2O. The catalyzed reaction was initiated by addition of 2 mL H_2O_2 where the time measurement started just after adding the last drop of the oxidant solution. The reaction mixture was transferred to the measuring quartz cell where the rate was followed spectrophotometrically by monitoring the increase in absorbance at 544 nm after 45s of the oxidant addition. Linear calibration graph was obtained by plotting the reaction rate (slope of the linear absorbance – time curve, $\Delta A/\Delta t$, tan α) against iodide in the concentration range 0.064–1.27 μg mL^{-1}.

Other dyes procedures

Different aliquots of iodide solutions were transferred to the reaction cells containing the appropriate dye concentration and 0.5 mL of 1 mol L^{-1} H_3PO_4. The reaction was initiated by addition of 2.5 mL of H_2O_2, and 2.0 or 0.75 mL of IO_3^- to RB, MB, or MG solutions, respectively. The reaction mixtures were completed to 10 mL with water and transferred to the measuring quartz cell, where the reaction rate was followed by monitoring the decrease of the dye absorbance at 558, 660, or 617 nm after 45s of oxidant addition for aforementioned dye – catalyzed reactions in the same order.

Results and discussion

Variamine blue method

Variamine blue (VB) was first suggested as a redox indicator by Erdey.[33] This reagent is water soluble and produces a colourless solution, which turns to blue violet upon oxidation. Different oxidizing agents such as persulfate, periodate, bromate, iodate, or hydrogen peroxide can oxidize VB, where the oxidation was instantaneous in the presence of persulfate and periodate, while in case of bromate or iodate, it is not as fast. Oxidation of VB with H_2O_2 takes place at slow rate, which is accelerated in presence of trace iodide causing rapid change from the colourless reduced form to deep violet blue colour with a maximum absorption at 544 nm (Figure 1). The high difference in the molar absorbitivty between both oxidized and reduced forms (about 6000-fold) greatly improves the sensitivity of the catalytic method. The reaction mechanism seemed to undergo through oxidation of iodide to iodine, the liberated iodine can oxidize VB present in the reaction medium producing a deep violet blue colour through the transfer of two electrons to give rise to N-(4-methoxyphenyl)-quinonedimine (VB_{ox}).[34]

The reaction variables such as reactant concentrations, reaction temperature, and the influence of acidic medium were optimized to achieve the highest sensitivity of the method. It was found that oxidation of iodide takes place in acidic medium, and the catalyzed reaction in H_3PO_4 was higher than in other tested acidic media (H_2SO_4, HCl, HNO_3 or acetic acid). The effect of H_3PO_4 was studied over the range 0.02–0.1 mol L^{-1} and 0.05 mol L^{-1} was selected.

The influence of VB concentration on the reaction rate was studied by varying the dye concentration in the reaction medium via addition of different increments of 7.4×10^{-5} mol L^{-1} VB solution. Addition of 2 mL was selected as it gave the highest reaction rate (Figure 2). Different increments of H_2O_2 (10^{-3} mol L^{-1}) were added to the reaction medium and for each volume the corresponding reaction rate was estimated; addition of 2.0 mL was the best (Figure 3). At the optimum concentration of dye and oxidant, the effect of temperature was also studied by

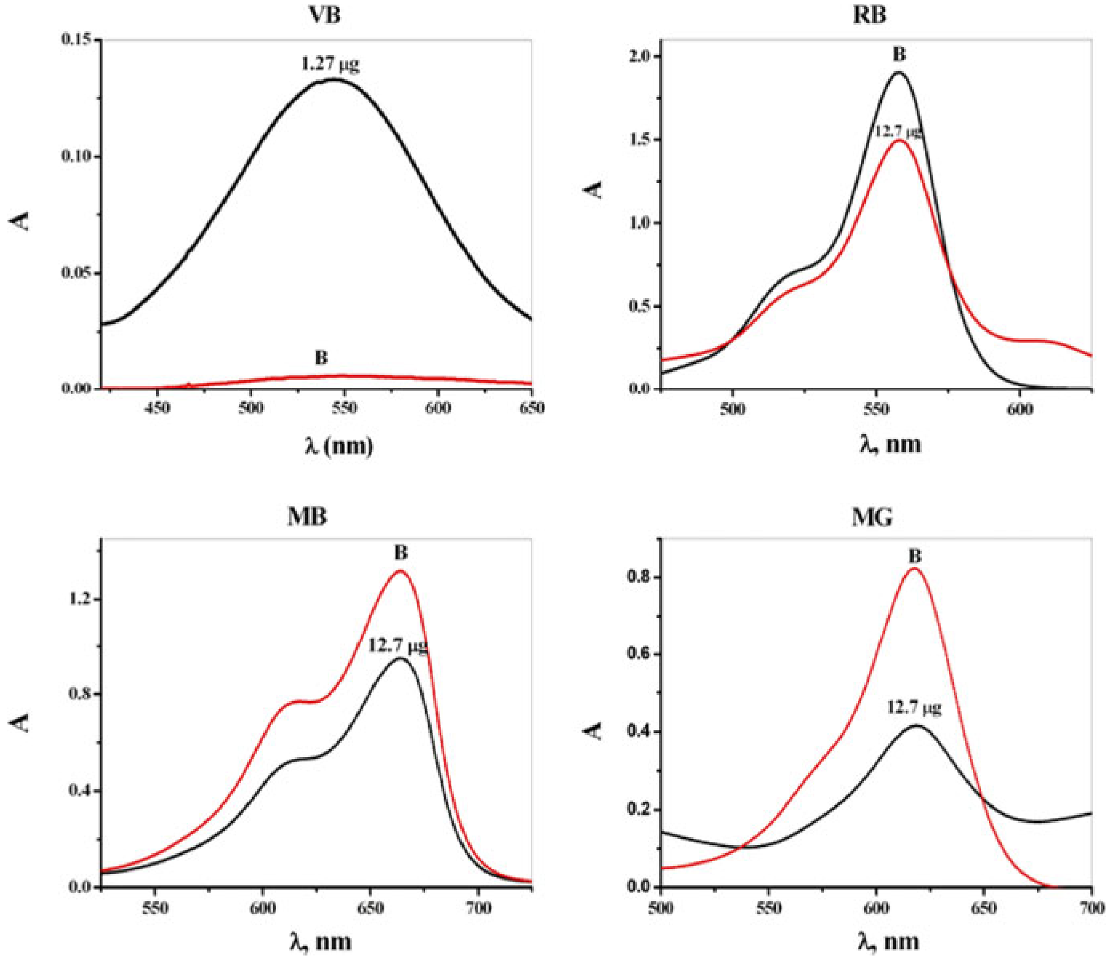

Figure 1. Variation of the absorbance of dye–oxidant systems via addition of iodide, conditions; 1.27 µg mL^{-1} iodide in case of VB and 12.7 µg mL^{-1} iodide with other dyes.

rising the reaction temperature from 25 to 55 °C. A noticeable decrease in the reaction rate was observed via raising the temperature, which may be due to the loss of iodide. Operating the catalytic reaction at room temperature was favourable to achieve the highest reaction rate and facilitate the analytical procedures as no additive equipment was needed.

Other dye methods

The absorption spectra of the RB, MB, and MG catalyzed as well as their corresponding uncatalyzed systems against water were recorded in the proper spectral ranges (Figure 1). The absorbance of dye solutions at 558, 660, and 617 nm, remarkably decreased after the addition of iodide due to its affect on the oxidation of such dyes.

Similar to VB procedure, the effect of the chemical variables was optimized for each dye catalyzed reaction. The catalytic effect of iodide on the oxidation of each of the three tested basic dyes undergoes at higher reaction rate in H_3PO_4 than in other tested acidic media, and 0.05 mol L[1] solution was selected.

The influence of the dye concentrations on the reaction rate was studied via addition of different increments of 8.4×10^{-5}, 6.9×10^{-5} or 10^{-4} mol L^{-1} of RB, MB or MG solutions, respectively. Addition of 2.5 mL of RB or 2.0 mL of both MB and MG gave the highest reaction rate compared with other tested concentrations (Figure 2).

Different oxidizing agents such as persulfate, periodate, bromate, iodate, or hydrogen peroxide can oxidize the aforementioned dyes causing decolourization of their solutions. The effect of the oxidant nature on the catalyzed reaction rate was investigated in detail, and H_2O_2 was selected for RB, while iodate produced the highest reaction rate in case of MB and MG catalyzed reactions. Furthermore, the influence of either H_2O_2 or iodate concentration on the reaction rate was also studied by varying their concentrations in the reaction medium. Addition of 2.5 of H_2O_2 to RB catalyzed reaction, 2.0 and 0.75 mL of iodate to MB and MG systems, produced the highest reaction rates (Figure 3). In addition, operating the catalytic reaction at room temperature was favourable to achieve the highest reaction rate.

Analytical characteristics

Under optimum working conditions for each catalyzed reaction, the absorbance-time curves at different iodide concentrations are shown in Figure 4. To evaluate the catalyzed reaction rate, such curves were treated by different kinetic methods such as tangent method (slope of the first linear part of the A-t curve, $\Delta A/\Delta t$, tan α), A_t/A_0 (where A_t is the absorbance after selected reaction time and A_0 is the absorbance at zero time), the logarithmic method ($\log A_t/A_0$) as well as the induction

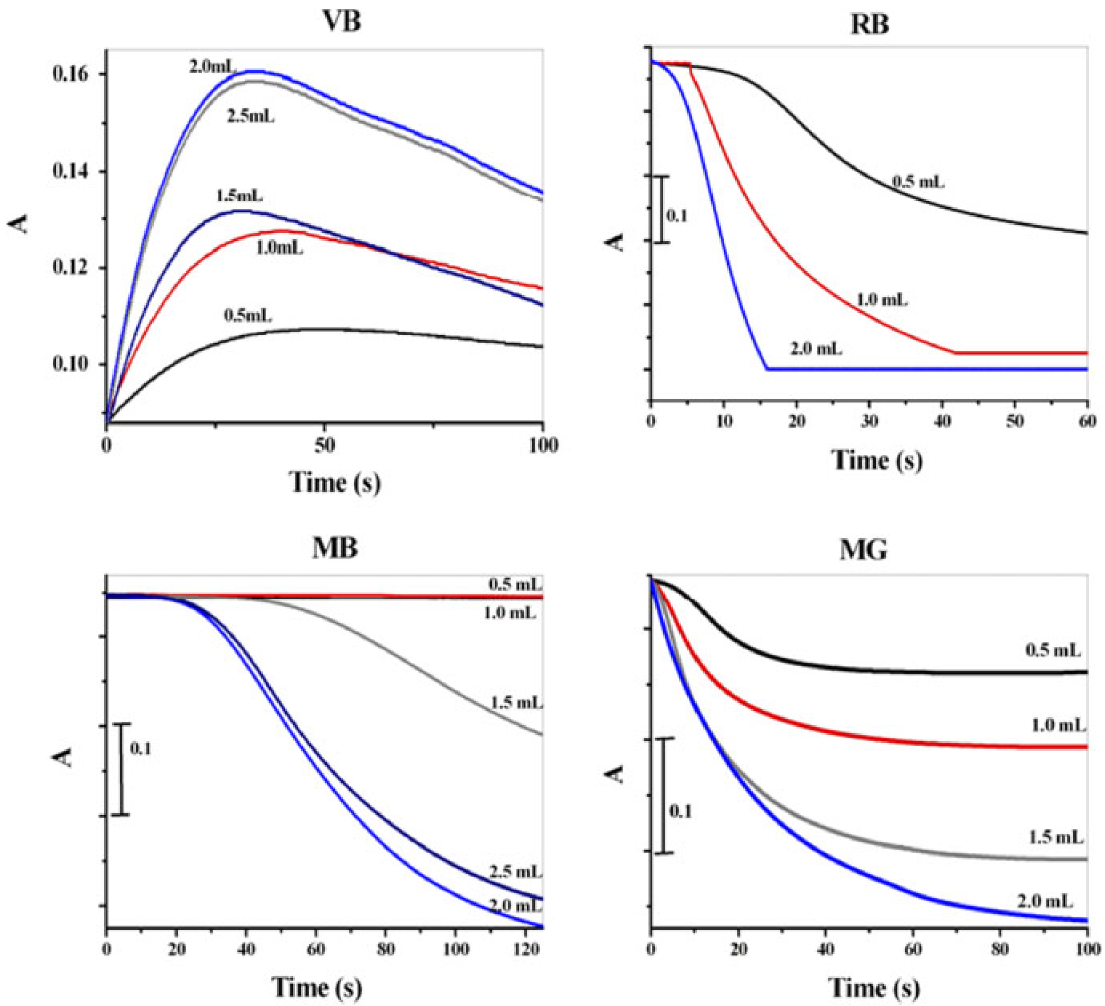

Figure 2. Influence of the dye concentration on the catalyzed reaction rates; conditions; 1.27 µg mL^{-1} iodide in case of VB and 12.7 µg mL^{-1} iodide with other dyes.

period method (time required to reach the maximum absorbance, T; where 1/T was plotted against iodide concentration). Results obtained (not showed) sustained application of the tangent method, as it possessed the highest reproducibility and sensitivity compared with other methods of reaction rate calculations.

Under the optimum working conditions corresponding to each dye catalyzed reaction, rectilinear relationships were obtained between the reaction rate ($\Delta A/\Delta t$) and iodide concentration over the ranges 0.064–1.27, 3.20–9.52, 5.00–19.0 and 6.35–19.05 µgmL^{-1} for VB, RB, MB and MG methods, respectively. The linear regression equations, precision, and detection limits of the tested methods were investigated and listed in Table 1.

It could be concluded that all the proposed methods have high sensitivity with good precision, and the VB method was the best regarding the sensitivity and detection limit. Another advantage of VB application is that the dye absorbance increased by proceeding the catalyzed reaction with low blank absorbance, which make the following of such reaction more convenient with minimal measuring error than other dye catalyzed reactions. The reaction times were quite short (within 1–3 min), and the sample analysis time was about 5 min, allowing fast and sensitive determination of iodide.

Interferences

The effect of different interfering ions on the trace determination of iodide by the VB method was examined by carrying out the catalyzed reaction in the presence of 0.635 µgmL^{-1} iodide and interfering ion. The amount of substance causing an error of 5% was denoted as the tolerance limit (Table 2).

However, iron (II, III) caused serious interference by catalyzing the oxidation of VB with H_2O_2[35] and addition of EDTA was required to mask iron up to 150-fold. The interference of copper can be suppressed using trien as a complexing agent without noticeable effect on the iodide determination. In the presence of oxidizing agents such as V (V) or Cr (VI), some colouration reactions occurred before the addition of hydrogen peroxide, such interference can be suppressed using the initial reaction rate as a parameter.

However, the tolerance limits of the aforementioned interfering ions are greater than the levels normally present in real samples and the proposed method can be directly applied for the determination of iodide without the need of separation or pre-concentration procedures.

Analytical application

To validate the proposed method, it was applied for the determination of iodide in edible salt and pharmaceutical samples.

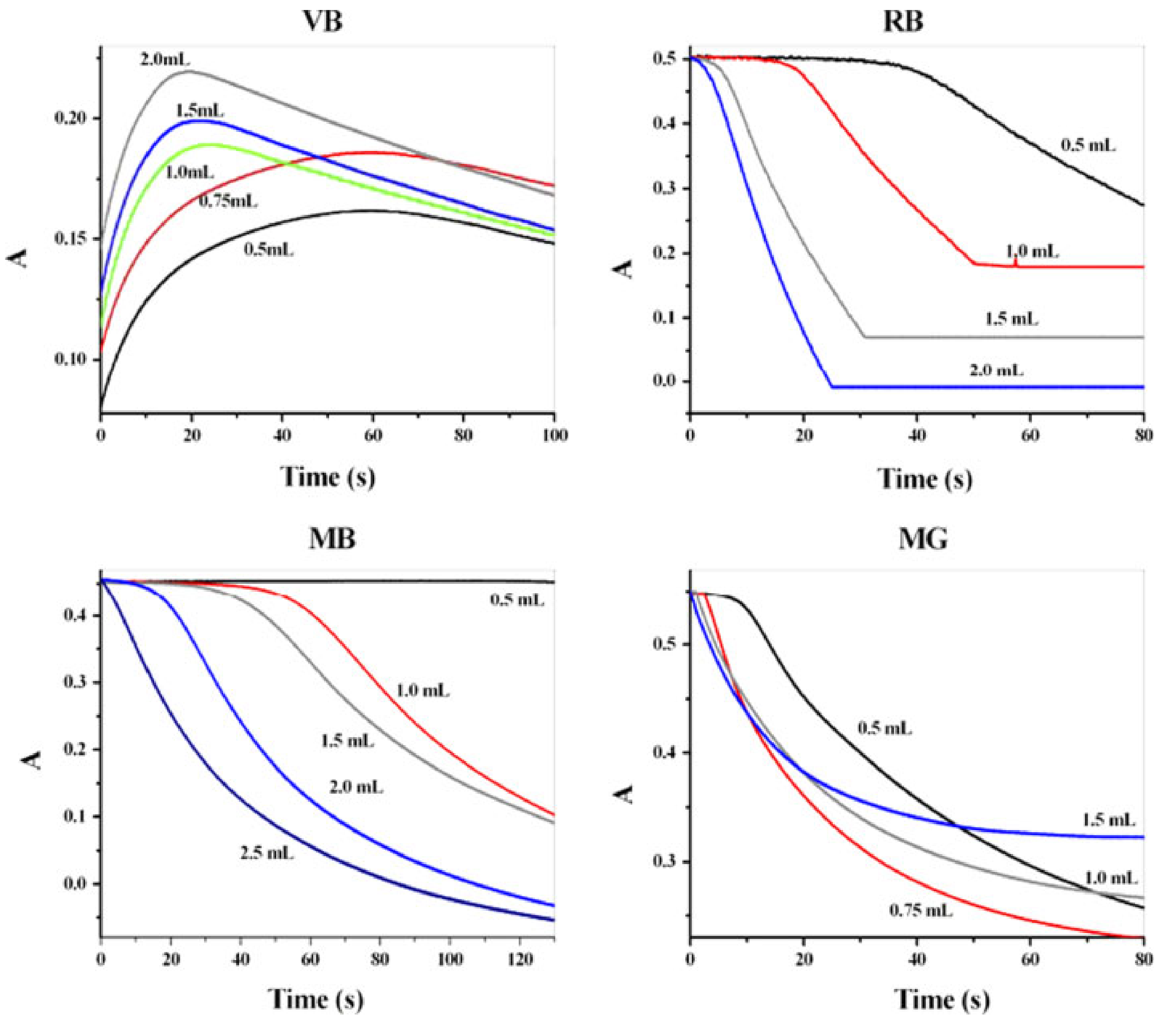

Figure 3. Influence of the selected oxidant concentration on the catalyzed reaction rates at the optimum dye concentration; conditions; 1.27 μg mL^{-1} iodide in case of VB and 12.7 μg mL^{-1} iodide in case of other catalyzed reactions.

Table 1. Analytical characteristics of the four suggested procedures

Method	VB	RB	MB	MG
A max (nm)	544	558	660	617
Dye concentration (mL)	2.0	2.5	2.0	2.0
Optimal oxidant	H_2O_2	H_2O_2	IO_3^-	IO_3^-
Oxidant concentration (mL)	2.0	2.5	2.0	0.75
Linear range (μg mL^{-1})	0.064–1.27	3.20–9.54	5.00–19.00	6.40–19.00
Regression equation[a]				
Slope (*b*) × 1000	4.7	−2.7	−0.86	−0.53
Intercept (*a*)	−0.0184	1.93×10^{-4}	8.44×10^{-4}	5.75×10^{-4}
r	0.99427	0.99625	0.99628	0.99927
Detection limit (μg mL^{-1})	0.004	0.500	0.800	1.000

[a] $\Delta A/\Delta t = a + bC$, C is the concentration of iodide in μg mL^{-1}.

Results (Table 3) showed non-significant differences between the proposed and the official methods, where the recovery values were found to be quantitative and the repeatability of the method was satisfactory with short analysis time less than 3 min.

Conclusion

The present work demonstrated that catalytic spectrophotometric method can be simply applied for trace iodide determination in pharmaceutical and edible salt samples. From the different

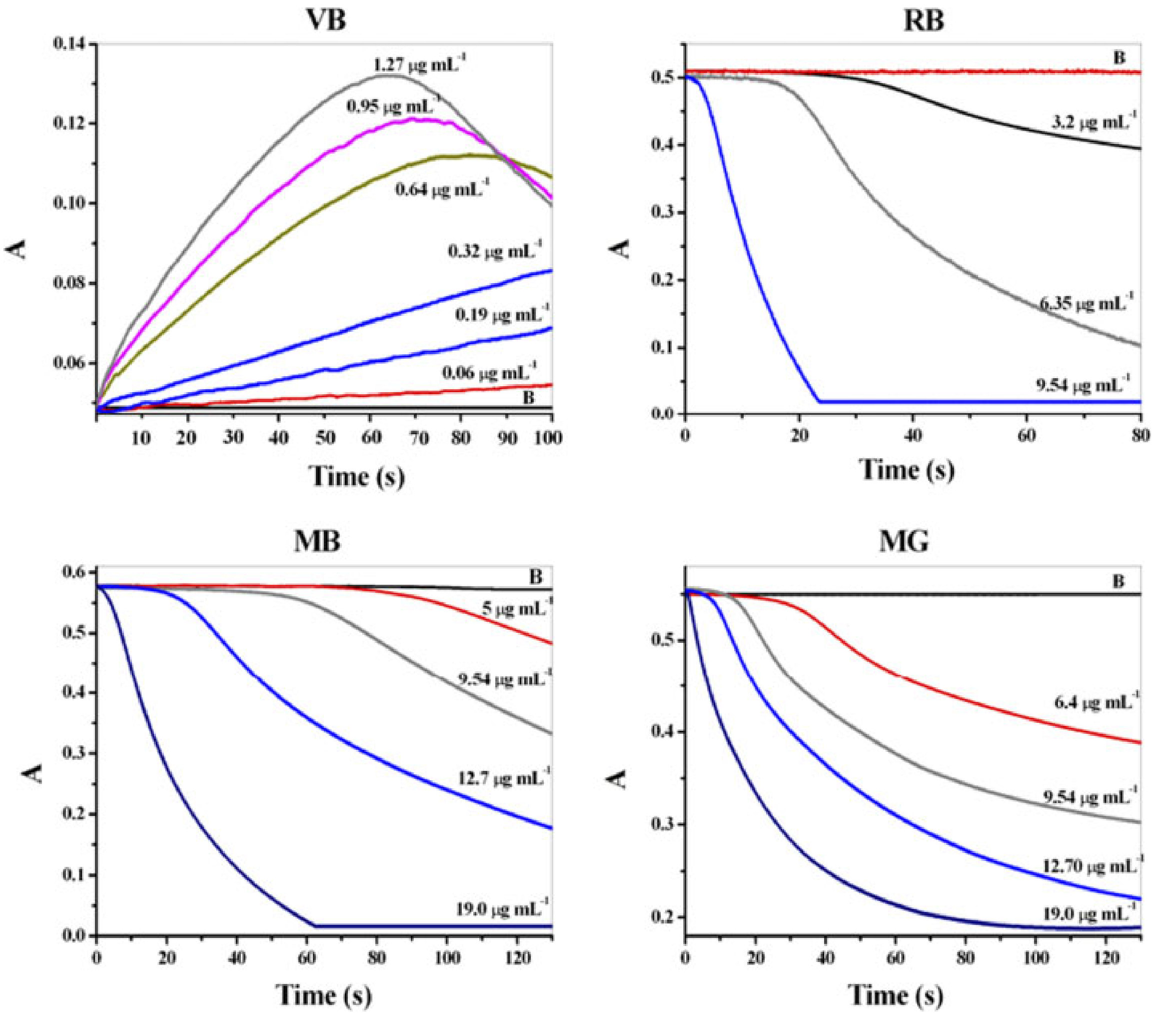

Figure 4. Catalytic spectrophotometric determination of iodide based on its effect on the oxidation of different dyes with selected oxidizing agents.

Table 2. Maximum tolerance limits of diverse ions in the determination of 0.65 μg mL^{-1} iodide using VB procedure

Element	Tolerance limit	Element	Tolerance limit
Cd^{2+}	500	V (V)	100
Ag^{+}	50	Fe^{2+}	150[a]
Pb^{2+}	1000	Fe^{3+}	150[a]
Cu^{2+}	300[b]	NO_3^{-}	1000
Sn^{4+}	100	NO_2^{-}	1000
Hg^{2+}	100	F^{-}	1000
Cr^{3+}	50	Cl^{-}	1000
Cr^{6+}	100	Br^{-}	300
Mn^{2+}	1000	CN^{-}	100
Zr^{4+}	100	EDTA	1000
Au^{3+}	50	Ascorbic	1000

[a] The tolerance limits were in the presence of EDTA.
[b] The tolerance limit was in the presence of triethylenetetramine.

Table 3. Catalytic spectrophotometric determination of iodide in different samples based on its effect on the oxidation of VB with H_2O_2

Sample	Taken (μg mL^{-1})	Recovery (%)	S.D.[a]
Authentic sample	0.317	97.30	3.10
	0.635	99.50	0.80
	0.952	100.0	1.80
	1.27	102.30	1.60
Edible Salt 1	0.315	95.50	1.40
	0.578	98.20	1.20
Edible Salt 2	0.315	96.40	1.90
	0.578	99.20	1.60
Povidone -iodine	0.325	98.50	2.70
	0.635	102.30	1.10
Eltroxine	0.654	95.80	3.60

[a] Mean recovery and standard deviations for five determinations.

investigated catalyzed reactions, VB was selected for accurate and precise determination of iodide down to nanogram levels. The sample analysis time was short when compared with some previously published methods and carried out at ambient conditions in one-step reaction. The behaviour of a selected system allowed the development of a kinetic method for the determination of trace amounts of iodide without any separation or pre-concentration step. Further investigation will be carried out for incorporating such catalyzed reactions in flow injection systems permitting high sampling output with good precision and automation.

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