Erzincan Binali Yıldırım Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
2019, 12(1), 158-169
ISSN: 1307-9085, e-ISSN: 2149-4584
Araştırma Makelesi

Erzincan Binali Yıldırım University
Journal of Science and Technology
2019, 12(1), 158-169
DOI: 10.18185/erzifbed.432836
Research Article

Voltammetric Determination of Rutin by Using Disposable Pencil Graphite Electrode

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Geliş / Received: 11/06/2018, Kabul / Accepted: 05/11/2018

Abstract

In this study, a voltammetric method was developed for the electrochemical determination of rutin. The pencil graphite electrode was a disposable and low cost electrode. It showed a very good catalytic effect with the significant augmentation of the peak current of rutin oxidation compared to the glassy carbon electrode. Under the optimized conditions, the pencil graphite electrode had two linear responses from 0.104 to 166.70×10^{-7} M and from 166.70 to 1060.60×10^{-7} M rutin, the detection and quantification limits were calculated, which were 1.13×10^{-9} M (S/N=3) and 3.42×10^{-9} M, respectively. The percentage of recoveries were obtained in a range between 98.98 and 101.02 % for five successive determinations of rutin, which show agreeable repeatability. The developed method was successfully employed for the direct determination of rutin in real samples such as buckwheat, green tea and red apple. Finally, the interference effects of some species to the determination of rutin were also evaluated.

Keywords: Flavonoid, Rutin, Pencil graphite electrode, Voltammetric determination

Tek Kullanımlık Kalem Grafit Elektrot Kullanılarak Rutinin Voltammetrik Tayini

Öz

Bu çalışmada, rutinin tayini için elektrokimyasal bir yöntem geliştirildi. Kalem grafit elektrot tek kullanımlık ve düşük maliyetli bir elektrottur. Kalem grafit elektrot, camsı karbon elektrota kıyasla pik akımının önemli ölçüde artmasıyla çok iyi bir katalitik etki göstermiştir. Optimize edilmiş koşullar altında, kalem grafit elektrot, 0.104 ile 166.70×10^{-7} M ve 166.70 ile 1060.60×10^{-7} M rutin olmak üzere iki doğrusal yanıta sahiptir, Tespit ve tayin limitleri sırasıyla 1.13×10^{-9} M (S / N = 3) ve 3.48×10^{-9} M olarak hesaplandı. Yüzde geri kazanım, kabul edilebilir tekrarlanabilirliği gösteren, ardışık beş tekrarlı rutin analizi için % 98.98 ile % 101.02 arasında bir aralıkta elde edilmiştir. Geliştirilen yöntem; karabuğday, yeşil çay ve kırmızı elma gibi gerçek numunelerde, rutinin doğrudan tayini için başarıyla uygulanmıştır. Son olarak, bazı türlerin rutin tayinine girişim etkileri de değerlendirilmiştir.

Anahtar Kelimeler: Flavonoid, Rutin, Kalem grafit elektrot, Voltammetrik tayin

1. Introduction

Flavonoids are derivatives of the benzo-γ-pyrone. They have several hydroxyl groups and these groups attach to the C6–C3–C6 ring. Flavonoids are commonly found in nature, in seeds, fruits and vegetables (Franzoi et al., 2008). Flavonoids have some biological effect such as, antiinflammatory, antibacterial, antiallergic and antithrombotic activities (Catunda et al., 2011). Flavonols are classes of flavonoids and they are widely spread in nature. Flavonols bind to one or more sugar molecules (Arvand et al., 2018). Rutin (Ru) (Figure 1) (3,3’4’5,7-entahydrohyflavone-3-rhamnoglucoside) is known a citrus flavonoid glycoside between the flavonol quercetin and the disaccharide rutinose (Attia, 2016). It is known vitamin P.

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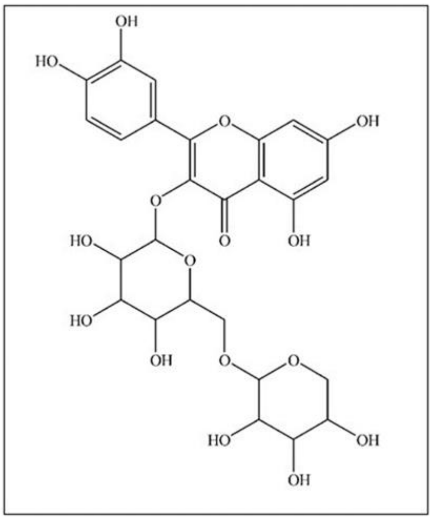

Figure 1. The chemical structure of rutin

Ru is used in clinical chemistry and human health due to its excellent pharmacological (vasoactive, antiviral, antiallergic and antiprotozoal) and physiological (antibacterial, antiinflammatory and antitumor) activities (Magarelli et al., 2014; Niu et al., 2018; Sengupta et al., 2018). From 500 mg to 2000 mg per day, oral dose range is offered to person and it can be safely continued for long periods, up to 6 months (Gullòn et al., 2017). Therefore, developing a sensitive, rapid and suitable method for the determination of rutin is very important and essential. Many analytical methods have been applied for the analysis of Ru. These methods were HPLC (high performance liquid chromatography) (Kuntic et al., 2007; Mesquita and Monteiro, 2018; Da Rocha et al., 2018), UHPLC (ultra high performance liquid chromatography) with quadrupole time-of-flight tandem MS (mass spectrometry) (Peng et al., 2016; Donato et al., 2016), LC–MS/MS (He et al., 2013), capillary electrophoresis (Marti et al., 2017). However, these methods have some disadvantages such as, time-consuming, expensive instruments and chemical, time for pre-treatment (Li et al., 2017); however, electroanalytical techniques are cost-effective, and have the features of enabling the use of portable instruments, easy operation, excellent simplicity and short analysis time. Pencil graphite electrode (PGE) was preferred in this study, due to its some advantages such as cost-effective, disposable, easily available, a low back ground current, good electrocatalytic effects and displays a wide potential range (Aziz and Kawde, 2013).

In this manuscript, an easy, rapid and high sensitivity method for the determination of Ru was described. Non-modified PGE was preferred for this purpose. The surface of PGE showed a good electrocatalytic property for the oxidation of Ru. It was discovered that this new determining system has such advantages as high sensitivity, quite simply, low detection limit and low cost. The pencil graphite electrode offers a renewable surface; for this reason, it does not need to be cleaned like a solid electrode, such as GCE and results are in good reproducibility for individual surfaces (Sağlam et al., 2016). The suggested new method was used on the determination of Ru in buckwheat, green tea and red apple.

2. Material and Method

2.1. Reagents and solutions

Rutin hydrate, glucose, fructose, methanol, mercury (II) chloride, manganese chloride, lead (II) acetate trihydrate, zinc chloride, copper (II) chloride, iron (III) chloride were received from Sigma-Aldrich (St. Louis, MO 63103 USA), rutin hydrate was HPLC grade and all the other chemicals were used analytical grade. Phosphoric acid (H_3PO_4), glacial acetic acid (HAc) and boric acid (H_3BO_3) were purchased from Merck (Darmstadt, Germany). Ultrapure water (resistivity was 18.2 MΩ cm) was obtained using with the Milli-Q water ultra purification system (Simplicity®, Millipore, USA) and all the solutions were prepared with this ultrapure water. The stock solution of Ru (1 mM) was prepared in methanol and this solution was kept in the refrigerator, at 4

°C temperature. 2.30 mL of HAc, 2.70 mL of H_3PO_4 and 2.47 g of H_3BO_3 was used for the preparation of 1.0 L B–R (Britton–Robinson) buffer solution; 100 mL portions of B-R buffer solutions were transferred to beakers, and 2.0 M NaOH was used for the desired pH.

2.2. Apparatus

Differential pulse voltammetry (DPV) and cyclic voltammetry (CV) measurements were performed using PalmSens3 Potentiostat/Galvanostat (PalmSens BV, Netherlands). A conventional three-electrode system, consisting of pencil graphite working electrode (Mikro Min, 2.0 diameter, 2B, Istanbul, Turkey), reference electrode (Ag/AgCl) (BASi, MF-2052, West Lafayette, IN 47906 USA) and platinum wire auxiliary electrode, was used. The glassy carbon electrode (GCE) (BASi, MF-2012 (3.0 mm dia., West Lafayette, IN 47906 USA, geometric area 0.0706 cm^2) was used for comparison of electrochemical behavior of Ru. The outside of the electrode was isolated with teflon tape leaving only a geometric area of 0.0942 cm^2. The pencil graphite surface was polished with emery paper (P-320) and cleaned with distilled water. Moreover, HPLC system (Agillent 1200 series) (Agilent Technologies, Inc., Santa Clara, CA 95051 United States) was used for the chromatographic analysis of Ru. The chromatographic analysis of Ru was performed at room temperature on a column of ACE C18 column (250 × 4.6 mm, Advanced Chromatography Technologies Ltd, Aberdeen, Scotland). The mobile phase was composed of methanol and water, 1:1 (v/v) and the pH was adjusted to 2.80 with H_3PO_4. The flow rate was 1mL/min and the wavelength was set 360 nm (Kuntic et al., 2007).

2.3. Analytical procedure

The necessary volume of Ru was pipetted to the electrochemical cell which was placed 5 mL B-R buffer (pH=5.0). Then, the CV and DPV methods were used for electrochemical behavior and quantitative analysis of Ru, respectively. The CV was recorded from 0.0 to 0.9 V at a scan rate of 200 mV/s quiet time of 5 s and the operating range of DPV was selected from 0.0 to 0.9 V with amplitude of 0.025V, quiet time of 5 s and pulse width of 0.025 s.

2.4. Sample preparation

Samples including buckwheat, green tea and red apple were procured from local grocery market in Çankaya/Ankara. 5 g of each sample was homogenized with a mixer in 50 mL methanol. After 30 min ultrasonication, the mixtures were filtered through a 0.22 µm syringe filter into a volumetric flask and the liquid phases were kept in a refrigerator (at 4 °C) until analysis.

3. Result and Discussion

3.1. Electrochemical behavior comparison of Ru on GCE and PGE

Figure 2. shows the cyclic voltammograms (CVs) of 37.7×10^{-6} M Ru in B-R buffer (pH=5.0) using GCE and PGE (curve a and curve b, respectively). The anodic peak currents of Ru at GCE and PGE were 0.99 µA and 3.58 µA, respectively. The value of oxidation peak current of Ru at the bare GCE was rather less than PGE. The PGE surface area is larger than GCE surface area, but using with the PGE, 3 times more current per unit area was obtained. The weak diffusion and slow transfer of electron on the electrode surface may be caused to reason of the low current; however, the value of peak current of Ru increased with using PGE, but the potential of oxidation of Ru was not changed significantly.

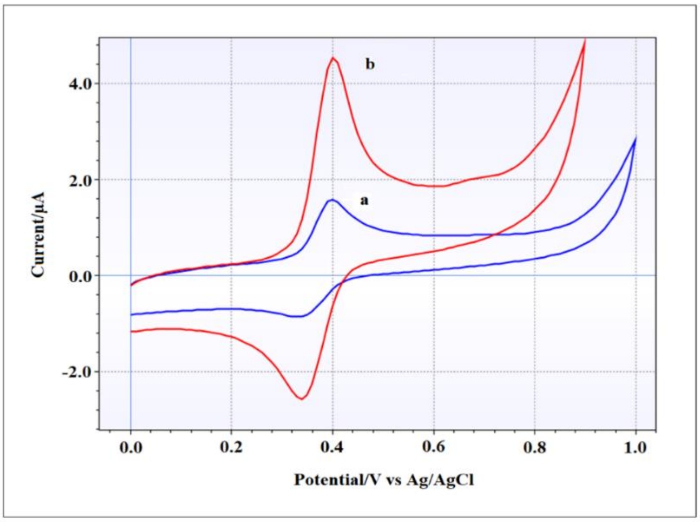

Figure 2. The CVs of Ru in B-R buffer (pH=5.0) containing 37.7 × 10^{-6} M Ru at GCE and PGE curve a and curve b, respectively.

The electrochemical behavior of Ru has been investigated in previous report (Dorraji and Jalali, 2015). This report indicated that two electron and two proton were involved in the reversible redox reaction of Ru (Figure 3.).

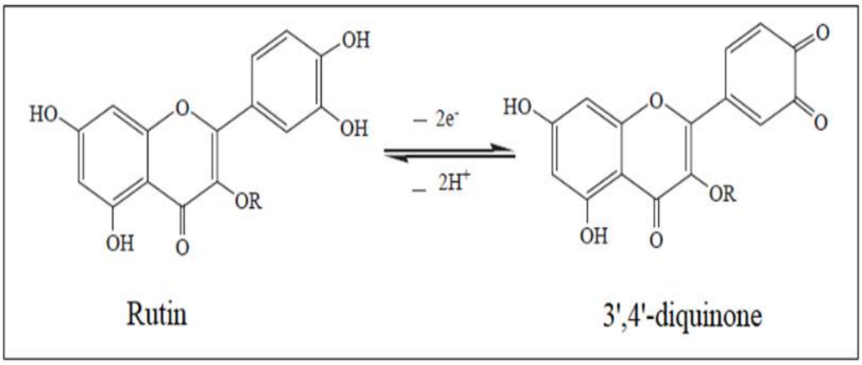

Figure 3. The redox reaction mechanism of Ru

3.2. pH effect

The peak potential and peak current of Ru were affected with the pH value of electrolyte solution. The pH of the B-R solution on the response of 19.6 × 10^{-6} M Ru at PGE was investigated over the pH range of 2.0 to 10.0 (Figure 4.). The peak current value decreased when the pH increased from 2.0 to 10.0 (Table 1.). When the pH value was increased to 10.0, the peaks of Ru disappeared. This experimental phenomenon is about that the proton involved in the electrochemical process, because Ru is in deprotonated form at the high pH. (Dorraji and Jalali, 2015).

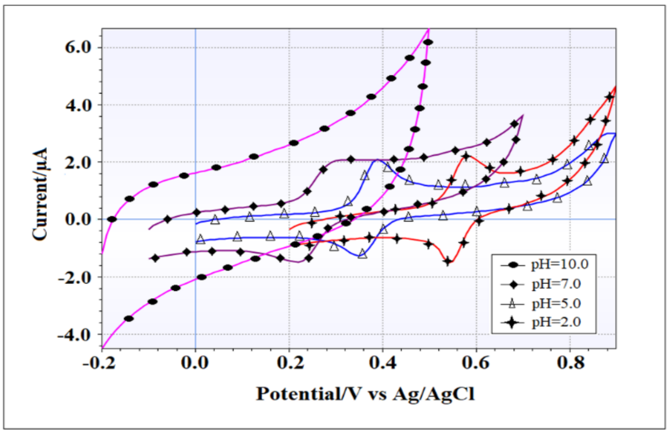

Figure 4. Cyclic voltammograms of 19.6 × 10^{-6} M Ru in different pH (from right to left pH=2.0→pH=10.0) at a scan rate of 200 mV/s

Table 1. Evaluation of peak potentials and currents of Ru at different pH

19.6 × 10^{-6} M Rutin (in Britton-Robinson buffer)			
pH of B-R buffer	Potential of oxidation/mV	Potential of reduction/mV	Current of Oxidation /µA
2.0	579	540	1.48
5.0	400	335	1.50
7.0	289	236	0.37
10.0	Not determined	Not determined	Not determined

pH=5.0 was preferred as the optimal pH of electrolyte for the subsequent studies. Besides, when the pH of the electrolyte increased, the redox peaks shifted negative potentials. This result indicates that the protons are included to the electrochemical process of Ru. The relationship between the anodic and cathodic peak potential (E_p) and pH can be stated as: E_{pa}(V)= 0.6939 - 0.0581pH (R^2= 0.9996) and E_{pc}(V)= 0.6568 - 0.0614pH (R^2= 0.9930). The slopes (−0.0581 V/pH and −0.0614 V/pH) are close to theoretical value (−0.059 V/pH) and indicate that the number of protons and electrons involved in the redox reaction is the same, which is compatible with the previous literature result for Ru (Deng et al., 2012; Chen et al., 2017).

3.3. Effect of scan rate

The influence of scan rate on the redox reaction of Ru at various scan rates were investigated by CV. Fig. 5A shows the effect of scan rate on the cyclic voltammetric response of PGE for determination of 35.8×10^{-6} M in B–R buffer (pH=5.0). As shown in Fig. 5, both the anodic and cathodic peak currents of Ru increased linearly with increasing the scan rate from 5 to 250 mV/s. Maximum anodic peak current was obtained at 200 mV/s. So, 200 mV/s of scan rate was used for the optimized conditions.

As shown in Figure 5B., logarithmic plot of peak current vs. scan rate has slope value of 0.5948, which indicates that the process is diffusion controlled.

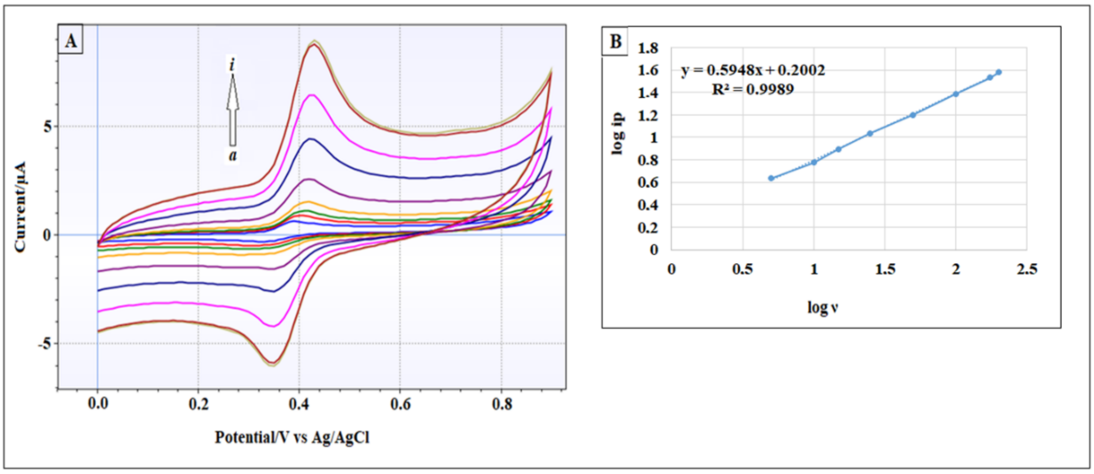

Figure 5. (A) Cyclic voltammograms of 35.8 × 10^{-6} M Ru in B-R solution pH=5.0 at PGE with different scan rates (a → i): 5 to 250 mV/s; (B) the relationship of logi_p with logv.

3.4. Analytical Application

DPV is a most sensitive electrochemical analysis method. Therefore, the determination of Ru was carried out by the DPV method using the pencil graphite electrode. Figure 6A. shows a linear relationship between the oxidation peak current and the concentration of Ru in the range of 0.104-1060.60×10^{-7} M. As can be seen in the insert Figure 6B, two linear responces can be obtained in the range of 0.104 to 166.70×10^{-7} M and 166.70 to 1060.60×10^{-7} M at the PGE, and the corresponding regression equations can be expressed as; i_{p1}= 0.0328C_1 + 0.0786 (R^2=0.997) and i_{p2}= 0.0063C_2 + 4.6417 (R^2=0.992). LOD and LOQ were calculated by use of the formulaes (S_b: the standard deviation of the black responce, m: the slope of the calibration plot) (Elyasi et al., 2013);

$$LOD = \frac{3.3 \times S_b}{\mathrm{m}} \qquad (1)$$

$$LOQ = \frac{10 \times S_b}{\mathrm{m}} \qquad (2)$$

The LOD and LOQ were found 1.13×10^{-9} M (S/N=3) and 3.42×10^{-9} M, respectively. Experimentally, the first significant signal was observed at addition of 1.15 × 10^{-9} M rutin (Fig. 7). There is an excellent agreement between experimental data and results of the calculation. Comparison with previous reported methods were listed in Table 2, the proposed approach shows some advantages such as, lower LOD, wider two linear responces and non-modification step and electrode.

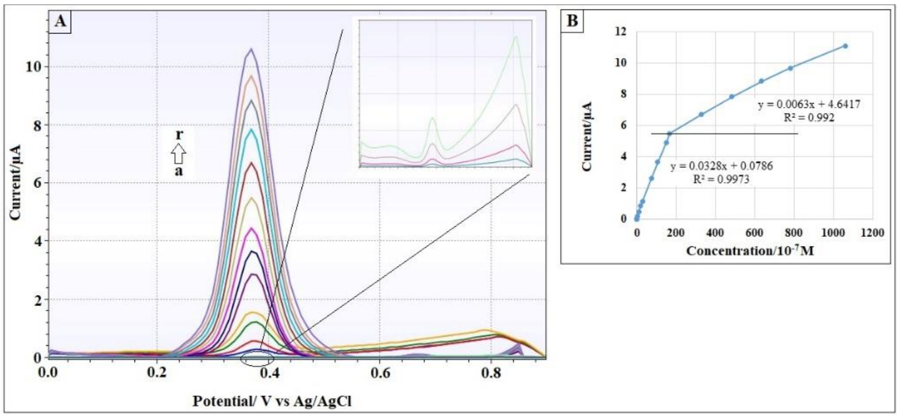

Figure 6. (A) DPV curves of Ru with different concentrations at PGE in pH=5.0 B-R support electrolyte. The concentrations of Ru were as follows: 0.104, 0.201, 0.257, 0.39, 3.98, 9.90, 19.60, 29.12, 74.07, 107.0, 150.5, 166.70, 327.90, 483.90, 634.90, 781.20, 1060.6×10^{-7} M (from a → r), (B) The linear relationship between the concentration and anodic peak currents of Ru (scan rate: 200 mV/s)

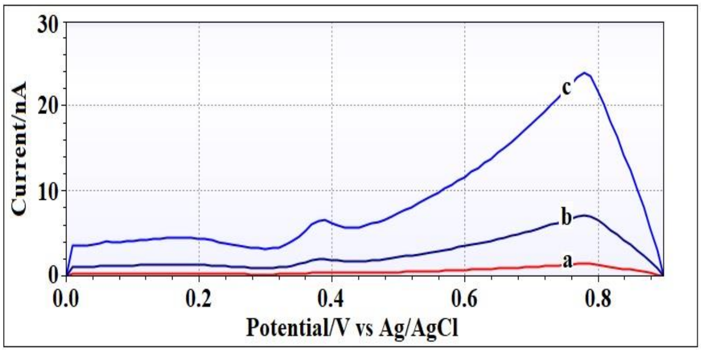

Figure 7. DPV curves of Ru with different concentrations at PGE in pH=5.0 B-R support electrolyte. The concentrations of Ru were as follows: 0.60, 0.95 and 1.15 nM (from a to c) (scan rate: 200 mV/s)

Table 2. Comparison with other reported methods for the determination of Ru.

Electrode	Technique	Linear range (M)	LOD (M)	Reference
MWNTs-IL-Gel/glassy carbon electrode	DPV	7.2×10^{-8} to 6.0×10^{-6}	2.0×10^{-8}	Liu et al., 2010
An acetylene black paste electrode coated with cetyltrimethyl ammonium bromide film	Second-order derivative linear sweep voltammetry	6.0×10^{-9} to 1.0×10^{-5}	4.0×10^{-9}	Deng et al., 2012
GR-MnO_2/CILE	DPV	0.01×10^{-6} to 500.0×10^{-6}	2.73×10^{-9}	Sun et al., 2013
GCE	DPV	1.0×10^{-6} – 1.2×10^{-5}	3.8×10^{-7}	Magarelli et al., 2014
Cu-CS/MWCNT/GCE	DPSV	$0.05\text{-}100\times10^{-6}$	0.01×10^{-6}	Gholivand et al., 2016
Cu_2O-Au/NG/GCE	DPV	0.06 to 512.90×10^{-6}	30×10^{-9}	Li et al., 2017
Graphene-gold nanoparticles screen-printed	Square-wave voltammetry (SWV)	0.1×10^{-6} to 15×10^{-6}	1.1×10^{-8}	Apetrei and Apetrei, 2018
PSSA/CNTs/MBT/Au	DPV	0.01–0.8 and 0.8–10.0×10^{-6}	1.8×10^{-9}	Arvand et al., 2018
BP–PEDOT:PSS/GCE	DPV	0.02–15.0 $\times10^{-6}$ and 15.0–80.0 $\times10^{-6}$	7.0×10^{-9}	Niu et al., 2018
PGE	DPV	0.104 to 166.70×10^{-7} M and from 166.70 to 1060.60×10^{-7} M	1.13×10^{-9}	This study

After the optimization of conditions, the electrochemical response of Ru at different concentrations of Ru was investigated by using DPV. The peak currents obviously increased with addition of Ru. The peak currents and the concentrations showed a good linearity at the optimized conditions.

This method was employed to the synthetic samples (with known concentrations). The statistically results were given in Table 3. The results showed that, the quantitative determinations of Ru involved very small error and standard deviation. These results were obtained with five parallel experiments.

Table 3. The statistical evaluations of Ru at different concentrations (synthetic samples)

Rutin					
No	Added (10^{-6} M)	Found (10^{-6} M)	Standard deviation	Recovery/%	Reliability range* (95 %) (10^{-6} M)
1	3.750	3.716	0.024	99.20	3.716±0.029
2	6.850	6.782	0.028	98.98	6.782±0.035
3	8.750	8.838	0.016	101.02	8.838±0.019

*n=5

3.5. Real samples analysis

To investigate the applicability of the developed method to determination of rutin in real samples, the content of rutin of buckwheat, green tea and red apple samples were measured by the standard addition method. As can be seen in Table 4, reference HPLC method (Kuntic et al., 2007) was used to determine the accuracy of the proposed method.

Table 4. Measurement results of rutin in real samples

Sample	Rutin (Found)				F_{test}	F_{table} (95%)	t_{test}	t_{table} (99%)
	Present method* (10^{-6} M)	RSD (%)	Reference Method (10^{-6} M)	RSD (%)				
Buckwheat	1.030±0.011	1.067	1.011±0.007	0.692	2.46	6.39	1.303	4.604
Green tea	0.869±0.008	0.921	0.854±0.007	0.820	1.31	6.39	1.262	4.604
Red apple	0.976±0.010	1.025	0.972±0.007	0.720	2.04	6.39	0.293	4.604

*$x = \bar{x} \pm s_x$ for n = 5.s_x denotes standard deviation.

The developed method is statistically validated with using F and t- tests against HPLC method in the literature. It is shown that between compared methods there is no significant difference with regard to F- test 95% on confidence level and t- test 99% on confidence level. Obtained results indicate that the development method is suitable for analysis of Ru in real samples with a sufficient precision. The developed method can be used to in industrial, environmental, biological and plant samples.

3.6. Interference study

The influence of some interferences such as, inorganic and organic species were evaluated. Some foreign species were added into the cell containing 19.9×0^{-6} M Ru. Experimental results showed that 1500-fold concentration of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, CO_3^{2-}, PO_4^{3-}, 25-fold Mn^{2+}, Pb^{2+}, Zn^{2+}, Hg^{2+}, 22-fold Cu^{2+}, Fe^{3+} and 20-fold concentration of glucose and fructose did not interfere with the determination of Ru (Ru oxidation peak current change below 5%). The results showed that the development method was adequate for the determination of Ru.

4. Conclusion

The development method for the electrochemical determination of Ru exhibited good catalytic performance with wide linear range, along with a low detection limit, good sensitivity, and high reliability; because, a huge enhancement in peak current at the PGE was observed compared those at the GCE and it was also successfully employed for the determination of Ru in real practical application. As a result, cheap and disposable electrode (PGE), with significant advantage in electro analysis was used for sensitive, selective, cheap and rapid determination of Ru, because of its porous surface, which indicate the novelty statement of this study.

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