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A modified nanostructured graphene-gold nanoparticle carbon screen-printed electrode for the sensitive voltammetric detection of rutin

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ABSTRACT

This study presents a graphene-gold nanoparticles screen-printed voltammetric sensor for the determination and quantification of rutin in pharmaceutics by means of square-wave voltammetry. The cyclic voltammetry electrochemical studies have demonstrated that the sensor has a large active surface and the transfer of electrons is facilitated by the nanostructured materials in the sensing material. To increase the performance of the sensor to rutin, the following experimental conditions were optimized: the detection method, the nature of the electrolyte solution and the pH. In optimum conditions of square-wave voltammetry in acetate buffer solution of pH 5.0, the sensor allows the detection of rutin on a potential of 0.44 V vs. Ag/AgCl. The current of the anodic peak varies linearly with the rutin concentration ranging in the domain 0.1×10^{-6} to 15×10^{-6} M, with a detection limit of 1.1×10^{-8} M. The nanomaterials-based sensor was effectively used for the quantification of rutin in the pharmaceutical products being characterized by precision, repeatability and great accuracy. Furthermore, the results obtained correspond with those obtained with the standard method and with the amounts indicated by the producer, respectively, having a 99% confidence level.

1. Introduction

Rutin is a flavonoid glycoside, also known as vitamin P. It is the most common flavonoid in people's diet and an activator factor of vitamin C. Rutin is found in *Flos Sophorae* buds, citrus fruits and different berries [1,2].

Rutin has the property to scavenge different radical chemical species, i.e. superoxide anion, hydroxyl and peroxyl radicals, therefore it has a noticeable antioxidant character. As a result, rutin is used as an active pharmacological substance with antibacterial, antioxidant, antiviral, antitumoral etc. properties in more than 150 pharmaceutical formulations worldwide [3–5].

Being a compound of great interest, the detection and quantification of rutin in vegetal or pharmaceutical products raises much attention. There are numerous analysis methods such as the capillary electrophoresis, chemiluminescence, HPLC, spectrophotometry, and electrochemistry, to mention only a few [6–15].

Table 1 presents a series of rutin electrochemical analysis methods, described by the technical literature, that encompass the main features of the analytical performance of the sensors used, and which are based on similar sensitive materials as the sensor developed in this work.

The electrochemical techniques can be successfully used for the detection of rutin mainly because they are simple, rapid, sensitive and cost effective. One of them, the square-wave voltammetry (SWV), evidenced to be particularly sensitive in the determination of the electroactive organic compounds due to the very low non-Faradaic current [16,17]. The advantage of SWV when compared to cyclic voltammetry (CV) and differential pulse voltammetry (DPV) lists: shorter time of analysis, reduced consumption of the electroactive compounds and minor problems with the electrode surface fouling [18]. Furthermore, with this technique, high sensitivities and very low detection and quantification limits can be obtained [3,15].

The development of novel methods of electroanalysis can be facilitated by using screen-printed electrodes (SPEs), which have a series of practical advantages when compared to the classical electrodes, such as the simplicity of use, the commercial availability, the low price and very good reproducibility in term of industrial production. Therefore, SPEs can be easily replaced after each analysis, which enhances the repeatability and reproducibility of the analyses [19,20].

The performance characteristics of SPEs can be further improved if the sensitive element is based on nanomaterials, such being the case of the sensitive element based on carbon or metallic nanoparticles.

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Table 1
Performance characteristics of carbonaceous material based sensors used in detection of rutin.

Sensitive material	Electrochemical technique	Linear range (M)	LOD (M)	Reference
Chitosan/graphene	DPV	5×10^{-7} to 1.04×10^{-5}	–	9
Electrodeposited graphene/gold nanoparticles	DPV	8×10^{-8} to 8×10^{-5}	2.55×10^{-8}	10
Chemically reduced graphene oxide/Pt nanoparticles	DPV	0.057×10^{-6} to 102.59×10^{-6}	2.0×10^{-8}	11
Reduced graphene oxide	DPV	0.1×10^{-6} to 2.0×10^{-6}	2.32×10^{-8}	12
Graphene oxide/multi-walled carbon nanotube	DPV	0.08×10^{-6} to 80×10^{-6}	2.0×10^{-8}	13
Electrochemically reduced graphene oxide	DPV	4.7×10^{-7} to 1.2×10^{-5}	1.8×10^{-8}	14
Graphene/n-octylpyridinum hexafluorophosphate	SWV	0.05×10^{-6} to 11×10^{-6}	1×10^{-8}	15

Graphene (GPH) have been extensively used in the development of sensors and biosensors for the distinctive properties related to two-dimensional nanostructure, for instance the high surface area, the outstanding electrical conductivity and the biocompatibility with organic molecules [21,22]. On the other hand, the incorporation of gold nanoparticles (AuNPs) with GPH could represent a promising way towards significant improvements of the electrochemical properties of the sensitive nanomaterials [10]. Due to its good compatibility and excellent electrical conductivity, chitosan is used for the better dispersion of the nanomaterials and the preservation of the nanostructures [22]. Generally, the effects of these nanomaterials are the increase of the performance characteristics, due to the facilitated transfer of electrons at the electrode-solution interface, characterized by the enhancement of the sensor response and the specific interactions with the target molecule [10,22,23].

To the best of our knowledge, the development of novel sensors using graphene and gold nanoparticles is a challenging and yet a promising way to accomplish sensitive, fast and simple detection of rutin. Therefore, the aim of this paper is to develop, optimize and validate an electroanalytical method based on the square-wave voltammetry technique for the assessment of rutin in pharmaceutical products using a sensitive voltammetric sensor based on graphene (GPH) and gold nanoparticles (AuNP).

2. Materials and methods

2.1. Reagents and solutions

All the chemicals were of the highest purity commercially available and were used without further purification. Rutin and ethanol (absolute, ≥99.8%) of analytical grades, were acquired from Sigma-Aldrich (St. Louis, USA). Chitosan, chloroauric acid, potassium ferricyanide, potassium chloride, hydrochloric acid, acetic acid, sodium acetate, sodium diphosphate, disodium phosphate, sodium hydroxide, trisodium citrate, lactic acid, ascorbic acid, lactose, sodium lauryl sulfate, starch, and sucrose were used in electrochemical studies.

The carbon screen-printed electrodes (CSPE), DRP-110 working in solution (the working electrode diameter of 4 mm) were purchased from Dropsens Ltd. (Llanera, Spain). The graphene (GPH), platelet planar size of 0.3–5 μm, from Sigma-Aldrich (St. Louis, MO, USA) was used for CSPE modification.

All the solutions were prepared with ultrapure water (resistivity was 18 MΩ cm) obtained from a Milli-Q water ultrapurification system (Simplicity®, Millipore, USA). In all electrochemical experiments, electrolytes buffer solutions with ionic strength 0.1 M were used. These buffer solutions were prepared with analytical grade substances and ultrapure water.

The stock rutin solution (10^{-3} M) was prepared in ethanol, in order to facilitate the dissolving process, by means of ultrasonication. The solutions used for the spectrophotometric and the electrochemical analyses were obtained right before utilization by diluting the stock solutions with buffer solution until the desired concentration was reached. The stock solution was kept in the fridge, at a 4 °C temperature and remained stable throughout the analyses.

2.2. The fabrication of voltammetric sensor

The commercial CSPEs were modified with graphene, chitosan, and Au nanoparticles in order to achieve a novel sensor with an improved sensitivity to rutin.

The GPH dispersion was prepared by mixing 1 mg GPH with 1 mL chitosan solution (0.2% in acetic acid, pH 5). To achieve a homogeneous dispersion the GPH-chitosan mixture was ultrasonicated for 2 h. The chitosan improved the dispersion of graphene.

The gold nanoparticles (AuNPs) were prepared through the reduction of $HAuCl_4$ with trisodium citrate in aqueous solution [24]. The synthesis reaction can be summarized as follows:

$$2HAuCl_4 + 3C_6H_8O_7 \text{ (citric acid)} \rightarrow 2Au + 3C_5H_6O_5 \text{ (3-ketoglutaric acid)} + 8HCl + 3CO_2$$

After the synthesis and the separation of the gold nanoparticles, 1 mg of AuNPs was added to homogeneous dispersion GPH-chitosan and ultrasonicated for 1 h.

The chemically modified carbon screen-printed electrodes were developed using the drop-and-dry method. 10 μL of the nanomaterials composite dispersion was dropped on the SPCEs using micropipette and then were dried in a desiccator at room temperature. The modified electrodes were the ones containing GPH (GPH/CSP sensor) and GPH and AuNPs (GPH-AuNP/CSP sensor) in the sensitive element. The prepared electrodes were positioned at 4 °C.

2.3. Equipment

The cyclic voltammetry (CV) and square-wave voltammetry (SWV) experiments were performed on a Biologic SP 150 (Bio-Logic Science Instruments SAS, France) potentiostat/galvanostat controlled by a microcomputer with EC-Lab Express software. A three-electrode system was used where a silver-silver chloride (Ag/AgCl in 3 M KCl) electrode was the reference electrode, a platinum wire electrode was the auxiliary electrode and the graphene-gold nanoparticles screen-printed (GPH-AuNP/CSP) sensor was the working electrode. Thus, the connections to the potentiostat/galvanostat were made through independent cables for each electrode. All the subsequent potentials indicated in this study were compared with the Ag/AgCl in 3 M KCl system.

The cyclic voltammograms were obtained for different potential ranges at 0.1 V s^{-1}, while the square wave voltammograms were obtained using a 90 mV pulse height, a 5 mV scan increment, and a 15 Hz frequency. All the electrochemical measurements were carried out at room temperature.

The morphology of the carbon screen-printed electrode modified with graphene - gold nanoparticles composite was characterized using the scanning electron microscope FlexSEM 1000 (Hitachi, Japan).

The S10H ultrasonic apparatus (Elmasonic, Germany) was used for the ultrasonic experiment. The pH of the buffer solutions was measured with an Inolab pH 7310 pH-meter (WTW, Germany). The spectrophotometric measurements in the ultraviolet range were carried out with a Rayleigh UV-1601 spectrophotometer (Beijing Beifen-Ruili Analytical Instrument Co. Ltd., China).