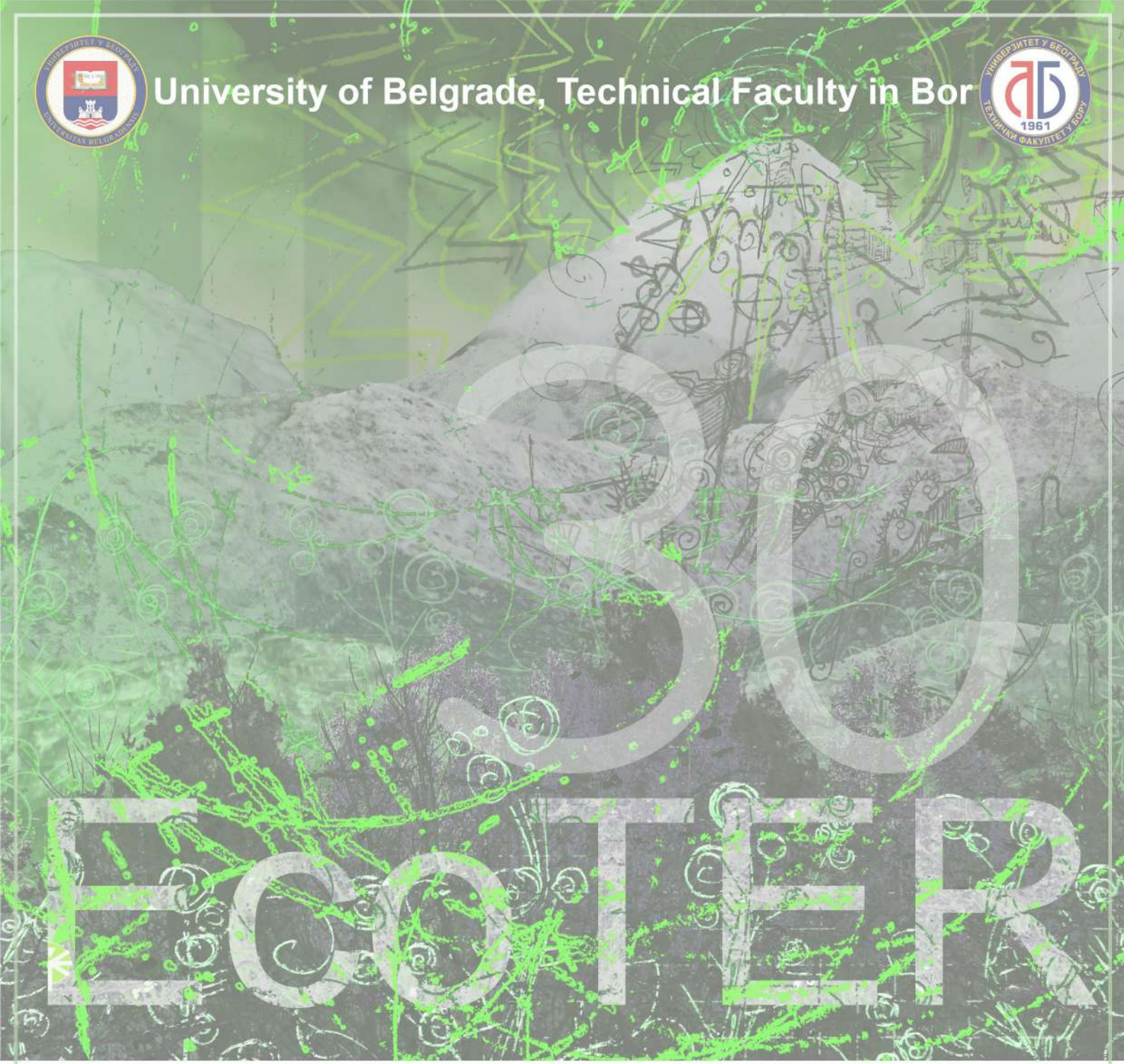
30th International Conference Ecological Truth & Environmental Research 2023

Proceedings

Editor
Prof. Dr Snežana Šerbula



30th International Conference Ecological Truth & Environmental Research 2023

Proceedings

Editor
Prof. Dr Snežana Šerbula

PROCEEDINGS

30th INTERNATIONAL CONFERENCE

ECOLOGICAL TRUTH AND ENVIRONMENTAL RESEARCH – EcoTER'23

Editor:

Prof. Dr Snežana Šerbula

University of Belgrade, Technical Faculty in Bor

Editor of Student section:

Prof. Dr Maja Nujkić

University of Belgrade, Technical Faculty in Bor

Technical editors:

Jelena Milosavljević, PhD, University of Belgrade, Technical Faculty in Bor

Asst. prof. Dr Ana Radojević, University of Belgrade, Technical Faculty in Bor

Sonja Stanković, **MSc**, University of Belgrade, Technical Faculty in Bor

Cover design:

Aleksandar Cvetković, **BSc**, University of Belgrade, Technical Faculty in Bor

Publisher: University of Belgrade, Technical Faculty in Bor

For the publisher: Prof. Dr Dejan Tanikić, Dean

Printed: University of Belgrade, Technical Faculty in Bor, 100 copies, electronic edition

Year of publication: 2023

ISBN 978-86-6305-137-9

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

502/504(082)(0.034.2)
574(082)(0.034.2)

INTERNATIONAL Conference Ecological Truth & Environmental Research (30 ; 2023)
Proceedings [Elektronski izvor] / 30th International Conference Ecological Truth & Environmental Research - EcoTER'23, 20-23 June 2023, Serbia ; organized by University of Belgrade, Technical faculty in Bor (Serbia) ; co-organizers University of Banja Luka, Faculty of Technology – Banja Luka (B&H) ... [et al.] ; [editor Snežana Šerbula]. - Bor : University of Belgrade, Technical faculty, 2023 (Bor : University of Belgrade, Technical faculty). - 1 elektronski optički disk (CD-ROM) ; 12 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Preface / Snežana Šerbula. - Tiraž 100. - Bibliografija uz svaki rad.

ISBN 978-86-6305-137-9

а) Животна средина -- Зборници б) Екологија – Зборници

COBISS.SR-ID 118723849

30th International Conference
Ecological Truth and Environmental Research – EcoTER'23

is organized by:

UNIVERSITY OF BELGRADE
TECHNICAL FACULTY IN BOR (SERBIA)

Co-organizers of the Conference:

**University of Banja Luka, Faculty of Technology,
Banja Luka (B&H)**

**University of Montenegro, Faculty of Metallurgy and Technology,
Podgorica (Montenegro)**

University of Zagreb, Faculty of Metallurgy, Sisak (Croatia)

**University of Pristina, Faculty of Technical Sciences,
Kosovska Mitrovica**

Association of Young Researchers Bor (Serbia)

Gold Donor of the Conference

HONORARY COMMITTEE

Dr. Petar Paunović
(Zaječar, Serbia)
Prof. Dr Zvonimir Stanković
(Bor, Serbia)
Prof. Dr Velizar Stanković
(Bor, Serbia)
Prof. Dr Milan Antonijević
(Bor, Serbia)
Dragan Ranđelović, Association of Young Researchers Bor
(Bor, Serbia)
Toplica Marjanović, Association of Young Researchers Bor
(Bor, Serbia)
Mihajlo Stanković, Special Nature Reserve Zasavica
(Sremska Mitrovica, Serbia)

SCIENTIFIC COMMITTEE

Prof. Dr Snežana Šerbula, *President*

Prof. Dr Alok Mittal (India)
Prof. Dr Jan Bogaert (Belgium)
Prof. Dr Aleksandra Nadgórska-Socha (Poland)
Prof. Dr Luis A. Cisternas (Chile)
Prof. Dr Wenhong Fan (China)
Prof. Dr Martin Brtnický (Czech Republic)
Prof. Dr Isabel M. De Oliveira Abrantes (Portugal)
Prof. Dr Shengguo Xue (China)
Prof. Dr Tomáš Lošák (Czech Republic)
Prof. Dr Maurice Millet (France)
Prof. Dr Murray T. Brown (New Zealand)
Prof. Dr Xiaosan Luo (China)
Prof. Dr Daniel J. Bain (United States of America)
Prof. Dr Che Fauziah Binti Ishak (Malaysia)
Prof. Dr Richard Thornton Baker (United Kingdom)
Prof. Dr Mohamed Damak (Tunisia)
Prof. Dr Jyoti Mittal (India)
Prof. Dr Miriam Balaban (United States of America)
Prof. Dr Yeomin Yoon (United States of America)
Prof. Dr Chang-min Park (South Korea)
Prof. Dr Faramarz Doulati Ardejani (Iran)
Prof. Dr Ladislav Lazić (Croatia)
Prof. Dr Natalija Dolić (Croatia)
Prof. Dr Milutin Milosavljević (Kosovska Mitrovica)
Prof. Dr Nenad Stavretović (Serbia)
Prof. Dr Ivan Mihajlović (Serbia)
Prof. Dr Milovan Vuković (Serbia)
Prof. Dr Nada Blagojević (Montenegro)
Prof. Dr Darko Vuksanović (Montenegro)
Prof. Dr Irena Nikolić (Montenegro)
Prof. Dr Šefket Goletić (B&H)
Prof. Dr Džafer Dautbegović (B&H)
Prof. Dr Borislav Malinović (B&H)
Prof. Dr Slavica Sladojević (B&H)
Prof. Dr Nada Šumatić (B&H)
Prof. Dr Snežana Milić (Serbia)

ORGANIZING COMMITTEE

Prof. Dr Snežana Šerbula, *President*

Prof. Dr Snežana Milić, *Vice President*

Prof. Dr Đorđe Nikolić, *Vice President*

Prof. Dr Marija Petrović Mihajlović

Prof. Dr Milan Radovanović

Prof. Dr Milica Veličković

Prof. Dr Danijela Voza

Prof. Dr Maja Nujkić

Prof. Dr Žaklina Tasić

Dr Ana Simonović

Dr Tanja Kalinović

Dr Ana Radojević

Dr Jelena Kalinović

Dr Jelena Milosavljević

Sonja Stanković, MSc

Miljan Marković, MSc

Vladan Nedelkovski, MSc

Aleksandar Cvetković, BSc

PREFACE

The 30th international conference Ecological Truth & Environmental Research – EcoTER'23 kept three areas in focus: ecology, environmental protection and sustainable development. The conference will be held on Mt Stara Planina in hotel Stara Planina, Serbia, 20–23 June 2023. The monograph is published on the occasion of the 30th anniversary of the conference. On behalf of the scientific and organizing committee, it is a great honor and pleasure to wish all the participants a warm welcome to the conference.

The monograph is published on the occasion of the 30th anniversary of the conference.

We hope to convey the message of the conference, which is that a transformation of attitudes and behavior would bring the necessary changes. This is also an opportunity for the participants who are experts in this field to exchange their experiences, expertise and ideas, and also to consider the possibilities for their collaborative research.

The 30th international conference Ecological Truth & Environmental Research – EcoTER'23 is organized by the University of Belgrade, Technical Faculty in Bor, and co-organized by the University of Banja Luka, Faculty of Technology, the University of Montenegro, Faculty of Metallurgy and Technology – Podgorica, the University of Zagreb, Faculty of Metallurgy – Sisak, the University of Pristina, Faculty of Technical Sciences – Kosovska Mitrovica and the Association of Young Researchers, Bor.

These Proceedings 103 papers from the authors coming from the universities, research institutes and industries in 11 countries: Australia, USA, Brazil, Spain, Portugal, Libya, Italy, Bulgaria, Bosnia and Herzegovina, North Macedonia, and Serbia.

As a part of this year's conference, the 5th Student Session – EcoTERS'23 is being held. We appreciate the contribution of the students and their mentors who have also participated in the conference.

The support of the Gold donor and their willingness and ability to cooperate has been of great importance for the success of the EcoTER'23. The organizing committee would like to extend their appreciation and gratitude to the Gold donor of the conference for their donation and support.

We appreciate the effort of all the authors who have contributed to these Proceedings. We would also like to express our gratitude to the members of the scientific and organizing committees, reviewers, speakers, chairpersons and all the conference participants for their support to the EcoTER'23. Sincere thanks go to all the people who have contributed to the successful organization of the EcoTER'23.

Prof. Snežana Šerbula,

President of the scientific and organizing committee

TABLE OF CONTENTS

Plenary Lecture

Invited Lectures

Conference Papers

Environmental monitoring and impact assessment

Student Section

ELECTROCHEMICAL SENSING OF FOLIC ACID

Žaklina Tasić[1*], Marija Petrović Mihajlović[1], Ana Simonović[1], Milan Radovanović[1], Milan Antonijević[1]

[1]University of Belgrade, Technical Faculty in Bor, V.J. 12, 19210 Bor, SERBIA

[*]*ztasic@tfbor.bg.ac.rs*

Abstract

The purpose of this article is to analyze the findings from studies on the electrochemical determination of folic acid (Vitamin B9). Folic acid is an important water-soluble vitamin for various biological processes, and its deficiency in human organisms can lead to health problems. Different electrochemical sensors are available for detecting folic acid in various mediums. These sensors provide rapid, selective and sensitive detection of folic acid, making them a valuable tool in analytical research. The results of researchers who used low-cost and environmentally friendly materials to prepare sensors are presented in this study. The limit of detection of one such sensor was 1.8×10^{-10} *mol* dm^{-3} *indicating its good selectivity and sensitivity.*

Keywords: electrochemical sensors, folic acid, vitamins, differential pulse voltammetry.

INTRODUCTION

Vitamins represent essential nutrients that are necessary for normal functioning of the human organism. They are introduced into the body through food or supplements because the body cannot synthesize them [1]. The B group vitamins include eight water-soluble vitamins that play important roles in cell metabolism. They are: B1 (thiamine), B2 (riboflavin), B3 (niacin), B5 (pantothenic acid), B6 (pyridoxine), B7 (biotin), B9 (folate), and B12 (cobalamin). Each B vitamin has its own unique function, but they all work together to help the body convert food into energy and to support the nervous system. Deficiencies in B vitamins can lead to various health problems, such as anemia, neuropathy, and birth defects [2]. Folic acid (vitamin B9) is important for several processes in the human body, including the formation of red blood cells, for cardiovascular health, nucleic acid synthesis, the normal development of the neural tube and to produce neurotransmitters [3]. B vitamins are commonly found in animal products such as meat, fish, and dairy products, as well as in supplements. Spinach, white beans, asparagus, soybeans, oranges and melons are also the important sources of folic acid [2].

There are several analytical methods that can be used to determine the level of folic acid (FA) in a sample, including: high-performance liquid chromatography (HPLC), capillary electrophoresis (CE), spectrophotometry [4]. Despite their high precision and sensitivity, these methods for determining folic acid have drawbacks such as time-consuming procedures, necessary sample preparation, expensive equipment, and complexity of procedures [5]. On the other hand, electroanalytical methods, which are frequently utilized due to their benefits of low cost, simple sample preparation, fast analysis time, high accuracy, and low detection

limits, are increasingly being used as alternatives. Electrochemical sensors can be used to detect folic acid, too. There are several advantages of using electrochemical sensors for the detection of folic acid compared to other analytical methods: sensitivity, selectivity, they are also portable and cost-effective.

Different electrodes were used for the determination of folic acid including glassy carbon electrode, carbon paste, pencil graphite electrode, silver solid amalgam, and mercury drop electrode [5,6]. The significance of the determination of folic acid in different mediums and using different sensors is highlighted in review works by Di Tino *et al*. [4] and Batra *et al*. [7]. Additionally, in the paper of Alizadeh *et al*. [6] the possibilities of using modified carbon-based electrodes for the determination of FA are summarized.

The aim of this paper is to point out the importance of using low-cost materials for developing electrochemical sensors for the determination of folic acid in different matrices.

ELECTROCHEMICAL SENSORS FOR THE DETERMINATION OF FOLIC ACID

In the early 2000s, bismuth-film electrodes (BiFEs) attracted an increasing interest from researchers in electroanalytical investigations, as an adequate replacement for mercury electrodes. Compared to the mercury electrodes, bismuth-based electrodes are non-toxic and have a wide potential window. Bismuth-film electrodes are a type of electrochemical sensor that can be used for the detection of various compounds, including folic acid. They are made by depositing a thin film of bismuth onto a conductive substrate, such as glassy carbon electrodes (GCEs), carbon paste electrodes (CPEs), screen-printed electrodes (SPEs) [8]. Bismuth-film electrodes can be used to detect a wide range of substances, including: heavy metals, and organic compounds (pesticides, vitamins, amino acids).

Pencil graphite electrodes belong to the carbon based electrodes. Carbon based electrodes stand out from other materials due to their properties, such as chemical stability, a large active surface, the ability to modify the surface, and electrocatalytic activity in various oxidation-reduction reactions [9]. In their papers, Tasić *et al*. [10,11] showed the applicability of low-cost electrochemical sensors, such as PGE and an electrochemical sensor prepared using recycled carbon from spent batteries, for the detection of target analytes.

The effectiveness of poly(cystine)/PGE in determining folic acid was studied through the use of differential pulse voltammetry (DPV) and cyclic voltammetry (CV) techniques. The peak current of the unmodified pencil graphite electrode was found to be 0.77 μA. However, the response of folic acid was enhanced to 3.56 μA with the use of poly(cystine)/PGE. This improvement was attributed to the presence of thiol groups in L-cystine, which facilitate electron transfer and enhance the conductive properties of the electrode [5]. The slope of the Ep versus pH plot was calculated to be -35 mV/pH, indicating that the oxidation of folic acid involves a transfer of two electrons and one proton [5].

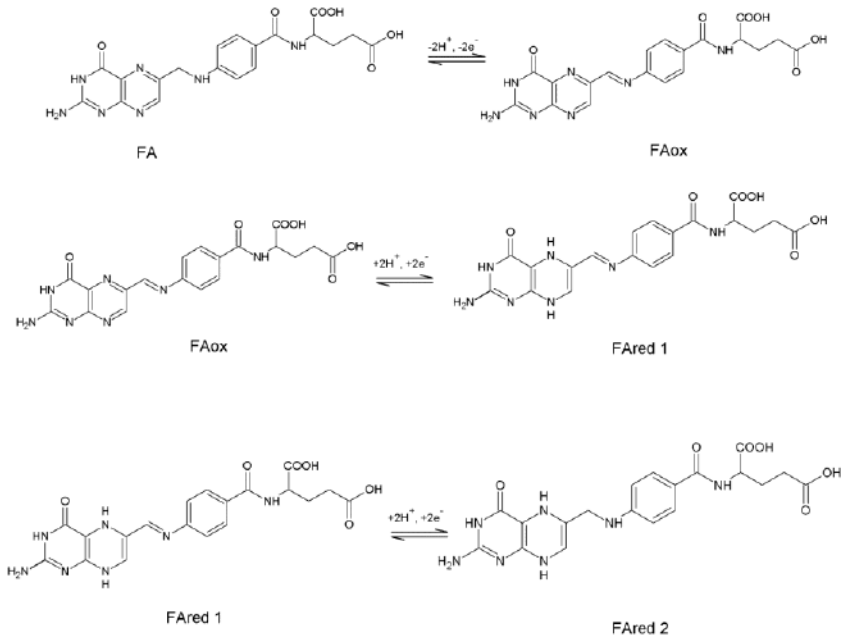


Figure 1 *Proposed mechanism of oxidation and reduction of FA on graphite paste electrode [12]*

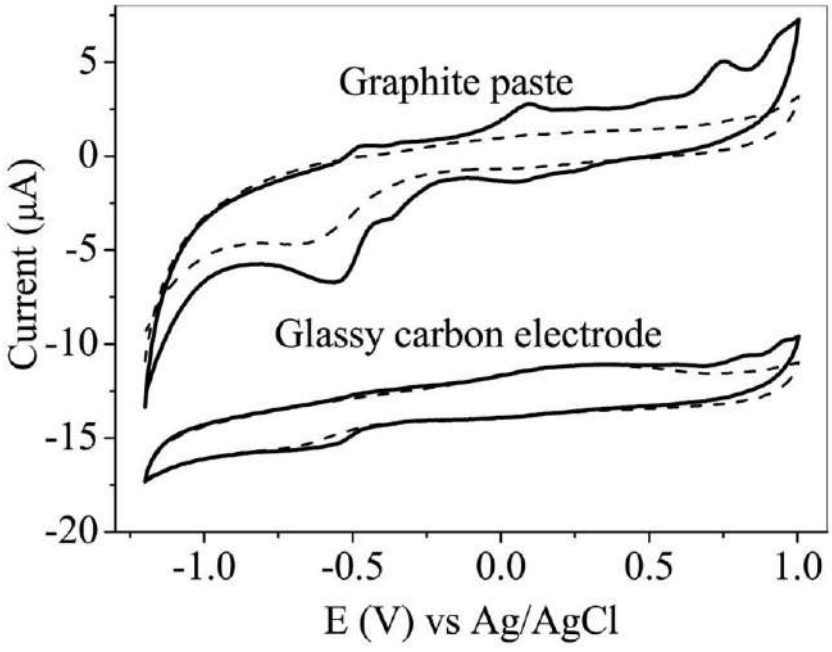


Figure 2 *Cyclic voltammograms obtained for 44.14 mg L^{-1} FA in 0.1 mol L^{-1} acetate buffer as supporting electrolyte at pH 4.5 with v = 50 mV s^{-1}, using graphite paste-based electrode (dashed line – blank solution) and glassy carbon electrode (dashed line – blank solution) [12; https://doi.org/10.1016/j.jelechem.2018.04.043].*

Table 1 summarizes the results obtained by different electrochemical sensors for determining FA.

Table 1 *Electrochemical characteristics of different electrodes as sensor for folic acid detection*

Sensor	Medium	Method	Linear range	LOD	Reference
FA-imp/CNDs/PGE	PBS (pH 6.2) + 0.1 M KCl	CV, DPV	2.2–30.8 ng mL^{-1}	2.02 ng mL^{-1}	[3]
poly(cysteine)/PGE	PBS pH 7	CV, DPV	1.0–100 µmol dm^{-3}	0.43 mol dm^{-3}	[5]
NiZCB-GCE		DPV	0.004–0.22 mg dm^{-3}	1.3 µg dm^{-3}	[13]
Bismuth film electrode		SWAdS	0.5–20 nmol dm^{-3}	0.2 nmol dm^{-3}	[14]
GPE modified with hybrid MIP (poly(methacrylic acid)-SiO_2)	pH 4.5	DPV, SWV	0.005–0.1 µg dm^{-3}	0.72 µg dm^{-3}	[12]
poly tyrosine modified PGE	PBS pH 7	CV, DPV	1µM–85 µmol dm^{-3}	/	[15]
BiFE-GCE	BR pH 2	CV, DCV	$2.5x10^{-8}$–$3x10^{-5}$ mol dm^{-3}	$4.1x10^{-9}$ mol dm^{-3}	[8]
BiFE-GCE	Acetate buffer solution pH 4.5	SWCSV, CV	0.1–10.0 µmol dm^{-3}	$1x10^{-3}$ µmol dm^{-3}	[16]

CV – cyclic voltammetry; DPV – differential pulse voltammetry; SWV – square wave voltammetry; DCV – direct current voltammetry; SWCSV – square wave cathodic stripping voltammetry; PGE – pencil graphite electrode; NiZCB-GCE – Ni-zeolite/carbon black-modified glassy carbon electrode; BiFE-GCE – a bismuth-film electrode prepared on the glassy carbon electrode; FA-imp/CNDs/PGE – folic acid imprinted on a pencil graphite electrode modified with carbon nanodots; PBS – phosphate buffer solution; BR – Britton-Robinson buffer solution; LOD – limit of detection.

Porada *et al*. [13] in their study presented a low-cost and highly specific voltammetric method for measuring vitamins B2, B9, B12, and B3 using a Ni-zeolite/carbon black-modified glassy carbon electrode (NiZCB/GCE). By using an environmentally friendly Ni-exchanged natural zeolite and conductive carbon black (CB) in a one-step modification of the GCE, a highly sensitive sensor capable of accurately detecting individual B-group vitamins, even in the presence of other vitamins, was obtained with a low limit of detection (Table 1). Kuceki *et al*. [12] initially compared the electrochemical responses of folic acid using graphite paste and glassy carbon electrodes (Figure 2). The results showed substantial improvements in both the anodic and cathodic peak currents when using the graphite paste electrode. This improvement may be due to the higher porosity of the graphite paste compared to the glassy carbon electrode, which makes the adsorption process easier [12]. As reported, the oxidation process at +0.8 V occurs on the side-chain, as demonstrated in Figure 1, which results in the loss of two protons and two electrons [12]. The reduction processes at -0.35 V and -0.50 V are likely attributed to the reduction of the pterin moiety of the FA molecule (Figure 1), and the reduction of the side-chain –CH=N–, respectively. According to the data reported by Kuceki *et al*. [12], the inclusion of a low amount (3% w/w)

of molecularly imprinted polymer in the graphite paste electrode enabled the development of a highly sensitive and selective sensor for folic acid without the need for a preconcentration step. Stepankova *et al*. [8] and Vladisavljevic *et al*. [16] used a bismuth-film prepared ex situ on a glassy carbon electrode for the determination of folic acid. No oxidation signal was recorded in Britton–Robinson buffer (pH 5) under the optimised conditions, indicating that the electrode process is irreversible with one reduction peak near -0.55 V [8,16]. The shift in the reduction potential to a less negative value and increasing the intensity of folic acid reduction peak on the BiFE compared to the GCE suggest the electrocatalytic nature of the BiFE. This behaviour was also seen with the BiNWs/GCE and is believed to be due to its high surface-to-volume ratio and uniform pore size that enhance the rapid reduction kinetics of folic acid [16]. Vladisavljević *et al*. [17] prepared BiFE on GCE at different pH, with or without the presence of a complexing agent (EDTA) and used the sensor to determine folic acid and glutathione. The findings in this study show a strong correlation between the bismuth film structure and the electrolyte composition and electrodeposition parameters. Typically, a thick, uniform, non-porous bismuth film was obtained when electrodeposition was carried out in an acetic buffer with a pH of 4.5. However, incorporating the complexing agent ethylenediaminetetraacetic acid (EDTA) into the acetic buffer produced a flake-like, dendritic structure. On the other hand, films produced in HNO_3 had a porous structure and lacked stability. The use of the BiF electrode in the determination of folic acid showed that the film created in the acetate buffer with the addition of EDTA has impressive stripping performance and improved sensitivity. Geca *et al*. [18] demonstrated that the solid bismuth microelectrode is a highly efficient tool for determining folic acid, providing a wide linear range, low limits of detection and quantification, and high selectivity. The lowest reported limit of detection for folic acid was 1.8×10^{-10} mol dm^{-3}. The adsorptive stripping voltammetry method with prepared sensor can be used in pharmaceutical analysis without complicated sample preparation. Furthermore, the solid bismuth microelectrode does not require the addition of Bi^{3+} to the supporting electrolyte, making it an environmentally-friendly alternative to bismuth film electrodes. Overall, the solid bismuth microelectrode is a convenient and superior alternative to previously reported bismuth microelectrode arrays and bismuth film electrodes [18]. According to the results summarized in Table 1, it can be said that the modified PGEs were better in near-neutral solution, while the sensory characteristics of BiFE were better in acidic environments.

CONCLUSION

The importance of folic acid in various vital biological processes, such as nucleic acid synthesis, cell division, fetus growth and development, has led to its widespread use as a supplement to prevent and treat folate deficiency in human organism. As a result, in recent years, there has been a significant effort in the analytical field to create precise and reliable sensors for the determination of folic acid due to its crucial role in human health. Based on a literature review, it can be seen that different prepared electrochemical sensors can be used to determine folic acid. Some of them were better in acidic solutions (BiFEs), while others were better in neutral solutions (modified PGEs). Depending on the experimental conditions and the type of sensor, the detection limits ranged from 1.8×10^{-10} mol dm^{-3} to 0.43 mol dm^{-3}.

In addition, the researchers showed that the modified electrodes have improved sensing capabilities than the unmodified ones. It is still a challenge for researchers to develop a suitable sensor that is sensitive and selective, while being cheap and environmentally friendly.

ACKNOWLEDGEMENT

The authors are grateful to the Ministry of Science, Technological Development and Innovation of the Republic of Serbia for financial support according to the contract with the registration number (451-03-47/2023-01/200131).

REFERENCES

[1] Bas B., Jakubowska M., Górski Ł., Talanta 84 (2011) 1032–1037.

[2] Ribeiro M. V. de M., Melo I. da S., Lopes C., *et al*., Braz. J. Pharm. Sci. 52 (2016) 741–750.

[3] Güney S., J. Electroanal. Chem. 854 (2019) 113518.

[4] Di Tinno A., Cancelliere R., Micheli L., Sensors 21 (2021) 3360.

[5] Dokur E., Gorduk O., Sahin Y., Anal. Lett. 53 (13) (2020) 2060–2078.

[6] Alizadeh M., Nejad F. G., Dourandish Z., *et al*., J. Food Meas. Charact. 16 (2022) 3423–3437.

[7] Batra B., Narwal V., Kalra V., *et al.*, Process Biochem. 92 (2020) 343–354.

[8] Stepankova M., Selesovska R., Janıkova L., *et al*., Monatsh. Chem. 148 (2017) 423–433.

[9] Tasić Ž. Z., Petrović Mihajlović M. B., Simonović A. T., *et al*., Sensors 22 (23) (2022) 9185.

[10] Tasić Ž. Z., Petrović Mihajlović M. B., Simonović A. T., *et al*., Results Phys. 22 (2021) 103911.

[11] Tasić Ž. Z., Petrović Mihajlović M. B., Radovanović M. B., *et al*., Sci. Rep. 12 (2022) 5469.

[12] Kuceki M., Oliveira F. M. de, Segatelli M. G., *et al*., J. Electroanal. Chem. 818 (2018) 223–230.

[13] Porada R., Fendrych K., Kochana J., *et al*., Food Control 142 (2022) 109243.

[14] Rutyna I., Anal. Lett. 48 (2015) 1593–1603.

[15] Santhy A., Beena S., Veena, *et al*., IOP Conf. Series: Mater. Sci. Eng. 872 (2020) 012128.

[16] Vladislavić N., Buzuk M., Buljac M., *et al*., Croat. Chem. Acta 90 (2) (2017) 231–239.

[17] Vladislavić N., Buzuk M., Brinić S., *et al*., J. Solid. State Electrochem. 20 (2016) 2241–2250.

[18] Gęca I., Korolczuk M., Electroanal. 32 (2020) 496–502.

eco.tfbor.bg.ac.rs ISBN 978-86-6305-137-9 tfbor.bg.ac.rs