ACADEMIA ROMÂNĂ
Revue Roumaine de Chimie
http://web.icf.ro/rrch/

Rev. Roum. Chim.,
2010, *55*(2), 109-115

ELECTROCHEMICAL STUDY OF CURCUMIN AND bisDEMETHOXYCURCUMIN ON ACTIVATED GLASSY CARBON ELECTRODE

Andreea LUNGU,[a] Ileana SANDU,[a] Cristian BOSCORNEA,[b] Stefan TOMAS[b] and Constantin MIHAILCIUC[a*]

[a] Physical Chemistry Department, Faculty of Chemistry, University of Bucharest, Regina Elisabeta 4-12, 030018 Bucharest, Roumania;
[b.] Organic Technology and Macromolecular Compounds, Faculty of Applied Chemistry and Material Sciences, University Politehnica of Bucharest, Calea Victoriei 149, 00702 Bucharest, Roumania

Received June 10, 2009

The curcumin and a curcumin-like compound were investigated by using cyclic voltammetry (CV) and differential pulse voltammetry (DPV) techniques at an anodically activated glassy carbon electrode (GCE) in non-aqueous media. The presense of two o-methoxy phenolic groups in curcumin in comparison with its analogue determines different cyclic voltammetric redox behaviour of curcumin and its analogue. The anodically activated GCE leads to a better electrochemical behaviour (much better defined and more stable peak currents) of the two compounds in comparison with their behaviour at the bare GCE. Both of the two compounds are adsorbed but in different degree to the anodically activated GCE surface.

INTRODUCTION

Curcumin is the main pigment present in the rhizomes of the *Curcumina longa* possessing biological properties as anti-inflammatory, anti-angiogenic, antioxidant, etc. It inhibits free radical formation in blood and body tissues. It also prevents some cardio-vascular deseases.[1,2] The powerful curcumin antioxidant activity,[3-5] working especially when diverse free radicals are produced as a result of physiological processes, is essentially an electrochemical property, so it has to be investigated from an electrochemical viewpoint in order to characterize its redox behaviour and its electrocatalytic role.

The curcumin (1,7-bis[4-hydroxy-3-methoxy-phenyl]- 1,6-heptadiene-3,5-dione) and its analogue *bis*demethoxycurcumin (1,7-bis[4-hydroxyphenyl]-1,6-heptadiene-3,5-dione) (see Fig. 1) exhibit different redox properties due to the presence of methoxy group in position 3 of the phenyl moiety in curcumin. Also the curcumin can be an efficient chelating agent for different metallic cations as Fe^{3+}, Fe^{2+}, Co^{2+}, and Ni^{2+} leading to formation of complexes,[6-12] besides it can inhibit the oxidation of certain metal ions.[7,10]

Both studied curcumins have the same moiety (i.e., bis-α,β-unsaturated β-diketo(heptadiene-dione)) and undergo keto-enol tautomerism. The biological activity of curcumin is associated with the phenolic hydroxyl group and the diketonic structure[13] especially under pH 8, where the ketonic form of the heptadieno-dione chain predominates. Above pH 8, the enolate form of the heptadieno-dione chain predominates and curcumin exhibites kelatic properties towards the cations as Fe^{3+}, Fe^{2+}, Cu^{2+}, Cd^{2+} and Ni^{2+}, the enolate form of curcumin acting as electron donor and good coordination sites. Curcumin can

* Corresponding author: cmpaul@gw-chimie.math.unibuc.ro

also protect against lead- and cadmium-induced lipid peroxidation and lead-induced tissue damage in rat brain,[13] or can participate in chelating the irons ions which, in turn, take part in oxygen transfer.[7]

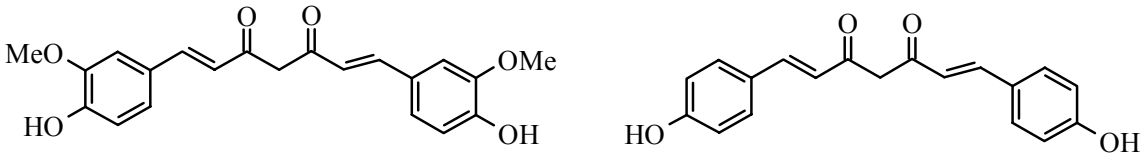


Fig. 1 – Curcumin and its analogue.

EXPERIMENTAL

Apparatus: Electrochemical experiments were carried out using the potentiostat-galvanostat system AutoLab PGStat 12, controlled by General Purpose Electrochemical System (GPES) electrochemical interface for Windows (version 4.9.007). Three electrodes in one-compartment cell (10 ml) were used in all experiments. Glassy carbon electrode served as a working substrate electrode. All potentials were measured and given referred to SCE used as reference electrode. The counter electrode was a glassy carbon electrode rod-shaped.

Measurements: All measurements were carried out at room temperature. All solutions were deaerated by dry argon stream for 5 min before every experiment and an argon atmosphere was maintained above the solution during the experiment.

Chemicals: All chemicals were reagent grade, DMSO (Carlo Erba) and $TEABF_4$ (Fluka) on one hand, and the curcumin and curcumin-like compound (these two last compounds were synthesised and purified in Organic Technology and Macromolecular Compounds Laboratory (Faculty of Applied Chemistry and Material Sciences, University Politehnica of Bucharest), on another hand, were used without further purification. Before modification, the glassy carbon electrode surface was polished with alumina slurry on a polishing pad, washed with distilled water and sonicated for 3 minutes in doubly distilled water.

Activation of GCE

The bare GCE was polished using 0.05 μm alumina slurry until a mirror-like finish was obtained; then it was rinsed with twice distilled water, cleaned by ultrasonication in twice distilled water for 3 min and finally dried in air. Then the GCE was anodically activated at +1.8 V for 60 s and, respectively, for 120 s. This procedure can improve the electrochemical response of biological compounds, increasing both the activity and reproducibility of carbon electrodes. In addition, at the pretreated GCE some biological compounds can be adsorbed and, as a consequence, accumulated at the electrode surface prior to CV and/or DPV experiments. Anodic activation of the surface of GCE at high anodic electrode potential results in an oxidized film containing functional group, especially of carbon-oxygen type (maybe of quinone type). As a result the number of active sites at the GCE surface increases and the rate of the electron transfer reaction can be improved.[14-16] The anodization of GCE results in more stable peak currents. It is also possible to increase the effective surface aria of the GCE due to the porous films formation. Curcumin and curcumin-like compound from Fig. 1 containing both aromatic rings and double bonds could give adsorption to the anodically activated GCE surface.

RESULTS AND DISCUSSION

Cyclic voltammetry behaviour of a solution containing 10^{-4} M curcumin-like compound in DMSO containing 0.1 M $TEABF_4$, for several scan rates, is presented in Fig.2 A for bare GCE, and in Fig.2 B for an activated GCE, for an initial positive-going electrode potential. In Fig.2 A, one can see the CV behaviour of curcumin-like compound on inactivated GCE, the peaks being ill-defined, the first is very round, the second almost unobservable and the third as a shoulder (the last being not so well developed because of the continuously increasing of the hysteresis of the cyclic voltammograms at very high electrode potentials). The DPV-trace, shown as inset in Fig. 2A, put in evidence three anodic peaks, first of them appearing at about $E_{pa,1}$ = 0.220 V, the second at $E_{pa,2}$ = 0.500 V and the third at $E_{pa,3}$ = 0.832 V. For the negative-going electrode potential there is only one cathodic peak at about E_{pc} = 0.400 V. In Fig.2 B, on anodically-activated GCE, one can notice one anodic peak, appearing at E_{pa} from 0.343 V for 25 mV/s sweep rate to 0.378 V for 250 mV/s. For the negative-going electrode potential there is only one observable cathodic peak at E_{pc} = 0.222 V for 25 mV/s to 0.284 V for 250 mV/s. As concerns the plot $\ln I_p$ versus $\ln v$, both of them show a linear behaviour with a slope of 1 and a regression coefficient of 1 for the anodic peak current and 0.997 for the cathodic peak current. Also the plot of I_p versus v is linear with a regression coefficient of 0.995 for the anodic case and of -0.996 for the cathodic case. This behaviour is consistent with an adsorption process of the electroactive species. Furthermore, the plots of I_p versus $v^{1/2}$ either for anodic case or for cathodic case are not linear, which is consistent with the fact that the curcumin-like compound does not

participate to the electrode reaction as a diffusional species, but as an adsorbed one. The area enclosed inside each cyclic voltammogram increases with increasing sweep rate, and is anyhow larger than expected, due to a larger contribution of the capacitive current component and perhaps to the adsorption of the curcumin-type compounds to the electrode surface.

Comparing the cyclic voltammograms obtained at the activated GCE and, respectively, at bare GCE (see Fig. 3), it is obvious that both peak currents are increased and the peak potentials are anticipated at the chemically modified (by activation) electrode in comparison with the bare case, reflecting the catalytic role of the modified GCE.

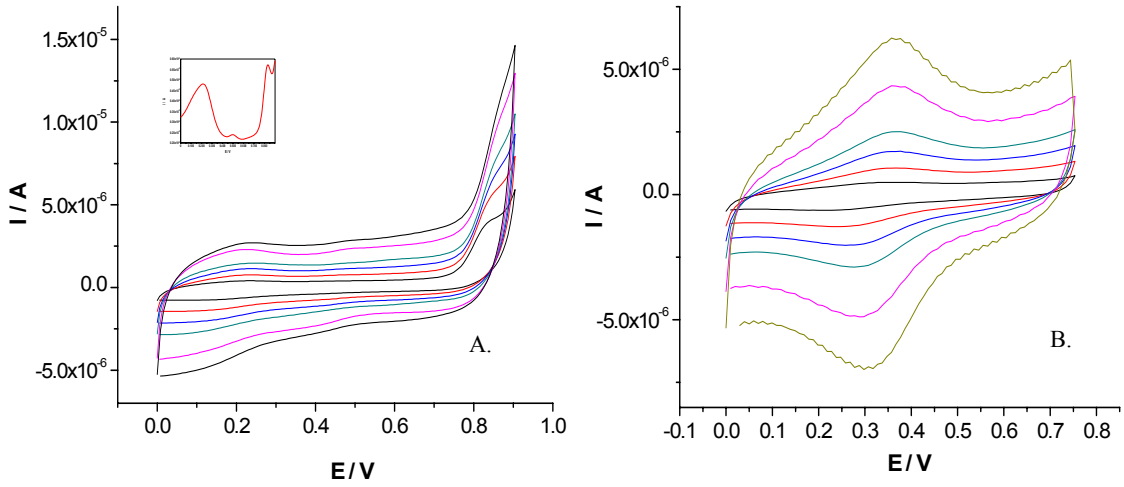


Fig. 2 – The behaviour of 10^{-4} M curcumin-like compound in DMSO containing 0.1 M $TBABF_4$ at GCE bare electrode (A) without activation, cyclic voltammograms in the range from 0.00 V to 0.90 V, and (B) with activation at 1.8 V for 60 s, cyclic voltammograms in the range from 0.00 V to 0.75 V at different scan rates 25, 50, 75, 100, 150, 200 and 250 mV/s.

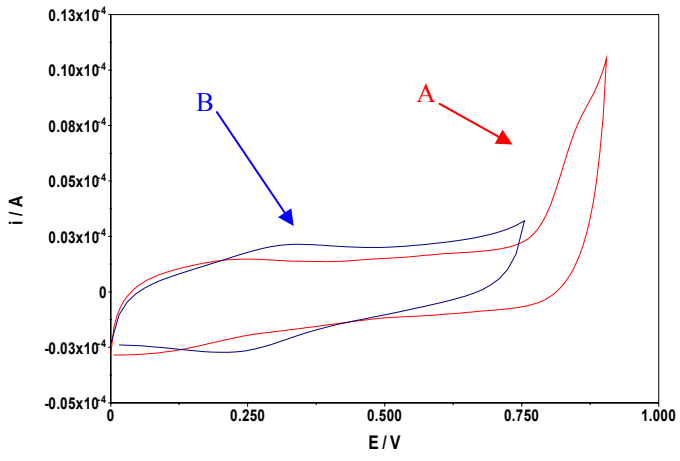


Fig. 3 – The behaviour of 10^{-4} M curcumin-like compound in DMSO containing 0.1 M $TBABF_4$ at GCE bare electrode (A) without activation, cyclic voltammogram in the range from 0.00 V to 0.90 V and (B) with activation at 1.8 V for 60 s, cyclic voltammogram in the range from 0.00 V to 0.75 V at 100 mV/s.

Cyclic voltammetry behaviour of a solution containing 10^{-4} M curcumin in DMSO containing 0.1 M $TEABF_4$, for several scan rates, is presented in Fig. 4 A, for bare GCE, and in Fig. 4 B, for an activated GCE, for an initial positive-going electrode potential. In the latter case, a second

conditioning electrode potential has been applied in order to preconcentrate the electroactive species at the electrodic interface. The effect of the anodically activated GCE in conjugation with the utilization of the preconcentration electrode potential is the better definition of the anodic peaks on one hand and the increase and the anticipation of the anodic peaks on the other hand.

The DPV-trace, shown as inset in Fig. 4 A, puts in evidence three anodic peaks, first of them appearing at about $E_{pa,1}$ = 0.220 V (large, ill-shaped), the second at $E_{pa,2}$ = 0.503 V (almost hardly visible) and the third at $E_{pa,3}$ = 0.820 V (well-shaped). The cyclic voltammograms expose rather an envelope than defined peaks (they are shoulder-shaped) due to the increase of the hysteresis with increasing scan rate. For the negative-going electrode potential there are two cathodic peaks shoulder-shaped. In Fig.4 B, on anodically-activated GCE, one can notice one anodic peak, appearing at $E'_{pa,2}$ = from 533 mV for 25 mV/s to 593 mV for 250 mV/s V, and two other anodic peaks at $E'_{pa,3}$ (well-shaped) from 732 mV for 25 mV/s to 777 mV for 250 mV/s, and at $E'_{pa,4}$ from 824 for 25 mV/s to 852 mV for 250 mV/s, each of the peak potentials for these last two anodic peaks becoming more anodic with increasing scan rate. For the negative-going electrode potential there are two hardly observable cathodic peaks, shoulder-shaped (at around 629 mV for 25 mV/s till 665 mV at for 250 mV/s and, respectively, 411 mV for 25 mV/s till 451 mV for 250 mV/s and,). As concerns the plot $\ln I_p$ vs. $\ln v$, for the more noticeable anodic peak, a linear behaviour with a slope of 0.62 is obtained at a regression coefficient of 0.998. This behaviour is consistent with the existence of a weak adsorption process of the electroactive species, the electrode reaction occurring with the participation of the diffusional electroactive species. Furthermore, the plots of I_p vs. $v^{1/2}$ is almost linear with a regression coefficient of 0.998, while the plot of I_p vs. v is not linear. So the curcumin participates to the electrode reaction especially like a diffusional species and, in a very small extent, like a weak adsorbed one. The area enclosed inside each cyclic voltammogram increases with increasing sweep rate especially for very anodic electrode potentials.

In the literature,[10] the study, on CPE (carbon paste electrode) as WE, in aqueous solution of acidic pH or basic pH, of curcumin electrochemistry points out the existence of three anodic peaks at acidic pH and of only two anodic peaks at basic pH for a first anodic-going scan. Cyclic voltammetry behaviour of a solution containing 10^{-4} M curcumin dissolved in DMSO containing 0.1 M $TEABF_4$, for several scan rates is presented in Fig.4 A, for bare GCE, and in Fig. 4 B, for an activated GCE, for an initial positive-going electrode potential. In Fig.4 A, one can notice the existence of an envelope enclosing the anodic peaks and making them appearing, in the best case, as shoulders. The effect of activation of the GCE is not only the increase of the peak current but also their better definition, although the capacitive current is more important at higher anodic electrode potential. So the first and the third peaks are not so well developed because of the continuously increasing of the hysteresis of the cyclic voltammograms at very high electrode potentials. They become better and better defined, but also more anodic, with increasing scan rate.

Comparing the cyclic voltammograms obtained for curcumin at the activated GCE and, respectively, at bare GCE (see Fig. 5) it is obvious that both peak currents are increased and the peak potentials are anticipated at the chemically modified (by activation) electrode in comparison with the bare case, reflecting the catalytic effect of the modified GCE.

According to Scheme 1, at pH 7 in aqueous electrolyte solution, the phenol group exists especially as phenol but a very little amount of phenolate ion still exists. Due to this very low concentration of phenolate ion the oxidation of this to a free-radical does not lead to an observable anodic peak as was reported in very strong alkaline solution. The free radical, having as a representative limit structure that with the unpaired electron at the carbon atom of the aromatic ring bearing methoxy group, gives rise to a chemical reaction consisting in a nucleophilic substitution of methoxy group with hydroxyl group. This new compound can loose, at least partially, the proton, and, in the radical anion form, can be oxidized to an ortho-quinone via another one-electron transfer reaction.

In fact, due to the small amount of the initial phenolate ion, a superposition between its oxidation (which starts at less anodic potentials) and the second anodic process (which starts at more anodic

electrode potentials) can appear. So the first anodic peak looks like a shoulder. This is the reason for the shape of the cyclic voltammogram enclosing a large area in the region of high anodic potentials studied.

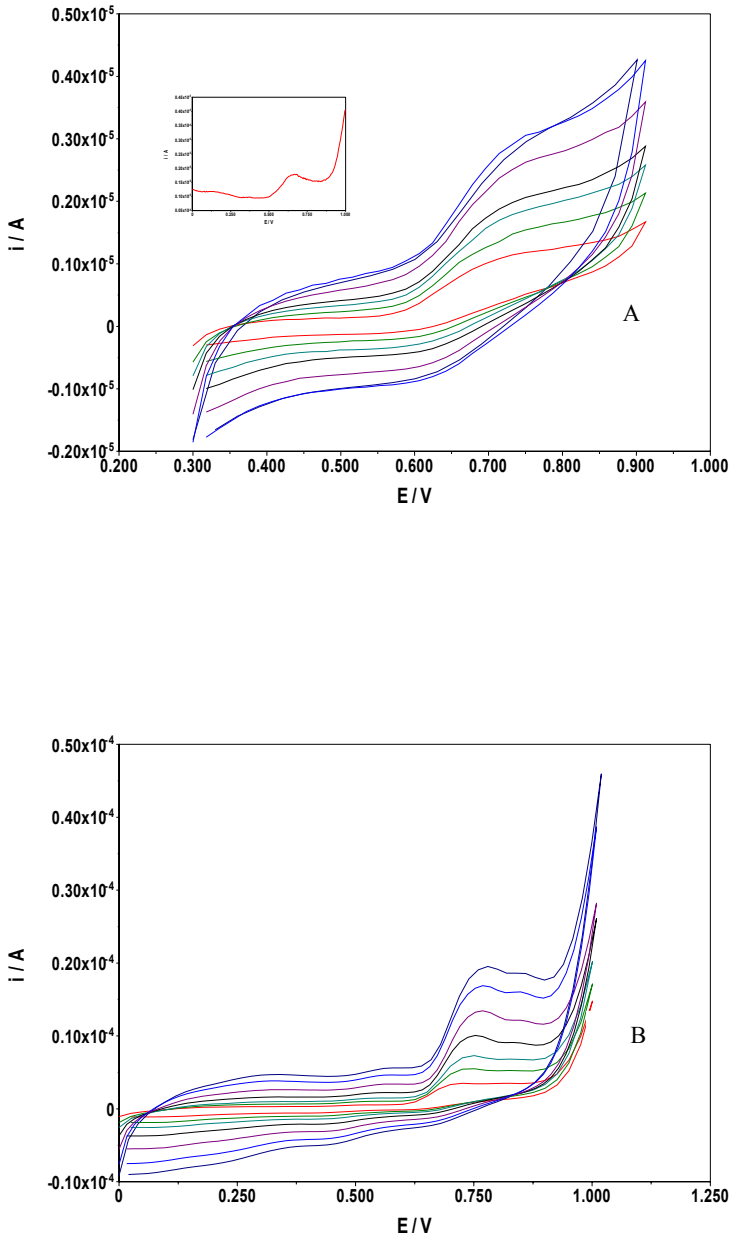


Fig. 4 – The behaviour of 10^{-4} M curcumin in DMSO containing 0.1 M $TBABF_4$ at GCE bare electrode (A) without activation, cyclic voltammograms in the range from 0.30 V to 0.90 V, and (B) with activation at 1.8 V for 60 s, and preconcentration electrode potential at 0.25 V for 30 s, cyclic voltammograms in the range from 0.00 V to 1.00 V at different scan rates 25, 50, 75, 100, 150, 200 and 250 mV/s.

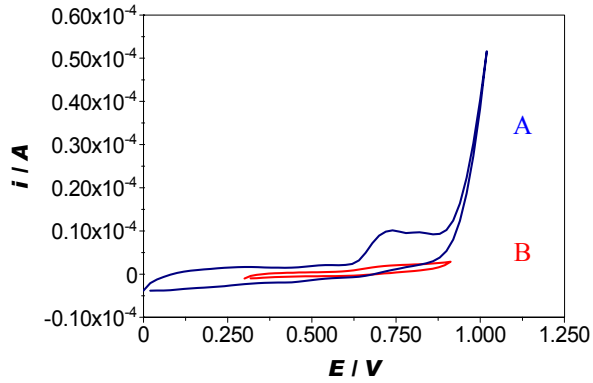
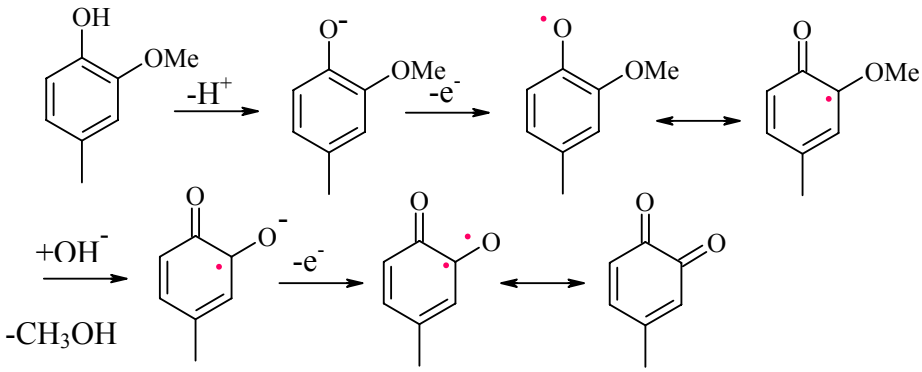


Fig. 5 – The behaviour of 10^{-4} M curcumin in DMSO containing 0.1 M $TBABF_4$ at GCE bare electrode (A) without activation, cyclic voltammogram in the range from 0.30 V to 0.90 V, and (B) with anodic activation at 1.8 V for 60 s, cyclic voltammogram in the range from 0.00 V to 1.00 V at a scan rate of 100 mV/s.



Scheme 1.

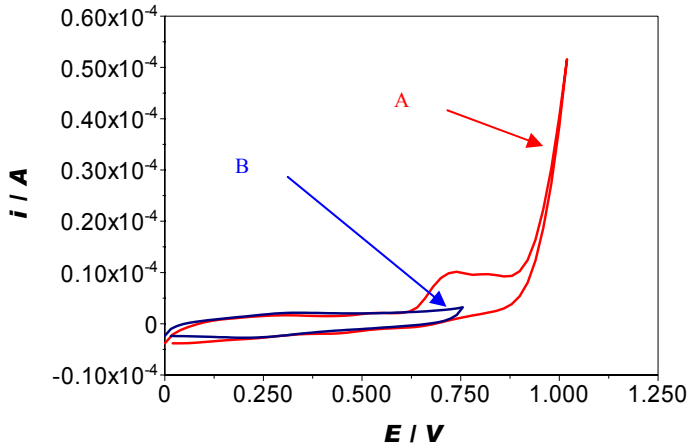


Fig. 6 – Comparison between the cyclic voltammograms of curcumin (A) and *bis*demethoxycurcumin (B) at an anodically activated GCE, (electrode potential 1.8 V for 60 s, accumulation electrode potential -0.25 V, kept for 60 s), 100 mV/s scan rate, different ranges of potential 0.0 V – 1.0 V (A) and 0.0 V – 0.75 V (B).

The second anodic peak (*i.e.*, of the anion radical) can be assigned to the oxidation of the other aromatic moiety of the molecule. Considering the small anodic peak separation, one can say that the two aromatic moieties of the entire molecule do not communicate one with the other. The two peak potentials are too close reflecting that the two oxidations processes involving the extreme aromatic moieties behave independently.

The two electrode processes do not communicate because there is an interruption in the conjugation caused by the methylene group situated between the two ketonic groups. So there are two anodic peaks ascribed to this second one-electron oxidation process which occur at different but enough close electrode potentials (the anodic peak separation being $\Delta E_{pa} = E'_{pa,4} - E'_{pa,3}$ and varying from 92 mV for 25 mV/s till 75 mV for 250 mV/s. The lack of a redox communication between the oxidations of chemical identical moieties seems to operate both for first and for second electron transfer describing the catechol-type oxidation. Comparing the influence of the anodic activation of GCE on the two studied curcumins, it results that the oxidation of curcumin is enhanced in a greater extent than the oxidation of *bis*demethoxycurcumin (see Fig. 6), probably due to the presence in the curcumin molecule of a methoxi group in ortho position in respect with phenolic hydroxy group, in each aromatic ring. This ortho arrangement helps the curcumin to be oxidized easier than the *bis*demethoxycurcumin.

CONCLUSIONS

Two compounds (curcumin and *bis*demethoxycurcumin) were studied in DMSO with 0.1 M $TBABF_4$ at anodically activated GCE. They show a complex redox behaviour consisting in combined E and C mechanism. The GCE, modified by anodic activation, allows a better definition of the peaks in comparison with the bare GCE. In addition, the peak currents are increased and the peak potentials are anticipated in respect with the inactivated GCE behaviour. Curcumin seems to have a mixed participation to the electron transfer reaction: most as diffusional species, but also as weakly adsorbed species. Curcumin-liked compound participates at the electron transfer only like an adsorbed species.

REFERENCES

1. L. A. Tavadian, H. G. Tonikyan, S. H. Minasyan, L. A. Harutyunyan, F. T. Greenaway, S. Williams, R. a. Gray-Kaufman and J. R. J. Sorensen, *Inorg. Chim. Acta,* **2002**, *328*, 1.
2. S. M. Khopde, K.I. Priyadarsini, P. Venkatesan and M. N. A. Rao, *Biophys. Chem.,* ***1999****, 80,* 85.
3. T. Masuda, T. Maekawa, K. Hidaka, H. Bando, Y. Takeda, H. Yamaguchi and J. Agric, *Food Chem.* **2001,** *49*, 2539.
4. T. Masuda, Y. Toi, H. Bando, T. Maekawa, Y. Takeda and H. Yamaguchi, *J. Agric. Food Chem.*, **2002**, *50*, 2524.
5. S. V. Jovanovic , S. Steenken, C. W. Boone and M. G. Simic, *J. Am. Chem. Soc.* **1999**, *121*, 9677.
6. H. H. Tonnesen and J. V. Greenhill, *Int. J. Pharm.,* ***1992***, *87*, 79.
7. M. Borsari, E. Ferrari, R. Grandi and M. Saladini, *Inorg. Chim. Acta*, **2002**, *328*, 61.
8. E. Kunchandy, *Int. J. Pharm.*, **1989**, *57*, 173.
9. M. Yousef Elahi, M. F. Mousavi and S. Ghasemi, E*lectrochim. Acta,* **2008**, *54*, 490.
10. M. Bernabe-Pineda, M. T. Ramirez-Silva, M. A. Romero-Romo, E. Gonzalez-Vergara and A. Rojas-Hermandez,**,** *Spectroch. Acta Part A*, **2004**, *60*, 1105.
11. J. Annaraj, K. M. Paonvel, P. Athappan and S. Srinivasan, T*ransit. Met. Chem.*, **2004,** *29*, 722.
12. A. Barik, B. Mishra, L. Shen, H. Mohan, R. M. Kadam, S. Dutta, H. Y. Zhang and K. I. Priyadarsini, *Free Radic. Biol. Med.*, **2005**, *39*, 811.
13. S. Daniel, J. L. Limson, A. Dairam, G. M. Watkins and S. Daya, *J. of Biochem.,* **2004**, *98*, 266.
14. R. C. Engstrom, *Anal. Chem.*, **1982**, *54*, 2310.
15. M. L. Bowers, *Anal. Chim. Acta*, **1991**, *243*, 43.
16. G. E. Cabaniss, A. A. Diamantis, W. R. Murphy, T. W. Linton and T. J. Mayer, *J. Am. Chem. Soc.*, **1985**, *107*, 1845.