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Voltammetric determination of sodium 5-(7-amino-3-cyanopyrazolo[1,5-a]pyrimidin-6-yl)tetrazol-2-ide as a promising antitumor molecule

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Abstract

The electrochemical behavior of sodium 5-(7-amino-3-cyanopyrazolo[1,5-a]pyrimidin-6-yl)tetrazol-2-ide (compound 1) as a promising inhibitor of casein kinase 2, a novel target in anticancer therapy, was investigated for the first time. Compound 1 undergoes irreversible electrooxidation on a glassy carbon electrode (GCE) in aqueous media, producing two poorly resolved peaks caused by amino group oxidation. The first oxidation step, involving a two-electron transfer, is diffusion-controlled and complicated by a preceding chemical reaction. The peak current of the first oxidation step of the amino group of compound 1 in the potential range 0.0–1.25 V was used as the response. The influence of voltammetric mode, electrolyte pH, potential scan rate, accumulation time and potential on the oxidation peak current of compound 1 was studied. A method of compound 1 quantification by direct differential pulse voltammetry was developed. The peak current obtained in 0.1 M KCl was linearly related to the compound 1 concentration in the range of 0–160 mg/L with the determination coefficient of 0.999. The method provided a detection limit of 1.9 mg/L and recovery close to 100%.

Key findings

- The electrooxidation of sodium 5-(7-amino-3-cyanopyrazolo[1,5-a]pyrimidin-6-yl)tetrazol-2-ide (compound 1) on a glassy carbon electrode in aqueous media was investigated for the first time.
- The electrooxidation of compound 1 proceeds irreversibly with two poorly resolved peaks, while the first oxidation step is diffusion-controlled and complicated by a preceding chemical reaction involving the transfer of two electrons.
- A quantification method for compound 1 by direct differential pulse voltammetry was developed.

Accompanying information

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Supplementary information
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1. Introduction

According to the World Health Organization (WHO), chemotherapy is becoming increasingly important in the treatment of malignant neoplasms. However, the efficacy of many drugs is limited by the pronounced resistance of cancer cells, making the search for new anticancer agents a critical priority [1]. Based on molecular docking with casein kinase 2, researchers at Ural Federal University synthesized a series of novel compounds [2, 3], which show potential as effective anticancer agents. One of these compounds is sodium 5-(7-amino-3-cyanopyrazolo[1,5-a]pyrimidin-6-yl)tetrazol-2-ide (compound 1). It is predicted to be a promising inhibitor of casein kinase 2, a recently identified anticancer target [4].

Currently, compound 1 is undergoing preclinical testing. At this stage, developing methods for the quantification of pharmaceutical substances is essential for accurate monitoring of pharmacokinetics, evaluation of bioavailability, toxicological assessment, and active substance stability — all of which are critical factors for further progression to clinical trials and eventual drug registration [5, 6]. Moreover, the absence of standardized analytical methods during preclinical development can lead to misinterpretation of data, potentially compromising the safety and efficacy of the drug under investigation.

No method for the compound 1 quantification has been reported to date. Pharmacopeias in Russia, the USA, and Europe typically employ titrimetry, high-performance liquid chromatography, and optical methods for quantitative pharmaceutical analysis [7-9]. Although electrochemical methods remain less widespread than chromatographic and spectroscopic techniques, the number of publications in this area has significantly increased in recent years [10].

The presence of an electroactive amino group in the studied molecule makes it suitable for quantitative analysis by electrochemical methods. Among them, voltammetry is particularly noteworthy due to its high sensitivity and selectivity, comparable to those of high-performance liquid chromatography when analyzing simple matrices such as pure pharmaceutical substances. In addition, voltammetry is cost-effective, requires relatively simple equipment (and thus does not demand highly trained personnel), and avoids the use of large volumes of toxic solvents when analyzing water-soluble compounds [11].

This study aims to develop a voltammetric method for the compound 1 quantification.

2. Experimental

2.1. Reagents

Compound 1, sodium 5-(7-amino-3-phenylpyrazolo[1,5-a]pyrimidin-6-yl)tetrazol-2-ide (compound 2), sodium 5-(7-aminopyrazolo[1,5-a]pyrimidin-6-yl)tetrazol-2-ide (compound 3), pyrazolo[1,5-a]pyrimidine (compound 4) and 5-methylpyrazolo[1,5-a]pyrimidin-7-amine (compound 5) were synthesized at the Department of Organic and Biomolecular Chemistry, Ural Federal University [12] (Figure 1). The structures of the compounds were confirmed by NMR, IR, and UV spectroscopy, and the composition – by elemental analysis. The purity of all compounds was determined to be 99.98%.

Analytical-grade acids and salts (Khimreaktivsnab, Russia) were used without further purification. Tris-HCl buffer was prepared by dissolving tris(hydroxymethyl)aminomethane (Panreac, USA) in water and adjusting the pH in the range of 4.5–9.0 using 1 M HCl, in 0.5-unit increments. Deionized water was obtained from a DVS-M/1NA(18)-N purification system (Mediana Filter, Russia). A stock solution (5 g/L) was prepared by dissolving 0.005 g of compound 1 (99.98% purity) in 1 mL of dimethylformamide (Panreac, USA) in an Eppendorf tube. The solution was stored in the dark at 5–10 °C.

2.2. Instrumentation and Measurement

Cyclic voltammograms (CVs) and voltammograms (VAs) were recorded using a μAutolab Type III potentiostat/galvanostat (Metrohm, Switzerland) with a thermostatically controlled three-electrode cell. The working electrode was a glassy carbon electrode (GCE) disk (3 mm diameter; Metrohm, Switzerland) for voltammetry, and 1 mm diameter for the rotating disk electrode (RDE). Electrode surfaces were polished using the Metrohm 6.2802.010 polishing kit, which included alumina powder (0.3 μm) and a polishing cloth. Residual abrasive particles were removed by rinsing the electrode with 0.1 M nitric acid followed by deionized water. An Ag/AgCl/KCl (sat.) electrode served as the reference, and a glassy carbon rod (Metrohm, Switzerland) was used as the auxiliary electrode.

3. Results and Discussion

3.1. Electrochemical behaviour of compounds 1-5

To elucidate the nature of the signal-forming process of compound 1, the electrochemical behavior of several pyrazolo[1,5-a]pyrimidine derivatives (compounds 2–5), both with and without an amino group, was investigated. The results are shown in Figure 2.

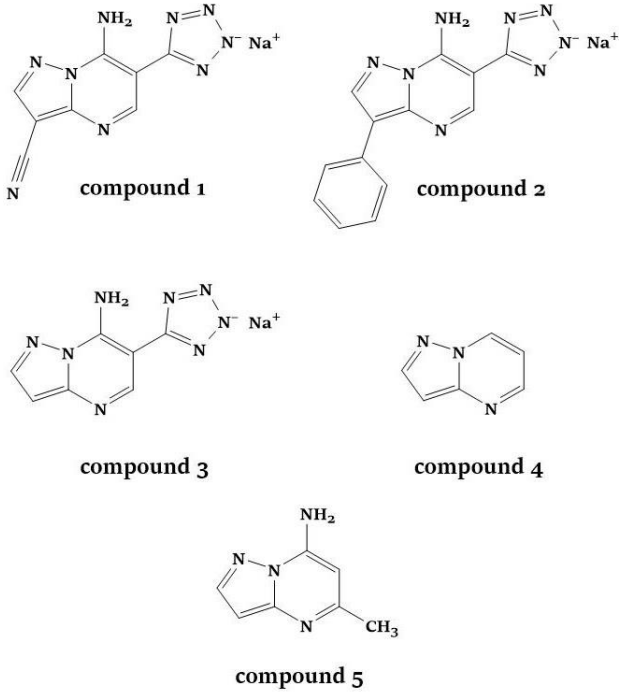

Figure 1 Structural formulas of the investigated compounds.

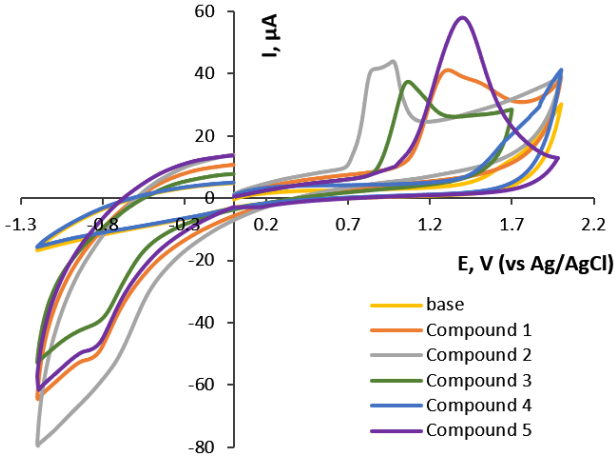

Figure 2 CVs of compounds 1–5 ($2.5 \cdot 10^{-3}$ M in 0.1 M KCl, recorded on a GCE at a scan rate = 0.1 V/s: yellow – background; orange – compound 1; gray – compound 2; green – compound 3; blue – compound 4; violet – compound 5.

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Figure 2 demonstrates the oxidation currents on CVs for compounds containing an amino group in the potential range of +0.8 to +1.3 V. In contrast, no such currents are observed for compound 4, which lacks the amino group. According to [13, 14], the oxidation potential of aniline in aqueous media falls within +0.8 to +1.2 V (vs. Ag/AgCl/SCE), depending on the electrode material and solution conditions. Shifts in peak potential may also arise from electron-donating or electron-withdrawing substituents in the molecule [15]. In some cases, electrooxidation of amino groups in heteroaromatic compounds gives rise to two or more poorly resolved peaks. This behavior is attributed to stabilization of the intermediate cation radical by the molecular environment, leading to slight differences in activation energies of consecutive one-electron transfer steps [16].

On the cathodic scan, after reversing the potential direction, irreversible reduction peaks of the oxidation products of compounds 1–3 and 5 are observed between –0.6 and –0.9 V. The proximity of these reduction potentials indicates the formation of structurally similar electrooxidation products of compounds 1–3. Based on these findings, the anodic currents observed in the CVs of compound 1 can be attributed to the irreversible oxidation of its amino group.

3.2. Investigation of the first electrooxidation process of compound 1

The development of reliable methods for the quantification of newly synthesized compounds with complex organic structures requires not only optimization of the analytical response but also elucidation of the probable underlying electrochemical reaction pathways. Establishing the reaction order is particularly important for understanding possible oxidation pathways of the amino group in compound 1 [17]. The slope of the logarithmic dependence of the first anodic peak current on analyte concentration (0–4 mM) was 0.64 ($\lg I = (0.64 \pm 0.03) \lg c + (2.010 \pm 0.001)$; $R^2 = 0.99$), indicating a fractional reaction order. This suggests the involvement of additional processes beyond diffusion. Nevertheless, the linear dependence of the first-step oxidation current on concentration implies that the initial electrooxidation of compound 1 is not complicated by second-order reactions.

Kinetic studies were carried out using cyclic voltammetry at scan rates from 0.025 to 10 V/s (Figure 3A) and by examining the dependence of the limiting oxidation current on the electrode rotation speed in the range of 600–1000 rpm (Figure 3B). As an overlap between the first and second oxidation currents of compound 1 was observed at a high concentration ($2.5 \cdot 10^{-3}$ M, Figure 2), the current of the first oxidation peak was measured along the rising portion of the curve, as shown in the inset to Figure 3A. The results showed that the first anodic process is diffusion-controlled but coupled with a preceding chemical step, likely involving dehydrogenation of the amino group followed by dimerization [16]. Evidence for this includes:

1. The Semerano criterion [18], obtained from the logarithmic dependence of current on scan rate, which gave a value of 0.45;
2. A linear dependence of the limiting oxidation current (I_d) on $\omega^{0.5}$ in the range 600–1000 rpm, which did not pass through the origin [19].

The anodic electron transfer coefficient, calculated using the temperature-kinetic method of Gorbachev [20, 21], was 0.55. The effective number of electrons involved, determined by the Randles–Ševčík equation for irreversible systems [22], was two.

Based on experimental data and literature reports, a probable reaction pathway was suggested for the first step of the amino group electrooxidation in compound 1 in aqueous solution, involving a two-electron transfer (Scheme 1).

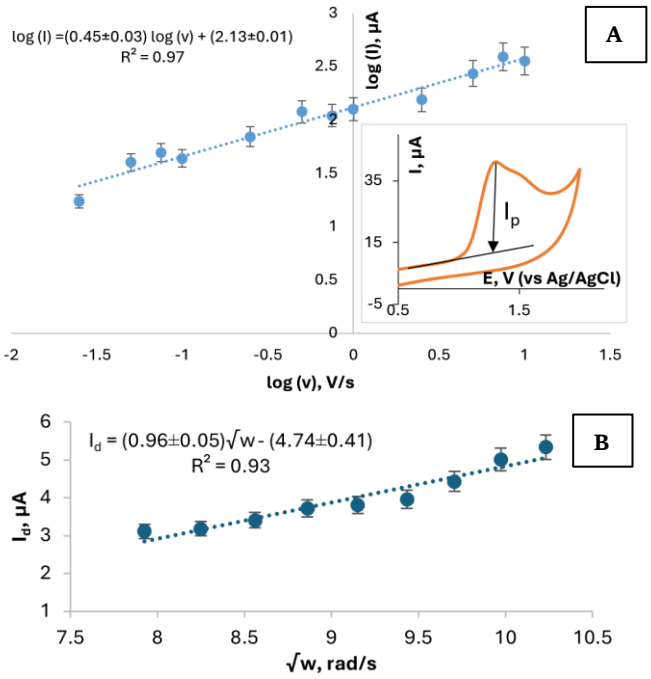
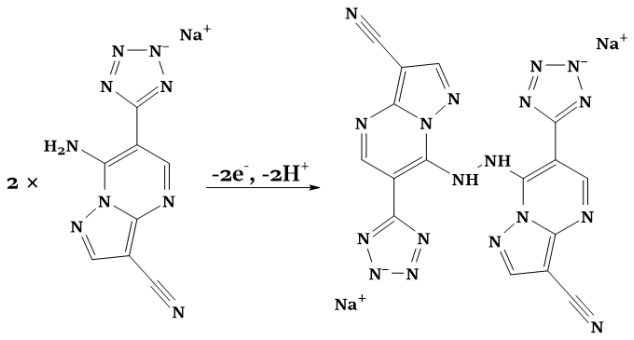


Figure 3 (A) Logarithmic dependence of the first anodic peak current of compound 1 on scan rate. Conditions: GCE (d = 3 mm), 0.1 M KCl. **(B)** Dependence of the limiting oxidation current of compound 1 ($c = 2.5 \cdot 10^{-3}$ M) on $\omega^{0.5}$. Conditions: Glassy carbon RDE (d = 1 mm), 0.1 M KCl, scan rate = 0.05 V/s.



Scheme 1 Probable scheme of the amino group electrooxidation of the compound 1 on the first step.

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3.3. Effect of pH on the electrochemical oxidation of compound 1

The electrochemical behavior of amino groups is known to be influenced by the pH of the medium [16]. To evaluate the effect of proton donors on the thermodynamic parameters of the oxidation process, CVs of $2.5 \cdot 10^{-3}$ M compound 1 were recorded on a GCE at a scan rate of 0.1 V/s in Tris-HCl buffer solutions of various pH (Figure 4A and 4B).

As shown in Figure 4A, increasing the pH from 4.5 to 6.0 caused a slight decrease in the first anodic peak current of compound 1. At higher pH values, the current decreased more substantially before leveling off in the range of pH 6.5–9.0. A decrease in the peak current in the pH range of 4.5–6.0 may indicate the presence of a chemical step preceding the electrooxidation, which is consistent with a classical CE-type pathway [23]. In this case, changing the pH of the solution can affect the rate of the chemical step and, consequently, the peak current. In contrast, the peak potential of the first anodic process remained essentially unchanged across the entire pH range from 4.5 to 9.0 (Figure 4B), indicating that the thermodynamic characteristics of the amino group oxidation are not pH-dependent.

Similar behavior has been reported for primary aromatic amines and can be explained by the fact that the preceding protonation–deprotonation equilibrium is fast relative to the electron-transfer step [16]. The RDE data (Figure 3B) indicate that the deprotonation step is a fast protolytic process occurring in the interfacial region and proceeding at a much higher rate than the subsequent electron-transfer step. Under such conditions, the electron-transfer step becomes rate - limiting. The peak potential is controlled solely by charge-transfer characteristics and becomes insensitive to pH, although the peak current still exhibits some pH dependence [23].

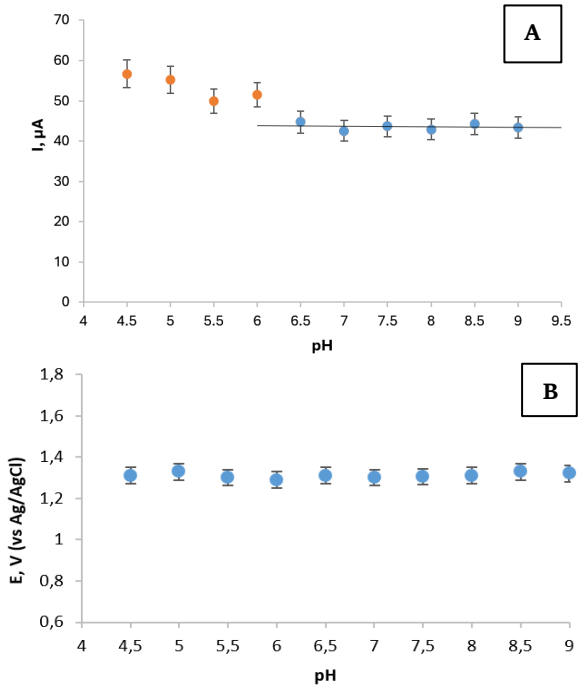

Figure 4 The dependence of the anodic peak **(A)** current and **(B)** potential of compound 1 ($2.5 \cdot 10^{-3}$ M; 622 mg/L) on pH. CVs were recorded on a GCE in Tris-HCl buffer; scan rate = 0.1 V/s.

Based on these observations, the maximum current of the first anodic peak was chosen as the response for compound 1. A supporting electrolyte of 0.1 M KCl (pH 5.5 ± 0.5) was selected as the optimal medium.

3.4. Selection of voltammetric measurement mode for the first oxidation peak of compound 1

3.4.1. Optimization of differential pulse voltammetry (DPV) parameters

The oxidation current of compound 1 under differential pulse voltammetry (DPV) conditions depends on both the step potential and the pulse amplitude. To optimize these parameters, the step potential was varied from 0.002 to 0.02 V, while the pulse amplitude was adjusted between 0.01 and 0.09 V (Figure 5A). Representative voltammograms recorded at a pulse amplitude of 0.06 V for different step potentials are shown in Figure 5B.

As shown in Figure 5, increasing the pulse amplitude above 0.08 V led to a decrease in the oxidation current of compound 1. At a step potential of 0.005 V, the oxidation current was approximately twice higher than that observed at 0.002 V. Further increasing the step potential to 0.01 V did not produce any significant change in the peak current. Therefore, the optimal analytical parameters for DPV were identified as the pulse amplitude of 0.08 V and the step potential of 0.005 V, corresponding to the potential sweep rate of 0.01 V/s.

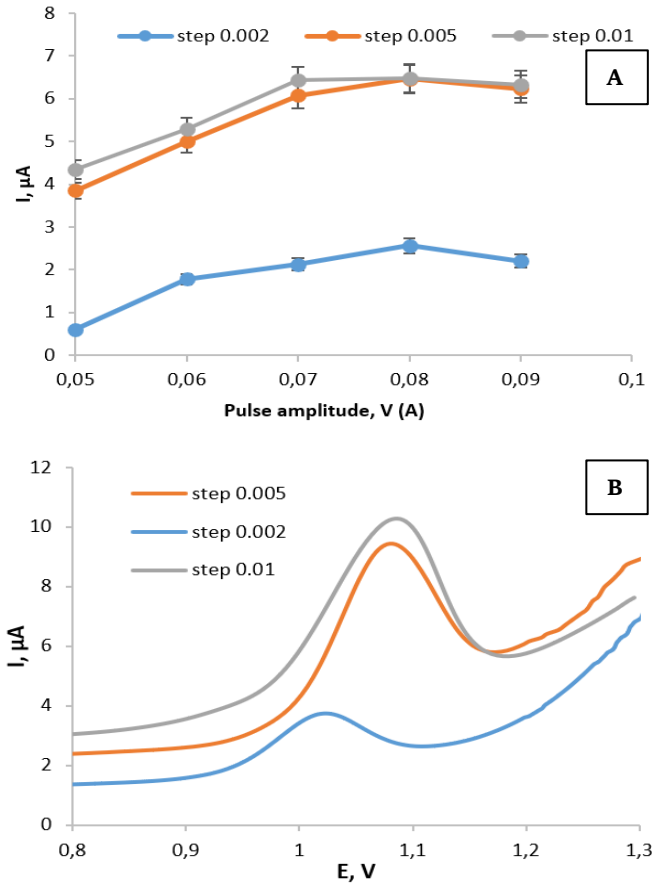

Figure 5 (A) The dependence of the oxidation current of compound 1 (50 mg/L) on pulse amplitude (0.05–0.09 V) at step potentials of 0.002, 0.005, and 0.01 V. **(B)** Example VAs recorded at a pulse amplitude of 0.06 V and step potentials of 0.002, 0.005, and 0.01 V.

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Operating conditions were also optimized for linear sweep voltammetry (LSV) and square wave voltammetry (SWV) in 0.1 M KCl. In the LSV mode, the anodic peak current increased linearly with scan rate over the range 0.05–1.0 V/s (R^2 = 0.98). However, peak symmetry was best maintained at lower scan rates, and 0.3 V/s was chosen for further measurements. In the SWV mode, a modulation amplitude of 0.03 V and a frequency of 35 Hz provided the maximum response. Representative VAs of compound 1 recorded under optimized LSV, DPV, and SWV conditions are shown in Figure 6. Among the tested methods, DPV provided the most favorable peak shape and voltammetric characteristics. In this mode, the anodic peak was symmetrical, well-resolved, and could be measured with high accuracy. By comparison, the oxidation current in DPV was nearly three times higher than in that SWV (Table 1), while the peak in LSV was less distinct. For this reason, DPV was selected for all the subsequent measurements.

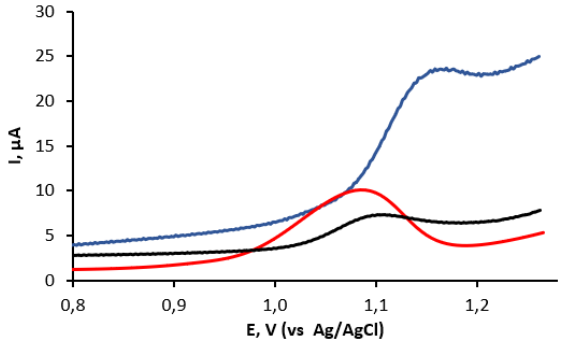

Figure 6 Anodic VAs of compound 1 (50 mg/L) recorded on a GCE in 0.1 M KCl: LSV (blue, v = 0.3 V/s), SWV (black, amplitude 0.03 V, frequency 35 Hz), and DPV (red, pulse amplitude 0.08 V, step 0.005 V).

Table 1 Comparative characteristics of voltammograms of compound 1 (c = 50 mg/L) obtained under optimized LSV, DPV, and SWV conditions (measurement conditions as in Figure 6).

Mode	Peak Current (μA)	Half-Width (V)	Peak Potential (V)	Area (·10⁶)
LSV	6.86 ± 0.07	0.09 ± 0.01	1.16 ± 0.03	0.605 ± 0.009
DPV	7.03 ± 0.05	0.10 ± 0.01	1.08 ± 0.01	0.826 ± 0.004
SWV	2.30 ± 0.05	0.07 ± 0.01	1.11 ± 0.02	0.240 ± 0.006

The possible adsorptive accumulation of compound 1 on the GCE surface was examined by holding the electrode in a stirred solution for 5–120 s within the potential range of 0.1–0.9 V, where compound 1 remains electrochemically inactive. No significant change in the response was observed. Therefore, direct voltammetry was applied for quantification.

3.4.2. Calibration curve

Differential pulse VAs for different concentrations of compound 1, recorded under optimized conditions, are shown in Figure 7A. In the range of 10–160 mg/L, two anodic peaks were clearly resolved, as illustrated for a 120 mg/L solution of the analyte (Figure 7A, inset). The height and area of the first oxidation peak were determined using NOVA 1.11 software, as indicated in the inset. At concentrations above 160 mg/L, overlapping of the peaks was observed, resulting in significant errors in current and area measurement.

In contrast to the peak area (Figure 7B), the height of the first oxidation peak is directly proportional to analyte concentration in the range of 10–160 mg/L (Figure 7C), providing a reliable basis for the standard addition method.

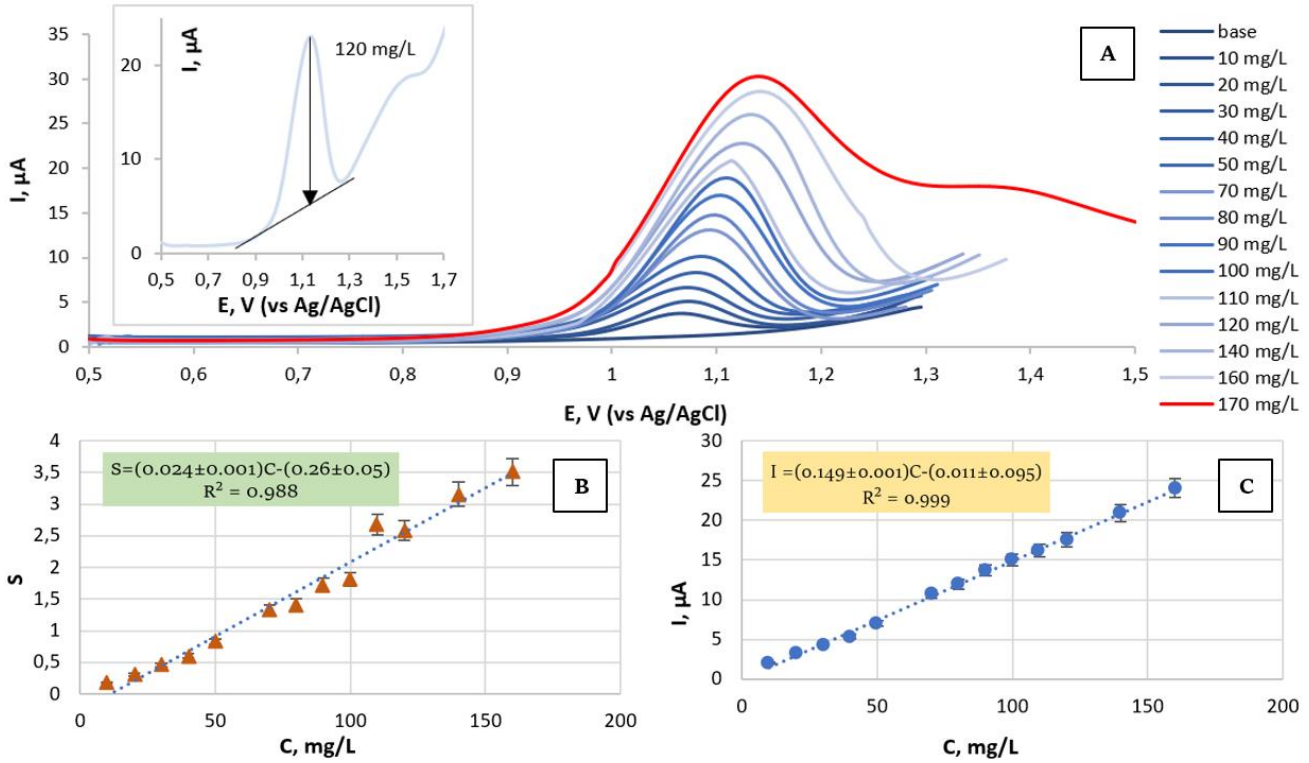

Figure 7 (A) DPVs of compound 1 (20–170 mg/L) recorded on a GCE in 0.1 M KCl; inset: resolved anodic peaks at 120 mg/L. **(B)** Calibration plot of peak area vs. concentration. DPV conditions: scan rate = 0.01 V/s, pulse amplitude = 0.08 V, step potential = 0.005 V. **(C)** Calibration plot of peak height vs. concentration.

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For this reason, peak height was selected as the response. Quantification of compound 1 was carried out using the standard addition (Equation 1):

$$X = \frac{I_1 \cdot c_{add} \cdot V_{add}}{(I_2 - I_1) \cdot V_{al}}, \quad (1)$$

where X is the analyte concentration in the sample (mg/L), I_1 is the mean peak height in the sample, I_2 is the mean peak height after addition of a standard solution, c_{add} is the concentration of the standard solution (mg/L), V_{add} is the volume of added standard (mL), and V_{al} is the aliquot volume of the sample (mL).

The calibration curve (Figure 7C) was described by the regression equation I(μA) = (0.149 ± 0.001)c(mg/L)–(0.011 ± 0.095) with a determination coefficient $R^2 > 0.99$. From this dependence, the limits of detection (LOD) and quantification (LOQ) were calculated as 1.9 and 6.3 mg/L, respectively. The LOD was calculated using the formula $3\sigma/k$ (σ is the standard deviation of the intercept, k is the sensitivity coefficient (slope of the calibration curve)).

Repeatability was assessed by ten consecutive measurements of 20 mg/L compound 1 using the same GCE. The mean peak height was 3.20 ± 0.07 μA, corresponding to a relative standard deviation (RSD) of 3.2%. It confirms good repeatability of the response at low analyte concentrations.

3.4.3. Recovery

The recovery of the method was assessed at concentration levels of 20, 40, and 60 mg/L of compound 1 using the added-found approach. Each experiment was performed six times. The recoveries obtained were close to 100% across all concentration levels, confirming the high recovery of the procedure developed (Table 2).

4. Limitations

A limitation of this study is that a full standard validation procedure could not be performed, since neither the pure substance nor a pharmaceutical formulation of sodium 5-(7-amino-3-cyanopyrazolo[1,5-a]pyrimidin-6-yl)tetrazol-2-ide has been developed yet. This limitation is temporary and does not compromise the applicability of the method for future studies.

5. Conclusions

A voltammetric method has been developed for the determination of a compound from the pyrazolo[1,5-a]pyrimidine class, a promising inhibitor of casein kinase 2 — a recently identified target in anticancer therapy.

Table 2 Metrological characteristics of compound 1 determination obtained during recovery evaluation (n = 6, P = 0.95).

Added, mg/L	Found, $C \pm \Delta C$, mg/L	Recovery, %	RSD, %
20	21.10±0.14	105	0.27
40	41.21±0.25	103	0.23
60	61.11±0.25	102	0.16

The electrochemical oxidation of sodium 5-(7-amino-3-cyanopyrazolo[1,5-a]pyrimidin-6-yl)tetrazol-2-ide was investigated by cyclic voltammetry on a glassy carbon electrode in aqueous media. The compound undergoes irreversible two-step oxidation of the amino group, giving two poorly resolved peaks in the potential range of 0.7–1.6 V (vs. Ag/AgCl) at concentrations above 150 mg/L. At lower concentrations, these peaks become well separated.

The first oxidation peak is well defined and symmetrical, which allowed it to be used as a response for the development of a reliable, accurate, and reproducible voltammetric method for quantifying the compound in aqueous media.

The proposed method can be applied in further preclinical studies and integrated into the analytical stages of anticancer drug development, helping to shorten the time required for pharmaceutical commercialization.

Supplementary materials

No supplementary materials are available.

Data availability statement

Data available within the article or its supplementary materials.

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None.

Author contributions

Conceptualization: N.A.M., V.L.R., A.Vl.I., A.N.K.
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Conflict of interest

The authors declare no conflict of interest.

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References

1. Wu Q, Yang Z, Nie Y, Shi Y, Fan D. Multi-drug resistance in cancer chemotherapeutics: Mechanisms and lab approaches.

Cancer Lett. 2014;347(2):159-166. doi:10.1016/j.canlet.2014.03.013
2. Rusinov VL, Charushin VN, Chupakhin ON. Biologically active azolo-1,2,4-triazines and azolopyrimidines. Russ Chem Bull. 2018;67:573–599. doi:10.1007/s11172-018-2113-8
3. Chupakhin ON, Rusinov Vl, Varaksin MV, Ulomskiy EN, Savateev RV, Butorin II, Du W, Sun Z, Charushin VN. Triazavirin — A Novel Effective Antiviral Drug. Int J Mol Sci. 2022;23(23):14537. doi:10.3390/ijms232314537
4. Ruzzene M, Pinna LA. Addiction to protein kinase CK2: a common denominator of diverse cancer cells? Biochim Biophys Acta. 2010;1804(3):499–504. doi:10.1016/j.bbapap.2009.07.018
5. Berber MR, Hafez IH, Minagawa K, Mori T, Tanaka M. Nanocomposite Formulation System of Lipid-Regulating Drugs Based on Layered Double Hydroxide: Synthesis, Characterization and Drug Release Properties. Pharm Res. 2010;27: 2394–2401. doi:10.1007/s11095-010-0175-x
6. Jain PS, Chaudhari AJ, Patel SA, Patel ZN, Patel DT. Development and validation of the UV-spectrophotometric method for determination of terbinafine hydrochloride in bulk and in formulation. Pharm Methods. 2011;2(3):198-202. doi:10.4103/2229-4708.72226
7. State Pharmacopoeia of the Russian Federation, 15th Edition [Internet]. Moscow: Ministry of Health of Russia; 2023. Russian. Available from: https://femb.ru/record/pharmacopea15, Accessed on 20 July 2025.
8. European Pharmacopoeia. 11th Edition [Internet]. Strasbourg: EDQM; 2025. Available from: https://www.edqm.eu, Accessed on 20 July 2025.
9. United States Pharmacopeia and National Formulary (USP-NF) [Internet]. Rockville: USP; 2024. Available from: https://www.usp.org, Accessed on 20 July 2025.
10. dos Santos AJ, Kronka MS, Fortunato GV, Lanza MRV. Recent advances in electrochemical water technologies for the treatment of antibiotics: A short review. Curr Opin Electrochem. 2021;26:100674. doi:10.1016/j.coelec.2020.100674
11. Malakhova NA, Ivanova AV, Kozitsina AN, Matern AI. Voltammetry In Pharmaceutical Analysis. Drug Development & Registration. 2014;2(7):90-99. Russian.
12. Urakov GV, Savateev KV, Kotovskaya SK, Rusinov VL, Spasov AA, Babkov DA, Sokolova EV. 6-(Tetrazol-5-yl)-7-amino-azolo[1,5-a]pyrimidines as Novel Potent CK2 Inhibitors. Molecules. 2022;27(24):8697. doi:10.3390/molecules27248697
13. Jannakoudakis AD, Jannakoudakis PD, Pagalos N, Theodoridou E. Electro-oxidation of aniline and electrochemical behaviour of the produced polyaniline film on carbon-fibre electrodes in aqueous methanolic solutions. Electrochim Acta. 1993;38(11):1559-1566. doi:10.1016/0013-4686(93)80290-G
14. Mitadera M, Spataru N, Fujishima A. Electrochemical oxidation of aniline at boron-doped diamond electrodes. J Appl Electrochem. 2004;34:249-254. doi:10.1023/B:JACH.0000015623.63462.60
15. Shikata M, Tachi I. Polarographic Studies with the Dropping Mercury Cathode - Part LXXIV - The Electronegativity Rule of the Reduction Potentials of Organic Compounds. Collect Czech Chem Commun. 1938;10:368-379. doi:10.1135/cccc19380368
16. Lund H, Baizer MM. Organic electrochemistry: an introduction and a guide. New York: M. Dekker. 1991. 1550 p.
17. Antropov LI. Theoretical electrochemistry, 4th Edition. Moscow: Graduate School. 1984. 261 p. Russian.
18. Budnikov GK, Maistrenko VN, Vyaselev MR. Fundamentals of Modern Electrochemical Analysis. Moscow: Mir: Binom LZ. 2003. 592 p. Russian.
19. Pleskov YuV, Filinovsky VYu. Rotating disk electrode. Moscow: Science. 1972. 344 p. Russian.
20. Gorbachev SV, Nikich VI. Temperature-kinetic method and its application. Tr. Moscow chemical technology Institute. 1974;101:101-110. Russian.
21. Gorbachev SV. The influence of temperature on electrolysis as a kinetic method for studying the nature of electrochemical processes, Sb. scientific works. Moscow: USSR Academy of Sciences. 1959 p. 61-71. Russian.
22. Bard AJ, Faulkner LR. Electrochemical methods: fundamentals and applications, 2nd ed. New York: John Wiley & Sons. 2001. 864 p.
23. Scholz F. Electroanalytical Methods. Berlin: Springer-Verlag Berlin Heidelberg. 2001. P. 347. doi:10.1007/978-3-642-02915-8_1