جامعة نايف العربية للعلوم الأمنية
NAIF ARAB UNIVERSITY FOR SECURITY SCIENCES
تأسست ١٩٧٨ Est. 1978

Naif Arab University for Security Sciences
Arab Journal of Forensic Sciences & Forensic Medicine
المجلة العربية لعلوم الأدلة الجنائية والطب الشرعي
https://journals.nauss.edu.sa/index.php/AJFSFM

الجمعية العربية لعلوم الأدلة الجنائية والطب الشرعي
Arab Society for Forensic Sciences and Forensic Medicine

Voltammetric Analysis of New Psychoactive Substances

التحليل بالمقياس الفولتميتري للعقاقير النفسية الجديدة

Ketan Patil [1,*], Astha Pandey [1]

[1,] School of Forensic Science, National Forensic Sciences University, Gandhinagar, Gujarat, India.*

Received 16 Mar. 2021; Accepted 18 May. 2021; Available Online 30 Dec. 2021

Abstract

New Psychoactive Substances (NPS) are synthetic drugs that create similar effects as various narcotic drugs and psychotropic substances. Different NPS such as mephedrone, synthacaine, synthetic cannabinoids, etc. are available today which are sold across numerous platforms like drug markets, head shops, the dark web, etc. They are emerging rapidly and becoming popular in society because of their variable nature and ease in avoiding breaking the law. Consequently, their analysis is extremely crucial in the prohibition of drug abuse and the development of laboratory methods. This review introduces a broad overview of the analysis of various new psychoactive substances by voltammetric techniques such as cyclic voltammetry, differential pulse voltammetry, square wave voltammetry, stripping voltammetry etc. It also focuses on various methodologies that were developed for the detection of these NPS which play a leading role in forensic investigation by providing a rapid, sensitive, and cost-effective platform of analysis. The need for the advancement of various detection methods and analysis of more drugs is additionally discussed.

Keywords: Forensic Science, New Psychoactive Substances, Voltammetric Techniques, NPS Analysis.

المستخلص

إن مواد العلاجات النفسية الجديدة (NPS) هي عقاقير اصطناعية ذات تأثيرات مماثلة لمختلف المواد المخدرة والمواد المؤثرة على العقل. وتتوافر اليوم أنواع مختلفة من مواد العلاجات النفسية الجديدة، مثل الميفيدرون، والسينثاكين، والقنب الاصطناعي، إلخ، والتي تباع عبر منصات متعددة مثل أسواق المخدرات، والمتاجر الكبيرة، أو عبر الشبكة السوداء. وهي تنتشر بسرعة، وتتسع شعبيتها في المجتمع بسبب طبيعتها المتغيرة، والسهولة في تفادي انتهاك القانون. وبالتالي، يعتبر تحليلها أمرًا بالغ الأهمية في منع إساءة استخدام العقاقير، و في تطوير أساليب مختبرية جديدة. وتقدم هذه الدراسة نظرة شاملة عن تحليل مختلف مواد العلاجات النفسية الجديدة بواسطة التقنيات الفولتميترية من أمثال، تقنية التحليل الفولتميتري الدوري، وتقنية التحليل الفولتميتري النبضي التفاضلي، وتقنية التحليل الفولتيمتري بالموجات المربعة، وتقنية التحليل الفولتيمتري التجريدي، إلخ. كما تُركز هذه الدراسة على مختلف المناهج التي تم تطويرها لكشف مواد العلاجات النفسية الجديدة التي تؤدي دورًا رائدًا في التحقيقات الجنائية، وذلك لأنها تقدم منصات سريعة، ودقيقة وقليلة التكلفة للتحاليل. علاوة على ذلك، ناقشت الدراسة أيضًا مدى الحاجة لتطوير مختلف طرق التحليل لمزيد من العقاقير.

الكلمات المفتاحية: علوم الأدلة الجنائية، مواد العلاجات النفسية الجديدة، التقنيات الفولتيمترية، تحليل مواد العلاجات النفسية الجديدة.

Production and hosting by NAUSS

* Corresponding Author: Ketan Patil
Email: forensicsketan@gmail.com

doi: 10.26735/MZYC3707

1. Introduction

New Psychoactive Substances (NPS) are synthetic substances that mimic illegal drugs by changes in their chemical structure [1]. These NPS are known by different terms such as “bath salts, legal and herbal highs, designer drugs, research chemicals, etc.” According to the United Nation Office on Drugs and Crime (UNODC), NPS are defined as “substances of abuse, either in a pure form or a preparation, that are not controlled by the 1961 Single Convention on Narcotic Drugs or the 1971 Convention on Psychotropic Substances, but which may pose a public health threat [1].” The key objective behind developing such substances is to avoid the legislation which is achieved by preparing different combinations of a target illegal drug having similar effects thereto [2]. These myriad of combinations make them extremely difficult to regulate [2]. The term NPS was standardized by UNODC and EMCDDA (European Monitoring Centre for Drugs and Drug Addiction) and they classified them in following sub-categories: synthetic cannabinoids, synthetic cathinones, tryptamines, phenethylamines, piperazines, plant-based substances, and miscellaneous [3]. Table-1 indicates the overview of the classification of NPS with different examples.

The word ‘new’ in NPS alludes to newly misused substances. Before the terminology NPS was used, the term “designer drugs” first entered the market in 1934 which were referred as “chemical cousins” of controlled substances [6]. These designer drugs came into the drug market from the entry of fentanyl derivatives within the USA; the evolution continued from amphetamine to piperazines which were

Table 1- *Classification of NPS [1-5].*

NPS sub-categories	Examples
Synthetic cathinones	N-Ethylcathinone, Ethylone, 3-Fluoromethcathinone, 4-methylmethcathinone, etc.
Synthetic cannabinoids	JWH-018, JWH-122, JWH-019, RCS-4, HU-210, etc.
Phenethylamines	2,5-dimethoxy-N-(2-methoxybenzyl) phenethylamines, etc.
Piperazines	Benzylpiperazines, meta-Chlorophenylpiperazine, para-Methoxyphenylpiperazine, Trifluoromethylphenylpiperazines, etc.
Plant- based substances	Mitragyna Speciosa, Khat, etc.
Aminoindane	2-Aminoindane, 5,6-methylenedioxy-2-aminoindane, 5-iodo-2- aminoindane, etc.
Tryptamines	5-methoxy-N,N-Dipropyltryptamine, 5-methoxy-N,N-Dimethyltryptamine, ą-Methyltryptamine, etc.
Phencyclidine-type substances	Ketamine, etc.
Other substances/ Miscellaneous	Stimulants, opioids, hallucinogens, benzodiazepines, etc.

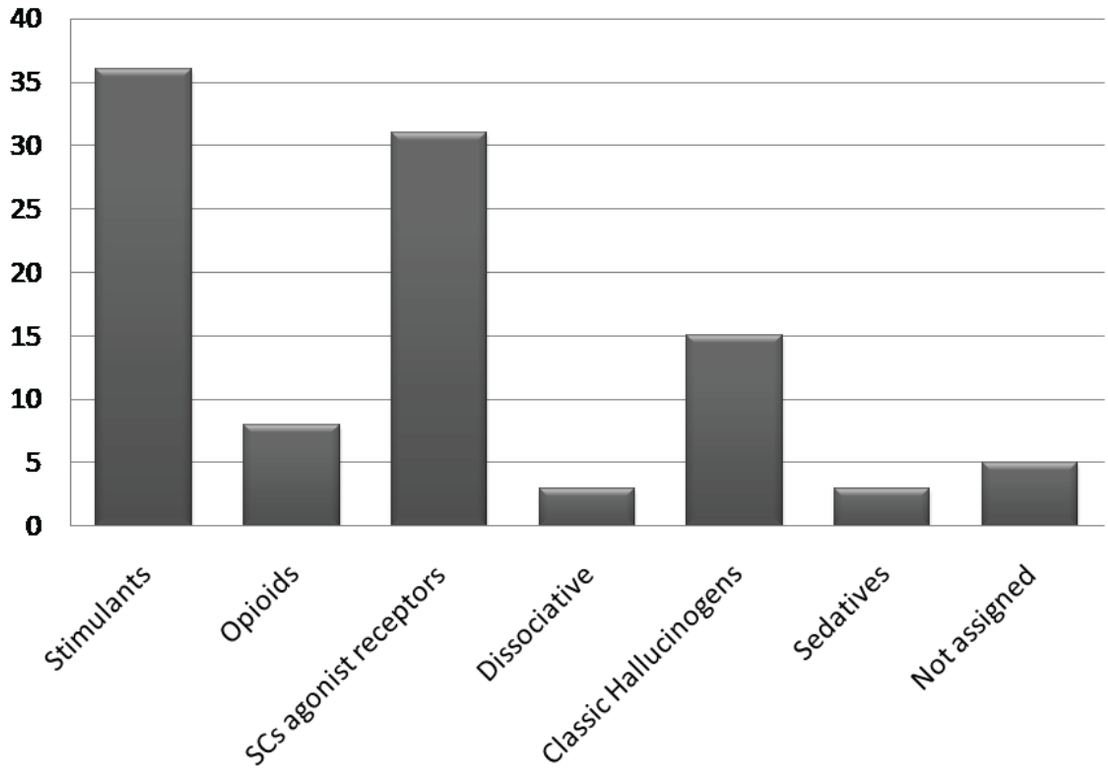


Figure *1- Total percentage (y-axis) of each category of drugs (x-axis) in illicit drug market (Source: UNODC, Early Warning Advisory on NPS, 2019).*

tagged as “failed pharmaceuticals”, but later entry of its prototype BZP i.e. benzylpiperazine into the drug market occupied a transition state within the marketing of ‘new psychoactive substances’ [6]. Initially BZP was legally sold into the drug market in nominal quantities, and in short period of time these NPS built market strength globally, in particular in Asia, Europe, and North America. [7]. In line with the UNODC, “up to December 2019, 950 substances were reported to the UNODC Early Warning System (EWA) on NPS by governments, laboratories, and partner organizations". Figure-1 shows the different drugs that occupied the market depending upon their popularity.

These substances are sold in head shops and on the internet through dark web channels with captivating marketing strategies. Currently, the internet is becoming the foremost convenient and simplest way to sell these NPS. Different websites have daily updates by adding new products and advertisements and introduce them as legal alternatives. These are advertised by using different brand names, for instance, Green Rolex, Green Apple, Pink McDonald’s, or Red Mitsubishi which contains PMA or MDMA [8]. Also fertilizers, party pills, bath salts, black mamba, etc. are other prevalent brand names of NPS [8]. As per the UNODC World Drug Report (2014), 3.5% to 7.0% of the world’s population aged 15 – 64 had used an illicit drug, including amphetamines, cocaine, and marijuana which contains Δ9-tetrahydrocannabinol (Δ9 -THC) as their potential psychoactive substance. In 2012, Bruno

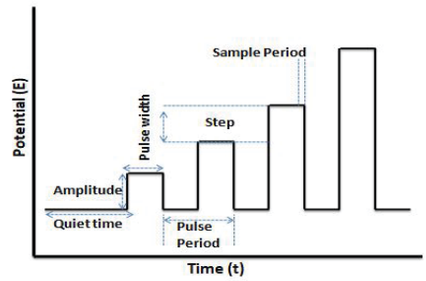
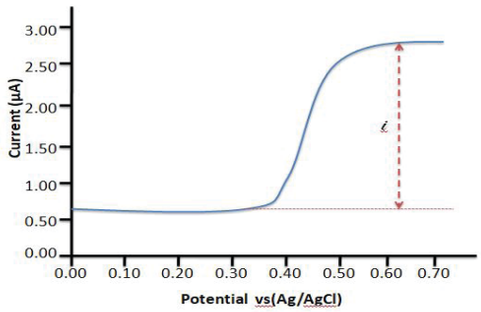
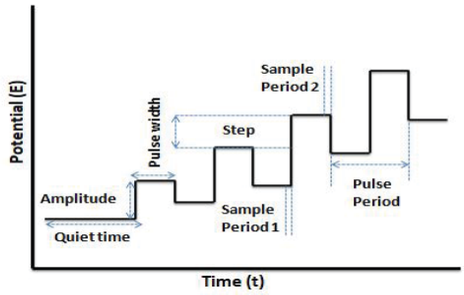
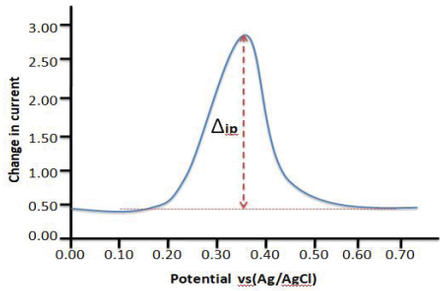
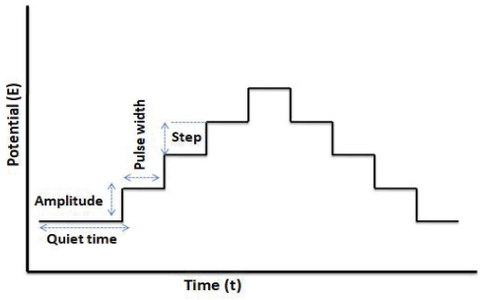
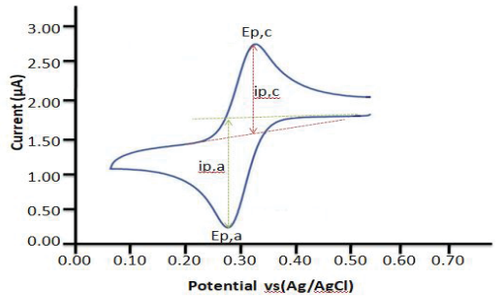
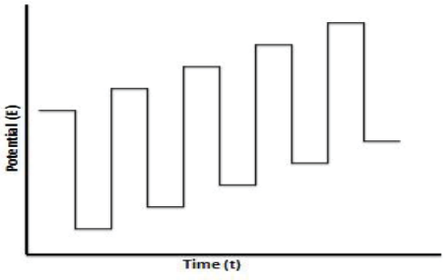
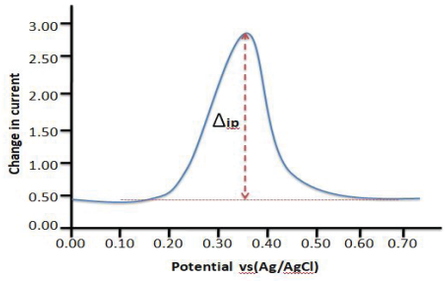
et al., carried out a study on 693 regular ecstasy users from Australia to detect the extent of use of emerging psychoactive substances from stimulant and psychedelic classes which showed that in past 6 months 28% of users used NPS; stimulants were used more than psychedelics [9].

Different studies were conducted to review how NPS affects society. Corazza et al., in 2014 studied 446 participants from the United Kingdom, among whom around one-third of participants had used new psychoactive substances with a minimum of once in their life [10]. Such surprising results were found because the popularity of NPS increased day by day. This resulted in the prohibition of several of the drugs in different countries when noticed. The significant problem is expounded in their examination. When synthetic or narcotic drugs were seized by police personnel then their examination is feasible by traditional methods. But in cases of NPS, their variable chemical nature makes them difficult to spot by such traditional or new methods. Thereby challenging standard methods of their examination performed in forensic laboratories.

When any drug comes to the laboratory its examination is performed by preliminary tests followed by confirmatory tests [11]. Preliminary tests are economical and time-efficient in nature but they can produce false positive or false negative results due to their low sensitivity [12]. Therefore, implementation of confirmatory analysis of drugs becomes necessary. There are some guidelines given by Scientific Working Groups for the Analysis of Seized Drugs which categorize the analytical methods into three different categories i.e. a: contains highly confirmatory techniques such as NMR, MS, etc.; b: contains specific tests such as GC, LC, CE, etc. and c: contains less specific techniques such as UV, colour tests, etc.[11]. By using these techniques various methods were developed for the detection of NPS. Although category "a" and "b" techniques are more specific but due to some limitations it is not possible for under-deloped or developing countries to establish these techniques [13]. Also, they require more space, proper lab settings, skilled manpower, more consumption of chemicals, which is not good from an environmental point of view, and regular maintenance. Comparatively, voltammetry doesn't face such issues which make it one of the emerging electrochemical techniques which can be used for analysis and development of detection methods for NPS [5]. It is known that hyphenated techniques such as GC-MS, LC-MS/MS are more selective and sensitive than other techniques including voltammetry but forensic analysis of each sample i.e. NPS is not possible by using these hyphenated techniques. It increases analysis cost per sample, requirement of more chemicals, etc. It is known that voltammetry can give better results up to the nanogram quantity which will be helpful for analysis of most of the samples. In case of complex materials where voltammetry is unable to detect NPSs, a forensic expert can apply GC-MS, LC-MS, or LC-MS/MS like techniques. It is similar concept to DNA analysis in the biological examination of body fluids. Though it is a very sensitive technique it is not used for the analysis of each sample. Most of the samples are detected by serological assays and where it fails then a forensic biologist applies DNA analysis. Also, voltammetry ranks high amongst all analytical methods when it comes to the range and scope of its use [5]. that is why it accomplishes the role of a sensitive, selective and cost effective technique in the area of forensic science.

Electrochemistry is a branch of science which deals with the study of electricity and how it's related to the chemical reaction [14]. "Voltammetry is the study of current as a function of applied potential and is a category of electroanalytical methods uti-

Table 2- *Different types of Voltammetry [17]*

Types	Waveform	Voltammogram
Normal pulse voltammetry		
Differential pulse voltammetry		
Cyclic voltammmetry		
Square wave voltammetry		

lized in analytical chemistry and various industrial processes [15].” The potential is applied on a working electrode with outcome of change in current which is monitored during this technique [16, 17]. Voltammetry was developed from the innovation of Polarography by the Czech chemist Jaroslav Heyrovsky in 1922 [18, 19]. Different types of voltammetric methods are used: hydrodynamic or normal

pulse voltammetry (NPV), differential pulse voltammetry (DPV), cyclic voltammetry (CV) and square wave voltammetry (SWV) [17, 19]. Table-2 shows different types of voltammetric techniques with their waveform pattern and voltammogram.

In the area of chemical analysis, diverse methods were developed by using voltammetry, especially in pharmaceuticals voltammetry where it plays a good role for monitoring the electrochemical behaviour of the drug and for method development [20-22]. By using these voltammetric techniques, a variety of methods were developed for the detection of NPS, but still further research is required because of variable nature of NPS. Voltammetry can play a prominent role in the detection of NPS. Table-3 discuss how the voltammetry is more advantageous when compared to category A and B methods given in SWGDRUG recommendations.

2. Voltammetric Analysis of NPS

2.1 Synthetic Cathinones

These substances are artificially prepared and derived from cathinone which is an active component of khat plant (Catha edulis) with a stimulating effect similar to amphetamines [23]. Among all NPS, synthetic cathinones and synthetic cannabinoids are preferred within the drug market. Butylone, Ethcathinone, methamfepramone, ehtylone, 3-fluromethcathinone, 4-fluromethcathinone, mephedrone, methcathinone, methedrone, 3,4-methylenedioxypyrovalerone, methylone, naphyrone, pyrovalerone, pentedrone, etc. are different synthetic cathinones available in the drug market [5, 24].

Synthetic cathinones are sold in several forms like tablet, powder or crystalline mixtures with different street names such as sextasy, bath salts, rocket fuel [4, 24]. There are different psychological and sympathomimetic effects of synthetic cathinones which are due to enhancing the discharge of norepinephrine, dopamine, and serotonin or by inhibiting the reuptake of them [25]. The market for these cathinones is increasing daily, which results in making stricter laws. For example, the mephedrone drug family was banned in the United Kingdom [26]. Analysis of these drugs is necessary to take control of them. From previous literature on synthetic cathinone, it became known that different types of voltammetry were used for the detection of these drugs [28-30, 32, 34, 35]. Among synthetic cathinones, mephedrone is the most popular drug.

Table 3- *Advantages of voltammetry over other techniques.*

Character	Voltammetry	Category A and B techniques
Detection limit	Generally micro to nanograms	Generally nano to femtograms
Samples	Organic and inorganic	Instrument-specific limited species
Analysis time	Seconds to few minutes	Minutes to few hours
Expense	Cost-effective	Costly
Maintenance & portability	Easily maintained and usually portable	Difficult to maintain and usually not portable
Temperature range	Wide range	Limited range
Reagents and energy	Limited energy and more reagents required	Generally more energy and reagents required

Therefore, most of the previous research focused on to provide an accurate protocol for onsite examination of mephedrone by deployment of a portable electrochemical workstation.

Mephedrone was first synthesized by Sanchez in 1929 carrying the chemical name of 4-MMC (i.e. (±)-4-methyl-N-methcathinone). The first reported seizure from 4-MMC abuse was reported in Finland in 2007 [27]. In 2013, Smith et al. performed the detection of cathinone-derivatives methcathinone, 4-methyl methcathinone and 4-methyl-N-ethylcathinone by a voltammetric method using different electrodes such as a boron-doped diamond electrode, glassy carbon electrode and disposable screen-printed graphite macro electrode [28]. For the primary time, the electroanalytical sensing of methcathinone (3a) and 4-methyl methcathinone (MMC i.e., Mephedrone) (3b) and 4-methyl-N-ethylcathinone (3c) are possible with linear accessible ranges found to correspond to 16-200 μg mL^{-1} for 3a (at pH 12) and 16-350 μg mL^{-1} for 3b and 3c (at pH 2), with LOD corresponding to 44.5, 39.8 and 84.2 μg mL^{-1}, respectively [28]. Successful voltammetric sensing of different adulterants is additionally performed for similar synthetic cathinone-derivates [28]. Later, Smith et al., also reported the voltammetric sensing of similar drugs i.e. 4-MMC and 4-MEC using comparatively more advanced platform i.e. screen-printed electrodes (SPE) modified with different metals, among which graphite screen printed macroelectrode showed more feasibility for detection; electrochemical reduction of both drugs was done which further resulted in the development and validation of novel voltammetric protocol offering 11.80 μg mL^{-1} and 11.60 μg mL^{-1} LOD for 4-MMC and 4-MEC, respectively [29]. The developed protocol provides a validated laboratory tool for the quantification of both drugs. With the progression of time, researchers focussed on improving the sensitivity, speed, accuracy, and cost of these methods by using different alternatives. One such effort was made by Tan et al. in 2015 where they developed voltammetric detection protocol for sensing 4-MMC and 4-MEC by using one British pence coin as electrochemical sensor and analyzing it by CV in acetate buffer (pH 8.5) with a scan rate of 50 mV s^{-1} (vs. SCE) [30]. The coin had different compositions; currently it's composed of steel while copper is used for its electroplating [31]. The developed protocol was validated by analysis of the street sample for both of these synthetic cathinones that indicates a good economic approach which was useful as an electrochemical detection tool for NPS analysis [30]. Elbardisy et al., in 2019, reported sensing of nor-mephedrone and dihydromephedrone by a voltammetric method of detection using CV and DPV on graphite screen-printed electrode, in several media i.e. phosphate buffer and spiked diluted human urine [32]. The cyclic voltammetry analysis showed the identical linearity of 40-300 μg mL-1 for 4-MC in phosphate buffer (pH 7.0) and spiked diluted human urine, whereas specifically for 4-MMC-R it absolutely was different in PBS (pH-3.0) which ranges from 15-300 μg mL^{-1} and in spiked diluted human urine it ranges from 25-300 μg mL^{-1}; analysis by differential pulse voltammetry shows more sensitivity of dihydromephedrone as compared to nor-mephedrone in both media [32]. The analysis shows the voltammetric method's ability as a completely unique laboratory tool for the identification and quantification of synthetic cathinone metabolites.

Along with mephedrone, which is a popular SC, there are other different emerging drugs like as MDPV, ethylone, etc. which belongs to the similar groups and are being focused by experts for analysis because to their harmful effects on the human body. Ethylone, also called 3,4-methylenedioxy-N-ethylcathinone, is a synthetic cathinone class of recent

drug with properties similar to MDMA [33]. Scheel et al., in 2018 studied the voltammetric behavior of ethylone using CV, DPV and SWV on the boron-doped diamond electrode as a working electrode which ended up in the successful development of detection method which was useful for analysis of seized drugs [34]. Effect of different factors on voltammetric behavior was also investigated with different validation parameters such as LOD and LOQ, linearity, etc. which indicated its applicability in the forensic analysis of 3,4-methylenedioxy-N-ethylcathinone [34]. Similarly, one such analysis was carried out on MDPV (3,4- methylenedioxypyrovalerone) in 2020 by Lima et al. [35] features a stimulant effect on the body which is analogous to the effects of cocaine and amphetamine. U.S. Drug Enforcement Administration first reported the MDPV use as a stimulant in 2008 [36]. Lima et al., (2020) analyzed the MDPV by CV to investigate its electrochemical behavior on glassy carbon electrode and screen printed graphite carbon electrode which results into development of a rapid and cost-effective method for detection of MDPV using CV and Adsorptive Stripping Differential Pulse Voltammetry (AdSDPV) with 0.5 μg mL^{-1} LOD and good stability [35]. The proposed method played a vital role in forensic analysis of MDPV in seized samples.

2.2 Phenethylamines

A family of alkaloids containing one amino group have similar effects of stimulants such as amphetamine, methamphetamine, and methylenedioxymethamphetamine [37]. Depending upon the substitution in the structure there are different series of phenethylamine like '2C series' or 'D series' [1]. NBOMes (2,5-dimethoxy-N-(2-methoxybenzyl) phenethylamines) are phenethylamine, like chemical structures belonging to 2C family of hallucinogens and are usually sold as lysergic acid diethylamine and can be found in diverse forms such as liquid, powder, and blotting paper in which the drug is soaked [38]. Routes of administration for NBOMes are nasal, sublingual or oral [39]. Generally adults and teenagers are becoming attracted towards NBOMes due to their stimulant and hallucinogenic effects [40]. Therefore, it becomes necessary to prevent the supply of these NPS within society which requires more effective technologies and methods to spot them. In recent years, different studies were conducted on NBOMes detection by using voltammetric techniques which resulted in the development of some methods for their detection. Andrade et al. (2016) studied the voltammetric behavior of two phenethylamines i.e. 25B-NBOMe and 25I-NBOMe on screen printed glassy carbon electrodes. The fast and sensitive method for their identification was developed with low LOD and LOQ which resulted in accurate screening tool in the area of forensic science [41]. In the same year, Cumba et al. performed CV and DPV analysis of MDMA and PMA using Palmsens3 potentiostat/galvanostat [42]. MDMA (3,4- methylenedioxymethamphetamine) was prepared from amphetamine which is a stimulant [43] whereas PMA is named para-methoxyamphetamine or 4-methoxyamphetamine, it is additionally an artificial drug which boosts mood, increases energy and sexual arousal and is also called as 'Dr. Death' [42- 44]. They developed a new electrochemical protocol for the detection of both the drugs by using unmodified screen printed graphite electrode with a LOD of 0.25 μg mL^{-1}/ 0.14 μg mL^{-1} for MDMA/PMA, 0.04 μg mL^{-1} for MDMA and 0.03 μg mL^{-1} for PMA which shows its viability and superiority in comparison with HPLC and Raman spectroscopy in terms of cost and speed [42].

In 2017, work was done on different NBOMes and their correlates 2C-X group by Souza et al. which included 25C-NBOMe and 2C-B. The use

of SWV on boron-doped diamond electrode rather than DPV resulted into development of screening method by SWV with detection limits of less than 0.1 μmol L^{-1} with high precision (RSD < 1.4 %, n = 10) for all analyte. The developed method will be useful for field drug detection with portable potentiostat which provides results in shorter times [45]. The next year, similar work was carried out by Soura et al., in different conditions where they got linear analytical curves in the range from 1 to 555 μ mol L^{-1} for three NBOMes and 2C-B with detection limit value between 0.1 and 0.3 μmol L^{-1} and repeatability around 1% (n=10) for the detection of all analytes [46]. Also, the seized samples which were analyzed by LC-MS were analyzed by the same developed method which indicated that the developed protocol was useful for onsite investigation of these NBOMes [46]. Oiye et al., developed the strategy for the detection and quantification of 25-H NBOMe by using SWV on glassy carbon disc electrode which shows the possibility to differentiate LSD and 25H-NBOMe by this method without any interference of LSD [47]. The developed method showed good LOD and LOQ which was 1.28 × 10-6 mol L^{-1} and 4.25 × 10-6 mol L^{-1}, respectively, with a linear range from 4.25 × 10-6 mol L^{-1} to 4.96 × 10-5 mol L^{-1} which showed first voltammetric detection and quantification of 25H-NBOMe successfully [47]. With the progression of time, research was continued to find out new approaches. One such effort was done by De Andrade and Gonzalez- Rodriguez in 2019 by analyzing 25I-NBOH and 2C-I on the screen-printed carbon electrode by using DPV [48]. Initially, voltammetric behaviour of both NPS was investigated by CV and DPV and used for the development of rapid and sensitive detection methods for 25I-NBOH [48]. It was also able to differentiate between 25I-NBOH, 25I-NBOMe and 2C-I.

2.3 Piperazines

As discussed above, piperazines were also known as failed pharmaceuticals which were often sold as MDMA [4, 6]. Benzylpiperazines, meta-Chlorophenylpiperazine, para- Methoxyphenylpiperazine, and 3-Trifluoromethylphenylpiperazine belongs to the current category of NPS [5]. Piperazines which are sold as 'Herbal Highs' or 'Party Pills' are classified into two groups i.e. Benzylpiperazines and phenylpiperazines [52]. Benzylpiperazine is an ecstasy-type drug acting as a stimulant which is structurally and functionally similar to amphetamine [49]. According to the EMCDDA, it's important to control BZP due to certain difficulties like stimulant nature, unavailability of proper medical treatment, health risk, etc. [50]. Therefore, it was necessary to develop new technologies to detect these drugs. Different work was done on chromatographic and spectroscopic methods, few voltammetric analyses were done. In 2017, Waddell et al., studied the voltammetric behavior of benzylpiperazine and developed the method which was used for their detection [51]. The cyclic voltammetry of BZP shows an oxidation peak by using different electrodes among which carbon was comparatively good for electrode material. Of the different pastes, a paste of 80% carbon and 20% nujol with particle size 2-12 μm showed the fastest heterogeneous electron transfer with good sensitivity and reversibility. Analysis of BZP by LSV at varying pH shows that peak potential was inversely proportional to pH which indicates an involvement of equal no. of protons and electrons in charge transfer mechanism according to the Nernst equation. An increase in scan rate shows the shifting of peak potential to the upper values. The method was developed by anodic stripping square wave voltammetry and it was optimized under various conditions. The LOD and LOQ of the developed method were 6 μM and 20 μM, respec-

tively. This shows the successful development of a method for BZP detection with good accuracy and speed [51]. 1-(3-chlorophenyl)piperazine is piperazine-based which belongs to the phenylpiperazine category. The results are same as ecstasy and thus experts classify it as “generic” of ecstasy. Rocha et al. in 2020 developed first-time the method for detection of mCPP by differential pulse voltammetry using cathodically pretreated boron-doped diamond electrode and SDS as surfactant [52]. The method was selective with low LOD of 1.1 µmol L^{-1} and had wide linearity for mCPP over a concentration range of 3.5–400.0 µmol L^{-1} even in presence of different adulterants which results in the provision of alternative techniques in the forensic analysis compared to chromatographic techniques [52].

2.4 Synthetic cannabinoids (SC)

Synthetic cannabinoids are those NPS that mimic the effects of cannabis having Δ9 Tetrahydrocannabinol as an active component [53]. Different drugs of this class that are sold in the drug market were chemically categorized into two groups: aminoalkylindoles and cyclohexylphenols among which aminoalkylindoles were further classified into naphthoylindoles (ex. JWH-018, JWH-073, JWH-122, AM-2201) [53] phenylacetylindoles (JWH-203, AM-2233, JWH-250) and benzoylindoles (AM-694, RCS-4) [1, 5].

SCs were sold by different street names such as “Spice, Black Mamba, Wolf Pack, King Kobra, Blaze, etc.” with false directions of ‘not for human consumption’ [1, 8, 54, 55]. Due to their emergence in the drug market it was necessary to detect them in different products. Different laboratory techniques were developed using various techniques among which voltammetry is one. Compared to other techniques, study of NPS using this technique is less incredible. Dronova et al. (2016) performed a voltammetric analysis of a large group of SCs i.e. indole and indazole using cyclic and differential pulse voltammetry on boron-doped diamond electrode, glassy carbon electrode and platinum electrode as working electrodes with suitable reference and counter electrodes [54]. In the manuscript entitled “Electrooxidation of new synthetic cannabinoids: voltammetric determination of drugs in seized street samples and artificial saliva” it was found that SCs exhibit voltammetric responses that can be used for their detection in smoking mixtures and artificial saliva with LOD within the nanomolar range [54]. The cyclic voltammetric analysis of selected cannabinoids on the boron-doped diamond, platinum, and glassy carbon electrode shows that the platinum electrode is more beneficial for investigation.

The examination by DPV of indole based SCs exhibited an anodic peak at ~1.5 V (vs Ag/AgCl) and ~1.2 (vs Ag/AgCl) in acetonitrile and artificial saliva, respectively, and indazoles exhibited corresponding peaks at ~1.7V and ~1.5V [54] using the similar electrode. Figure-2 shows the results of the analysis in an organic medium which is acetonitrile in this study. The developed method was applied on street seized herbal samples, collected by Israeli police, for the detection of the above-identified synthetic cannabinoids. All samples were first analyzed by GC-MS and LC-MS techniques with different combinations proceeded by electrochemical detection with the aim of comparison of chromatographic techniques with the developed one. As discussed above they come under category A & B type of techniques under SWGDRUG recommendations. The average relative difference between data obtained by chromatographic and electrochemical methods is 12-18%. Figure-3 shows the DPV curves of the herbal mixture. The developed electrochemical protocol proves itself helpful and plays the role of a screening method for examination of these SCs in street

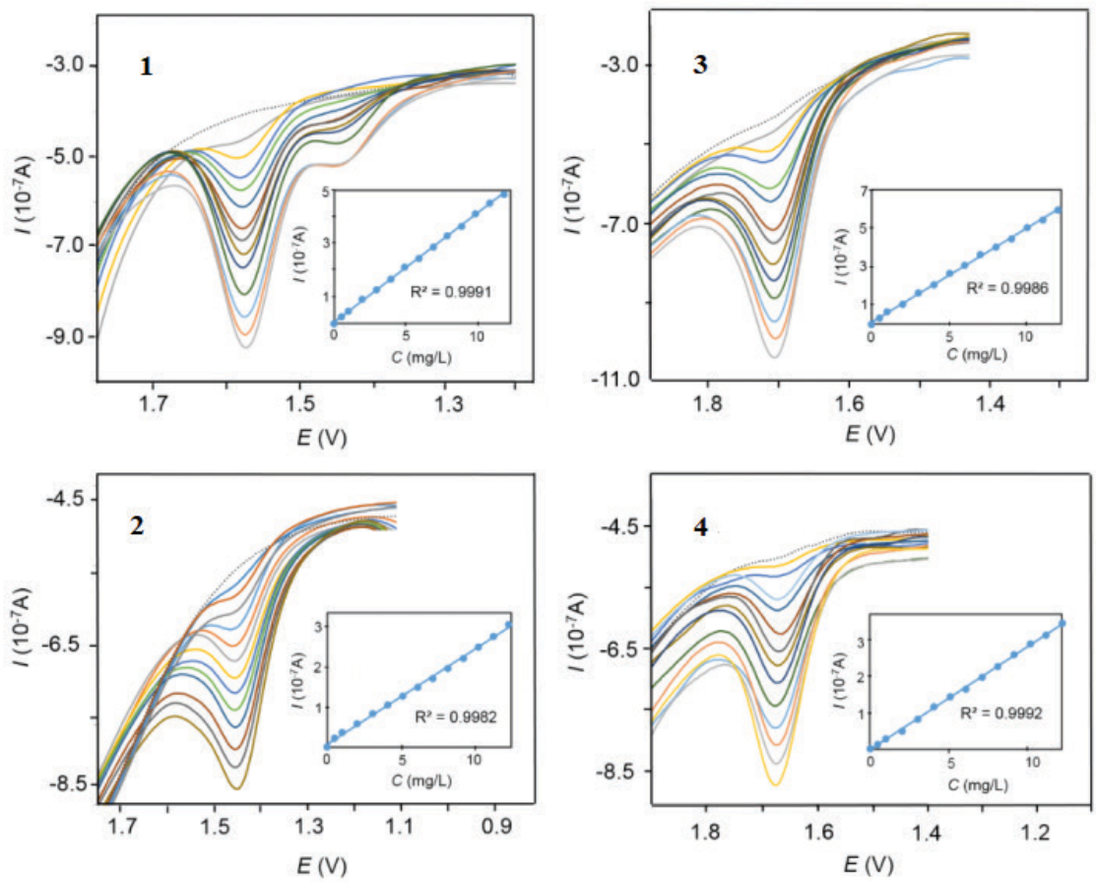


Figure 2- *Differential Pulse Voltammetric analysis of indole (1. FUB-PB-22, 2. AM-2201) and indazole (5F-AMB, THJ 2201) based synthetic cannabinoids for different concentrations (range: 0.5-12 mg/L, blank- dotted line) in 0.01M TBAP/CH3CN solution [54].*

samples and artificial saliva samples.

"Reprinted (adapted) with permission from Dronova M, Smolianitski E, Lev O. Electrooxidation of New Synthetic Cannabinoids: Voltammetric Determination of Drugs in Seized Street Samples and Artificial Saliva. Analytical Chemistry. 2016;88(8):4487-4494. Copyright 2016 American Chemical Society."

2.5 Other Substances/ Miscellaneous

New psychoactive substances belonging to the current group have different structures and pharmacological effects on the human body. They are unlike any above category of NPS. Synthacaine is a new psychoactive drug which is also called as 'synthetic cocaine' having a distinct composition. For example, synthacaine sold in the UK is composed of aminoindane and methiopropamine which shows a stimulant effect on the human body after consumption [56]. Cumba et al. in 2015 developed the indirect voltammetric method for the detection of various components of "Synthacaine." The manuscript entitled "Forensic electrochemistry: indirect electrochemical sensing of the components of the new psychoactive substance Synthacaine" reported the detection of methiopropamine (MPA) and 2-Aminoindane (2-AI) which are the components of Synthacaine by linear sweep voltammetry using screen-printed graphite electrode [56]. The developed method shows the involvement of a mediator which provides an electrochemical sig-

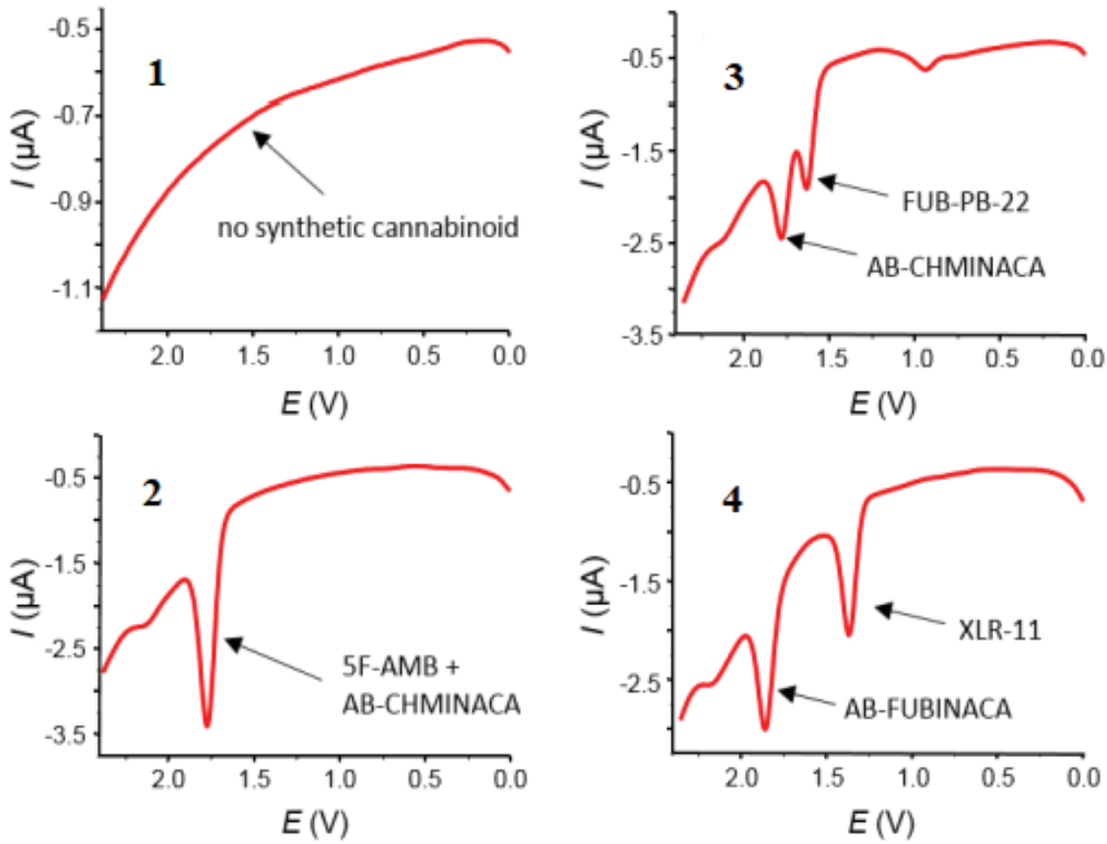


Figure 3- *Differential pulse analysis of street samples for investigation of Synthetic cannabinoids [54].*

nal when chemically reacted with the target compound [56]. Sensing of both compounds i.e., MPA and 2-AI show three reduction peaks (i) reduction of mediator at -0.01 V (ii) reduction of 2-AI at -0.16 V and (iii) reduction of MPA at -0.36 V (vs Ag/AgCl) [56]. The developed indirect voltammetric method was successfully explored with the street sample of synthacaine and validated with HPLC [56]. Analogs of fentanyl are newly emerging NPS which are difficult to detect in a forensic laboratory due to the variation in the core fentanyl structure. Fentanyl is a form of synthetic opium which is more powerful than morphine, a primary material obtained from poppy straw [57]. Ott et al., in 2020, developed a cost-effective detection method based on square wave adsorptive stripping voltammetry using screen-printed carbon electrode as a working electrode [58]. Under optimized conditions, the voltammetric measurement of fentanyl standards was done which shows 0.037 μg/mL LOD. The proposed method was useful for detection, identification, and semi-quantitation of fentanyl in seized drug samples [58].

3. Conclusions and Future Work

This review explained voltammetry as a useful instrumental technique for the detection of various new psychoactive substances. As discussed above, NPS are emerging drugs that are harmful to the body and challenging to detect because of their variable nature. Various methods have been developed for their detection by using voltammetry which plays a

role of a sensitive, accurate, and rapid tool in the area of forensic science. But due to their increasing importance in the drug market and variable nature more research should be conducted in the area of voltammetry for their accurate detection. The development of detection methods for recent NPS which has not been currently studied is required. Also, it is important to note that voltammetric techniques are able to detect unknown substances collected from crime scene. Similar to chromatography, a data of reference standard material is required in voltammetry for comparison with unknown substances. In chromatographic techniques, an expert determines the retention time of the reference standard by a particular developed method followed by analysing known substance by similar method. The values of reference standard and unknown are compared and the identity of the unknown is established. In similar manner, voltammetric techniques require data from reference standards which includes oxidation and reduction potential or any one peak potential in the voltammogram that is unique for a particular substance. Analysing the unknown substance by same method, the potentials values are compared and identity of the unknown is established. Though most countries follow SWGDRUG guidelines and do not recommend voltammetry for analysing seized drugs, it gives conclusive analysis similar to other sensitive techniques. As explained in this review, voltammetric techniques proves their sensitivity, stability, accuracy, wide range and scope of sample analysis, etc. which indicates its ability to give better results in forensic examination. By reviewing various applications of voltammetry for NPS analysis, it is also recommended to include this technique in the list of methods recommended by SWGDRUG.

Future research can be done in the area of different NPS by using voltammetric techniques. They are:

(i) In the previous ten years' research on the voltammetric analysis of synthetic cathinone, most of the research work was administered on the particular drugs methcathinone, 4-methylmethcathinone, 4-methyl-N-ethylcathinone, 3,4- Methylenedioxypyrovelrone and Ethylone. Apart from these drugs, it is necessary to develop detection methods using voltammetric techniques for other synthetic cathinones such as methylone, butylone, N-Ethylcathinone, 3-Fluromethcathinone, pyrovalerone, methamfepramone, etc.

(ii) Similarly, in case of phenethylamines the majority of the work was focused on NBOMes group only. Voltammetry can be carried out of different phenethylamine aside from NBOMes which will help with the development of rapid and sensitive detection methods.

(iii) SCs are one of the most popular NPS in the drug market. But the use of voltammetry in analysing SCs is incredibly less. In the past ten years, very little research has been done on limited SCs which are FUB-PB-22, FDU-PB-22, 5F-PB-22, XLR-11, AM2201, JWH-018, AB-FUBINACA, AB-CHMINACA, ABPINACA, 5F-AMB, THJ-2201. Voltammetric studies can be done on different SCs such as AB-PINACA, 5F-AMB, AB-FUBINACA, THJ-2201, etc. which are also used in different products.

(iv) Piperazines, also known as failed pharmaceuticals, have two types of drugs depending on their chemical structures. They're Benzylpiperazines and phenylpiperazines. Research on these drugs also lack the utilization of voltammetry for their analysis. So, voltammetry can be used for the analysis of different piperazines which further help for their onsite detection.

(v) NPS which belong to a miscellaneous class are extremely diverse due to their chemical structure and nature. Voltammetry based research has been done on limited NPS belonging to this category such

as synthacaine, etc. It's necessary to analyze NPS belong to the present category and voltammetry can be a higher choice to provide a straightforward and sensitive technique for their detection.

Even though most of the work was administered by using a macro or micro working electrodes like mercury drop electrode, carbon electrode, etc., screen-printed electrodes are comparably better option for use as a working electrode. They are more sensitive and cost effective than mercury drop or carbon electrodes. Though different mercury electrodes such as Dropping Mercury Electrode (DME), Hanging Mercury Drop Electrode (HDME), Mercury Film Electrode (MFE), etc. have good sensitivity for drug detection there are also some drawbacks. DME use more amounts of mercury and current, whereas HDME is bulky and requires regular maintenance [59]. MFE overcome limitations of DME and HDME but it has limited potential range along with lower reproducibility and precision. Similar to HDME, it requires regular maintenance [59]. Moreover, mercury is highly toxic and some countries like Columbia completely ban use of mercury. Some researchers used screen printed electrodes and tried to develop methodologies for detection of NPS. Also, a number of new technologies which are more advanced than screen printed electrodes are available but still needs further research to be used in forensic analysis of NPS.

Funding

This article did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. What are NPS? United Nations: United Nations Office on Drugs and Crime;15 March 2021. Available form: https://www.unodc.org/LSS/Home/NPS
2. O'Hagan A, Smith C. A new beginning: an overview of new psychoactive substances. Forensic res criminol Int J. 2017;5(3):00159. https://doi.org/10.15406/frcij.2017.05.00159
3. Smith JP, Sutcliffe OB, Banks CE. An overview of recent developments in the analytical detection of new psychoactive substances (NPSs). Analyst. 2015;140(15):4932-48. https://doi.org/10.1039/C5AN00797F
4. Patil V, Tewari A, Rao R. New psychoactive substances: Issues and challenges. J Ment Health Human Behav. 2016 Jul 1;21(2):98. https://doi.org/10.4103/0971-8990.193427
5. Smith JP. Forensic electrochemistry: developing electrochemical sensors for the detection of illicit compounds (Doctoral dissertation, Manchester Metropolitan University).
6. King LA, Kicman AT. A brief history of "New psychoactive substances." Drug Test Anal. 2011;3(7-8):401-403. https://doi.org/10.1002/dta.319
7. Understanding the synthetic drug market: the NPS factor. United Nations: United Nations Office on Drugs and Crime;2018.Global Smart Update.
8. Corazza O, Valeriani G, Bersani FS, Corkery J, Martinotti G, Bersani G, Schifano F. "Spice," "Kryptonite," "Black Mamba": An Overview of Brand Names and Marketing Strategies of Novel Psychoactive Substances on the Web. J Psychoactive Drugs. 2014;46(4):287-294. https://doi.org/10.1080/02791072.2014.944291
9. Bruno R, Matthews AJ, Dunn M, Alati R, McIlwraith F, Hickey S, Burns L, Sindicich N. Emerging psychoactive substance use among regular ecstasy users in Australia. Drug Alco-

hol Depend.2012;1249(1-2):19-25. https://doi.org/10.1016/j.drugalcdep.2011.11.020
10. Corazza O, Simonato P, Corkery J, Trincas G, Schifano F. “Legal highs”: Safe and legal “heavens”? A study on the diffusion, knowledge and risk awareness of novel psychoactive drugs among students in the UK. Rivista Di Psichiatria.2014;49(2):89-94.
11. Scientific working group for the analysis of seized drugs (SWGDRUG) recommendations. United States: United States department of justice drug enforcement administration; 2016.
12. Kelly JF, Addanki K, Bagasra O. The nonspecific of Duquenois-Levine field test of marijuana. Open Forensic Sci J. 2012;5:4-8. https://doi.org/10.2174/1874402801205010004
13. Balbino, M. A., Eleoterio, I. C., Oliveira, M. F. de, & Mccord, B. R. (2016). Electrochemical Study of Delta-9-Tetrahydrocannabinol by Cyclic Voltammetry Using Screen Printed Electrode , Improvements in Forensic Analysis. Sens Transducers. 207(12), 73–78.
14. Elgrishi N, Rountree KJ, McCarthy BD, Rountree ES, Eisenhart TT, Dempsey JL. A Practical Beginner’s Guide to Cyclic Voltammetry. J Chem Educ. 2018;95(2):197-206. https://doi.org/10.1021/acs.jchemed.7b00361
15. Saito Y, Kikuchi T. Voltammetry Theory, Types and Applications.1st ed. New York: Nova science publishers;2014.
16. Thomas D. Developemnt of electrochemical and fluroscent sensors [thesis]. Kochi: Cochin University of Science and Technology. 2014.
17. Skoog DA, West DM, Holder FJ, Crouch SR. Fundamental of Analytical Chemistry. 9th ed. Belmont:Brooks/Cole Cengage Learning; 2014.
18. Gambhir G, Gautam A. Significance of Instrumental Methods in Forensic Science. New Delhi: Ministry of Human Resource Development; Instrumental methods and analysis.
19. Kounaves SP. Voltammetric Technoques. In: Settle FA, editor. Handbook of Instrumental Techniques for Analytical Chemistry. New Jersey: A Simon and Schuster Company;1997.711-728.
20. Nandibewoor JI. Simultaneous electrochemical determination of 4-aminophenozane and caffeine at electrochemically pretreated graphite pencil electrode. Anal methods. 2014;6(14):5147-5154. https://doi.org/10.1039/c4ay00467a
21. Sri Vidya D, Chandra Sekhar G, Rao PV, Aruna K. Differential pulse voltammetrric determination of cinitrapride using carbon paste elctrode. Int J Eng Sci Technol.2017;6(8):220-224.
22. Katarzyna ML, Staskowska E. Sensitive and rapid voltammetric determination of phenothiazine and azaphenothiazine derivatives in pharmaceuticals usinf boron-doped diamond electrode. Anal Sci.2015;31:961-969. https://doi.org/10.2116/analsci.31.961
23. Khan JI, Kennedy TJ, Christian DR. Basic Principles of Forensic Chemistry. New York: Humana Press;2012. https://doi.org/10.1007/978-1-59745-437-7
24. Karila L, Megarbane B, Cottencin O, Lejoyeux M. Synthetic cathinones: a new public health problem. Curr Neuropharmacol.2015;13(1):12-20. https://doi.org/10.2174/1570159X13666141210224137
25. Watterson LR, Olive MF. Synthetic cathinones and their rewarding and reinforcing effects in rodents. Advances in Neuroscience. 2014;2014. https://doi.org/10.1155/2014/209875
26. Morris K. UK places generic ban on mephedrone drug family. The Lancet. 2010 Apr 17;375(9723):1333-4. https://doi.org/10.1016/S0140-6736(10)60559-4
27. Dargan PI, Sedefov R, Gallegos A, Wood DM. The pharmacology and toxicology of the syn-

thetic cathinone mephedrone (4-methylmethcathinone). Drug Test Anal. 2011;3(7-8):454-463. https://doi.org/10.1002/dta.312

28. Smith JP, Metters JP, Irving C, Sutcliffe OB, Banks CE. Forensic electrochemistry: the electroanalytical sensing of synthetic cathinone-derivatives and their accompanying adulterants in "legal high" products. Analyst. 2013;139(2):389-400. https://doi.org/10.1039/C3AN01985C
29. Smith JP, Metters JP, Khreit OIG, Sutcliffe OB, Banks CE. Forensic electrochemistry applied to the sensing of new psychoactive substances: Electroanalytical sensing of synthetic cathinones and analytical validation in the quantification of seized street samples. Anal Chem. 2014;86(19):9985-9992. https://doi.org/10.1021/ac502991g
30. Tan F, Smith JP, Sutcliffe OB, Banks CE. Regal electrochemistry: Sensing of the synthetic cathinone class of new psychoactive substances (NPS). Anal Methods. 2015;7(16):6470-6474. https://doi.org/10.1039/C5AY01820J
31. The Royal Mint. One Penny Coin. United Kingdom. The Royal Mint; 15 March 2021. Available from: https://www.royalmint.com/discover/uk-coins/coin-design-and-specifications/one-penny-coin/
32. Elbardisy HM, Ferrari AGM, Foster CW, Sutcliffe OB, Brownson DAC, Belal TS, Talaat W, Daabees HG, Banks CE. Forensic Electrochemistry: The Electroanalytical Sensing of Mephedrone Metabolites. ACS Omega. 2019;4(1):1947-1954. https://doi.org/10.1021/acsomega.8b02586
33. Maheux CR, Alarcon IQ, Copeland CR, Cameron TS, Linden A, Grossert JS. Identification of polymorphism in ethylone hydrochloride: synthesis and characterization. Drug Test Anal. 2016;8(8):847-857. https://doi.org/10.1002/dta.1859
34. Scheel GL, de Oliveira FM, de Oliveira LLG, Medeiros RA, Nascentes CC, Tarley CRT. Feasibility study of ethylone determination in seized samples using boron-doped diamond electrode associated with solid phase extraction. Sensors and Actuators, B: Chemical. 2018;259:1113-1122. https://doi.org/10.1016/j.snb.2017.12.129
35. Lima CD, Couto RAS, Arantes LC, Marinho PA, Pimentel DM, Quinaz MB, da Silva RAB, Richter EM, Barbosa SL, dos Santos WTP. Electrochemical detection of the synthetic cathinone 3,4-methylenedioxypyrovalerone using carbon screen-printed electrodes: A fast, simple and sensitive screening method for forensic samples. Electrochimica Acta. 2020;354:136728. https://doi.org/10.1016/j.electacta.2020.136728
36. Anizan S, Ellefsen K, Concheiro M, Suzuki M, Rice KC, Baumann MH, Huestis MA. 3,4-Methylenedioxypyrovalerone (MDPV) and metabolites quantification in human and rat plasma by liquid chromatography-high resolution mass spectrometry. Anal Chim Acta. 2014;827:54-63. https://doi.org/10.1016/j.aca.2014.04.015
37. Hill SL, Thomas SH. Clinical toxicology of newer recreational drugs. Clin Toxicol. 2011;49(8):705-719. https://doi.org/10.3109/15563650.2011.615318
38. Angela Me. Amphetamine-type sti mulants and new psychoactive substances. Vienna: United Nations Office on Drugs and Crime; 2014. Global Synthetic Drugs Assessment.
39. Nichols DE. Psychedelics. Pharmacol Rev. 2016;68(2):264-355. https://doi.org/10.1124/pr.115.011478
40. Lawn W, Barratt M, Williams M, Horne A, Winstock A. The NBOMe hallucinogenic drug series: Patterns of use, characteristics of users and self-reported effects in a large international sample. J psychopharmacology.2014;28(8):780-788. https://doi.org/10.1177/0269881114523866

41. Andrade AFB, Mamo SK, Gonzalez-Rodriguez J. Rapid screening method for new psychoactive substances of forensic interest: Electrochemistry and analytical determination of phenethylamines derivatives (NBOMe) via cyclic and differential pulse voltammetry. Anal Chem.2016;89(3):1445-1452. https://doi.org/10.1021/acs.analchem.6b02426
42. Cumba LR, Smith JP, Zuway KY, Sutcliffe OB, Do Carmo DR, Banks CE. Forensic electrochemistry: Simultaneous voltammetric detection of MDMA and its fatal counterpart “dr Death” (PMA). Anal Methods. 2016;8(1):142-152. https://doi.org/10.1039/C5AY02924D
43. Pentney AR. An Exploration of the History and Controversies Surrounding MDMA and MDA. J Psychoactive Drugs.2001;33(3):213-221. https://doi.org/10.1080/02791072.2001.10400568
44. Caldicott DGE, Edwards NA, Kruys A, Kirkbride KP, Sims DN, Byard RW, Prior M, Irvine RJ. Dancing with “death”: p-methoxyamphetamine overdose and its acute management. Journal of Toxicology: Clin Toxicol.2003;41(2):143-154. https://doi.org/10.1081/CLT-120019130
45. Souza GA, Arantes LC, Guedes TJ, de Oliveira AC, Marinho PA, Muñoz RA, dos Santos WTP. Voltammetric signatures of 2,5-dimethoxy-N-(2-methoxybenzyl) phenethylamines on boron-doped diamond electrodes: Detection in blotting paper samples. Electrochem Commun. 2017;82:121-124. https://doi.org/10.1016/j.elecom.2017.08.001
46. Souza GA, Pimentel DM, Lima AB, Guedes TJ, Arantes LC, De Oliveira AC, Sousa RMF, Muñoz RAA, dos Santos WTP. Electrochemical sensing of NBOMes and other new psychoactive substances in blotting paper by square-wave voltammetry on a boron-doped diamond electrode. Anal Method. 2018;10(20):2411-2418. https://doi.org/10.1039/C8AY00385H
47. Oiye ÉN, Midori Toia Katayama J, Fernanda Muzetti Ribeiro M, de Oliveira MF. Electrochemical analysis of 25H-NBOMe by Square Wave Voltammetry. Forensic Chem.2017;5:86-90. https://doi.org/10.1016/j.forc.2017.07.001
48. De Andrade AFB, Gonzalez-Rodriguez J. Electroanalytical identification of 25I-NBOH and 2C-I via differential pulse voltammetry: A rapid and sensitive screening method to avoid misidentification. Analyst.2019;144(9):2965-2972. https://doi.org/10.1039/C9AN00062C
49. Wikström M, Holmgren P, Ahlner J. A2 (N-benzylpiperazine) a new drug of abuse in Sweden. J Anal Toxicol. 2004;28(1):67-70. https://doi.org/10.1093/jat/28.1.67
50. Sedefov R. Report on the risk assessment of BZP in the framework of the Council decision on new psychoactive substances. Luxembourg: European Monitoring Centre for Drugs and Drug Addiction; 2009. EMCDDA risk assesment.
51. Waddell SA, Fernandez C, Inverarity CC, Prabhu R. Extending the capability of forensic electrochemistry to the novel psychoactive substance benzylpiperazine. Sensing and Bio-Sensing Research.2017;13:28-39. https://doi.org/10.1016/j.sbsr.2016.12.001
52. Rocha LR, de Cássica Mendonça J, Capelari TB, Medeiros RA, Tarley CRT. Development of a reliable and selective voltammetric method for determination of designer drug 1-(3-chlorophenyl)piperazine (mCPP) using boron-doped diamond electrode and exploiting surfactant-mediated measurements. Sensors and Actuators, B: Chemical. 2020;310:127812. https://doi.org/10.1016/j.snb.2020.127812
53. Wong YL. Synthetic cannabinoids in herbal products. United Nations: United Nations Office on Drugs and Crime;2011.
54. Dronova M, Smolianitski E, Lev O. Electrooxidation of New Synthetic Cannabinoids: Vol-

tammetric Determination of Drugs in Seized Street Samples and Artificial Saliva. Anal Chem. 2016;88(8):4487-4494. https://doi.org/10.1021/acs.analchem.6b00368

55. Vandrey R, Dunn KE, Fry JA, Girling ER. A survey study to characterize use of Spice products (synthetic cannabinoids). Drug Alcohol Depend. 2012;120(1-3):238-241. https://doi.org/10.1016/j.drugalcdep.2011.07.011
56. Cumba LR, Kolliopoulos AV, Smith JP, Thompson PD, Evans PR, Sutcliffe OB, do Carmo DR, Banks CE. Forensic electrochemistry: Indirect electrochemical sensing of the components of the new psychoactive substance "synthacaine." Analyst. 2015;140(16):5536-5545. https://doi.org/10.1039/C5AN00858A
57. Vardanyan RS, Hruby VJ. Fentanyl-related compounds and derivatives: current status and future prospects for pharmaceutical applications. Future Med Chem. 2014; 6(4): 385-412. https://doi.org/10.4155/fmc.13.215
58. Ott CE, Cunha-Silva H, Kuberski SL, Cox JA, Arcos-Martínez MJ, Arroyo-Mora LE. Electrochemical detection of fentanyl with screen-printed carbon electrodes using square-wave adsorptive stripping voltammetry for forensic applications. J Electroanal Chem. 2020;873:114425. https://doi.org/10.1016/j.jelechem.2020.114425
59. Vyskočil V, Barek J. Mercury electrodes-possibilities and limitations in environmental electroanalysis. Critical Reviews in Analytical Chemistry.2009;39(3):173-188.