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Carbon Electrode-Based Sensors for Detecting Endocrine-Disrupting Chemicals: A Literature Review and Development Prospects

Muh Aryo Zulkarnain *

Department of Chemistry, Faculty of Science Technology and Health, Institut Sains Teknologi dan Kesehatan 'Aisyiyah Kendari, Indonesia

*Email (Corresponding author): muharyoZ01@gmail.com

Abstract
Stunting remains a serious global health issue, with its impact particularly felt in developing countries. The problems arising from this issue are not only related to nutritional intake but also to exposure to toxic substances known as Endocrine-Disrupting Chemicals (EDCs), such as pesticides, which have become one of the key indicators of the primary causes. Pesticide exposure can disrupt thyroid hormone function in the body, as this hormone plays a crucial role in the growth and development of children. This article presents a literature review on detection technologies for pesticides categorized as Endocrine-Disrupting Chemicals (EDCs) and recent efforts in developing voltammetry-based electrodes for the early detection of stunting. Exposure to EDCs, such as fipronil and bisphenol-A, has been linked to stunting, reinforcing the urgency for early detection. Electrochemical methods, particularly voltammetry, show promise for detecting EDCs with high sensitivity. Recent research highlights the use of carbon electrodes, including those derived from agricultural waste like palm oil shells, as cost-effective and environmentally friendly alternatives for working electrodes. Although still in the development stage, carbon electrodes offer a promising solution for early stunting detection through EDC detection. This study underscores the importance of developing rapid, accurate, and economical detection technologies to address global health challenges.

Keywords: *Sensor, EDCs, voltammetry, electrode, carbon*

1. Introduction

Stunting remains an unresolved global health issue to this day. According to the latest data from UNICEF and the WHO-World Bank in 2020, approximately 22.2% or 150.8 million children worldwide experience stunting (Rakotomanana et al., 2020). Stunting also has implications for Indonesia's demographic bonus peak in 2030, which is at risk of being wasted (Dewi et al., 2018). Malnutrition and exposure to toxic substances are indicated as causes of this high incidence. Research reported by Özel & Rüegg (2023) and Predieri et al. (2022) suggests that toxic substances, such as pesticide compounds categorized as Endocrine-Disrupting Chemicals (EDCs), are major factors disrupting thyroid hormone function in the body, which plays a critical role in children's growth and development.

The use of EDC pesticides has been linked to harmful toxic effects, particularly on children's development. The presence of these compounds is extremely dangerous even at low concentrations and is also difficult to detect. Common methods for pesticide detection typically use instrumentation such as gas chromatography (Tay & Wai, 2021), high-performance liquid chromatography (Darvishnejad et al., 2020a), and mass spectrometry (Darvishnejad et al., 2020b). However, these detection methods remain complicated, expensive, and time-consuming. Therefore, sensitive pesticide detection technology is crucial to ensure food and environmental safety, as well as to prevent pesticide exposure that can lead to stunting in children. Voltammetric sensors have emerged as an attractive alternative due to their high sensitivity, good stability, low analysis costs, simple equipment preparation, short measurement times, and suitability for field applications (Raymundo-Pereira et al., 2021; Umapathi et al., 2022).

Current research directions in voltammetric electrochemical methods are largely focused on modifying electrodes to be used as working electrodes. Generally, the working electrodes reported for the detection of EDC pesticides are carbon-based electrodes, such as graphite carbon (Saranya & Deepa, 2022), carbon nanotubes (Huang et al., 2020), glassy carbon (Hou et al., 2020), and carbon fibers (Shan et al., 2023). In recent years, carbon electrodes made from agricultural waste, such as palm kernel shells, have become an intriguing research subject in the field of electrochemical sensors. Palm kernel shells, being agricultural waste, have the potential to serve as a carbon source due to their richness in lignin, cellulose, and hemicellulose, which can be converted into carbon through hydrothermal processes (Salim et al., 2023). Thus, it is essential to consider the application of carbon from palm kernel shells as a potential working electrode for detecting insecticides that are more affordable and environmentally friendly.

Nevertheless, the development of new electrodes continues to be anticipated. An approach to addressing the stunting issue can be through early detection. This serves as an alternative to controlling pesticide residues that contribute to stunting. The research focus will be on developing an effective and sensitive electrochemical device for pesticide detection.

2. Literatur Review of EDCs Detection

The exposure of EDCs to humans is increasing, particularly in developing countries with less stringent regulations on the use of hazardous substances. EDCs can affect the human endocrine system and lead to various health problems, including stunting. EDCs such as fipronil, chlorpyrifos, atrazine, and bisphenol-A can impact children's growth, potentially resulting in stunting (Predieri et al., 2022). Currently, existing methods for detecting EDCs have limitations, such as low sensitivity, high time and cost requirements, and difficulty in field applications. Therefore, there is a need for detection technology that is faster, more accurate, and easier to use.

Electrochemical methods have become a superior alternative for detecting various types of pesticides (De Luna & Bensalah, 2022). Carbon electrodes have been widely utilized as potential working electrodes for detecting various pesticides, such as phenoxybenzyl (Manisankar et al., 2008), cypermethrin (Nurdin et al., 2018), fipronil (Nurdin et al., 2022), profenofos (Arumugam et al., 2023), diazinon (Ghiasi et al., 2021), and others. Additionally, several electrochemical methods have also been extensively developed for detecting EDCs, including potentiometric sensors (Ghosh et al., 2022), capacitive sensors (Scognamiglio et al., 2016), and impedimetric sensors (Christinelli et al., 2021). Specifically, some studies on the voltammetric detection of EDC pesticides have been reported previously, as shown in Table 1.

Table 1. Reported electrochemical detection research of EDCs pesticides

Working electrode	Methods	LOD (µg/L)	Referensi
CLDH-AChE/GNAuNPs/GCE	Voltammetry	50 µg mL^{-1}	(Zhai et al., 2014)
Fc@MWCNTs/OMC/GCE	Voltammetry	3,33 × 10-4 µg mL^{-1}	(Jiao et al., 2016)
AChE/ZrO_2/RGO	Voltammetry	$3{,}50\times10^{-8}$ µg mL^{-1}	(Mogha et al., 2016)
NA/Ag@rGO-NH_2/AChE/GCE	Voltammetry	$1{,}4\times10^{-2}$ µg mL^{-1}	(Guler et al., 2017)
MIP-B-TiO_2 NRs	Voltammetry	$7{,}4\times10^{-6}$ µg mL^{-1}	(Sun et al., 2017)

Electrochemical techniques using carbon electrodes can be employed to detect stunting through the detection of fipronil compounds, which act as EDCs. Electromedicine is a field of study that focuses on using electronic technology and electrodes to diagnose and monitor health conditions. So far, the use of CND electrodes as carbon electrodes has demonstrated quite good performance in the sensor field (Nurdin, Agusu, et al., 2019). Due to the increasing demand for the performance of CND electrodes for the sensitive detection of EDC pesticide compounds, efforts to enhance the detection capabilities of CND electrodes must continue to be demonstrated..

2. Carbon Electrodes for Detecting EDCs Compounds

The use of carbon electrodes in detecting EDC compounds promises exciting advancements in the field of environmental pollution detection. This means we can more effectively identify traces of harmful substances in water or soil that can disrupt the endocrine system. As shown in Table 2, various types of modified carbon electrodes demonstrate the ability to detect specific compounds sensitively. However, challenges in developing detection technology with carbon electrodes still exist. One of these challenges is finding ways to enhance the sensitivity and stability of carbon electrodes so that they can be more efficient in detecting various types of EDCs at very low concentrations. Additionally, attention must also be given to integrating this technology into a more comprehensive and user-friendly detection system for field applications.

Table 2. Various types of modified carbon electrodes demonstrate the ability to detect specific compounds sensitively

Working electrode	Methods	LOD (µg/L)	References
Multi-walled carbon-nanotube (MWCNT)-modified glassy carbon electrodes (GCEs)	Amperometric	1.88	(Montes et al., 2016)
Graphite-polyurethane (GPU)	CV and SWV	0.80	(Okumura et al., 2016)
ZnO/g@C_3N_4/ glassy carbon electrode	Electrochemiluminscence (ECL)	0.65	(Yin et al., 2019)
Ilmenite-CPE	CV	1.04	(Nurdin et al., 2019)
Al(III)-TiO_2/Graphene	CV	0.0164	(Nurdin et al., 2020)
NC@ZnO	CV	0.00393	(Salim et al., 2023)

Conclusion

Overall, the literature review conducted underscores the critical importance of developing detection technology using carbon electrodes for identifying EDC compounds as an effort to address health issues and environmental pollution. By utilizing local natural resources, such as agricultural waste, to produce carbon electrodes, opportunities for environmentally friendly and cost-effective innovations are opened up. The advancements achieved indicate that carbon electrodes can detect various types of EDCs with high sensitivity, enabling more effective early detection. Although challenges remain in enhancing the sensitivity and stability of carbon electrodes and integrating them into a more comprehensive detection system, their potential use offers great hope for overall environmental protection efforts.

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