



From Preservative to Environmental and Health Hazards: A Review on Diverse Applications, Health Impacts and Detection Methods of Paraben(s)

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ABSTRACT

Paraben(s), or p-hydroxybenzoate derivatives, have been extensively used as preservatives in catalogs of products for decades. The chemical(s) of the group are well known for their water solubility, chemical stability, and low production costs. Additionally, these synthetic organics can be used as supplements in cosmetics, packaged foods, pharmaceuticals, and many other products requiring prolonged shelf lives. However, recent reports of paraben-mediated endocrine disruptions, allergic responses, cancer, loss of fertility, and respiratory disorders are alarming and are the signs of growing health and environmental hazards. The unregulated disposal of packaged products supplemented with parabens and unintended uses may increase the environmental burden in the time to come. Recent studies exploring the health hazards associated with the use or consumption of compounds have provided insight into the underlying mechanisms of action. The paraben(s) are assimilated through two routes: oral administration and skin permeation. The ability to detect compounds in different environmental habitats with robust and specific techniques is important due to the unintended public health burdens of these compounds. This review presents the recent findings on the health burden of the compounds, fallacies in detection, and chronological advancements in the detection of paraben(s). This review assesses the impact of the increasing use of parabens on different cohorts, health hazards, and the need to develop more robust and accurate tools for detecting parabens in different environments.

INTRODUCTION

Growing industrialization, globalization, and the intervention of modern techniques and technologies have revolutionized the world by meeting the pressing needs of humans. However, this has also created an economic imbalance between the resources and their negative effects. Chemical additives, pesticides, preservatives, taste enhancers, and several other products that have affected human life are an intriguing part of daily life and hold a special significance in the existing food web. One economically obtruding product range is personal care products (PCPs), with diverse compositions, including creams, soaps, shampoos, face washes, toothpaste, deodorants, conditioners, and sun protectants. Often, the ingredients have been tested for their negative health impacts and bioaccumulation (of hazardous chemicals) (Berger et al. 2020). Most of these hazardous chemicals were associated with endocrine disruption, mutagenic, carcinogenic, and other health burdens towards cohorts (Aeling & Nuss 1974, Harvey 2003, Handa et al. 2006, Tavares et al. 2009, Ali & Elgoly 2013, Jia et al. 2015, Vitku et al. 2018). Paraben(s), the alkyl (and often aryl) esters of p-hydroxybenzoic acid, have been exploited as low-cost preservatives due to their excellent preservation activities, biodegradability, thermal stabilities, neutral pHs, lack of color, nonvolatile nature, imperceptible taste and odor, broad antimicrobial spectra (particularly antifungal),

and relatively non-irritating and non-sensitizing properties (Michalkiewicz 2013, Calafat et al. 2010). Furthermore, the low frequencies of sensitization, adequate solubilities in aqueous solutions, and inertness of paraben add to its features (Francisco & Fonseca 2016).

PARABEN: AN EMERGING ENVIRONMENTAL CONTAMINANT

Paraben(s) use has greatly expanded in daily life products, and with limited knowledge of its health impact for different cohorts, it is difficult to avoid (Yang et al. 2018, Lincho et al. 2021). The urgent need to regulate the use of Paraben(s) in different daily need products has already been mentioned as a concern by different government agencies throughout the world (Vale et al. 2022). Previous studies exploring the

existence of Paraben in different environment matrices have reported half-life time of paraben(s) differing in demography, ranging from around 28h in Spain to 36,000 h in China (Delgado et al. 2016, Song et al. 2017, Vale et al. 2022)

Concerning the severe health impact paraben(s) can pose, and their reported abundance in water bodies and effluents, different physical, biological, and chemical approaches have been noted for their removal or the removal of their transformational products (Ma et al. 2018) (Table 1).

Although the compound has been in use for more than a few decades, utilization has increased since the 1990s as a preservative in food items, drinks, medications, cosmetics, and personal care products (Haman et al. 2015). The alkyl derivatives of paraben are often used in catalogs of products like methylparaben (MP), ethylparaben (EP), propylparaben

Table 1: A few techniques for the removal of Paraben(s) (as reported in prior studies).

Name of Paraben	Removal Percentage (%)	Source	Removal Strategy	Amount of Paraben present initially	References
Methylparaben, Propylparaben	100	Wastewater	Adsorption by Magnetic waste tire-activated carbon-chitosan composite	$1293 \pm 20, 2113 \pm 15 \text{ ng.L}^{-1}$	Mashile et al. 2020
Paraben	99.7	Synthetic solution	Ceramic ultrafiltration membrane developed natively from CuO/TiO ₂ nanoparticles	500 ppb	Bhattacharya et al. 2021
Methylparaben, Ethylparaben, Butylparaben	77.2, 88.0, 96.3 (at 90 min)	Water Samples	Photodegradation by direct UV irradiation	$0.6 \times 10^{-3} \text{ mol.L}^{-1}$	Álvarez et al. 2020
Paraben	100	Pure Compound	Transition- and lanthanide-metal co-doped manganese oxide octahedral molecular sieve (Cu-Nd-OMS-2) in peroxymonosulfate (PMS)	30 mg.L^{-1}	Wang et al. 2022
Paraben	100	Pure Compound	Photo-Fenton process	5 mg.L^{-1}	Alvarado et al. 2022
Methylparaben, Ethylparaben, Propylparaben, Butylparaben	91.6, 94.0, 97.1, 95.3	Wastewater	aerobic granular sludge (AGS) system-biodegradation and adsorption on sludge	205, 245, 235, 214 $\mu\text{g.L}^{-1}$	Argenta et al. 2021
Ethylparaben	92	Pure Compound	CoxNi1-xTiO ₃ nanorods as visible light responsive photocatalysts (Calcined at 600 °C)	250 mg.L^{-1}	Moschogiannaki et al. 2020
Methylparaben	62.16	Wastewater	Adsorption onto oxalic acid pretreated organo-modified bentonite and direct organo-modified bentonite adsorbent	-	Abdulsalam et al. 2023
Benzylparaben	61.3	Pure Compound	S-scheme heterojunction photocatalyst, consisting of monoclinic bismuth vanadate (BiVO ₄) and graphitic carbon nitride (g-C ₃ N ₄)	20 mg.L^{-1}	Hu et al. 2022
Methylparaben	100, 34.2	Pure Compound	Biodegradation by microalgae <i>Phaeodactylum tricornutum</i> and <i>Chlorella vulgaris</i>	80 mg.L^{-1}	Chang et al. 2023
Benzylparaben	85.7 in 150 min	Pure Compound	Modified g-C ₃ N ₄ (GCN) and BiVO ₄ (BVO) composite under Irradiation through visible light by carbon quantum dots (CQDs)	-	Tian et al. 2023
Benzylparaben dye	100	Wastewater	Zeolitic Imidazolate-67 Modified by Fe ₃ O ₄ Nanoparticles	10 mg.L^{-1}	Pourmohammad et al. 2024

(PP), and butylparaben (BP) (Liao et al. 2013). The paraben(s) have been found in various natural resources as well, including carrots, mulberries, blueberries, olives, vanilla, strawberries, and mangoes, preserving by protecting against various microorganisms and pathogens (Sellappan et al. 2002, Kang et al. 2008, Kirchhof & de Gannes 2013, Li et al. 2016). Prior studies have also noted associations between antimicrobial activities and the alkyl chain lengths of parabens, coupled with a reduction in water solubility (Flasiński et al. 2016).

In recent years, there have been mounting concerns about the health impacts of parabens as the rate of human exposure to these compounds has increased. The paraben(s) have been used in more than thousands of personal care products at concentrations up to 0.4% to 0.8% (by weight) (Andersen et al. 2007). In a recent study by Li et al. 2020, several noninvasive biomarkers, such as human fingernails, were used to assess paraben contamination. The concentrations reached 39.9 to 27400 ng.g⁻¹ of methylparaben, propylparaben, or ethylparaben in fingernails, indicating their use in cosmetics (Li et al. 2020). Most of these studies have reported endocrine disruption effects and imbalanced reproductive function due to paraben in humans and animals (Koeppel et al. 2013, Boberg et al. 2010, Aker et al. 2016, Darbre & Harvey 2008). The paraben(s) enter the human body mainly through absorption or ingestion and are generally detected in blood, breast milk, and urine (Popa et al. 2011, Leppert et al. 2020). Parabens are excreted through the urinary system as mixtures of various paraben metabolites (Ye et al. 2006, Upadhyay et al. 2020). Further analyses of the antimicrobial activity showed better efficacy against fungi than against bacteria, and the impact was greater against gram-positive bacteria than against their gram-negative bacteria counterparts (Wang et al. 2013). The efficiencies of parabens in combination with each other agents have also been explored (Soni et al. 2002). Parabens disturb the hypothalamic-pituitary-gonadal axis by imitating female hormone actions, thereby hindering or destabilizing normal hormonal functions and compromising male reproductive abilities. This endocrine disruptor interferes with overall hormone activity, synthesis, transport, and metabolism. The composites may induce changes in the typical operations of the nervous system, thyroid function, immune system, glucose levels, and lipid balance. Additionally, they can serve as epigenetic regulators, initiating effects that span generations (Bledzka et al. 2014, Lincho et al. 2021). It has been reported that paraben(s) exposure can also cause mitochondrial dysfunction (Martins et al. 2020). In recent studies, their associations with breast cancer and changes in the ovarian and pituitary hormone levels have been discovered (Amin et al. 2019, Khanna et al. 2013, Charles et al. 2013, Hajizadeh et al. 2020). These compounds are responsible

for the dislocation of [3H]estradiol from the estrogen receptor in the MCF7 cell cytosol, increased expression of a stably transfected estrogen-responsive reporter gene in MCF7 cells, and increased growth of estrogen-dependent human breast cancer cells (MCF7 and ZR-75-1). This association connects the estrogenic response of breast tumor cells with the presence of parabens in human breast tissue, as estrogen plays a role in breast cancer development. (Lincho et al. 2021). The health impacts of these treatments are not limited to this, but a study by Meeker et al. 2011 showed a positive correlation between the concentration of urinary butyl paraben (BP) and male sperm DNA damage. Due to the widespread use of parabens, human exposure to these chemicals is inevitable. Therefore, a suitable, specific, cost-effective detection technique is necessary to regulate the increasing exposure to these adverse effects.

Numerous studies have shown the presence of parabens in diverse personal care products and food items at the nanomolar level (Table 2).

DETECTION METHODS FOR ALKYL DERIVATIVES OF PARABEN

Qualitative and Quantitative Estimates of Paraben Concentrations

A permanent tool for primary detection and monitoring of this preservative is vital (Alhadrami et al. 2017). Various analytical

Table 2: Amounts of Paraben present in various products (as reported in prior studies).

S. No	Sample Product	Concentration of Methylparaben	Reference
1.	Iced tea	97 ng.g ⁻¹	(Liao et al. 2013)
2.	Pudding	51 ng.g ⁻¹	
3.	Muffins	83 ng.g ⁻¹	
4.	Turkey Roast	44 ng.g ⁻¹	
5.	Hair conditioner	21.6 ± 0.79 nM	(Baytak et al. 2017)
6.	Baby wipes	24.0 ± 0.67 nM	
7.	Shaving lotion	31.8 ± 0.95 nM	
8.	Hair gel	34.7 ± 0.88 nM	
9.	Syrup	13.1 ± 0.39 nM	
10.	Eye drop	15.8 ± 0.40 nM	
11.	Mouthwash	21.0 ± 0.67 nM	
12.	Deodorant	2.89 x10 ⁻³ mol/L	(Mendonca et al. 2017)
13.	Cyprodien Syrup	1.57 mM	(Dhahir & Hussein 2013)
14.	Ketofen Syrup	4.21 mM	
15.	Conditioner	20 nM	(Gholivand et al. 2014)

techniques with different principles and methodologies have been used for the detection of these pollutants in ecosystems. However, the selectivities and sensitivities differed. Furthermore, with the increasing need for early detection of carcinogens, mutagenic agents, and various other toxic materials, there is also a need for bioassays that monitor and report bio-availabilities and their impacts on humans. All optimized and tested techniques are thought to be highly accurate with a low detection limit, although they are laborious and expensive (Gurban et al. 2011).

- a) **Spectrophotometric analysis:** Spectrophotometric methods determine the presence of paraben in pure and combined forms, as reported by Dhahir and Hussein (2013). The process is based on the diazotization of the compound with sodium nitrite, which is subsequently coupled with ortho-aminobenzoic acid to produce an orange-colored product. The method requires an acidic medium and a low temperature to reach a concentration range of 1–9 $\mu\text{g}\cdot\text{mL}^{-1}$ for detection at 442 nm (in accordance with Beer's law). The detection limit of this procedure was 0.0065 $\mu\text{g}\cdot\text{mL}^{-1}$, and the limit of quantitation was 0.02 $\mu\text{g}/\text{mL}$. Different variables were studied to optimize the reaction, including the concentrations of the reagents, reaction time, mole ratio, and color stability period. The analytical results were statistically validated with recovery studies. These methods successfully determined the concentrations of methylparaben in some oral solutions (Dhahir & Hussein 2013). Even though the method is simple, repetition of the method with promising results exhibited limitations (Wasito & Phechkrajung 2015).
- b) **Chromatographic analysis:** Many analytical techniques have been designed for quantitative determinations of parabens. These include microbiological assays, which are less accurate than HPLC and insensitive to low concentrations of parabens, while colorimetric and spectrophotometric methods are tedious and nonspecific (Abuirjeie et al. 1990). Gas chromatography, although specific and sensitive, is not commonly used with pharmaceuticals because prior derivatization is needed. Thin-layer chromatography is suitable for qualitative determinations of parabens in preservative mixtures, and more recently, thin-layer HPLC densitometry has been employed for quantitative determinations (Tománková

& Pinkasová 1990). Esters of p-hydroxybenzoic acids undergo hydrolysis to the parent acid and subsequent degradation to phenol via decarboxylation. The process is faster at $\text{pH}>5$ (Lachman 1968, Dhaliwal & Theobald 1995). Chromatography is undoubtedly an accurate method, but it has various limitations related to the costly instruments used, locations, skilled labor, and method of operation (Wasito & Phechkrajung 2015).

- c) **Sensor-based analysis:** The prevailing need for field monitoring has spurred the advancement of sensors into analytical tools that offer swift, cost-efficient, precise, and highly sensitive analysis. Other analytical methods cannot be applied at the location or site of analysis. Therefore, alternative robust analytical methods with high accuracies, selectivities, and sensitivities for the detection of many such analytes need to be developed and explored. Additionally, sensors often provide versatile solutions for on-site monitoring. A sensor is an instrument that responds to changes in environmental variables such as pressure, heat, movement, humidity, etc. These changes alter the chemical, physical, or electromagnetic properties of the sensor, which are converted into more usable and comprehensible forms (Fig. 1). The signal produced by the equipment corresponds to the quantity to be determined. Sensors measure a particular characteristic of any object, compound, or disease.

Sensors have been used in many fields, such as the food industry and the marine and medical sectors, and they exhibit better stabilities and sensitivities than traditional methods (Mehrotra 2016). The types of sensors used depend on the reaction, analyte, and element involved and include physical sensors, chemical sensors, and biosensors (Naresh & Lee 2021). Food contaminants, environmental pollutants, and medical applications require the same limits of detection, sensitivities, and stabilities. However, various parameters, such as the sample volume, matrix density, and continuous on-site monitoring, complicate the development of these sensors. The sensor must be stable in a normal storage environment. In the case of *in vivo* monitoring, the sensor should be sterile, biocompatible, and non-toxic. Additionally, the sensor should be small, portable, easy to use, and inexpensive, and the various parameters on which the performance of a sensor depends are listed in Table 3.



Fig. 1: Principal operation of electrochemical (bio)sensors (Alhadrami et al. 2017).

The typical sensor structure can be segregated into three major parts: recognition components, interfaces (immobilization techniques), and transducing elements (Fig. 2).

Different Sensor Design/Immobilization Techniques for the Detection of Paraben

Parabens are found in various environmental niches and exert both acute and chronic effects on living beings. Recently, numerous sensors and biosensors have been deployed for the determination of paraben concentrations based on the techniques and methods used. Significant achievements in sensing have been attained by the integration of biomolecules into devices. Various studies have shown the use of different techniques for sensing parabens, ranging from the use of nanomaterials to hemoglobin, glassy carbon electrodes, and screen-printed electrodes

have been used for the detection of various parabens (Tables 4-7).

The diverse development of paraben sensors with different electrodes, receptor systems, and immobilization methods makes every sensor unique and shows the growing scientific interest in harnessing sensor technology for the detection of paraben(s). The limits of detection are also affected by changes in the transducer and receptor used. It is evident that the unique reactions between receptor(s) and parabens, along with signal transduction with electrochemical methods, play pivotal roles in the development of paraben sensors with dynamic accuracies and limits of detection. These studies may be extended further to explore the potential roles of biomolecules, including enzymes, as alternative receptors. However, exploratory studies on potential enzyme sources are limited by major bottlenecks (such as enzyme stability and cost of production), which may be specific to paraben detection.

Table 3: Parameters that affect the analytical capabilities of the sensors (Slaughter 2018).

Parameters of Biosensor	Description
Sensitivity	The slope of the calibration curve (ratio of the change in the output signal for a given change in the analyte concentration)
Selectivity	The ratio of the change in the output signal for a given change in the concentrations of analyte and interfering species
Specificity	The biocatalyst used for detection is highly specific and displays adequate stability over many assays (>>100)
Signal-to-noise ratio	Measure of the statistical instability in a blank signal (ratio of the suitable analytical signal to the background noise)
Limit of detection (LOD)	Certain concentrations obtained from the smallest detectable output signal
Reproducibility	Precision of the output signal when engaged over a long time interval/performed in different locations
Repeatability	Precision in the output signal over a brief time
Response time	The time required for the output signal to reach 90% steady-state value.

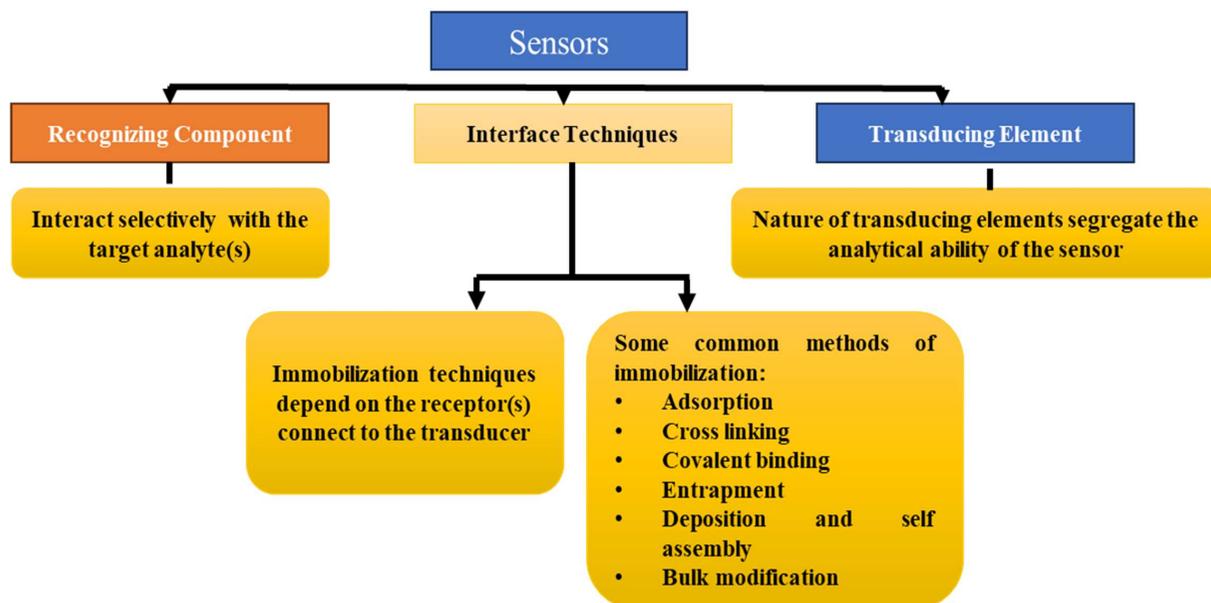


Fig. 2: Paraben detection, component, and properties of the sensors.

Table 4: Advances in sensors for the detection of methylparaben.

Receptor used	Immobilization technique used	Transducer	Reaction	Modification of Electrode	Range of Detection	Limit of Detection	Advantages	Reference
The ability of reduced Graphene Oxide (rGO) to adsorb MP	Drop-coating Nanocomposite onto the electrode surface	Carbon Nanocrystal (CNC)	Formation of benzoquinone due to the oxidation of phenolic group in the methylparaben	Nanocomposite of Cellulose nanocrystal – reduced Graphene Oxide (CNC-rGO) modified electrode	2×10^{-4} M to 9×10^{-4} M	1×10^{-4} M	Reproducibility and reusability	(Khalid et al. 2019)
Langmuir Blodgett (LB) film	Vertical dipping of compressed LB film on the layer of MWCNTs-ODA (Multi-Walled Carbon Nano Tubes-Octadecylamine)	Glassy Carbon Electrode (GCE)	Release of electron	Langmuir Blodgett film of Multi-Walled Carbon Nano Tubes (MWCNTs) on GCE	1×10^{-6} mol.L ⁻¹ to 8×10^{-5} mol.L ⁻¹	4×10^{-7} mol.L ⁻¹	Stability and reproducibility	(Wang et al. 2015)
Hemoglobin	Composite of hemoglobin-MWCNTs was packed by piston piston-driven CPE holder	Carbon Paste Electrode (CPE)	Hemoglobin acts as an electron transfer mediator between MP and electrode.	Hemoglobin and MWCNTs on CPE	0.1 to 13 μ mol.L ⁻¹	25 nmol.L ⁻¹	Accurate, rapid response and Adequate sensitivity, stability, and repeatability.	(Haijin et al. 2015, Haijin et al. 2016)
Nanoparticles of Carbon Nanofibers and Cobalt-Nickel-Palladium	The composite was cast and left to dry	Glassy Carbon Electrode (GCE)	One-electron transfer accompanied by one proton.	Carbon Nanofibers and Nanoparticles Complex of Cobalt-Nickel-Palladium ((Co-Ni-Pd) NPs) and Nanofibers of Carbon on GCE	3–300 nM	1.2 nM	Reproducibility, excellent accuracy, decreased overpotential, Precision, lower limit of detection, and increased sensitivity.	(Baytak et al. 2017)
Reduced Graphene Oxide decorated along with Ruthenium Nanoparticles	Dropped over GCE	Glassy Carbon Electrode (GCE)	electro-oxidization of Hydroxyl group on the aromatic ring, releasing one electron and one proton generating a quinone	Reduced Graphene Oxide decorated along with Ruthenium Nanoparticles (rGO/Ru NPs) on GCE	5.00×10^{-7} to 3.00×10^{-6} mol.L ⁻¹	2.40×10^{-7} mol.L ⁻¹	Low LOD	(Mendonca et al. 2017)
Nanoparticles Reduced graphene oxide (CNC-rGO) nanocomposite	Drop coating	Screen Printed Electrode (SPE)	The electrochemically active surface area of the electrode (i.e., CNC-rGO, rGO)	Cellulose Nanocrystal-Reduced Graphene Oxide Nanocomposite (CNC-rGO) on SPE	2×10^{-4} to 9×10^{-4} M	1×10^{-4} M	Stability	(Khalid et al. 2019)
Nafion Film	Coating	Glassy Carbon Electrode (GCE)	Oxidation of MP	MWCNT-Nafion Film on GCE	3.00×10^{-6} to 1.00×10^{-4} mol.L ⁻¹	1.00×10^{-6} mol.L ⁻¹	Good Sensitivity	(Luo et al. 2012)
Zinc Hydroxide	Not mentioned	Carbon Paste Electrode (CPE)	Electrocatalytic oxidation	Zinc Hydroxide Nanoparticles on CPE	1.26×10^{-3} mol.L ⁻¹ to 1.0×10^{-4} M	3.21×10^{-6} mol.L ⁻¹	Not mentioned	(Hasanzadeh et al. 2012)
Molecularly imprinted polymers (MIPs)	Tripropylene glycol diacrylate cross-linking the functional monomer (i.e., Methacrylic acid) on Molecularly Imprinted Polymer film.	Glassy Carbon Electrode (GCE)	Analyte Specific recognition sites by formation of a vacant shape, same as the analyte, Cross-linking (functional groups rebind target using the same noncovalent bonds)	For the dual templates sensor, Methylparaben and Propylparaben were imprinted on the surface of the sensor.	2.0×10^{-5} to 1.0×10^{-4} M	4.0×10^{-7} M	Less Response Time	(Wang et al. 2010)

Table 5: Advances in propylparaben sensors.

Receptor used	Recognition method	Transducer	Reaction	Mechanism	Range	Limit of Detection	References
Molecularly imprinted polymers (MIPs)	Tripropylene glycol diacrylate cross-linking the functional monomer (i.e., Methacrylic acid) on Molecularly Imprinted Polymer film.	GCE	Analyte Specific recognition sites by formation of a vacant shape, same as the analyte, Cross-linking (functional groups rebind target using the same noncovalent bonds)	For the dual templates sensor, Methylparaben and Propylparaben were imprinted on the surface of the sensor.	5.0×10^{-6} to -1.0×10^{-4} M	2.0×10^{-7} M	(Wang et al. 2010)
Poly(methacrylic acid) (PMAA)	Poly(methacrylic acid) and functionalized carbon nanotubes nanocomposite	GCE	synergetic effect of f-CNTs and PMAA	synergetic effect of f-CNTs and PMAA	5×10^{-6} to 1×10^{-4} M	2×10^{-7} M	(Xin et al. 2023)

Table 6: Advances in sensors for ethylparaben.

Receptor used	Immobilization technique used	Transducer	Mechanism	Modification of Electrode	Range	Limit of Detection	Advantages	Reference
poly-(2-hydroxyethyl methacrylate-N-methacryloyl-L-phenylalanine) (PHEMA-MAPA) nanofilm	Polymerization of paraben imprinted polymeric film	SPE	Unavailable	N-methacryloyl-(L)-cysteine (MAC) Coating	1 to 30 mM	μ M	Highly selective	(Yücebaşı et al. 2020)
Fullerene nanorods (f-NR)	C_{60} NRs were immobilized at the surface of GCE-Ph-NH ₂ by N-H addition over a p-bond of fullerene	GCE	Electrooxidation of ethyl paraben at the ERC ₆₀ NRs-NH-Ph-GCE sensor	ERC ₆₀ NRs-NH-Ph-GCE sensor	0.01–0.52 mM	3.8 nM	High electrocatalytic detection activity	(Rather et al. 2016)
Poly(methacrylic acid)	Crosslinking	GCE	synergetic effect of f-CNTs and PMAA	Poly(methacrylic acid) and functionalized carbon nanotubes nanocomposite	2×10^{-5} to 10×10^{-5} M	4×10^{-7} M	Sensitive detection	(Xin et al. 2023)

Table 7: Advances in sensors for butylparaben.

Receptor used	Immobilization technique used	Transducer	Reaction	Modification of Electrode	Range	Limit of Detection	Advantages	References
ds DNA	electrochemically entrapped on CPE	Silver nanoparticles	Not mentioned	Not mentioned	0.362 to $100 \mu\text{g.L}^{-1}$	0.109 $\mu\text{g.L}^{-1}$	Electrochemically large active surface area, good selectivity, excellent reproducibility and sensitivity.	(Karastogianni et al. 2017)
Poly(methacrylic acid)	Crosslinking	GCE	synergetic effect of f-CNTs and PMAA	Poly(methacrylic acid) and functionalized carbon nanotubes nanocomposite	5×10^{-6} to 8×10^{-5} M	2×10^{-7} M	Sensitive detection	(Xin et al. 2023)
In ₂ O ₃ nano bricks	Not mentioned	GCE	OH Benzoquinone (Single electron oxidation)	Indium Oxide (In ₂ O ₃) Nano brick on GCE	Not mentioned	0.08 μ M	Increased conductivity and surface area	(Qurashi et al. 2015)

CONCLUSIONS

The presence of paraben alkyl derivatives to meet the daily needs of humans is of paramount importance, and the possibility that these compounds may be present in ecological niches cannot be ruled out. The irreplaceable property of paraben is that it is a preferred choice for society. Previous studies have highlighted the advantages of sensor technology as a suitable, highly sensitive approach to supersede the conventional technique. Growing health-related concerns associated with different alkyl derivatives of parabens may impose a negative burden on the health of society at large. Early detection via the design of POC (point of care) devices would aid in the detection of parabens through more accurate analyses and with lower limits of quantification. These techniques could be extended by exploring a more diverse range of analytes to improve their accuracy and make them economically viable and sustainable solutions for society at large.

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