Prepublished copy

Nature Environment & Pollution Technology

This is a peer-reviewed prepublished version of the paper

# From preservative to environmental and health hazards: A review on diverse applications, health impacts and detection methods of paraben(s)

**Pooja Upadhyay, Pammi Gauba, Ashwani Mathur***

Department of Biotechnology, Jaypee Institute of Information Technology

A-10, Sector-62, Noida, Uttar Pradesh-201309, India

*Corresponding Author: ashwani.mathur@jiit.ac.in

## ABSTRACT

Paraben(s), or p-hydroxybenzoate derivatives, have been extensively used as preservatives in catalogues 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 sign of growing health and environmental hazards. Unregulated disposal of the packaged products supplemented with parabens, and unintended uses may increase the environmental burden in 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 through 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 finding on 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 paraben in different environments.

| | |
|---|---|
| Key Words | Parabens, Endocrine disruptor, environmental epidemiology, Sensor |
| DOI | https://doi.org/10.46488/NEPT.2025.v24i02.B4209<br><br>(DOI will be active only after the final publication of the paper) |
| Citation of the Paper | Pooja Upadhyay, Pammi Gauba, Ashwani Mathur, 2025. From preservative to environmental and health hazards: A review on diverse applications, health impacts and detection methods of paraben(s). *Nature Environment and Pollution Technology*, 24(2), B4209. https://doi.org/10.46488/NEPT.2025.v24i02.B4209 |

## 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 burden towards cohorts (Aeling and Nuss 1974; Harvey 2003; Handa et al. 2006)

Tavares et al. 2009; Ali and 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 and 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 cataloges of products like methylparaben (MP), ethylparaben (EP), propylparaben (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 and 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 (Flasin´ski et al. 2016).

Prepublished copy

Nature Environment & Pollution Technology

This is a peer-reviewed prepublished version of the paper

Table 1: 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 tyre activated carbon-chitosan composite | 1293 ± 20; 2113 ± 15 ng/L | Mashile et al. 2020 |
| Paraben | 99.7 | Synthetic solution | Ceramic ultrafiltration membrane developed natively from CuO/TiO2 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 | $0.6 \times 10^{-3}$ mol/L | 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 | Wang et al. 2022 |
| Paraben | 100 | Pure Compound | Photo-Fenton process | 5 mg/L | 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 µg/L | Argenta et al. 2021 |

| | | | | | |
|---|---|---|---|---|---|
| Ethylparaben | 92 | Pure Compound | CoxNi1-xTiO3 nanorods as visible light responsive photocatalysts (Calcined at 600 °C) | 250 mg/L | 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 monoclinic bismuth vanadate (BiVO4) and graphitic carbon nitride (g-C3N4) | 20 mg/L | Hu et al. 2022 |
| Methylparaben | 100, 34.2 | Pure Compound | Biodegradation by microalgae *Phaeodactylum tricornutum* and *Chlorella vulgaris* | 80 mg/L | Chang et al. 2023 |
| Benzylparaben | 85.7 in 150 min | Pure Compound | Modified g-C3N4 (GCN) and BiVO4 (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 Fe3O4 Nanoparticles | 10 mg/L | Pourmohammad et al. 2024 |

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 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 (Koeppe et al. 2013; Boberg et al. 2010; Aker et al. 2016; Darbre and 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 hypothalamo-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).

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 | (Liao et al. 2013) |
| 2 | Pudding | 51 ng/g | |
| 3 | Muffins | 83 ng/g | |
| 4 | Turkey Roast | 44 ng/g | |
| 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 x$10^{-3}$ mol/L | (Mendonca et al. 2017) |
| 13 | Cyprodien Syrup | 1.57 mM | (Dhahir and Hussein 2013) |
| 14 | Ketofen Syrup | 4.21 mM | |
| 15 | Conditioner | 20 nM | (Gholivand et al. 2014) |

**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 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 limit of detection, 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 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 μg/ml for detection at 442 nm (in accordance with Beer's law). The detection limit of this procedure was 0.0065 μg/ml, and the limit of quantitation was 0.02 μg/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 methyl paraben in some oral solutions (Dhahir and Hussein 2013). Even though the method is simple, repetition of the method with promising results exhibited limitations (Wasito and Phechkrajung 2015).

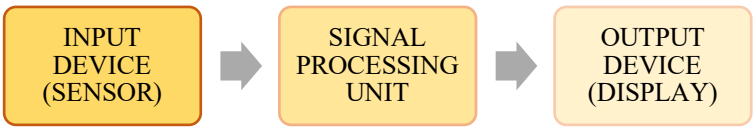
b) **Chromatographic analysis**

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, M. 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 pH>5 (Lachman 1968; Dhaliwal and 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 and 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 to more usable and comprehensible forms (Figure 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.

Figure 1: Principle operation of electrochemical (bio)sensors (Alhadrami et al. 2017).




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 sensor used depends on the reaction, analyte and element involved and includes: physical sensors, chemical sensors, and biosensors (Naresh and 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

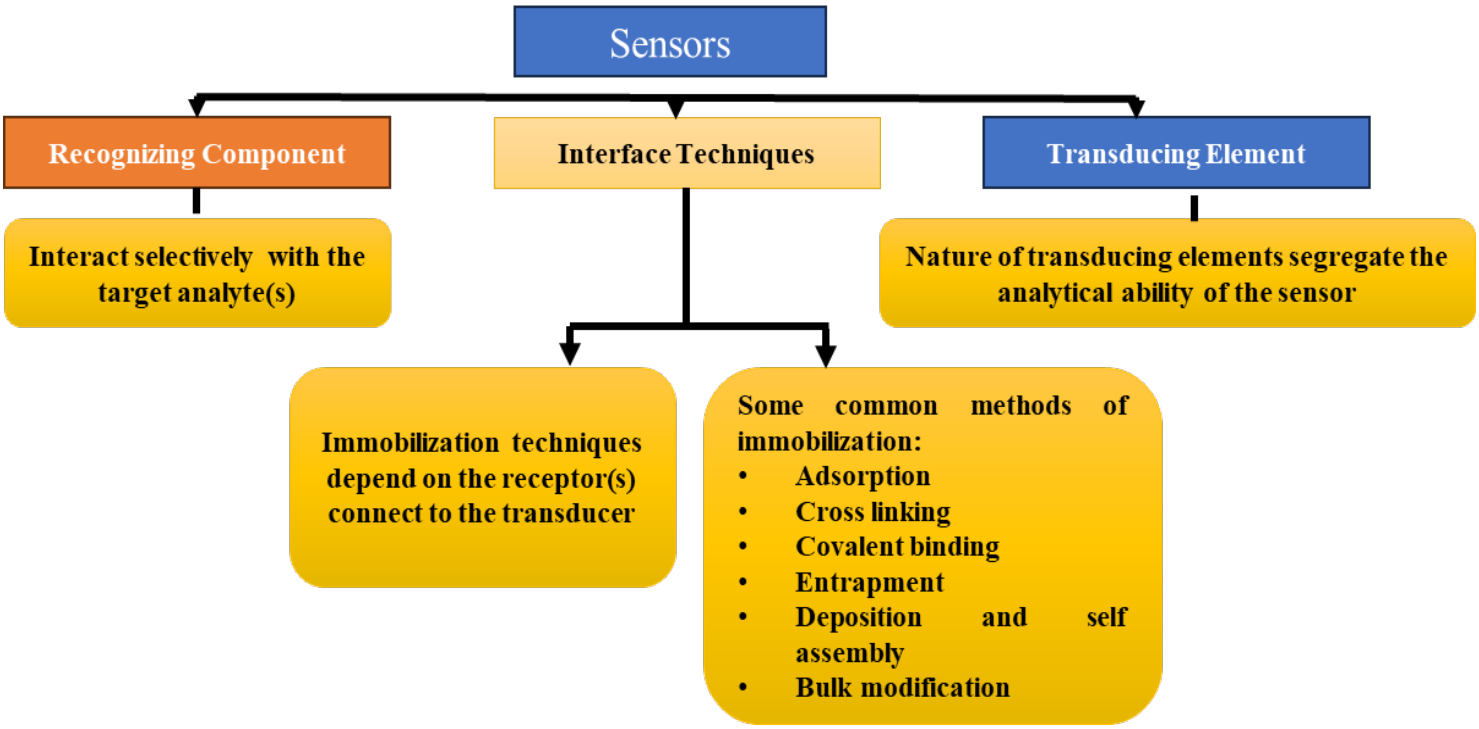
monitoring, complicate the development of these sensors. The sensor must be stable in a normal storage environment. In the case of in vivo monitoring, the sensor should be sterile, biocompatible, and nontoxic. Additionally, the sensor should be small, portable, easy to use, and inexpensive, and the various parameters on which the performance of a sensor depends are listed in Table 3.

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 concentration 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 span required for the output signal to reach 90% steady-state value |

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

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




**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 determinations of paraben concentrations based on the techniques and methods used. Significant achievements in sensing have been attained by 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 detection of various parabens (Tables 4–7).

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** |
|---|---|---|---|---|---|---|---|---|
| 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 | $2 \times 10^{-4}$ M to $9 \times 10^{-4}$ M | $1 \times 10^{-4}$ 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 | $1 \times 10^{-6}$ mol/L to $8 \times 10^{-5}$ mol/L | $4 \times 10^{-7}$ mol/L | Stability and reproducibility | (Wang et al. 2015) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hemoglobin | Composite of hemoglobin-MWCNTs was packed by piston driven CPE holder | Carbon Paste Electrode (CPE) | Hemoglobin acts as electron transfer mediator between MP and electrode. | Hemoglobin and MWCNTs on CPE | 0.1 to 13 µmol/L | 25 nmol/L | 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 for drying | Glassy Carbon Electrode (GCE) | One-electron transfer accompanying 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 alongwith 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 alongwith Ruthenium Nanoparticles (rGO/Ru NPs) on GCE | $5.00x10^{-7}$ to $3.00x10^{-6}$ mol/L | $2.40x10^{-7}$ mol/L | Low LOD | (Mendonca et al. 2017) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Reduced graphene oxide (CNC–rGO) nanocomposite | Dropcoating | Screen Printed Electrode (SPE) | Electrochemically active surface area of electrode (i.e., CNC-rGO, rGO) | Cellulose Nanocrystal-Reduced Graphene Oxide Nanocomposite (CNC-rGO) on SPE | $2 \times 10^{-4}$ to $9 \times 10^{-4}$ M | $1 \times 10^{-4}$ M | Stability | (Khalid et al. 2019) |
| Nafion Film | Coating | Glassy Carbon Electrode (GCE) | Oxidation of MP | MWCNT-Nafion Film on CGE | $3.00x10^{-6}$ – $1.00x10^{-4}$ mol/L | $1.00x10^{-6}$ mol/L | Good Sensitivity | (Luo et al. 2012) |
| Zinc Hydroxide | Not mentioned | Carbon Paste Electrode (CPE) | Electrocatalytic oxidation | Zinc Hydroxide Nanoparticles on CPE | $4.00x10^{-6}$ – $1.26x10^{-3}$ mol/L | $3.21x10^{-6}$ mol/L | 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 same noncovalent bonds) | For the dual templates sensor, Methylparaben and Propylparaben were imprinted on the surface of sensor. | $2.0\times10^{-5}$ – $1.0\times10^{-4}$ M | $4.0\times10^{-7}$ M | Less Response Time | (Wang et l. 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 same noncovalent bonds) | For the dual templates sensor, Methylparaben and Propylparaben were imprinted on the surface of sensor. | $5.0\times10^{-6}$ – $1.0\times10^{-4}$ M | $2.0\times10^{-7}$ 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 | $5\times10^{-6}$ to $1\times10^{-4}$ M | $2\times10^{-7}$ 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-meth acryloyl-L-phenylalanine) (PHEMA-MAPA) nanofilm | Polymerization of paraben imprinted polymeric film | SPE | Unavailable | N-methacryloyl-(L)-cysteine (MAC) Coating | 1 to 30 mM | 0.706μM | Highly-selective | (Yücebaş 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 | $2\times10^{-5}$ to $10\times10^{-5}$ M | $4\times10^{-7}$ 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 µg/L | 0.109 µg/L | 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 | $5\times10^{-6}$ to $8\times10^{-5}$ M | $2\times10^{-7}$ M | Sensitive detection | (Xin et al. 2023) |
| $In_2O_3$ nanobricks | Not mentioned | GCE | OH▼ Benzoquinone (Single electron oxidation) | Indium Oxide ($In_2O_3$) Nano brick on GCE | Not mentioned | 0.08 µM | Increased conductivity and surface area | (Qurashi et al. 2015) |

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 for paraben detection.

## CONCLUSION

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.


## Acknowledgment

This work was funded by the Department of Biotechnology (DBT), Ministry of Science and Technology, Government of India [vide Project No. BT/PR40549/MED/32/756/2020]. We acknowledge the Jaypee Institute of Information Technology for providing the required infrastructure.


## Roles of Authors

Upadhyay P. is a doctoral student in Biotechnology under the guidance of Dr. Mathur A. and Prof. Gauba P., Department of Biotechnology, Jaypee Institute of Information Technology, Noida 201309, India. She completed her Master's in Technology in Biotechnology from Jaypee Institute of Information Technology, Noida in 2019. In addition, her research interest involves the designing of enzyme-based sensors for the detection of parabens.

Dr. Mathur A. and Prof. Gauba A. are actively involved in development of Biosensors at the Department of Biotechnology, Jaypee Institute of Information Technology, India.

## Conflict of Interest

The authors declare no conflict of Interest during the manuscript preparation.

## References


1. Abdulsalam, A., Ibrahim, Y.S., Yaro, N.A., Olanrewaju, O.A., Alhassan, B., Iyayosa, D.A., Lawal, K. (2023). Emerging Contaminants Removal from Wastewater Using Organo-Modified Bentonite Clay. J. Eng. Res. Rep. 25(10), 121–144. 10.9734/jerr/2023/v25i101006.

2. Abuirjeie M.A., Abdel-hamid, M.E., Abdel-aziz, A.A., Ibrahim, E.A. (1990). A Comparative Study on HPLC and Microbiological Determination of p-Hydroxybenzoate Esters (Parabens) in Pharmaceutical Formulations. Analytical Lett. 23(1), 67-82. https://doi.org/10.1080/00032719008052426
3. Aeling, J.L., Nuss, D.D. (1974). Letter: Systemic eczematous "contact-type" dermatitis medicamentosa caused by parabens. Arch. Dermatol. 110(4), 640. PMID: 4278178.
4. Aker, A.M., Watkins, D.J., Johns, L.E., Ferguson, K.K., Soldin, O.P., Anzalota Del Toro, L.V., Alshawabkeh, A.N., Cordero, J.F., Meeker, J.D. (2016) Phenols and parabens in relation to reproductive and thyroid hormones in pregnant women. Environ. Res. 151, 30–37. https://doi.org/10.1016/j.envres.2016.07.002
5. Alhadrami, H. (2017). Biosensors: Classifications, medical applications, and future prospective. Biotechnol. Appl. Biochem. 2017; 65(3), 497-508. https://doi.org/10.1002/bab.1621
6. Ali, E.H., Elgoly, A.H. (2013). Combined prenatal and postnatal butyl paraben exposure produces autism-like symptoms in offspring: comparison with valproic acid autistic model. Pharmacol. Biochem. Behav. 111, 102–110. https://doi.org/10.1016/j.pbb.2013.08.016
7. Álvarez, M.A., MartínezM M.R., Quesada, G.C., Ramón, M.V.L., Utrilla, J.R., Polo, M.S., Mota, A.J. (2020). Removal of parabens from water by UV-driven advanced oxidation processes. J. Chem. Eng. 379, 122334, ISSN 1385-8947. https://doi.org/10.1016/j.cej.2019.122334.
8. Amin, M.M., Tabatabaeian, M., Chavoshani, A., Amjadi, E., Hashemi, M., Ebrahimpour, K., Klishadi, R., Khazaei, S., Mansourian, M. (2019). Paraben content in Adjacent Normal-malignant Breast Tissues from Women with Breast Cancer. Biomed. Environ. Sci. 32 (12), 893–904. https://doi.org/10.3967/bes2019.112
9. Andersen, H.R., Lundsbye, M., Wedel, H.V., Eriksson,E., Ledin, A. (2007). Estrogenic personal care products in a greywater reuse system" Water Sci. Tech. 56(12), 45-49. https://doi.org/10.2166/wst.2007.821
10. Argenta, T.S., Barros, A.R.M., Carvalho, C.A., Santos, A.B., Firmino, P.I.M. (2021). Parabens in aerobic granular sludge systems: Impacts on granulation and insights into removal mechanisms. Sci. Total Environ. 753, 142105, ISSN 0048-9697. https://doi.org/10.1016/j.scitotenv.2020.142105.
11. Baytak AK, Duzmen S, Teker T, Aslanoglu M (2017). Voltammetric determination of methylparaben and its DNA interaction using a novel platform based on carbon nanofibers and cobalt-nickel-palladium nanoparticles. Sens. Actuators B Chem. 239, 330-337. https://doi.org/10.1016/j.snb.2016.08.029
12. Berger, K., Coker, E., Rauch, S., Eskenazi, B., Balmes, J., Kogut, K., Holland, N., Calafat, A.M., Harley, K.(2020). Prenatal phthalate, paraben, and phenol exposure and childhood allergic and respiratory outcomes: Evaluating exposure to chemical mixtures. Sci Total Environ. 725, 138418. https://doi.org/10.1016/j.scitotenv.2020.138418
13. Bhattacharya, P., Mukherjee, D., Deb, N., Swarnakar, S., Banerjee, S. (2021). Indigenously developed CuO/TiO2 coated ceramic ultrafiltration membrane for removal of emerging contaminants like phthalates and parabens: Toxicity evaluation in PA-1 cell line. Mater. Chem. Phys. Volume 258, 123920, ISSN 0254-0584. https://doi.org/10.1016/j.matchemphys.2020.123920.

14. Bledzka, D., Gromadzińska, J., Wasowicz, W. (2014). Paraben. From environmental studies to human health. Environ. Int. 67, 27-42. https://doi.org/10.1016/j.envint.2014.02.007.
15. Boberg, J., Taxvig, C., Christiansen, S., Hass, U. (2010) Possible endocrine disrupting effects of parabens and their metabolites. Repro. Toxicol. 30(2), 301-12. https://doi.org/10.1016/j.reprotox.2010.03.011.
16. Calafat, A.M., Ye, X., Wong, L.Y., Bishop, A.M., Needham, L.L. (2010). Urinary concentrations of four parabens in the U.S. Population: NHANES 2005-2006. Environ. Health Perspect. 118, 679–685. https://doi.org/10.1289/ehp.0901560
17. Chang, X., He, Y., Song, L., Ding, J., Ren, S., Lv, M., Chen, L. (2023). Methylparaben toxicity and its removal by microalgae Chlorella vulgaris and Phaeodactylum tricornutum. J Hazardous Materials. 454, 131528, ISSN 0304-3894. https://doi.org/10.1016/j.jhazmat.2023.131528.
18. Charles AK, Darbre PD (2013). Combinations of parabens at concentrations measured in human breast tissue can increase proliferation of MCF-7 human breast cancer cells. J. Appl. Toxicol. 33(5), 390-398. https://doi.org/10.1002/jat.2850
19. Darbre PD, Harvey PW (2008). Paraben esters: review of recent studies of endocrine toxicity, absorption, esterase and human exposure, and discussion of potential human health risks. J. Appl. Tox. 28(5), 561-78. https://doi.org/10.1002/jat.1358.
20. Dhahir SA, Hussein HJ (2013). Spectrophotometric Determination of Methyl Paraben in Pure and Pharmaceutical Oral Solution. Adv. Nat. Sci. 6(4), 69-74. https://doi.org/10.3968/j.ans.1715787020130604.2601
21. Dhaliwal K, Theobald AE (1995). The Determination of Paraben Preservatives in Syrup Formulations. Pharm. Sci. 1(2), 99-101. https://doi.org/10.1111/j.2042-7158.1995.tb00401.x
22. Alvarado DV, Santos-Juanes L, Arques A, Amat AM (2022). Mild Fenton Processes for the Removal of Preservatives: Interfering Effect of Methylisothiazolinone (MIT) on Paraben Degradation. Catalysts. 12(11), 1390. https://doi.org/10.3390/catal12111390
23. Flasin´ski M, Gawrys´ M, Broniatowski M (2016). Studies on the interactions between parabens and lipid membrane components in monolayers at the air/aqueous solution interface. Biochim Biophys Acta. 1858(4), 836-44. https://doi.org/10.1016/j.bbamem.2016.01.002.
24. Francisco A, Fonseca AP (2016). Parabens paradoxes in cosmetic formulations: a review, Int. J. Med. Res. Pharm. Sci. 3(8). https://doi.org/10.5281/zenodo.61076
25. Gholivand MB, Shamsipur M, Dehdashtian S, Rajabi HR (2014). Development of a selective and sensitive voltammetric sensor for propylparaben based on a nanosized molecularly imprinted polymer–carbon paste electrode. Mater. Sci. Eng. 36, 102-107. https://doi.org/10.1016/j.msec.2013.11.021
26. Gurban AM, Rotariu L, Baibarac M, Baltog I, Bala C (2011). Sensitive detection of endocrine disrupters using ionic liquid – Single walled carbon nanotubes modified screen-printed based biosensors. Talanta 85, 2007– 2013. https://doi.org/10.1016/j.talanta.2011.07.045
27. Haijin A, Ghodsi J, Afraz A, Rafati AA, Shoja Y, Yurchenko O, Urban G (2015). Development of a Novel Biosensor for Nanomolar Detection of Methylparaben. Procedia Eng. 2015; 120, 552-555. https://doi.org/10.1016/j.proeng.2015.08.714
28. Haijin A, Ghodsi J, Afraz A, Yurchenko O, Urban G (2016). Nanomolar detection of methylparaben by a cost-effective hemoglobin-based biosensor. Mater Sci Eng C Mater Biol Appl. 1(69), 122-127 https://doi.org/10.1016/j.msec.2016.06.061.

29. Hajizadeh Y, Feizabadi KG, Ebrahimpour K, Shoshtari-Yeganeh B, Fadaei S, Darvishmotevalli M, Karimi H (2020). Urinary paraben concentrations and their implications for human exposure in Iranian pregnant women. Environ. Sci. Pollution Res. 27, 14723–14734 https://doi.org/10.1007/s11356-020-07991-2
30. Haman C, Dauchy X, Rosin C, Munoz JF (2015). Occurrence, fate and behavior of parabens in aquatic environments: a review", Water Res. 2015; 1(68), 1-11. https://doi.org/10.1016/j.watres.2014.09.030.
31. Handa O, Kokura S, Adachi S, Takagi T, Naito Y, Tanigawa T, Yoshida N, Yoshikawa T (2006). Methylparaben potentiates UV-induced damage of skin keratinocytes. Toxicol. 227 (1-2), 62–72.
32. Harvey PW (2003). Parabens, oestrogenicity, underarm cosmetics and breast cancer: a perspective on a hypothesis. J. Appl. toxicol. 23 (5), 285–288. https://doi.org/10.1002/jat.946
33. Hasanzadeh M, Shadjou N, Saghatforoush L, Mehdizadeh R, Sanati S (2012). Electrocatalytic oxidation of selected parabens on zinc hydroxide nanoparticles. Catal. Commun. 19, 10-16. https://doi.org/10.1016/j.catcom.2011.12.012
34. Hu C, Tian M, Wu L, Chen L (2022). Enhanced photocatalytic degradation of paraben preservative over designed g-C3N4/BiVO4 S-scheme system and toxicity assessment. Ecotoxicology and Environmental Safety, Volume 231, 113175, ISSN 0147-6513. https://doi.org/10.1016/j.ecoenv.2022.113175.
35. Jia M, Dahlman-Wright K, Gustafsson JA (2015). Estrogen receptor alpha and beta in health and disease. Best practice & research. J. Clin. Endocrinol. Metab. 29 (4), 557–568. https://doi.org/10.1016/j.beem.2015.04.008.
36. Kang YH, Parker CC, Smith AC, Waldron KW (2008). Characterization and distribution of phenolics in carrot cell walls. J. Agri.Food Chem. 56 (18), 8558-8564. https://doi.org/10.1021/jf801540k.
37. Karastogianni S, Girousi S (2017). A Novel Electrochemical Bioimprinted Sensor of Butyl Paraben on a Modified Carbon Paste Electrode with Safranine-O capped to Silver Nanoparticles. Int. J. Curr. Res. 9(11), 61118-61124.
38. Khalid WEFW, Arip MNM, Jasmani L, Lee YH (2019). A New sensor for methyl paraben using an electrode made of a cellulose nanocrystal-reduced graphene oxide nanocomposite. Sens. 19(12), 2726; https://doi.org/10.3390/s19122726
39. Khanna S, Darbre PD (2013). Parabens enable suspension growth of MCF-10A immortalized, non-transformed human breast epithelial cells. J. Appl. Toxicol. 33 (5), 378–382. https://doi.org/10.1002/jat.2753
40. Kirchhof MG, de Gannes GC (2013). The health controversies of parabens. Skin Therapy Letter, 18(2), 5-7.
41. Koeppe ES, Ferguson KK, Colacino JA, Meeker JD (2013). Relationship between urinary triclosan and paraben concentrations and serum thyroid measures in NHANES 2007-2008. Sci. Total Environ. 445–446, 299-305. https://doi.org/10.1016/j.scitotenv.2012.12.052
42. Lachman L (1968). The instability of antimicrobial preservatives. Bull Parenter Drug Assoc. 22(3), 127-144.
43. Leppert B, Strunz S, Seiwert B, Schlittenbauer L, Schlichting R, Pfeiffer C, Röder S, Bauer M, Borte M, Stangl GI, Schöneberg T, Schulz A, Karkossa I, Rolle-Kampczyk UE, Thürmann L,

Bergen MV, Escher BI, Junge KM, Reemtsma T, Lehmann I, Polte T (2020). Maternal paraben exposure triggers childhood overweight development. Nat. Commun. 11(561) https://doi.org/10.1038/s41467-019-14202-1

44. Li C, Cui X, Chen Y, Liao C (2020). Paraben concentrations in human fingernail and its association with personal care product use. Ecotoxicol. Environ. Safety 202. https://doi.org/10.1016/j.ecoenv.2020.110933
45. Li W, Gao L, Shi Y, Wang Y, Liu J, Cai Y (2016). Spatial distribution, temporal variation and risks of parabens and their chlorinated derivatives in urban surface water in Beijing, China. Sci. of the Total Environ. 539, 262-270. http://dx.doi.org/10.1016/j.scitotenv.2015.08.150
46. Liao C, Liu F, Kannan K (2013). Occurrence of and dietary exposure to parabens in foodstuffs from the United States. Environ. Sci. Technol. 47 (8), 3918–3925. https://doi.org/10.1021/es400724s
47. Lincho J, Martins RC, Gomes J (2021). Paraben Compounds—Part I: An Overview of Their Characteristics, Detection, and Impacts. Appl. Sci. 11(5), 2307. https://doi.org/10.3390/app11052307
48. Luo P, Liu J, Li Y, Miao YH, Ye B (2012). Voltammetric Determination of Methylparaban in Cosmetics Using a Multi-Wall Carbon Nanotubes/Nafion Composite Modified Glassy Carbon Electrode. Analytical Lett. 45, 2445-2454. https://doi.org/10.1080/00032719.2012.691589
49. Ma WL, Zhao X, Zhang ZF, Xu FJ, Li YF (2018). Concentrations and fate of parabens and their metabolites in two typical wastewater treatment plants in northeastern China. Science of the Total Environment, 644, 754–761. 10.1016/j.scitotenv.2018.06.358
50. Martins FC, Videira RA, Oliveira MM, Silva-Maia D, Ferreira FM, Peixoto FP (2020). Parabens enhance the calcium-dependent testicular mitochondrial permeability transition: Their relevance on the reproductive capacity in male animals. J. Biochem. Mol. Toxicol. 35(3), 1-8. https://doi.org/10.1002/jbt.22661
51. Mashile GP, Mpupa A, Nqombolo A, Dimpe KM, Nomngongo PN (2020). Recyclable magnetic waste tyre activated carbon-chitosan composite as an effective adsorbent rapid and simultaneous removal of methylparaben and propylparaben from aqueous solution and wastewater. Journal of Water Process Engineering. Volume 33, 101011, ISSN 2214-7144. https://doi.org/10.1016/j.jwpe.2019.101011.
52. Meeker JD, Yang T, Ye X, Calafat AM, Hauser R (2011). Urinary concentrations of parabens and serum hormone levels, semen quality parameters, and sperm DNA damage. Environ. Health Perspect. 119 (2), 252–257. https://doi.org/10.1289/ehp.1002238
53. Mehrotra P (2016). Biosensors and their applications-A review. J. Oral Biol. Craniofacial Res. 6, 153-159. https://doi.org/10.1016/j.jobcr.2015.12.002
54. Mendonca CD, Prado TM, Cincotto FH, Verbinnen RT, Machado SAS (2017). Methylparaben Quantification via electrochemical sensor based on reduced graphene oxide decorated with ruthenium nanoparticles. Sens. Actuators B Chem. 2017; 251. https://doi.org/10.1016/j.snb.2017.05.083
55. Michalkiewicz S (2013). Anodic oxidation of parabens in acetic acid–acetonitrile solutions, J Appl Electrochem. 43(1), 85–97. https://doi.org/10.1007/s10800-012-0502-5

56. Delgado MD, Cruz DMS, Barcel´o D. (2016). Ecological risk assessment associated to the removal of endocrine-disrupting parabens and benzophenone-4 in wastewater treatment. J. Hazard Mater. 310, 143–151. https://doi.org/10.1016/j.jhazmat.2016.02.030
57. Moschogiannaki M, Frontistis Z, Kiriakidis G, Mantzavinos D, Binas V (2020). Porous CoxNi1-xTiO3 nanorods for solar photocatalytic degradation of ethyl paraben. J. Materiomics. 6(4), 788-799, ISSN 2352-8478. https://doi.org/10.1016/j.jmat.2020.05.006.
58. Naresh V, Lee N (2021). A Review on Biosensors and Recent Development of Nanostructured Materials-Enabled Biosensors. Sens. 21(4), 1109. https://doi.org/10.3390/s21041109
59. Popa DS, Kiss B, Vlase L, Pop A, Iepure R, Păltinean R, Loghin F (2011). Study of oxidative stress induction after exposure to bisphenol A and methylparaben in rats. Farmacia. 59(4), 539-549.
60. Pourmohammad M, Ghadi A, Beni AA (2024). Removal of Benzyl Paraben from Wastewater Using Zeolitic Imidazolate-67 Modified by Fe3O4 Nanoparticles with Response Surface Methodology. J. Appl. Chem. Res. 18(1), 88-107.
61. Qurashi A, Rather JA, Yamazaki T, Sohail M, Wael KD, Merzougui B, Hakeem AS (2015). Swift electrochemical detection of paraben an endocrine disruptor by $In_2O_3$ nanobricks. Sens. Actuators B: Chem. 221, 167-171, 18603. https://doi.org/10.1016/j.snb.2015.06.026
62. Rather JA, Harthi AJA, Khudaish EA, Qurashi A, Munam A, Kannan P (2016). An electrochemical sensor based on fullerene nanorods for the detection of paraben, an endocrine disruptor†. Anal. Methods. 2016; 8(28), 5690-5700. The Royal Society of Chemistry. https://doi.org/10.1039/c6ay01489e
63. Sellappan S, Akoh CC, Krewer G (2002). Phenolic compounds and antioxidant capacity of Georgia-grown blueberries and blackberries. J. Agri. Food Chem. 50 (8), 2432-2438. https://doi.org/10.1021/jf011097r
64. Slaughter G (2018). Current Advances in Biosensor Design and Fabrication. R.A. Meyers (Ed.) Encyclopedia of Analytical Chemistry. John Wiley, Chichester. https://doi.org/10.1002/9780470027318.a0505.pub2
65. Song, C., Hu, H., Ao, H., Wu, Y., Wu, C. (2017). Removal of parabens and their chlorinated by-products by periphyton: influence of light and temperature. Environ. Sci. Pollut.Res. 24, 5566–5575. https://doi.org/10.1007/s11356-016-8301-x
66. Soni MG, Taylor SL, Greenberg NA, Burdock GA (2002). Evaluation of the health aspects of methyl paraben: a review of the published literature. Food Chem Toxicol. 40(10), 1335-73. https://doi.org/10.1016/s0278-6915(02)00107-2.
67. Tavares RS, Martins FC, Oliveira PJ, Ramalho-Santos J, Peixoto FP (2009). Parabens in male infertility-Is there a mitochondrial connection. Reprod. Toxicol. 27, 1–7. https://doi.org/10.1016/j.reprotox.2008.10.002.
68. Tian M, Hu C, Yu J, Chen L (2023). Carbon quantum dots (CQDs) mediated Z-scheme g–C3N4–CQDs/BiVO4 heterojunction with enhanced visible light photocatalytic degradation of Paraben. Chemosphere. 323, 138248, ISSN 0045-6535, https://doi.org/10.1016/j.chemosphere.2023.138248.
69. Tománková H, Pinkasová M (1990). Determination of Parabens and their Degradation Product p-Hydroxy-Benzoic Acid in Pharmaceutical Dosage Forms by Hptlc Densitometry, Analytical Lett. 23(7), 1319-1332. https://doi.org/10.1080/00032719008054356

70. Upadhyay P, Gauba P, Mathur A (2020). Paraben: A Boon or Bane for Society, in: P. Gauba, I.P. Sarethy, and A. Mathur (Eds.), Advances in Bioresources, Biodiversity and Therapeutics, I.K. International Pvt. Ltd., pp. 79-93.
71. Vale F, Sousa CA, Sousa H, Santos L, Simões M (2022). Parabens as emerging contaminants: Environmental persistence, current practices and treatment processes. Journal of Cleaner Production, 347, 131244 https://doi.org/10.1016/j.jclepro.2022.131244
72. Vitku J, Kolatorova L, Franekova L, Blahos J, Simkova M, Duskova M, Skodova T, Starka L (2018). Endocrine disruptors of the bisphenol and paraben families and bone metabolism. Physiol. Res. 67 (Suppl 3), S455–S464. https://doi.org/10.33549/physiolres.934005.
73. Wang L, Li Y, Li G, Ye B (2015). A new strategy for enhancing electrochemical sensing from MWCNTs modified electrode with Langmuir-Blodgett film and used indetermination of methylparaben. Sens. Actuators B Chem. 211, 332–338. http://dx.doi.org/10.1016/j.snb.2015.01.056
74. Wang S, Wang X, Poon K, Wang Y, Li S, Liu H, Lin S, Cai Z(2013). Removal and reductive dechlorination of triclosan by Chlorella pyrenoidosa. Chemosphere 92, 1498–1505. https://doi.org/10.1016/j.chemosphere.2013.03.067.
75. Wang X, Bi X, Yao N, Elmaci G, Ertürk AS, Lv Q, Zhao P, Meng X (2022). Doping strategy-tuned non-radical pathway on manganese oxide for catalytic degradation of parabens. J. Chem. Eng. 442, Part 1, 136180, ISSN 1385-8947. https://doi.org/10.1016/j.cej.2022.136180.
76. Wang Y, Cao Y, Fang C, Gong Q (2010). Electrochemical sensor for parabens based on molecular imprinting polymers with dual-templates" Analytica Chimica Acta. 673(2), 145–150. https://doi.org/10.1016/j.aca.2010.05.039
77. Wasito H, Phechkrajung C (2015). Validated Visible Spectrophotometry for Quantitative Analysis of Pirenoxine in The Presence of Paraben Preservatives in Eye Drop Preparations. 4th International Conference on Instrumentation, Communications, Information Technology, and Biomedical Engineering (ICICI-BME), Bandung, Indonesia, pp. 327-331, https://doi.org/10.1109/ICICI-BME.2015.7401388.
78. Xin T, Chen W, Su N, Wang Z (2023) Synthesis of poly(methacrylic acid)/functionalized carbon nanotubes nanocomposite modified electrode for electrochemical sensitive determination of acrylamide in food sample, International Journal of Electrochemical Science, 18(3), ISSN 1452-3981, https://doi.org/10.1016/j.ijoes.2023.01.025.
79. Yang H, Zhang F, Wu H (2018). Review on life cycle of parabens: synthesis, degradation, characterization and safety analysis. Curr. Org. Chem. 22(8), 769-779. https://doi.org/10.2174/1385272822666180123150323
80. Ye X, Bishop AM, Reidy JA, Needham LL, Calafat AM (2006). Parabens as urinary biomarkers of exposure in humans. Environ. Health Perspect. 114, 1843–1846. https://doi.org/10.1289/ehp.9413.
81. Yücebaş BB, Yaman YT, Bolat G, Özgür E, Uzun L, Abaci S (2020). Molecular imprinted polymer based electrochemical sensor for selective detection of paraben. Sens. Actuators B Chem. 305, 127368. https://doi.org/10.1016/j.snb.2019.127368

**Graphical Abstract**