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A study on Biosensor and their Pharmaceutical Applications

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ABSTRACT: In recent years, the biomedical field has increasingly centred its focus on biosensors, which rank among the most reliable analytical devices available for environmentally friendly, accurate, and rapid analysis. These instruments facilitate the detection of biological signals through both chemical and physical technologies, demonstrating high sensitivity in pharmaceuticals, healthcare and biotechnology. The advancement of biosensors has garnered significant attention from scientists, resulting in the development of various types, including enzyme-based, tissue-based, immunosensors, DNA biosensors, thermal biosensors, and piezoelectric biosensors. The diverse applications of these technologies span multiple disciplines, as biosensors contribute to both financial and regulatory measures within the food industry, as well as to clinical diagnosis, environmental remediation, drug development, and forensic analysis. Moreover, biosensors provide a cost effective and safer alternative for research, enhance public safety, enable label-free detection methods, and improve healthcare delivery to populations. Recent innovations indicate that biosensors possess considerable potential in the detection of pharmaceuticals such as neostigmine, ketoconazole, and donepezil. They also enhance the detection of carcinogenic properties and support the validation and development of biomarkers, paving the way for the creation of anti-tumor elements and drugs by analysing various cancer-related markers simultaneously. Importantly, biosensors can be integrated with physicochemical transducers, which convert the recognition of substances into a detachable output signal.

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INTRODUCTION:

This comprehensive overview presents various types of biosensors designed for specific biological applications [1]. A biosensor is an analytical instrument that integrates a transducer and a biological component sensitive to biological signals to detect analytes [2,3]. These analytical tools convert a biological reaction into an electrical signal, which makes biosensors highly valuable in clinical treatment, pharmaceuticals, the biomedical industry, and healthcare [4,5]. Research in this field is receiving increasing attention due to the ability of biosensors to identify, prevent, monitor, and manage human health effectively [6,7].

Biosensors utilize a diverse range of biological materials including Aptameters, tissues, microorganisms, organelles, mammalian cells, bacteria, enzymes, antibodies, and nucleic acids. Different types of biosensors are referred to by various terms based on their applications, such as immunosensors, optrodes, and chemical canaries, resonant mirrors, glucometers, biochips, and bio computers [8,14,17]. The term "biosensor" was first coined by Cammann, and its definition was provided by IUPAC (Cammann, 1977; Thevenot, 1999; Thevenot, 2001). Technically, Biosensing refers to the predefined techniques that generate an accessible detection signal from the interaction between biological molecules (e.g., a protein and an analyte of interest, such as small elements and compounds) [3, 8,10].

Biosensors consist of two primary components: the molecular recognition element (MRE) and the transducer [14,9]. A wide variety of materials have been used as MREs, including plant and animal cells, organelles, tissues, microorganism, and enzymes. Additionally, synthetic materials such as peptide nucleic acids (PNAs) and molecularly imprinted polymers (MIPs) can also serve as MREs. MREs can be categorized into two bases: affinity and catalytic. Examples of catalytic base MREs include microbes, organelles, enzymes, and plant or animal cells [11,12].

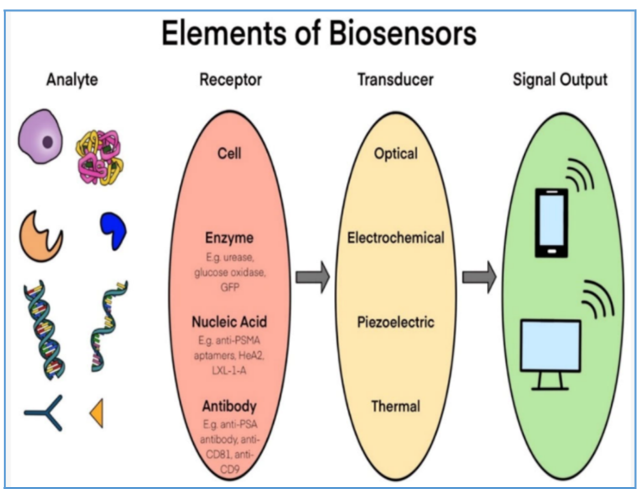

Fig 1.The elements of Biosensor.

Biosensors can be classified according to their mechanisms into three types: biocatalytic materials (which include enzymes), affinity materials (which include nucleic acids and antibodies), and microbe-based materials. Enzymes are particularly crucial for analytical applications due to their many favourable qualities, including accuracy in measuring enzymatic reaction rates, sensitivity to substrates because of the "key-lock" configuration, sustainability for specific tasks, and the wide availability of various analytical enzymes [13,16]. Enzymatic electrochemical biosensors, particularly those based on inhibition, are promising for clinical and pharmaceutical applications due to their durability, mobility, and cost-effectiveness. This comprehensive overview presents various types of biosensors designed for specific biological applications [7,22]. A biosensor is an analytical instrument that integrates a transducer and a biological component sensitive to biological signals to detect analytes. These analytical tools convert a biological reaction into an electrical signal, which makes biosensors highly valuable in clinical treatment, pharmaceuticals, the biomedical industry, and healthcare. Research in this field is receiving increasing attention due to the ability of biosensors to identify, prevent, monitor, and manage human health effectively [5].

PRINCIPLE OF BIOSENSOR:

A biosensor is an advanced analytical system designed to collect information and analyze biological models, ultimately providing valuable insights for various applications [4,13]. This system leverages a recognition element to detect the presence of an analyte, defined as the specific species to be identified. The target biological material interacts with a transducer through covalent or non-covalent binding, resulting in the formation of a bound analyte that generates a biological response. This response is subsequently converted into an electrical signal, which is measured by the transducer [2].

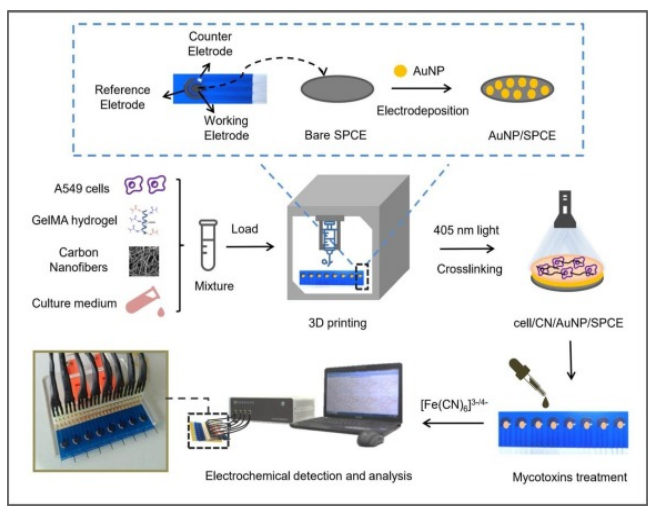

Fig 2. The Electrochemical detection and Analysis by Biosensor.

FUNCTIONALITY OF BIOSENSORS:

The operation of biosensors encompasses a complex interaction of biological, chemical, and physical principles. The two primary components of a biosensor are the recognition element and the transducer then transforms this change into an electric or optical signal, which is amplified for accurate measurement [1,17].

TYPES OF BIOSENSORS:

Biosensors are classified into six categories according to their mechanism of transduction.

- Optical Biosensor.
    - Surface Plasmon Resonance (SPR) Biosensor.
    - Piezoelectric Biosensor.
- Thermal Biosensor.
- Calorimetric Biosensor.
- Potentiometric Biosensor.
- Electrochemical Biosensor.
- Voltammetric Biosensor.

Optical Biosensor:

Optical biosensors are sophisticated devices that utilize light to detect and measure biological or chemical interactions. They incorporate optical fibres to identify analytes based on absorption, fluorescence, and light scattering. These sensors are particularly effective in the identification of bacteria, capable of detecting minute changes in the thickness or refractive index of the transducer's surface. Generally, optical components direct a beam of light to a mediator, sensor, and image detector.

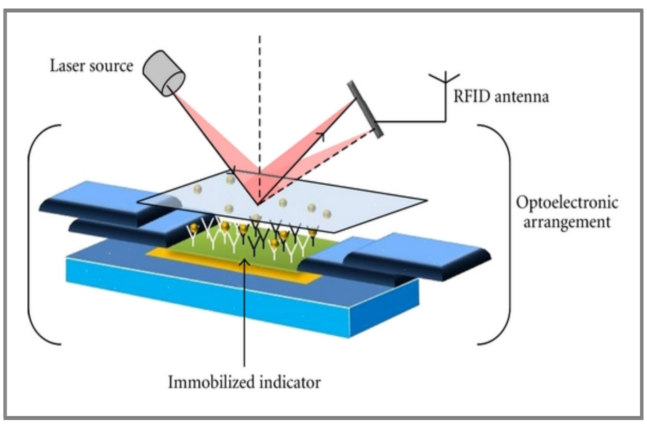

Fig 3. The Optical Biosensor.

***Surface Plasmon Resonance (SPR) Biosensor*:**

SPR biosensors are highly sensitive devices that utilize surface plasmons to detect biological or chemical interactions. They function based on oscillation characteristics determined by the dielectric constants of two media [6]. Surface plasmons generate free electrons, which are activated by appropriate photons. The composition of SPR biosensors include a light source and multiple optical components that transmit a specific light beam to a mediator, sensor, and image detector, where the peak medium enhances the breadth of the resulting Plasmon wave [18].

***Piezoelectric Biosensor*:**

Piezoelectric biosensors operate based on acoustic principles, commonly referred to as acoustic biosensors. The two primary types include surface acoustic wave devices and quartz crystal microbalances (QCMs). These biosensors are need for their user-friendliness and cost-effectiveness [10]. QCMs operate through the thickness-shear mode, making them advantageous for viscosity and density measurements. A significant limitation of QCMs is the damping phenomenon that occurs when biological liquids are introduced to the top electrode. To address this, piezoelectric thickness-shear mode resonators are utilized for various biological applications [14].

Thermal Biosensor:

Thermal biosensors quantify the heat generated by biochemical reactions within a sample. A key application of thermal sensors involves cantilever beams made from composite materials. Cantilever beam temperature calorimetry offers distinct advantages recognized in conventional calorimetry, particularly within the sphere of bio analysis. Since biological reactions can be exothermic or endothermic, calorimetry operates on a detection principle that is independent of the sample's optical properties [9,12]. Various calorimetric biosensors have been developed over recent years as reliable diagnostic tools, supported by a systematic classification based on operational principles, sensing performance, design, and applications. When thermal sensors are combines with enzyme molecules, they function as thermal biosensors [8,17].The concentration of an analyte can be detected when heat is produced through the reaction between the analyte and the enzyme, enabling the measurement of concentrations below 10M with thermal biosensors. A biosensor is an advanced analytical system designed to collect information and analyze biological models, ultimately providing valuable insights for various applications [5]. This system leverages a recognition element to detect the presence of an analyte, defined as the specific species to be identified. The target biological material interacts with a transducer through covalent or non-covalent binding, resulting in the formation of a bound analyte that generation a biological response. This response is subsequently converted into an electric signal, which is measured by the transducer [19].

Calorimetric Biosensors:

Calorimetric biosensors are primarily classified into two types: thermometric and thermal transducers. These devices function by detecting the heat produced during biological reactions at the sensing element and are widely applied in bio-analytical processes. Research employing traditional calorimetric methodologies has revealed various characteristics of these sensors. In contrast to other detection methods that are reliant on changes in the concentration of colored reactants, enzymatic reactions are typically associated with substantial enthalpy changes, approximately 20 to 100 kJ mol. Furthermore, measurements can concentrate on individual enzymatic steps, while a temperature differential between the reaction vessel and an isothermal heat sink is monitored.

The droperidol calorimeter is the most frequently used type of conduction calorimeter in this context. Presently, there is considerable interest in the development of plasmonic calorimetric interest in the development of plasmonic calorimetric biosensors, which promise to be advanced tools in the field of Biosensing.

Potentiometric Biosensors:

Potentiometric biosensors belong to the category of electrochemical sensors that require a steady supply of electric current for their operation. These sensors are employed top evaluate the redox potential associated with electrochemical reactions. While they generally exhibit lower sensitivity in comparison to amperometric biosensors, potentiometric biosensors are esteemed for their capacity to rapidly and accurately detect changes in the concentration of specific ions [6,15]. Comprising an enzyme transducer that detects variations in the number of protons or other ions, as well as a bio-recognition element, the analytical signal obtained can be logarithmically associated with the concentration of the analyte [8].

One of the most prevalent transducers in the development of potentiometric biosensors is the glass pH electrode, which can be applied to bio-catalytic reactions such as glucose oxidation facilitated by glucose oxidase [23]. This innovative device has the capability to monitor multiple antigen layers simultaneously while purifying monoclonal antibodies.

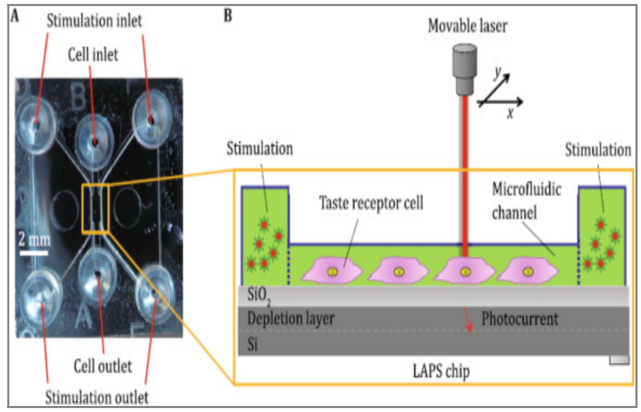

Fig 4. The Potentiometric Biosensors.

Electrochemical Biosensors:

Electrochemical biosensors primarily utilize a reference electrode to detect the current generated on the electrode surface by reduced or oxidised species. Their applications particularly beneficial for identifying hybridized DNA, glucose levels, and pharmaceutical agents that interact with DNA [9, 14]. These biosensors typically include a selective membrane or electron mediator that reacts at lower potentials within the sample matrix containing the analyte.

Electrochemical biosensors predominantly employ three types of transducers: amperometric, conduct metric, and potentiometric [15].

Amperometric Biosensors:

These sensors are recognized for their high sensitivity in detecting electroactive species. They leverage enzymes to catalyse the production of electrical signals, given that biological models often lack inherent electrical properties.

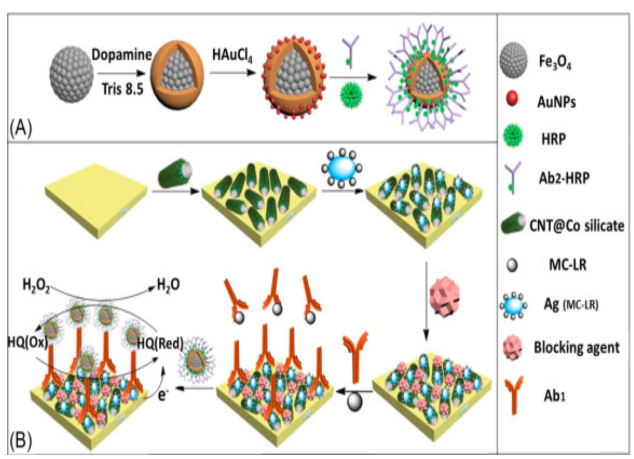

Fig 5. The Amperometric Biosensors.

The signal transduction process maintains a constant potential difference between the reference and working electrodes, with the latter usually made from an inert metal [7,18].

Conductometric Biosensors:

These sensors establish a linkage between electrical conductance and biorecogntion events. Common responses entail changes in the concentration of ionic species, which can lead to variations in current flow or electrical conductivity [5]. A conductometric biosensor typically consists of two metal terminals, often composed of platinum or silver, with an alternating current (AC) applied across then to maintain continuous current flow. Changes in conductance resulting from biorecogntion events due to fluctuations in ionic concentrations are assessed using an ohmmeter or multimeter [5,17]. However, a notable limitation of conductometric measurements lies in their generally lower sensitivity compared to other electrochemical approaches.

Voltammetric Biosensors:

The sensitivity and selectivity can be increased by choosing an appropriate voltammetric approach, which is beneficial for the research of Biosensing mechanisms techniques have become commonplace in biosensing. The most popular electrochemical method is cyclic voltammetry.

Constant oxidation and reduction processes of electroactive molecules in solutions are driven by potential cycling at the working electrode [10]**.** The response current increases and the amount of oxidized/reduced species on the electrode surface gradually decreases when the voltage put on the working electrode gets closer to the equilibrium potential of the species in solution. By utilizing functions of potential, current and time, a voltammetric analysis represents the chemical characteristics of analytes from various angles [23].

APPLICATIONS OF BIOSENSORS IN THE MEDICAL FIELD:

The evolution of biosensors has significantly transformed the medical field, leading to the development of highly effective and precise analytical instruments. These biosensors facilitate the examination of various medical processes, including the interactions between the antibodies and catalytic enzymes, monitoring of glucose levels, detection of microbiological diseases, and identification of cancerous growths, pathogens, and toxins [9,16]. Currently, there is widespread utilization of nanomaterial-enabled biosensors for COVID-19 diagnostics. Furthermore, medical biochemistry laboratories have begun transitioning away from traditional electrochemical methods for measuring lactic acid and glucose, particularly for blood component analysis [8]. Contemporary commercial biosensors have advanced from single-use devices to reusable options that incorporate calibration and quality control features. This evolution aims to improve the efficiency of patient care by replacing time-consuming and labour-intensive testing procedures, ultimately facilitating rapid clinical decision-making and enhancing the accessibility of medical assessments at the bedside [20].

Fluorescent Biosensors:

Fluorescent biosensors serve as sophisticated imaging tools that are essential in cancer research and drug development. In particular, genetically encoded Forster Resonance Energy Transfer (FRET) biosensors and FRET Green Fluorescent Protein (GFP)-dependent biosensors are integral to ongoing research efforts. These biosensors function as compact platforms that are chemically, genetically, or enzymatically linked to fluorescent indicators, enabling straightforward detection and analysis [4,19]. Fluorescent biosensors allow for accurate assessment of the presence, mobility, and condition of ions, protein biomarkers, and metabolites across various sample types, including serum and cell extracts. They are employed in applications such as protein localization, gene expression probing, and the evaluation of the cellular processes, including apoptosis, signal transduction, and the cell cycle [2,11].

Food Industry:

In the food industry, commercial biosensors play a critical role in measuring acids, alcohols, and carbohydrates. These instruments are primarily utilized in laboratory settings for quality assurance or are integrated into processing lines via flow injection analysis systems [13]. However, their application in continuous production environments is often constrained by requirements for sterility, regular calibration, and analyte dilution. Enzyme-based biosensors can effectively measure amino acids, amines, heterocyclic compounds, carbohydrates, carboxylic acids, gases, cofactors, inorganic ions, alcohols, and phenols to ensure food quality control. This technology is particularly advantageous for manufacturers of products such as beer, wine, yogurt, ad soft beverages [16,20]. Furthermore, immunosensors demonstrate significant potential to enhance food safety by detecting harmful microorganisms in fresh meat, poultry, and fish [9].

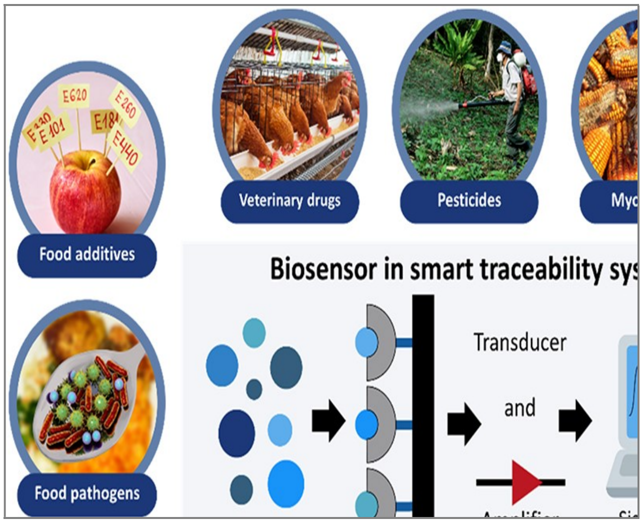

Fig 6. The Biosensors in smart traceability system.

Detection of small Molecules, including Glucose, Hydrogen Peroxide, and Adenosine:

Various biosensing methodologies have been proposed for glucose monitoring, with electrochemical biosensors being the predominant technology for detecting glucose oxidase or glucose dehydrogenase in non-blood fluids [24]. Recent advancements have emphasized that applicability of biosensor technology for monitoring blood glucose levels in individuals with diabetes.

Abnormal levels of hydrogen peroxide (H_2O_2) can adversely affect biological systems. Consequently, electrochemical and fluorescence-based techniques have been extensively employed in tissue engineering applications for the detection of H_2O_2 [5,14]. The development of stable and sensitive relies on effective bonding processes between enzymes and solid electrode surfaces, and nanoprobes or sensors for H_2O_2 detection offer distinct advantages for both ex vivo and in vivo tissue engineering applications [12].

Agriculture Industry:

Recent research has identified organophosphate and carbamate residues from pesticides using enzyme biosensors that act via the suppression of cholinesterase. Investigations are currently focused on the development of sensitive and selective microbial sensors for the measurement of methane and ammonia [21]. Presently, the only commercially available biosensors designed for the monitoring of wastewater quality are Biological Oxygen Demand (BOD) analyzers, which utilize *Rhodococcus erythropolis* bacteria immobilized in collagen or polyacrylamide [6,15].

Wearable Biosensors for Wellness monitoring:

Wearable biosensors have gained considerable attention for their applications in health monitoring. These innovative devices employ wireless electrodes integrated into pads, bandages, or wearable forms, facilitating efficient data collection [9,24]. The data obtained can be analyzed to evaluate the outcomes of critical clinical treatments and to anticipate potential deadlines in patient health. Typical analyses include assessments of blood, sweat, and other biological indicators. Additionally, the development of non-invasive glucose monitoring technology it establish it as the next standard in the wearable technology market [4]. Over the past three decades, significant advancements in biosensor technology have enabled the miniaturization and increased accessibility of these devices by integrating multiple sensor systems within a single unit capable of analyzing a wide range of analytes [8,22].

Biodefense Sensing:

Biosensors are essential tools in military applications for the detection of biological agents. The rapid and accurate identification of bio warfare agents (BWAs), including viruses, toxins, and both spore-forming and vegetative bacteria, is crucial for effective biodefense strategies [17]. Significant advancements have been made in developing biosensors that utilize molecular methods to identify the chemical markers associated with BWAs [23].

CONCLUSION:

Early detection and diagnosis of a wide range of human diseases are fundamentally important for the effective treatment of affected individuals. Therefore, to successfully identify these diseases, it is imperative to develop simple, sensitive and affordable diagnostic technologies like biosensors. Biosensors are valuable in the medical profession for various application that benefit both patients and healthcare providers. These applications include disease screening, clinical care, disease management, preventive therapy, and providing health information to patients. In recent years, nanomaterials have shown great potential in the development of biosensors.

The primary objective of clinical medicine is to utilize easily performed biosensors to classify patients. There is a consensus that a biosensor facilitates personalized medicines, offering a new perspective on modern medical practice. This approach, with its expensive range of therapeutic and diagnostic solutions, has significant impact on healthcare. Collaboration between biosensors and advancements in science and technology can lead to a broader range of experiences and more competitive products and services.

This technology offers a valuable solution to critical challenges in the medical field by enabling the measurement of rapid changes in tumor responses to radiation therapy and chemotherapy thereby facilitating the development of personalized cancer treatments. This application of nanomaterials in biosensors allow for the addressing of diverse and complex medical issues, thereby creating numerous opportunities for advancement. The successful detection of diseases necessitates the development of diagnostic technologies, such as biosensors, that are characterized by simplicity, sensitivity, and affordability. These tools are instrumental in enhancing the healthcare experience for both patients and providers, with applications including disease monitoring, clinical care, and preventive therapy. Recent advancements in nanomaterials have understood their significant potential in biosensor development, which supports the implementation of personalized medicine and positively affects healthcare outcomes. Moreover, collaboration between biosensors and advancements in scientific and technological fields may result in expanded range of experiences and the introduction of products that are more competitive and services, ultimately overcoming challenges within the medical industry and advancing the effectiveness of tailored cancer therapies.

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REFERENCES:

1. Huang P, Xu L, Xie Y. Biomedical Applications of Electromagnetic Detection: A Brief Review. Biosensors (Basel), 2021; 11(7): 225.
2. Mehrotra P. Biosensors and their applications - A review. J Oral Biol Craniofac Res, 2016 6(2): 153-159.
3. Pohanka M. Biosensors and Bioassays Based on Lipases, Principles and Applications, a Review. Molecules, 2019; 24(3): 616.
4. Lavecchia T, Tibuzzi A, Giardi MT. Biosensors for functional food safety and analysis. Adv Exp Med Biol, 2010; 698: 267-281.
5. Banik S, Melanthota SK, Arbaaz Vaz JM, Kadambalithaya VM, Hussain I, Dutta S, Mazumder N. Recent trends in smartphone-based detection for biomedical applications: a review. Anal Bioanal Chem, 2021; 413(9): 2389-2406.
6. Singh PK, Jairath G, Ahlawat SS, Pathera A, Singh P. Biosensor: an emerging safety tool for meat industry. J Food Sci Technol, 2016r; 53(4): 1759-1765.
7. El Harrad L, Bourais I, Mohammadi H, Amine A. Recent Advances in Electrochemical Biosensors Based on Enzyme Inhibition for Clinical and Pharmaceutical Applications. Sensors (Basel), 2018; 18(1): 164.
8. Bhardwaj SK, Singh H, Khatri M, Kim KH, Bhardwaj N. Advances in MXenes-based optical biosensors: A review. Biosens Bioelectron, 2022; 202:113995.
9. Yunus G, Singh R, Raveendran S, Kuddus M. Electrochemical biosensors in healthcare services: bibliometric analysis and recent developments. Peer J, 2023; 11: e15566.
10. Varshney A, Sharma L, Pandit C, Gupta PK, Mathuriya AS, Pandit S, *et al*. Microbial Fuel Cell-Based Biosensors and Applications. Appl Biochem Biotechnol, 2023; 195(5): 3508-3531.
11. Herrera-Domínguez M, Morales-Luna G, Mahlknecht J, Cheng Q, Aguilar-Hernández I, Ornelas-Soto N. Optical Biosensors and Their Applications for the Detection of Water Pollutants. Biosensors (Basel), 2023; 13(3): 370.
12. Fritea L, Banica F, Costea TO, Moldovan L, Dobjanschi L, Muresan M, *et al*. Metal Nanoparticles and Carbon-Based Nanomaterials for Improved Performances of Electrochemical (Bio) Sensors with Biomedical Applications. Materials (Basel), 2021; 14(21): 6319.
13. Kulkarni MB, Ayachit NH, Aminabhavi TM. Biosensors and Microfluidic Biosensors: From Fabrication to Application. Biosensors (Basel), 2022; 12(7): 543.

14. Fogel R, Limson J, Seshia AA. Acoustic biosensors. Essays Biochem, 2016; 60(1): 101-110.
15. Chen S, Li M, Weng T, Wang D, Geng J. Recent progress of biosensors for the detection of lung cancer markers. J Mater Chem B, 2023; 11(25): 5715-5747.
16. Alhadrami HA. Biosensors: Classifications, medical applications, and future prospective. Biotechnol Appl Biochem, 2018; 65(3): 497-508.
17. Hasan A, Nurunnabi M, Morshed M, Paul A, Polini A, Kuila T, *et al*. Recent advances in application of biosensors in tissue engineering. Biomed Res Int, 2014; 2014: 307519.
18. Reder-Christ K, Bendas G. Biosensor applications in the field of antibiotic research--a review of recent developments. Sensors (Basel), 2011; 11(10): 9450-9466.
19. Li BR, Chen CC, Kumar UR, Chen YT. Advances in nanowire transistors for biological analysis and cellular investigation. Analyst, 2014; 139(7): 1589-1608.
20. Zhao H, Su R, Teng L, Tian Q, Han F, Li H, *et al*. Recent advances in flexible and wearable sensors for monitoring chemical molecules. Nanoscale, 2022; 14(5): 1653-1669.
21. Yunus G, Singh R, Raveendran S, Kuddus M. Electrochemical biosensors in healthcare services: bibliometric analysis and recent developments. Peer J. 2023; 11: e15566.
22. Mauriz E, Lechuga LM. Plasmonic Biosensors for Single-Molecule Biomedical Analysis. Biosensors (Basel), 2021; 11(4): 123.
23. Kaur B, Kumar S, Kaushik BK. Recent advancements in optical biosensors for cancer detection. Biosens Bioelectron, 2022; 197: 113805.

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