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Review Article

Nanobiosensors: application in healthcare, environmental monitoring and food safety

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Abstract

This review article summarized the diverse kinds of nanobiosensors along with their uses in healthcare, environmental monitoring, and food safety, while also defining present challenges and opportunities for future investigation and augmentation. In healthcare, for instance, they have been employed for glucose monitoring, cholesterol detection, antibiotic monitoring, and the production of new types of antibiotics that are effective against resistant strains. This enables a highly efficient method that is both accurate and reliable when detecting biomarkers. Nanobiosensors have been overwhelmingly successful in aiding in environmental monitoring. With its ability to effectively screen groundwater, detect pollutants, and monitor toxicity, this emerging technology has become a force to be reckoned with for detecting hazardous substances. Similarly, the food industry has seen remarkable benefits from nanobiosensors as well. The use of nanobiosensors for dynamic food safety monitoring enables prompt detection of dangerous foodborne pathogens and spoilage issues while providing real-time data on the quality of consumables. Even though nanobiosensors possess enormous potential, there are still numerous limitations to overcome.

Keywords: Nanobiosensors, Healthcare, Environmental monitoring, Food safety, Diagnosis, Monitoring, Antibiotics, Pollution

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Introduction

A nanobiosensor is a “device” capable of sensing the existence of an analyte in a sample and measuring it. It contains the following regions: a sensor or receptor, a transducer, and a readout system (Huang et al., 2021). A nanosensor has dimensions at the nanoscale and has the ability to detect various analytes, namely biological agents, various chemical species, gases, and other physical factors. Huang et al. (2021) described a nanobiosensor as “sensors containing a biological element as a diagnostic component and the electrode as a transducer”. Nanobiosensors are a promising technology that can be applied to healthcare, environmental monitoring, and food safety (Alhalaili et al., 2020). The use of both nanotechnology and biosensor principles enables these sensors to provide highly sensitive and specific detection capabilities (Figure 1). Nanobiosensors have opened up new ways to detect and monitor various analytes such as glucose, cholesterol, DNA, proteins, and toxins. Nanobiosensors can be categorized into different types depending on their mechanism of detection, sensing materials, and transducers used.

Figure-1. The structure of a nanobiosensor, various domains of nanobiosensor connecting nanotechnology, biotechnology and sensor technologies.

Nanobiosensors are highly advantageous due to their capability of functioning on a nanoscale level. They can be incorporated into devices that have the potential for implantation inside the body or wearing externally, enabling prompt tracking of critical health metrics. Nevertheless, there are some challenges, such as ensuring device safety within the body and maintaining stability over extended periods while achieving mass production and affordability (Alhalaili et al., 2020).

Nanobiosensors are tiny instruments that merge biology and nanotechnology to recognize and analyze substances. They possess a broad spectrum of applications and afford accurate as well as sensitive detection of molecules. As they exploit molecular materials on the nanoscale level, these sensors offer possibilities for breakthroughs in sectors such as healthcare, food safety, and environmental monitoring, despite still facing certain challenges. The advancement of nanobiosensors holds an appealing implication for enhancing human health.

Due to their diverse surface properties, electrical advantages, and optical benefits, carbon-based nanoparticles are among the most often employed nanomaterials in biological studies (Wen et al., 2015; Ramnani et al., 2016). The production process has a considerable impact on the optical characteristics of nanomaterials when combined with structural changes. According to the tubular axis indices and folding patterns of carbon nanotubes, similar size features can exhibit metal-like, semiconductor-like, or chiral characteristics (Yüce and Kurt, 2017). The production procedure for graphene, which involves chemical vapor deposition, liquid phase exfoliation, and the Hummers method, can substantially alter the material's electrical and optical properties. Each of these approaches adds novel surface characteristics that are beneficial for surface biomodification as well as a variety of flaws to the material's two-dimensional structure (Yüce and Kurt, 2017). The use of carbon nanomaterials as signal transducers in biosensing platforms, such as single-wall carbon nanotubes, multiwall carbon nanotubes, chiral nanotubes, graphene, graphene oxide, reduced graphene oxide, carbon, or graphene quantum dots, is a fast-emerging field (Lim et al., 2015; Qian et al., 2015; Xia et al., 2016; Bhardwaj et al., 2017; Khosravi et al., 2017; Hou et al., 2017; Tabasi et al., 2017).

The biosensors created with carbon-based nanomaterials can be categorized into three types: piezoelectric, optical, and electrochemical. The study published by Tran and Mulchandani (2016) and Pasinszki et al. (2017) provides information on several types of carbon nanomaterial-based biosensors, the structural and physical characteristics of sensing nanomaterials, important detection processes, and recent developments in the field (Pasinszki et al., 2017). Noble metals like gold and silver offer distinctive and durable optical features for the field of biosensing (Špringer et al., 2017). They are frequently employed as signaling or signal-enhancing components in a variety of biosensing platforms. Because they are capable of maintaining the surface-bound collective oscillation of electrons, or surface plasmon, on their dielectric-metal interfaces in the visible to near-infrared spectrum, noble metals have unique optical attributes (Yüce and Kurt, 2017). The surface-bound plasmon can be locally contained and activated resonantly at specific wavelengths of the incoming electromagnetic radiation under certain size regimes. The refractive index variations in the dielectric medium have a significant impact on localized surface plasmon resonance (LSPR), and these changes in resonance wavelength are tightly constrained to the area around the nanoparticle (Yüce and Kurt, 2017).

Depending on the application of interest, LSPR response can be easily modified by utilizing different geometries of nanoparticle substrates or directly in solution (Abkenar et al., 2017). The foundation for plasmonic nano-biosensing has been created by combining the distinctive optical features of plasmonic nanomaterials with the target-specific nature of affinity probes (Jeong et al., 2016). Recently, Lim and Gao (2016) and Daraee et al. (2016) reviewed the general operating principles of plasmonic nanoparticles, including surface plasmon resonance (SPR), localized surface plasmon resonance (LSPR), surface enhanced Raman scattering (SERS), and the recent applications of plasmonic nanoparticles in biosensing, cancer diagnosis, drug delivery, and photodynamic and photothermal therapy (Daraee et al., 2016).

Lanthanide or actinide-doped nanoscale ceramic crystals, for instance, upconverting nanoparticles, have been used in biosensing applications for the past ten years (Lay et al., 2017). A single higher-energy photon is released after two or more incident low-energy photons are absorbed and converted by upconverting nanoparticles. To minimize potential auto-fluorescence coming from biological entities in the ultraviolet-visible (UV-Vis) region, photon absorption energy is typically achieved by utilizing a larger concentration of dopant ions in the infrared area. Following activation with an infrared light source, certain visible spectrum wavelengths exhibit fluorescence emission of higher-energy photons. The fluorescence emission's Full-Width Half-Maximum (FWHM) values are noticeably smaller than those produced by quantum dots. As opposed to this, semiconductor quantum dots are only a few nanometers in size and are easily tailored to create a range of fluorescence emission signals in the visible spectrum. Quantum dots' size, surface features, and optical behaviors have made it possible for them to be used in a variety of industries, including biosensing, bioimaging, and energy (Çolak et al., 2016; Tang et al., 2016; Tang et al., 2017). Numerous sensing mechanisms, such as direct fluorescence, fluorescence resonance energy transfer, bioluminescence resonance energy transfer, chemiluminescence energy transfer, photon-induced electron transfer, and electrochemiluminescence, have made extensive use of inorganic fluorescent nanoparticles. In the most recent review study by Ng et al. (2016), general structures of fluorescent inorganic nanomaterials, principles of molecular sensing techniques, and a helpful sensing optimization guideline are discussed.

The main objective of this article review is to present a comprehensive analysis of nanobiosensors and their potential applications in transforming health care, food safety, and environmental monitoring. Precisely, the objective includes highlighting recent technological advancements in nanobiosensor research while discussing its benefits as well as the challenges associated with incorporating it into these fields. Additionally, it aims at a deeper look at environmental monitoring processes, where they could serve crucial roles in detecting contaminants such as pollutants or pathogens. It is also important to spotlight how researchers are exploring ways that advanced sensor technology can improve food quality control measures through various techniques used to detect allergens or chemical contamination. Moreover, it also identifies some current limitations experienced by such technologies but does not overlook their future prospects. Lastly, the study recommends further areas needing immediate attention considering emerging innovations taking place, which include advancing biosensors examination across several sectors, including both developed and developing ones.

Types of Nanobiosensors

An organism, cell, tissue, or other biological system that employs a biochemical method of sensing is referred to as a bioreceptor. Biological molecular species that fall under this category include antibodies, enzymes, proteins, and nucleic acids. The interactions between antigen and antibody, nucleic acid (two complementary strands), enzyme and substrate, cellular (microorganisms, proteins), and biomimetic or synthetic bioreceptors provide the basis for the majority of bioreceptors (Hunter et al., 2013; Chen et al., 2019; Zhang et al., 2020).

There are various nanobiosensor types, each designed to serve a particular purpose. Ronkainen et al. (2010) have presented a basic classification of biosensors based on the type of element they contain and the transducers present in their structure. While some depend on electrical signals or alternative methods for the detection and measurement of substances, others utilize light wavelengths. In numerous industries like healthcare, environmental monitoring, and food safety, their practical applications prove effective as they aid in detecting diseases early, customizing medical treatments, and enhancing drug delivery effectiveness, besides identifying contaminants and harmful substances present in the environment and food products (Alhalaili et al., 2020).

The first form of nanobiosensor uses optical detection. This type of nanobiosensor uses the properties of light for detecting and measuring changes in the analyte concentration. Alterations in the refractive index of the sensing material are what underlie the detection mechanism. According to Song et al. (2021), a change occurs in the resonance wavelength of the optical sensor. The category of optical nanobiosensors includes surface plasmon resonance (SPR) sensors, localized surface plasmon resonance (LSPR) sensor, and photonic crystal sensor.

Electrochemical detection forms the basis of the second type of nanobiosensor. An electrode acts as a transducer in this type of nanobiosensor, converting the biological recognition event into an electrical signal (Meng et al., 2021). Electrochemical property fluctuations result from sensing material and are responsible for causing variations in either current or voltage as part of a detection mechanism. Electrochemical nanobiosensors encompass amperometric, potentiometric, and impedimetric sensors as examples.

Magnetic detection is what the third type of nanobiosensor relies on. This sort of nanobiosensor employs magnetic nanoparticles as its sensing material, which has been functionalized using biomolecules to give very precise detection abilities (Wu et al., 2020). A change in magnetic field results from changes in the magnetic properties of the sensing material, which forms the basis for the detection mechanism. Magnetic nanobiosensors, such as magnetic resonance imaging (MRI) contrast agents, magnetic particle imaging (MPI) sensors, and magnetic nanotransducers (Wu et al., 2020), are examples.

The fourth kind of nanobiosensor is founded on mass detection. This type of nanobiosensor detects and measures changes in mass using the principles of nanomechanics. It is based on changes in the mechanical properties of sensing materials where a detection mechanism can be created. Rodrigues et al. (2017) state that a change in the resonant frequency occurs. Examples of mass nano-biosensors are given by cantilever sensor technology and the use of nanomechanical resonators in addition to quartz crystal micro-balances (QCM).

Nanobiosensor development contributed to the creation of a new generation of biosensors that can detect with high sensitivity and specificity. To identify and track different analytes, depending on the application requirements, a varied range of alternatives are given through different kinds of nanobiosensors. Choosing a nanobiosensor type depends on various factors, like the target analyte, sensitivity, specificity, and more. Nanobiosensors are predicted to remain critical in several areas as additional advances in nanotechnology and biosensor technology arise (Alhalaili et al., 2020).

Application of Nanobiosensors

Nanobiosensors are innovative instruments covering a broad spectrum of uses in many important sectors and industries, including agriculture, health, and food safety. These compact devices combine biological recognition elements with nanotechnology to provide unmatched detection power for scrutinizing substances at the microlevel. This overview looks into how nanobiosensors can revolutionize many vital fields by discussing their extraordinary contributions to areas such as glucose monitoring, cholesterol detection, environmental monitoring, and food safety.

Glucose monitoring

Managing diabetes effectively requires monitoring glucose levels, a chronic condition impacting countless people. Traditional methods like finger-stick testing can prove uncomfortable and time-consuming. Fortunately, advancements in nanotechnology have enabled the development of glucose nanobiosensors that provide an accurate means to monitor blood sugar without being invasive or lengthy.

Utilizing nanotechnology to detect biological molecules, these sensors are able to identify and gauge concentrations of glucose in bodily fluids such as sweat or blood (Ardakani et al., 2022). Constructed with enzymes, including those found within glucose oxidase, along with transducer technology, which transforms biochemical signals into electrical ones for clear readouts, Glucose nanobiosensors come with several benefits, aside from offering continuous glucose monitoring in real-time. Patients living with diabetes can leverage the results to make better dietary and exercise choices as well as medication decisions based on their glucose levels (Ardakani et al., 2022). Besides being non-invasive, these sensors avoid blood sample collection requirements that could induce discomfort during finger-stick testing for some patients. Glucose nanobiosensors have various applications, ranging from hospitals to clinics and even homes. Moreover, wearable gadgets like smartwatches or fitness trackers enable real-time glucose monitoring capabilities. Besides assisting athletes and physically active individuals in tracking their blood sugar levels during workouts, this technology is also helpful for everyone else who desires easy access to such information.

One of the major challenges of glucose nanobiosensors is the need to calibrate and validate them, which can be time-consuming and complex. A number of concerns have been expressed about the accuracy and reliability of glucose nanobiosensors, since errors in measurement can cause serious problems for diabetic patients (Kulkarni et al., 2022). The glucose nanobiosensors hold great promise for diabetes management in spite of these challenges (Ardakani et al., 2022). With further research and development in nanotechnology, glucose nanobiosensors are expected to become even more accessible and beneficial for diabetes patients as further advancements in their design and functionality are expected.

Nanobiosensors have the potential to revolutionize diabetes management and monitoring in the future. Due to their high sensitivity, specificity, real-time monitoring capabilities, and requirement for smaller sample sizes compared with traditional methods, they offer numerous benefits. However, ensuring nanobiosensors remain dependable and precise over time poses a significant challenge that must be addressed through continued research and development efforts, which may lead to further enhancement of these sensors.

Cholesterol detection

There is a well-established link between high blood cholesterol and associated cardiac risks in humans (Kannel et al., 1979). A range of nanobiosensors can be utilized for detecting cholesterol. Electrochemical nanobiosensors employ transducers that undergo changes in electrical properties upon binding with the biorecognition element and subsequently change again when bonded to the target molecule. Meanwhile, Shoaie et al. (2019) findings indicate that optical nanobiosensors track fluctuations in a transducer's optical characteristics following attachment to the biorecognition element by said targeted molecule.

One kind of nanobiosensor made for detecting cholesterol is the electrochemical biosensor, which utilizes graphene oxide (GO) and gold nanoparticles (AuNPs). Cholesterol oxidase is the biorecognition element used in this biosensor that catalyzes the oxidation of cholesterol to produce hydrogen peroxide. A change in the electrical properties of GO/AuNPs is caused by the presence of hydrogen peroxide, which is measured by the transducer (Shoaie et al., 2019).

The optical biosensor using surface-enhanced Raman scattering (SERS) is another example. The biorecognition element for this sensor is an antibody that recognizes cholesterol. In the transducer, gold nanoparticles are functionalized with Raman molecules to function as a Raman transmitter. A Raman spectrometer can be used to measure the change in Raman signal induced by cholesterol molecules binding to the antibody (Wu et al., 2022).

Nanobiosensors have several benefits in detecting cholesterol, such as their heightened sensitivity, selectivity, and capacity to detect molecules even at low concentrations. Additionally, they offer swift real-time detection with minimal sample preparation (Shoaie et al., 2019). These sensors can be smoothly integrated into portable devices for point-of-care delivery while being cost-efficient too.

Despite the potential benefits, there are certain constraints and obstacles associated with nanobiosensors. To ensure precision, it is essential to optimize their stability and reproducibility while also guaranteeing the biocompatibility of the nanomaterials employed in them for safe application. In addition, ethical issues as well as regulatory requirements need careful consideration when utilizing these sensors.

Antibiotic resistance

The global problem of antibiotic resistance is growing and is a threat to public health. Recently, nanobiosensors have emerged as promising tools for fighting it. Antibiotic-resistant bacteria are detected and monitored in real time using nanotechnology and biological sensing elements. Here, we will discuss the application of nanobiosensors to antibiotic resistance and how we can use them to develop new strategies to combat it.

Antibiotic resistance occurs when bacteria develop resistance mechanisms that make antibiotics ineffective. A variety of mechanisms can lead to resistance genes being acquired, such as mutation or horizontal gene transfer. Detection of and monitoring of antibiotic-resistant bacteria at an early stage is essential to combating antibiotic resistance. Nanobiosensors play a critical role here. Biosensors can detect and monitor antibiotic-resistant bacteria using proteins, antibodies, or nucleic acids that have specific bacterial and resistance characteristics. The sensor elements bind to their targets to trigger a signal that can be measured and quantified. Based on this signal, antibiotic-resistant bacteria's presence and concentration can be detected (Garzón et al., 2020).

Nanobiosensors are being used for the development of rapid diagnostic tests for antibiotic resistance. Healthcare providers can use these tests to accurately identify resistant bacteria in patient samples, allowing them to prescribe appropriate treatment and minimize the spread of antibiotic resistance (Garzón et al., 2020). Nanobiosensor-based tests can be used, for example, to identify the mecA gene, a gene associated with resistance to methicillin. Nanobiosensors have made it feasible to monitor the efficacy of antibiotic treatment in real-time. Medical professionals can track the number of bacteria that are resistant to antibiotics over time, enabling them to determine whether a specific method is effective or if an alternate approach should be pursued. This process optimizes management and eradicates resistance while enhancing patient outcomes.

Additionally, nanobiosensors provide another avenue for combating antibiotic resistance through new drug development research studies. Researchers use this technology to identify mechanisms by which bacteria become immune so that they can develop new drugs tailored specifically against bacterial immunity (Garzón et al., 2020). Detection of changes associated with metabolism arises during testing using these biosensor technologies; targets such as protein-binding sites and receptors are ideal for application in achieving desired results efficiently.

The detection and combating of antibiotic resistance could undergo a dramatic transformation with the advent of nanobiosensors. By utilizing these devices, we can effortlessly recognize resistant bacteria and oversee the effectiveness of antibiotic treatments while also developing new antibiotics in an expeditious and precise manner. Given that there has been a boost in this problem, it is imperative that we persistently explore novel tactics along with cutting-edge technology like nanobiosensors to counteract growing resistance levels, and nanobiosensing bears immense potential towards achieving our ultimate goal.

Agriculture

According to Singh (2021), the effectiveness of nanobiosensors in advancing agricultural efficiency, productivity, and sustainability has been proven. These state-of-the-art devices have shown their capability to detect and monitor different parameters accurately and instantly, a remarkable feature for efficient agriculture practices. In agriculture, the detection of pathogens and contaminants is a crucial application for nanobiosensors. These sensors are capable of identifying harmful bacteria and viruses present in food or water supplies (Singh, 2021), facilitating disease containment, and minimizing instances of foodborne illnesses. Moreover, nanobiosensors enable farmers to detect hazardous chemicals or pesticides residing within crops so that well-informed decisions can be made about their usage (Singh, 2021).

Nanobiosensors are crucial in agriculture for monitoring soil quality, particularly by measuring the levels of various nutrients and pH. With this information, farmers can optimize their use of fertilizers and other inputs to enhance crop yields while reducing expenses (Rai et al., 2012). Plant health can also be monitored in real-time with nanobiosensors (Figure 2). A plant's hormone levels, enzyme concentrations, and other biochemical markers can be measured by these sensors, indicating stress or disease (Rai et al., 2012) (Figure 2). Using this information, crops can be kept healthy and yield better before the problem becomes severe.

Aside from the above applications, nanobiosensors are also effective at detecting and monitoring environmental variables such as humidity, temperature, and light intensity (Rai et al., 2012) (Figure 2). By using this information, crops can be grown in better conditions, improving yields and reducing costs. Agricultural nanobiosensors can provide farmers with real-time information about soil quality, plant health, and pathogen and contaminant presence, which will revolutionize the industry (Figure 2). It is predicted that as technology develops, agriculture will begin to see new applications of nanobiosensors as well, which will result in higher productivity, sustainability, and efficiency.

Figure-2. Application of nanobiosensors in agriculture

Groundwater monitoring

Humans, animals, and plants depend on groundwater for drinking water. It is the primary source of drinking water for billions of people worldwide. The quality of groundwater plays a crucial role in human health and environmental conservation. Various pollutants, including pesticides, heavy metals, and organic compounds, can pollute groundwater, harming people and the environment. The quality of groundwater must therefore be monitored regularly. The detection of contaminants in groundwater is a highly promising field with the application of nanobiosensor technology. With high accuracy and real-time readings, this biosensor proves to be an efficient environmental monitoring tool (Steffens et al., 2022). To quantify various underground pollutants, including toxins and impurities, at lower levels than what traditional techniques allow for, nanoparticles are blended into biomolecules such as enzymes or antibodies, resulting in these revolutionary nanobiosensors (Steffens et al., 2022).

Groundwater screening with nanobiosensors offers the advantage of simultaneously detecting multiple contaminants. As an example, a single nanobiosensor can detect multiple heavy metals, pesticides, and organic compounds in groundwater (Ganesan and Vasudevan, 2020). Since nanobiosensors do this, they are more efficient than conventional analytical techniques, which require multiple tests in order to detect different contaminants. Ganesan and Vasudevan (2020) have demonstrated the use of nanobiosensors for in-situ groundwater screening, so the screening can take place on-site without sending water samples to a laboratory for testing. As opposed to laboratory testing, in-situ screening using nanobiosensors is both faster and more cost-effective, making it an attractive environmental monitoring option.

There are several types of nanobiosensors that can be used for screening groundwater, including optical, electrochemical and magnetic versions (Ganesan and Vasudevan, 2020). The choice of biosensor depends on the application in question as well as which pollutants need to be detected. While electrochemical nanobiosensors are highly sensitive and capable of detecting contaminants at very low concentrations (Meng et al., 2021), they also have their drawbacks. Despite being easy to operate with real-time detection capabilities, these sensors may sometimes provide inaccurate results due to interference from other compounds present in the water.

In contrast to the optical nanobiosensor, the highly specific magnetic nanobiosensor has been found effective in detecting certain contaminants present in groundwater (Wu et al., 2020). These biosensors have a remarkable ability to identify low levels of pollutants and can be used for on-site analysis. Unlike their counterparts using other technologies, they are not influenced by various compounds that may exist in groundwater. Nevertheless, due to instrumentation complexity issues, performing an examination at remote locations becomes challenging with these new types of sensors.

Environmental monitoring

Nanobiosensors have revolutionized the detection and monitoring of environmental pollution and toxic substances. According to Ganesan and Vasudevan (2020), these advanced sensors have exceptional capabilities in detecting even minute concentrations of pollutants, making them ideal for effective environmental management. Moreover, nanobiosensors are not limited to heavy metals only, as they can also detect organic compounds, pesticides, and other toxins with high selectivity by targeting specific contaminants (Figure 3).

This state-of-the-art technology holds impressive promise in detecting harmful pathogens such as *E. coli* that cause water-borne diseases. Identifying any potential sources of contamination present within water through early detection using the nanosensor-based approach will help prevent possible outbreaks from occurring (Ganesan and Vasudevan, 2020). Moreover, nanobiosensors can also monitor the quality of air and detect airborne pollutants such as volatile organic compounds, particulate matter, and nitrogen oxides (Figure 3). With the real-time data reports provided by these sensors, identification of potential sources of pollution is made easier (Kapil et al., 2022).

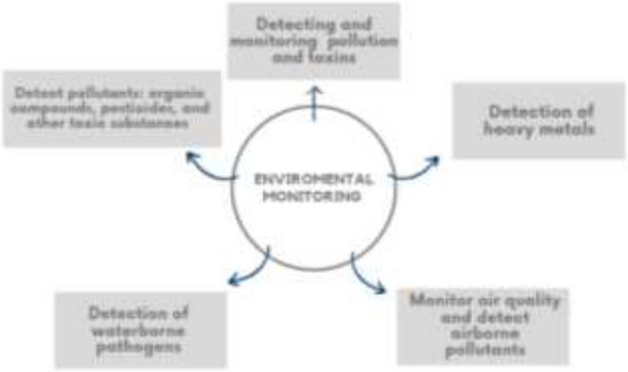

Figure-3. Application of Nanobiosensors in Environmental monitoring

Table-1. Advantages and disadvantages of nanobiosensors

S.No	Advantages	Reference
1	Large volume and surface increasing the bio-receiver's surface area	Yang et al., 2014
2	High adsorption power	Wang et al., 2020
3	Biocompatibility	Zhang et al., 2020
4	Amplification of the diagnostic signal,	Yang et al., 2015
5	Direct attachment of the enzyme to the electrode surface	Wang et al., 2020
	Disadvantages	
1	The conjugated DNA on the NP surface may undergo conformational changes that modify its propensity for binding to the target. Consequently, decreased sensitivity and specificity might happen.	Chiu and Huang, 2009
2	Some nanobiosensors are too toxic or they lack sufficient specificity for practical applications	Chiu and Huang, 2009; Singh et al., 1982
3	Fabrication of these devices is costly and time intensive	Denmark et al., 2019

Various advantages and disadvantages of nanobiosensors have been mentioned in Table 1. Although nanobiosensors have many advantages, they face numerous challenges when utilized for the purpose of environmental monitoring. Specifically, specialized expertise and equipment must be employed to create and design these sensors, in addition to calibration procedures that ensure the accuracy and dependability of the data collected from them. However, utilizing these sensors for environmental monitoring presents a great opportunity to elevate our capacity to discover and address instances of environmental pollution as well as hazardous materials. It is believed that with much more research-oriented development time, nanobiosensors hold immense potential for improving methods used for managing and monitoring ecological systems, working towards ensuring the safety and security of humans as well as wildlife creatures alike.

Food safety

High-tech methods are frequently used in the modern world to help the agricultural industry thrive. Similar to China, rice output has increased three times over the previous 50 years; the increased grain yield, not the planted area, is to blame. In fact, unless basic management problems are resolved, the agriculture sector cannot be efficiently managed in any state (Ahmad et al., 2013). The sensitivity, specificity, and rapid response times of nanobiosensors make them increasingly utilized in various fields. The field of food safety can greatly benefit from the application of nanobiosensors (Yang et al., 2016). As concerns about contamination and illnesses caused by food increase, it is crucial to develop methods for quick and sensitive detection. Nanobiosensors provide a promising solution as they have the ability to detect an array of contaminants present in edibles, like allergens, toxins, or viruses, among others (Yang et al., 2016). Food safety applications have led to the development of multiple nanobiosensors. A case in point is the surface plasmon resonance (SPR) biosensor, which identifies shifts in refractive index that arise when target analytes bind to its sensor surface (Adányi et al., 2017). Due to their effectiveness, SPR biosensors can detect various food contaminants, such as bacterial pathogens, toxins, and allergens. Similarly, an electrochemical biosensor detects changes made by a range of detected food contaminants, like pesticides and heavy metals, among others, via modifications done to electrochemical signals generated (Yang et al., 2016). Nanobiosensors bring a significant benefit to food safety by being proficient in detecting low levels of contaminants. Unlike conventional methods, which might demand extensive sample sizes and long incubation periods, nanobiosensors offer prompt outcomes with minimal preparation. Therefore, they are highly suitable for implementing large-scale screening campaigns or conducting on-site testing right away (Yang et al., 2016). They offer a unique advantage in terms of specificity. In contrast to conventional methods that have the potential to detect both harmless and harmful bacteria and chemicals, nanobiosensors can be tailored to target specific contaminants under inspection. The outcome is reduced chances of identifying false positives, which might otherwise cause unnecessary food recalls and adverse economic impacts. Although nanobiosensors provide numerous benefits, their application in ensuring food safety comes with certain drawbacks and obstacles.

A challenge lies in establishing standardization procedures and validating the detection techniques employed by these sensors. Establishing reliable protocols that are consistent across different laboratories and testing platforms is crucial to ensuring accurate results (Yang et al., 2016).

Nanobiosensors present a viable option for addressing the difficulties pertaining to food safety. With their ability to quickly, accurately, and uniquely detect contaminants in food, they possess the capability of mitigating threats linked to consuming contaminated foods while ensuring that what we consume is safe. As more investigations are carried out on this subject matter, it's probable that nanobiosensors will rise up as an indispensable instrument employed towards testing and observing compliance levels associated with food safety standards.

Future perspectives

The emergence of nanobiosensors has expanded the range of potential applications, encompassing fields like healthcare delivery, environmental surveillance, and food safety testing. With ongoing progress in this field, there are myriad prospects for integrating these sensors into various areas to bolster their utility and efficacy.

Nanobiosensors have promising applications in the healthcare industry, as they can enhance disease diagnosis and monitoring by identifying biomarkers with greater sensitivity and specificity. Further exploration could concentrate on creating nanobiosensors that are capable of accommodating body fluids like urine or sweat to facilitate non-invasive, continuous detection of biomarkers. Moreover, these biosensors may assist in targeted drug administration, enabling more accurate treatment alternatives for patients.

Due to the industrial revolution and other breakthroughs in other industries, climatic change is being seen all over the world (Ullah et al., 2015). In a changing world, nanobiosensors have the potential to be a crucial aspect of environmental monitoring as they can aid in detecting and overseeing pollutants, toxins, and pathogens present in both air and water. There may be more emphasis on discovering nanobiosensors that are highly selective and sensitive towards identifying any substances causing pollution while being cost-effective. Therefore, there is an increase in the widespread use of these biosensors in environmental monitoring practices.

Nanobiosensors have the potential to detect foodborne pathogens and contaminants, thus guaranteeing that food products are safe for human consumption. Further advancement in nanotechnology could focus on creating multiplexed biosensors capable of detecting several different types of contaminants at once, thereby offering a more thorough and all-encompassing approach towards maintaining optimal levels of safety while handling consumable goods.

In general, the possibility of utilizing nanobiosensors in healthcare, environmental monitoring, and food safety forecast a bright future. The sector's potential for further development is expected to proliferate as research progresses, propelling an array of practical applications. The utilization of nanobiosensors is rapidly transforming healthcare, environmental monitoring, and food safety domains. These tiny sensors hold great prospects to address some fundamental hurdles in these sectors, such as speedy and precise diagnosis of diseases, continual tracking of pollution levels in real-time, and identification of microorganisms responsible for causing infections from contaminated foods.

Conclusion

The use of nanobiosensors presents a remarkable opportunity to enhance the rapidity, precision, and selectivity of disease diagnosis while also improving the efficacy and accuracy of therapeutic monitoring. Furthermore, they offer an optimistic prospect for detecting environmental pollutants early on and keeping their spread at bay, thereby reducing any negative impact they might have on human health or ecological balance. Additionally, these sensors provide a reliable method that is effective in recognizing foodborne contaminants and pathogens, which can boost safety standards when producing our diet.

Despite the potential of nanobiosensors, certain hindrances and constraints need to be overcome in order for them to reach their maximum capability. Among these are concerns regarding expenses, precision levels, selectiveness, and obtaining approval from regulatory bodies. In general, the use of nanobiosensors has considerable potential to revolutionize healthcare, food safety, and environmental monitoring. In order to fully harness this potential, it is crucial that research and development continue unabated so as to overcome any obstacles standing in its way.

Contribution of Authors

Mahmood Q: Prepared and edited the manuscript draft and approved the final manuscript and submitted the final approved manuscript as corresponding author.
Shaheen S & Azeem M: Participated in preparation of manuscript draft and editing and approved the final manuscript.

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