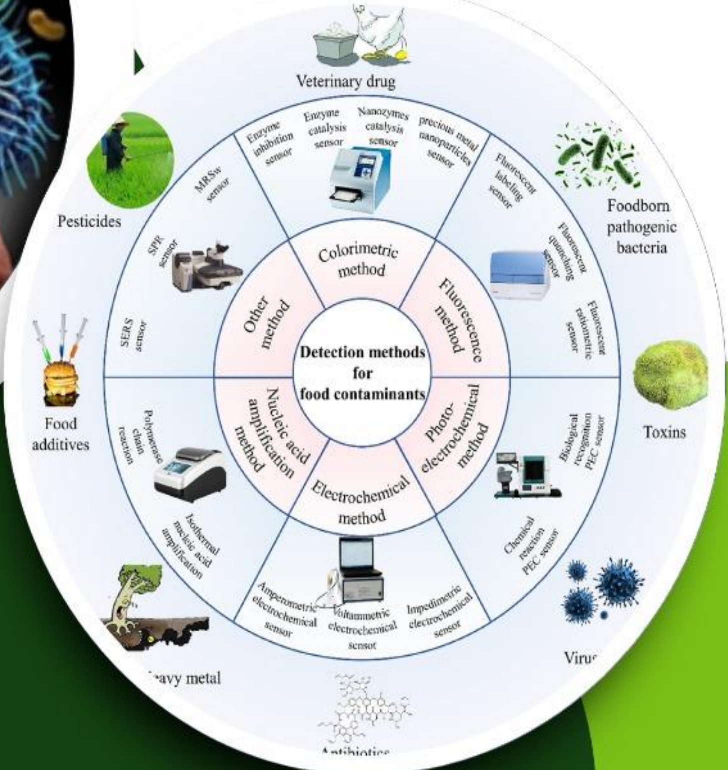
rebioin journal
OF BIOSCIENCES

Application of Bio sensors in detecting Food contaminants: A comprehensive review



admin@reboin.com

www.rebioin.com

Application of Biosensors in detecting Food contaminants: A comprehensive review

Bhavna Sharma and Deepika Raghuvanshi

Department of Biotechnology, Chaudhary Charan Singh University, Meerut, Uttar Pradesh 250004

***Corresponding author's email:** bs5302133@gmail.com

ABSTRACT

Biosensors technology represents an extremely wide field with a great impact to healthcare, environmental and food quality control. The aim of this review is limited to biosensors developing in the very last year's specifically for monitoring food contaminants. The review covers the basic principles and types of electrochemical biosensors reported for food specific applications. The various type of biosensors such as enzyme-based, tissue-based, immunosensors, DNA-biosensors, thermal and piezoelectric biosensors have been deliberated here to highlight their indispensable applications in multitudinous field. The use of biosensors is considered a novel approach for the rapid detection of foodborne pathogens in food products. Food adulteration is the purposeful altering of food quality. It involves adding additives to alter the qualities of food products for commercial purposes. Such food attributes include color, appearance, taste, weight, volume, and shelf life. Substituting food or nutritious content enhances the overall quality. Food substitutions include species, protein, fat, and plant elements. Organic and synthetic substances are introduced to have a quick impact on the human body. Adulterated food can have negative health and economic consequences. Symptoms may include diarrhea, nausea, allergies, diabetes, and cardiovascular disease.

Biosensors for sensitive and specific detection of foodborne and waterborne pathogens are particularly valued for their portability, usability, relativity low cost, real time or near real time response. Their application is widespread in several domains, including environmental monitoring. Biosensor applications are prevalent in the plant biology sector to find out the missing links required in metabolic processes. Food safety always remains a grand global challenge to human health, especially in developing countries. To solve food safety pertained problems numerous strategies have been developed to detect biological and contaminants chemical in food.

INTRODUCTION

Food is essential for all living beings and consists of carbohydrates, water, fats, and proteins. It can be consumed by animals and humans for both sustenance and enjoyment [1].

Food safety and quality issues are growing more complicated. Toxic foods, especially those of anthropogenic origin, are on the market, posing a risk. Sewage from industrial and agricultural operations contains leftover pesticides, fertilizers, growth stimulants, and other dangerous compounds, causing environmental degradation and toxic accumulation in fish, meat, and dairy products. Many people around the world become ill each year by consuming food pathogens. Foodborne infections are associated with physical and chemical pollution, as well as pathogenic microorganism.[2]

Foodborne infections are associated with physical and chemical pollution, as well as pathogenic microorganisms. Foodborne diseases are primarily caused by bacteria, viruses, and parasites, however fungal infections have also been reported. Bacteria are the leading cause of foodborne disease.

FOOD ADULTERATION

Adulteration involves adding or removing important nutrients from food for financial gain or owing to poor hygiene during production, storage, transportation, and marketing. This can lead to consumer fraud or illness [3].

Food adulteration is a long-standing issue, particularly when a food item is in short supply and in high demand [4]. Food adulteration deceives consumers and poses health hazards. It's challenging to locate a non-adulterated food industry today [11]. Consumers should understand the impact of common adulterants on their health. Examples include adding water to milk, animal carcasses to meat, stones, gravel, sand, insects, or animal hairs to grains. Food adulteration is purposely lowering the quality of food for sale.

Biosensors are used to detect adulteration in Food. The term Biosensor was coined by Cammann and its definition was introduced by IUPAC [5].

BIOSENSOR

A biosensor is a device that detects an analyte by providing an electrical signal proportional to its concentration. It typically consists of three components: receptor, transducer, and electronics [6]. Biosensors are analytical devices that converts a biological response into an electrical signal. Biosensors, which combine molecular biology and information technology, can quickly detect pathogens and contaminants, including chemical/biological agents, during outbreaks [7]. This reduces health risks and medical costs associated with foodborne illnesses. Quintessentially Biosensors be highly specific, independent of physical parameters including as pH and temperature and should be reusable.

The term Biosensor refers to an innovative analytical gadget that uses biological sensing for several purposes, including food safety, environmental monitoring, biomedicine, and drug development [8]. Biosensors are widely used for identifying and detecting bacteria and are considered one of the most efficient and accurate ways of food analysis and safety monitoring.

TYPES OF BIOSENSORS

Biosensors are classified into several categories based on their operating principles. Biosensors can be electrochemical, mechanical, biological, acoustic, SPR, or optical. Three major biosensors are discussed below [6].

1. ***Optical Biosensors*** – Optical biosensors are important detecting technologies with numerous uses in food, biomedicine, healthcare, pharmaceuticals, and environmental monitoring It consists of a light source and various optical components that generate a light beam with specific properties and direct this light to a modulating agent via a modified sensing head and a photodetector. Optical biosensor approaches with great sensitivity, simple handling, and rapid detection have been widely employed to identify vast numbers of bacteria.
2. ***Electrochemical Biosensors*** – Electrochemical biosensing techniques are among the most used platforms for the detection of foodborne pathogens. It has been stated that these techniques are effective for bacteria detection due to their low cost, precision, miniaturization capacity, and ability to detect changes directly based on the contact between the sensor and the sample. However, the time necessary to detect food contamination using electrochemical biosensors has decreased dramatically as new approaches have been developed, some of which take as little as 10 minutes.

3. ***Mechanical Biosensors***- Mechanical can measures a mass sensitive sensor surface deflection because the target analytes will be bonded on the functionalized surface. They are typically classified into four broad groups according to the sensor-analyte chemical interactions: affinity-based assays, fingerprint assays, separation-based assays, and spectrometric assays. Quartz crystal microbalance [QCM] is a mechanical biosensor that is widely used due to its capacity to track shift in mass in sub-nanogram amounts.

CLASSIFICATION OF BIOSENSOR

Biosensors are classed based on the transducer type or biological component. There are four distinct types of transducers [2].

Electrochemical Transducers

Potentiometric Transducers – The analytical signal in this situation is the potential drop between the working electrode and reference electrode, or between two reference electrodes separated by a semipermeable membrane (at zero current through the electrochemical cell). Transducers are often ion-selective electrodes (ISEs). The most common potentiometric biosensors use pH electrodes [13].

Voltametric Transducers- The electroactive species' oxidation or reduction current is measured. The latter is induced by creating a predefined potential drop between electrodes. Typically, the working electrode (or bundle of electrodes) receives a constant potential compared to the reference electrode. The current detected in a biocatalytic layer is proportional to the volume concentration of electroactive species or their rate of disappearance or production [9].

Conductometric Transducers- Transducers assess electrical conductivity during biological reactions. They are less typically utilized in biosensors, especially for enzyme-based recognition. However, they should not be dismissed while detecting affine interaction [13]

Impedimetric Transducers- These devices measure an electrochemical cell's impedance and how it changes with alternating current frequency. Transducers built with field-effect transistors. Ion-sensitive silicon field-effect transistor systems are like potentiometric systems, with the exception that the high-resistance voltmeter's input transistor is transposed into the solution under analysis. This significantly improves the transducer's resolving power, increasing biosensor sensitivity. The bio sensitive layer is often applied directly to an ion-sensitive membrane as part of the field-effect transistor gate. Biologically modified ion-selective field-effect transistors enable direct detection of tiny peptides and proteins characteristics charge [22].

Transducers built with Field-Effect Transistors (FETs) – Ion-sensitive silicon field-effect transistor systems are like potentiometric systems, with the exception that the high-resistance voltmeter's input transistor is transposed into the solution under analysis. [14]. This significantly improves the transducer's resolving power, increasing biosensor sensitivity. [15]. The bio sensitive layer is often applied directly to an ion-sensitive membrane as part of the field-effect transistor gate. [16]. Biologically modified ion-selective field-effect transistors enable direct detection of tiny peptides and proteins characteristics charge. [17].

Optical transducers- Optical transducers may use absorption, fluorescence, luminescence, internal reflection, surface plasmon resonance, or light scattering spectroscopy. For instance, a localized immunosensor. The interaction involves antibodies and antigens. Antibodies in blood can indicate infection or toxicity from specific chemicals. Antigens can be detected in several media, including the natural environment. Immunosensors with antibodies can detect almost any molecule with great specificity and selective [26].

Table 1. Biosensors for the identification of various contaminants in Food Products:

Type of Sensor	Contaminant	Food Items	Detection Limit	Consuming Times
• ***Optical Biosensor***				
Chemiluminescence	*Listeria monocytogenes*	Milk	1.1log CFU/mL	40 min.
Colorimetric	*Cronobacter sakazakii*	Powdered Milk	3.85log CFU/mL	30 min.
Surface Plasmon Resonance [SPR]	*Pseudomonas*	Water	7.09log CFU/mL	25 min.
Interferometric	*Escherichia coli*	Buffer	0.34log CFU/mL	2 hours
• ***Mechanical Biosensor***				
Multi- Channel Series Piezoelectric Guartz Crystal [MSPQC]	*Mycobacterium tuberculosis*	Buffer	1log CFU/mL	1 day
QCM	*Campylobacter jejuni*	Poultry	1.30log CFU/mL	30 min
Quartz Crystal Microbalance [QCM]	*Salmonella*	Milk	2log CFU/mL	10 min
• ***Electrochemical Biosensor***				
Impedimetric	*Salmonella Typhimurium*	Apple juice	0.47log CFU/mL	45 min

Amperometric	*Streptococcus agalactiae*	Fish	1-7log CFU/mL	90 min.
Photoelectrochemical Biosensor				
Visible- Light Photoelectrochemical Aptasensing	*Sulfadimethoxine*	Milk	0.55 nM	50 s
Tungsten Disulfide [WS2] Nanosheet- Based Photoelectrochemical	*Chloramphenol*	Milk Powder	3.6 pM	105 min
Electrochemical Chemiluminescence				
Aptamer- Based ECL Sensor	*Escherichia coli*	Luria-Bertsani Broth	0.17 CFU/mL	40min
ECL Immunosensor	*Vibrio parahaemolyticus*	Seafood	0.69log CFU/mL	1hour
Paper based aptasens	*Organophosphate pesticides*	Fruits, Vegetables	0.1ng/mL	5-10 min
Smartphone-integrated Biosensor	*Aflatoxin B1*	Nuts, grains	1 ppb	15 min

DNA SENSOR

A DNA biosensor includes a nucleic acid probe or aptamer, which can bind specifically to its complementary DNA or RNA target [18]. DNA Sensors' biological components include nucleic acids (DNA). DNA probes or primers are often fragments of live organisms, rather than isolated components. They are chosen to accurately represent the DNA structure. It may also use DNA enzymes that produce a signal upon interaction [20]. These things include regulatory proteins, tumour indicators that damage DNA, and anti-cancer medications. These biosensors are valuable for detecting pathogens, genetically modified organisms (GMOs), and allergen DNA in food [21]. They are fast, label-free, and enable direct and highly specific recognition of target sequences [22].

MICROBIAL BIOSENSORS

Microbial biosensors use whole microbial cells as biorecognition elements. These living cells can detect a variety of analytes due to their natural metabolic activity [23]. Typically, the cells are immobilized on transducers to convert biological reactions into readable signals. They are slower than enzyme-based biosensors but offer excellent stability and lower cost. All microbial biosensors separate the biological component from the recording equipment [25]. Microorganisms respond slowly to changes in the medium's chemical composition, unlike enzymes or antibodies. This is due to matter transfer across a bio membrane. To achieve a higher concentration of living cells than the transducer's design allows, further measures must be taken [26]. A microbial biosensor can be a columnar or membrane reactor, or a suspension of microorganisms with an immersed sensor. Microbial biosensors are used in water testing, biochemical oxygen demand (BOD) measurements, and detection of toxins or heavy metals [27].

Thermometric transducers

Thermal biosensors work on the principle that many biochemical reactions release or absorb heat [28]. Thermal biosensors are rather uncommon. Biochemical elements can be mixed with various transducers to create diverse biosensors. Up to 80% of biosensors are electrochemical, also known as enzyme electrodes, immunosensors, and DNA sensors. Biosensors use recognition elements, which are biological entities capable of distinguishing between many substrates. This criterion is supplied by four entities: enzymes, antibodies, nucleic acids and receptors. They use thermistors to measure these changes, giving an indication of reaction activity [29]. Although not widely used in the food industry, they are effective in monitoring enzyme kinetics and metabolic activities. [30]

Enzymatic sensors- Enzymatic biosensors are some of the oldest and most reliable biosensors in food safety [31]. They use enzymes that specifically catalyze reactions involving the analyte of interest [32]. The simplest enzymatic biosensor design involves using electrochemically active substrates or products that may be promptly and reversibly oxidized or reduced on an electrode with a suitable voltage. Substrate-based biosensors monitor target compound conversion (like glucose), while inhibitor-based biosensors detect substances that interfere with enzymatic reactions (like pesticides). They are commonly used in fermentation control and food quality monitoring [34]. Enzymatic sensors are classified as substrate or inhibitor, depending on their function. Substrate biosensors identify specific substrates in enzymatic processes.

Determination utilizing Examples include glucose urease sensor is used for enzymatic and urea determination. Inhibitor sensors detect chemicals that reduce the activity of enzymes. An example is the identification of organic phosphate insecticides that inhibit acetylcholine breakdown by acetylcholinesterase. The most used enzymatic biosensors are glucose and urea biosensors.

Immunosensors- Immunosensors utilize the specific interaction between an antibody and its antigen [35]. These biosensors can detect toxins, viruses, allergens, and pathogens with high specificity. Immunoglobulin, proteins released by an organism's immune system in reaction to foreign chemicals (antigens), serve as a biochemical receptor. Immunoglobulins (antibodies) form strong complexes with antigens. Immunosensors detect participants in immunochemical reactions. They are extremely sensitive and ideal for use in food safety, clinical diagnostics, and environmental testing [37]. Depending on the transducer type, immunosensors can be optical, electrochemical, or piezoelectric [38]. Toxin detection technologies often rely on inhibiting luciferase, a microbial enzyme that produces light during oxidation.

Microbial sensors can also be used to study the impact of chemicals on cells, providing a model for multicellular organisms. Biosensors are used in toxicological investigations to determine the median fatal concentration of toxicants, as well as to optimize antibiotic doses and antimicrobial and antifungal additives for paints and finishes. Microbial biosensors are used to assess the health of natural microorganisms, including monitoring the effectiveness of biological wastewater treatment systems.

APPLICATION OF BIOSENSORS: -

Biosensors have been used in a variety of industries, including the food industry, the medical field, and the marine sector, and they offer greater stability and sensitivity than traditional approaches [5].

1. **In Food processing, monitoring, food authenticity, quality, and safety-**
   Biosensors play a key role in food safety monitoring by detecting contaminants, spoilage, toxins, and adulterants in raw and processed foods [39]. They enable real-time, on-site, and high-sensitivity detection without the need for sophisticated lab infrastructure [40]. Enzyme-based biosensors are used for freshness detection, such as measuring glucose, ethanol, or peroxide in food samples [41]. Additionally, biosensors support food authentication, ensuring that ingredients match product labels and quality standards [42].

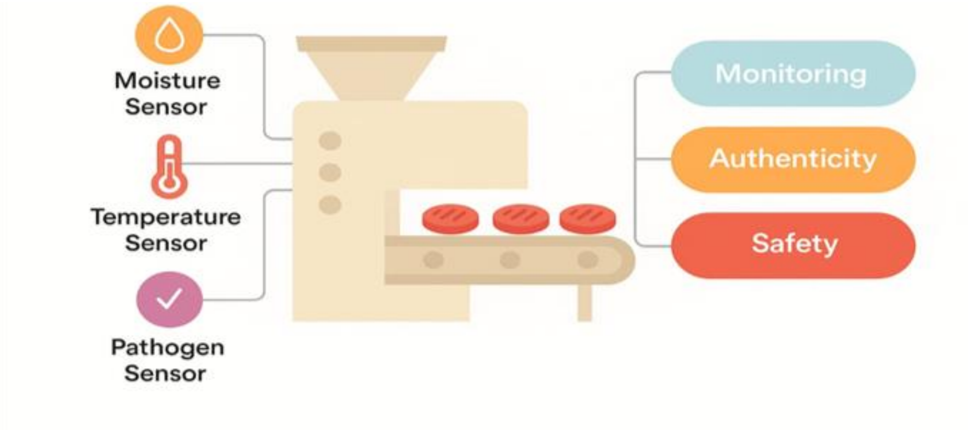


Fig.1. Biosensors in Food processing, Monitoring, Authenticity, Quality and Safety.

2. In Fermentation process-

Glucose biosensors have been integrated into industrial fermentation systems to monitor sugar levels and optimize yield. They ensure controlled fermentation in processes like brewing, yogurt, and vinegar production [43]. Monitoring of metabolites like ethanol and lactic acid through biosensors helps maintain product consistency and safety [4].

In the fermentation industry, process safety and product quality are critical. Thus, accurate monitoring of the fermentation process is critical for developing, optimizing, and maintaining biological reactors at peak efficiency. During the fermentation process, saccharification was monitored using the classic Fehling method.

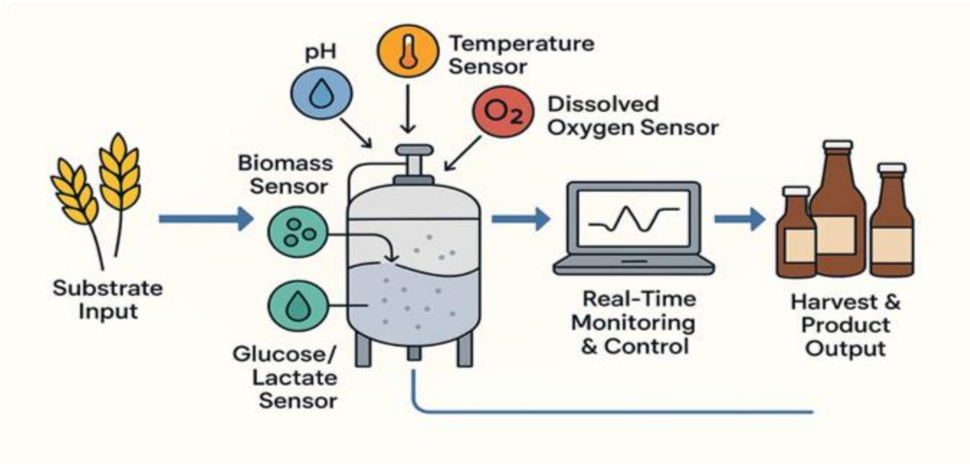


Fig.2. Role of Biosensors in Fermentation process

3. In Medical field-

Biosensors are widely used for clinical diagnostics and therapeutic monitoring. Glucose biosensors for diabetes management account for the majority of the biosensor market globally. In addition, biosensors detect cancer biomarkers, urinary tract infections, infectious diseases, and sepsis [44]. They are also embedded in portable and wearable medical devices to enable real-time patient health tracking [45].

Biosensors are finding new uses in medical science. Glucose biosensors are commonly employed in clinical settings to diagnose diabetes mellitus, which necessitates precise monitoring of blood glucose levels. Biosensor's uses in medical science are fast expanding. Glucose biosensors are frequently used in clinical applications to diagnose diabetes mellitus, which necessitates careful management of blood glucose levels. Biosensors are widely utilized in the medical field to detect infectious infections.

4. Fluorescent biosensor-

Fluorescent biosensors use fluorophores like GFP or fluorescent dyes to report molecular interactions, ion concentrations, or analyte presence. These are applied in disease diagnosis, drug screening, and imaging of metabolic processes [46]. Fluorescent biosensors are used in drug discovery programs to identify medicines using high throughput, high content screening methodologies, as well as for post screening hit analysis and lead optimization. Fluorescent biosensors are effectively employed for early detection of biomarkers in molecular and clinical diagnostics, for monitoring disease progression and response to treatment/therapeutics, for intravital imaging and image guided surgery.

FRET-based biosensors allow detection of conformational changes in proteins or enzyme-substrate interactions in live cells [47].

5. In metabolic engineering-

Biosensors are used in synthetic biology and metabolic engineering to identify strains producing target compounds. Earlier approaches used spectroscopy-based enzymatic assay analytics, but they had restricted throughput. Transcription factor-based biosensors detect the intracellular concentration of a specific metabolite and trigger expression of reporter genes [48]. Transcription factors are natural sensory proteins that have evolved to regulate gene expression in response to environmental changes, allowing for high-throughput screening. It is performed by breaking into the host transcription system and using a synthetic condition-specific promoter to trigger the production of a reporter gene. This helps in the selection of high-yield microbes for biofuel, pharmaceutical, and food production [49].

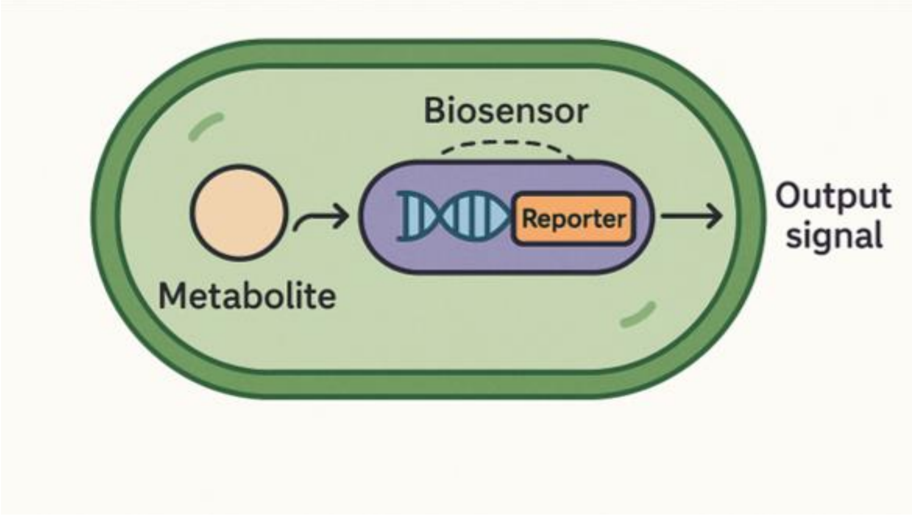


Fig.3. Biosensors in Metabolic Engineering.

6. Biosensing technology for sustainable food safety-

Food safety is an essential component of public health, requiring rapid and reliable tools for contaminant detection [50]. Biosensors offer powerful solutions to identify biological and chemical threats in food through specific, sensitive, and fast responses [51]. They help detect foodborne pathogens, pesticides, antibiotics, and heavy metals at very low concentrations [52]. Sustainable biosensing technology combines sensitivity with environmental responsibility, using biodegradable materials, miniaturized designs, and portable formats [53]. Smart packaging equipped with biosensors can detect spoilage or contamination in real-time, reducing food waste [56].

7. Biodefense biosensing applications-

Biosensors are crucial in national security for detecting biowarfare agents such as viruses, toxins, and bacteria. Biosensors can be utilized for military purposes in the event of biological assaults. The primary goal of such biosensors is to detect and selectively identify organisms posing a threat in real time known as biowarfare agents (BWAs), which include bacteria (vegetative and spores), poisons and viruses. Their ability to rapidly detect harmful biological materials makes them ideal for military, public health, and border applications [54]. Unlike traditional laboratory methods, biosensors provide immediate results on-site, reducing response time in emergencies. DNA-based biosensors have shown superior sensitivity for identifying threats like anthrax, ricin, and botulinum toxin [55].

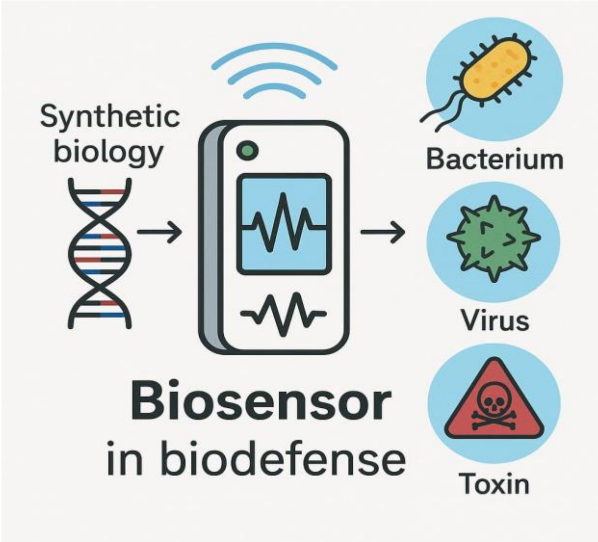


Fig.4. Biosensors in Biodefense.

8. Biosensors in plant biology-

Plant science has advanced thanks to revolutionary new technologies such as DNA sequencing and molecular imaging. Traditional mass spectroscopy methods for determining cellular and subcellular localization, as well as measuring ion and metabolite levels, offered exceptional precision, but lacked crucial information about the position and dynamics of enzyme substrates, receptors, and transporters.

In plant biology, biosensors enable monitoring of intracellular signals, nutrient status, and metabolite dynamics without damaging the tissue. FRET-based biosensors have been applied to track sugar and ion transport between cells [57]. They provide precise data on plant responses to drought, heat, and nutrient deficiencies, supporting genetic improvements [58]. These biosensors are used to develop stress-tolerant crop varieties and optimize fertilizer use [59].

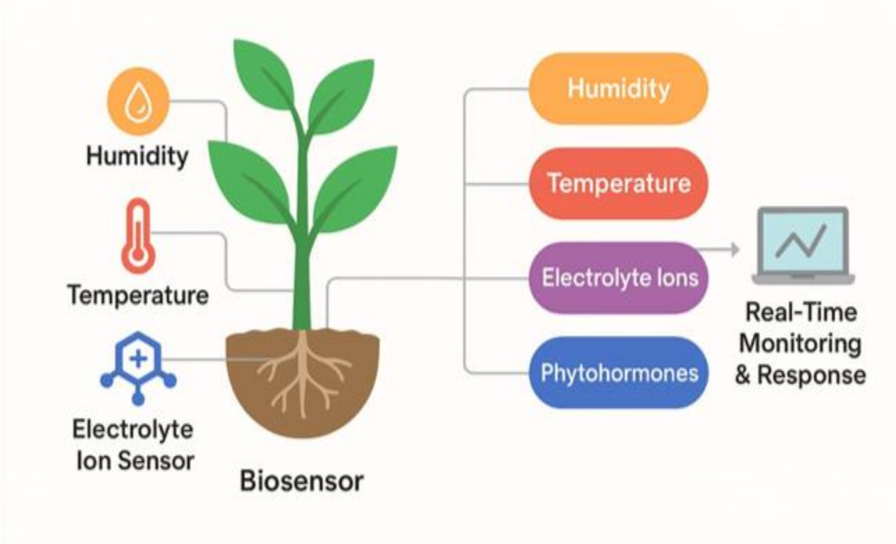
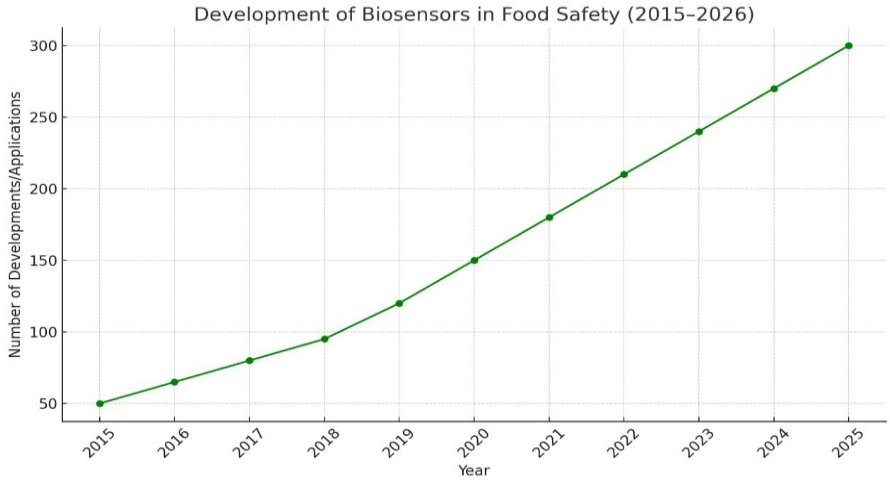


Fig. 5. Biosensors in Plant Biology.



Graph 1.1. Development of biosensors in food safety (2015-2026):

- The graph illustrated the remarkable growth in biosensors tech ology applications within food safety from 2015-2026. Starting at 50 developments in 2015, the field has grown steadily, reaching an estimated 300 by 2026. This upward trend highlights increasing global emphasis on rapid, non- invasive, and eco-friendly detection methods. Technological advancements in nanomaterials, fluorescence systems, and portable diagnostics have played a pivotal role in shaping this progress, reinforcing biosensing as a cornerstone of sustainable food safety solutions.

FUTURE SCOPE OF BIOSENSOR:

Biosensor technology is evolving rapidly and expanding into domains like marine biology, smart agriculture, wearable health monitors, and environmental remediation [4]. In marine systems, biosensors detect algal toxins, nitrate levels, and heavy metals, ensuring ecological balance [60]. Agricultural applications include soil nutrient monitoring, pest control alerts, and automated irrigation systems [61]. One of the primary goals is to detect pollutants, heavy metals, and pesticides using biosensors. Sensors can monitor raw materials, trace compounds, sugars, alcohols, amino acids, vitamins, taste additives, and pollutants such as antibiotics, bacteria, enzymes, and toxins. Beer, wine, bread, and some dairy products require controlled microbial growth conditions. Biosensors can monitor component and microbe levels to manage similar activities on a continuous or periodic basis.

Future biosensors will likely integrate with AI, IoT, and cloud technologies to deliver predictive analytics and remote diagnostics [62]. The continued development of flexible, low-cost, and smartphone-integrated biosensors will make personalized and public health surveillance more accessible [63].

REFERENCES

1. Choudhary A, Gupta N, Hameed F, & Choton S. An overview of food adulteration: Concept, sources, impact, challenges and detection. *International Journal of Chemical Studies* 2020; *8*(1): 2564–2573.

2. Korotkaya E. v. Biosensors: Design, classification, and applications in the food industry. *Foods and Raw Materials* 2014; *2*(2): 161–171.

3. Banti M. Food Adulteration and Some Methods of Detection, Review. *International Journal of Nutrition and Food Sciences* 2020; *9*(3): 86.

4. Schaertel B. J, & Firstenberg-Eden R. Biosensors in the food industry: present and future. *Journal of food protection* 1988; *51*(10): 811-820.

5. Mehrotra P. Biosensors and their applications - A review. In *Journal of Oral Biology and Craniofacial Research* 2016; (Vol. 6, Issue 2: pp. 153–159). Elsevier B.V.

6. Ali A. A, Altemimi A. B, Alhelfi N, & Ibrahim, S. A. Application of biosensors for detection of pathogenic food bacteria: a review. *Biosensors* 2020; *10*(6): 58.

7. Akyilmaz E, Yorganci E, & Asav E. Do copper ions activate tyrosinase enzyme? A biosensor model for the solution. *Bioelectrochemistry* 2010; *78*(2): 155-160.

8. Thévenot D. R, Toth K, Durst R. A, & Wilson G. S. Electrochemical biosensors: recommended definitions and classification. *Analytical Letters* 2001; *34*(5): 635-659.

9. Sankarankutty K. M. Biosensors and their applications for ensuring food safety. *Global J Pathol Microbiol* 2014; (*2)*: 15-21.

10. Mishra R. K, Dominguez R. B, Bhand S, Muñoz R, & Marty J. L. A novel automated flow-based biosensor for the determination of organophosphate. 2012.

11. Momtaz M, Bubli S. Y, & Khan, M. S. 2023. Mechanisms and Health Aspects of Food Adulteration: A Comprehensive Review. In *Foods* 2023; (Vol. 12: Issue 1). MDPI. https://doi.org/10.3390/foods12010199

12. Abalea V, Cillard J, Dubos MP, Sergent O, Cillard P, Morel I. Free Rad Bio Med. 1999); 26:1457.

13. Blackburn G. F. Chemically sensitive field effect transistors. *Biosensors: fundamentals and applications* 1987; 481-530.

14. Faour-Klingbeil D, & CD Todd E. Prevention and control of foodborne diseases in Middle-East North African countries: Review of national control systems. *International Journal of Environmental Research and Public Health* 2020; *17*(1): 70.

15. Agrawal A, Tripp R. A, Anderson L. J, & Nie S. Real-time detection of virus particles and viral protein expression with two-colour nanoparticle probes. *Journal of virology* 2005. *79*(13): 8625-8628.

16. Alocilja E. C, & Radke S. M. Market analysis of biosensors for food safety. *Biosensors and Bioelectronics* 2003; *18*(5–6): 841–846.

17. Arora P, Sindhu A, Dilbaghi N, & Chaudhury A. Biosensors as innovative tools for the detection of food borne pathogens. *Biosensors and Bioelectronics* 2011; *28*(1): 1-12.

18. Aruoma O. I. The impact of food regulation on the food supply chain. *Toxicology* 2006 ;*221*(1): 119-127.

19. Ayza A, & Belete E. *Food Adulteration: Its Challenges and Impacts* 2015; *41*. www.iiste.org

20. Bansal S, Singh A, Mangal M, Mangal, A. K, & Kumar S. Food adulteration: Sources, health risks, and detection methods. *Critical Reviews in Food Science and Nutrition* 2017; *57*(6): 1174–1189. https://doi.org/10.1080/10408398.2014.967834

21. Belkin S. Microbial whole-cell sensing systems of environmental pollutants. *Current opinion in microbiology* 2003; *6*(3): 206-212.

22. Bergveld P. The development and application of FET-based biosensors. *Biosensors* 1986; *2*(1): 15-33.

23. Blackburn G. F. Chemically sensitive field effect transistors. *Biosensors: fundamentals and applications* 1987; 481-530.

24. Jia C, & Jukes D. The national food safety control system of China–a systematic review. *Food control* 2013; *32*(1): 236-245.

25. Cavalcanti A, Shirinzadeh B, Zhang M, & Kretly L. C. Nanorobot hardware architecture for medical defense *Sensors* 2008; *8*(5): 2932-2958.

26. O'Connell P. J, O'Sullivan, C. K, & Guilbault G. G. Biosensors for food analysis. *Irish Journal of Agricultural and Food Research* 2000;321-329.

27. Dhiman, B, & Singh, M. Molecular detection of cashew husk (Anacardium occidentale) adulteration in market samples of dry tea (Camellia sinensis). *Planta medica* 2003; *69*(09): 882-884.

28. Di Stefano V, Avellone G, Bongiorno D, Cunsolo V, Muccilli V, Sforza S, & Vékey K. Applications of liquid chromatography–mass spectrometry for food analysis. *Journal of Chromatography A* 2012; *1259*: 74-85.

29. Eed H. R, Abdel-Kader, N. S, El Tahan, M. H, Dai, T, & Amin, R. Bioluminescence-Sensing Assay for Microbial Growth Recognition. *Journal of Sensors*, *2016;* (1): 1492467.

30. Erhun W.O. Ask your pharmacist. Nigerian Journal of Pharmacy 1992; 23(3):13-18.

31. European Food Safety Authority. (2011). Use of the EFSA comprehensive European food consumption database in exposure assessment. *EFSA journal* (2011); *9*(3): 2097.

32. FSAAI, 2011. National Survey in India of Adulteration in Liquid Milk. <http://www.fssai.gov.in/Portals/0/Pdf/sample_analysed(02-01-2012).pdf> (accessed 23.04.2013).

33. Ganjavi M. *Characterization of luminous bacteria as a biosensing element for detection of acrylamide in food* (Doctoral dissertation, University of Maryland, College Park) 2014.

34. Giardi M. T, Koblížek M, & Masojídek, J. Photosystem II-based biosensors for the detection of pollutants. *Biosensors and Bioelectronics* 2001; *16*(9-12): 1027-1033.

35. Grumezescu A. M, & Holban, A. M. (Eds.). *Microbial contamination and food degradation* 2017; (Vol. 10): Academic Press.

36. Jain A, Martin MC, Parveen N, Khan NU, Parish JH, Hadi SM. Phytother Res 1999; 13:609

37. Kallenberg D, Tripathi V, Javaid F, Pilotti C, George J, Davis S, & Moss S. E. A humanized antibody against LRG1 that inhibits angiogenesis and reduces retinal vascular leakage. *BioRxiv* 2020; -07.

38. Larson E. L, Aiello A. E, Gomez-Duarte C, Lin S. X, Lee L, Della-Latta P, & Lindhardt C. Bioluminescence ATP monitoring as a surrogate marker for microbial load on hands and surfaces in the home. *Food microbiology* 2003; *20*(6): 735-739.

39. Law J. W. F, Ab Mutalib N. S, Chan K. G, & Lee L. H. Rapid methods for the detection of foodborne bacterial pathogens: principles, applications, advantages and limitations. *Frontiers in microbiology* 2015; *5*: 770.

40. Li L, Liang B, Li F, Shi J, Mascini M, Lang Q, & Li, A. Co-immobilization of glucose oxidase and xylose dehydrogenase displayed whole cell on multiwalled carbon nanotube nanocomposite films modified electrode for simultaneous voltammetric detection of D-glucose and D-xylose. *Biosensors and Bioelectronics* 2013; *42*: 156-162.

41. Manning L, & Soon J. M. Developing systems to control food adulteration. *Food Policy* 2014; *49*(P1): 23–32.

42. Maurer M, Burri S, De Marchi S, Hullin R, Martinelli M, Mohacsi P, & Hess O. M. Plasma homocysteine and cardiovascular risk in heart failure with and without cardiorenal syndrome. *International journal of cardiology* 2010; *141*(1): 32-38.

43. Molecular-genetic characteristics of bacteriophage Bacillus cereus FBC - 28 UGSKHA / N.A. Feoktistova D.A. Vasilev A.V. Mastilenko E.V. Suldina S.N. Zolotukhin A.L. Toigildin I.A. Toigildina A.V. Dozorov V.A. Isaichev I.L. Obukhov B.I. Shmorgun // Research Journal of Pharmaceutical, Biological and Chemical Sciences 2018; -V. 9. -№ 4. -P. 345-354.

44. Momtaz M, Bubli S. Y, & Khan M. S. Mechanisms and Health Aspects of Food Adulteration: A Comprehensive Review. In *Foods* 2023;(Vol. 12: Issue 1). MDPI. https://doi.org/10.3390/foods12010199

45. Murugaboopathi G, Parthasarathy V, Chellaram C, Anand T. P, & Vinurajkumar S. Applications of biosensors in food industry. In *Biosciences Biotechnology Research Asia* 2013; (Vol. 10: Issue 2, pp. 711–714). https://doi.org/10.13005/bbra/1185

46. Neethirajan S, Karunakaran C, & Jayas D. Biosensors—An Emerging Technology for the Agricultural and Food Industry. In *Proceedings of the CSAE/SCGR 2005 Meeting, Winnipeg, MB, Canada* 2005; (pp. 26-29).

47. Niinomi M. Recent metallic materials for biomedical applications. *Metallurgical and materials transactions A* 2002; *33*: 477-486.

48. Park Je-K, Yee H.-J, Lee K. S, Lee W.-Y, Shin M.-C, Kim T.-H, and Kim S.-R, *Analytica Chimica Acta* 1999; vol. 390: pp. 83–91.

49. Pérez-López B, & Merkoçi A. Nanomaterials based biosensors for food analysis applications. In *Trends in Food Science and Technology* 2011; (Vol. 22: Issue 11, pp. 625–639). .

50. Rajapaksha P, Elbourne A. Gangadoo S. Brown R. Cozzolino D. Chapman J. A review of methods for the detection of pathogenic microorganisms. *Analyst* 2019; *144*: 396–411.

51. Zhang J, Wang L, Pan, D, Song S, Boey F. Y, Zhang H, & Fan C. Visual cocaine detection with gold nanoparticles and rationally engineered aptamer structures. *Small* 2008; *4*(8): 1196-1200.

52. Rechnitz G. A. Biochemical electrodes use tissues slice. *Chem Eng News* 1978; *56*: 16-21.

53. Saini R. V, Vaid P, Saini N. K, Siwal S. S, Gupta V. K, Thakur V. K, & Saini A. K. Recent advancements in the technologies detecting food spoiling agents. *Journal of functional biomaterials* 2021; *12*(4): 67.

54. Scognamiglio V, Arduini F. A. B. I. A. N. A, Palleschi G. I. U. S. E. P. P. E, & Rea G. Biosensing technology for sustainable food safety. *TrAC Trends in Analytical Chemistry* 2014; *62*: 1-10.

55. Selzer S. M, Colomer J. P, Arriaga M. E, Ferreyra N. F, & Vico R. V. One-Pot Strategy for Conjugation of Amine-Covered Iron Oxide Nanoparticles with Carbohydrates: A Sustainable Alternative. *ACS Sustainable Chemistry & Engineering* 2024; *12*(32): 11928-11939.

56. Shigella phages isolated during a dysentery outbreak reveal uncommon structures and broad species diversity/ S.M. Doore, J.R. Schrad, W.F. Dean, J. Dover, K.N. Parent // J. Virol 2018; Vol. 92: P. 02117-17 DOI: 10.1128/JVI.02117-17

57. Shukla S, Shankar R, & Singh S. P. Food safety regulatory model in India. *Food Control*2014; *37*: 401-413.

58. Tipu M. S, Altaf I, Ashfaq M, & Siddique S. Monitoring of chemical adulterants and hygienic status of market milk. *Quality Control Laboratory, University of Veterinary and Animal Sciences* 2007;

59. Turner A, Karube I, & Wilson G. S. *Biosensors: fundamentals and applications*. Oxford university press 1987;

60. Qiao Z, Fu Y, Lei C, Li Y. Advances in antimicrobial peptides-based biosensing methods for detection of foodborne pathogens: A review. *Food Control* 2020; 107116

61. Holmberg S. D, & Blake P. A. Staphylococcal food poisoning in the United States: new facts and old misconceptions. *Jama* 1984; *251*(4): 487-489.

62. Voeller J. G. (Ed.). *Food Safety and food security*. John Wiley & Sons 2014;

63. Watanabe H, Humio, I, and Hastings, W.J, *Arch. Microbiol*, 1991; vol. 156: no. 1, pp. 1–4.

Application of Bio sensors in detecting Food contaminants: A comprehensive review

Plot no 977, GMS Road, near Balliwala Flyover, opposite Cubic Plaza, Dehradun, Uttarakhand 248001

admin@reboin.com

www.rebioin.com