# Advances in Food Biosensors

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**1. INTRODUCTION:**

With the advancements in food industry, in recent years the food industry has been dominated by the use of a wide array of biosensors. The diversifying applications of biosensors in various sectors including environment, clinical diagnostics, drug development, food processing, quality control and safety standards has proved it to be an important tool in several industries (Bănică, and Gabriel, 2012). Biosensorsare analytical devices destined for detecting chemical substances or biological entities bycombining a biological component with a physicochemical detector. The biological component used in biosensors may be an enzyme, an antibody, a nucleic acid, or any other biologically derived material which interacts with the target molecule. This interaction is then transformed by a transducer into a measurable signal, such as optical, electrochemical, or electronic, allowing for the detection and quantification of the target molecule. In the food industry, they are used to analyze nutrients, detect toxins, monitor food processing, and ensure food safety and quality. The continuous technical advancements in biosensors have led to improved efficiency and cost-effectiveness in various analytical applications (Bankole et al, 2022).

Biosensors have brought about an analytical revolution to address the problems facing the food and agriculture industries. Recent advances in biosensors used in the food industry have led to the development of more efficient and cost-effective methods for detecting contaminants, verifying product contents, monitoring raw materials conversion, and ensuring food safety and quality. Biosensors have been employed to analyze nutrients, detect natural toxins and anti-nutrients, monitor food processing, and detect genetically modified organisms (Murugabopathi et al, 2013; Lim and Ahmed, 2017). Enzyme based biosensors are mainly used in the liquor and beverage industry for detecting or measuring carbohydrates from alcohol, amino acids, amines, amides, phenol, etc. Both enzymatic and immunogenic reaction based biosensors can be used to determine the level of pesticides, antibiotics, proteins, vitamins B-complex and fatty acids found in food (Lim and Ahmed, 2017). Biosensors can even detect microorganisms through direct and indirect detection methods for optical biosensors are used for the direct detection of bacteria in food products. Recent researches leading to technical advancements in biosensors have fostered the low manufacturing costs, enhanced food quality and increased customer safety. The major advantages of biosensors over conventional analytical techniques are broad applicability, stability, ease of modification, reusability, and miniaturization (Murugabopathi et al, 2013).

The use of biosensors in the food industry is predicted to grow steadily as robust analytical tools for quick onsite and remote analysis (Lim and Ahmed, 2017).

## 2. DESIRABLE QUALITIES OF A FOOD BIOSENSOR

The efficiency and quality of a food biosensor may be defined on the basis of some parameters which are discussed below-

**Sensitivity:** The detection of the target analyte should be in measureable range and must not require any additional steps such as pre-cleaning or pre-concentration.

**Specificity:** Specificityof a biosensor refers that a biosensor must be selective for a target analyte molecule showing least or no cross-reactivity with other chemical entities having similar structures.

**Linearity:** The linear response range of the system should include the concentration range over which the target analyte is measurable.

**Short Response Time:** The device must be fast enough to monitor the target molecules in real-time samples.

**Recovery:** Like the response time, the recovery time of the biosensor should be short enough for effective reusability

**Reproducibility:** The biosensor device should be reproducible to avoid any discrepancies in the result. Repeated analysis of the samples having same concentrations should generate same signal intensity or magnitude.

**Stablity:** It is necessary that the response signal of the biosensor device should be stable for real-time monitoring of the target analyte. Also, the components of the biosensor device should be resistant to deterioration throughout the operating period. Most of the biological components are unstable in different biochemical conditions (Lee and Reilly, 2011).

Theoverall experimental performance of a biosensor is mainly based on its sensitivity, limit of detection, linear range, reproducibility, selectivity, interference response, response time, easy operation, portability, storage, and operational stability (Lee and Reilly, 2011).

## 3. TYPES OF BIOSENSORS USED IN FOOD INDUSTRY

Biosensors used in the food industry can be categorized based on two things-

(A) Receptor Systems (Biological element) or

(B) Transducers Systems

The different types of receptors systems used are- Enzymatic, Immunologic and Cellular Biosensors.

**Enzymatic Biosensors:** The enzymatic biosensors utilize enzymes to catalyze specific reactions producing signals related to the concentration of the targeted compound (Schaertel and Eden, 1988).

**Immunological Biosensors:** The immunological biosensors are based on antibodies or immune receptors that recognize specific antigens, such as pathogens or allergens (Schaertel and Eden, 1988).

**Cellular Biosensors:** Cellular biosensors employ living cells or cell fragments capable of responding to specific analytes (Schaertel and Eden, 1988).

**(B) Transducer Systems:**

**Electrochemical:** Electrochemical system based biosensors convert the biochemical reaction into an electric signal/current or potential difference (Murugabopathi et al, 2013).

**Optical:**Biosensors based on optical transducers mainly detect the changes in light absorption, scattering, fluorescence, or luminescence (Murugabopathi et al, 2013).

**Mechanical:** Mechanical transducer systems measure changes in mass, thickness, or vibrational frequency (Murugabopathi et al, 2013).

**Thermometric:** Thermometric transducers monitor temperature variations associated with the biological reaction (Murugabopathi et al, 2013)

**Piezoelectric:** Piezoelectric transducers systems use crystals whose electrical properties depend on applied pressure or stress(Murugabopathi et al, 2013)

These biosensors play crucial roles in detecting contaminants, verifying product contents, monitoring raw materials conversion, and ensuring food safety and quality. Examples of biosensors used in the food industry include enzyme biosensors for detecting or measuring carbohydrates, amino acids, and phenols, as well as optical biosensors for direct detection of bacteria in food products.

### 3.1 Receptors or Biological element used in food biosensors

#### 3.1.1 Enzyme based bio-receptors

Enzymeshave unique property of enzyme specificity; their ability to specifically recognize a substrate and catalyze their specific conversion into product makes it a powerful analytical tool to be exploited in the fabrication of different biosensor devices. The particular region of the enzyme where the interaction between enzyme and substrate occurs is named as binding sites. It is due to the exclusive complementarity between the enzyme and its specific substrate for each other leading to the specific binding of an enzyme to its substrate at thebinding site of the enzyme (Justino et al, 2015). In this way, it is possible to determine the concentration of target analyte by measuring the product or the catalytic transformation by the enzyme. Another strategy involves the use of the fact that, enzymes are sometimes inhibited by the action of some enzyme inhibitors, the concentration of target analyte in correlation with the decrease in the magnitude of enzymatic product formed (Lim and Ahmed, 2017). Some of the enzymes extensively used in food biosensors are Glucose oxidase for glucose and sucrose detection, Invertase for sucrose detection, Fructose-5-dehydrogenase for Fructose detection, Galactose oxidase and Peroxidase for lactose detection, Glutamate oxidase for glutamate detection, Cholesterol oxidase for cholesterol detection, Alcohol dehydrogenase for ethanol detection, etc.

An important issue related to enzyme based biosensors is the immobilization of the enzyme on transducer surface. The immobilization strategy depends on various factors, as listed below-

- Enzyme must be stable in during the reaction
- The mechanical properties of the carrier should be considerably strong (Bouvier and Blum, 2010)
- The washing out of the unbound enzymes must not be disadvantageous to the immobilized enzyme
- The active site of the enzyme must be protected from other reagents forming cross-linking bonds

#### 3.1.2Antibody based bio-receptors

Antibody-based bio-receptors are widely utilized in biosensors for the food industry due to their high specificity and affinity toward target molecules. These antibodies can originate from either monoclonal or recombinant sources, offering superior control over their characteristics and production processes (Sharma et al, 2016).Polyclonal and monoclonal antibodies possess target specificity and affinity due to which they are primarily used in the bio-molecular recognition component of biosensors (Saerens et al, 2008). The use of monoclonal antibodies is more common in immunosensor studies because they are quite homogeneous in their molecular structure, have similar binding characteristics, and can be produced in large quantities (Dunbar and Skinner, 1990). Monoclonal antibodies also eliminate the problem associated with the density of binding sites that can be immobilized on the surface of the signal transducer due to the absence of serum proteins and other non-analyte-specific antibodies (Rogers, 1998).

#### 3.1.3 Nucleic acid based bio-receptors

Like enzymes and antibodies, nucleic acids are also used as bio-receptors in food biosensors. Nucleic acid-based biosensors utilize single-stranded DNA, RNA, peptide nucleic acid, or aptamers as biorecognition elements to detect specific nucleic acid sequences. These sensors convert the biorecognition events - which typically involve hybridization or conformation change upon binding - into a measurable signal through the use of a transducer (Hashkavayi and Raoof). The principles underlying nucleic acid-based biosensors rely on sequence complementarity, whereby a probe sequence is designed to bind specifically to a target sequence via Watson-Crick base pairing rules.

Nucleic acids containing single stranded oligonucleotides are immobilized onto the transducer surface in order to detect their target complementary sequence (Wang, 2000). For the attachment of aDNA probe to a transducer surface, different strategies are employed to ensure optimal probe orientation for the target recognition event. These strategies include straightforward adsorption on carbon surfaces, carbodiimide attachment to functional groups on carbon electrodes, thiolated DNA to form a self-assembly monolayer on a gold surface, biotylated DNA coupling with avidin or strepvadin, andthe use of functional alkanethiol-based monolayers for covalent attachment to a gold surface (Wang, 2001).Nowadays, engineered peptide and nuclei acid are paving new ways of nucleic acid recognition and impressive sequence specificity for DNA biosensors.

### 3.1.4 Whole cells as receptors

Whole-cell biosensors utilize living cells as the bio-recognition element in bio-sensing applications. These biosensors offer the unique advantage of providing functional information about the effect of a stimulus on a living system, which is particularly valuable in applications such as pharmacology, cell biology, toxicology, and environmental measurements(Feller, 2021).Thistype of biosensors exploits the ability of the microorganisms to identify and respond to a number of stimuli (Su et al., 2011). Microbial metabolic products such as protons and ammonia liberated during metabolic processes can also be detected and converted to an electronic signal by a transducer.Whole-cell based biosensors might be used to observe changes in the vicinity of the cells by examining their electrical properties. This makes them a reliable tool for the detection of pathogens in food samples (Su et al., 2021).

## 4. Commercial biosensors used in food industry

In the past two decades, extensive work has been done in the field of biosensing. Still, there is a long way to go before the conventional methods are totally replaced by biosensors. The use of biosensors has gained success to a large extent in the field of biomedical and diagnostics market, yet their potential in the sector of food industries need to be evaluated and established more intensely. Commercial availability of many food biosensors are been recorded, which are used in the fish deterioration tracking, detection of E.coli and Salmonella, detection of staphylococcal enterotoxin and botulinum toxin. Detection of protein, virus, bacteria, fungi, and mycotoxins, etc. Regardless of a lot of researches being done around the globe, commercial availability of biosensors for food sector, still remain limited.



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