Application of Biosensors in Food Fermentation

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Abstract

The application of biosensors in food fermentation processes has revolutionized the monitoring and control of microbial activity, ensuring improved quality, safety, and efficiency in food production. Biosensors offer rapid, real-time, and specific detection of various biochemical parameters such as pH, sugar content, alcohol levels, and microbial metabolites. These devices combine biological recognition elements with transducers to convert biochemical signals into measurable outputs, enabling precise control of fermentation stages. Their integration into fermentation systems allows for automation, reduction of human error, and enhancement of product consistency. Moreover, biosensors play a crucial role in detecting contamination and spoilage early in the process, thereby ensuring food safety. This abstract highlights the growing significance of biosensor technology in modern food industries, particularly in the fermentation of dairy, alcoholic beverages, and traditional fermented products. The continued advancement of biosensor design and functionality promises a future of smarter, more sustainable food processing methods.

1. Introduction

Food types are raw, processed, or prepared substances that people or other living things take orally for various reasons, such as growth, wellbeing, satisfaction, joy, and gratification of social needs. Food protection is a practise or a tactic for maintaining food types at the appropriate level of qualities or nature for their greatest benefits. The properties of food are generally influenced by each phase of care, handling, storage, and distribution, which may or may not be pleasant. Understanding how each protection approach affects food sources and how to take care of them is essential for handling food that results in protected food (Rahman 2007). Keeping an eye on the health and wholesomeness of food is crucial. There is a requirement to develop quick, delicate, and reliable procedures for swiftly monitoring food quality and security because the conventional logical techniques for quality and wellbeing

investigations are really dull, laborious, and demand prepared individuals. In this context, a biosensor is a good alternative to the conventional methods.

Because of their speed, specificity, ease of mass production, cost, and applicability in specific fields, biosensor devices are emerging as one of the most important analytical tools for food, clinical, and environmental testing. They derive their uniqueness from the natural limiting response, which is brought about by a variety of interactions, including those between an antigen and its counteracting agent, a protein and a substrate or cofactor, a receptor and a ligand, compound interactions, and nucleic acid corrosive hybridization in combination with a variety of transducers. The current study illustrates a few applications for biosensors in food processing and security.

1. Biosensor

It is defined as a quantitative or semiquantitative logical instrumental technique that incorporates a natural-source detection component that is either built into or in close proximity to a physicochemical transducer (Turner et al. 1987). A synthetic sensor is a device that transforms compound data into a scientifically useful signal by centralising one specific example portion to doing an extensive organisation analysis. Typically, synthetic sensors consist of a physicochemical transducer and a compound (sub-atomic) acknowledgment system (receptor), which are connected in series. Moreover, biosensors are artificial sensors in which the acknowledgement framework connects the optoelectronic framework using a biochemical tool (Cammann 1977; Turner et al. 1987). a device that distinguishes material compounds typically using electrical, thermal, or optical signals by using specific biochemical reactions mediated by tissues, organelles, immune systems, or entire cells (Nic et al. 2006).

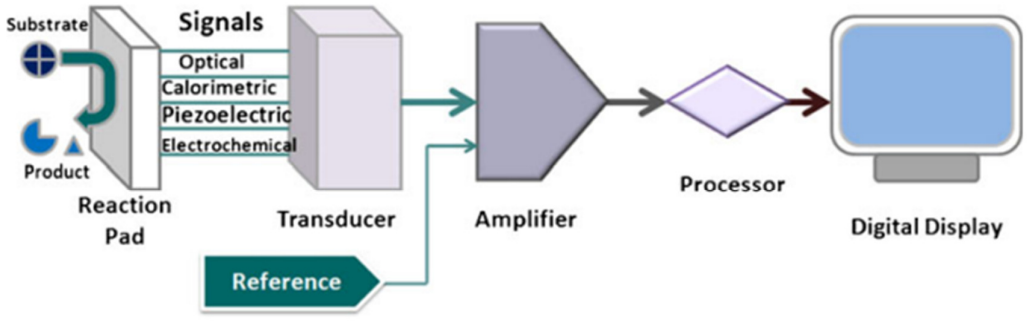

Fig. 1 Schematic representation of biosensor components

Prerequisites for a biosensor

The following conditions must be met in order to develop a biosensor framework that will be successful and appropriate for use in industry.

1. **Selectivity**: The biosensor gadget ought to be profoundly specific for the target analyte and demonstrate least or no cross reactivity with moieties having comparable substance structure.
2. **Sensitivity:** The biosensor device should be able to measure within the range of interest for a specific objective analyte with the least number of further advancements, such as precleaning and recentralization of the samples.
3. **Linearity of response:** The concentration range over which the target analyte is to be tested should be covered by the system's linear response range.
4. **Reproducibility of signal response:** The results of many analyses of samples with the same concentrations should be consistent.
5. **Quick response time and recovery time:** The response time of the biosensor device should be quick enough to allow for effective real-time monitoring of the target analyte. For the biosensor system to be reused, the recovery time must be brief.
6. **Stability and operating life:** Because of this, the majority of biological molecules are unstable under various biochemical and environmental circumstances. In order to make the gadget marketable and realistically effective in the field, the biological element employed should be interfaced such that the activity is retained for a long period.

Working principle

The basic operation of a biosensor is explained here. The transducer which makes advantage of a physical change that comes along with the reaction, is the essential part of a biosensor. This may be

- The reaction's emission (or absorption) of heat (Calorimetric biosensors)
- modifications to electrical or electronic output (Electrochemical biosensors)
- Redox response (Amperometric biosensors)
- Depending on the mass of the reactants or products (Piezo-electric biosensors) or the difference in light output or light absorption between the reactants and products (Optical biosensors).

The transducer's electrical signal is frequently erratic and noisy. A "reference" baseline signal produced from a transducer with a similar signal but no bio catalytic membrane should be utilised to improve the signal to noise ratio. The signal difference is incredibly small and

amplified as a legible output. The signal's undesirable noise is eliminated via the aforementioned technique. An amplifier produces an analogue signal, which is often transformed to a digital signal and sent to a microprocessor. The information is processed, transformed into concentration units, and output to a display or data repository (Chaplin 2004).

3. Historical Developments

First generation enzyme sensors

The study on biosensors is credited to Leland Charles Clark Jr. His initial work on the electrode to measure blood oxygen levels appeared in 1956. (Clark 1956). In 1962, he discussed "how to make electrochemical sensors (pH, polarographic, potentiometric, or conductometric) smarter" by include "enzyme transducers as membrane encased sandwiches" in his talk at a symposium hosted by the New York Academy of Sciences. An experiment that used a dialysis membrane to trap glucose oxidase at a Clark oxygen electrode served as an illustration of the model. As glucose concentration rose, so did the measured oxygen concentration. (1962, Clark and Lyons). The work of Clark was expanded upon by Updike and Hicks in 1967, and they developed the first working enzyme electrode based on glucose oxidase mounted on an oxygen sensor. In vitro glucose measurements were made in biological fluids and tissues (Updike and Hicks 1967). The first potentiometric enzyme electrode was introduced by Guilbault and Montalvo in 1970. It was an ammonium (NH_4^+) selective liquid membrane electrode-based urea-sensor, according to Guilbault and Montalvo in 1970. A glucose and lactate enzyme sensor based on hydrogen peroxide detection at a platinum electrode was first described by Guilbault and Lubrano in 1973. (Guilbault and Lubrano 1973). A heat-sensitive enzyme sensor known as a "thermistor" was created by Klaus Mosbach in 1974. (Mosbach and Danielsson 1974).

With the successful re-launch (original launch 1973) of the Yellow Springs Instrument Company's glucose analyser based on the Amperometric detection of hydrogen peroxide, Clark's concepts became a commercial reality in 1975. When Divis proposed that bacteria may be used as the biological element in microbial electrodes for the measurement of alcohol in 1975, the biosensor experienced another novel evolutionary step (Divis 1975). The term "optode" was first used in 1975 by Lubbers and Opitz to refer to a fiber-optic sensor that measures carbon dioxide or oxygen (Lubbers and Optiz. 1975). They expanded the idea by paralysing alcohol oxidase on the end of a fiber-optic oxygen sensor to create an optical

biosensor for alcohol.

Second generation enzyme sensors

A bedside artificial pancreas with an electrochemical glucose biosensor was built by Clemens et al. in 1976, and Miles later sold it as the Bio-stator. Notwithstanding the Bio-commercial stator's unavailability, VIA Medical unveiled a cutting-edge, catheter-based semi-continuous blood glucose analyzer. Later in 1976, La Roche (Switzerland) released the Lactate Analyzer LA 640, in which lactate dehydrogenase's electrons were transferred to an electrode using the soluble mediator hexacyanoferrate (Geyssant et al. 1985).

Third generation enzyme sensors

Based on the utilisation of electron mediators, third generation enzyme sensors resemble second generation enzyme sensors. Instead of freely diffusing mediators in the electrolyte, they have advanced to the point where they apply co-immobilized enzymes and mediators onto the same electrode. There was no need for a mediator or enzyme because there was a direct contact between the redox centre of the enzyme and the electrode. Recurrent measurements were thus made possible, which lowers the price of sensor design (Cass et al. 1984).

Liedberg employed the surface Plasmon resonance (SPR) technology in 1983 to continuously monitor affinity processes (Liedberg et al. 1983). Turner and his associates were there in 1984.

released a study on the use of ferrocene and its derivatives as immobilised mediators for use with oxidoreductases in the construction of inexpensive enzyme electrodes. The screen-printed enzyme electrodes that MediSense, Cambridge, USA, introduced in 1987 with a pen-sized metre for at-home blood-glucose monitoring was built on this foundation. The electronics were redone in the style of popular credit cards and computer mice, and MediSense’s sales increased exponentially, reaching US $175 million by 1996. The market for biosensors has enormous potential for growth and will reach $12 billion by 2015 (Anon 2012b).

4. Types of Biosensors

S. N	TYPE OF BIOSENSOR	MECHANISM	ANALYTE	REFERENCE
1	Polarographic oxygen electrode	Electrode based	Oxygen in Blood	Clark 1956

2	Electrochemical	Enzyme electrode (Glucose oxidase)	Glucose	Updike and Hicks 1967
3	Potentiometric	Enzyme electrode (Urease)	Urea	Guilbault and Montalvo 1970
4	Amperometric	Electrode with immobilised glucose oxidase Blood	glucose	Guilbault and Lubrano 1973
5	Optical	Fluorescence	pCO2 - /pO2 - in fluids and gases	Lubbers and Optiz 1975
6	Amperometric	Dual enzyme electrode system	Organophosphorous pesticides	Gouda et al. 1997
7	Immuno-chemiluminescence	Charge coupled device	Methyl parathion	Chouhan et al. 2006
8	Optical	FRET (Forster resonance energy transfer)	Formaldehyde	Akshath et al. 2012
9	Immuno-chemiluminescence	Dipstick	Vitamin $_{B12}$	Selvakumar and Thakur 2012a
10	Microbial	Whole cell immobilization	Caffeine	Babu et al. 2007
11	Optical microbial biosensor	Bioluminescence	Heavy metals and pesticides	Ranjan et al. 2012
12	Aptasensors	Aptamer	Vitamin $_{B12}$	Selvakumar and Thakur 2012b

5. Biosensors

Importance and Applications of Biosensors in Fermentation Monitoring

Biosensors can provide real-time feedback on the progress of fermentation by monitoring:

- pH levels
- Sugar consumption
- Ethanol and lactic acid production
- Microbial activity
- Oxygen and carbon dioxide levels

These parameters are critical in ensuring product quality, taste, texture, and safety.

5.1. Dairy Industry

In yogurt and cheese production, biosensors are used to monitor:

- Lactic acid concentration (critical for fermentation end-point detection)
- Glucose levels
- Enzyme activity

Example: Lactate biosensors help optimize fermentation time, reducing production costs and ensuring consistent flavor and texture.

5.2. Beverage Industry

In wine and beer production:

- Ethanol biosensors measure alcohol content during fermentation.
- Glucose and fructose biosensors assess residual sugars.
- pH biosensors ensure ideal conditions for yeast activity.

Example: Electrochemical biosensors are employed in breweries to monitor glucose and ethanol levels, providing data to control fermentation speed.

5.3. Soy Sauce and Fermented Vegetables

- Monitoring salt concentration and amino acid profiles using biosensors.
- Detection of spoilage microorganisms through biosensor arrays.

Example: Optical biosensors can detect histamine levels in fermented soy products, which is essential for food safety.

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6. Advantages of Using Biosensors in Fermentation

- **Speed**: Immediate feedback compared to traditional analytical methods.
- **Accuracy**: High specificity to target molecules.
- **Portability**: On-site, real-time measurements are possible.
- **Automation**: Compatible with automated systems for large-scale production.
- **Cost-effectiveness**: Reduces the need for extensive lab tests and personnel.

7. Future Prospects

Despite their advantages, biosensors face challenges:

- Stability and lifespan of biological components.
- Calibration and maintenance requirements.
- Integration with large-scale production systems.

Future advancements may include:

- **Nano-biosensors** with higher sensitivity.
- **Wireless and IoT-enabled sensors** for remote monitoring.
- **Multi-analyte sensors** capable of monitoring several fermentation parameters simultaneously.

8. Conclusion

In the food sector, quality control is a major focus area. Quick methods to check the quality of the food are urgently needed. The process of quality monitoring is sped up by improvements in adept sensors, which are also economical. Before the advantages of the nano-biosensor can be effectively employed in the identification of contaminants in foods, a number of scientific

and technological challenges must be overcome. Biosensors have undergone significant miniaturisation recently. High enzyme activity microbial cells might be necessary to keep up with such advancements. This is particularly important when using microbial cells in place of enzyme-based sensors. Due to their low cost, long lifespan, and wide range of acceptable pH and temperature, microorganisms have been widely used as the biosensing component in the development of biosensors. A more thorough investigation of the relationship between the food system and technological factors must be conducted in order to overcome the difficulties associated with biosensor technologies and their use in the food matrix. Future sensor developments should concentrate on signal transmitters for remote sensing in conjunction with multiple-analyte identification. These developments will greatly speed up a number of application areas in the food industry while maintaining a certain degree of normative animal, human, and environmental health for a rapidly evolving world.

It is necessary to lower the physical size of the biosensing devices for numerous food analyses without sacrificing the device's specificity and sensitivity. The market for lab-on-chip biosensor systems is expanding. The market for biosensors as well as their applications in various foodstuffs will grow as a result of new biosensing materials that are designed for high sensitivity, selectivity, stability, and low material synthesis costs. It should be easy to handle biosensors so that anyone may utilise them. To advance in the field of biosensing, biosensor research should be supported with adequate funding and facilities for research teams. Because they combine the great sensitivity of biosensing and the high specificity of biochemical reactions, biosensors have drawn attention recently. The recognition element and the electrode are the two fundamental parts of a biosensor. The recognition component (bioreceptor), which is immobilised on the electrode surface, is in charge of detecting the target analytes through particular biochemical processes. For the purpose of creating prototypes for applications such as environmental monitoring, food safety, or clinical analysis, it is crucial to improve the analytical performance of biosensors. As a result, current research has concentrated on improving the analytical performance of biosensors. When developing biosensors, it's crucial to consider factors like high sensitivity, a broad operating range, excellent selectivity, and strong reproducibility and repeatability. The subject of biosensors is expanding quickly and includes a number of disciplines, including environmental science, agriculture, and medicine. The use of biosensors in the medical industry has expanded significantly, particularly in the realm of medical diagnostics. The need for quick methods to assess food quality is important because quality control is a significant emphasis area in the food business. Conventional techniques are pricy, labour-intensive, and pricey. The process will go more quickly and more

cheaply when effective sensors are developed. Research in material science, microfabrication, and nanofabrication will advance the creation of appropriate sample preparation stages, such as extraction, concentration, and isolation. Biosensor is an interdisciplinary field covering several domains. Future sensor innovations must prioritise the provision of multi-analyte detection together with distant signal transmitters.

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