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Intelligent packaging applications in food industry

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Food packaging is an inevitable component of the food supply chain as it aids as the protection layer from contamination, surroundings and mechanical damage during handling; otherwise, product quality deterioration would be the consequence. It also acts as a preventive tool to ensure that the product seals are intact at all stages of the supply chain until it is opened by the consumer, with no spillage and tampering issues. Packaging also acts as an identification and communication unit, presenting product details such as nutritional facts, direction to use and store, place of manufacture, date of manufacture, expiry date, health benefits and other relevant information.

In recent times the emerging approaches in food packaging are intelligent packaging. Intelligent packaging takes part of an intelligent function (communication) with existing packaging systems. It communicates to the consumer about the state of the product based on sensing, detecting, or recording the changes that took place inside the package and package surroundings. The various intelligent packaging solution such as indicators and sensors are discussed in the following sections.

Indicators : The indicator is a device that communicates information regarding food quality, microbial activity and other properties. It is deliberately included in the package that works based on specific characteristics such as presence or absence of a target chemical and biological substance, rate and extent of reaction between two or more molecules or substances, different concentration levels of chemicals present in food as marked through permanent and visible colour change or movement of colour borderlines. In a general sense, indicators can be divided into external and internal categories. The former refers to indicators that are typically mounted outside the box, whereas the latter refers to indicators that are physically present within the package.

Temperature indicators : These are indicators that work based on changes in the product's temperature or the package containing the product. Temperature sensors or integrators are usually eco-friendly and cost-effective and they calculate and monitor the temperature. They are further listed as critical temperature indicators, critical temperature/time integrators and time-temperature indicators based on their functions.

Critical temperature indicators : This temperature indicator shows the spoilage and organoleptic food changes when the food is exposed to abnormal temperature ranges for extended periods more than specified levels. The irreversible and visual changes in the colour of the indicator communicate such information. These indicators have versatile applications in perishable foods and frozen food products by taking irreversible changes after exceeding threshold temperatures.

Critical temperature/time integrators : These indicators exhibit a reaction above a reference critical temperature, which could be converted in equivalent contact time at that critical temperature. Critical temperature/time integrators (CTTIs) can be used to determine the product's consistency and protection above the critical temperature as a function of exposure time.

Time-temperature indicators : TTIs are easy and cost-effective devices that record a food package's temperature history throughout its entire life cycle, including packaging, storage, distribution, and retailing. Data is recorded in terms of irreversible adjustments that help consumers understand food safety and quality. TTIs are divided into two categories: full history indicators and partial history indicators. These indicators are mostly used for temperature-sensitive foods like chilled and frozen foods.

Fig. 1: Time temperature indicator

Freshness indicators : Freshness indicators are direct food quality indicators, examining chemical reactions that cause spoilage by target micro-organisms and their metabolites. The underlying principle is that as the target micro-organisms evolve, they induce permanent changes in pH (which eventually results in a colour change), providing a clear indicator of the food product's nature within the box. These indicators are used in various items, such as fresh foods, vegetables and seafood.

Fig. 2: Freshness indicator

Leak indicators : In modified atmosphere packaging, the atmosphere (*i.e.*, gas concentration levels) inside the package is changed to increase the product's shelf-life. Leaks or distortions in the package's integrity, on the other hand, may be problematic. Defects in the box can also cause differences in the optimum concentration of gases, which can significantly impact the quality of foods. This can affect the flavor, nutrition, texture and overall acceptability of the product. Hence, leak indicators are useful for maintaining and monitoring package integrity.

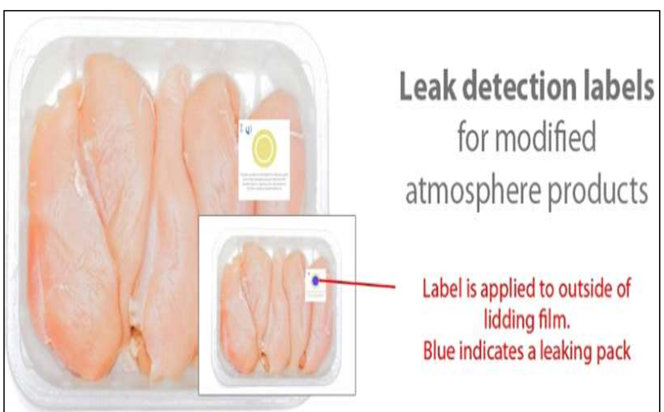

Fig. 3: Leakage indicator

pH indicators : This is not the same form of measure that has been used to track food freshness and consistency using pH variations. Instead, it refers to a group of indicators because it simply conveys pH variations that can create a variety of other methods. Agar was used to creating a colourimetric pH indicator. Natural dye was immobilized using potato starch (anthocyanin). Variations in pH were inferred directly as the spoilage in meat.

Radio frequency identification : RFID stands for radio frequency identification and it is a data-storage technology that is widely available as a chip made up of tags. Depending on how much power they need, they are divided into two categories: active and passive. Active types use a battery, while passive types generate power from signals obtained. Low frequency (125 kHz–134 kHz) and high frequency (13.56 MHz) ranges are used in most food packaging applications. An antenna acts as a conduit for data transmission between a tag and a reader by acting as an intermediate electromagnetic wave medium. The reader is a small component whose primary function is to analyze and receive data from the tag to be further processed. Electronic chips are used to encrypt information in the form of bits in the electronic product code. Data filtering, data integration, reader coordination, and proper process management are all tasks that RFID middleware performs. RFID tags have helped horticultural products, meat and fishery products, dairy and bakery products, drinks, and other foods.

Sensors : Sensors are electronic instruments that detect and convert one type of signal to another using a transducer. Depending on the working form of the transducer, sensors are classified as active or passive. Chemical and biosensors have been used as intelligent packaging instruments for common analytes such as pH, humidity, colour and biological species. Another recent breakthrough, the edible sensor, is a non-destructive method of detecting spoilage that can revolutionize food packaging. The pectin-based edible sensor developed combines anthocyanin (red cabbage extract) colourimetric changes with variations in total volatile basic nitrogen to detect meat-based product spoilage. A membrane film sensor for golden pomfret fillet freshness was developed and characterized using an inkjet-assisted layer-by-layer and polyelectrolyte multilayer film fabrication method based on a similar principle. The idea was to use a fluorescent-sensitive dye to detect spoilage of fish fluids caused by pH variations.

Chemical sensors : Chemical interactions between

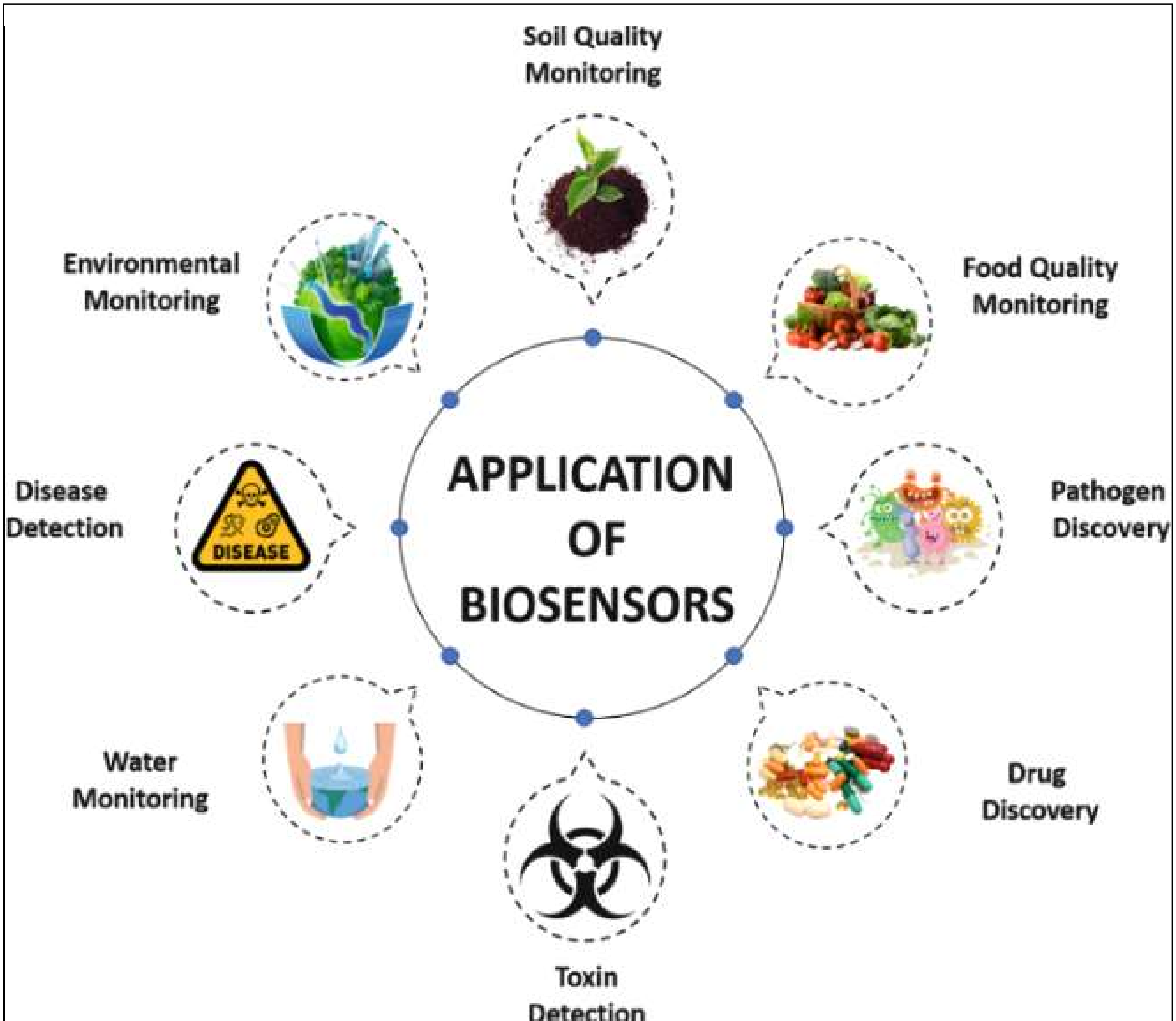

Fig. 4: Applications of biosensors

substrate and analyte molecules occur in sensors used for detection/sensing purposes.

Gas sensors : Gas sensors identify and show gaseous or reactive compounds such as carbon dioxide, oxygen, volatile amines and other gases. With the aid of an indicator dye (phosphorescent Pt-porphyrin) and naphtholphthalein, a carbon dioxide sensor is based on a forester resonance energy transfer mechanism and a solid-state polymeric optochemical sensor has been used to detect accurate levels of carbon dioxide.

Biosensors : A *biosensor* is a sensor that uses a biological analyte to detect a shift and then converts that signal into an electric signal using a transducer. To illustrate spoilage history, a biosensor based on strong analyte interactions for quality monitoring of muscle-based products (beef and chicken fillets) was developed to indicate colour changes from green to red after 9 and 10 days of storage for beef and chicken fillets, respectively. An electrochemical biosensor based on nylon-6 nanofibrous membrane functionalized with glucose oxidase (GOX) enzyme was developed to sense glucose in various beverages. Some of the applications of biosensors are shown in Fig. 4.

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