

Chapter: 08

INDICATORS OF INTELLIGENT FOOD PACKAGING

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DOI: <https://doi.org/10.52458/9788196897437.nsp.2023.eb.ch-08>

Ch.Id:-GU/NSP/EB/RTFP/2023/Ch-08

ABSTRACT

This chapter focuses on the importance of indicators in smart food packaging. With people wanting fresher and safer food, indicators are key to meeting these demands. There are different types of indicators available, like ones that check time and temperature, ones that sense gases, and moisture, and even those that detect harmful microbes. This chapter explains how these indicators work and how they help make sure food is safe and stays fresh for longer.

Keywords: *Food Packaging, Indicators, Food-shelf life.*

1. INTRODUCTION

Indicators in Smart Food Packaging represent a crucial element in the ever-evolving landscape of food technology. In recent years, there has been a surge in innovation and development within the realm of indicators for smart food packaging. One notable trend is the integration of more advanced and accurate sensor technologies [1]. For instance, gas sensors can now detect trace amounts of specific gases associated with food spoilage, providing even more precise information about a product's freshness. Additionally, there is a growing emphasis on sustainability and environmental consciousness. Manufacturers are exploring biodegradable and eco-friendly materials for indicators to reduce the environmental footprint of packaging. Moreover, indicators are becoming increasingly interactive, with some linking to smartphone apps that enable consumers to access real-time information about a product's quality and shelf life [2]. These indicators are like intelligent watchdogs that provide vital information about the condition and quality of packaged food products [3]. They come in various forms, including time-temperature indicators (TTIs), gas sensors, moisture sensors, and microbial sensors. The primary objective of these indicators is to communicate essential data to consumers, suppliers, and producers along the food supply chain [4]. For example, a TTI might change color to signal that a product has been exposed to undesirable temperatures for too long, alerting consumers to potential spoilage. Indicators serve as invaluable tools in smart food packaging systems, offering a means to communicate critical information concerning the condition of both the food materials inside the package and the environment surrounding it. These indicators operate by detecting and translating changes into easily perceptible visual cues. This immediate visual feedback is often conveyed through various means, such as altering color concentrations, which effectively signal shifts or alterations in the food environment.

One of the remarkable features of indicators is their versatility. They possess the unique capability to provide a range of distinct visual signals, each tailored to specific

characteristics of the food environment. Unlike some other monitoring systems, indicators don't rely on specific receptors or complex technology to relay information about food quality. Instead, they offer a direct and intuitive way for both consumers and industry professionals to assess the status and freshness of packaged food products [3-5]. Within the realm of smart food packaging, indicators encompass a diverse range of functionalities. These may include time-associated temperature indicators, which inform consumers if a product has been exposed to unfavorable temperature conditions for an extended period, freshness indicators that provide insights into the product's peak quality, and gas indicators that monitor and signal changes in gas composition within the package. By integrating such indicators into food packaging materials, manufacturers and consumers alike gain an effective means to enhance food safety, reduce waste, and make informed decisions about the products they handle and consume.

2. SIGNIFICANCE OF INDICATORS

The significance of indicators in smart food packaging cannot be overstated, especially concerning the extension of food shelf life. By providing real-time data on the condition of packaged food, indicators empower consumers to make informed choices, reducing the likelihood of consuming spoiled or unsafe products. This not only enhances food safety but also minimizes food waste. Furthermore, indicators aid producers and suppliers in monitoring and managing their inventory effectively, reducing the risk of selling expired or subpar products. In the broader context, the use of indicators contributes to the sustainability of the food industry by helping to reduce food waste and improve resource management. Overall, indicators play a pivotal role in ensuring that food products reach consumers in their freshest and safest state, ultimately benefiting both consumers and the industry as a whole.

3. TYPES OF INDICATORS

3.1 Temperature indicator

Temperature plays a pivotal role in determining the shelf life and quality of food products, with even minor fluctuations having a significant impact. It is essential to monitor temperature throughout the entire journey of food products, from packaging to consumer consumption, to ensure their quality. Intelligent temperature indicators are indispensable tools in this regard, categorized into simple temperature indicators (STIs) and time-temperature indicators (TTIs). STIs alert consumers to temperature variations and potential risks, such as protein denaturation and microbial activity, within the packaged food, fostering informed decision-making and enhancing food safety and

quality. Time-temperature indicators (TTIs) are ingenious devices that function based on fundamental principles involving various reactions, including mechanical, enzymatic, microbiological, chemical, or electrochemical, resulting in observable changes, such as shifts in mechanical properties or alterations in color. In a notable example, Kim et al. (2016) introduced a diffusion-based TTI employing isopropyl palmitate (IPP) to evaluate the microbial quality of unpasteurized juice [6]. The concept is ingenious: by measuring the diffusion of IPP within the indicator, specific temperature ranges within the TTI can be calculated. Remarkably, a 7mm diffusion depth from the indicator has been identified as a precise indicator level, effectively reflecting the microbial spoilage evaluation within the packaged unpasteurized juice. Moreover, advancements in TTI technology have demonstrated the potential to detect microbial spoilage even at higher temperatures, such as 13°C or above [7,8].

Anthocyanin, known for its responsiveness to changes in pH levels, serves as a remarkable natural indicator. This enables the assessment of food product quality by detecting pH variations within the packaged food, thereby indirectly indicating temperature fluctuations. Over recent years, there has been a notable surge in the development and application of various TTI categories, encompassing photochrome-driven, polymer-based, microbe-based, diffusion-based, and enzyme-based TTIs. These advancements have significantly expanded our ability to assess the effects of time and temperature on various unpreserved food items, paving the way for enhanced food safety and quality assurance.

3.2 Gas indicators

Preserving the freshness and quality of unprocessed, organic foods, particularly fruits and vegetables, poses a significant challenge in the realm of packaging and storage. Several factors contribute to this challenge, including the natural respiration of these food items, the exchange of gases between the food and its packaging material, and fluctuations in gas concentrations. Additionally, the presence of gases produced by microbial growth and metabolic activities within the packaged environment further compounds these issues [3,7]. To address these complexities and extend the shelf life of these perishable goods, gas indicators emerge as a valuable solution. Gas indicators play a pivotal role in maintaining the optimal atmosphere within food packaging, effectively mitigating the challenges associated with respiration and gas exchange. These indicators, often integrated into the packaging materials, allow for the continuous monitoring of gas levels and compositions. By providing real-time information about the gas environment inside the package, gas indicators enable producers and consumers to make informed decisions about the freshness and quality of the food products. In

essence, they serve as guardians against the detrimental effects of gases on organic foods, ensuring that these products remain at their peak quality for an extended period, promoting sustainability, reducing food waste, and enhancing the overall consumer experience.

These gas indicators provide information on the concentration of O₂ and CO₂ inside the packaging system by varying the colour of the package which is due to the particular enzymatic or chemical reaction. These indicators provide information regarding the presence or absence of gases as the indicator is directly attached to the packaged food materials.

3.3 Freshness indicators

The development of freshness indicators has been driven by the increasing consumer preference for foods that are not only nutritious but also unspoiled and of the highest quality. These indicators are envisioned as smart devices capable of autonomously assessing and communicating the quality of packaged food products throughout their journey, from production to transportation and storage. By harnessing the power of technology and science, freshness indicators empower consumers with real-time insights, ensuring that they can make informed decisions about the products they purchase and consume [1,8]. This not only enhances food safety but also reduces the likelihood of food waste, aligning with the global call for sustainability in the food industry. In essence, freshness indicators exemplify the convergence of consumer demands for fresh, healthy foods and cutting-edge technology, revolutionizing the way we perceive and interact with packaged food products.

Freshness indicators represent a remarkable innovation aimed at addressing one of the most critical aspects of food safety and quality: microbial contamination. These indicators are ingeniously designed to serve as vigilant guardians, continuously monitoring the condition of food materials within the packaging system [4]. Their primary function is to relay vital information to consumers regarding the freshness of the enclosed food products. In an era marked by an escalating demand for fresh and wholesome food options, the past two decades have witnessed a significant upsurge in research and development activities focused on freshness indicators.

3.4 Sensors

A sensor, in its essence, represents a sophisticated system comprising several integral components working in harmony. At its core, a sensor features a processing and control unit, constructed using electronic principles and a myriad of electronic components [8]. This unit is not merely a mechanical assembly but a dynamic interface

between the physical world and digital technology. Accompanying the hardware aspect, sensor systems incorporate specialized software, providing the intelligence needed to interpret and process data collected from the surrounding environment. This software often encompasses algorithms and logic that transform raw signals into meaningful information.

Furthermore, sensors are by no means isolated entities; they are part of a broader ecosystem facilitated by an intricate interconnection network. This network enables the seamless exchange of data between sensors, control units, and other relevant components, ensuring the timely and coordinated response of the system to the detected signals. At the heart of a sensor's functionality lies its primary purpose: to detect and capture signals indicative of specific physicochemical properties. These properties can encompass a vast array of factors, including temperature, pressure, humidity, light intensity, chemical composition, and more. Essentially, sensors serve as the vigilant eyes and ears of various systems, continuously monitoring their environment and providing invaluable insights that drive informed decision-making and efficient control processes across diverse domains and industries.

In a general sense, sensors are ingeniously designed with four primary functional components. First and foremost, we have the "Receptor," which acts as the signal-receiving component of the sensor. This receptor is akin to the sensor's senses, where it comprises a sampling unit responsible for facilitating the interaction between the analyte (the substance being measured) and the sensor's surface molecules. During this interaction, the analyte becomes adsorbed onto the sensor's surface. This pivotal step triggers a reaction between the analyte and the surface chemicals, leading to an alteration in energy levels. This change in energy is intimately linked to the detection of the analyte and results in the transformation or modification of the physicochemical characteristics of the receptor, such as redox potential, pH, or temperature.

An exemplary sensor should exhibit the following essential attributes: (i) a high degree of specificity toward the target species, denoting selectivity; (ii) remarkable sensitivity to alterations in target species concentrations; (iii) rapid response time; (iv) a prolonged operational lifespan, ideally extending to several months; and (v) a compact and diminutive form factor, allowing for the potential of cost-effective mass production. Within the realm of sensors designed for food applications, diverse sensor types have been proposed and developed, with notable examples including electrochemical sensors and luminescence sensors. These sensors are engineered to meet the rigorous demands of the food industry, offering precise and reliable measurements while catering to the practical constraints of size and cost.

4. CONCLUSION

In conclusion, the pursuit of an ideal sensor for various applications, including those in the realm of food science, hinges on key attributes such as specificity, sensitivity, rapid response, extended lifespan, and miniaturization potential. These characteristics collectively ensure that sensors can meet the stringent requirements of modern industries, offering accurate and dependable measurements while remaining economically viable. In the context of food applications, various sensor types, such as electrochemical and luminescence sensors, have been proposed and developed to address these critical criteria. As technology continues to advance, the ongoing refinement and innovation in sensor design promise to play an increasingly pivotal role in enhancing the quality, safety, and efficiency of processes across a wide array of industries, including food production and monitoring.

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