

Smart Packaging Technologies

Özlem Erol¹, İlknur Uçak²

¹ Department of Animal Production and Technologies, Faculty of Agricultural Sciences and Technologies, Niğde Ömer Halisdemir University, Niğde, Turkey

² Department of Animal Production and Technologies, Faculty of Agricultural Sciences and Technologies, Niğde Ömer Halisdemir University, Niğde, Turkey

Abstract

The time period from the production of food products to the logistics and quality management processes that extend to the final consumption point is of critical importance in terms of preserving the freshness and nutritional value of the product. For this reason, many food preservation methods have been used from the past to the present. With the developing technology, increasing consumer awareness has also been reflected in product packaging, and importance has begun to be given to issues such as providing functional features to packages, minimizing food waste, and developing environmentally compatible materials. In this context, modern packaging methods have been developed and started to be used. Smart packaging is the newest packaging system that draws attention with its innovative features in the sector. In addition, smart packaging systems are an innovative approach that contributes to reducing waste on a global scale in line with food safety and sustainability goals. This review aims to provide information about smart packaging methods and their related applications.

Key Words: *Smart Packaging, Food Safety, Consumer Safety*

Introduction

Packaging in the food industry is a type of protection system that prevents contamination of food products with unwanted microorganisms and provides product preservation during product logistics and all subsequent stages, as well as containing information about the product (Otlés and Sahyar, 2016; Drago et al., 2020). The main goal of food packaging is to protect the safety and nutritional value of food from production to the consumer (Cutter, 2006). In addition, it is aimed to minimize food loss and waste that may occur in the process, to have a positive effect on consumer health by using less food preservative additives and to ensure that the consumer is satisfied with the product (Inamuddin et al., 2023). Smart packaging systems are divided into two main categories according to their functional mechanisms: active packaging and smart packaging. While smart packaging is divided into three groups: sensors, indicators and data carriers, active packaging is divided into two groups: retaining materials and releasing materials (Vasuki et al., 2023).

Smart packaging is a system designed to provide information about the food product to the consumer and has two types: those that show the external conditions of the packaging and those that directly measure the quality of the food product. Smart packaging devices are labels or receipts that are added to the inside or outside of the product packaging or printed on the packaging material (Dainellia et al., 2008). It varies not only in physical context but also in the amount and type of information it can carry and how it receives and distributes this information. Multiple smart components can be integrated simultaneously onto packages (Yam et al., 2005). This review aims to provide information about smart packaging technology systems used in meat and meat products.

Smart Packaging

Smart packaging includes systems that are combined with food packaging material or work with the principle of labeling on food. It is aimed to provide more comprehensive information to the consumer by monitoring product quality and critical points throughout the supply chain (Han and Rodrigues, 2005). In smart packaging, various systems are generally used, including indicators, barcodes, radio frequency identification labels and sensors (Akkemik and Güner, 2020).

Indicators

The indicators used in smart packaging are divided into three groups: leakage, freshness and temperature-time indicators. Leakage indicators are systems that monitor the presence of certain gases in the environment and provide information about the integrity of the food product's packaging and possible leaks. There are two types of leakage indicators, oxygen and carbon dioxide indicators, and their working principle is that they cause a color change in the presence of chemical and enzymatic reactions when placed inside the packaging (Yezza, 2008; Özçandır and Yetim, 2010).

The main purpose of freshness indicators is to detect product losses that occur due to reactions that may occur in the food during the shelf life of the food product in its physical and chemical properties. Freshness indicators that are sensitive to pH, volatile nitrogenous compounds, hydrogen sulfide and microbial metabolites can be given to the freshness indicators used in recent years (Üçüncü, 2011). Finally, when looking at temperature-time indicators, it is a small measurement tool that provides visual information about the temperature history of food throughout the distribution chain (Purma and Serdaroglu, 2006). It is primarily preferred in perishable foods such as fish, dairy products, meat, poultry, frozen fruits and vegetables, and frozen meats (Kocaman and Sarimehmetoğlu, 2010). Table 1. Commonly used indicators, their working principles, the information they provide, and their application areas are given (Kaur and Puri, 2017).

Indicators	Principle/Reactants	Information Provided to Consumer	Application
Time-temperature indicators (External)	Mechanical Chemical Enzymatic	Storage condition	Foods stored under refrigerated and frozen conditions
Oxygen indicators (Internal)	Redox dyes pH dyes Enzymes	Storage condition Package leakage	Foods stored in low-oxygen concentration packages
Carbon dioxide indicators (Internal)	Chemical	Storage condition Package leakage	Modified or controlled atmosphere food packaging
Microbial growth or Freshness indicators (Internal/External)	pH dyes Dyes that react with specific metabolites (volatile or non-volatile)	Spoilage (Microbial food quality)	Perishable foods such as meat, fish, and poultry
Pathogen indicators (Internal)	Dyes that react with toxins Various chemical and immunochemical methods	Specific pathogenic bacteria such as Escherichia coli O157:H7	Perishable foods such as meat, fish, and poultry

Table 1. Some commonly used indicators (Kaur and Puri, 2017)

Barcodes

It is the cheapest and most commonly used information carrier used to introduce the product or material. Information about the product consists of a linear symbol, a line and a field, and is expressed with 12 digits. Due to the limited data storage volume of Universal Product Code (UPC) barcodes, existing data has been optimized with RSS (Reduced Space Symbology) barcodes, which allow more product information to be effectively included in smaller areas, 2-dimensional barcodes such as Portable Information File (PDF) - 417, and barcodes called "composite symbol", where linear barcode and 2-dimensional barcode are used together (Yam, 2000; Yam et al., 2005). As a result of this optimization, various data entry options such as nutritional value, cooking recommendations, and the manufacturer's web address, which are impossible to achieve with one-dimensional barcodes, are made possible (Yam, 2000). Barcodes also provide heating options according to the type of food product, save labor by preventing manual entry of heating commands, and provide convenience for people with vision problems or difficulty understanding languages (Yam, 2000). Figure 1. Examples of some barcode applications are given (Anonymous, 2021).

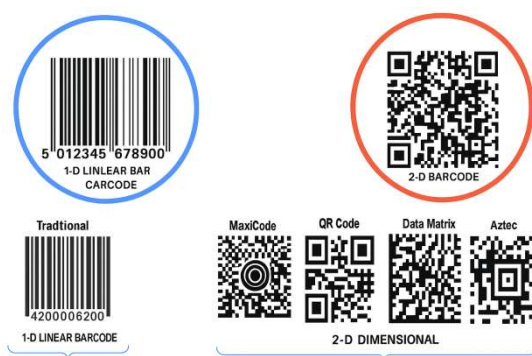


Figure 1. Some Barcode Applications (Anonymous, 2021)

Radio Frequency Identification (RFID) Tags

RFID, which allows wireless information transfer, is a system that plays a role in automatic product recognition and traceability. Recently, it has been used in packaging (Yam et al., 2005). The main elements of the system are; tag, antenna, reader, interrogator and controller (Yuksel and Zaim, 2009). While it is divided into two parts as active and passive tags according to the power source used, semi-passive tags have also been added recently. Passive tags are activated by the reader and have a reading distance of up to 4.5 meters. The difference between active tags and passive tags is that active tags have their own battery and generate their own energy and send signals to the reader. The reading distance of active tags is 30 meters and more (Angeles, 2005; Yam et al., 2005). The operating principle of the system is based on the fact that information and energy transfer occurs between the RFID tag and the reader without contact. The electromagnetic waves emitted by the reader are transmitted to the antenna on the tag, providing interaction and activating the circuits in the microchip to operate the system. The microchip regulates the waves and gives feedback to the reader, and the reader creates digital data and transmits it to a computer with an internet or network connection (Angeles, 2005). Using these labels provides benefits such as taking precautions against problems that may occur during the production and distribution process, ensuring that products are positioned regularly and strategically in the warehouse and distribution processes, thus enabling easy product sales transactions, minimizing product entry and exit traffic control times, actively monitoring the expiration date, reducing labor costs, improving customer experience and increasing service quality (Angeles, 2005). The success of RFID tag usage can be achieved by the design of this system and the adoption of the application by all actors in the supply chain and their integration into their processes (Kelepouris et al., 2007). It is stated that the world's leading retail companies such as WalMart, Marks & Spencer, Chevrolet Creative, FedEx, and Metro Future Store use these tags (Angeles, 2005).

Sensors

Gas sensors are systems that help maintain the quality and safety of food by providing information about the amount of gas in the package and/or in the environment. The content of the gas to be placed in the package changes frequently as a result of the activity of the food product or leaks in the packages, depending on the nature of the package and the environmental conditions of the package (Yam et al., 2005). These changes are usually detected using oxygen and carbon dioxide indicators, and leakage/leakage indicators in package integrity checks. Indicators are in direct contact with the food inside the package (De Jong et al., 2005).

The working principle of biosensors, which are mostly used in smart packaging as toxin indicators, is that toxin indicators have a specific effect on the toxin found in a single microorganism. The critical difficulty that arises during the use of these indicators is that pathogenic microorganisms are mostly found in low amounts inside or on the surface of food and pose a health risk even at these low concentrations, and in addition, they are not distributed evenly within the food. Therefore, the sensor to be used must be highly sensitive and have maximum contact with the food (De Jong et al., 2005). In order to detect the presence of pathogens, SIRA Technology (USA) has developed a biosensor/barcode combination called 'Food Sentinel System' for food packages, which is shaped according to the principles of immunochemical reactions (Yam et al., 2005; Zeuthen and Bogh-sorensen, 2003).

Results and Discussion

Smart food packaging technology has the function of providing information to the consumer, extending the shelf life of food products by protecting them against microbial contamination, maintaining quality stability and maximizing safety. Therefore, smart packaging, which has been developed and used within modern packaging methods, has many advantages for both the consumer and the producer. The increasing number of studies on this subject in recent years provides information about the topicality of the subject.

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