Intelligent Packaging : Types, Concepts and Applications

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Abstract

Intelligent packaging is an emerging technique and is a culmination of "intelligent functions" that aids in decision making to achieve the benefits of enhanced food quality and also its safety. It uses communication function of the package for performing intelligent functions such as detecting, sensing, recording, tracing, communicating and applying scientific knowledge. Not only this, it also warns about possible dangers. A conceptual framework is also developed to provide more precise meaning to the definition and to explicate the structure of this advanced system. Latest advances in this field include barcode labels, radio frequency identification tags, time temperature indicators, user friendly software, robotics and sensors. This promising technique also offers considerable potential as a marketing tool and the establishment of brand differentiation in certain products. Though various arduous challenges are posing as an impediment for this technology yet this branch has propagated with enormous boom. Recognition of the benefits of this technology by the food industry, development of economically viable packaging systems and increased consumer acceptance is necessary for commercial realisation of these packaging technologies.

Keywords: Intelligent, Packaging, Technology, Functions.

1. Introduction

Due to increased demands for greater stringency in relation to hygiene and safety issues associated with fresh products, their costs, meet consumer expectations in relation to both convenience and quality, the food packaging industry has rapidly developed to meet and satisfy expectations. In addition to packaging improvements, other novel technologies include the development of detectors for oxygen levels, bacterial toxins, and microbial growth, or the integration of time-temperature indicators for detection of improper handling or storage. As consumers demand improved product quality and longer shelf life, there is a continuing need for improved barrier properties and extended shelf life in packaging for food and beverages, cosmetics and pharmaceuticals. Additives that help to create a protective package environment, polymers with good barrier properties, processes for creating Modified Atmosphere Packaging (MAP) and sensors to measure the package environment can be combined. Within the next decade, active and intelligent packaging options will become key elements in how food processors and manufacturers protect the longevity and nutrient value of their products. In fact, this development is so rapid that has this development been that food companies, and more specifically meat processors, struggle to keep pace with developments[3].

1.1 Intelligent Packaging

Intelligent Packaging (IP), also known as smart packaging, is packaging technique that in some way senses some properties of the food it encloses or the environment in which it is kept and is able to inform the manufacturer, retailer and consumer about the state of these properties. Although distinctly different from the concept of active packaging, features of intelligent packaging can be used to check the effectiveness and integrity of active packaging systems. Condition of the packaged foods is monitored to give information about the quality of the packaged food during transport and storage. Smart packaging devices, which may be an integral component or inherent property of a foodstuff's packaging, can be used to monitor a plethora of food pack attributes. A package is "intelligent" if it can perform intelligent functions like tracking the sensing the environment around the product and also if it has ability to communicate with the humans. Intelligent packaging uses the potential of sensor technologies, indicators (including integrity, freshness and Time-Temperature Indicators (TTIs) and Radio Frequency Identification (RFID) in meat and meat products[4].

1.1.1 Conceptual Frame Work of Intelligent Packaging

Intelligent packaging can play an important role in facilitating the flow of both information in the food supply chain cycle. In figure 1, outer circles represent the supply chain cycle from raw materials through manufacturing, packaging, distribution, product use and disposal. The package, in one form or another (such as pouch, container, drum), is traditionally used to facilitate the flow of materials (figure 1) from one location to another, by performing basic functions of containment and protection of the product. In addition, the package can also facilitate the flow of information (as shown by communication links between inner and outer circles). The package can indeed be a highly effective communicator, it can carry actual information in the direction of material flow (for example via truck, ship or train) or electronically (for example through a barcode) through every phase of the supply chain. A conceptual framework describing the flow of information in an IP system is illustrated below, in figure 1.

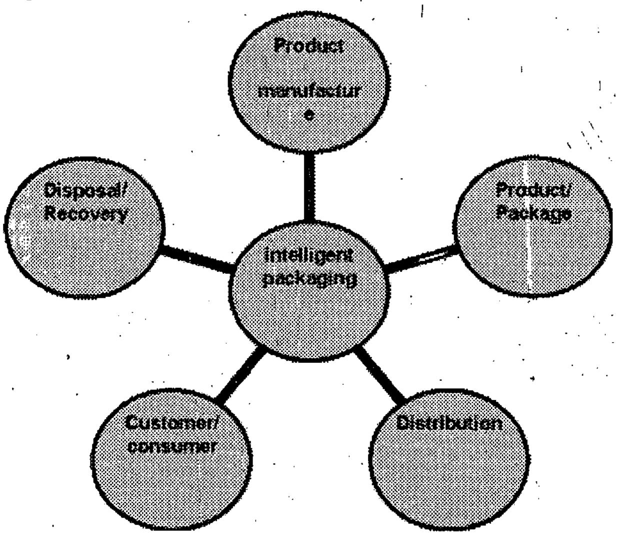

Figure 1: Material flow and information flow in the food supply chain[3].

2. Intelligent/Smart Package Devices

Intelligent package devices are small, inexpensive labels or tags that are either attached onto primary packaging systems (for example, pouches, trays, and bottles) or more often attached to secondary packaging systems (for example shipping containers) to facilitate communication throughout the supply chain. This information can be used to achieve desired food benefits in food quality and food safety.

2.1 Types of Smart Package Devices

There are basically two types of smart package devices that are currently available in the market:

- Data carriers(for example bar code labels and radio frequency identification tags)
- Package indicators(such as time temperature indicators, gas indicators, sensors)

As shown in figure 2, these devices provide a communication channel between the external environment and other components in the system. These devices differ in physical makeup and in the amount and type of data that can be carried. In a typical IP system, multiple smart package devices are employed at several strategic locations through out the supply chain.

2.1.1 Barcodes

Barcodes are the least expensive and most popular form of data carriers. The first barcode Universal Product Code (UPC) was introduced in 1970s and now it is ubiquitous in the grocery stores.

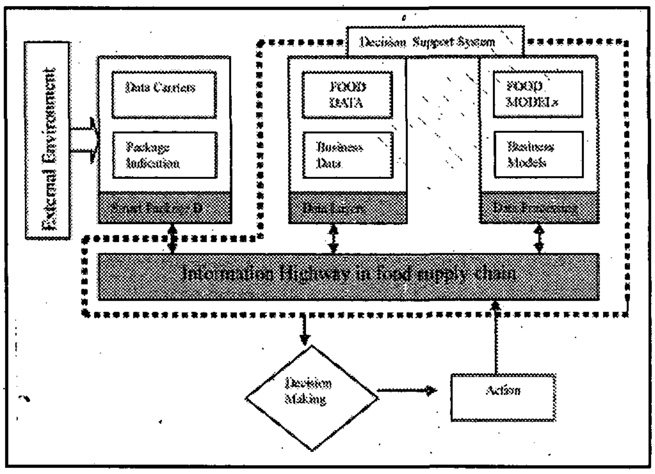

Figure 2: Information flow in intelligent packaging systems[3].

Many standards have been developed in order to enable barcodes to communicate with scanners and printers. These standards have been developed in to common language called "symbologies".

To address the growing demand for encoding more data in a reduced form, a new family of barcode symbologies known as Reduced Space Symbology (RSS) is recently used. RSS-14 Stacked Omni-directional barcode encodes the full 14-digit Global Trade Item Number (GTIN), and it may be used for loose produce items such as apples and oranges where space limitation requires a narrow symbol. The RSS Expanded Barcode (also available in stacked format) encodes up to 74 alphanumeric characters, and it may be used for a variety of products such as meat and sea food that are sold by weight where larger data capacity is required to encode additional information such as packed date, batch or lot number.

2.1.2 Radio Frequency Identification Tags (RFID)

The radio frequency identification tags are sophisticated form of data carrier for product identification and traceability. Its widespread application has begun in recent years. At its most basic level, an RFID tag contains a tiny transponder and antenna that have a unique number or alpha numerical sequence; the tag responds to signals received from a reader's antenna and transmits it's number back to the reader. While the tags are relatively simple, much better inventory information than barcode or human entry systems can be gained through tracking software. RFID tags have the advantage over bar-coding in that tags can be embedded within a container or package without adversely affecting the data. RFID tags also provide a non-contact, non-line-of-sight ability to gather real-time data and can penetrate non-metallic materials including bio-matter.

RFID uses tags affixed to assets (cattle, containers, pallets, etc.) to transmit accurate, real-time information to a user's information system. RFID is one of the many automatic identification technologies (a group which includes bar-codes) and offers a number of potential benefits to the meat production, distribution and retail chain. These include traceability, inventory management, labor saving costs, security and promotion of quality.[3]

2.1.3 Indicators

An indicator may be defined as a substance that indicates the presence or absence of another substance or the degree of reaction between two or more substances through a characteristic change, especially in color. In contrast with sensors, indicators do not comprise receptor and transducer components and communicate information through direct visual change[1].

2.1.3.1 Integrity Indicators

An alternative approach to package-destructive, quality assurance techniques is the use of non-invasive indicator systems as part of an MA package. Such systems usually provide qualitative or semi-quantitative information through visual colorimetric changes or through comparison with standard references. The majority of indicators have been developed for package integrity testing, an essential requirement for the maintenance of quality and safety standards in packaging of meat products. The most common cause of integrity damage in flexible plastic packages is associated with leaking seals. Although a number of destructive manual methods are available for package integrity and leak testing such tests are laborious and can test only limited numbers of pack[6]. Available non-destructive detection systems (which include a number of stimulus response techniques) have other disadvantages such as the need for specialized equipment and slow sampling time[2].

2.1.3.2 Freshness Indicators

Freshness indicators provide direct product quality information resulting from microbial growth or chemical changes within a food product. Microbiological quality may be determined through reactions between indicators included within the package and microbial growth metabolites. As yet the number of practical concepts of intelligent package indicators for freshness detection is very limited. Despite this, considerable potential exists for the development of freshness indicators based on established knowledge of quality indicating metabolites. The chemical detection of spoilage of foods and the chemical changes in meat during storage provide the basis for which freshness indicators may be developed based on target metabolites associated with microbiologically induced deterioration. Using the marker concept in this manner may result in the more widespread commercial development of freshness indicators for meat products in the not too distant future. This freshness indicator for modified atmosphere packed poultry meat is based on the indication of the presence of hydrogen sulphide (H_2S), which is produced in considerable amounts during the ageing of packed poultry during storage. In the preliminary evaluation of the indicator principle promising results were obtained for H_2S-sensitive indicators based on a visually detectable colour change of agarose immobilised myoglobin. The colour change of the indicators attached into the packages containing unmarinated broiler correlated with the microbiological and sensory quality of broiler samples and the onset of the colour change took place concurrently with the sensory rejection of the odour[6].

2.1.3.3 Time-Temperature Indicators

Temperature is usually the most important environmental factor influencing the kinetics of physical and chemical deteriorations, as well as microbial growth in food products. Time Temperature Indicators (TTIs) are typically small self-adhesive labels attached onto shipping containers or individual consumer packages. These labels provide visual indications of temperature history during distribution and storage, which is particularly useful for warning of temperature abuse for chilled or frozen food products. They are also used as 'freshness indicators' for estimating the remaining shelf life of perishable products. The responses of these labels are usually some visually distinct changes that are temperature dependent, such as an increase in color intensity and diffusion of a dye along a straight path.

TTIs currently commercially available include a number of diffusion, enzymatic and polymer-based systems. All of which offer potential in meat and poultry products[2].

Infratab (Oxnard, California) is also developing a battery powered TTI/RFID tag. Unlike the traditional TTI, it is based on diffusion or a biochemical reaction[1].

2.1.3.4 Gas Indicators

The gas composition in the package headspace often changes as a result of the activity of the food product or the environmental conditions. For example, respiration of fresh produce, gas generation by spoilage microorganisms through the packaging material or package leaks, may cause the gas composition inside the package to change. Gas indicators in the form of a package label or printed on packaging films can monitor changes in the gas composition, thereby providing a means of monitoring the quality and safety of food products. Since oxygen in air can cause oxidative rancidity, color change, and microbial spoilage, a number of oxygen indicators are designed to show color changes due to leaking or tampered packages[5].

2.1.4 Sensors

Many intelligent packaging concepts involve the use of sensors. The use of these systems is generally envisaged in terms of incorporation into established packaging techniques such as MAP and vacuum packaging. A sensor is defined as a device used to detect, locate or quantify energy or matter, giving a signal for the detection or measurement of a physical or chemical property to which the device responds. To qualify as a sensor, a device must be able to provide continuous output of a signal. Most sensors contain two basic functional units: a receptor and a transducer. In the receptor, physical or chemical information is transformed into a form of energy, which may be measured by the transducer. The transducer is a device capable of transforming the energy carrying the physical or chemical information about the sample into a useful analytical signal.

2.1.4.1 Gas Sensors

Gas sensors are devices that respond reversibly and quantitatively to the presence of a gaseous analyte by changing the physical parameters of the sensor and are monitored by an external device. Systems presently available for gas detection include amperometric oxygen sensors, potentiometric carbon dioxide sensors, metal oxide semiconductor field effect transistors, organic conducting polymers and piezoelectric crystal sensors. Conventional systems for oxygen sensors based on electrochemical methods have a number of limitations. These include factors such as consumption of analyte (oxygen), cross-sensitivity to carbon dioxide and hydrogen sulphide and fouling of sensor membranes. Such systems also involve destructive analysis of packages.

2.1.4.2 Fluorescence-Based Oxygen Sensors

Fluorescence-based oxygen sensors represent the most advanced and promising systems for remote measurement of headspace gases in packaged meat products. Reiniger et al., (1996) first introduced the concept of using luminescent dyes quenched by oxygen as non destructive indicators in food packaging applications. These sensors can be produced cheaply, are disposable and when used in conjunction with accurate instrumentation provide rapid determination of oxygen concentration[3]. The active component of a fluorescence-based oxygen sensor normally consists of a long-delay fluorescent or phosphorescent dye encapsulated in a solid polymer matrix. The dye-polymer coating is applied as a thin film coating on a suitable solid support. Molecular oxygen, present in the packaging headspace, penetrates the sensitive coating through simple diffusion and quenches luminescence by a dynamic, i.e. collisional mechanism. Oxygen is quantified by measuring changes in luminescence parameters from the oxygen-sensing element in contact with the gas or liquid sample, using a pre-determined calibration[5].

2.1.4.3 Biosensors

A biosensor is a compact analytical device that detects, records, and transmits information pertaining to biochemical reactions. This smart device consists of two primary components: a bioreceptor that recognizes a target analyte and a transducer that converts biochemical signals into a quantifiable electrical response. The bioreceptor is an organic or biological material such as an enzyme, antigen, microbe, hormone or nucleic acid. The transducer can assume many forms (such as electrochemical, optical, acoustic) depending on the parameters being measured. Some important characteristics of a biosensor are its specificity, sensitivity, reliability, portability, and simplicity. The majority of available biosensor technology is not yet capable of commercial realisation[7].

2.1.4.4 Use of Robotics

The use of robotics in the food industry has increased over recent years, particularly in the field of packaging systems. However, the industry has not taken to the technology with the same enthusiasm as the automotive and other industries. Now that the technology is becoming more affordable and the systems more intelligent, it may be feasible to automate many of the complex and repetitive tasks that are carried out in the food industry. The opportunity still exists in terms of increased food shelf life, cost reductions and flexibility[8].

2.1.4.5 Development of User Friendly Software

Software can be developed and used as a tool to speedily analyze the adequacy of various packaging systems to generate a proper equilibrium modified atmosphere for each package. The software can select suitable packaging materials and define the amount of product to be packed or the area of the film that should be available for gas exchange. Two databases have been built in the software, which include recommended gas composition for 38 products, 75 respiration rate models, and permeability data for 27 polymeric films. This software was successfully tested for some products and an example for mango and Galega kale[4].

3. Applications

3.1 Enhancing Food Safety and Biosecurity

Intelligent packaging, especially when integrating with science based principles, is a tool for tracking products and facilitating real time data access and exchange, and enabling rapid response and timely decision making.

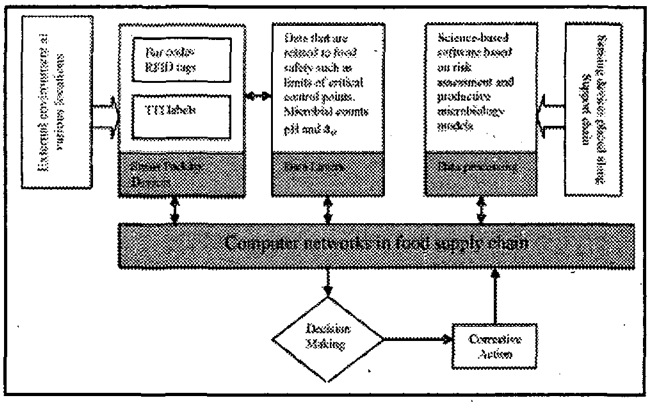

Figure 3: An example of IP and HACCP system[3]

3.2 Enhancing Food Quality and Convenience

IP may also be used to cooking appliances such as intelligent microwave oven system shown in figure 11. The uniqueness of the system is in its use information sharing food quality and convenience. The PDF 417 barcode in the package carries data about the food product, and the data processing system generates the proper heating instructions for the microwave oven.

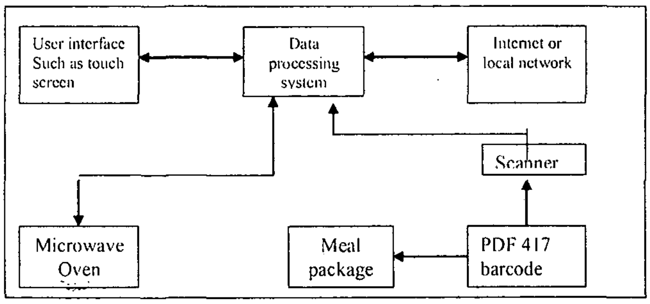

Figure 4: Intelligent microwave oven system[3]

4. Future of intelligent packaging and challenges

A multidisciplinary approach is needed to develop smaller, more powerful, and less extensive intelligent package devices for IP applications. Advanced smart package devices such as biosensors are still at a rudimentary stage. Most of the prototypes are limited by slow response time or short shelf life. Opportunities also exist in integrating data carriers and package indicators. As various smart package devices are being developed, it is imperative to establish universal standards to allow efficient data exchange[3].

5. Conclusion

Intelligent packaging is emerging as a new branch of science and technology that offers exciting opportunities for enhancing food safety, quality and convenience. It Combines packaging science, food science, nanotechnology, biotechnology, sensor science, information technology and other disciplines to develop a breakthrough packaging technology, which is also cost effective. Research opportunities also exist to integrate data carriers and package indicators into small hybrid devices. As this technology is develops, issues such as those relating to legislation, economics, and consumer privacy also need to be addressed.

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