

Intelligent Packaging (IP): An Innovation Technology

Khushal Solanki^{1,*}, Arun Kumar H.², Harini Venugopal³

Abstract

Today's consumer wants healthy and nutritious food products which could be preserved, convenient, easy to serve and free from microbial contamination. Packaging is an indispensable vehicle to deliver product to the consumer. In today's era of convenience based food products, a need for an overall packaging system is highly felt. Intelligent packaging is beneficial to communicate the content and status of packaged food to the consumer. This has the potential to be one of the greatest achievements in the field of food science and technology as this system can work efficiently to reduce the waste and shortage of the food supply. This study presents the importance of intelligent packaging, various tools which help to make convenient and communicate the products to the consumer and application of IP technology.

Keywords: IP, packaging, sensors, indicators, RFID

INTRODUCTION

Food packaging technologies are developing as a response to consumer demands and industrial production trends towards mildly preserved, fresh, tasty and convenient food products with prolonged shelf life and controlled quality. In addition, changes in retailing practices or consumers' lifestyle present major challenges to the food packaging industry and act as driving forces for the development of new and improved packaging concepts that extend shelf-life while maintaining and monitoring food safety and quality.

The safety of food products is one of the main objectives of food law. Quality control in food manufacturing is closely related to technology, physical and sensory attributes of the product, the microbiological safety, the chemical composition, and nutritional value [1].

The main purpose of packaging is to protect a product against deteriorative effects caused by exposure to and usage in the external environment. In addition, product packaging serves as an effective means of marketing to communicate with the consumer. It comes in various shapes and sizes and as a user interface provides consumers with both ease of use and convenience. The main functions of product packaging have been categorized as follows: protection, communication, convenience, and containment [2].

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For example, packaging used in food products usually serves the following purposes:

- To prevent the product from leaking or breaking and to protect it against possible contaminations.
- To communicate important information about the contained food product and its nutritional content and to provide cooking instructions.
- To provide convenience such as allowing consumers to reheat the contained food in a microwave.
- To provide containment for ease of transportation and handling.

According to the Food and Drug Administrative (FDA) report of 2011, about 1.3 billion tons of food is thrown away every year. Every year, only Europe produces 89 million tons of wasted food and the average rubbish thrown by European house-hold constitutes 20–30% of food purchased. New packaging solutions allow improving the economic aspect. The interest in intelligent packaging is successively increasing [3]. According to the United Nations Development Programme, up to 40% of the food produced in India is wasted. In fact, according to the agriculture ministry, INR 50,000 crores worth of food produced is wasted every year in the country. Per capita consumption of packaging material in India is 4.3 kg/person/annum and still to be increased. In response to changing consumer lifestyles, large retail groups and food service industries have introduced highly competitive mix of marketing and trading strategies which depends on quality of packaging material and technology employed.

To reduce this unintentional product waste, so-called intelligent packaging concepts could be utilized. But this is not the only advantage these technologies provoke (Table 1) [4].

Table 1. History of Packaging.

Year	Development	References
1500 BC	Ancient Egyptians developed glass water pots for stored food/water	[5]
1800	Paperboard was first used to manufacture folding cartons	[6]
1962	First commercially available Time–Temperature Indicators (TTI) by Honeywell Corporation	[7]
2012	Wheat Flour Milling Traceability System (WFMTS) incorporating 2D barcode and radio frequency identification technology	[8]

CLASSIFICATION OF PACKAGING SYSTEM

A broad classification of packaging of food can be comprised into four types: Passive, Active, Intelligent and Smart packaging [9]. They are different solutions to serve the basic and fundamental properties of package: protect, preserve, and present. So far, the dominant packaging is the basic one, based on low-cost material and no interaction with the inside food. In this passive packaging, the traditional packaging systems are included, as the use of covering material, characterized by some inherent insulating, protective, or ease of handling qualities.

Usually, the ordinary packaging is not able to preserve the food and is a source of a great quantity of waste with enormous damage to the environment. This situation is increasing in consideration of the growing of consumers in emerging countries, where these consequences are not adequately considered. The packaging is considered active, when the package can interact in same way and/or react to various stimuli, in order to keep the internal environment favorable for the maintenance of the quality of the products. Several environmental, biotic and abiotic factors must be considered, in order to face positively the degradation process. The involved activity could be the presence of oxygen scavenger (an oxygen scavenger can absorb high-energy oxygen inside a package and therefore increase the shelf life of product) or anti-ROS (scavenger of radicals by oxygen or other origins) activity. Smart packaging relies on the use of chemicals, electrical, electronic or mechanical technology or any combinations of them. In particular, smart packaging involves the use of technology that adds feature such that packaging becomes an irreplaceable part of the whole product. According to what above reported, interest in the use of active and intelligent packaging systems for agricultural fresh products has increased in recent years. Active packaging refers to the incorporation of additives into packaging systems, with the aim of maintaining or extending fresh vegetable or livestock products quality and shelf life, while intelligent packaging systems are those that monitor the condition of packaged foods to give information regarding the quality of the packaged food during transport and storage [10].

OVERVIEW OF INTELLIGENT PACKAGING TECHNOLOGIES AND CONCEPTS

Intelligent packaging is defined as science and technology that use the packaging system's communication function to facilitate decision making by monitoring changes in the internal and external environments and communicating the conditions of the packaged food product [11, 12].

The European food safety authority (EFSA) defines intelligent packaging materials as “materials and articles that monitor the condition of packaged food or the environment surrounding the food”. They have the ability to communicate the conditions of the packaged product, but they do not interact with the product [13].

The package can also facilitate the flow of information. The package can indeed be a highly effective communication. The package devices and the decision support system are designed to work together to monitor changes in the internal and external environments of the food package and to communicate the conditions of the food product, so that timely decisions can be made and appropriate actions taken. From the quality and safety viewpoint, the external environment can be further divided into the ambient, physical, and human environments which are the factors important for determining shelf life. However, the business environment is also an important factor; in fact, the development of smart package devices (especially data carriers) and the information highway is largely motivated by the desire to increase profit and operation efficiency. Figure 1 shows that intelligent packaging systems provide the user with information on the conditions of the food or its environment (temperature, pH). It is an extension of the communication function of traditional packaging and communicates to the consumer based on its ability to detect sense and record the changes in the products environment [11].

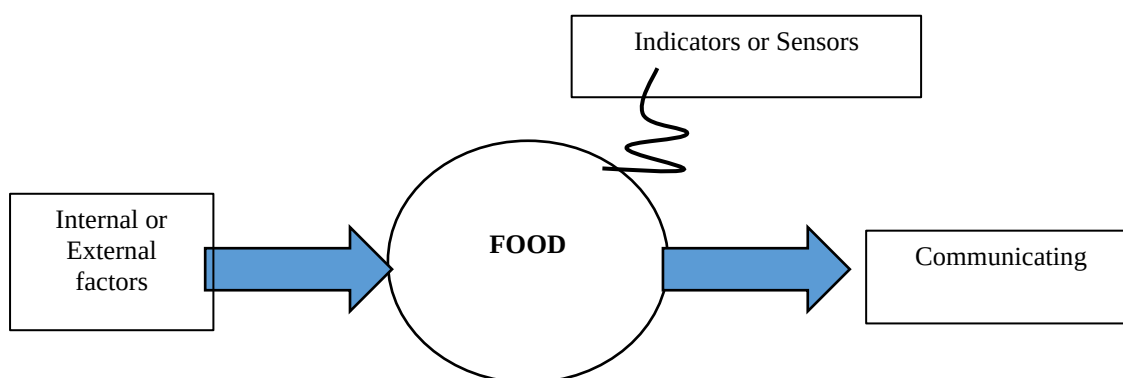


Figure 1. Basic Concept of IP.

Market Scenario

The global intelligent packaging market was valued at US\$4.674 billion in 2017 and is projected to expand at a CAGR of 11.18% over the forecast period to reach US\$8.828 billion by 2023. The need for machine-readable data to be incorporated in packaging has given rise to the introduction of intelligent or smart packaging systems. Intelligent packaging is a part of the communication system which is capable of providing knowledge and information about a product. The complexity of products, advances in packaging technology and investments in research and development are some of the major market drivers.

North America and Europe hold a significant market share due to the stringent government regulations regarding food and beverages packaging along with a high adoption rate of technological advancements. On the other hand, the Asia-Pacific is experiencing a fast growth in the global intelligent packaging market. These solutions offer benefits like convenience, tamper-proof and theft resistance among others. The demand for these solutions is expected to witness maximum growth due to increasing penetration of technologies and focus on curbing counterfeit products [14].

Mechanism behind Intelligent Packaging (IP)

Figure 2 shows that the product is kept inside the packaging material in which we used the internal and environmental sensor for detecting any changes from inside or outside of the packaging materials. If there are any changes that happen due to environmental factor (CO₂, O₂, Temperature, Pressure)

and internal factor (Acidity, Rancidity, Volatiles, Microbial growth) in product, by using this sensor, users can easily understand that product is fresh or spoiled; by sensory visualization indication given to the user [15].

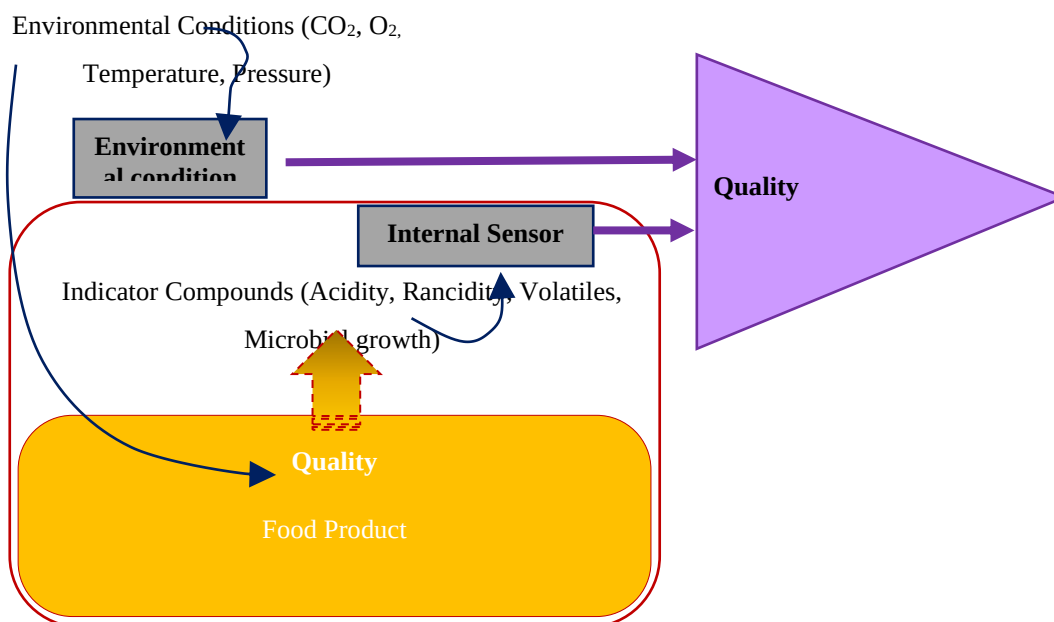


Figure 2. Mechanism behind IP [16].

Types of Intelligent Packaging Systems

Basically there are three intelligent systems:

- A. Sensors;
- B. Indicators; and
- C. Radiofrequency identification (RFID) systems [17]

Sensors

A sensor can be 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. Sensors provide continuous output of signals [18]. Some types of sensors used in intelligent packaging are physical sensors, chemical sensors, biosensors, and gas sensors. Sensors are considered the most promising and innovative technology for future intelligent packaging systems. A sensor is used to detect, locate, or quantify energy or matter, by giving a signal for the detection or measurement of a physical or chemical property to which the device responds [19]. In practice, a sensor replies to a chemical or physical quantity to make a quantifiable output that is proportional to the measure. Most sensors are made up of four major components:

- i. The first is a receptor, i.e., the sensing part of the sensor, represented by a sampling area (generally a chemo-selective coating) where the surface chemistry occurs. Here, the analytical information is obtained from the adsorption of the target analyte on the recognition layer. The energy variation associated with detecting the analyte induces a change of a property of the receptor in terms of, for example, redox potential, pH, temperature, or light.
- ii. The second is the transduction element, i.e., the measuring part of the sensor (e.g., an electrode), which is capable of transforming the energy variation and carrying the physical or chemical information into a useful analytical signal (e.g., electrical, optical, thermal, or chemical).
- iii. The signal processing electronics, and
- iv. A signal display unit.

The ideal sensor should possess the following characteristics:

- i. Specificity for the target species (i.e., selectivity);
- ii. Sensitivity to changes in target-species concentrations;
- iii. Fast response time;
- iv. Extended lifetime of at least several months; and
- v. Small size.

Biosensors: Biosensors are an innovative type of indicators based on measurement of food quality, i.e. devices for detection and transmission of information on biological reactions occurring in a product. Their operation is based on reactions taking place between compounds of biological origin (enzymes, antibodies, and nucleic acids) and microorganisms and/or products of their metabolism. Biosensors consist of a receptor which monitors the microbiological conditions of food and activity of enzymes and a transducer which converts biological signals into electrical ones and enables their reading. Detection of contamination with pathogens and/or their metabolites is generally illustrated using colorimetric methods [2].

Example: ToxinGuard, Food Sentinel System, LactoSens.

Food Sentinel System: In Figure 3 the food Sentinel System (SIRA Technologies Inc.) is a commercial biosensor developed to detect the food pathogens. Specific antibodies are attached to the membrane forming part of the sensor or the barcode. The pathogens cause localized dark bar formation which results in making the barcode unreadable [18]. In the presence of contaminating bacteria, an ink incorporated into the biosensor will turn red, and the barcode will be rendered incapable of transmitting data when scanned. Visual diagnostic tool used to detect pathogens or other selected micro-organisms that may contaminate food, such as *Campylobacter spp.*, *Escherichia coli*, *Listeria spp.*, and *Salmonella spp.*



Figure 3. Food Sentinel System [20].

Indicators

Indicators convey information to the consumer that is linked to the presence or absence of a substance, the extent of a reaction between two or more substances, or the concentration of a specific substance or class of substances. Most often, such information is displayed by immediate visual changes, e.g., different color intensities or the diffusion of a dye along the indicator geometry [21].

A distinct feature of indicators is the type of information involved, which is qualitative or semi-quantitative in nature. Despite the large varieties of indicators, all of them can be reasonably included within three categories: time-temperature indicators, freshness indicators, and gas indicators [22].

All of them fall within the main category of “product quality and value-improving systems,” which are undoubtedly the most widely used devices for food packaging applications. Nowadays, most commercial systems employ these types of indicators for intelligent packaging [23].

Gas Indicator: After food packaging, the gas composition within the package often changes as a result of the activity of the food, the package nature, or/and the environmental conditions, such as respiration of fresh produce in the case of plant products, gas generation by spoilage microorganisms, gas transmission through the packaging material or package leaks [11].

Gas indicators are small devices that come in the form of a package label or they are printed on packaging films that respond to the changes of a gas composition, thereby helping to monitor the quality, safety and integrity of packaged food products. Typically, a gas indicator also induces a color change on the packaging to reflect the gas composition changes [23].

Ageless Eye Oxygen Indicator: The ageless eye is based on simple reversible redox chemistry as shown in Figure 4. The system is typically comprised of a redox dye, such as methylene blue (MB), and a strong reducing agent, such as glucose in an alkaline medium. This system changes color from purple to pink after 2–3 h, when the ambient gas is changed where the level of oxygen is 0.1%, and reverts back to purple in 5 min upon exposure to an ambient atmosphere containing 0.5% oxygen (Figure 4). These systems require anaerobic storage and handling condition, since after less than 10 min of exposure to air, the absorbance of this indicator decreases drastically [24, 25].



Figure 4. Ageless Eye Oxygen Indicator [26].

- **OxySense:** OxySense is manufactured by OxySense Inc. Las Vegas, Nevada, USA. It is based on metal organic fluorescent dye. To ensure durability and for ease of handling, the dye is immobilized in a gas permeable hydrophobic polymer mixture coated onto a small glass disc, termed as Oxydot. Disc can be placed anywhere in the inner surface of the bottle allowing for oxygen measurement to be made at any discrete point within the bottle, including the headspace (gas-phase) of liquid phase. The dye absorbs light between 400 and 500 nm and has a strong

emission peak at 600 nm. The width of the emitted peak provides a measure of the duration of fluorescence. It is inversely related to the concentration since the latter exerts a quantifiable quenching effect on the duration of fluorescence. The fluorimeter takes the form of a “pen” which in order to make measurement is placed on the surface of the bottle adjacent to the disc. The pen is linked with optical fiber to associated electronic packages that regulate the high voltage supply to the photomultiplier detector (Figure 5). The color of glass is important. The technique most successfully for clear glass. In the case green glass, the signal is weaker and the gain of an amplifier must be increased in order to make measurement. This increases both the sensitivity and background noise of the instrument. In case of brown glass, the signal is completely absorbed rendering this technique unusable [27].



Figure 5. Oxy Sense Sensor [28].

Freshness Indicators: The development of freshness indicators over the last two decades stemmed from increasing consumer demand for healthy and fresh foods. Freshness indicators provide the product quality information resulting from microbial growth or chemical changes within a food product. The reaction between the microbial growth metabolites and the integrated indicators within the package provide visual information regarding the microbial quality of the product [18].

A freshness indicator directly indicates the quality of the product; it is usually in the form of labels on the container. Typically, these indicators focus on the detection of the first kind of change (pH, gas composition, etc.). These changes are detected by the indicators and transformed into a response, usually a color response which can be easily measured and correlated with the freshness of food. Freshness decay may be due to both exposure to detrimental conditions and exceeded shelf life [19].

Freshness indicators are also used as fruit ripening indicators informing the consumer when the fruit is ripe and ready to eat [23]. To be able to be in contact with the compounds the freshness indicators must be placed inside the packaging. Depending on the indicator, this information can be detected by different methods.

- OnVu: The OnVu (Ciba Specialty Chemicals and fresh point, Sweden) is a newly introduced solid state reaction based on a solid-state reaction; but in this case, in a crystal phase (Figure 6). Photosensitive compounds (e.g. benzylpyridines) are excited and colored by exposure to low wavelength light. The colored state (dark blue) is reversible and goes back to its initial colorless state at a temperature-dependent rate. The temperature sensitivity and response lives can be set by controlling the type of photochromic compound and the time of light exposure during activation. The OnVu can take the form of a photosensitive ink and thus gives a wide range of applications [29].

It is one of the leading TTIs as it can be easily activated at the point of application by exposure to UV light from a special activator supplied by the manufacturer. It can be printed directly onto packaging in a cost-effective manner [18].

- Time-Temperature Indicators (TTIs): Time-temperature indicators or integrators (TTIs) are defined as simple, cost-effective and user-friendly devices to monitor, record, and cumulatively indicate the overall influence of temperature history on the food product quality from the point of

manufacture up to the consumer. Temperature indicators show whether products have been heated above or cooled below a reference (critical) temperature, warning consumers about the potential survival of pathogenic micro-organisms and protein denaturation during, for example, freezing or defrosting processes [3].

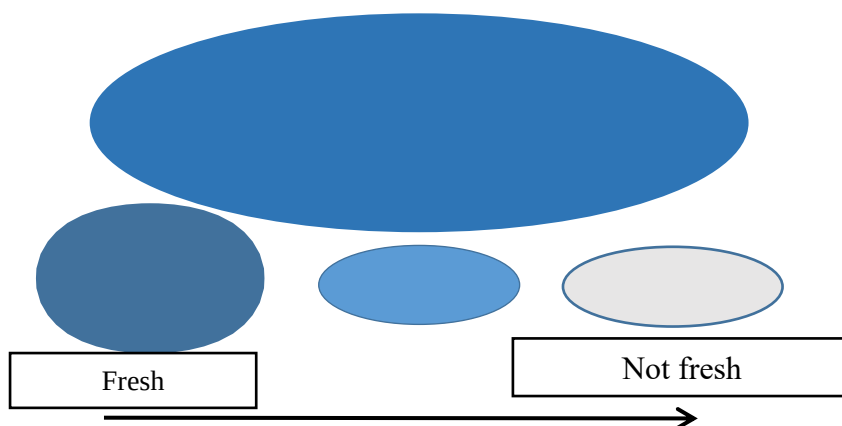


Figure 6. OnVu Indicator [18].

Temperature is a crucial factor affecting the quality and safety of food products during both distribution and storage. The difficulty in controlling and monitoring the temperature history of food products makes it difficult to precisely predict shelf life. Time-temperature indicators (TTIs) provide a visual summary of a product's accumulated chill-chain history, recording the effects of both time and temperature. TTI is a reliable IP concept that can be adapted to the temperature sensitivity of the quality changes of specific food products [30].

The principle of TTI operation is a mechanical, chemical, electrochemical, enzymatic or microbiological irreversible change usually expressed as a visible response, in the form of a mechanical deformation, color development or color movement. The rate of change is temperature dependent, increasing at higher temperatures. The visible response thus gives a cumulative indication of the storage conditions that the TTI has been exposed to. The extent to which this response corresponds to a real time-temperature history depends on the type of the indicator and the physicochemical principles of its operation. Indicators can thus be classified according to their functionality and the information they convey [31, 32].

TTIs may be classified as either partial history or full history indicators, depending on their response mechanism (Table 1). Partial history indicators will not respond unless some temperature threshold has been exceeded, while full history indicators respond independent of a temperature threshold. TTIs are today the most common systems used in packaging, since they are simple and their response does not depend on the nature of the food or the concentration of chemical substances but on temperature variations. They offer visual changes that are accelerated with increasing temperature based on physical (Monitor-Mark), chemical (Keep-it, Fresh-Check, Fresh-Code), enzymatic (VITSAB), polymer (TEMPTIME) or microbiological processes [33].

- **VITSAB (Check point):** The VITSAB Time-Temperature Indicator is an enzymatic indicator. It is the successor of the I-Point Time-Temperature Monitor (VITSAB A.B., Malmo, Sweden). The indicator is based on a colour change caused by a pH decrease which is the result of a controlled enzymatic hydrolysis of a lipid substrate. Before activation, the indicator consists of two separate compartments, in the form of plastic mini-pouches. One compartment contains an aqueous solution of a lipolytic enzyme, such as pancreatic lipase. The other contains the lipid substrate absorbed in a pulverised PVC carrier and suspended in an aqueous phase and a pH indicator mix.

Glycerinetricapronate (tricaproin), tripelargonin, tributyrin and mixed esters of polyvalent alcohols and organic acids are included in substrates [34].

Different combinations of enzyme-substrate types and concentrations can be used to give a variety of response lives and temperature dependencies. At activation, enzyme and substrate are mixed by mechanically breaking the barrier that separates the two compartments as shown in Figure 7. Hydrolysis of the substrate (e.g., tricaproin) causes acid release (e.g., caproic acid) and the pH drop is translated in a colour change of the pH indicator from deep green to bright yellow. Reference starting and end point colors are printed around the reaction window to allow easier visual recognition and evaluation of the colour change. The continuous colour change can also be measured instrumentally. The TTI is claimed to have a long shelf-life if kept chilled before activation.



Figure 7. Check Point Indicator [27].

- **TEMPTIME (Fresh-Check):** Fresh check is based on polymerization reactions dependent on temperature, resulting in changes in the appearance of a label. This indicator has the shape of a small circle surrounded by another circle in a reference colour.

When the packing is exposed to temperatures or its shelf life expires, the internal circle begins to darken. During the chemical reaction, the crystal structure of the monomer (starting substance) remains unchanged and the one-dimensional net does not change its optical properties. The change in the colour of the indicator is measured as a reduction in the coefficient of light reflection and the visible change of the colour from white to black. Comparison (e.g. by a consumer) of the shade of the internal part of the circle with the external part allows for determining (on a three-stage scale) the suitability of the product for consumption. If the center of the circle has a lighter colour than the external part, the product is considered fresh, as shown in Figure 8. The same colour of the internal and external circle indicates that the product is still suitable for consumption but the shelf life has been significantly reduced due to negative effects of temperature. The freshness of the product is not guaranteed when the internal circle is clearly darker than the external one [35].

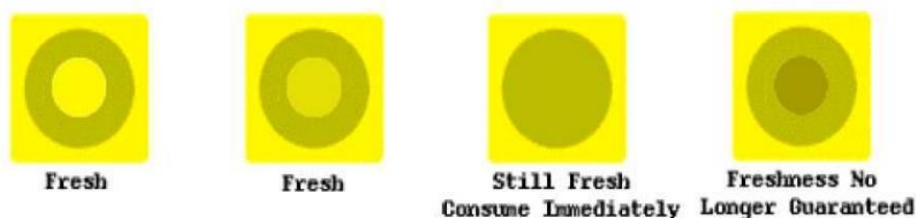


Figure 8. Fresh Check TTI's Indicator [36, 37].

Radio Frequency Identification Device (RFID)

Rapid identification technologies have led to a better handling of raw materials and finished products in the food industry. Traditionally, Universal Product Code (UPC) barcodes have been used to automate and standardize the identification process. Even though the barcodes are less expensive, they require a clear line of sight between the reader and tag. Radio frequency identification (RFID) is

an alternative technology that has been recently used to speed the handling of manufactured goods and materials. RFID is a generic term for technologies that use radio frequency waves to identify an object. RFID enables identification of an object from a distance without requiring a line of sight [38].

Table 2. Application of Various Indicators with Principle [20].

Indicator	Principle/Reagents	Information Given	Application
Time-Temperature indicators	Mechanical Chemical Enzymatic	Storage Conditions	Foods stored under chilled and frozen conditions
Oxygen- Indicators	Redox dyes pH dyes Enzymes	Storage Conditions Package Leak	Foods stored in packages with reduced oxygen concentration
Microbial growth Indicators or Freshness Indicators	pH dyes	Spoilage (Microbial quality of food)	Perishable foods such as meat, fish and poultry
Pathogen Indicators	Various chemical and immunochemical methods reacting with toxins	Specific pathogenic bacteria such as <i>Escherichia coli</i>	Perishable foods such as meat, fish and poultry

RFID tags can incorporate additional data such as details of product and manufacturer and can transmit measured environmental factors such as temperature and relative humidity. Storage capacity of RFID tag is 1 MB for high-end RFID tags. RFID tags can be printed on packaging like bar codes. Normally, they are applied to secondary or tertiary packaging. Radio frequency identification (RFID) is an automatic identification technology that uses wireless sensors to identify items and gather data without human intervention. An RFID is based on tags and readers. RFID tags are of two categories; passive and active [18].

RFID technology can improve replenishment productivity as well as reduce stock loss in the supply chain of short-shelf-life products. RFID technology can be used throughout the supply chain for the UK retail foods industry, including tighter management and control of the supply chain, reduced shrinkage, reduced labor costs, improved customer service and improved compliance with traceability protocols and food safety regulations. The food production can be traced so that consumers can get the complete food production information to choose and buy the safety food [3].

- **Fresh Time RFID Tag:** It is a semi-active RFID tags from Infratab Inc. (Oxnard, Calif., USA) to monitor the shelf life of foods to which they are attached. The tag senses temperature and integrates it over time to determine the shelf life of a product, which can be communicated to the reader. The tags also have a battery and an optional visual display that provides green, yellow, and red indicators depending upon the status of the item (Table 2) (for example, green for fresh and red for unsafe), as shown in Figure 9. The range of operation for these tags is from -25 to 70°C [39, 40].



Figure 9. Freshtime RFID Tag [39].

APPLICATIONS OF INTELLIGENT PACKAGING

• Wheat Flour Milling Traceability System

Qian and his co-worker in 2012 carried out a study that primarily aimed to develop a wheat flour

milling traceability system (WFMTS), incorporating 2D barcode and radio frequency identification (RFID) technology. A QR Code has been selected to identify wheat flour in small packages, because it has a high capacity and low cost; a 2D barcode is therefore best fitted to identify small wheat flour packages. Compared to other 2D barcodes, a QR Code was selected for its large capacity, small size and high scanning speed. Figure 10 shows the identification model with a QR Code on small packages. The traceability batch code is stored in the QR Code. To obtain traceability information rapidly, some product and processing information, including enterprise name, product name, product level, product date and testing parameters (e.g. water content, ash content, wet gluten) is directly stored in the QR Code. The Uniform Resource Locator (URL) for a trace website is also stored in the QR Code. If consumers want to obtain detailed traceability information, consumers have access to a tracing website. The total data capacity of a QR Code includes approximately 150 characters that mix numbers, letters and Chinese characters.

QR Code Recognition and RFID Reading

The QR Code and RFID recognition accuracy results are shown in Table 3. In QR Code recognition, the ra was highest at a 10 cm distance and reached 100%. With increasing or decreasing distances, the ra visibly reduced. In RFID recognition, except for the 200 cm distance, the recognition accuracy (ra) difference was not obvious and was over 80%. Based on the experiment results, some attention was given to improving the WFMTS application. The QR Code scanning distance was maintained in the range of 10–15 cm. A fixed platform for the QR Code scanner was preferred to reduce human error. For RFID reading, a distance of 10–100 cm must be maintained.

Table 3. QR Code and RFID Recognition Accuracy [39].

QR Code Recognition		RFID Recognition	
Distance (cm)	Recognition Accuracy (%)	Distance (cm)	Recognition Accuracy (%)
3	26	5	84
5	64	10	92
10	100	20	98
15	82	50	100
20	30	100	90
25	14	200	42

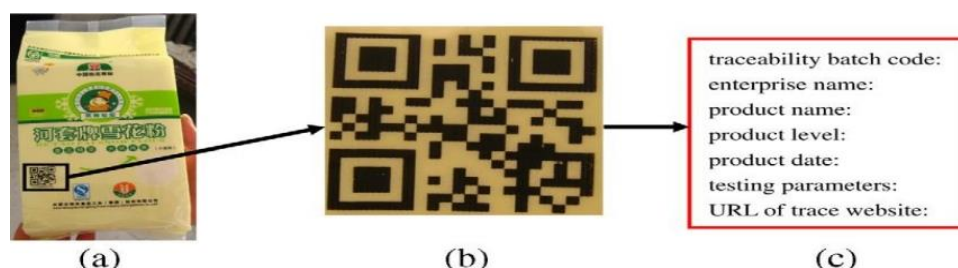


Figure 10. Identifying Small Packages with QR Codes. (a) A Small Package of Wheat Flour with the QR Code Printed on the Surface; (b) An Amplificatory QR Code; (c) Product Information Stored in the QR Code [8].

• Freshness Indicator for *Kimchi* Food

KIMCHI, a group of traditional fermented, vegetable foods (in Korea), is a product of natural mixed-fermentation due principally to lactic acid bacteria (Figure 11). *Kimchi* is characterized by its sour, sweet and carbonated taste, and it differs considerably in this respect from sauerkraut flavor, taste, and texture are optimal when *kimchi* is properly fermented to pH 4.2 and titratable acidity (as lactic acid) of 0.6~0.8% [41, 42].

After optimum fermentation, *kimchi* quality deteriorates due to formation of excessive organic acids and loss of texture. Commercial *kimchi* products that are mostly packaged in flexible film pouches or rigid plastic trays with lid film have greatly increased their share of the Korean food market.

Mechanism for Color Change of the Kimchi Indicator

The color changes of the indicators were probably caused by the combined function of calcium hydroxide and chemical dye. A mechanism for the color change of the indicators can be proposed as follows: Bromocresol purple is yellow at pH 5.2 (and lower) and changes to purple at about pH 6.8. Methyl red is red at pH about 4.2 (and lower) and changes to yellow at about pH 6.2. Since both chemical dyes were mixed with calcium hydroxide, they would be on the basic side and show the basic color initially.

During fermentation, carbon dioxide produced by fermentation permeates into the color indicators within the packages of the closed system, and chemically reacts with calcium hydroxide to form water in the indicator film matrix. More CO₂ molecules and some organic acid vapors (as minor contributors) permeate into the indicators and dissolve in the water, resulting in neutralization of the relative basic mixture. This pH change causes color changes in the indicator [43].

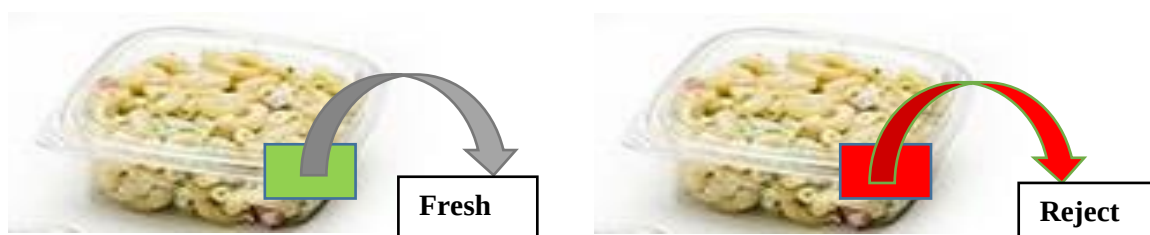


Figure 11. Kimchi Freshness Indicator for Kimchi Korean Product [43].

- **Novel Colorimetric Indicator for Golden Drop Product**

Nopwinyuwong and his co-worker developed a colorimetric mixed pH dye-based indicator with potential for the development of intelligent packaging, as a “chemical barcode” for real-time monitoring of intermediate-moisture dessert spoilage. This on-package indicator contains mixed pH-sensitive dyes, bromothymol blue and methyl red, that respond through visible color change to carbon dioxide (CO₂) as a spoilage metabolite. Both indicator solution and indicator label characteristics were studied, as well as their response to CO₂. The visual color changes of colorimetric mixed-dye-based indicator labels are depicted in Figure 12. It was found that indicator labels showed a clear spectrum from bright light green to orange-red when exposed to a level of CO₂ in a range of 0–2.5% (v/v). The main purpose for applying colorimetric mixed-dye-based indicators to food packaging is to easily and reliably monitor the level of food spoilage of packaged food products in a non-destructive manner during distribution and retail sale. The levels of food spoilage via the formation of CO₂ were correlated to the TCD values of each indicator label [44].

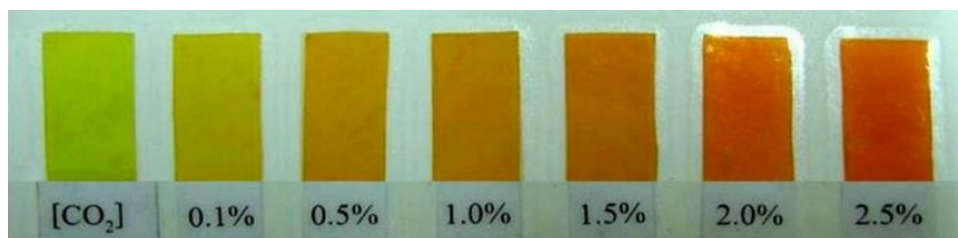


Figure 12. Change in Color of Indicator Label in Response to CO₂ [44].

Color Changes of Indicator Labels during Golden Drop Spoilage: Figures 13 and 14 shows the change in CO₂ level monitored by colorimetric mixed-dye-based indicator labels in golden drop at 25 and 10°C. These findings showed that the minimal spoilage level of golden drop occurred on days 6 and 28 during storage at 25 and 10°C, respectively. Indicator labels showed a clear spectrum from bright light green to orange-red when exposed to CO₂ during storage time. Carbon dioxide from headspace dissolved in the filter layer, which is hydrophilic material, forms carbonic acid in the

presence of moisture. Carbonic acid is diprotic, having two hydrogen atoms which may dissociate from the parent molecule, forming hydrogen ions (H^+) and bicarbonate ions (HCO_3^-) with pK_a of 6.36 at $25^\circ C$. Then, as a proton, a hydrogen ion combines with a water molecule to form a hydronium ion, H_3O^+ . Hydronium ions react with the basic form (In^-) of the indicator label, resulting in an acid form which in turn produces a color change of the indicator label.

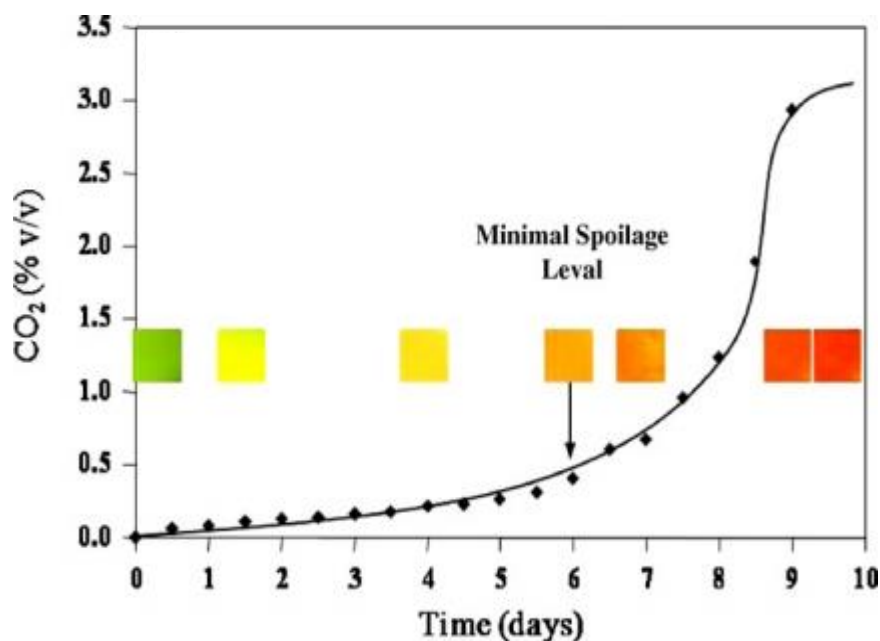


Figure 13. Change in CO_2 Level in Golden Drop at $25^\circ C$ [44].

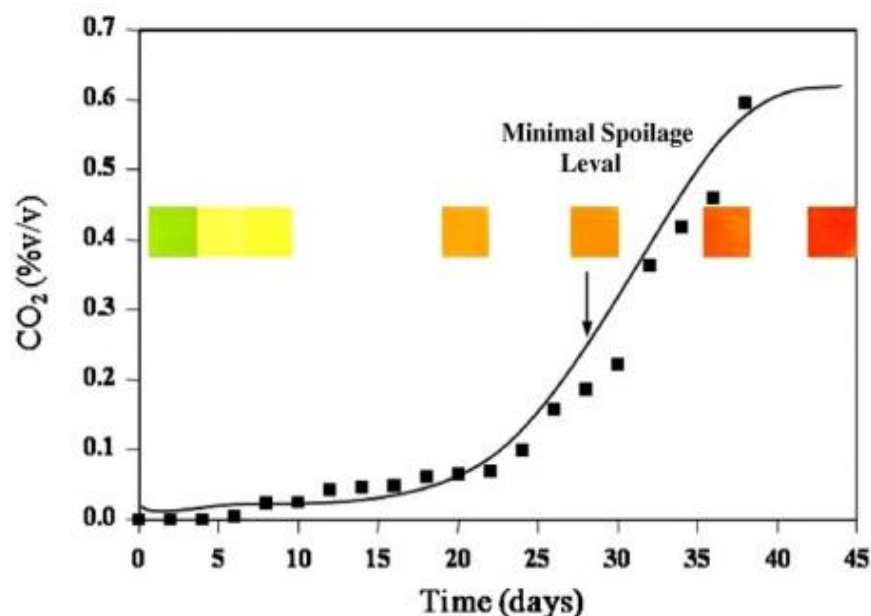


Figure 14. Change in CO_2 Level in Golden Drop at $10^\circ C$ [44].

Golden drop is highly nutritious (protein from egg yolk, carbohydrate from sugar and rice flour) (Figure 15). It possesses a slightly acid pH (6.60) and high moisture content (25–28%), and therefore permits growth of a wide range of microorganisms. The pattern of CO_2 formation has been found to be similar to the general pattern of the chemical spoilage index.



Figure 15. Packaged Golden Drop with Food Spoilage Indicator Label (Green = Fresh; Orange = Warning) [44].

- **Study of Market Milk Using Anthocyanins from Red Cabbage**

Pereira Jr and his co-worker developed and characterized a Time-Temperature Indicator (TTI) based on a PVA/Chitosan polymeric doped with anthocyanins in order to indirectly indicate food quality changes through the detection of changes in the pH of packaged food products when subjected to improper storage temperatures. The TTI was produced from chitosan, PVA and anthocyanins extracted from *Brassica oleracea* var. capitata (Red Cabbage) [35, 45]. After the TTI was in contact with solutions at different pH, a visible colour change was detectable in the samples, ranging from bright red to bright green from pH 1.0 to pH 12.0 (Figure 16). The colour change in the TTI settled at bright light red at pH 1.0 and pink colouration at pH 2.0 and 3.0. When it was in contact with the lactic acid solution at pH 4.0, the TTI showed a purple colour, while at pH 5.0 and 6.0, it showed a not very noticeable purple tone. At pH 7.0, the TTI showed a visible colour change to light blue. At pH 8.0, the TTI appeared a bright green colour. This colour intensified as the pH increased further from to pH 9, 10, 11 and 12 as shown in Figure 16 [40].

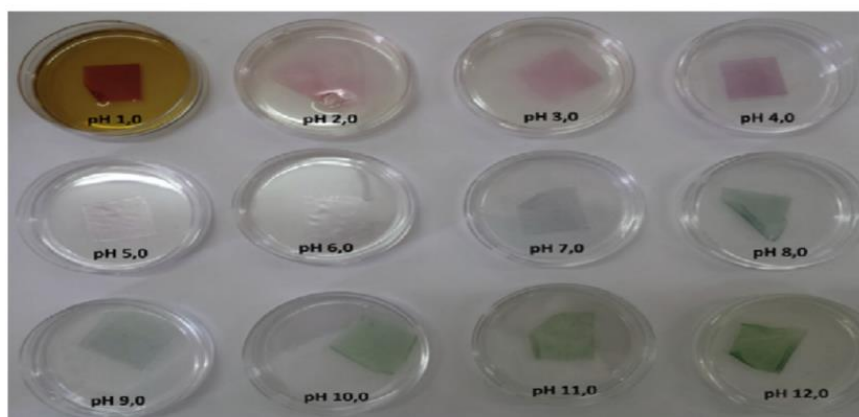


Figure 16. Indicator Colour Response at Different pH Conditions [40].

Potential Application of the TTI (Activation Test in Milk)

The pH of fresh milk is slightly acidic, ranging between 6.6 and 6.8, with an average of 6.7 at 20°C or 6.6 at 25°C. When milk is at a temperature that is above the maximum described for as ideal for cooling (7°C), it begins to decompose, which changes the medium's pH, reducing the stability of the milk. Many different factors, such as microbial contamination and subsequent accumulation of lactic acid due to microbial metabolism, can cause the pH of milk to lower. Therefore, milk spoilage can be

detected and monitored through a colourimetric pH monitoring system such as the TTI developed in this work. After coming into contact with the milk, a visible colour change was detected in the TTI samples (Figure 17), which at pH 6.7 (unspoiled milk) showed a dark grey colour that, as the pH decreased from 6.7 to 5.0, gradually became clearer, as shown in Figure 17. At pH 4.6 (spoiled milk), the TTI changed to a dark pink colour, clearly indicating milk spoilage [40].

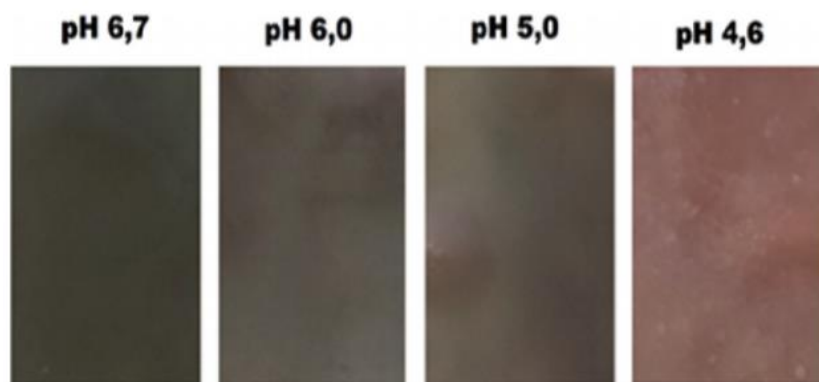


Figure 17. Indicator Colour Response in Contact with Pasteurized Milk at 25°C [40].

ADVANTAGES AND DISADVANTAGES OF INTELLIGENT PACKAGING

Advantages

- Provides the user with reliable and correct information on the conditions of the food, environment and packaging integrity.
- Enhanced food quality assurance.
- Monitoring quality reduces time and material costs in the analysis methods of packaged food.
- It helps to make good image of brand (d) advantages.

Disadvantages

- Extra cost and lack of recyclability of disposable packages.
- Possible mistrust/confusion of technology.

Table 4. Commercially Available IP System in Market with Trade Name [18].

Trade Name	Manufacturer	Products
Ageless Eye (Gas indicator)	Mitsubishi Gas Company, Japan	Sausage, chicken nuggets, nuts, dried fish
Freshtag (Freshness indicator)	COX Technologies, USA	Beef, meat, poultry, fresh seafood and fresh mushroom
Timestrip Complete (Time temperature indicator)	Timestrip UK Ltd., U.K.	Seafood, Frozen food
Checkpoint (Time temperature indicator)	Vitsab, Sweden	Meat, Poultry, Fish, dairy products
Easy2log (RFID)	CAEN RFID, Italy	Fresh food, Seafood, Meat, poultry, Milk based products

CONCLUSION

IP is an innovative technology in packaging industry for reducing the waste of packaging materials. Intelligent packaging is emerging as a new branch of packaging science and technology that offers exciting opportunities for enhancing food safety, quality, and convenience. It helps in product quality, shelf life of the products and more efficient supply chain management has to outweigh production costs. It has integrated to packaging system to meet the requirement of the consumer. This IP system can assist in the detection, monitoring, tracking, recording, and communication throughout the supply chain. It can increase consumer confidence in the safety of packaged food by indicating visual

indication by indicator (Table 4); reduce food waste by using indicators. The cost of the indicator is too high, so, further research is necessary to develop low cost indicators.

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