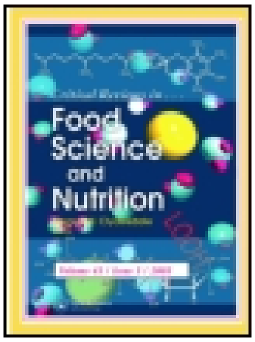

Critical Reviews in Food Science and Nutrition

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/bfsn20

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CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
https://doi.org/10.1080/10408398.2020.1817847

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REVIEW

Trends and applications of intelligent packaging in dairy products: a review

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ABSTRACT
Dairy products contain high contents of nutrients that favor the growth and proliferation of spoilage and pathogenic microorganisms, contributing to high risk in terms of quality deterioration and food safety. It has been demonstrated that packaging could protect airy products after manufacturing and it is capable of extending the shelf-life of these products. Among various kinds of packaging, intelligent packaging can utilized as an effective instrument for preservation of dairy products and also informs users about the entire background of the product. This review will address the attempts made toward developing intelligent packaging for dairy products including indicators (time temperature, gas & integrity and freshness), data carriers (RFID, barcode) and sensors.

KEYWORDS
Dairy products; intelligent packaging; shelf life; indicators; sensors; data carrier

Introduction

The main functions of food packaging are known as protection, containment, communication, marketing and ergonomics (Fuertes, Soto, Carrasco, et al. 2016). Packaging must provide food stuffs a powerful barrier to environmental influences like temperature fluctuation, light, moisture alteration, gasses, pressure, spurious odors, microorganisms, insects, dirt and dust particles, etc. (Kour et al. 2013). Nowadays due to changes in life style and increasing demand for packaged foods, packaging should not only represent a role as product's cover but also eventuate to competitive success in a global market.

These requirements toward packaging and articles intended to come into contact with food are systematically growing. In consequence of the growing consumers' interest and demand in consumption of fresh products with extended shelf life and controlled quality, producers have to provide modern and also safe packaging. It is a challenge for the food packaging industry and also is a driving force for the development of novel packaging technology (Wyrwa and Barska 2017, Zabihzadeh Khajavi et al. 2020). With the purpose of fulfillment these requirements, intelligent packaging is used in the food packaging sector. Intelligent packaging differs products from similar ones, since it can inform consumers about the shelf-life of packed products (Lee and Rahman 2014b).

This novel packaging technology reduces the pathogen detection time, improves the food safety, and helps us to monitor and proclaim information about the food quality, all over the supply chain (Majid, Thakur, and Nanda 2018). Intelligent or smart packaging is designed to monitor and proclaim information about the food quality. One of the fundamental properties of intelligent packaging is that it makes the consumer aware of the condition that the product has encountered during transport and storage chain (Kour et al. 2013). Occasionally it is also possible that product become spoiled before determined printed expiration date and can lead to food poisoning but by use of intelligent packaging we can prevent these circumstances, since these packaging can monitor temperature changes, microbial spoilage, package integrity, physical shock and the freshness of the packed products (Lu, Shiau, et al. 2013).

The food and beverage packaging has dramatically changed from traditional to advanced packaging. Traditional packaging only deals with the issues related to protection from external causes. Nevertheless, smart packaging cooperates internally (active packaging) and externally (intelligent packaging) with the environment and improves the visual attraction of the packed-products (MarketsandMarkets 2011).

Intelligent packaging is described as a packaging system that can perform smart functions such as sensing, detecting, recording, tracing, applying scientific logic and communicating information to extend shelf life, increase safety, improve quality, provide information for the consumer, and warn about external and internal problems in the products (Yam, Takhistov, and Miltz 2005, Lee et al. 2015).

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Microbiological and chemical tests of the products are regularly performed at the company level during production and before delivery. But in most cases, there is no such control after delivery to the supermarket. Intelligent packaging will close this gap as it monitors and displays the quality status from the point of manufacture up to the customer. This permanent monitoring minimizes unnecessary food waste and protects consumers against potential food poisoning, maximizes the efficiency of the food industries, and improves traceability (Müller and Schmid 2019). This novel packaging technology has great commercial potential with reducing food loss, food poisoning and allergic reactions. Intelligent packaging will also provide the consumers the opportunity to conduct in-house quality control (Ahvenainen 2003).

Rising health awareness among the customers is one of the most critical factors, which is anticipated to trigger smart packaging demanding during 2017–2025. In the current generation, consumers are becoming more health-conscious. Toxic materials used in traditional packaging, especially food packaging, are hazardous to consumer health. Consequently, consumers prefer smart packaging since they are safe and hygienic (Transparency 2017). The global smart packaging market has been segmented into regions of North America, Europe, Asia-Pacific, and the rest of the world (RoW). North America held the largest share in the global smart packaging market, followed by Europe and Asia-Pacific in 2018. Moreover, Asia-Pacific is the fastest-growing region and is expected to register a high compound annual growth rate (CAGR) during the forecast period (Market Research Future 2019). The global market for smart packaging systems was at a level of $31.4 billion in 2011 and $33.3 billion in 2012, respectively. The global demand for smart electronic packaging is expected to grow to over $1.45 billion over the next decade. In the US this type of packaging is anticipated to keep developing with an annual growth rate of 7.4%, reaching US $3,600 million in the current decade. The second largest market is Japan reaching the equivalent of US $2,360 million, followed by Australia with the equivalent of US $1,690 million; the UK, at the equivalent of US $1,270 million; and finally Germany, at a level equivalent to US $1,400 million (Schaefer and Cheung 2018).

Milk and its derivatives have high nutritional value which limits their shelf-life and challenges their handling process. Dairy products are included in highly perishable foods category since they are excellent medium for the growth of microorganism especially bacterial pathogens that can result in food spoilage and consumers diseases (Karaman et al. 2015). It has been proved that packaging has vital role in protection of dairy products after manufacturing and can be applied as an effective approach for prolonging the shelf-life of these products. Among different type of packaging, intelligent packaging can applied as a powerful tool for protection of dairy products and also informs users about the entire background of the product. As presented in Figure 1, this review will address the attempts made toward developing intelligent packaging for dairy products including indicators (time temperature, gas & integrity and freshness), sensors and data carriers (RFID, barcode).

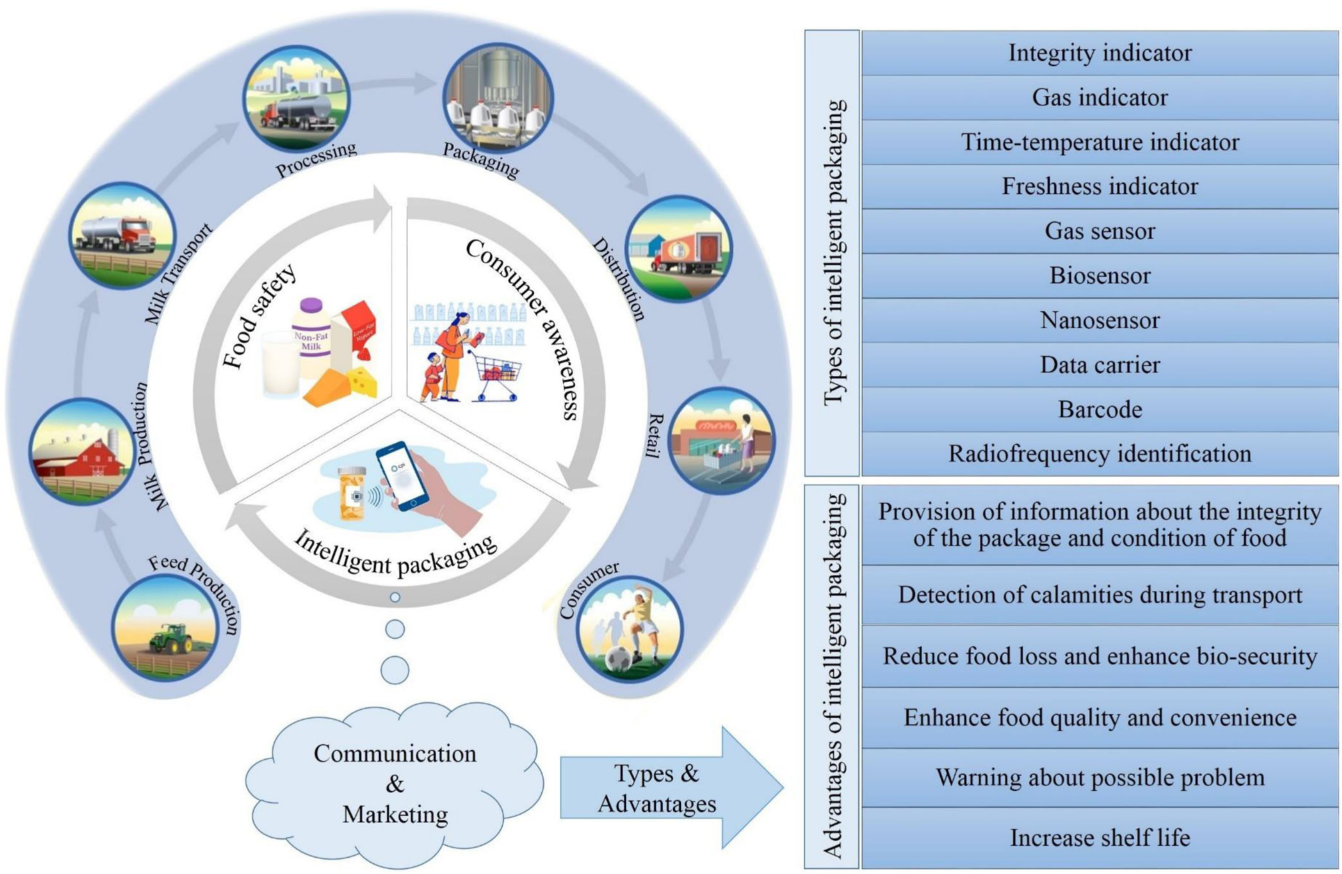

Figure 1. Graphical summary of the application and benefits of intelligent packaging in the dairy industry.

Search methodology

According to the present study in August 2020, published articles on trends and applications of intelligent packaging in dairy products were collected for the assessed. The search strategies and criteria for entering the study were as follows: the searching process were carried out utilizing keywords of "food packaging", "novel packaging", "intelligent packaging", "smart packaging", "milk", "dairy products", "indicators", "sensors", "integrity indicators", "gas indicators", "time-temperature indicators", "freshness indicators", "gas sensors", "biosensors", "nanosensors", "data carriers", "barcodes", and "radiofrequency identification" in titles and/or abstracts. All searches contained "food safety" or "food quality" or "shelf-life" or "consumer awareness" or "marketing" or "communications" or "smart labels" as the main goal of investigation. Databases, including Science Direct, PubMed, Embase, Scopus, Web of Science, and Google Scholar published from 1948 to August 2020.

Entry criteria

In this study, selected original books and articles were used, which were accepted in reputable journals and publications on the application of intelligent or smart packaging in milk and dairy products.

Exclusion criteria

Literatures, presentations and books related to other novel packaging, such as active packaging, were eliminated from the study. In addition, studies on the application of smart packaging in other food products such as meat products, fruit and vegetable products and etc. were excluded.

Data collection process

All the collected literatures were evaluated in two stages and through two reviewers for titles and abstracts. The final editing of the text and the final decision on the structure was conducted by the third reviewer after reading the complete article. Selected articles were classified according to the types of smart packaging.

Intelligent packaging in dairy industry

The packaging system has significant impact on the quality, safety, cost and even marketing of the dairy products. Packaging systems must preserve dairy products against physical damage, environmental pollutants, aroma alterations and moisture losing (Sohail, Sun, and Zhu 2018). Since dairy products particularly pasteurized milk are extremely perishable, it is crucial that packaging shields its protective properties during the whole supply chain until consumer consumption (Karaman et al. 2015; Ščetar et al. 2019). As a consequence of mentioned issues, currently interest has moved toward novel applications such as intelligent packaging, which beside the conventional properties of packaging, has the capability to apprize its consumers about the entire background of the dairy product including. Intelligent packaging can provide users wide variety of information regarding producing approach, expiry date, components, storage condition, informing the packaging material's damage, temperature variation, gas concentration alterations and microorganism growth inside the package environment (Bagchi 2012; Vanderroost et al. 2014). In the following parts, we will discuss the latest achievements and progress in the context of intelligent packaging for preserving the quality and safety of dairy products.

Indicators

Indicators are known intelligent or interactive as a result of their interaction with compounds in the food (Robertson 2006). The indicators directly visualize the alterations, which are happened in the packaging and they do not have receptor and transducer components in contrast to sensors (Mohebi and Marquez 2015). The regular indicators applied in the dairy packaging will be discussed in the following parts.

Integrity and gas indicators

Due to respiration of fresh foods, leakage, the permeation of gas through the packaging materials from the surrounding area and gas produced by microbial spoilage, the amount and composition of gases in the packaging headspace can be easily altered. Gas indicators in the form of printed on the packaging films or labels can be utilized in order to monitor the gas profile changes inside the package, as a result these kind of indicators can help us to ensure the quality and safety of the packed products (Lee and Rahman 2014b). By either a chemical or enzymatic reaction procedure, the color of these indicators changes, which could provide us information about the absence or presence of determined gases (De Jong et al. 2005). Among the gases, the level of oxygen (O_2) and carbon dioxide (CO_2) have critical role in quality of the packed dairy products. Accumulation of elevated level of oxygen in the packed dairy products can contributed to the spoilage, through oxidation of lipids and micronutrients, accelerating respiration, enhancing the growth of aerobic microbial and offensive changes in color, flavor, and odor. For this reason, several food products have modified atmosphere packaging (MAP) with decreased level of oxygen in the headspace. This kind of MAP can prolong the shelf life by about 3–4 times compared to not modified atmosphere packaging.

Generally dairy products are packed in modified atmosphere do not containing oxygen in the headspace for instance: Cheddar cheese packed in gas mixtures containing 70% nitrogen (N_2) and 30% carbon dioxide (CO_2), Fiordilatte cheese in 50% N_2 and 50% CO_2, Graviera Agraphon cheese in 50% N_2 and 50% CO_2, paneer in 50% N_2 and 50% CO_2, lal peda in (70% nitrogen (N_2) and 30% carbon dioxide (CO_2), dietetic rabri in 100% N_2 and Kalakand in 50% N_2 and 50% CO_2. Either due to the loss of seal integrity, presence of pinholes, or oxygen permeability

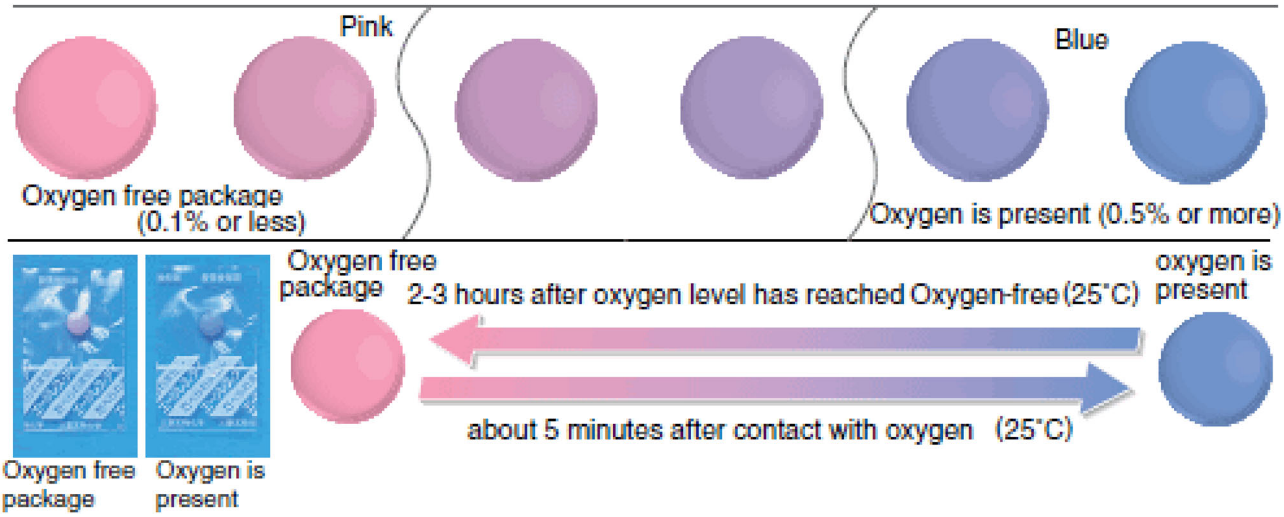

Figure 2. Schematic of a commercial integrity indicator.

of the packaging material, the concentration of oxygen in the headspace during storage could be changed. Compared to oxygen sensors, indicators are economical, portable and convenient to use, which make indicator an appropriate choice for integrating with packaging. Among the various types of gas indicators, the colorimetric oxygen indicators are the most commonly used ones specifically with MAP packaging. These indicators consist of a redox dye, a reducing agent, a photo-catalyst, and an encapsulating polymer (Deshwal et al. 2018). The colorimetric oxygen sensors could be competently used as the straightforward package integrity indicator given information about the opening of the package or entrance of oxygen or atmosphere modification in MAP systems. A commercial model of these indicators is Ageless Eye (Figure 2). This is an in-package indicator which indicates the existence of oxygen with only a quick look. When the oxygen level in the packaging goes up, the color the Ageless Eye will change from blue to pink (MGC).

Time-temperature indicators (TTI)

Nowadays, people are focusing on monitoring and controlling critical parameters through the whole food chain, instead of focusing on testing and verification of final products (Taoukis, Koutsoumanis, and Nychas 1999). Temperature is one of the most significant environmental factors, because temperature fluctuation has substantial impact on the quality and safety of packed dairy products. Therefore it is important to control continuously the time-temperature conditions of dairy products in cold chain system and also storage (Meng et al. 2018).

Time–temperature indicator (TTI) is an easy quality recording device that can show irreversible visual responses to inform ate important parameters all over the whole food chain from production to distribution and storage that gives shelf life information of food. Several perishable dairy products such as sterilized milk, have been studied and researched with TTI to show effectiveness and validity of this indicator (Lu, Zheng, et al. 2013). A time temperature integrator or indicator can be described as a simple, cheap device that can show a full or partial temperature history of a food product. The TTIs which are presently available on the market, are working with mechanisms based on different principles. The principle of TTI function is a mechanical, chemical, enzymatic or microbiological irreversible change, usually shown as a visible respond in the format of a mechanical transfiguration, color development or color movement or color changes (Pavelková 2013). Because of its easiness, low price, affordability, and efficiency, TTI has been widely used to monitor and give information to consumer about quality of the food. Different types of TTI trade are developed based on the enzymatic and polymeric and biological reactions (Fuertes, Soto, Carrasco, et al. 2016). Most commonly used TTI in dairy packaging are contingent on enzymatic reactions. Enzymatic types have many advantages compared to other types of TTI which have stable performance, low production cost and easy control. Its operation principle is based on producing an acid with the help of enzymatic hydrolysis in order to reduce pH value and then to dynamically show the cumulative effect of time and temperature by color change of an pH indicator (Lu, Zheng, et al. 2013).

Researchists focused on enzymatic TTI and developed numerous enzymatic TTIs over many years. Vitsab TTI (1981) was a typical commercial enzymatic TTI. Its functional principle was that the lipid substrate underwent hydrolysis by lipase at controlled situation, and the pH reduction caused irreversible color change duo to the pH reagent (Taoukis and Labuza 1989). In 1998, ProM TreVna developed a polyphenol oxidase TTI, which make use of the degree of enzymatic browning based on polyphenol reaction to show the shelf life of food. Later many kinds of TTIs were developed based on several types of enzymatic chemical reactions (Sigmund 1948). In 2006, Rani and Abraham developed an enzymatic TTI by anion peroxide dismutase extracted from plants. A newer amylase type TTI was developed by Sun Yan in 2008 (Riva, Piergiovanni, and Schiraldi 2001).

In 2012, an enzymatic TTI based on the reaction between Burkholderia cepacia Lipase and tricaprylin was developed (Kim, Park, and Hong 2012). The data gained with this TTI were in accordance with the predicted and measured values, which indicated its efficiency for shelf life prediction of packed products. In another study, laccase was used to make an enzymatic TTI by Keehyuk Kim. They defined the TTI's activation energy and verified the applicability of it (Kim, Park, and Hong 2012).

Freshness indicators

Freshness indicators is has been developed to provide consumers direct information about product quality, rather than only indicating temperature abusements or package leakages, using microbial growth metabolites which indicate that changes have been occurred inside the food (Lee and Rahman 2014a). Food freshness indicators are capable of ascertaining the freshness of the packed food products through reaction with microbial growth metabolites including: organic acids, glucose, volatile nitrogen compounds, carbon dioxide, ethanol, biogenic amines and sulfuric compounds (Sohail, Sun, and Zhu 2018). Conventionally freshness indicators are utilized in the form of labels on the packaging in order to indicate the quality of the products. Generally, these indicators concentrate on the detection of the first kind of alterations, which are occurred as a result of microbial growth (pH, gas composition, etc.). These changes are detected by the indicators and transformed into a response, usually a color change which can be easily measured and correlated with the freshness of food (Fuertes, Soto, Carrasco, et al. 2016). As an illustration Mimica Touch is a commercial freshness indicator that particularly applied for milk packaging. This indicator is compromised of three distinguishable regions as can be seen in Figure 3: the first region has a permanent smooth surface and is applied as reference for comparison with third region (bumpy region). The second region is where the predicated expiration date is written. Third region has a smooth surface until the food becomes spoiled and then it converted to a bumpy surface, indicating that food is not appropriate for consumption (Mimica). Another newly developed commercial freshness indicator is in form of a smart cap, which can be applied as a nondestructive device for detecting milk freshness without need to open it. This cap is manufactured by 3D printing and is enclosed several advanced constituents including: indicator, resistor, capacitor and a LC tank (Pendrill 2015). Other smart packaging designs with the freshness indicators utilized in the dairy products are shown in Figure 4 (Innovation2Market 2020, Weston et al. 2020).

Sensors

A sensor is a system to measure physical values and convert them to a signal which can be read by an instrument or via an observer. The most crucial features about sensors are their selectivity, sensitivity, and time of response. The selectivity of sensor is specified as the capability to separate a gas of interest aside from any interference. Sensitivity is applied to explain the ability to quantitatively measure the trial gas at assumed conditions, which depends on the intrinsic chemical and physical characteristics of the operate materials.

The response time is applied to evaluate the rate of the signal change throughout the difference in gas concentration. Additionally, irreversibility is a considerable factor for evaluating sensors performance (Ramamoorthy, Dutta, and Akbar 2003). In general, sensors can be categorized into three types; (I) gas sensors such as O_2 and CO_2 sensors which have been expanded for utilization in food packaging technologies (McEvoy et al. 2003), (II) biosensors are instruments, which make responds to the presence of a specific component (a biological or chemical analyte) that needs to be measured by generating an electrical signal proportional to the concentration of desired analyte (Gurtas 1997), and (III) Nanosensors which detect and measure chemical materials by physical or chemical responses to monitor external and internal conditions (to determination of microbes, contaminants, pollutants and food freshness) of the products (Ramachandraiah, Gu Han, and Chin 2015; Joyner and Kumar 2015). All these instruments have to be linked to a transducer in order to form an observable response.

Gas sensors

Detection of food spoilage by gas sensors is done in the beginning of the spoiling process. Gas sensors contain some

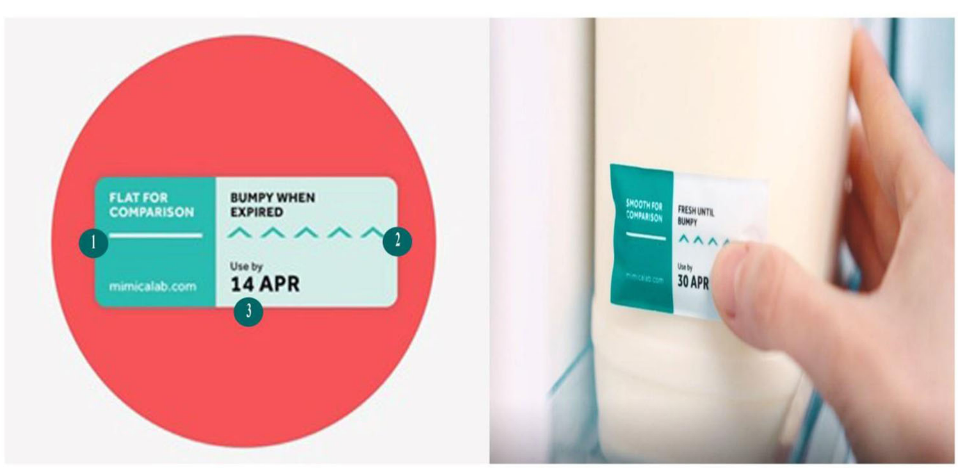

Figure 3. Schematic of a commercial freshness indicator.

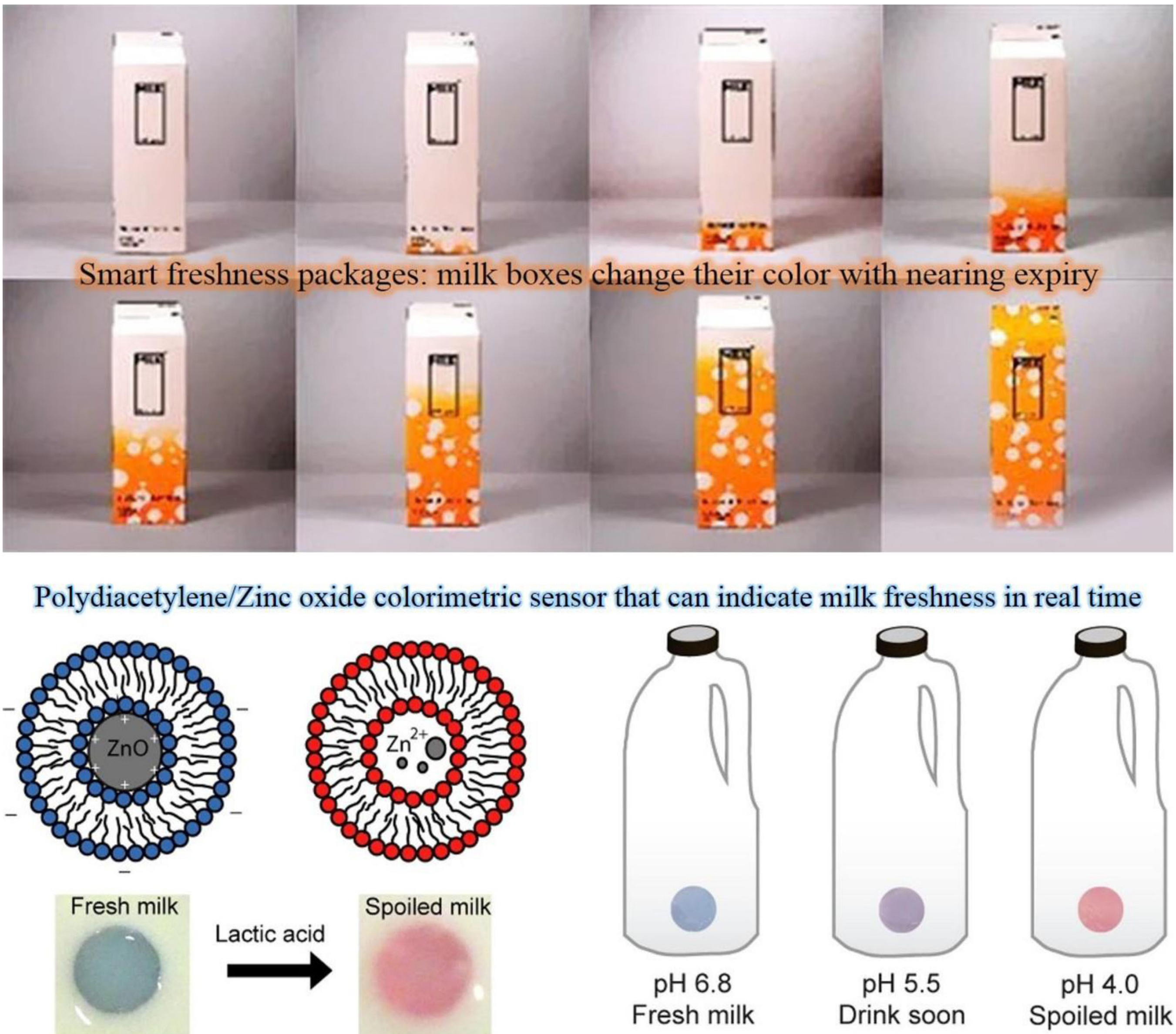

Figure 4. Examples of intelligent packaging schemes with freshness indicators in dairy products.

gas-sensitive components which can be activated by an operator. As the sensors are activated in its using temperature, the gas-sensitive components start a specified chemical reaction and cause a variation in electric resistance (Matindoust et al. 2016). The sensors can be utilized simultaneously and independently in a product. Usually, these sensors are optimized for a single analyte such as: H_2S, CO, SO_2, NO, NO_2, O_3, CL_2 and N_2H_4 (Gardner and Bartlett 1999). Communication is established, through readers and sensors. Information systems can control readers by instructing readers or applying middleware to immediately read and write data on sensors. Gas sensors can be applied in dairy packaging to assess alteration in gas concentration which could be a sign of microorganism existence or their growth, for instance a commercial solid-state gas-sensor array system has been developed for monitoring the growth of disinfectant-resistant bacteria in milk, which known to cause spoilage, namely some Serratia spp., Pseudomonas pp., Bacillus spp., *Staphylococcus aureus*, *Candida pseudotropicalis* and *Kluyveromyces lactis* (Gutiérrez-Méndez et al. 2008). The sensors such as oxygen and carbon dioxide are classified mainly in two types, electrochemical and optical sensors, on the basis of their immanent chemical or physical properties (Cammaroto et al. 1998; Yao and Wang 2002; Puligundla, Jung, and Ko 2012). In food products packaging, the amount of carbon dioxide and oxygen gasses are important factors to foretelling their microbial and chemical quality. Determination of carbon dioxide level in the headspace of food packages can also be applied as a method for detecting ripeness or spoilage of food products because carbon dioxide is generated continuously during the growth of microorganisms, spoilage or fermentation (Meng et al. 2014).

Hempel et al., (Hempel et al. 2012) have studied the capacity of optical oxygen sensors in commercial vacuum packed cheddar cheese to detect containment packaging failures. They have shown that, oxygen levels present in packs instantly after packaging and over first six days of storage at 4 °C, were 3 percent on average. Further ingress of oxygen into all packs occurred over time and oxygen levels ranged from 3.6% to 8.2%. The results of this research have approved the effectiveness of oxygen sensors application for identification of the packaging containment failure.

In another study, the nondestructive assessment of optical oxygen levels in 67 samples of industrial modified atmosphere packaged cheddar cheese (MAP conditions of 70% N_2: 30% CO_2) was carried by O'Mahony et al. (2006). They have indicated that, three faulty packs with oxygen leakage were distinguished during 1–11 days after packaging, while in the remaining packs low levels of residual oxygen were observed (<0.75%). Residual oxygen was investigated during four months of product shelf life at +4 °C, along with evaluation of microbial growth. The system of oxygen sensor was shown to provide precious information about efficiency of the packaging technology, storage conditions of product and food quality. In addition this sensor was cost-efficient and nondestructive.

Dissolved oxygen (DO) is a critical quality parameter in dairy products and must be monitored. High level of DO reduces shelf life and compatibility for consumption, also affects the main quality parameters of dairy products such as nutritive value, color and taste. Natural milk contains about 8 mg/kg oxygen which is desired to be decreased to 1 mg/kg (Carlsson and Jönsson 2012). To assure DO level of dairy product, Oxy 510 Inline Oxygen Sensor© (produced by Anton Paar Co.), can be employed. This sensor can be directly utilized in the production line in order to provide an accurate and reliable monitoring of DO for a wide range of concentrations (Anton Paar Co. 2018).

Another study have been conducted by O'Callaghan, Papkovsky, and Kerry (2016) on the assessment of oxygen levels in cheddar cheese (commercial MAP) by nondestructive oxygen sensor system. They have inserted oxygen sensors into flow-wrapped cheese packs (768 sensors in 384 packs). The findings indicated that oxygen contents increased in both groups examined over the 30 day evaluation period. The group which simulated industrial distribution path and handling manners of commercial retailing exhibited the highest content of oxygen and the highest rate of package failure.

Carbon dioxide can be used to increase the shelf life of raw milk, pasteurized milk, and dairy products at low temperatures. CO_2 is a unique antimicrobial compound capable of improving the quality of dairy products. It also has a preventing and controlling role in spoilage by bacteria, molds and fungi in milk-based products. CARBOTEC TR-PT© (produced by Centec Co.) is a carbon dioxide sensor for determination of CO_2 in carbonated drink and dairy products (Centec Co. 2018). The carbonated foods flows through the head of sensor (chamber) and CO_2 is measured. Several times the chamber is closed and its volume quickly increases. This extension has produced a gas phase in the chamber. The major partial pressure difference of carbon dioxide, forces the CO_2 out of the matrix (liquid in the chamber) into the gas phase.

Biosensors

A biosensor is an analytical system with a bio-diagnosis element that converts the biological response into a traceable and quantifiable electrical signal. There are various classifications of biosensors for analyzing a wide range of materials based on different operating principles such as electrochemical biosensors (Hansen et al. 2006), optical biosensors (Haes and Van Duyne 2002), immobilized based biosensors (Sassolas, Blum, and Leca-Bouvier 2012), piezoelectric (Zhou et al. 2002), microbial biosensors (Su et al. 2011) and nanomaterials based biosensors (Pérez-López and Merkoçi 2011). Biosensors are made up of three main components (Adley 2014): (I). the base material of sensor has made of polymer, glass, metal or even paper, which is coupled with bioreceptor, (II) the bioreceptor such as enzymes, antibodies, cellular structures/cells, nucleic acid aptamers/single stranded DNA, bacteriophage and biomimetic (Velusamy et al. 2010), which is coupled in the sensor via physical or chemical immobilizing techniques, and (III) the transducing element. Biosensors can be used for detection of urea (Verma and Singh 2003), *Escherichia coli* (Anko, Kurittu, and Karp 2002), Listeria spp., Micrococci spp., and full-spectrum antibiotics (Thapar, Salooja, and Malik 2017, Kumar et al. 2013), aflatoxin M1 in milk and dairy products (Paniel, Radoi, and Marty 2010). Figure 5 illustrates a schematic diagram of a biosensor. At the first, target analyte is identified by bioreceptor and the transducer system converted biological responses into equivalent electrical signals. The

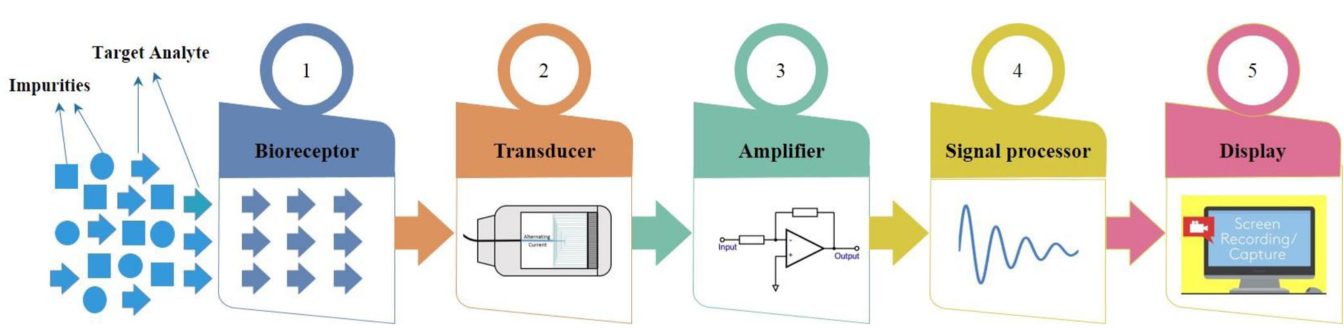

Figure 5. Schematic diagram of principle function of a biosensor.

amplifier enhances the small signal from the transducer and releases and converts it to a large output signal that contains the main wave shape features of input signals. Eventually, the signals are then processed by the signal processor to the stored or recorded, displayed and analyzed forms.

Trivedi et al., (Trivedi et al. 2009) have applied the potentiometric biosensor for urea determination in milk. They have used thick film screen printing technique for the fabrication of the basal conducting route of the potentiometric electrode and also Ag/AgCl as a reference electrode. The ion sensitive polymer matrix membrane was made in the presence of an electrochemically inert filter paper. Urea biosensor have developed by immobilizing the urease enzyme via entrapping onto the ion sensitive membrane utilizing a polymer matrix of polyethyleneimine and poly(carbamoyl)-sulphonate. The limit of detection and average slope in the linear range of biosensor were 2.5×10^{-5} mol/L and 51.7 ± 0.5 mV/decade, respectively.

The presence of allergens in food products such as milk and dairy products has increased the safety consternations. A label-free electrochemical immunological biosensor for detection and determination of β-lactoglobulin, as an allergen found in milk, was developed with a detection limit of 0.85 pg/mL by Eissa et al. (2012). The biosensor was formed on organic film (graphene-modified screen printed electrode) with immobilized β-lactoglobulin antibodies. The bound β-lactoglobulin was quantified by determining the reduction peak of ferricyanide and ferrocyanide ($[Fe(CN)_6]^{3-/4-}$), which linearly decreased with the increase of β-lactoglobulin content.

Another analyte of concern in milk and dairy products is bisphenols A (BPA). BPA is widely used as monomer in the manufacturing of polycarbonate plastics and epoxy resin, which are employed in production of a variety of food packaging materials such as water and dairy bottles and coating material for processed food cans (Kang and Kondo 2003; Szymański, Rykowska, and Wasiak 2006; Lim et al. 2009; Goodson et al. 2004). Alkasir, Ornatska, and Andreescu (2012) developed an enzyme based nanoparticle functionalized electrochemical biosensor for fast and sensitive detection of BPA. The biosensor modified with Nikel nanoparticles displayed higher sensitivity and a lower detection limit of 7.1 nM, in comparison with the biosensors modified with ferric oxide (Fe_2O_3) with limit of detection, 8.3 nM and gold nanoparticles (AuNPs) with detection limit of 10 nM. In addition, a paper based colorimetric biosensor was applied for detection of phenolic compounds like as BPA. The paper biosensors showed a detection limit of 0.86 µM and indicated high stability during long term application (260 days), maintaining 92% of its activity.

Melamine is a high-rich nitrogen content organic compound associated with severe toxicity for humans (kidney failure), which illegally added into milk and dairy products. Rovina, Siddiquee, and Wong (2015) have developed a melamine biosensor based on ionic liquid/nanoparticles/chitosan with modified gold electrode for detection and determination of melamine in milk products. They have reported that melamine biosensor can be applied for the determination of melamine with detection limit of 9.6×10^{-16} M and concentration in the range of 9.6×10^{-15}–3.3×10^{-3} M. Thus, it can be applied for the determination of melamine in milk products during food inspection.

Lactose intolerance is a disorder resulting from the decreased ability to digest lactose (a sugar found in milk). It occurs in individuals lacking the enzyme (β-galactosidase), which is responsible for digestion of lactose into galactose and glucose (Paige et al. 1975; Mustafa and Andreescu 2018). Several types of electrochemical biosensors have been developed for lactose quantification utilizing co-immobilized glucose oxidase and β-galactosidase enzymes (Ammam and Fransaer 2010; Watanabe et al. 1991; Marrakchi et al. 2008). Various enzymatic sensors have been produced for the determination of low amounts of lactose in lactose-free dairy products, such as LactoSens® (Directsens, Klosterneuburg, Austria) biosensors. This biosensor has been applied for the detection of residual lactose in lactose-free milk and dairy products. The LactoSens® sensor is formed of the core element by use of an optimized enzyme, which is immobilized on an expendable test strip (Alkasir, Ornatska, and Andreescu 2012).

Nanosensors

Nanotechnology in consist of the study, plan, development, combination, utilization, and usage of materials, systems, and functional devices through the control and operation of characteristics of material on a nanoscale length (1 to 100 nm). The smart food packaging has been expanded by development of new technologies for instance application of nanomaterials, nanoparticles and nanosensor in packaging material. The nanosensor interacts with food components (as internal factors) and packaging materials (as environmental factors). As a consequence, the nanosensor will generate a detectable response (such as visual or electric signal) that relates with the condition of the food product (Fuertes, Soto, Vargas, et al. 2016). The nanosensor is made of bio-nanocomposite polymer matrices reinforced with a nanofillers material such as silica nanoparticles (SiO_2), clay nanoplatelets, starch nanocrystals, carbon nanotubes or graphene, chitin or chitosan nanoparticles, cellulose nanofibers, and metal oxide nanoparticles (for example, Ag, Cu, CuO, TiO_2, ZnO, Pd, Fe) (Ranjan, Dasgupta, and Lichtfouse 2016). The nanosensors are planned to increase the rate of detection and quantification of hazardous chemical substances, such as allergens, pesticides, chemical and microbial toxins, spoilage products, and environmental changes including: humidity, temperature, and gas level (Kim et al. 2013). Generally, nanosensors are used in food packaging for monitoring internal and external conditions of the foods, during the various stages of process and storage and also for evaluating possible contaminants in products to ensure the consumer from the quality of foods to (Fuertes, Soto, Vargas, et al. 2016). In common with sensor, nanosensor is fabricated of two basic components: receptor and transducer. The receptor can be organic or inorganic substance which interacts with a selected analyte and

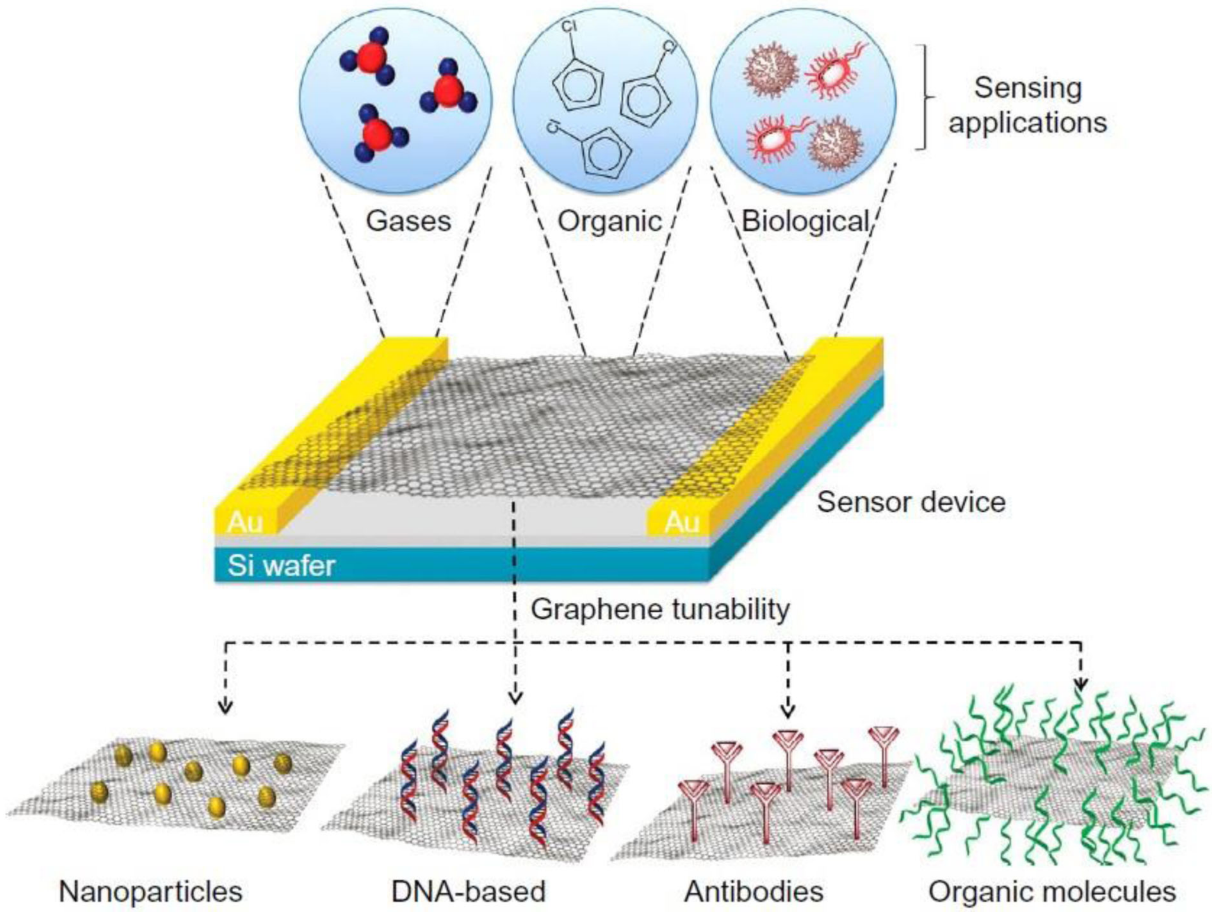

Figure 6. A scheme of modified graphene-based nanosensor effect transistor system for various sensing applications.

transducer transforms the identification event which occurred between the receptor and analyte into a measurable signal (including: electrical, electrochemical and optical signals). For example, graphene-based nanosensor devices (Figure 6) have been developed for detection of environmental contaminants, gases, pH, DNA fragments, antibiotics and chemical components (Sundramoorthy, Vignesh Kumar, and Gunasekaran 2018; Perreault, Fonseca De Faria, and Elimelech 2015).

Nanosensors are exercised extensively in dairy industry for detection of microorganisms such as: *Mycobacterium avium* subsp. paratuberculosis by a sonicate immunoassay based on surface-enhanced raman scattering (Yakes et al. 2008), *Brucella abortus* antibodies in milk by fluorescent, micellar silica nanosensors (Vyas et al. 2015) and *Escherichia coli* O157:H7 in milk by Au nanoparticles modified screen-printed carbon electrodes (Lin et al. 2008). In addition, nanosensors technology can be applied in milk and dairy products for detection of various kind of compounds including: β-lactoglobulin protein as allergen by antibody modified graphene film (Eissa et al. 2012), antibiotics residues in milk by quadruplex gold immunochromatogaraphic assay (Zhou et al. 2018), melamine in raw milk and infant formula by hydrogen-bonding recognition-induced color change of gold nanoparticles (Ai, Liu, and Lu 2009), and different types of estrogens (estrone, estradiol and estriol) in milk and milk powder samples by Fe_3O_4/TiO_2/graphene oxide magnetic microspheres (Tian et al. 2013).

Methods for detecting biomarkers of inflammation, infection, and/or bacterial activity in dairy production, which indicate issues with the milk itself or issues related to the health of the cow. Troyer et al., (2019) have invented new nanosensors for detecting enzymatic activity in dairy products. The methods generally comprise contacting a milk sample with a nanoplatform assembly to create an assay solution, and detecting spectral changes in the assay solution that are triggered by enzymatic activity (when present) in the sample. The nanoplatform was a pyrene-fluorophore and a coumarin acceptor with $Fe/Fe_3O_4^-$ nanoparticle for detecting biomarker activity based upon surface plasmon resonance and Förster resonance energy transfer (FRET). The nanoplatform assembly comprises a first particle (a core/shell nanoparticle comprising a metal or metal-alloy core and a metal shell), a second particle (is selected from the group consisting of nanoparticles, chromophores/luminophores, quantum dots, viologens, and combinations thereof.), and a linkage there between, wherein the linkage comprises a protease consensus sequence (the sequence of amino acids cleaved by the protease), or an ester linkage (cleaved by a protease or lipase). A plurality of second particles can also be linked to the first particle. Test strips are also described, which undergo a visual color change in the presence of the target enzyme in the milk sample (Troyer et al. 2019).

Data carriers

Data carrier devices can be defined as automatic identification devices that facilitate flow of information in food supply chain and allow the promotion of food quality and safety (McFarlane and Sheffi 2003). Carrier devices are mainly intended for traceability, automatization, labor saving costs, prevention of product recalls, theft prevention, or counterfeit protection (Hozak and Collier 2008; Tajima 2007; Ustundag and Tanyas 2009). Barcode labels and RFID tags are the most common data carrier devices, which are utilized in the food packaging sector (Ghaani et al. 2016).

Barcodes

Nowadays the barcode has almost entirely become an inalienable part of conventional packaging with an aim of simplifying distribution and retail checkout. Barcodes are the most economical category of data carriers, which were introduced in the 1970s in the form of Universal Product Code, known as UPC barcode. The UPC barcode is a linear one-dimensional symbolism of bars and spaces, which depicts 12 digits of data. Due to the sparse storage capacity, these kinds of barcodes provide the maintenance of extremely limited data like producer distinguishing number or item number (Butler 2008). Despite of UPC, two-dimensional data matrix code has substantially greater content, which allows the transfer of data up to 1.1 kilobytes. Two-dimensional barcodes provide the encoding of supplementary information like nutritional value, cooking recipes and even through these barcodes consumer can get access to manufacture's website, where they can find further information about the product (Yam 2012). Tingting et al. have examined the efficiency of a recently developed barcode in china defined as Chinese-Sensible code, for traceability of dairy product from field to table. They have gathered data about feed origin, cow health, responsible man, raw milk production and transportation system and have coded them. The results indicated that these barcodes are capable of providing appropriate traceability system for dairy products (Li, Li, and Liu 2015).

Radiofrequency identification (RFID)

Radio frequency identification (RFID) tag is an advanced form of wireless data information carrier that applies radio waves to identify and trace a product. In this system RFID tag provides unique identifiers and important information that can be captured by a reader through emission of radio signal. The data is then passed to a computer for analysis so users can receive alerts and view data for instance, temperature and relative humidity data, nutritional information and cooking instructions. Typically, RFID tags are attached to the products that are to be tracked (Ghaani et al. 2016). A RFID tag is consisted of a tag chip attached to an antenna that has been printed, etched, stamped or vapor-deposited onto a mount which is regularly made of paper materials or Polyethylene terephthalate (PET). The combined chip and antenna, is then converted or sandwiched between a printed label and in this form can be attached to the products. Tag antenna is responsible for collecting energy and transforming it to the chip to turn it on. In general, the antenna with larger area will be able to collect and channel more energy toward the tag chip, so that the tag will have the further read range (Ali and Haseeb 2019). Tags can be divided into three main categories including: passive, semipassive and active:

- ***Passive tag:*** this tag is powered by harvested energy from the electromagnetic field produced by the interrogator and does not encompass a battery itself.
- ***Semipassive tag:*** this tag contains the battery, which just supplies power for to the tag IC.
- ***Active tag:*** this kind if tag provides power to all functions.

Application of RFID technology in the food system has the potential to revolutionize the way checkout at grocery stores, since RFID does not need to be in a direct line of sight to be identified by a scanner like conventional barcode (Dabbene, Gay, and Tortia 2014).

De Las Morenas et al. (2014) have developed an RFID solution for monitoring and tracing the temperature of collected milk sample vials during the transportation from farm to factory. The results indicated that utilization of RFID in raw milk transport chain can prevent unwanted deterioration of milk and ensure its safety (De Las Morenas, García, and Blanco 2014). In another study two different systems for doing reading/writing tasks in cheese factory were developed based on implementation of RFID tags. The main purpose of these systems was to provide complete traceability of the products, both in individual and batches forms and also to facilitate the process of quality certification by technical staffs. In one system traceability and controlling was performance by the personal computer whereas in the other system Pocket-PC was utilized. It was demonstrated that approximately two hundred variables related to the different stages of the cheese production platform can be stored in the tag, which contributes to significant improvement in the quality and yield control of the production plant (Pérez-Aloe et al. 2010). In another investigation, a quality analysis system for a typical Italian cheese called "*Caciottina massaggiata di Amaseno*" based on the integration of RFID tags was performed.

Quality analyses including: chemical, sensorial and spectrophotometric tests were done on a total of 23 selected cheese wheels and also for three cheese maturation periods (3, 6 or 9 months after production) and the obtained dada from experimental test were compared to reflectance values from RFID tags. It was revealed that RFID system had made a good estimation of maturation degree, which makes it an effective reliable process tool. It could also provide a web-based system for identifying the single and specific cheese product and improve information transparency for the consumer (Papetti et al. 2012). In another study a RFID traceability system was presented for a high-value, pressed, long-ripened cheese. In this research different approaches were examined for fixing tags to the cheese, in order to find best method for automatic identification of different steps

Table 1. Some commercial RFID tags applied in intelligent dairy packaging.

Product	Description					Brand	Country
	Chip	Conduct Material	Substrate	Tag Size	Frequency		
NFC Counter Sticker Milk Powder Source Tracking tag	Ntag 213, Ntag 216, Ntag 203 or Compatible chips	Aluminum Etching / 9um thickness	PET of 50um thickness	45*25mm	13.0-14.5 MHz	[GRAPHIC]	China
NFC seal anti-counterfeiting label tag for Milk powder can	SIC 43N1F, Higgs 3, M4 or customized	Aluminum Etching / 9um thickness	PET of 50um thickness	Customized	13.0-14.5 MHz	[GRAPHIC]	China
13.56 MHz NFC metal tag for milk powder Brand Anti-counterfeiting	Ntag 213, Icode slix, 43NT etc	Aluminum Etching / 9um thickness	PET of 50um thickness	38*38 mm	13.0-14.5 MHz	[GRAPHIC]	China
RFID Hf Anti Metal Tag Sticker for Milk Powder Checking	Ntag 213	Aluminum Etching	PET	45*30mm	13.0-14.5 MHz	[GRAPHIC]	China

(including: the production, handling in the maturing room and warehouse, delivery, packing and selling phases) in a dairy factory (Barge et al. 2014). Some commercial RFID tags applied in intelligent dairy packaging have been summarized in Table 1 (Xminnov 2020).

Legal and safety aspects of intelligent packaging

Industrialization is always accompanied with exposure of human to more organic and inorganic pollutants, chemical contaminants, which are introduced and released with the development of technology and these are influencing not only human but also biological life (Alp and Yerlikaya 2020). There are several sources of contaminant residues in the food supply chains, but of the most significant portion of residues could be aroused from packaging materials including plasticizers, surfactants, stabilizers, antioxidants, resins, antimicrobials, inks, resins, polymers, adhesives, pigments, solvents, oils, monomers and other additives (Karmaus, Osborn, and Krishan 2018).

Currently, most studies concentrate on the investigation of intuitive migration rolls. However it is also important to study the migration of compounds from food packaging material (Ji et al. 2020). Therefore identifying the substances, which are released from food packaging is vital due to their potential impact on consumer safety as well as alteration of sensory and nutritional characteristics of packed food (Karmaus, Osborn, and Krishan 2018). Although food contact materials are suggested to protect food from external contamination and preserve nutritional value, physical and sensory quality of food, they could also have undesirable effects on aforementioned properties as a result of migration phenomenon (Zabihzadeh Khajavi et al. 2019). Migrating substances from food contact materials could be categorized as intentionally or non-intentionally added. The latter contamination is difficult to control, since they are not chemically well characterized and generally are presented at low concentration levels (Ubeda et al. 2020). While the main function of the novel food packaging technology is to increase the margin of food quality and safety, besides its basic function of containment, it also could release some unwanted components to the packed foods. Generally the safety concern related to intelligent packaging should be noticed in the context of following important points:

1. Labeling: Suitable labeling should be done so that prevent misuse and misunderstanding by the users, e.g. to prevent sachets from being eaten from consumers (Majid et al. 2018).
2. Migration: The migration of intelligent substances in terms of their toxicity should be kept in consideration and their migration process should comply with food legislation. Monitoring the migration means to adapt some mass transfer modeling tools and migration tests other than those applied or recommended for conventional plastics, as they cannot be adapted to intelligent system (Restuccia et al. 2010).
3. Efficient packaging: Most importantly the claimed function of food packaging in few cases can give rise to safety concern as for any food preservation technology (Dainelli et al. 2008).

For authorization, a petition should be prepared of the intelligent substance in a similar way as is required for normal plastic packaging. Some other items that will likely be included in the draft regulation are (Dainelli et al. 2008):

- The released substance is excluded from the overall migration;
- Food shall comply with food regulation;
- The intelligent packaging should be suitable and effective for the intended purpose;
- Materials that may be mistaken as a part of the food (e.g. loose sachets) must be labeled using the symbol for the non-edible part;
- The declaration of compliance and supporting documentation.

According to EU Commission Regulations No 450/2009 on the safety assessment of smart and active packaging, not introduce any ingredients into the food to the extent that it poses a risk to human health, and also does not lead to an unacceptable change in the composition of the food and their taste or smell, while it should not mislead consumers through its labeling, presentation or advertising components. The following should be considered in assessing the risks associated with diet exposure to chemicals resulting from this type of packaging: I) the migration of the active and/or intelligent substance(s), II) the migration of their degradation and/or reaction products, and III) their toxicological properties (Authority, European Food Safety 2009).

Conclusion

Intelligent or smart packaging is purposed to control and proclaim information about the food quality. These packaging are capable of making the consumer aware of the condition that the product has encountered during transport and storage chain. Periodically it is possible that product become spoiled before determined printed expiration date and can lead to food poisoning but by use of intelligent packaging we can inhibit these circumstances, since these packaging can monitor temperature changes, microbial spoilage, package integrity, physical shock and the freshness of the packed products. This novel packaging technology has great commercial potential with reducing food loss, food poisoning and allergic reactions. Intelligent packaging will also provide the consumers the opportunity to conduct in-house quality control.

Acknowledgements

This study is related to the project NO. 1397/68947 from Student Research Committee, Shahid Beheshti University of Medical Sciences, Tehran, Iran. We also appreciate the "Student Research Committee" and "Research & Technology Chancellor" in Shahid Beheshti University of Medical Sciences for their financial support of this study.

Disclosure statement

No potential conflict of interest was reported by the authors.

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