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ORIGINAL PAPER

Smart packaging: sensors for monitoring of food quality and safety

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Abstract The development of chemical sensors and biosensors over several decades has been investigated resulting in novel and very interesting sensor devices with great promise for many areas of applications including food technology. The incorporation of such sensors into the food packaging technology has resulted what we call smart or intelligent packaging. These are truly integrated and interdisciplinary systems that invoke expertise from the fields of chemistry, biochemistry, physics and electronics as well as food science and technology. Smart packaging utilises chemical sensor or biosensor to monitor the quality & safety of food from the producers to the costumers. This technology can result in a variety of sensor designs that are suitable for monitoring of food quality and safety, such as freshness, pathogens, leakage, carbon dioxide, oxygen, pH, time or temperature. Thus, this technology is needed as on-line quality control and safety in term of consumers, authorities and food producers, and has great potential in the development of new sensing systems integrated in the food packaging, which are beyond the existing conventional technologies, like control of weight, volume, colour and appearance.

Keywords Smart packaging · Intelligent packaging · Chemical sensor · Biosensor · Food quality and safety

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Introduction

Over the years, the food industry has answered the call for diverse choices of convenient food items, with food and beverage packaging paving the way. Packaging materials have traditionally been chosen for convenient and to avoid unwanted interaction with food [1]. In 20th-century packaging developments such as packages incorporating antimicrobials and oxygen scavengers have been established new precedents for prolonging shelf-life and protecting food from environmental influences. These new packaging systems are called active packaging [2].

Nevertheless, omnipresent global trends such as increased industrial processing of food, greater importation and exportation of food products, and less time for preparation of fresh foods compel the food and beverage packaging industry to investigate newer, more advanced packaging solutions to meet the demand for healthier, safer, functional, and cheaper, as well as more convenient processed foods. Thus, while protecting and preserving food were once perceived as the principal roles of food packaging [3], facilitating convenience has quickly emerged as equally important. Other elements of increasing importance in food packaging include traceability, tamper indication, and sustainability [4]. These newer packaging systems are called smart or intelligent packaging.

In this review, we focus on the aspects of smart packaging that are related to the integration of sensor technology for food quality and safety, it's concept and principle, as well as it applications for food quality and safety are described including sensors for the detection of microbial and contaminants. In addition, we also discuss the application of radio frequency identification (RFID) tags on food packaging as identification, tracking and authentication.

Smart packaging concept

Smart or intelligent packaging was defined as an integral part or inherent property of a pack, product, or pack/product configuration, which confirm intelligence appropriate to function and use of product itself [5]. Other definition stated that intelligent packaging is the package function switches on and off in response to changing external/internal conditions, and can include a communication to the customers or end users as to the status of the product [6]. Therefore, intelligent packaging can be stated as system that monitor the condition of the package food to provide information about the quality during transport and distribution [7] or by simple definition, smart packaging is packaging which senses and informs the condition of the product. Thus, the term can be used in a broad sense including features concerning product identity, authenticity and traceability, tamper evidence and theft protection as well as safety and quality issues.

There is an important distinction between package functions that are smart, and those that become active in response to a triggering event, for example, filling, exposure to ultraviolet, release of pressure etc., and then continue until the process is exhausted. Figure 1 shows the model of packaging function between active packaging and smart packaging [7]. Table 1 list some active packaging that are already exist in the market and smart packaging concepts that are under development. A good example of active packaging is oxygen scavengers that can be incorporated into the packaging system itself rather than being added as sachets or label. One example is the Darex oxygen scavenger that can be incorporated into crowns, cans and a variety of metal and plastic closure. The system offers flavour stability and extended shelf-life for products such as beer, wine, tomato-based products, fruit drinks, etc. [8]. While, a good example of smart packaging is time–temperature indicators (TTIs) that show irreversible change in a physical characteristic, usually colour or shape, in response to temperature history. These devices are expected to mimic the change of a certain quality parameter of the food product undergoing the same exposure to temperature. Some are designed to monitor the evolution of gases and changes in temperature along the distribution chain, while others are designed to be used in consumer packages. In order to be used as food quality and safety monitoring devices, the rate of change in the device must correlate well with the rate of deterioration of the food product. The rate of device changes must also correlate with the temperature variation over time during transportation and distribution [9].

While active packaging incorporates robust ways to control oxidation, microbial growth, and moisture, smart packaging designs facilitate the monitoring of food quality [10]. TTIs, ripeness indicators, chemical sensors, biosensors and RFID are all examples of components in smart packaging. Most of these smart devices have not had widespread commercial application, but two are gaining more notoriety namely TTIs and RFID.

TTIs can play a critical role in indicating the freshness and safety of a food product. They monitor and communicate which food products are safe to consume, and which are not. This becomes extremely important when food is stored in less than optimal conditions such as extreme heat or freezing. In the case of foods that should not be frozen, a TTI would indicate whether the food had been improperly exposed to cold temperatures. Conversely, a TTI could specify whether foods sensitive to heat had been exposed to unnaturally high temperatures and the duration of exposure.

Radio frequency identification provides wireless monitoring of food packages through tags, readers, and computer systems. Its uses within the food industry are numerous and range from facilitating the traceability of

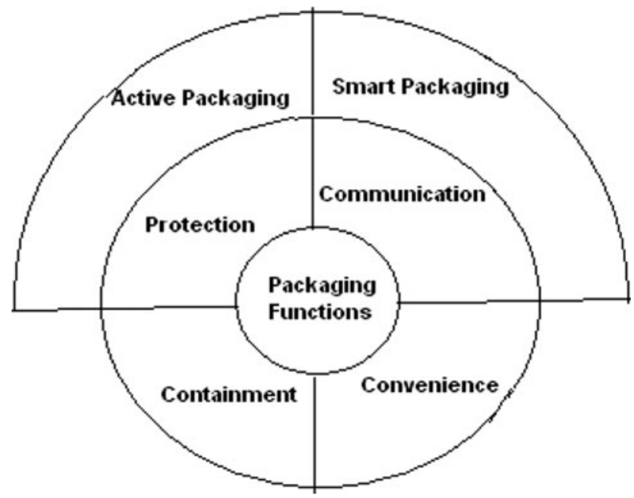

Fig. 1 Model of packaging functions [7]

Table 1 Examples of active and smart packaging

Active packaging	Smart packaging
Anti-microbial	Time–temperature indicators
Ethylene scavenging	Microbial spoilage sensors/indicators
Heating/cooling	Physical shock indicators
Moisture absorbing	Leakage sensors
Odour and flavour absorbing/releasing	Allergen sensor
Oxygen scavenging	Microbial growth sensors
Spoilage retarder	Pathogens and contaminants sensors

food to improving the efficiency of supply chains. But perhaps the ultimate benefits of RFID in food packaging are that it speeds stock rotation and improves tracking. RFID systems are beneficial for many food manufacturing operations and supply chains. Developing a smart food packaging for food quality and safety would require RFID to become more established in the food industry and the integration of food science [7]. Retail chains such as Wal-Mart and Home Depot already use RFID, because RFID systems provide safety and security benefits by tracking the origin of food supplies, retailers are considering ways to integrate this technology into the management of their supply chains.

Smart packaging principle

'Smartness' in packaging is a broad term that covers a number of functionalities, depending on the product being packaged, including food, beverage, pharmaceutical, and various types of health and house hold products. Examples of current and future functional 'smartness' would be in packages that (a) retain integrity and actively prevent food spoilage (shelf-life); (b) enhance product attributes (e.g. appearance (colour), taste, flavour, aroma, viscosity, and texture); (c) respond actively to changes in product or package environment; (d) communicate product information, product history or condition to consumers; (e) assist with opening and indicate seal integrity and (e) confirm product authenticity or anti-counterfeit and act to counter theft. However, not all these features will be shown in smart packaging. Practically smart packaging will be focussed on sense and inform the status of a product in term of its safety (showing either food to be safe or food to be unsafe) and quality (showing the freshness, ripeness or firmness). In this direction, the smart packaging is a packaging that has ability to tract the product, sense the environment inside or outside the package and inform the manufacture, retailer and consumer regarding the condition of the product [11].

The growing needs for information on packaging will means there has to be a step change in providing this information, and this will drive the need for smart packaging, particularly for the food products. Consumers increasingly need to know what ingredients or components are in the product and how the product should be stored and used. Smart labelling and sticker, for instance, will be capable of communicating directly to the customer via thin film devices providing visual information. Visual safety and disposal instructions contained on pharmaceutical and health products will be used to tell the consumer how they should be consume and disposed after consumption. Furthermore, drug delivery systems in the smart packaging will be programmed to communicate patient information back to healthcare centres. Both drug delivery and the communication of patient information either via wireless or electronically are in their relatively infant stages and their integration in packaging might be appeared in the coming years.

Another important need is consumer security assurance, particularly for perishable food products. The question is whether, for instance, a chilled ready-meal is safe to use or consume, currently this is answered by 'best by' date stamping. However, this does not take into account whether the product has inadvertently been exposed to elevated temperatures during storage or transportation. In the future, microbial growth and time–temperature visual indicators (TTIs) based on physical, chemical or enzymatic activity in the food will give a clear, accurate and unambiguous indication of product quality, safety and shelf-life condition. Many new types of TTIs have recently been developed. For example, Rani and Abraham [12] developed a new enzyme reactions for a low-cost TTI. Yan et al. [13] developed a new amylase-type TTI based on the reaction between amylase and starch. Galagan and Su [14] developed a novel colorimetric TTI based on fadable ink. Vaikousi et al. [15] developed a new TTI system based on the growth and metabolic activity of a *Lactobacillus sakei* strain for monitoring food quality throughout the chilled-food chain.

When sensors are integrated with food packaging, they can detect chemicals, pathogens, and toxins in food. Many biosensors incorporate integrated optics, immunoassay and surface chemistry have been developed to detect deadly salmonella bacteria in the meat. For example, biosensors that detect *Staphylococcus* enterotoxin B, *Escherichia coli*, *Salmonella* spp. [16] and *Listeria moncytogenes* have been developed [17]. Sensors can also detect proteins allergen from foods, such as to prevent adverse reactions to peanuts, tree nuts, and gluten [18]. Nevertheless, progression in this area moves significantly in recent years, due to many works in sensor field associated with food stuff.

Applications

Time–temperature indicators

Give a self-heating or self-cooling container a sensor to tell the consumer it is at the correct temperature and the package becomes 'smart' (such packaging is currently commercially available). The most commonly used TTIs are a thermochromic ink dot to indicate the product is at the correct serving temperature following refrigeration or microwave heating. Plastic containers of pouring syrup for pancakes can be purchased in the USA and UK that are labelled with a thermochromic ink dot to indicate that the syrup is at the right temperature following microwave heating. Similar examples can be found on supermarket shelves with orange juice pack labels that incorporate thermochromic-based designs to inform the consumer when a refrigerated orange juice is cold enough to drink as given in Fig. 2 [19].

The TTIs presently available on the market have working mechanisms based on different principle namely chemical, physical and biological. For chemical or physical response, it is based on chemical reaction or physical change towards time and temperature, such as acid–base reaction, melting, polymerization, etc. While for biological response, it is based on the change in biological activity, such as microorganism, spores or enzymes towards time or temperature. Commercially available TTIs are given in Table 2.

MonitorMark™ [20] from 3M™ has two versions, one intended for monitoring distribution, the threshold indicator for industry, and other intended for consumer information, the smart label. The former is an abuse indicator, which means that it yields no response unless a predetermined temperature has been exceeded. It is based on a special substance having a selected melting point and blue dye. A film strip separates the wick from the reservoir that is removed at the activation stage. At this point, the porous wick, white in colour, is shown in the window. Upon exposure to a temperature exceeding the critical temperature, the substance melts and begins to diffuse through the porous wick, causing a blue colouring to appear as given in Fig. 3. There are available indicators with different critical temperatures from −15 to 26 °C.

The consumer label is a partial-history indicator that change colour when exposed to higher than recommended storage temperature and will also change as the product reaches the end of its shelf-life. The working principle is

Fig. 2 Application of thermochromic ink [15]

Table 2 Examples of commercially TTIs

Product	Company
MonitorMark™	3M™
Timestrip®	Timestrip Plc
Fresh-Check®	LifeLines
CheckPoint®	Vitsab

Fig. 3 MonitorMark™ TTIs product from 3M™ [16]

based on the melting and diffusion of the blue dye as described previously [16].

Timestrips® [21] are smart labels that monitor how long a product has been open or how long it has been in use. They can measure elapsed time from minutes up to over a year, in the freezer, refrigerator, at normal ambient or even at elevated temperatures. Inside the Timestrip® is a special porous membrane through which a food-grade liquid diffuses in a consistent and repeatable way. The Timestrip® is activated by squeezing a start button which moves the liquid into direct contact with the membrane. The laws of physics then take over and the liquid diffuses through the membrane in a consistent and totally repeatable way. On the top surface of the Timestrip®, the markers has been printed which communicate the all important time since activation, as well as space for branding and other graphics as given in Fig. 4. Since most applications require the Timestrip® to adhere to a package or a product, they can be chosen from a wide range of adhesive tapes on the underside to suit the specific needs of the customer.

Fresh-Check® [22], this fresh indicator is supplied as self-adhesive labels, which may be applied to packages of perishable products to ensure consumers at point-of-purchase and at home that the product is still fresh. As given in Fig. 5, the active centre circle of the Fresh-Check darkens irreversibly, faster at higher temperatures and slower at lower temperatures, so it is easy to see when to use or not

Fig. 4 Timestrips® TTIs product from Timestrip Plc [17]

Fig. 5 Fresh-Check® TTIs product from LifeLines [18]

use the food product within the product date codes. As the active centre is exposed to temperature over time it gradually changes colour to show the freshness of the food product. This full history indicator whose working mechanism is based on the colour change of a polymer formulated from diacetylene monomers. It consists of a small circle of polymer surrounded by a printed ring for colour reference. The polymer, which starts lightly coloured, gradually darken depends on the colour that tend to reflect the cumulative exposure to temperature. The polymer changes colour at a rate proportional to the rate of food quality loss, thus the higher the temperature, the more rapidly the polymer change in colour. Consumers may be advised on the package not to consume the product, if the colour of the centre is darker than the reference ring [18].

CheckPoint® [23] is a simple adhesive label attached to food cartons to check for temperature abuse. CheckPoint® monitors a carton or food package from the processor to the retailer and stays with the package until the point of retail sale. These labels react to time and temperature in the same way that food product react, and thus give a signal about the state of freshness and remaining shelf-life. This signal is an easy to read colour dot as given in Fig. 6. This is full history indicator based on enzymatic reaction. The device consists of a bubble-like dot containing two compartments: one for the enzyme solution, lipase plus a pH indicating dye and the other for the substrate, consisting primarily of triglycerides. The dot is activated at the beginning of the monitoring period by application of pressure on the plastic bubble, which breaks the seal between compartments. The ingredients are mixed and as the reaction proceed a pH change results in a colour change. The dot, initially green in colour, becomes progressively yellow as product approaches the end of shelf-life. The reaction is irreversible and will proceed faster as temperature is increased and slower as temperature reduced.

This device is available in two basic configurations, i.e. CheckPoint®I for single dot, and CheckPoint®III, for triple dot. Single dot tags are used for transmit temperature monitoring of cartons and pellets of product and for consumer packages as well. While triple dot tags are especially used in the wholesale distribution chain and incorporate three graded responses in a single label. The sequential development of colour is appropriate for signposts in the management of the self-life of the product [19].

Sensors for fish and meat freshness

Besides employing TTIs as freshness indicators for fish and meat as the application of Fresh-Check® and CheckPont®, inexpensive and simple chemical sensors that allow the real-time, non-invasive and non-destructive determination of fish freshness were described in literature based on a pH change. In an enclosed food package, as the fish product spoils, a pH increase occurs over time within the headspace, which can be detected with an appropriate pH indicating sensor. The fundamental characteristic of pH indicator dyes that change colour when placed in an acidic or basic environment is the key element of this sensor. This is due to the fact that when fish spoils, it releases a variety of basic volatile amines which are detectable with appropriate pH indicating sensors. Practically, these could be prepared by entrapping within a polymer matrix a pH sensitive dye (e.g. bromocresol green) that responds, through visible colour changes to the spoilage volatile compounds that contribute to a quantity known as total volatile basic nitrogen [24].

By using this sensor system, a fast and sensitive detection of spoilage compounds in fish can be achieved by a non-invasive colorimetric method. The sensor response was found to correlate with bacterial growth patterns in cod and whiting fish samples, thus enabling the "real-time" monitoring of spoilage [20]. These colorimetric sensors offers the potential of developing dynamic "best-before" dates that may lead to important and exciting improvements in the quality assurance sector and a sensor as an on-package food quality indicator. This colorimetric method could also be further developed by using mixed-dye-based food spoilage indicator [25] that allows the food product to have an effective shelf-life by permitting dynamic freshness to be monitored visually alongside the best-before date, consequently decreasing margins of error. The expansion of the concept of a colorimetric mixed-dye-based food

Fig. 6 CheckPoint® TTIs product from Vitsab [19]

spoilage indicator to other food products (such as easily prepared foods, fresh meat and meat products, poultry and poultry products, seafood products, bakery products, desserts, and fresh-cut fruits and vegetables) is a possible area for future developments.

However a variety of different concepts for freshness indicators have been presented in the literature. Freshness indicators or sensors concepts have been proposed for e.g. CO_2 [26], amines [27], ammonia [28, 29], ethanol [30] and hydrogen sulphide (H_2S) [31]. By integrating the indicator into the food package, the freshness indicators can be realised as visible indicator tags going through a colour change in the presence of the analyte.

Sensors for fruit ripeness

Once fruit is picked from orchards, the challenge to present fruit in a top condition increases with distance from markets to fulfil more sophisticated consumer demands and need for year-round supply. In the past, loose fruit, often unripe, was sold from bins where it was easily bruised, squeezed and prodded to determine its ripeness. Then came "ready to eat" fruit, bundled and pre-packaged, but in a manner whereby it is still difficult to determine its ripeness.

Since, it is difficult to know when, the fruit has reached their preferred state of ripeness, this condition become a barrier to purchase for frustrates consumers. *ripeSense*™ [32] eliminates this problem by using a sensor label that reacts to the aromas released by fruit as it ripens. The sensor is initially red and graduates to orange and finally yellow. By viewing the colour of the sensor, consumers choose fruit which is at their preferred ripeness, as given in Fig. 7. Damage in and shrinkage are reduced as this sensor significantly reduces damage by consumers as they inspect fruit before purchase; and the recyclable sensor pack provides improved hygiene security. Extra handling can lead to high levels of shrinkage in store. This sensor has already applied for pears, and can also be applied as ripeness indicator for kiwifruit, melon, mango, avocado, and other stone fruit etc. [27].

Leak indicators

Modified atmosphere packaging (MAP) and equilibrium MAP are classified as active packaging methods [33]. In these cases, the atmosphere of package is not air but

Fig. 7 *ripeSense*™ the world's first smart ripeness indicator label [27]

consists of a lowered level of O_2 and a heightened level of CO_2. The MAPs for non-respiring food typically has a high concentration of CO_2 (20–80%) and a low concentration of O_2 (0–2%). Therefore, a leak in MAP means a considerable increase in the O_2 concentration and a decrease in the CO_2 concentration, which in turn, enable aerobic microbial growth to take place. In the worst case scenario, the CO_2 concentration will thus remain high despite leakage and permit microbial growth. Thus, the leak indicators for MAPs are much more than active packaging, since they become smart packaging, and they should rely on the detection of O_2 rather than on the detection of CO_2 [34].

At present, the main application of the commercially available O_2 sensitive MAP indicators is to ensure the proper functioning of O_2 absorption. For example, Mitsubishi Gas Chemical Company (Japan) commercialized their O_2 absorbing sachets under the trade name "Ageless" [35]. There are also some other companies producing commercial O_2 indicators to confirm proper O_2 removal by O_2 absorbers [36]. Another company Cryovac-Sealed Air Ltd has developed indicator type for the checking of correct gas composition [37].

Usually a typical visual O_2 indicator consists of a redox-dye (e.g. methylene blue [38, 39], 2,6-dichloroindophenol [40] or *N,N,N′,N′*-tetramethyl-*p*-phenylenediamine [41]), a reducing compound (e.g. reducing sugars) [42] and an alkaline compound (e.g. sodium hydroxide [43], potassium hydroxide [44], calcium hydroxide [45] or magnesium hydroxide [46]). Oxygen indicators based on oxidative enzymes have also been reported in literature [26, 47]. In addition to these main components, compounds such as a solvent (typically water and/or an alcohol) and bulking agent (e.g. zeolite, silica gel, cellulose materials, polymers) can also be added to the indicator. The indicator can be formulated as a tablet [34, 40], a printed layer [41, 48] or laminated in a polymer film [34].

In the case of CO_2-indicators as leak detection, it does not appear to be more reliable leak detection compared to O_2-indicators. This is due to the fact that during the first 1–2 days after the packaging procedure, CO_2 will be dissolved into the product, then its concentration in the headspace increased, and will be decreased in the final concentration. After this period a considerable decrease in CO_2 concentration, is certainly an evident sign of leakage in a package. Another drawback of CO_2 indicators is related to the production of CO_2 in the microbial metabolism. A leak in a package by decreasing in the CO_2, is often followed by microbial growth, which means increase in the CO_2, in the worst case, due to this phenomena, the CO_2 will remain constant even in the case of leakage and microbial spoilage.

There are some aspects, which have to be taken into account if O_2 and CO_2 indicators are used as leak indicators of MAP. The very low sensitivity of O_2 indicators is not advantageous as the sensitive indicator might also react with the residual O_2 which is often entrapped in the MAP (typically 0.5–2.0%) [49]. Very low sensitivity can also complicate the handling of the indicator, and requiring anaerobic conditions during the preparation of the indicator and the packaging procedure. In addition it has been claimed that the colour change of the O_2 indicators used in MAPs containing acidic CO_2 gas is not definite enough [45, 50]. Furthermore, the reversibility is undesirable if the indicator is used for leakage control since the O_2 entering the package through the leak will be consumed in the microbial growth likely to follow the loss of the package integrity [45], which in turn causes the indicator colour will be same as that for intact packages, even if the product has been spoiled.

Sensors for food pathogens and contaminants

Many great and innovative platforms are being developed for the detection of pathogens and contaminants. However, most of these are incorporated within devices, and require the extraction of a sample to determine the presence of the target molecule. When considering such systems for food packaging, these are focused on detecting microbial contaminant growth. The challenge for such systems is that they must be capable of being integrated within the packaging, provide an easily distinguished response (most likely a colour change), and be cheap to manufacture. It is most likely that the presence of microbial contamination will be detected indirectly by measuring changes in gas composition within the package as a result of microbial growth, using gas sensor as described earlier. The numbers of concepts of package indicators for contaminants or pathogens are still very low. Even if the indication of microbial growth by CO_2 is difficult in MAPs, which often already contain a high concentration of CO_2, it is possible to use the increase in CO_2 concentration as a means of determining microbial contamination or pathogen only in packages not containing CO_2 as protective gas [26].

The colour indicators based on reactions caused by microbial metabolites and other concepts for contamination indicators have been proposed in the literature. The colour indicators could be based on a colour change of chromogenic substrates of enzymes produced by contaminating microbes [51], the consumption of certain nutrients in the product or on the detection of micro-organism itself [52]. For this reasons, instead of electrochemical transduction method, optical-based biosensors systems have also been widely developed together with biosensors based on acoustic transduction which intended to be used mainly for detecting microbial contaminants. These methods have been used for targeting the presence of contaminating microorganisms on food such as *Staphylococcal* enterotoxin A and B*, Salmonella typhimurium*, *Salmonella* group B, D and E, *E. coli* and *E. coli* 0157:H7 [12, 53]. Nano-spheres silica immobilized with a fluorescent dye has also been developed to be compatible with meat packaging, where they can detect the presence of the poisonous *E. coli* 0157 [54]. Furthermore, biosensors that detect *L. moncytogenes* have already been recently developed [13].

Alternatively, systems based on caged biomolecules (e.g. fullerenes, liposomes, or nanoporous silica) that are linked to a colorimetric dye, could be developed for this purpose, as they provide stability for the detector molecule, and could be incorporated in a permeable membrane within the main package, and do not require additional factors (e.g. pre-processing, power). One example is the employment of nanostructured silk as a platform for biosensors. This silk could be incorporated within the package, since the silk is biodegradable and edible [55]. The silk fibrils can be shaped into ‘lenses’ and modified with various biomolecules, which when bound to targets (such as microbial proteins) alter the shape of the silk lens resulting in a colour change [55].

Biosensors such as conducting polymers can also be used by detecting the gases released during microbe metabolism [56, 57]. The biosensors are formed through inserting conducting nanoparticles into an insulating matrix, where the change in resistance correlates to the amount of gas released. Such sensors have been developed for detecting food borne pathogens through quantification of bacterial cultures [58]. Furthermore, such sensors coupled with a neural network were demonstrated to provide a means of evaluating meat freshness [59].

Identification, authentication and tracking

Currently, identification of products via RFID tags have been in use for a number of years, but mainly employed for high value products e.g. electronics and clothing. Typically, RFID tags consist of two modules; one is used for processing and information storage, while the second (an antenna) is used for transmitting and receiving information. A second device, the reader, is used to obtain information from the tag, and depending on the radio frequency used, this can be at distance of several meters. RFID tags in the packaging industry are passive, since they have no associated power source, and gain energy to transmit information from the incoming radio waves from the reader.

Their advantage is that multiple items can be monitored at every stage in the supply chains; which in turn can increase the speed and efficiency of distribution. This is a very crucial factor in modern supply chains where large amounts of raw materials may be coming from different regions to be processed in one site, then distributed to consumers (in many different regions). It is widely envisioned that RFID tags are expected to replace barcodes that are commonly used today [60].

Currently, RFID tags are mainly based on silicon semiconductor technologies; however it could be changed for cheaper and easier production on a number of different materials. This is due to the fact that printable electronics (using conducting polymers, such as pentacene and oligothiophene, and metallic inks, including copper, silver and gold) are being developed by a number of institutes and companies [56, 61] based on desktop ink-jet printing, other forms more suited to high production levels could be developed. In addition to printed systems, some developments are exploring the use of carbon nanotubes as antenna [62, 63]. However, this technology is not as highly developed as conductive inks. Interestingly, there is some development into combining RFID tags with chemical sensing functions. This development has produced a prototype for ethylene sensing (for fruit ripeness) [64], while another has shown the potential of this technology by constructing a moisture sensor [65].

Since, these systems are microelectronic systems, the potential for nanotechnology to enhance such systems is clear. As a result many different systems are being developed including nanoscale bar-codes, quantum dots, and magnetic nanoparticles. Nanotechnology utilises nanoscience and phenomenon constituting a new approach that concern the study of manipulation of materials at molecular level. Packaging based on nanotechnology can reduce spoilage significantly, and secure production, processing and shipment [2]. However, whether these are likely to be used widely within food packaging is unclear, and will be dependent on cost/unit and ease of use. Regarding RFID, it is more likely that RFID tags will serve as multiple purposes, for tracking, authenticating or anti-counterfeiting and even more act to counter theft.

Conclusion and future prospect

The current advance of smart packaging relies on the development of sensor technology and materials which in some way sense the condition of the product to inform its quality, safety, shelf-life and usability. Therefore, the future of smart packaging to enhance packaging technology is clear. It will increasingly operate as a sensor system incorporating both smart and conventional materials, adding value and benefits across the food packaging supply chain. For smart materials as a sensor system to be integrated in packaging, they need to be suitable with printing technology for mass production, low-cost relative to the value of the food product, ease to used, accurate, reliable, simple and reproducible in their range of operation, and environmentally gentle as well as food contact safe.

The integration of a sensor in food packaging has made great advances in smart packaging solutions. These advances have led to improve food quality, safety, shelf-life and usability. While most packaging innovations have been the result of global trends and consumer preferences, some innovations have stemmed from unexpected sources, such as the emergence of nanosensor technologies, the technology of sensing material in nm size. Undoubtedly, new smart packaging development will focus more on food safety (detecting microbial growth, oxidation, improving tamper visibility), food quality (detection of volatile flavours and aromas), shelf-life, tracking, authentication, convenience, and sustainability of food products.

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