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Recent Developments in Intelligent Packaging for Enhancing Food Quality and Safety

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Abstract

The role of packaging cannot be denied in the life cycle of any food product. Intelligent packaging is an emerging technology in the food packaging sector. Although it still needs its full emergence in the market, its importance has been proved for the maintenance of food quality and safety. The present review describes several aspects of intelligent packaging. It first highlights different tools used in intelligent packaging and elucidates the role of these packaging devices for maintaining the quality of different food items in terms of controlling microbial growth and gas concentration, and for providing convenience and easiness to its users in the form of time temperature indication. This review also discusses other intelligent packaging solutions in supply chain management of food products to control theft and counterfeiting conducts and broaden the image of the food companies in terms of branding and marketing. Overall, intelligent packaging can ensure food quality and safety in the food industry, however there are still some concerns over this emerging technology including high cost and legal aspects, and thus future work should be performed to overcome these problems for further promoting its applications in the food industry. Moreover, work should also be carried out to combine several single intelligent packaging devices into a single one, so that most of the benefits from this emerging technology can be achieved.

Keywords: Intelligent packaging, indicators, food quality, RFID, counterfeiting

1. Introduction

Packaging is the last step in food processing, however it is one of the most important steps as it has great influence on the storage life of the food product. The main purpose of packaging is to protect the food material from the external environmental hazards (Yam *et al*., 2005). It not only maintains the quality of the food product but also provide information about the ingredients and aids in distribution and marketing of the product to the final consumer. Of all these, preserving the quality of the packaged food is the main aim of packaging as quality maintenance of the food product is the most critical issue during the whole supply chain (Han, 2014). In the last few years, new techniques such as modified atmosphere packaging (MAP), edible coating, antimicrobial packaging and antioxidant packaging have been developed. These techniques play a significant role in extending the storage life and maintaining the quality of a variety of fresh and processed food products to meet the need of the consumers.

Since the successful development and commercialization of modified atmosphere packaging technology several decades ago (Phillips, 1996), MAP is largely used for packaging different food products, which mainly include fruit and vegetables, muscle foods, dairy foods, bakery products, ready meals and dried foods. As a result, a number of review papers have been published to address the preservation aspects of these food products. Sivertsvik *et al*. (2002) reviewed applications of MAP for enhancing the storage life of fish and fishery products and Mcmillin (2008) discussed applications of MAP for raw fresh meat in his review paper, while a recent review (Oliveira *et al*., 2015) focused on applications of MAP for fresh cut fruit and vegetables.

On the other hand, intelligent packaging is a new emerging technique in the food packaging circle, protecting the food material as well as informing the consumer about the environmental condition of the packaged food. It should be noted that the concept of intelligent packaging is closely related to that of active packaging. Active packaging usually means that the package has active functions beyond the inert passive containment and protection of the food product, while intelligent packaging emphases the ability to sense or measure an attribute of the packaged food product, the atmosphere inside the package, or the environment of shipping. The information received from intelligent packaging can be communicated to users or can trigger the functions of active packaging. There are a number of reviews available addressing the different aspects and concepts of intelligent packaging systems. Kerry *et al*. (2006) studied the historical background and current uses of active and intelligent food packaging for muscle foods such as meat, Vanderroost *et al*. (2014) provided an insight into the next generation of intelligent food packaging, Lee *at al*. (2015) discussed active and intelligent packaging for various fresh foods, while Ghaani *et al*. (2016) presented different features and market potentiality of various types of intelligent tools such as sensors, indicators, and RFID tags and bar codes. Most recently Fang *et al*. (2017) studied the application of smart packaging technology that can be successfully applied in the meat industry.

The objective of the current review is to stipulate knowledge of the recent technological development in the field of intelligent food packaging for maintaining quality and safety of different food and food products. The principles of intelligent packaging and the different devices used in it are also presented. This review also covers other important aspects of intelligent packaging in supply chain management of different food items. In addition some future developments are also discussed in the current review.

2. Principles of Intelligent Food Packaging

2.1 Intelligent packaging

In intelligent packaging, the communication functions of the packaging materials are used to make it easy for recording the changes in the internal and external environments and then to inform the users about the status of the packaged food products (Yam, 2012). Therefore, intelligent packaging has the ability to sense and note the attributes of the packaged foods or their environments and convey messages about the deterioration or quality of the packaged foods to their processors or users (Hutton, 2003).

For the food quality and safety point of view, intelligent packaging is very useful to the industry and consumers to provide timely information regarding the status of the foods through a change within the package system. In some intelligent packaging systems, the packaging has the ability to inform its users about the whole history of the food product such as providing information regarding manufacturing process, expiry date, ingredients and storage specifications (Bagchi, 2012).

In some cases, intelligent packaging is so designed to inform its users of an event that may damage the packaging material or affect its protected life. Research has been done on developing such labels or seals that are transparent until the package is opened. Once the package is damaged, the label or seal will change its colour and in some cases it will spell out “opened” or “stop” (Vanderroost *et al*., 2014). These functions can be achieved by putting sensors or instruments capable of sharing the relevant information of the packaging system. Therefore intelligent packaging is a great achievement for the maintenance of food quality and safety, making the foods available for the longer duration to the consumers (Realini and Marcos, 2014).

2.2 Integration of intelligent devices with conventional food packaging

Conventional food packaging can extend the storage life of the food product by protecting the food material, however it has no ability to inform users about quality deterioration in terms of temperature fluctuation, gas concentration change and microorganism growth inside the package environment. Similarly fresh fruits and vegetables respire even after harvesting. Simple packaging is thus not enough for quality maintenance, there should be an intelligent system that can constantly monitor the gas concentration within the package environment (Kader and Ben-Yehoshua, 2000) and provide correct information at the right time regarding the quality characteristics of the food products.

For this purpose different intelligent components should be integrated into different food packaging systems to make the environment intelligent and to communicate with the consumers regarding the changing condition of the package. Figure 1 presents the structure of the intelligent packaging system, including various kinds of substances and devices used in this kind of advanced packaging system.

3. Types of Intelligent Tools Used for Food Packaging

During processing, food quality can be checked regularly by microbial and chemical analyses. However, there are some quality attributes that need constant vigilance during the whole supply chain. These quality parameters change regularly after processing and can affect the quality of the product. These changes are difficult to assess by the consumers within the packaged food (Luning *et al*., 2002). With the help of intelligent packaging, it becomes possible to check the quality characteristics of the food within the package. These intelligent packaging tools or devices bring some changes in themselves with the change in the quality parameter of the packaged foods. They are mostly placed within the package to monitor quality changes of the product, while some can be placed outside to inform the users about the safety related issues of the food products.

Generally speaking, there are three main types of tools that are used for intelligent packaging (Kerry *et al*., 2006), which include sensors, indicators, and barcodes and radiofrequency identification (RFID) devices. Table 1 presents different types of tools used in intelligent packaging systems.

3.1 Sensors

A sensor is an instrument that is used to detect, locate or quantify a problem and then send signals to measure its physical or chemical characteristics. A sensor has the ability to frequently detect an event or changes in the surrounding environment. Usually sensors are made up of a receptor and transducer. The function of a receptor is to convert physical or chemical information into a form of energy, and a transducer changes the energy to an analytical signal (Demas *et al*., 1999).

For food quality and safety assurance, it may be very important to develop intelligent food packaging systems using portable chemical sensors to check different compounds and gas molecules, specially, H_2, O_2, NO_2 and CO_2 in modified atmosphere packaging. These chemical sensors are best alternatives to the time-consuming analytical instruments such as gas chromatography-mass spectrometer (GC-MS), which can only be applied by breaking the food package integrity (Llobet, 2013). Figure 2 indicates different types of sensors used in intelligent packaging systems.

Baleizao *et al*. (2008) developed a high sensitive optical dual sensor for the detection of oxygen using different levels of temperature. Their developed sensor was composed of two light emitting compounds, one can be used for the detection of temperature while the other for the detection of oxygen. As Ruthenium tris-1, 10-phenanthroline is highly luminescent compound, it was used as the temperature-sensitive dye. The probe used for the detection of oxygen-sensitivity was fullerene C70 because of its strong, thermally activated and delayed fluorescence at high temperatures. Their results confirmed that the dual sensor had the capacity of detecting temperature change ranging from 0 to 120^{o}C and the minimum detection limits for oxygen was 50 ppmv.

An optochemical CO_2 sensor was developed by Borchert *et al*. (2013), composing of a Pt-TFPP dye and a colorimetric pH indicator α-naphtholphthalein bounded in a plastic shield combined with a tetraoctyl- or cetyltrimethylammonium hydroxide that acts as a phase transfer agent. After the optimization of the composition and the working conditions of the developed sensor for the measurement of CO_2 in foods stored under modified atmosphere packaging, it was concluded that the sensor could retain its sensitivity to CO_2 at 4°C for almost three weeks.

On the other hand, Heising *et al*. (2015) developed a sensor for the checking of the freshness of packaged cod fillets. The working principle of the developed sensor is to monitor the volatile compounds released from the fish in the storage. The sensor has the ability to monitor the freshness of the fish at temperatures as low as 0^{o}C. For temperatures higher than 4^{o}C, a conductivity meter should be combined with the temperature sensor to successfully check the freshness of the packaged fish. Most recently, Ma *et al*. (2017) prepared a biosensor by integrating curcumin (Cur) into a tara gum (TG)/polyvinyl alcohol (PVA) film. The colour response was visible within 1-3 min in the NH_3 environment. As a proof, shrimp was tested to evaluate its spoilage using the developed film, and positive results were obtained, indicating the possibility of using the film as a sensor in the food industry.

3.2 Indicators

Indicators are used to provide information regarding any change taking place in a food product or its surrounding condition (*e.g.*, temperature, pH, etc.) by observing visual changes usually in colour. The speciality of indicators is that they do not have any receptor or transducer like sensors, instead they only provide information through direct visual changes in the food environment (Mills, 2005). Indicators applied to food packaging are time-temperature indicators, gas indicators and freshness indicators (Hogan and Kerry, 2008).

Time-temperature indicators are used to check whether the food product is at lower or higher than the specific temperature. It also informs the users regarding the presence of microorganism and the structural changes occurred in protein during different food processing operations (Kerry *et al*., 2006).

Freshness indicators tell us about the food quality in terms of microbial growth and/or chemical changes occurred in the food products (Siro, 2012). On the other hand, gas indicators are used in the form of labels to check the gas concentration within the package system. Their purpose is to monitor the leakage of any gas specially oxygen and carbon dioxide (Lee and Ko, 2014; Vu and Won, 2014).

3.2.1 Time-temperature indicators

Temperature is critical in the determination of the storage period of a specific food product. Sudden changes in the temperature causes great concern over the quality of a processed food material. Nowadays, for the purpose of the food quality, food processors and suppliers are checking the temperature of the food materials at every stage during the supply chain from the harvesting to the end use (Giannakourou *et al*., 2005). The wisely use of such tools for checking the time and temperature history of the food products are termed as time-temperature evaluation (Pereira *et al*., 2015; Galagan *et al*., 2010). The operational principles of the majority of TTIs depend on chemical, enzymatic, mechanical, electrochemical, or microbiological reactions, which depict the outcomes in the form of colour changes (Brody, 2001; Mehauden *et al*., 2008; Vaikousi *et al*., 2008; Yan *et al*., 2008).

A prototype isopropyl palmitate (IPP) diffusion-based time temperature indicator has been developed by Kim *et al*. (2016) and was used for the determination of microbiological quality of unpasteurized angelica juice. The diffusion of isopropyl palmitate in the designed indicator was calculated at different temperature ranges. It was proved that diffusion of IPP up to 7 mm in the TTI could be best used as a successful level for the determination of microbial spoilage in the prepared juice sample. However the developed time temperature indicator could only be successfully used for the indication of microbial growth at temperature level of 13^{o}C or higher.

Pereira *et al*. (2015) developed a very economical and accurate TTI from natural ingredients to use as intelligent packaging device. They extracted anthocyanin from red cabbage and combined it with polyvinyl alcohol (PVA) and chitosan to work as labelling film for the purpose to develop a time temperature indicator. As anthocyanin can goes through chemical changes due to pH variation, it can be successfully used as natural indicator for the quality deterioration of the food products. The developed system had the ability to detect the quality changes by monitoring the alteration in the pH of the packaged food such as milk during storage. As long as the food material is stored at a different temperature, the system had the ability to monitor the changes in temperature indirectly with the help of pH variation of the product, which occurred due to the unsuitable temperature for the storage.

In the last couple of years, the commercial use of several indicators has been increased such as photochromic TTIs, polymer based TTIs, microbial TTIs, diffusion based TTIs and enzymatic TTIs for the evaluation of time temperature of different perishable foods developed by different packaging companies (Table 2).

3.2.2 Gas indicators

It is very hard to maintain the quality of food materials within the packaging system, due to many reasons such as respiration of fresh fruits and vegetables, changing gas concentration and gas leakage from inside or outside of the packaging materials, or due to gas produced by microbial growth within the package (Brody, 2001). For the solutions of such problems, gas indicators are introduced. These indicators are used to provide information about the concentration of oxygen or carbon dioxide gas within the packaging material by changing their colour due to a specific chemical or enzymatic reaction. As these indicators have direct contact with the food materials, they are able to give information about the presence or absence of a gas (Han, 2014). Gas indicators are mainly available in the form of a label, as a tablet, a printed layer or laminated in a polymer film (Kuswandi *et al*., 2011). An improved and easy to use oxygen gas indicator was developed by Vu and Won (2013) for the detection of oxygen gas and the prevention of dyes from leaching out in the packaging material. The UV activated oxygen concentration indicator film was prepared using thionine, P25 TiO_2, glycerol, and an encapsulating polymer with zein as redox dye. The leakage of dye reached to almost 80% when the zein coated film was dipped in water for one day. As the ion binding capability can stop cation dye from leaching into water, the introduction of alginate in the indicator system can reduce the dye leakage to nearly 6%. This improved system can not only prevent the dye from leaching out, but can also be used successfully as a gas indicator, which can attain its initial colour very rapidly with the help of oxygen gas.

Nopwinyuwong *et al*. (2010) has proposed a packaging system to check intelligently the quality of intermediate moisture dessert by monitoring the growth of carbon dioxide gas within the package system. In the spoiled dessert the growth of microorganism was detected by the development of specific colour as a result of increased level of carbon dioxide gas.

Hong and Park (2000) introduced an indicator for the detection of carbon dioxide gas without harming the packaging material of the food. It was basically bromocresol purple or methyl red, which was integrated into polymeric films (polypropylene resin and calcium hydroxide). This indicator not only helps in the detection of carbon dioxide gas concentration within the package, but also helps in the detection of food spoilage during storage and transportation. This device works on the bases of pH dependent colour changes irrespective of the temperature. As the concentration of the carbon dioxide changes within the package of the food, the colour of the device changes due to the change in pH of the system.

Other commercially available devices are Ageless Eye™ developed by Mitsubishi Gas Chemical Co.(Tokyo, Japan), Vitalon® by Toagosei Chemical Inc.(Tokyo, Japan), Shelf Life Guard by UPM-Kymmene Corporation (Helsinki,Finland), Tufflex GS by Sealed Air Ltd.(Telford,UK), Freshilizer by Toppan Printing Co. (Japan) and gas absorbing packets Freshpax™ produced by Multisorb Technologies Inc. (USA) (Fang *et al*., 2017; Ghaani *et al*., 2016; O'Grady & Kerry, 2008). Details of some of these devices are presented in Table 3.

3.2.3 Freshness indicators

For the purpose of checking microbial growth and informing the users about the freshness of food products, freshness indicators are developed. These devices provide information about product quality in terms of microbial growth and food spoilage (Lund *et al*., 2000). Food freshness indicators are usually developed by using different organic acids (such as acetic acid or lactic acid), glucose, ethanol, volatile nitrogen compounds (such as trimethyl amine for packed fish products), carbon dioxide, biogenic amines (for chicken and beef) and sulfuric compounds to determine the freshness of the packaged food products (Heising *et al*., 2015; Pereira *et al*., 2011).

Rukchon *et al*. (2014) developed an indicator for the determination of freshness of chicken breast. It was basically a pH and dye based system, which works on the determination of colour produced by different levels of carbon dioxide gas in the packaged chicken breast. Also Rokka *et al*. (2004) developed a system to determine the freshness of broiler chicken. It worked on the development of biogenic amines such as tyramine, putrescine and cadaverine as quality indicators under different storage temperatures. As the temperature increased, the levels of different amines also increased in the stored broiler chicken, representing different levels of the freshness of the chicken.

Recently, Zhai *et al*. (2017) prepared a colorimetric film for the monitoring of fish freshness based on starch/polyvinyl alcohol (SPVA) incorporated with roselle (*Hibiscus sabdariffa* L.) anthocyanins (RACNs). The film was used to monitor the freshness of silver carp (*Hypophthalmichthys molitrix*) at refrigeration temperature. The colorimetric films presented visible color changes over time due to the presence of total volatile basic nitrogen (TVB-N) amines. Therefore, the film could be used to check the real-time fish freshness as intelligent packaging device.

Besides work conducted on developing different freshness and microbial growth indicators, A New Zealand based company "Jenkins Group" has introduced Ripe Sense®, which can be used to indicate various stages of the ripeness of fruit for representing their freshness levels. Basically this device is designed to work on the detection of the aroma present in the fruit. At the beginning, the indicator shows a red colour, with the passage of time this colour changes to orange and then yellow, representing different maturity and freshness stages of the fruit. Besides using pear fruit, this device can also be used for other fruits such as melon, mango, kiwifruit and stone fruits (*e.g.* peach, apricot, plum, etc.) to check various stages of their ripeness (Pocas *et al*., 2008).

Commercially available freshness indicators, such as Toxin Guard® by Toxin Alert Inc. (Ontario, Canada), Sensor Q™ by FQSI (Food Quality Sensor International) Inc. (Massachusetts, USA), Fresh Tag® by COX Technologies (Belmont, North Carolina, USA) and Food Sentinel System by SIRA Technologies Inc. (California, USA) are common for monitoring freshness and growth of microorganisms in different food products (Realini and Marcos, 2014). Some of them are also highlighted in Table 3.

3.3 Barcodes and radio frequency identification devices (RFID)

Barcodes and RFID tags are mainly data carrier devices. A barcode is widely utilised in multi-scale departmental stores to expedite record keeping, goods reordering and price checking (Manthou and Vlachopoulou, 2001). Usually barcode is the arrangement of systematic side by side lines, which contains hidden encoded data. The message is decoded and interpreted by an optical barcode scanner that conveys the required message to a system where it is kept for further necessary action (Han, 2014). Figure 3 presents different types of barcodes used in the food sector.

RFID tags mainly consist of three components: a tag made from a microchip linked to a small aerial, a reader capable of discharging radio signals and also accepting answers from the tag in reply to the sent signals, and a network system or web server that connects the company and the RFID equipment (Kumar *et al.*, 2009). Most advanced RFID systems have the capacity of accepting data from 100 m distance, with the storage range of 1MB. Presently, RFID system is comprised of two types of tags: active and passive tags. The usage of battery in the active tags makes it different from the passive one, in which no battery is installed.

Eom *et al*. (2012) designed a RFID based system containing O_2 and CO_2sensors for the determination of freshness of vegetables, while Sen *et al*. (2013) proposed a system to monitor the freshness of meat with the help of a system containing RFID tag combined with a temperature sensor, a gas sensor, a reader, and a server. This monitoring system successfully showed the meat freshness for four grades, *i.e.* high, medium, low and spoiled.

On the other hand, Martínez-Olmos *et al*. (2013) developed a RFID label integrated with an optical oxygen indicator containing a platinum octa ethyl porphyrin film and an e-system for communication with the RFID. The indicator was copied on the interior part of an adaptable polymer based substrate, *i.e.*, polyethylene naphthalate (PEN), which was used as an envelope for the packaged food. Martínez-Olmos *et al*. (2013) showed that the system was suitable for food packaging having oxygen concentration less than 2%, a detection limit of 40 ppm and a resolution as low as 0.1 ppm of O_2 with a 3.55 mA electricity usage. Recently, Amin *et al*. (2016) developedaunique chipless RFID sensor system for wireless sensing of food and other tagged items. The specialty of the developed chipless RFID sensor is that it is without chip and requires no electricity source like other RFID systems. Thus its application is easy and can be used without any maintenance requirements.

3.4. Other intelligent tools

Besides the above mentioned tools, holograms and specialised thermo chromic inks are also useful tools that can be used in food packaging to make them intelligent.

3.4.1 Holograms

Hologram is an emerging tool in the field of intelligent packaging. It can help to protect the brand name of the product as well as to combat counterfeiting of a product.Due to the attractiveness and creativeness of the holographic packaging, manufactures should be able to develop a distinctive edge over the other competitors in the market (David Bellm, 2010).

Besides enhancing the brand image of the product, holograms are also used to prevent food products and packaging from tempering. With the help of the changing pattern of the hologram, the counterfeiters are unable to alter the food product or the label of the product. If a counterfeiter tries to remove the hologram, the upper polyester film will also be removed, leaving a message regarding tempering of the product (Pareek and Khunteta, 2014).

Holograms are mostly used in the pharmaceutical industry for highly sophisticated drug products. However, their application in the food packaging sector is very limited. With the technological advancement of the intelligent packaging system, it is expected that holograms for food applications should be available in near future.

3.4.2 Thermo chromic inks

Thermo chromic inks have the ability to change their colour on exposure to elevated temperature. These types of inks are mostly used for beverage packaging or for microwave food products, allowing consumers to know whether the product is hot or cold to be served. Based on temperature, the colour pattern of theses inks are either reversible or irreversible. Irreversible inks remain constant on exposure to a certain temperature and do not change once they have attained a specific colour. Reversible ink has the ability to change the colour once reached to a certain temperature and as the temperature falls back, the ink reverses back to its original colour (Vanderroost *et al*., 2014).

Usually these thermo chromic inks work on leuco dyes, and these dyes have the ability to change their molecular structure once exposed to a known temperature, producing a change in the colour of the dyes. These types of inks are also used for controlling counterfeiting and increasing the brand name of a specific product as thermo chromic labels instead of working as a quality measurement tool (Robertson, 2012).Similar to holograms, the use of thermo chromic inks in the food packaging sector is also very limited.

4. Other Intelligent Packaging Solutions in Supply Chain

As foods are delicate products, their quality attributes deteriorate during the whole supply chain. Constant vigilance is necessary during their life cycle. Food quality can be deteriorated either microbiologically or by any physical phenomena such as mishandling during the whole supply chain, There should be a system which can have the ability to closely monitor the food product from the field to processing and then from a valuable product to its end users.

Moreover, consumers require food products with more convenience and less preparation steps. These food products should also be fresh and provide high quality attributes. This ultimately requires a systematic approach that can have the ability to check the food products before processing, during processing and after processing. Intelligent packaging can be used for this purpose to check the quality of the food products during the supply chain and provide the necessary information to the end users (Heising *et al*., 2014).

4.1 Provision of convenience to consumers

Convenience has become a necessity for most people because of their busy schedule and hectic life. A breakthrough in providing the convenience is the development of intelligent films that can be used for conventional heating as well as microwave heating. This can be achieved by combining amorphous polyethylene terephthalate (APET) with crystallized polyethylene terephthalate (CPET), so that their properties can be combined for the heating and storage purpose. Due to the crystalline nature, CPET is heat resistance and can be easily used in traditional heating or microwave ovens bearing the temperature up to 200^{o}C. The amorphous polyethylene terephthalate (APET) is used as a packaging material in combination with CPET to lower the temperature of the packaged food product (Eilert, 2005).

On-tech Delaware Inc. (San Diego, USA) developed a self-heating packaging system for beverages such as coffee, which has the ability to heat up to 62^{o}C in almost 6-7 minutes. The system is composed of two cans, one inside the other can. The inner can has calcium oxide in the form of limestone, while the outer can has the beverage to be heated up. This packaging system also has a closed disc containing water. There is a foil tab at the bottom of the can, which can be pulled to mix the water into the particles of limestone, resulting in an exothermic reaction. As a result the beverage in the container heats up (Han, 2014).

Another type of intelligent packaging for providing convenience to the consumers is Soup at Hand® developed by Cambell Soup (Camden, NJ, USA). The soup is packaged in a high density polyethylene container that is contour in shape. By removing the top of the package, the soup can be heated inside the container. Besides heating, the container provides additional convenience for the consumers, as there is a plastic cap fitted on the top of the container, which helps in sipping the hot soup without spilling. Therefore a can opener or a spoon is not required for the spilling of the soup (Han, 2014).

4.2 Marketing and branding of food products

Packaging plays a main role in the marketing and branding of a food product as packaging is the first thing that affects consumer decision to purchase the product. Therefore, it is the integral part in the whole marketing process, describing the image and portfolio of the product and even of the entire company (Keller, 2003). Thus intelligent packaging is a great tool for increasing the sales of the food products. The creation of eye appealing characteristics and attractions on the packages along with information on the quality and safety of the specific food product help consumers to make more intelligent decisions (Mohebbi, 2014).

One such product was developed by ASAP Food Products Company (Solon, OH, USA). The company developed "A Super Amazing Popcorn", which has printed cartoons, sports items or other kid appealing characters on the popcorn packaging pouches. The company has gained a great fame in the popcorn industry due to these attractions for children since its starts from the last 20 years. These pouches are printed with different colour graphics on character shaped microwavable polyethylene terephthalate (PET) with a protective varnish covering. Besides these attractions, the company also provides high quality nutrient rich popcorns for the children (Han, 2014).

Hologram, which is another emerging intelligent packaging material, can increase the brand image of a product in the market. A holographic foil is an optical tool that is made from a polyester film. The changing pattern of the holographic picture can attract the consumer eye, thus increasing the brand name of the product (Pareek and Khunteta, 2014).

4.3 Controlling counterfeiting and theft

Theft, counterfeiting and tempering is a world-wide concern both for the food industry and consumers. In order to tackle the danger of theft and counterfeiting for the food products, besides the commonly used RFID system, bar codes, thermo-chromic inks, dyes, holograms, tear taps, specialized laser labels and electronic tags,there are also some special closures developed that are able to identify the tempered food products. These plastic and aluminium based closures are broken down during any attempt of counterfeiting before reaching the final user (Robertson, 2012).

Papetti *et al*. (2012) developed an integrated electronic tracking system with a non-destructive quality analysis system for a traditional Italian cheese. The system was developed for the identification of cheese products in such a way to acquire and connect the necessary information that can be available to the consumers or to related concern people with the help of the RFID code. Moreover, A RFID based system integrated with wireless sensor network was designed by Rahman (2016) for the traceability of wine components (*e.g.*, pallet, container and beverage bottle) during supply chain. The performance of the system was analysed with the help of numerical simulations. The simulation results revealed the effectiveness of the system for the tracking of wine components in real-time environment.

Recently a food traceability system utilizing RFID technology to track and trace food product location and wireless sensor network to collect temperature and humidity during storage and transportation was proposed by Alfian *et al*. (2017). The designed system was used for kimchi supply chain in Korea, and showed positive results to suppliers as well as consumers to detect the real-time location of the product as well as provide complete temperature and humidity history. Therefore, the proposed e-pedigree food traceability system could be helpful in maximizing food distribution while also increasing customer satisfaction, as it could also monitor product freshness (Figure 4).

5. Decision Support System for Intelligent Food Packaging

Decision support system is used to take right and timely decision for the corrective use of intelligent devices in order to enhance food quality and safety. Usually the purpose of this system is to control the growth of microorganisms in fresh or processed foods. One such conceptual framework of intelligent decision support system proposed by Yam (2012) is presented in Figure 5.

The use of decision support system is common in business related tasks. As far as its use in intelligent food packaging is concerned, it requires more scientific knowledge to maintain food quality and safety. Earlier different mathematical models such as kinetic models are commonly used to determine the microbial growth and food quality in food packaging system, however these techniques are now not adequate for food packaging systems such as intelligent packaging. Instead of using the old techniques, inductive learning technique, fuzzy logic system, neural network and artificial intelligence techniques can be adopted for successful decision support systems in intelligent packaging (Yam *et al*., 2005).

One example is the work of Ahsyar *et al.* (2015), who used C4.5 decision tree algorithm for packaging of different meat products. It was a web-based decision support system for packaging of meat products with the help of PHP programming language and MySQL database. The main features of this system include user profile, types of meat products, types of packaging materials and comments from the user. The developed system can be successfully run on different web browsers.

6. Conclusions and Future Prospective

Intelligent packaging is an innovation in the food packaging sector. This technology has the ability to provide better quality food products to the users. With the implementation of some useful devices such as time temperature indicators, freshness indicators, gas concentration indicators, etc., consumers can obtain fresher and better quality food products. Similarly bar codes, RFID tags, thermo-chromic inks, holograms and tear taps provide solutions to the industry, retailers and consumers to protect food products from counterfeiting and theft.

With the advancement in the technology, the future of the intelligent packaging is very bright. More advanced tools should be available to replace the existing intelligent packaging system such as electronic labeling comprising of chip with ink technology during printing of labels. It is also expected that future packages might be able to chat with users. Thus mishandling of food products during freezing, refrigeration, cooking and microwaving could be minimized by consumer interaction. Moreover, thermo chromic materials could be used in the food packaging containers to protect the food materials from direct sun light by changing the container colour.

It can be assumed that in the near future all the single devices such as time temperature indicators, gas concentration and freshness indicators can be integrated into one single device. Such a combined single device would be powerful and useful for providing information regarding the quality characteristics of the food product. Therefore integrated advance research in the field of electronics, mechanical engineering and food engineering should be conducted for the successful growth of the intelligent food packaging. By this way, intelligent packaging should be able to play an even critical role in enhancing the quality and safety of perishable food materials.

Similarly, work should be done to reduce the price of the intelligently packaged food products. It is estimated that the cost of the original food product is almost doubled with the use of intelligent packaging. There are also legal issues raised by the food administrative agencies, which are related to the successful implementation of the intelligent packaging system rather than just focusing on the development of new tools and instruments, and these issues should be solved for further applications of the technology.

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Table 1. Summary of intelligent packaging system in the food sector

Type of intelligence	Objective/Purpose	Food product	References
Freshness indicator	Determining freshness by showing color changes due to the presence of amines	Silver carp	Zhai *et al*. (2017)
Freshness indicator	Determining freshness of the product by showing different colours	Chicken breast	Rukchon *et al*. (2014)
Freshness indicator	Determining biogenic amines as quality indicators	Broiler chicken	Rokka *et al*. (2004)
Gas Indicator	Checking the growth of microorganisms by increasing level of carbon dioxide gas	Intermediate moisture dessert	Nopwinyuwong *et al*. (2010)
Gas Indicator	Detecting carbon dioxide gas without harming the packaging material	Kimchi (fer ted food product)	Hong and Park (2000)
Gas Indicator	Detecting oxygen gas and the prevention of dyes from leaching out	Any food packaging system	Vu and Won (2013)
Gas indicator	Detecting improper sealing and quality deterioration of the package	Pizza and beef products	Smiddy *et al*.(2002)
RFID system	Determining different maturity and quality levels	Italian cheese	Papetti *et al*. (2012)
RFID system	Monitoring the product during supply chain	Cheese products	Regattieri *et al*. (2007)

RFID tag + freshness indicator	Monitoring the freshness of the product	Pork	Sen *et al*. (2013)
RFID + WSN	Tracking and tracing food product location along with temperature and humidity data	Kimchi	Alfian *et al*. (2017)
RFID + GPS+ WSN	Tracking the products during storage and transportation	Chilled and frozen food products	Zhang *et al*. (2009)
RFID + CO_2 and O_2 sensor	Determining freshness of the product	Broccoli	Eom *et al*. (2012)
RFID system (Chipless)	Sensing and identifying tagged product during supply chain	Different food items	Amin *et al*. (2016)
Sensor	Detecting spoilage of the tested product	Shrimp	Ma *et al.* (2017)
Sensor	Determining freshness of the product at temperatures as low as 0^oC	Cod fish/ Cod fish fillets	Heising *et al*. (2015)
Sensor	Measuring headspace CO_2 in MAP storage	Salad leaves	Borchert *et al*. (2013)
Time temperature indicator	Determining microbiological quality of unpasteurized angelica juice	Angelica juice	Kim *et al*. (2016)
Time temperature indicator	Determining quality of the stored food items using natural ingredients, i.e. red cabbage and chitosan	Milk	Pereira *et al*. (2015)

Time temperature indicator	Monitoring the quality of food during storage or distribution	Any food item	Lim *et al*. (2014)

Table 2. Some commercially available time-temperature indicators

Type of indicator	Commercial name	Company/country	Working principle	Websites
Photochromic TTIs	Onvu™	Freshpoint, Switzerland	Change of colour of photochromic dyes and pigments	http://www.onvu.com/
Polymer TTIs	Fresh-Check®	TEMPTIME Corporation USA	Solid state polymerisation reactions	http://fresh-check.com/about.asp
Microbial TTIs	(eO) ® and TRACEO ®	Cryolog, France	Change of colour over time	http://cryolog.com/en/company/
Diffusion based TTIs	Monitor Mark™ and Freeze Watch ™	3 M Company, USA	Diffusion of coloured materials	http://www.3m.com/
Enzymatic TTIs	Check point ®	Vitsab International AB, Sweden	pH dependant colour changes	http://vitsab.com/index.php/en/startpage/

Table 3. Some commercially available gas and freshness indicators in intelligent food packaging system

Indicator type	Indicator name	Company name	Purpose	Indicating point	References
Gas indicator	Ageless Eye™	Mitsubishi Gas Chemical Co. Japan	Detection of oxygen gas	Change of colour from pink to blue or purple	Fang *et al*. (2017), Kuswandi *et al*. (2011), Ahvenainen (2003)
	Shelf Life Guard	UPM-Kymmene Corporation, Finland	Detection of air within the package environment	Change of colour from transparent to blue	Ghaani *et al*. (2016)
	Tell-Tab	IMPAK Corporation, Los Angeles, USA	Detection of oxygen gas within the package	Change of colour from pink to blue or purple	Han (2014), Realini and Marcos (2014)
Freshness indicator	Fresh Tag®	COX Technologies, USA	Detection of decomposition in seafood and other protein products	Change of colour from yellow to dark blue or pink	Realini and Marcos (2014)
	Sensor Q®	FQSI (Food Quality Sensor International) Inc. Massachusetts, USA	Detection of bacterial growth inside the package	Change of colour from orange to tan (brown) and then to green or blue, denoting "beyond spoiled"	Ghaani *et al*. (2016) Realini and Marcos (2014)
	Food Sentinel System	SIRA Technologies Inc. California, USA	Detection of pathogens in food packages	The bar code becomes unreadable upon scanning	Ahvenainen (2003)
	Toxin Guard	Toxin Alert Inc. Ontario, Canada	Incorporation of antibodies into plastic packaging films to detect pathogens	Packaging material displays a visual signal to alert the consumer	Ghaani *et al*. (2016), Realini and Marcos (2014)

List of figures

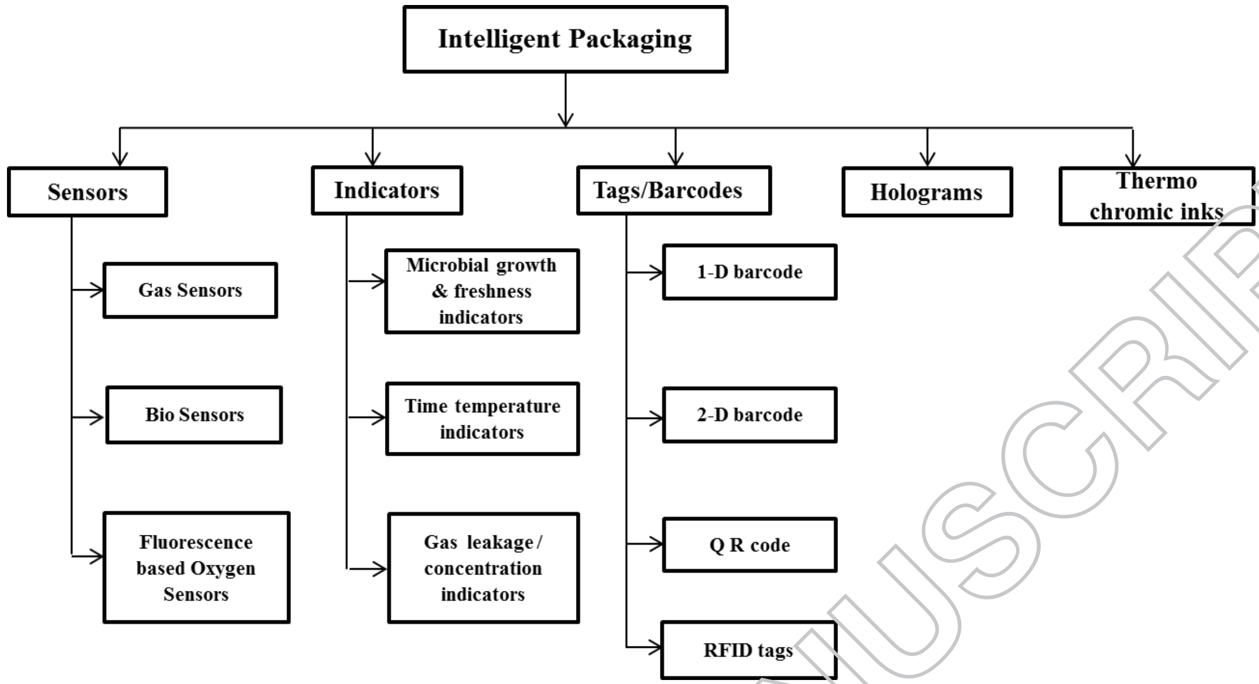

Figure 1. Schematic diagram of intelligent packaging system.

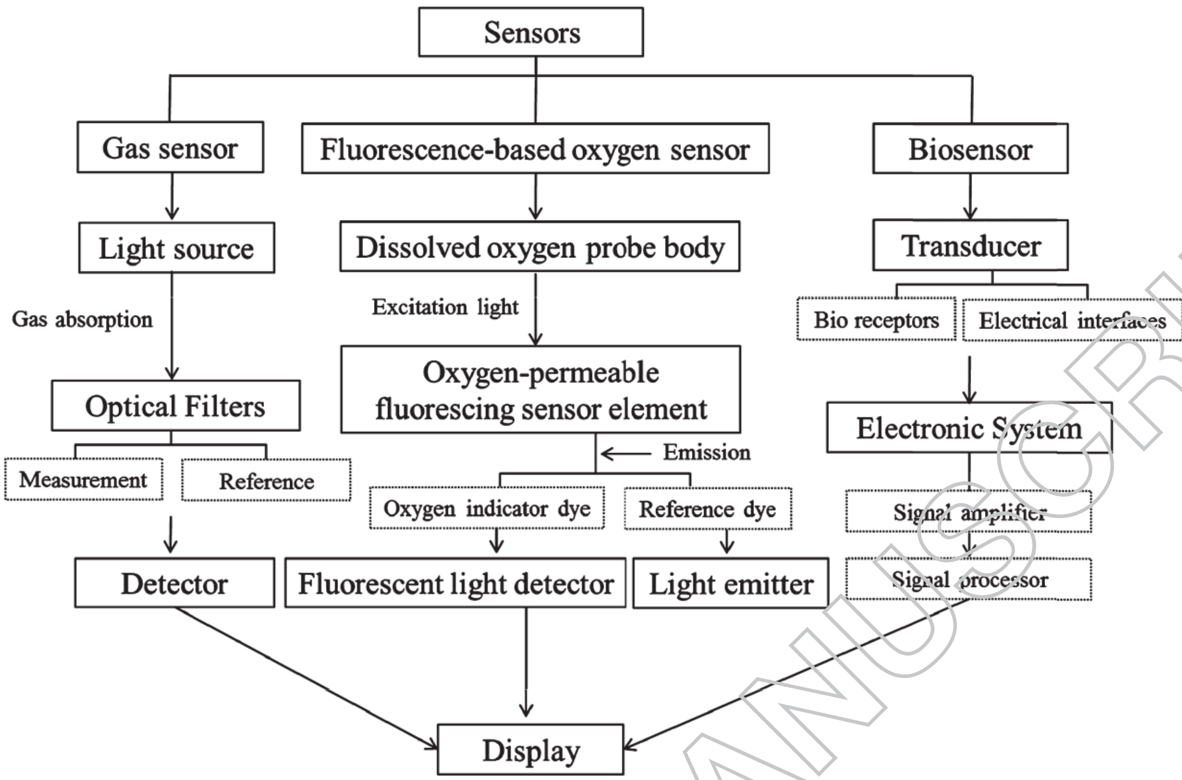

Figure 2.Different types of sensors used in intelligent packaging system (Lee *et al*., 2015).

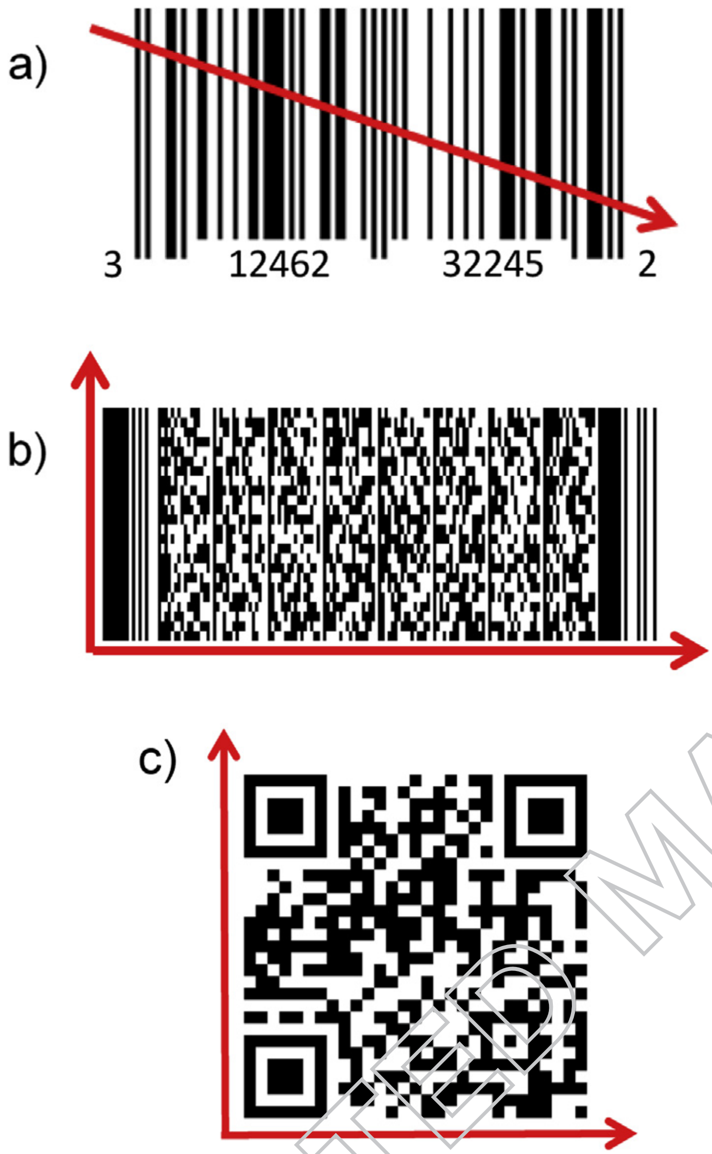

Figure 3.Some common types of barcodes used in the intelligent food packaging sector (Ghaani*et al.*, 2016).

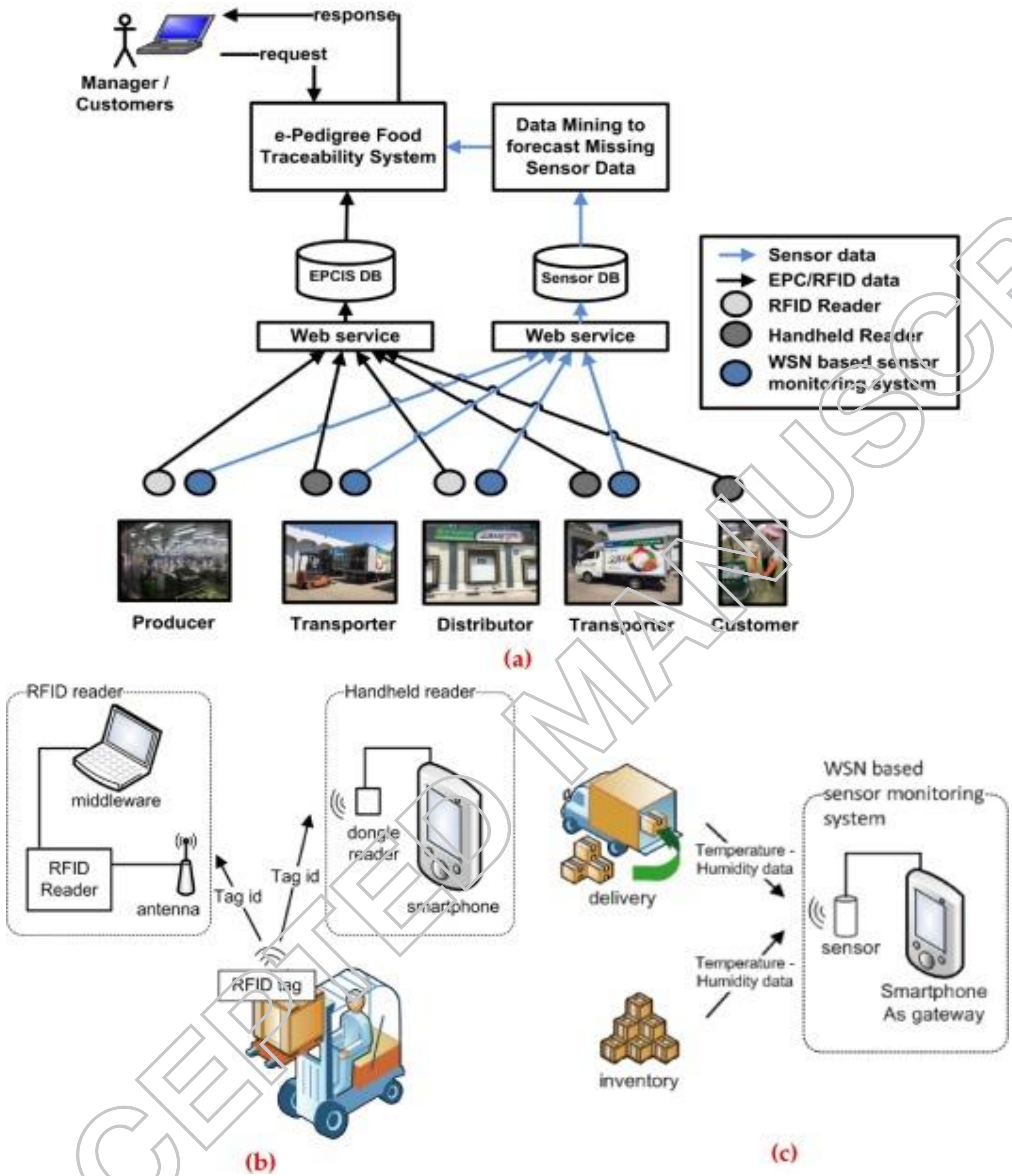

Figure 4.Traceability system in food supply chain (Alfian *et al*., 2017) (a) Proposed e-pedigree food traceability system architecture, (b) RFID and handheld reader to read RFID tag, (c) Sensor reads temperature-humidity from cold storage.

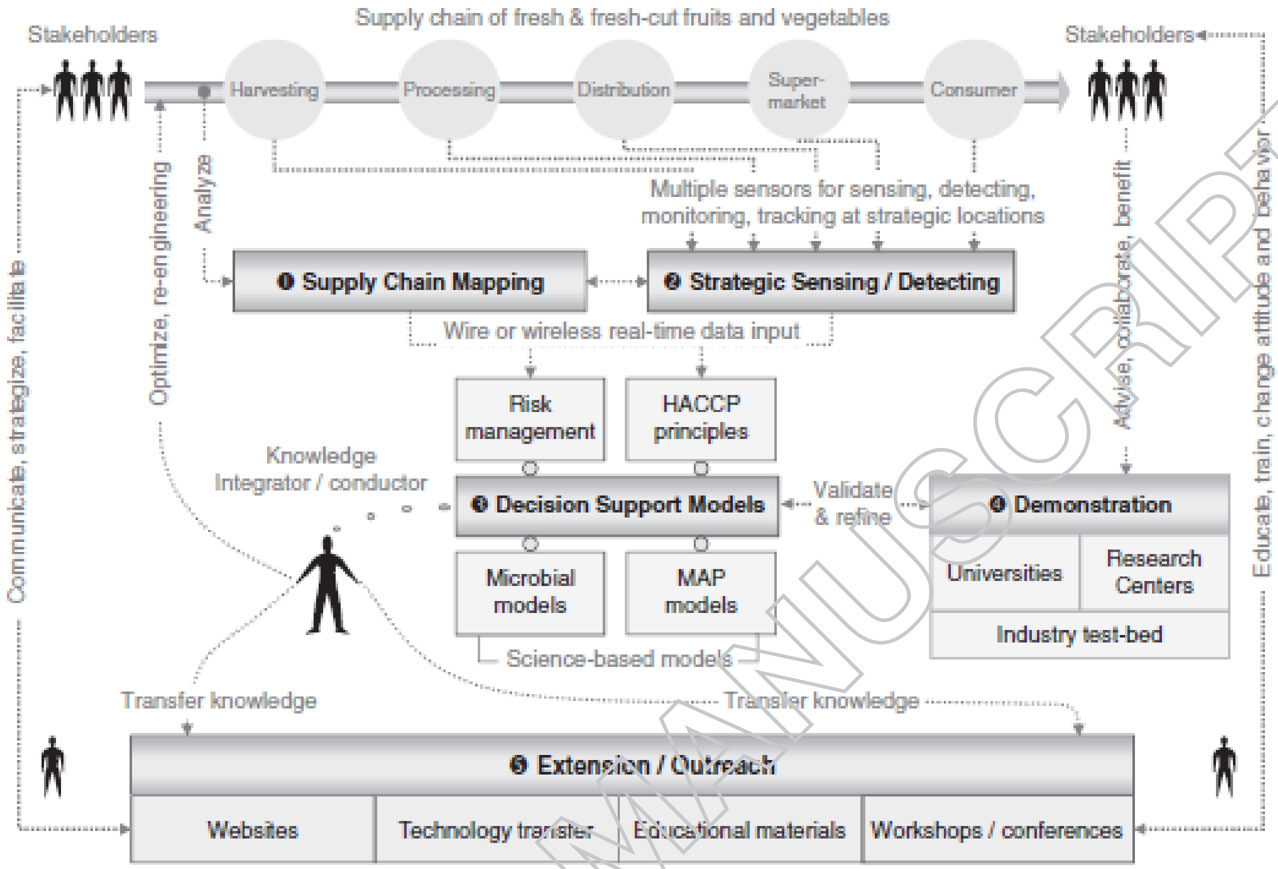

Figure 5. Conceptual frame work of intelligent decision support system (Yam, 2012).