Journal of the Saudi Society of Agricultural Sciences (2018) 17, 454–462

King Saud University

Journal of the Saudi Society of Agricultural Sciences

www.ksu.edu.sa
www.sciencedirect.com

REVIEW ARTICLE

Novel food packaging technologies: Innovations and future prospective

Ishrat Majid *, **Gulzar Ahmad Nayik, Shuaib Mohammad Dar, Vikas Nanda**

Department of Food Engineering and Technology, Sant Longowal Institute of Engineering and Technology, Sangrur, Punjab, India

Received 21 May 2016; revised 13 November 2016; accepted 16 November 2016
Available online 23 November 2016

KEYWORDS

Innovative;
Shelf life;
Packaging;
Bio active

Abstract Novel food packaging technologies arose as a result of consumer's desire for convenient, ready to eat, tasty and mild processed food products with extended shelf life and maintained quality. Recent trend of lifestyle changes with less time for consumers to prepare foods posed a great challenge toward food packaging sector for the evolution of novel and innovative food packaging techniques. The novel food packaging techniques, viz. active packaging, intelligent packaging and bio active packaging which involve intentional interaction with the food or its surroundings and influence on consumer's health have been the major innovations in the field of packaging technology. These novel techniques act by prolonging the shelf life, enhancing or maintaining the quality, providing indication and to regulate freshness of food product. The advancement in novel food packaging technologies involves retardation in oxidation, hindered respiratory process, prevention of microbial attack, prevention of moisture infusion, use of CO_2 scavengers/emitters, ethylene scavengers, aroma emitters, time-temperature sensors, ripeness indicators, biosensors and sustained release of antioxidants during storage. The novel food packaging technologies besides the basic function of containment increase the margin of food quality and safety. The novel food packaging techniques thus help in fulfilling the demands throughout the food supply chain by gearing up toward persons own lifestyle. The main objectives of this review article are to provide basic knowledge of different new and innovative food packaging techniques about their way of preservative action, effectiveness and suitability in various types of foods.

* Corresponding author.
E-mail address: ishratmajid89@gmail.com (I. Majid).
Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jssas.2016.11.003
1658-077X

Contents

1. Introduction

Novelty and recent trends in food packaging techniques are the result of consumer preferences toward mild processed food products with enhanced shelf life and convenience (Dobrucka and Cierpiszewski, 2014). Moreover, modern trend of retail practices and changing lifestyle are the incentives for the evolution of novel and innovative packaging techniques without compromising food safety and quality characteristics (Dainelli et al., 2008). Rapid growth of novel packaging in food segment is contributed by the enormous use of packaged foods, rising need of prepared foods like use of microwave meals and growing use of smaller size food packages (Restuccia et al., 2010). Another important reason for innovative food packaging is the rising issues of food borne microbial outbreaks which demands the use of packaging with antimicrobial effects along with retention of food quality (Appendini and Hotchtkiss, 2002). Innovations in packaging started earlier in the form of electrically driven packaging machinery, metallic cans, aseptic packaging, flexible packaging, aluminum foils and flexographic printing. Additionally, the introduction of various materials, viz. polyester, polypropylene, and ethylene vinyl alcohol polymers led to drastic evacuation from metal, paperboard and glass packaging to plastic and flexible packaging. Moreover, in 20th century more advancement in packaging technology appeared as intelligent or smart packaging and active packaging (oxygen scavengers, antimicrobial agents, respiration controllers, and aroma/odor absorbers) (Brody et al., 2008). The emerging changes in packaging industry will strengthen the economy by improving food safety, quality and by minimizing product losses (Vanderroost et al., 2014). In an attempt of changing market opportunities packaging industry has resulted in succession of numerous niche markets (Rooney, 2005). Since these newer ideas of active, intelligent and bioactive packaging had a greater impact on marketing of food, their way of action and suitability for food applications is mentioned in the following sections.

2. Active packaging

Active packaging came into existence with the aim of satisfying the consumer demand for natural, recyclable, and biodegradable packaging materials (Lopez-Rubio et al., 2004). Thus renewable resource based active packaging material capable of degrading by natural compositing process and with less environmental effect was developed (Jin and Zhang, 2008). Active packaging prolongs the storage life and enhances the margin of food safety by altering the condition of the food (De Kruijf et al., 2002). Active packaging is used as a substitute to conventional food processing techniques (high thermal treatments, brining, acidification, dehydration and additive preservation) (Lopez-de-Dicastillo et al., 2011). The basic underlying principle behind the use of active packaging depends on the incorporation of particular components inside the polymer and intrinsic characteristics of the polymer itself used as packaging vehicle (Gontard, 2000). A new advancement in the use of active packaging is the addition of polymer materials containing some additives that impart anti microbial properties (Suppakul et al., 2003). These polymeric matrices have the potential of releasing active agents (antioxidants and antimicrobials), retaining compounds (ethylene, oxygen and water) or undesirable food components (Flores et al., 2007). The potential scavengers like cyclodextrins used in the latter application act irreversibly and are either inorganic metals or salts (Lopez-de-Dicastillo et al., 2011). Controlled delivery of active agents into the food via packaging films for extended periods of storage and distribution restricts the development of undesirable flavors produced as a result of directly incorporating additives into the food (Peltzer et al., 2009). The use of artificial antioxidative agents like butylated hydroxytoluene, thioester and organophosphate compounds as active packaging additives is limited due to toxicity as a result of their migration into the food products (Gomez-Estaca et al., 2014). Hence, the use of synthetic additives is now replaced by the use of essential oils as natural extracts obtained from herbs and spices, tocopherol and extracts from plant which are generally recognized as safe (Persico et al., 2009) and enable the chemical stability of oxygen sensitive foods (Gomez-Estaca et al., 2014). In active packaging system choosing an antioxidant is critical step which requires due considerations. The antioxidant compound should be compatible with the packaging material and able to form homogenous distribution to the food or package headspace. The choice of antioxidant used should be based on the type of food for its characteristic effectiveness (Decker, 1998). Use of edible films and coating technology in active packaging contributes to the reduction of oxidative damage to foods by decreasing oxygen transmission rate. The addition of antioxidants to the edible film and coating material adds the added advantage of close contact between food and the coating matrix (Falguera et al., 2011). Furthermore, these natural additives are good sources of various bioactive phenolic compounds (Bakkali et al., 2008), and are used as excellent form of active packing in meat products because of their antimicrobial properties (Stefania and Vicini, 2002; Lopez et al., 2007). Use of antimicrobial agents in packaging is one form of active packaging which aims to decrease or inhibit the microbial growth in the food packed or itself within food package (Appendini and Hotchtkiss, 2002). In packaging materials use of antimicrobial agents can be done either by directly adding for gradual diffusion via food surface or infused in vapor form (Wilson, 2007). Oxygen scavengers used in packaging materials inhibit oxidative reactions by removing oxygen and can be directly added to the package enclosure or as sachets or labels. Among the oxygen scavengers ferrous oxide is most commonly used that reacts with oxygen to decrease its concentration (Kerry et al., 2006). Carbon dioxide scavengers and mediators are incorporated inside packaging materials. Carbon dioxide decreases the rate of respiration of fresh foods and prevents vacuum difference thereby, preventing collapsing of package due to presence of oxygen absorbers (Vermeiren et al., 1999). Carbon dioxide can be added in many different forms like absorbent pads and moisture-mediated bicarbonate chemicals in packets (Brody et al., 2008). Active packaging also involves moisture controlling agents like natural clays, calcium oxide and silica gel which are used as desiccants in case of dry foods while, in case of foods with high moisture content internal humidity regulators are used. These moisture absorbing agents can be added either as interior porous packets or as porous water-vapor barrier plastic cartridges with desiccants. Humidity regulators within package act by decreasing the moisture loss, retain desirable relative humidity and decrease extra moisture content present within voids and headspace (Brody et al., 2001).

3. Intelligent packaging

Intelligent packaging is rooted on involvement of intentional association of food with its package or surroundings with an attempt to enhance food quality characteristics and safety. Intelligent packaging is linked to the advancement in time–temperature regulators, ripeness monitors, biosensors and radio frequency indicators and regulators (Restuccia et al., 2010). Therefore, intelligent packaging provides signal for perceiving and evaluating the freshness of food (Han et al., 2005). Intelligent packaging provides knowledge about properties of the enclosed food and its existing environment and helps in providing basic idea to the retailer, customer and manufacturer about the state of these properties (Restuccia et al., 2010). Intelligent packaging provides additional function to the basic communication function of conventional packaging because it provides knowledge to the consumer on the basis of its ability to observe or record internal and external changes in the product surroundings. The two important functions performed by intelligent packaging are to monitor both internal and external conditions that is to record changes occurring both outside and inside the packaging. The latter function of intelligent packaging that is assessing the quality of the food product directly within package involves intimate association with the headspace or food which necessitates the use of indicators for the safety and quality of packaged food item. Typical indicators represent signaling gas leakage, ripeness regulators and indicators, time-temperature monitors, bio probes, radio frequency indicators and toxin indicators (Stauffer, 2005). The concept of intelligent packaging in real sense is to evaluate efficacy and strength of active packaging system (Kerry et al., 2006). Intelligent packaging offers greater significance by providing detailed knowledge throughout the supply chain and maintains food quality by finding out critical points by the use of attached, incorporated or printed labels onto packaging material (Dainelli et al., 2008). Another important aspect of this smart packaging is the self heating and cooling systems used as temperature regulators. In self heating packaging heating occurs as a result of exothermic reaction that is produced by using calcium or magnesium oxide or water. The major limitation that lies with this heating system is that major portion of package space is occupied by the heating device. Self cooling packaging induces evaporative cooling effect by evaporating external components like water that removes heat and gets adsorbed onto surface (Brody et al., 2008). Intelligent packaging also employs ethylene adsorbers and absorbers because ethylene removal from inside the package helps in exceeding the storage life and retaining quality features of fresh food commodities. Potassium permanganate widely used ethylene absorber that oxidizes ethylene to ethanol and acetate. Ethylene from package environment can also be removed by the process of adsorption via activated carbon or zeolite. These absorbers and adsorbents can be supplied either as sachets or added to the package itself (Lopez-Rubio et al., 2004). Radio frequency identification (RFID) used in intelligent packaging is radio wave based system that wirelessly tracks items. RFID consists of readers (receivers), labels or radar (data carriers) and computer software, hardware, networking, and database. Employment of wireless technique for transfer of data between reader and radar makes RFID technology superior over other direct identifications, like the barcode system (Finkenzeller, 2003). Use of RFID in food industry has emerged as a gateway, starting from monitoring of food to its traceability in order to enhance food safety and improve supply chain effectiveness. In the food industry accelerated rate and effectiveness of RFID technology in stock rotation and traceability of several commodities throughout the supply chain led to increased on-shelf availability at the retail level (Yam et al., 2005). Besides these important forms intelligent packaging has taken role in all fields of nanotechnology and resulted in quality and safety monitoring along with sustainability of packaging.

4. Bioactive packaging

Bioactive packaging is the novel packaging technology that alters the package or coating in a way so as to have positive effect on consumer's health. Various techniques known to retain characteristic properties of biopolymers and employed in this novel packaging approach include enzyme encapsulation, nanoencapsulation, microencapsulation and enzyme immobilization. Keeping in view the required functional properties of particular bioactive components, functional or bioactive packaging has the potential to maintain bioactive substances in desired proportions until their controlled or fast diffusion within the packed food during its storage or prior to its consumption (Lopez-Rubio et al., 2006). Process of bioactive packaging technology is implemented via (i) utilization of biodegradable packaging materials for the release of functional or bioactive components, (ii) encapsulating bio active ingredients into the foods or to the packaging materials, and (iii) introducing packaging materials exhibiting enzyme activity and capable of transforming some food components in order to deliver health benefits. The development of such packaging systems exerting health promotion effect involves the concept of marine oils, prebiotics, probiotics, encapsulated vitamins, phytochemicals, lactose free foods, bioavailable flavonoids and many more will boost the packaging industry in near future because of growing human health consciousness (Lagaron, 2005).

5. Innovative packaging technologies

5.1. Functional barrier

Functional barrier consists of one or more layers of food-contact materials and it should ensure the compliance of product with Article 3 of regulation 1935/2004/EC and Regulation 450/2009/EC. As, per definition the substances at the rear side of functional barrier will not, migrate in the food and thus will not have deleterious effects on human health nor will result in unacceptable changes in the composition and organoleptic properties. This implies that these intelligent and active substances do not arise from the concern of safety issue which is not also required by Regulation 450/2009/EC and certain substances can be used at the rear side of functional barrier provided they migrate through the functional barrier below a certain detection limit. In case of articles for infants and other susceptible persons the prescribed limit of un authorized substances that might through the functional barrier should not exceed 0.01 mg per kg food.

5.2. High chemical barrier material innovations

The quality of food can be maintained by preventing adsorption, desorption, diffusion of gases, liquids, penetration of other molecules such as oxygen, pressurized liquid or gas, and water vapor by the use of high-barrier packaging. The process of polymer blending, coating, lamination, or metallization is used to enhance the barrier property of packaging materials by combining the package materials with other high-barrier materials. The structural network of blend of packaging material with high barrier packaging material affects its permeability. Combining high-barrier materials on packaging material by the process of lamination or coating provides laminar structure, the permeability of which decreases linearly with the square thickness. The process of blending with platelets or droplets of high-barrier materials also reduces permeability but the decrease is less as compared to coating or lamination at the same mass as that of high barrier materials (Lange and Wyser, 2003). Most commonly used blends are aluminum-metallization on PET, polyethylene terephthalate (PET) lamination on coextruded polypropylene/polyethylene, polymers with planar clay particles, mixture of beeswax in edible polymer as particulate system films and polyvinylidene chloride (PVdC) coating on oriented polypropylene (OPP) (Avella et al., 2005; Han et al., 2006). The innovative technique used to improve barrier property with commercial applicability include epoxy spray on PET bottles, transparent vacuum-deposited or plasma-deposited coating of silica oxide on PET films and composites of plastics with nanoparticles (Lopez-Rubio et al., 2004).

5.3. Intelligent supply chain

In developing newer value added services, supply chain provides a provision of increasing efficiency by automating simple and valuable data flows. This intelligent supply chain can lay down flat form for value addition of fresh products. In response to larger retailer mandates and compliance with regulatory bodies requirements a Spanish company ECOMOVISTAND developed an innovative and ecological packaging and transport unit, called MT, for the grocery supply chain, which can be used in the entire product cycle; that is, the MT serves (1) as packaging at the producer, (2) as transport unit, (3) as storage at warehouses, and (4) as display stand at the supermarket, all in the same mechanical system, being thus a Returnable Packaging and Transport Unit (Martinez-Sala et al., 2009).

6. Interactions of active/intelligent packaging with supply chain

A special feature of supply chain is inclusion of several actors together for sound collaboration, coordination, and information exchanges between them for better efficiency and productivity (Choi et al., 2006). The major problem faced in transportation of boxes, containers, pallets and cases is lack of information and control on their status influenced by the actors in the supply chain. The world's largest container and pallet producing company encounters economical and logistics problems to provide on time service with a bounded quantity of pallets due to lack of information on where a pallet is and for how long it has been there. Thus, it does not seem astonishing why major retailers put thrust to come up with this lack of regulation and control by pushing suppliers toward the implementation of newer appropriate technologies (the Wal-Mart mandate, for instance) (Martinez-Sala et al., 2009).

7. Nanotechnologies in food packaging

Nanotechnology has proven most promising innovative technique by introducing latest enhancements in food packaging by providing mechanical and barrier properties, detecting pathogens and introducing smart and active packaging keeping in consideration food quality and safety aspects. Presently, the nanotechnology that is playing part in the market is the nanolayer of aluminum that coats the interior of many snack food packages (Brody, 2006).

Nanomaterials produced by the methods of solvent extraction/evaporation, crystallization, self-assembly, layer-by-layer deposition, microbial synthesis, and biomass reactions are being tested for their applications in food packaging (Doyle, 2006). Among the various nanomaterials the most promising for food packaging is nanocomposites.

7.1. Nanocomposites

Nanocomposite packages for food have taken their place in the market and many are yet to be launched to contribute major portion in the future to food packaging (AZoNano, 2004). The maximum attention is being paid toward beverage packaging and the driving agent for this overwhelming rise is the amazing benefit nanoscience offers toward the improvement in food packaging. Nanocomposite materials have played a vital role in improving the strength, barrier properties, antimicrobial properties, and stability to heat and cold (fundamental properties) of food packaging materials.

The use of nanocomposites for food packaging started in the year 1990s and use of montmorillonite clay as the nanocomponent has been used in a wide range of polymers such as polyethylene, nylon, polyvinyl chloride, and starch. The quantity of nanoclays used varied from 1% to 5% by weight and the nanocomponents used should have 1 dimension less than 1 nm wide. On the contrary, the high aspect ratios (ratio of length to thickness) of several of these materials can be produced by using lateral dimensions, as large as several micrometers. The high surface area of nanocomposites is responsible for imparting unique properties when they are incorporated into packages.

The transparent nanocomposite coatings and plastic films known as Durethan, produced by Bayer contain clay nanoparticles dispersed throughout the plastic. A huge quantity of silicate nanoparticles is mixed together in polyamide films and these nanoparticles have the property to prevent oxygen, carbon dioxide, and moisture from reaching fresh meats and others foods. The nanoclay particles hinder the process of diffusion by acting as impermeable barrier and as a result of which shelf life and quality of foods are enhanced. The resulting food package is also strong, more heat-resistant and light weight, thereby reducing transportation costs (ETC Group, 2004). The problem of oxidation and flavor due to packaging of beer in plastic bottles has also been tackled by the process of nanotechnology. As an example, Nanocor, a subsidiary of Amcol International Corp., has designed nanocomposites that are employed in plastic beer bottles and can provide shelf life of 6 months. The most recent concept of barrier nylons used in case of multilayer, co-injection blow-molded PET bottles, are produced by blending nanocomposites and oxygen scavengers. Use of nanocrystals incorporated in plastic bottles can extend the shelf life of beer by 18 months by preventing loss of carbon dioxide from and infusion of oxygen into the bottles. The same packaging materials are being designed for shelf life extension in case of soft drinks (ETC Group, 2004).

7.2. Other Nanotechnologies

The mechanical strength of food packaging materials can be improved by incorporation of carbon nanotubes of diameter in nanometers which are cylindrical in shape with antimicrobial properties. It was found that these carbon nanotubes resulted in cellular damage in *Escherichia coli* by puncturing cells and eventually leading to their death. These carbon nanotubes in antimicrobial materials act as building blocks when they are single walled **(Kang et al., 2007). In food packaging these has also been used in the form of nano-wheels to improve food packaging. The mechanical and barrier properties of plastics were improved by incorporation of self-aggregated inorganic alumina platelets in the shape of wagon-wheel (Mossinger et al., 2007).

Nanotechnology has wider applications in the near future in the form of nanosensors in food packages for detection of chemicals, bacteria, viruses, allergens, pathogens, and toxins in foods. With the advent of nanotechnology nanovesicles have been developed for detection of *E. coli* 0157:H7, *Salmonella* spp., Listeria monocytogenes and Liposome nanovesicles for detection of peanut allergen proteins. It has been found that association of antibodies to Staphylococcus enterotoxin B onto poly(dimethylsiloxane) chips led to formation of biosensors with a detection limit of 0.5 ng/mL (Doyle, 2006). Further, a NanoBioluminescence detection spray has been devised that contains an engineered luminescent protein capable of binding to the microbial surface (*Salmonella* and *E. coli*) (Joseph and Morrison, 2006). Microbes such as *Salmonella* and *E. coli* can be detected by a nanoporous silicon-based biosensor and prototype nanobiosensor was recently developed for detection of Bacillus cereus and *E. coli* and was reported to detect multiple pathogens faster and more accurately than other currently available devices (Liu et al., 2007). Recently, nanocomponents are being integrated in ultra-thin polymer substrates for RFID chips with biosensors that are capable of detecting foodborne pathogens or sense the moisture or temperature of a product (Nachay, 2007). DNA biochips which get repaired itself if damaged have been developed to detect pathogens for example, carbon tubes with nano-size diameters and coated with strands of DNA are used to provide nanosensors that are capable to detect odors and tastes. In these nanosensors one strand of DNA acts as the sensor and the carbon nanotube serves as the transmitter. The most striking advancement of this technology is development of electronic tongue nanosensors which can be to used to stimulate color changes in food packages in order to provide indications to consumers when food is spoiled and can also detect substances in parts per trillion (Univ. of Pennsylvania 2005). In food packages the change in color is also detected by use of color-changing film that is polymer opal films. These polymer opal films consist of photonic crystals that are used to produce special type of food packaging materials that can change color (Pursiainen et al., 2007). Nowadays synthetic DNA barcodes have been devised to tag pathogens and monitor pathogens. When target compounds are detected these nanobarcodes fluoresce under ultraviolet light (Steele, 2005).

8. Food safety issues

The present food legislation keeping in consideration the consumer desire for natural, minimally processed and convenient food products in addition to un ending changes at industrial, retail and distribution levels considers food safety as a global concern. This concern provides a stimulus to the packaging

Table 1 Some of the active packaging systems are listed below; (Ozdemir and Floros, 2004).

Active packaging system	Mediators used
Oxygen absorbers	Enzymatic agents (glucose oxidase glucose, alcohol oxidase-ethanol in vapor form) Chemical agents in powder form, viz. iron oxide, ferrous carbonate, catechol, iron-sulfur, sulfite salt of copper sulfate, photosensitive dye oxidation, oxidation of ascorbic acid, conversion of oxygen catalytically by platinum)
Carbon dioxide scavenging/releasing	Powder of calcium hydroxide and Iron, metal halide of ferrous carbonate
Moisture binding	Kieselguhr, Silica gel, propane-1,2-diol, polyvinyl alcohol (PVOH),
Ethylene binding agents	Embers, silica gel-potassium permanganate, diatomaceous earth, anti caking agent (bentonite), China clay, quartz, Oya stone in powder form, natrolite, ozone
Ethanol releasing	Ethanol in encapsulated form
Antimicrobial emitting	Sorbic acid, benzoic acid, propionic acids, ethanol, sulfur dioxide, ozone, peroxide, microbial secondary metabolites, silver-zeolite, quaternary ammonium salts
Antioxidant emitting	Vitamin C, vitamin E, synthetic anti oxidants like; BHA, TBHQ and BHT
Flavor binding agents	Bi carbonate of soda, activated charcoal
Flavor enhancing substances	Several natural and synthetic food flavors
Color providing agents	Many food derived colorants and pigments
Anti-foaming agent and anti-caking	Plastic polymer of propylene (Biaxially oriented vinylon), HDPE
Light monitoring/ absorbing	UV retardant, hydroxybenzophenone
Regulators	Time–temperature monitors
Temperature regulating and monitoring	Un-woven plastic with micro perforations
Gas penetrable/ absorbent	Superficially treated surfaces, films with micro pores or perforations
Microwave detectors	Thermoplastics with metalized surfaces
Insect repelling agents	Fumigants with minute toxic effects, viz. pyrethrins and permethrin

industry in order to present numerous innovative techniques to tackle with the legal and regulatory requirements along with the changing needs of the food industry and consumers (Realini and Marcos, 2014) (see Tables 1 and 2).

In food supply chain the concern of food safety and quality has given way to exercise more control and explore information within supply chains as well as to the consumers on processing, sourcing and distribution of food products. This concern has arisen as a result of problems encountered in logistic chain for chilled food where source of origin is far away from the destination, involving on board handling in ships, air transport and more intermediate points in the logistic chain. In an attempt to address this issue several logistic companies now use strip chart recorder inside few marked boxes per shipment to monitor the temperature and a conventional paper labels for traceability information. Now a days, RFID tags with embedded temperature sensors (Jedermann and Lang, 2007) as well as integration of these tags with physical and chemical sensors are used as temperature managed traceability systems (Abad et al., 2009).

Table 2 Some of the food applications of intelligent packaging are listed as follows (Ozdemir and Floros, 2004).

Tamper proof, package strength and integrity	Infringement of packed items
Signs of product quality/ safety	Time–temperature monitors and regulators, gas detecting devices, microbial invasion, pathogen growth sensing
Tracing and theft detecting devices	Radio frequency identification (RFID) chips, logos, stamps
Product genuinity	Holographic contents, tags, concealed print layout aspects, Radio-frequency identification for automatic identification and data capture

The safety concern related to active and intelligent packaging should be addressed based on following three important considerations:

(1) Labeling: Proper labeling should be done in order to prevent misuse and misunderstanding by the consumers or downstream users, e.g. to prevent sachets from being eaten.
(2) The migration of active and intelligent substances with respect to their toxicity should be kept in consideration and their migration process should comply with food legislation. Monitoring the phenomena of 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 active and intelligent systems. The safety concern in case of active packaging is to determine the adequacy of analytical methods used in migration studies to detect as well as quantify to which the consumer would be exposed to, and at what level. Potential migration outside the packaging is considerably reduced as the systems do not require migration testing as there will be a "functional barrier" (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 e.g. delivering a preservative or absorbing oxygen in a suitable way for preventing microbial growth without inducing antimicrobial resistance or pathogen over growth, or giving reliable information on pathogenic bacteria presence for direct indicators (Dainelli et al., 2008).

9. Environmental issues (biosourced, biodegradable, recyclable)

Starch and chitosan are the two biodegradable matrices used in food packages (Weiss et al., 2006). Within the grocery supply chain of fresh fruit and vegetables use of several levels of fresh products packaging (primary, secondary, and tertiary)

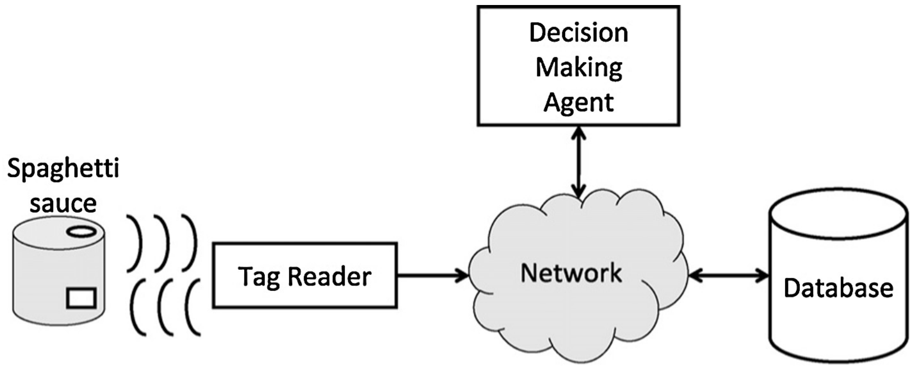

Figure 1 Intelligent jar of spaghetti sauce. Source (Wong et al., 2002).

is responsible for generation of thousands of tons of residues at different stages of the product cycle. In order to address this problem, the European Union, has passed demanding packaging directives to be complied with (European parliament, 2004). The environmental policy objectives include decrease or even to prevent the use of packaging, to recover and recycle all residues, and to make the producer responsible for the waste, as well as for the costs of recovering and recycling. These environmental policies certainly add extra cost all over the supply chain but are equally important for a sustainable growth (Bechini et al., 2008). The use of returnable transport units in addition to operational and ecological benefits will help to comply with waste regulation (Martinez-Sala et al., 2009). The issues within the grocery supply chain, necessitate the need for an intelligent supply chain with automated collaboration and exchange of information among their actors (Pramatari, 2007) (see Fig. 1).

10. Future trends

Nanotechnology is likely to play important part in the near future keeping in consideration the safety concern associated with packaging. To address the safety as well as other additional issues research and development in the field of active and intelligent packaging grew at dynamic pace with the aim to provide ecofriendly packaging alternatives. This posed a challenge of designing packaging materials by employing reverse engineering approach on the basis of requirements of food product besides on the availability of packaging materials. The aforementioned approach resulted in the tailoring of stimulated/controlled release of active agents and for specific target indicators. Another area of development is the use of innovative non-migratory materials in case of functional in-package food processing (Dainelli et al., 2008).

10.1. Future advances of active packaging

The advancement in the area of active food packaging led to the development of stimuli-responsive polymer materials. These unique materials offer amazing, innovative and functional features that fully comply with existing environments and regulate the release of molecules in response to external stimuli. As a consequence to retain biological function and provide particular chemical function, selectively designed molecular assemblies which allow release of active ingredients only when required by the system have been recently designed. These stimuli-responsive macromolecular nanostructures are tailored to bring about conformational as well as chemical changes as a reaction to external stimuli such as change in chemical composition, temperature or pH (Stuart et al., 2010).

10.2. Edible coatings

Edible films and coatings offer huge future potential to satisfy the consumer desire for environment friendly and natural foods. They do not completely replace traditional food packaging materials but provide extra functionalities to the food. Since, these packaging materials are produced from agricultural wastes and/or commodities of industrial food production, thus impart value addition to biomass. Use of edible films and coatings can enhance the process of preservation of food in addition to reducing the traditional packaging both in cost and bulk. Edible coatings and films are developed from biopolymer based on hydrocolloids, such as polysaccharides like cellulose, starch, alginates, chitosan, gums, pectins and proteins, from vegetable or animal origin. In addition to the basic functional properties of providing barrier to gases and moisture the new innovative development includes use of composites or blends to regulate the release of food additives and nutrients (Campos et al., 2011).

Films made from cellulose and cellulose derivatives by chemical absorb moisture water but are resistant to oil and fat uptake. These edible films can be enriched with additional functional features such as incorporation of additives and antimicrobials, for example, nisin or rosemary, and tea extract to reduce lipid oxidative rancidity, potassium sorbate or chitosan to impart anti microbial properties to the films.

Proteins both agro- and animal-based such as wheat gluten, corn zein, soy protein, whey proteins, casein, egg white, keratin, collagen, gelatin and myofibrillar proteins known for excellent barrier properties have been widely used to develop edible films and coatings by the process of solvent casting. Very little attention has been paid toward the preparation of protein based coatings and films using thermoplasticization and extrusion process. The major hurdle encountered while employing the thermoplasticization and extrusion process with efficient reproducibility is the control over the molecular architecture and spatial arrangement of the natural macromolecule (Mensitieri et al., 2011). Thus, thermoplasticization of proteins needs to be done on a larger scale as successfully done in case of starches by proper optimization of protein/plasticizer systems and processing conditions (Oliviero et al., 2010).

11. Conclusion

Trends in the emergence of biodegradable packaging technology with improved quality and safety resulted in innovations in packaging techniques. Research and development in response to consumer preferences gave rise to active, intelligent and bio active food packaging techniques that are purely innovative. These innovative packaging technologies contributed toward the enhancement of food quality, safety, feasibility and bioactivity of functional components. Applicability of novel and innovative packaging techniques is growing widely because of their health impact and thus resulted in reduced consumer complaints. In the near future traditional packaging will be completely replaced by innovative food packaging techniques as these techniques are rapidly making their way into the global market.

References

Abad, E., Palacio, F., Nuin, M., Gonzalez de Zarate, A., Juarros, A., Gomez, J.M., Marco, S., 2009. RFID smart tag for traceability and cold chain monitoring of foods: demonstration in an intercontinental fresh fish logistic chain. J. Food Eng. 93, 394–399.

Appendini, P., Hotchtkiss, J.H., 2002. Review of antimicrobial food packaging. Innov. Food. Sci. Emerg. Technol. 3, 113–126.

Avella, M., De Vlieger, J.J., Errico, M.E., Fischer, S., Vacca, P., Volpe, M.G., 2005. Biodegradable starch/clay nanocomposite films for food packaging applications. Food Chem. 93, 467–474.

AZoNano, The A to Z of Nanotechnology, 2004. Nanotechnology and food packaging, Article 857. AZoJono—J Nanotechnology Online. Available from: <http://www.azonano.com/Details.asp?ArticleID=857>, (Accessed 2016 Sept 24).

Bakkali, F., Averbeck, S., Averbeck, D., Idaomar, M., 2008. Biological effects of essential oils–a review. Food. Chem. Toxicol. 46, 446–475.

Bechini, A., Cimino, M., Marcelloni, F., Tomasi, A., 2008. Patterns and technologies for enabling supply chain traceability through collaborative e-business. Inf. Softw. Technol. 50, 342–359.

Brody, A., Strupinsky, E.R., d Kline, L.R., 2001. Odor Removers. In: Brody, A., Strupinsky, E.R., Kline, L.R. (Eds.), Active Packaging for Food Applications. Technomic Publishing Inc., Lancaster, pp. 107–117.

Brody, A., 2006. Nano and food packaging technologies converge. Food Tech. 60, 92–94.

Brody, A.L., Bugusu, B., Han, J.H., koelsch sand, C., Mchugh, T.H., 2008. Innovative food packaging solutions. J. Food Sci. 73, 107–116.

Campos, C.A., Gerschenson, L.N., Flores, S.K., 2011. Development of edible films and coatings with antimicrobial activity. Food Bioprocess Technol. 4, 849–875.

Choi, T.Y., Krause, D.R., 2006. The supply base and its complexity: implications for transactions costs, risks, responsiveness and innovation. J. Oper. Manage. 24, 637–652.

Dainelli, D., Gontard, N., Spyropoulos, D., Zondervan-van den Beuken, E., Tobback, P., 2008. Active and intelligent food packaging: legal aspects and safety concerns. Trends. Food. Sci. Technol. 19, 103–112.

De Kruijf, N., Beest, M.V., Rijk, R., Sipiläinen-Malm, T., Losada, P. P., De Meulenaer, B., 2002. Active and intelligent packaging: applications and regulatory aspects. Food Addit. Contam. 19, 144–162.

Decker, E.A., 1998. Strategies for manipulating the prooxidative/antioxidative balance of foods to maximize oxidative stability. Trends. Food Sci. Technol. 9, 241–248.

Dobrucka, R., Cierpiszewski, R., 2014. Active and intelligent packaging food – research and development – a review. Polish. J. Food Nutri. Sci. 64, 7–15.

Doyle, M.E., 2006. Nanotechnology: A Brief Literature Review. Food Research Institute Briefings [Internet]. June 2006. Available from: <http://www.wisc.edu/ fri/briefs/FRIBrief Nanotech Lit Rev.pdf> (Accessed 2016 Sept 24).

ETC Group Report, 2004. Down on the farm: the impact of nanoscale technologies on food and agriculture Available from: <http://www.etcgroup.org/ en/materials/publications.html?pub id=80> (Accessed 2016 Sept 29), pp. 1–75.

European Parliament, Directive 2004/12/EC of the European Parliament and of the Council of 11 February 2004 amending Directive 94/62/EC on packaging and packaging waste – Statement by the Council, the Commission and the European Parliament, Official Journal of the European Communities, L 47,18.2.2004, pp. 26–32.

Falguera, V., Quintero, J.P., Jimenez, A., Munoz, J.A., Ibarz, A., 2011. Edible films and coatings: structures, active functions and trends in their use. Trends. Food Sci. Technol. 22, 292–303.

Finkenzeller, K., 2003. RFID Handbook: Fundamentals and Applications. West Sussex, U.K.

Flores, S., Conte, A., Campos, C., Gerschenson, L., Del Nobile, M., 2007. Mass transport properties of tapioca-based active edible films. J. Food Eng. 81, 580–586.

Gomez-Estaca, J., Lopez-de-Dicastillo, C., Hernandez-Munoz, P., Catala, R., Gavara, R., 2014. Advances in antioxidant active food packaging. Trends. Food. Sci. Technol. 35, 42–51.

Gontard, N., 2000. In: Gontard, N. (Ed.), Les Emballages Actifs. Tech & Doc Editions, Lavoisier, Paris, France.

Han, J.H., Ho, C.H.L., Rodrigues, E.T., 2005. Intelligent packaging. In: Han, J.H. (Ed.), Innovations in Food Packaging. Elsevier Academic Press, Oxford.

Han, J.H., Seo, G.H., Park, I.M., Kim, G.N., Lee, D.S., 2006. Physical and mechanical properties of pea starch edible films containing beeswax emulsions. J. Food Sci. 71, 290–296.

Jedermann, R., Lang, W., 2007. Semi-passive RFID and beyond: steps towards automated quality tracing in the food chain. Int. J. RF Identif. Technol. Appl. 2, 247–259.

Jin, T., Zhang, H., 2008. Biodegradable polylactic acid polymer with nisin for use in antimicrobial food packaging. J. Food Sci. 73, 127–134.

Joseph,T., Morrison, M., 2006. Nanotechnology in agriculture and food. A nanoforum report, May. Available from: <http://www.nanowerk.com/nanotechnology/ reports/reportpdf/report61.pdf>, (Accessed 2016 Sept 29), pp. 1–14.

Kerry, J.P., O'Grady, M.N., Hogan, S.A., 2006. Past, current and potential utilization of active and intelligent packaging systems for meat and muscle-based products: a review. Meat Sci. 74, 113–130.

Lagaron, J.M., 2005. Biodegradable and sustainable plastics as essential elements in novel bioactive packaging technologies. In: First conference on biodegradable polymers for packaging applications. PIRA International, Leatherhead (UK). 5–6 July 2005.

Lange, J., Wyser, Y., 2003. Recent innovations in barrier technologies for plastic packaging—a review. Packag. Technol. Sci. 16, 149–158.

Liu, Y., Chakrabartty, S., Alocilja, E., 2007. Fundamental building blocks for molecular biowire based forward error-correcting biosensors. Nanotechnology 18, 1–6.

Lopez, P., Sanchez, C., Batlle, R., Nerin, C., 2007. Vapor-phase activities of cinnamon, thyme, and oregano essential oils and key constituents against food borne microorganisms. J. Agric. Food Chem. 55, 4348–4356.

Lopez-de-Dicastillo, Catala C.R., Gavara, R., Hernandez-Munoz, P., 2011. Food applications of active packaging EVOH films containing cyclodextrins for the preferential scavenging of undesirable compounds. J. Food Eng. 104, 380–386.

Lopez-Rubio, A., Almenar, E., Hernandez-Munoz, P., Lagaron, J.M., Catala, R., Gavara, R., 2004. Overview of active polymer-based

packaging technologies for food applications. Food Rev. Int. 20, 357–387.
Lopez-Rubio, A., Gavara, R., Lagaron, J.M., 2006. Bioactive packaging: turning foods into healthier foods through biomaterials. Trends. Food. Sci. Technol. 17, 567–575.
Martinez-Sala, A.S., Egea-Lopez, E., Garcia-Sanchez, F., Garcia-Haro, J., 2009. Tracking of returnable packaging and transport units with active RFID in the grocery supply chain. Comput. Ind. 60, 161–171.
Mensitieri, G., Di Maio, E., Buonocore, G., Nedi, I., Oliviero, M., Sansone, L., Iannace, S., 2011. Processing and shelf life issues of selected food packaging materials and structures from renewable resources. Trends Food Sci. Technol. 22, 72–80.
Mossinger, D., Hornung, J., Lei, S., De Feyter, S., Hoger, S., 2007. Molecularly defined shapepersistent 2D oligomers: the covalent-template approach to molecular spoked wheels. Angew. Chem. Int. Ed. 46, 6802–6806.
Nachay, K., 2007. Analyzing nanotechnology. Food Tech. 61, 34–36.
Oliviero, M., Di Maio, E., Iannace, S., 2010. Effect of molecular structure on film blowing ability of thermoplastic zein. J. Appl. Polym. Sci. 115, 277–287.
Ozdemir, M., Floros, J.D., 2004. Active food packaging technologies. Crit. Rev. Food. Sci. Nutri. 44, 185–193.
Peltzer, M., Wagner, J., Jimenez, A., 2009. Migration study of carvacrol as a natural antioxidant in high-density polyethylene for active packaging. Food. Addit. Contam: Part A: Chem., Anal., Contr. Exposure Risk Assess. 26, 938–946.
Persico, P., Ambrogi, V., Carfagna, C., Cerruti, P., Ferrocino, I., Mauriello, G., 2009. Nanocomposite polymer films containing carvacrol for antimicrobial active packaging. Polym. Eng. Sci. 49, 1447–1455.
Pramatari, K., 2007. Collaborative supply chain practices and evolving technological approaches. Supply Chain Manage. Int. J. 12, 210–220.
Pursiainen, O., Baumberg, J., Winkler, H., Viel, B., Spahn, P., Ruhl, T., 2007. Nanoparticletuned structural color from polymer opals. Opt. Exp. 15 (15), 9553–9561. Available from: <http://www.opticsexpress.org/abstract.cfm?id=139950> [Accessed 2016 Sept 29].
Realini, C.E., Marcos, B., 2014. Active and intelligent packaging systems for a modern society. Meat Sci. 98, 404–419.
Restuccia, D., Spizzirri, U.G., Parisi, O.I., Cirillo, G., Curcio, M., Lemma, F., Puoci, F., Vinci, G., Picci, N., 2010. New EU regulation aspects and global market of active and intelligent packaging for food industry applications. Food Control 21, 1425–1435.
Rooney, M.L., 2005. Introduction to active food packaging technologies. In: Han, J.H. (Ed.), Innovations in Food Packaging. Elsevier Ltd, London, UK, pp. 63–69. ISBN: 978–0-12–31632–1.
Stauffer, J.E., 2005. Radio frequency identification. Cereal Food World 50, 86–87.
Stefania, Q., Vicini, L., 2002. Antimicrobial food packaging in meat industry. Meat. Sci. 62, 373–380.
Steele, B., 2005. Researchers make synthetic DNA 'barcodes' to tag pathogens, providing an inexpensive, off-the-shelf monitoring system. Cornell Univ. News Service [Internet]. Available from: <http://www.news.cornell.edu/stories/ June05/Luo.barcodes.ws.html>, (Accessed 2016 Sept 24).
Stuart, M.A.C., Hyck, W.T.S., Genzer, J., Muller, M., Ober, C., Stamm, M., Sukhorukov, G.B., Szleifer, I., Tsukruk, V.V., Urban, M., Winnik, F., Zauscher, S., Luzinov, I., Minko, S., 2010. Emerging applications of stimuli-responsive polymer materials. Nat. Mater. 9, 101.
Suppakul, P., Miltz, J., Sonneveld, K., Bigger, S.W., 2003. Active packaging technologies with an emphasis on antimicrobial packaging and its applications. J. Food Sci. 68, 408–420.
Vanderroosta, M., Ragaerta, P., Devlieghere, F., De Meulenaer, B., 2014. Intelligent food packaging: the next generation. Trends. Food. Sci. Technol. 39, 47–62.
Vermeiren, L., Devlieghere, F., van Beest, M., de Kruijf, N., Debevere, J., 1999. Developments in the active packaging of foods. Trends. Food. Sci. Technol. 10, 77–86.
Weiss, J., Takhistov, P., McClements, J., 2006. Functional materials in food nanotechnology. J. Food Sci. 71, 107–116.
Wilson, C., 2007. Frontiers of Intelligent and Active Packaging for Fruits and Vegetables. CRC Press, Boca Raton, Fla., p. 360.
Wong, C.Y., McFarlane, D., Zaharudin, A., Agarwal, V., 2002. The intelligent product driven supply chain. In: Proceedings of SMC'02.
Yam, K.L., Takhistov, P.T., Miltz, J., 2005. Intelligent packaging: concepts and applications. J. Food. Sci. 70, 1–10.