NUTRITION AND FOOD SCIENCE

Application of plastics and paper as food packaging materials – An overview

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Abstract

The role of plastics and paper as food packaging materials is reviewed with a brief outlook on the historical background of food packages in general. The inherent properties of these food packages that should be considered by food processors are also discussed. The current efforts in meeting the needs of consumers in ensuring food's quality with prolonged shelf life during storage and distribution were highlighted. This review article also reflects on the emerging trends in technology that address innovations on Modified atmosphere packaging (MAP), Active packaging (AP), Intelligent packaging (IP) and the use of anti-microbial agents to extend the shelf life of foods under storage and distribution conditions. The future of these packaging materials in the food industries and their impacts on the environment and the society at large will continue to receive attention.

Key words: Food, Packaging materials, Paper, Plastics, Antimicrobial

Introduction

Packaging materials provide a means to preserve, protect, merchandise, market and distribute foods. They play a significant role in how these products reach the consumers in a safe and wholesome form without compromising quality. The relationship between the food and contact with the packaging material continuously interact and contribute to changes that can occur over time in these products. It is therefore important that several factors are considered when choosing the right package for a particular food product. Generally, the packaging material may either be rigid or flexible. Rigid containers include glass and plastic bottles and jars, cans, pottery, wood boxes, drums, tins, plastic pots and tubes. They give physical protection to the food inside that is not provided by flexible packaging. Flexible packaging is a major group of materials that includes plastic films, papers, foil, some types of vegetable fibres and cloths that can be used to make wrappings, sacks and sealed or unsealed bags.

Both flexible and rigid packaging materials, alone or in combination with other preservation methods, have been developed to offer the necessary barrier, inactivation, and containment properties required for successful food packaging. The combination of rigid packaging materials made from metal, glass, or plastic with heat was shown to provide the most effective and widely used method for inactivating microorganisms (Cutter, 2002). However, there are other means by which plastic or paper packaging materials can inactivate microorganisms associated with foods, they include controlled atmosphere, vacuum, modified atmosphere, active, and edible packaging (Suppakul et al., 2003).

Since early man first used a variety of locally available natural containers to store and eat foods, significant developments in food packaging materials have provided the means to lower the growth of microbes as well as protect foods from external microbial contamination. Packaging materials were developed over the years to prevent the deterioration of foods by microbes resulting from exposure to air, moisture, or pH changes associated with the food or its surrounding atmosphere.

Food industries have to decide which packaging material will be more appropriate for their food product taking note of the advantages and disadvantages of their choice or perhaps what other attributes can be incorporated in the packaging material based on the end use properties of the food product. This review is mainly on the characteristics of plastics, paper as flexible

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packaging materials and their roles in food quality and safety.

Historical background

The earliest forms of packaging materials were leaves, hollowed-out tree limbs, grounds, skins, reed baskets and earthenware vessels as containers. As civilization developed, more complex containers were developed to meet specific needs. Large ceramic vessels, amphoras were used from 1500 BC to 500 AD to ship wine and other products commercially throughout the Mediterranean. The most large-scale use was to serve the ancient Greek and Roman empires. Although their form is much different from our current packages, the shape and design were clearly the result of the same reasoning that we use to design successful packaging today. They were designed to be economical, to produce and ship. The unusual shapes, and especially the pointed base, facilitated handling, storage, transport and use in logistical systems that were very differently shaped from those that we use today (Twede, 2002).

Glass-making began in 7000 B.C. as an offshoot of pottery, and was first industrialized in Egypt in 1500 B.C. Glass is made from base materials (limestone, soda, sand and silica), which were in plentiful supply, all ingredients were simply melted together and molded while hot. Although the mixing process and the ingredients have changed very little, the molding techniques have progressed dramatically. Paper (from stems of papyrus in ancient Egypt) is the oldest form of what is referred to as "flexible packaging". It was reported that sheets of treated mulberry bark were used as a flexible packaging material by the Chinese to wrap foods as early as the First or Second century B.C and during the next fifteen hundred years, the paper-making technique was refined and transported to the Middle East, then Europe and finally into the United Kingdom (Welt, 2005).

The use of metal containers as packaging materials started from ancient boxes and cups, made from silver and gold, which were too valuable for common use. Cheaper metals, stronger alloys, thinner gauges and coatings were eventually developed and mass produced. After metal cans were invented and progressively improved, it was necessary to find a way to open them. Until 1866, the only method was by hammer and chisel. It was during this period that the keywind metal tear-strip was developed and after nine years in 1875, the can opener was invented. The can opener remained for more than 100 years, the most efficient method of retrieving the contents from metal cans. In the 1950s, the pop top/tear tab can lid appeared and now tear tapes that open and reseal are popular (Hook and Heimlich, 2011).

Plastic is the youngest in comparison with other packaging materials. It was discovered in the 19th century, most plastics were reserved for military and wartime use. Styrene was first distilled from a balsam tree in 1831. But the early products were brittle and shattered easily. Germany refined the process in 1933 and by the 1950s foam was available worldwide. Insulation and cushioning materials as well as foam boxes, cups and meat trays for the food industry became popular. Vinyl chloride was discovered in 1835 and provided the opportunity for the further development of rubber chemistry. For packaging, molded deodorant squeeze bottles were introduced in 1947 and in 1958; heat shrinkable films were developed from blending styrene with synthetic rubber. Cellulose acetate was first derived from wood pulp in 1900 and developed for photographic uses in 1909.

DuPont manufactured cellophane in New York in 1924 but was not commercially used for packaging until the late 1950s and early 1960s. In 1933, films protected submarine telephone cables and later were important for World War II radar cables and drug tablet packaging. After the war, the new plastics that had been developed entered the consumer mainstream in a flood and 'Tupperware' polyethylene food containers with air tight seal entered the market in 1946 (Plastics Make It Possible report, 2010).

There were new manufacturing processes developed using various methods such as forming, molding, casting, and extrusion to churn out plastic products in vast quantities (Packaging Today report, 2012). Other cellophanes and transparent films have been refined as outer wrappings that maintain their shape when folded. Originally clear, such films can now be made opaque, coloured or embossed with patterns. The polyethylene terephthalate (PETE) container became available during the last two decades with its use for beverages entering the market in 1977. By 1980, foods and other hot-fill products such as jams could also be packaged in PETE. In 1986, aluminium trays were replaced by plastic, microwavable trays. Metallocene catalysed polyolefins was introduced in 1996 to reduce food waste. In 2000 polylactic acid from corn entered the packaging market signalling the return of bio based plastic (Plastics Make It Possible Report, 2010).

Commonly available food packaging materials

The most common food packaging materials are glass, wood, metal, plastics, paper and other flexible packages such as coatings and adhesives. Each of these packages offers unique advantages and disadvantages that have to be critically considered in making the right choice by the food processor.

Plastic materials are made up of large, organic (carbon-containing) molecules that can be formed into a variety of useful products, they are fluid, moldable, heat sealable, easy to print, and can be integrated into production processes where the package is formed, filled, and sealed in the same production line (Marsh and Bugusu, 2007). The major disadvantage of plastics is their variable permeability to light, gases, vapours, and low molecular weight molecules. Structural polymers such as polyethylene and polypropylene provide mechanical properties at low cost, while barrier polymers such as polyvinyldene chloride and ethylene vinyl alcohol provide protection against transfer of gases, flavours and odours through the package. Tie resins, co-extrudable adhesive resins, bond the structural and barrier resins together.

The use of plastics in packaging has increased worldwide with an estimate at 280 metric tonnes (Paine and Paine, 2012). The packaging industry is the largest user of plastics; more than 90% of flexible packaging is made of plastics, compared to only 17% of rigid packaging. Barrier resins are generally being employed for plastic containers by modifications to improve product protection and make them more cost effective.

Recyclable and Recycled Plastics

There are more than thirty different plastics in packaging; the most common are polyolefins, polyvinyls and polyesters. There are possibilities that chemical contaminants in plastic packaging intended for recycling may remain in the recycled material and could migrate into the food. Other aspects of plastics recycling, such as microbial contamination and structural integrity of the recycled plastic, are also important considerations for the safe use of recycled plastics for food-contact applications.

Plastic recyclers must be able to demonstrate that contaminant levels in the reformed plastic have been reduced to sufficiently low levels to ensure that the resulting packaging is of purity suitable for its intended use. The production of a polymer with the desired qualities will require additional antioxidants, processing aids, or other adjuvants that may need to be added to the recycled polymer (CFSAN, 2006).

As petroleum reserves become more limited, new varieties of plastics are likely to increasingly be made from renewable biomass. These will contribute to the already extensive array of mechanical and aesthetic performance properties that plastics are well known for. The utilization of fossil fuels in the manufacture of plastics accounts for about 7% of worldwide oil and gas (Okada, 2002). These resources will arguably be depleted within the next one hundred years, and the peak in global oil production as estimated by some will occur within the next few decades. The plastic industry will be faced with real issues associated with the use of an essentially non-renewable feedstock for the majority of their products and there is an urgent need to develop new synthetic routes to polymeric materials using renewable resources (Williams and Hillmyer, 2008). Current packaging designs are beginning to incorporate recyclable and recycled plastics but the search for reuse functions continues. There are several factors that play into the economic assessment of recycling, including costs for collection, separation, cleaning or reprocessing, and transportation (energy).

Table 1. Common abbreviations for different plastic films and coating materials.

Abbreviation	Full form
PE	Polyethylene
PP	Polypropylene
PET or PETE	Polyethylene terephtalate
PEN	Polyethylene naphthalene dicarboxylate
PC	Polycarbonate
EVA	Ethylene vinyl acetate
PA	Polyamide
PVC	Polyvinylchloride
PVdC	Polyvinylidene chloride
PS	Polystyrene
SB	Styrene butadiene
ABS	Acrylonitrile butadiene styrene
EVOH	Ethylene vinyl alcohol
TPX	Polymethyl pentene
HNP	High nitrile polymers
PVA	Polyvinyl alcohol
HMT	Hexamethylene-tetramine

Recycling diverts materials from the waste stream to material recovery. It is different from reuse, which involves using a returned product in its original form, recycling involves reprocessing material into new products. The recycling program entails collection, sorting, processing, manufacturing, and sale of recycled materials and

products. It was shown that in order to make recycling economically feasible, recycled products and materials must have a market and the rates of recycling for plastics is on the rise in the United States of America (EPA, 2006).

Commonly used plastic films and their abbreviations are shown in Table 1. There are several plastic packaging materials for foods as shown in Figure 1. All thermoplastics are recyclable i.e they can be melted and re-used as raw materials for the production of new products. The recycling process requires separation by resin type as identified by the American Plastics Council and shown in Table 4.

PVC and PS are difficult to recycle. There are concerns that plasticizers such as adipates in PVC may leach to foods and incineration is a problem because of its chlorine. PS in an expanded form may be used for non-food packaging and cushioning and can then be recycled or incinerated (Marsh and Bugusu, 2007).

The above six commonly recycled plastic resin find wide applications in the following:

- PET: beverage bottles, mouthwash bottles, boil in bag pouches
- HDPE: milk jugs, trash bags, detergent bottles
- PVC: cooking oil bottles, packaging around meat
- LDPE: grocery bags, food wrap, bread bags
- PP: yoghurt containers, shampoo bottles, straws, margarine tubs, diapers
- PS: hot beverage cups, take-home boxes, egg cartons, meat trays

Apart from plastics and plastic products, other flexible packages include:

Paper products - Paper like webs of mixed cellulose and plastics, papers made from plastics, bonded fibre plastics, cloths and scrims, spun bonded fabrics, regenerated cellulose films, aluminium and steel foils.

Coatings and adhesives - Cellulose esters, cellulose ethers, rubber hydrochloride, chlorinated rubbers, chlorinated polyolefins, natural and synthetic bitumens and asphalts, natural and synthetic resins, adhesives of all types, prime, key, bond or sub-coats, latex bond mineral coatings, deposited metal layers.

Figure 1. Some examples of plastic packaging materials.

Table 2. Resin identification codes for plastics.

Resin	Code	Amount generated (thousand tonnes)	Amount recycled (thousand tonnes)
Polyethylene terephthalate	1	2860	540
High-density polyethylene	2	5890	520
Polyvinyl chloride	3	1640	-
Low-density polyethylene	4	6450	190[a]
Polypropylene	5	4000	10
Polystyrene	6	2590	-
Other resins	7	5480	390

Adapted from American Plastics Council, 2006b; a   includes linear low density polyethylene

Paper and paperboards

Paper and paperboard are sheet materials made from an interlaced network of cellulose fibers derived from wood by using sulfate and sulfite. The fibers are then pulped and/or bleached and treated with chemicals such as slimicides and strengthening agents to produce the paper product. Paper and paperboards are commonly used in corrugated boxes, milk cartons, folding cartons, bags and sacks, and wrapping paper.

Paper and paperboards provides mechanical strength, they are biodegradable and have good printability. Coatings such as waxes or polymeric materials can be used to improve their poor barrier properties. Apart from their poor barrier properties to oxygen, carbondioxide and water vapour other drawbacks include their being opaque, porous and not heat sealable (FCIS report, 2011).

A few examples of paper packages for foods are shown in Figure 2 below. Polyethylene terephthalate (PET) is a desirable packaging material. It combines good barrier properties, clarity, impact resistance, and high speed processes have made PET containers a choice for carbonated beverage containers, dressings, edible oils, peanut butter and many other products. The many different types of paper used in food packaging can be categorized as follows (Kirwan, 2003, Marsh and Bugusu, 2007):

Kraft paper—produced by a sulfate treatment process, kraft paper is available in several forms: natural brown, unbleached, heavy duty, and bleached white. The natural kraft is the strongest of all paper and is commonly used for bags and wrapping. It is also used to package flour, sugar, and dried fruits and vegetables.

Sulfite paper—lighter and weaker than kraft paper, sulfite paper is glazed to improve its appearance and to increase its wet strength and oil resistance. It can be coated for higher print quality and is also used in laminates with plastic or foil. It is used to make small bags or wrappers for packaging biscuits and confectionary.

Greaseproof paper—greaseproof paper is made through a process known as beating, in which the cellulose fibers undergo a longer than normal hydration period that causes the fibers to break up and become gelatinous. These fine fibers then pack densely to provide a surface that is resistant to oils but not wet agents. Greaseproof paper is used to wrap snack foods, cookies, candy bars, and other oily foods, a use that is being replaced by plastic films.

Glassine—glassine is greaseproof paper taken to an extreme (further hydration) to produce a very dense sheet with a highly smooth and glossy finish. It is used as a liner for biscuits, cooking fats, fast foods, and baked goods.

Figure 2. Some examples of paper food packages, polyethylene (PE) added to increase stiffness and strength.

Parchment paper—parchment paper is made from acid-treated pulp (passed through a sulfuric acid bath). The acid modifies the cellulose to make it smoother and impervious to water and oil, which adds some wet strength. It does not provide a good barrier to air and moisture, is not heat sealable, and is used to package fats such as butter and lard.

Paper laminates are coated or uncoated papers based on kraft and sulfite pulp. They can be laminated with plastic or aluminum to improve various properties. For example, paper can be laminated with polyethylene to make it heat sealable and to improve gas and moisture barrier properties. Laminated paper is used to package dried products such as soups, herbs, and spices (Marsh and Bugusu, 2007).

Paperboards on the other hand are thicker than paper with a higher weight per unit area and often made in multiple layers. They are commonly used to make containers for shipping—such as boxes, cartons, and trays—they are seldom used for direct food contact. The various types of paperboard are as follows (Soroka, 1999; Marsh and Bugusu, 2007).

White board—made from several thin layers of bleached chemical pulp, white board is typically used as the inner layer of a carton. White board may be coated with wax or laminated with polyethylene for heat sealability.

Solid board—possessing strength and durability, solid board has multiple layers of bleached sulfate board. When laminated with polyethylene, it is used to create liquid cartons (known as milk board). Solid board can also use to package fruit juices and soft drinks.

Chipboard—chipboard is made from recycled paper and often contains blemishes and impurities from the original paper, which makes it unsuitable for direct contact with food, printing, and folding. It is often lined with white board to improve both appearance and strength. The least expensive form of paperboard, chipboard is used to make the outer layers of cartons for foods such as tea and cereals.

Fiberboard—Fiberboard can either be solid or corrugated. The solid type has an inner white board layer and outer kraft layer and provides good protection against impact and compression. When laminated with plastics or aluminum, solid fiberboard can improve barrier properties and is used to package dry products such as coffee and milk powder. The corrugated type, also known as corrugated board, is made with two layers of kraft paper with a central corrugating (or fluting) material. Fiberboard's resistance to impact abrasion and crushing damage makes it widely used for shipping bulk food and case packing of retail food products.

The packaging material as a barrier to gases and vapours

The food manufacturer incorporates food packaging materials that will act as a barrier to gases and water vapour. Oxygen and water vapour are major concerns in food packaging in relation to shelf life. The presence of oxygen in a packaged food is often a key factor that limits the shelf life of a product. Oxidation can cause changes in flavour, colour, and odour, as well as destroy nutrients and facilitate the growth of aerobic bacteria, moulds, and insects. Therefore, the removal of oxygen from the package headspace and from the solution in liquid foods and beverages has long been a target of the food-packaging scientists. The deterioration in quality of oxygen sensitive products can be minimized by oxygen scavengers that remove the residual oxygen after packing. Existing oxygen scavenging technologies are based on oxidation of one or more of the following substances: iron powder, ascorbic acid, photo-sensitive dyes, enzymes (such as glucose oxidase and ethanol oxidase), unsaturated fatty acids (such as oleic, linoleic and linolenic acids), rice extract, or immobilized yeast on a solid substrate (Floros et al., 1997). These materials are normally contained in a sachet. Oxygen scavenging is an effective way to prevent the growth of aerobic bacteria and moulds in dairy and bakery products. There are more details on oxygen scavenging from other reviews (Miltz et al., 1995; Miltz and Perry 2000; Floros et al., 1997; Vermeiren et al., 1999).

The barrier properties and capacity to protect foods depends largely on the permeability of the packaging material to gases and vapours. It was shown that the protection of foodstuffs may be achieved with a single layer of polymer or the use of multi-layered films including different polymers, coating and metal foils (Robertson, 2006). The moisture vapour transmission rate (MVTR) of single – ply films is an important criterion in the prevention of moisture and subsequent reduction of microbial growth that can lead to food spoilage. Hirsch (1991) investigated the MVTR for several single-ply packaging materials kept at 40ºC and 90% relative humidity. It was observed that Polyvinyldene chloride (PVDC) with a very low MVTR of 0.9 $g/25\mu/m^2/24h$ was better at preventing moisture when compared to Barex 210 with a high MVTR of 94.6 $g/25\mu/m^2/24h$.

As with all food products, it is necessary to integrate a HACCP-based program to assure quality throughout the packaging operation. In addition to packaging improvements, other novel technologies that can be employed include the development of detectors for oxygen levels, bacterial toxins, and microbial growth, or the integration of time-temperature indicators for detection of improper handling or storage (Cutter, 2002). The main criterion to extending shelf life is to find a material that will balance the oxygen and carbon dioxide permeability and water vapour in a package.

Recent innovations on food packaging agents

Modified Atmosphere Packaging (MAP) is a form of packaging that involves the removal of air from the pack and its replacement with a single gas or a mixture of gases (Blakistone, 1999). Active packaging has been defined as a form of modified atmosphere packaging, which 'changes the condition of the packed food to extend shelf-life or to improve safety or sensory properties, while maintaining the quality of packaged food'. This can be achieved by the incorporation of certain additives into the packaging film or within a packaging container to modify the headspace atmosphere and to extend the product's shelf life. Intelligent packaging system monitors the condition of packed foods to give information about the quality of the packaged food during transportation and storage (Ahvenainen, 2003).

In recent years, antimicrobial packaging has attracted much attention from the food industry because of the increase in consumer demand for minimally processed, preservative-free products. As a result of this demand, the preservative agents must be applied to packaging in such a way that only low levels of preservatives comes into contact with the food (Cha and Chinnan, 2004). The use of appropriate film or coatings can impart anti-microbial (AM) effectiveness. An et al. (2000) claimed that a polymer-based solution coating would be the most desirable method in terms of stability and adhesiveness of attaching a bacteriocin to a plastic film. It was found that low-density polyethylene (LDPE) films coated with a mixture of polyamide resin in *i*-propanol/*n*-propanol and a bacteriocin solution provided anti-microbial activity against *Micrococcus flavus*.

The potential of incorporating nisin directly into LDPE film for controlling food spoilage and enhancing product safety was highlighted by Siragusa et al. (1999). Devlieghere et al. (2000b) were the first investigators to use hexamethylene-

tetramine (HMT) as an anti-microbial packaging agent. Chung et al. (1998) found that LDPE films (48 to 55 µm thick) impregnated with either 1.0 % w/w *Rheum palmatum* and *Coptis chinensis* extracts or silver-substituted inorganic zirconium retarded the growth of total aerobic bacteria, lactic acid bacteria and yeast on fresh strawberries. Preliminary studies by Suppakul and others (2002) with linear low-density polyethylene LLDPE films (45 to 50 µm thick) containing 0.05% w/w linalool or methyl chavicol showed a positive activity in controlling the growth of *E. coli.*

The recent increase in environmental awareness has contributed toward the development of edible packaging materials. Viable edible films and coatings have been successfully produced from whey proteins; their ability to serve other functions, viz. carrier of antimicrobials, antioxidants, or other nutraceuticals, without significantly compromising the desirable primary barrier and mechanical properties as packaging films, will add value for eventual commercial applications in food industries (Ramos et al., 2012). Edible films and various antimicrobial compounds incorporated in edible food packages have also been investigated (Rodrigues and Han 2000; Coma et al., 2001; Appendini and Hotchkiss, 2002). Rodrigues and Han (2000) investigated the edible anti-microbial materials produced by incorporating lysozyme, nisin and ethylenediamine tetracetic acid (EDTA) in whey protein isolates (WPI) films. Both lysozyme and nisin-containing films are effective in inhibiting *Brochothri thermosphacta* but fail to suppress *Listeria monocytogenes*. The incorporation of EDTA in WPI films improved the inhibitory effect on *L. monocytogenes* but had a marginal effect only on *E. coli* O157:H7.

Coma et al. (2001) studied the moisture barrier and the anti-microbial properties of hydroxypropyl methyl cellulose (HPMC)-fatty acid films (30-50 µm thick) containing Nisin (105 IU/mL) as the anti-microbial agent and its efficacy against *Listeria innocua* and *Staphilococcus aureus* growth in food products. Stearic acid was chosen as the fatty acid because of its ability to reduce the rate of water vapour transmission. However, it impaired the effectiveness of the film against both strains. This may be explained by electrostatic interaction between the cationic nisin and the anionic stearic acid.

Foods with different biological and chemical characteristics are stored under different environmental conditions, which, in turn may cause different patterns of microflora growth. The

interactions between the package coatings and anti-microbial agents (AM) are important. For example, aerobic microorganisms can exploit headspace oxygen for their growth. The mechanism and kinetics of growth inhibition are generally studied in order to permit mathematical modelling of microbial growth. The pH of a product was shown to affect the growth rate of target microorganisms and changes the degree of ionization of the most active chemicals, as well as the activity of the antimicrobial agents (Han, 2000). Tobias et al. (2000) reported that LDPE film containing benzoic anhydride was more effective in inhibiting molds at low pH values. Guillard et al. (2009) found that the diffusion of sorbic acid decreased with an increase in pH. The food water activity may also alter the microflora, AM activity, and chemical stability of active ingredients that are applied by impregnation (Kasapis et al., 2009). Rojas-Grau et al. (2008) showed that the diffusion of potassium sorbate through polysaccharide films increases with water activity and this has a negative impact on the amount available for protection.

Anti-microbial packaging is a rapidly emerging technology. The need to package foods in a versatile manner for transportation and storage, along with the increasing consumer demand for fresh, convenient, and safe food products presages a bright future for anti-microbial packaging (Floros et al., 1997). However, more information is required on the chemical, microbiological and physiological effects of these systems on the packaged food especially on the issues of nutritional quality and human safety (Floros et al., 1997). Current research on anti-microbial packaging has focused primarily on the development of various methods and model systems, whereas little attention has been paid to its preservation efficacy in actual foods (Han, 2000; Cha and Chinnan, 2004). Research is essential to identify the types of food that can benefit most from AM packaging materials. It is likely that future research into a combination of naturally-derived AM agents, biopreservatives and biodegradable packaging materials will highlight a range of the merits of AM packaging in terms of food safety, shelf-life and environmental friendliness (Nicholson, 1998; Rodrigues and Han, 2000; Coma et al., 2001).

The storage temperature may affect the activity of AM packages. Several researchers found that the protective action of AM films deteriorated at higher temperatures, due to high diffusion rates in the polymer (Wong et al., 1996). The diffusion rate of the AM agent and its concentration in the film must be sufficient to remain effective throughout the shelf life of the product (Cooksey, 2000).

Polymer nanotechnology in packaging

The worldwide sales of nanotechnology products to the food packaging sector rose from US$ 150 million in 2002 to US$ 860 million in 2004 and has risen steadily (Verbeke, 2006; Meetoo, 2011). There are new innovations to encourage active packaging which involves the combination of food-packaging materials with antimicrobial substances such as the incorporation of antibacterial nanoparticles into polymer films to control microbial surface contamination of foods. It was observed for both migrating and non-migrating antimicrobial materials, an intensive contact between the food product and packaging material is required and therefore potential food applications include vacuum or skin-packaged products, e.g. vacuum-packaged meat, fish, poultry or cheese.

Nanocomposites are known to exhibit increased barrier properties, increased mechanical strength, and improved heat resistance compared to their neat polymers and conventional composites (Sorrentino et al., 2007). Nanoclays, kaolinite, carbon nanotubes and graphene nanosheets that are used as fillers were shown to have potentials that will improve the ability of plastic packaging against migration of gases and flavour compounds, as well as boosting shelf life (Arora and Padua, 2010).

Cellulose, polylactic acid (PLA) have received attention as sustainable, biocompatible, biodegradable materials with good mechanical and optical properties. Lactic acid, the monomer of PLA, may easily be produced by fermentation of carbohydrate feedstock such as corn. Thus, PLA offers more disposal options and its manufacture is less environmentally burdensome than traditional petroleum-based plastics (Arora and Padua, 2010). There are also possibilities to combine antimicrobial compounds with different types of carriers (plastic and rubber articles, paper-based materials, textile fibrils and food-packaging materials). Antibodies may also be attached to fluorescent nanoparticles to detect chemicals or foodborne pathogens. A successful polymer nanotechnology in food packaging will have to take into consideration the complete life cycle of the packaging material (Silvestre et al., 2011). The life cycle assessment consider the overall impact on the environment from all the stages of raw materials sourcing to the production process, transportation and delivery until it reaches end users and finally being disposed (Chaffee and Yoros, 2007). The

sustainability goal inherent within the cradle-to-cradle concept (imposing zero impact on future generations) builds on life cycle analysis to address the material and energy recovery (McDonough and Braungart, 2002). Furthermore, new packaging materials are being developed to facilitate the goal of true sustainability

Multidisciplinary approach to solve future problems

A symposium devoted to the "Plastic Packaging of Foods - Problems and Solutions" identified plastics as the consumer preference of tomorrow and suggested that consumers need to be provided with packages that are economic, convenient and environmentally sound. The major demands by consumers which are still relevant today were identified as - convenience, quality, safety and recyclability (Fox, 1989).

Convenience: Consumers demand products and packaging that make life easier and allow them to enjoy more available leisure time. This convenience applies to closure systems, consumers look for easy open ends, dispensing closures and re-sealable packaging.

Quality: Consumers are usually willing to pay for high quality products they can rely on. Aseptic packaging, irradiation processing and controlled atmosphere packaging are examples of innovations that enhance product shelf life and quality.

Safety: With more dual career families, children are playing an ever larger role in the home, and consumers are looking for packaging that is shatter resistant and easy for children to use. A substantial majority of consumers are willing to pay extra for tamper evident packaging.

Recyclabilty: Consumers want packaging materials that are environmentally friendly.

In the past twenty three years after the 1989 symposium, the production and the use of plastics in the world have been enormously increased, worsening the problem of the waste disposal. The growing interest in environmental impact of discarded plastics has directed research on the development of plastics that degrade more rapidly in the environment, leading to a complete mineralization or bioassimilation of the plastics (Mergaert and Swings, 1996; Tokiwa et al., 2009, Thompson et al., 2009). Biopolymers should be used in those applications where biodegradability and/or the derivation of natural resources gives added value, particularly, where valuable petroleum-based plastics are used for applications with a short life time.

Currently, WikiCells have just been developed at Harvard University; they are novel edible forms for eating and drinking transportable foods and drinks without plastic and would help to reduce waste. They use special membrane technology that permits the fabrication of thin delicious membranes with significant water diffusional resistance and adjoined shells that allow for stability of the WikiCells over long periods of time (WikiCells report, 2012).

There are health concerns regarding residual monomer and components in plastics and paper, including stabilizers, plasticizers, and condensation components such as bisphenol A (BPA). Some of these concerns are based on studies using very high intake levels; others have no scientific basis. The active form of BPA binds to the steroid receptors and can affect estrogen, thyroid and testoterone functions (Science Daily report, 2011). In order to ensure public safety, national and international regulatory bodies such as the Food and Drug Administration (FDA), European Food Safety Authority (EFSA) carefully reviews and regulates substances used to make plastics and other packaging materials. Any substance that can reasonably be expected to migrate into food is classified as an indirect food additive subject to regulations. The Swedish government recently introduced a ban on bisphenol A in food packaging intended for children under the age of three from the beginning of 2013 (Food Production Report, 2012).

There was also a recent study about the effects of chemicals such as perfluorinated compounds (PFC) which are widely used in food packaging. They are found in teflon cookware, microwave popcorn bags and stain-resistant carpets. These chemicals can weaken the ability of vaccination jabs to protect young children. Grandjean et al. (2012) reported that children exposed to perfluorinated compounds (PFCs) in the womb or in the first years of life had lower immunity to tetanus and diphtheria.

The choice of a particular plastic or a flexible package will be linked to developments in engineering and consumer studies. There will continuously be new packaging materials that will reflect developments in the technology of food processing, life style changes, political decision making, and environmental issues. These challenges will be best tackled by multi-disciplinary approach that addresses these issues in the nearest future.

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