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Innovative Food Packaging

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Abstract: ***Food processing and packaging industries spend an estimated 15% of the total variable costs on packaging materials . Industrial processing of food, reduced consumption of animal protein, importation of raw materials and ingredients to be converted in the India , and scarcity of time to select/prepare food from fresh ingredients have enhanced innovation in food and beverage packaging. The principal function of packaging is protection and preservation from external contamination . This function involves retardation of deterioration, extension of shelf life, and maintenance of quality and safety of packaged food. Traditional food packages are passive barriers designed to delay the adverse effects of the environment on the food product. Active packaging, however, allows packages to interact with food and the environment and play a dynamic role in food preservation. The presence of oxygen in a package can trigger or accelerate oxidative reactions that result in food deterioration: Oxygen facilitates the growth of aerobic microbes and molds. RFID has recently found its way into numerous applications in the food industry, ranging from food monitoring and traceability to enhancing food safety, to improving supply chain efficiency.***

Keywords: absorption, active food packaging, adsorption, electronic product code (EPC), food scalping, intel- ligent food packaging, migration, nanocomposites, nanosensors, nanotechnology, nanotubes, oxygen scavenger, permselectivity, radio frequency identification (RFID), time-temperature indicator (TTI)

1. Introduction

Food processing and packaging industries spend an estimated 15% of the total variable costs on packaging materials (Esse 2002). Industrial processing of food, reduced consumption of animal protein, importation of raw materials and ingredients to be converted in the India , and scarcity of time to select/prepare food from fresh ingredients have enhanced innovation in food and beverage packaging. The continued quest for innovation in food and beverage packaging is mostly driven by consumer needs and demands influenced by changing global trends, such as increased life expectancy, fewer organizations investing in food production and distribution (Lord 2008), and regionally abundant and diverse food supply. The use of food packaging is a socioeconomic indicator of increased spending ability of the population or the gross domestic product as well as regional (rural as opposed to urban) food availability.

This Scientific Status Summary provides an overview of the latest innovations in food packaging. It begins with a brief history of food and beverage packaging, covering the more prominent pack- aging developments from the past, and proceeds to more modern advances in the packaging industry. The article then delves into current and emerging innovations in active and intelligent packaging (such as oxygen scavengers and moisture control agents), pack- aging mechanisms that control volatile flavors and aromas (such as flavor and odor absorbers), and cutting-edge advances in food packaging distribution (such as radio frequency identification and electronic product codes). Finally, the article discusses nano-sized components that have the potential to transform the food packaging industry.

2. Innovative Food Packaging Solutions

Expandable Role of Packaging

The principal function of packaging is protection and preservation from external contamination (Robertson 2006). This function involves retardation of deterioration, extension of shelf life, and maintenance of quality and safety of packaged food. Packaging protects food from environmental influences such as heat, light, the presence or absence of moisture, oxygen, pressure, enzymes, spurious odors, microorganisms, insects, dirt and dust particles, gaseous emissions, and so on. All of these cause deterioration of foods and beverages (Marsh and Bugusu 2007). Prolonging shelf life involves retardation of enzymatic, microbial, and biochemical reactions through various strategies such as temperature control; moisture control; addition of chemicals such as salt, sugar, carbon dioxide, or natural acids; removal of oxygen; or a combination of these with effective packaging (Robertson 2006). Precise integration of the product, process, package, and distribution is critical to avoid recontamination. The ideal packaging material should be inert and resistant to hazards and should not allow molecular transfer from or to packaging materials (Robertson 2006).

Other major functions of packaging include containment, convenience, marketing, and communication. Containment involves ensuring that a product is not intentionally spilled or dispersed. The communication function serves as the link between consumer and food processor. It contains mandatory information such as weight, source, ingredients, and now, nutritional value and cautions for use required by law. Product promotion or marketing by companies is achieved through the packages at the point of purchase (Kotler and Keller 2006). Secondary functions of increasing importance include traceability, tamper indication, and portion control (Marsh and Bugusu 2007). New tracking systems enable tracking of packages though the food supply chain from source to disposal. Packages are imprinted with a universal product code to facilitate checkout and distribution control. More recent inno- vations used include surface variations sensed by finger tips and palms, sound/music or verbal messages, and aromas emitted as part of an active packaging spectrum (Landau 2007).

3. Active and Intelligent Food Packaging

Traditional food packages are passive barriers designed to delay the adverse effects of the environment on the food product. Active packaging, however, allows packages to interact with food and the environment and play a dynamic role in food preservation (Brody and others 2001; Lo`pez-Rubio and others 2004**)**. Developments in active packaging have led to advances in many areas, including delayed oxidation and controlled respiration rate, microbial growth, and moisture migration. Other active packaging technologies include carbon dioxide absorbers/emitters, odor absorbers, ethylene removers, and aroma emitters. While purge and moisture control and oxygen removal have been prominent in active packaging, purge control is the most successful commercially. An example is the drip-absorbing pad used in the poultry industry (Suppakul and others 2003a).

In addition, active packaging technology can manipulate perm- selectivity, which is the selective permeation of package materials to various gases. Through coating, microperforation, lamination, coextrusion, or polymer blending, permselectivity can be manipulated to modify the atmospheric concentration of gaseous com- pounds inside a package, relative to the oxidation or respiration kinetics of foods. Certain nanocomposite materials can also serve as active packaging by actively preventing oxygen, carbon dioxide, and moisture from reaching food.

Intelligent or smart packaging is designed to monitor and communicate information about food quality (Brody and others 2001; Kerry and others 2006). Examples include time-temperature indicators (TTIs), ripeness indicators, biosensors, and radio frequency identification. These smart devices may be incorporated in pack- age materials or attached to the inside or outside of a package. As of summer 2008, the commercial application of these technologies to food packaging has been small. However, the U.S. Food and Drug Administration (FDA) recognizes TTIs in the 3rd edition of the *Fish and Fisheries Products Hazards and Control Guidance*, so their importance may increase in the seafood industry. Moreover, WalMart, Home Depot and other retail outlets use radio frequency identification, so it is likely to become very prominent as a mechanism for tracking and tracing produce and others perishable commodities.

4. Oxygen Scavengers

The presence of oxygen in a package can trigger or accelerate oxidative reactions that result in food deterioration: Oxygen facilitates the growth of aerobic microbes and molds. Oxidative reactions result in adverse qualities such as off-odors, off-flavors, undesirable color changes, and reduced nutritional quality. Oxygen scavengers remove oxygen (residual and/or entering), thereby retarding oxidative reactions, and they come in various forms: sachets in headspace, labels, or direct incorporation into package material and/or closures. Oxygen scavenging compounds are mostly agents that react with oxygen to reduce its concentration. Ferrous oxide is the most commonly used scavenger (Kerry and others 2006). Others include ascorbic acid, sulfites, catechol, some nylons, photosensitive dyes, unsaturated hydrocarbons, ligands, and enzymes such as glucose oxidase. To prevent scavengers from acting prematurely, specialized mechanisms can trigger the scavenging reaction. For example, photosensitive dyes irradiated with ultraviolet light activate oxygen removal (Lo`pez-Rubio and others 2004). Oxygen scavenging technologies have been successfully used in the meat industry (Kerry and others 2006).

5. Carbon dioxide absorbers and emitters

Carbon dioxide may be added for beneficial effects, for example, to suppress microbial growth in certain products such as fresh meat, poultry, cheese, and baked goods (Lo`pez-Rubio and others 2004). Carbon dioxide is also used to reduce the respiration rate of fresh produce (Labuza 1996) and to overcome package collapse or partial vacuum caused by oxygen scavengers (Vermeiren and others 1999). Carbon dioxide is available in various forms, such as moisture-activated bicarbonate chemicals in sachets and ab- sorbent pads. Conversely, high levels of carbon dioxide resulting from food deterioration or oxidative reactions could cause adverse quality effects in food products.

6. Moisture Control Agents

For moisture-sensitive foods, excess moisture in packages can have detrimental results: for example, caking in powdered products, softening of crispy products such as crackers, and moistening of hygroscopic products such as sweets and candy. Conversely, too much moisture loss from food may result in product desiccation. Moisture control agents help control water activity, thus reducing microbial growth; remove melting water from frozen products and blood or fluids from meat products; prevent condensation from fresh produce; and keep the rate of lipid oxidation in check (Vermeiren and others 1999). Desiccants such as silica gels, natural clays and calcium oxide are used with dry foods while internal humidity controllers are used for high moisture foods (for example, meat, poultry, fruits, and vegetables). Desiccants usually take the form of internal porous sachets or perforated water-vapor barrier plastic cartridges containing desiccants. They can also be incorporated in packaging material. Humidity controllers help maintain optimum in-package relative humidity (about 85% for cut fruits and vegetables), reduce moisture loss, and retard excess moisture in headspace and interstices where microorganisms can grow. Purge absorbers remove liquid squeezed or leaking from fresh products and can be enhanced by other active additives such as oxygen scavengers, antimicrobials, pH reducers, and carbon dioxide generators (Brody and others 2001).

7. Antimicrobials

Antimicrobials in food packaging are used to enhance qual-ity and safety by reducing surface contamination of processed food; they are not a substitute for good sanitation practices (Brody and others 2001; Cooksey 2005). Antimicrobials reduce the growth rate and maximum population of microorganisms (spoilage and pathogenic) by extending the lag phase of microbes or inactivating them

(Quintavalla and Vicini 2002). Antimicrobial agents may be incorporated directly into packaging materials for slow release to the food surface or may be used in vapor form. Research is under- way on the antimicrobial properties of the following agents (Wilson 2007):

- Silver ions: – Silver salts function on direct contact, but they mi- grate slowly and react preferentially with organics. Research on the use of silver nanoparticles as antimicrobials in food pack- aging is ongoing, but at least 1 product has already emerged: FresherLonger™ storage containers allegedly contain silver nanoparticles infused into polypropylene base material for inhibition of growth of microorganisms (NSTI 2006).
- Ethyl alcohol – Ethyl alcohol adsorbed on silica or zeolite is emitted by evaporation and is somewhat effective but leaves a secondary odor.
- Chlorine dioxide: – Chlorine dioxide is a gas that permeates through the packaged product. It is broadly effective against microorganisms but has adverse secondary effects such as darkening meat color and bleaching green vegetables.
- Nisin :– Nisin has been found to be most effective against lactic acid and Gram-positive bacteria. It acts by incorporating itself in the cytoplasmic membrane of target cells and works best in acidic conditions (Cooksey 2005).
- Organic acids: – Organic acids such as acetic, benzoic, lactic, tartaric, and propionic are used as preservative agents (Cha and Chinnan 2004).

8. Ethylene absorbers and adsorbers

Ethylene is a natural plant hormone produced by ripening pro- duce. It accelerates produce respiration, resulting in maturity and senescence. Removing ethylene from a package environment helps extend the shelf life of fresh produce. The most common agent of ethylene removal is potassium permanganate, which oxidizes ethylene to acetate and ethanol (Lopez-Rubio and others 2004). Ethylene may also be removed by physical adsorption on active sur- faces such as activated carbon or zeolite. Potassium permanganate is mostly supplied in sachets while other adsorbent or absorbent chemicals may be distributed as sachets or incorporated in the packaging materials.

9. Advances in Controlling Volatile Flavors and Aromas

The mass transfer of components between and within food and packaging leads to the loss of volatile flavors and aromas from food. The most common methods of mass transfer food packaging systems are migration, flavor scalping (Figure 1), selective permeation, and ingredient transfer between heterogeneous parts of the food. Migration is the transfer of substances from the package into the food due to direct contact. Migration of packaging components to food must be understood and considered with toxicological risk analysis. Most incidences of migration occur in plastic packaging systems; thus, the most commonly studied migrants are plastic monomers, dimers, oligomers, antioxidants, plasticizers, and dye/adhesive solvent residues. Migration of packaging material components is examined in 2 ways, based on the migrating chemicals. One is global migration (that is, total migration); the other is specific migration of chemicals of interest. Migration of chemical substances is determined by the units of mg/kg for food or mg/m^2 for package surface. The degree of migration depends on several variables: contact area between food and package material, contact time, food composition, concentration of migrant, storage temperature, polymer morphology, and polarity of polymeric pack- aging materials and migrants (Brown and Williams 2003; Linssenand others 2003).

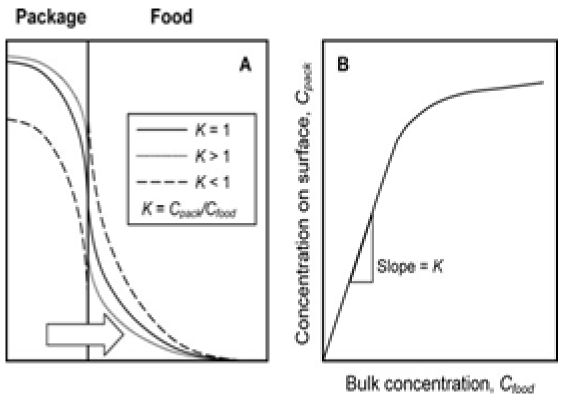

Figure 1: Effect of interfacial partitioning of molecules on mass transfer between food and packaging materials: (A) migration of package constituents into foods, (B) scalping of food flavor into packaging materials. K is a partition coefficient of a migrant.

Flavor scalping is caused by the absorption of desirable volatile food flavors by package materials (for example, absorption of volatile flavors of orange juice and citrus beverages by polyethylene) (Roland and Hotchkiss 1991). Polyethylene materials are known to scalp many volatiles from food (Sajilata and others 2007). This is due to polyethylene's lipophilic nature, which at- tracts large amounts of nonpolar compounds such as volatile flavors and aroma in foods. In fact, certain products—especially high-fat foods or vacuum-packaged foodpick up odors from adjacent strong odor foods when stored or distributed in the same case, storage room, or trailer (Brown and Williams 2003). The absorption of undesirable flavors by packaging materials follows the same theory and principles of migration but is generally not considered flavor scalping. Unacceptable odor pick-up can be avoided by proper package wrapping with high-barrier materials. The use of high-barrier packaging materials can also prevent the absorption of other nonfood odors such as taints.

Because they result in deterioration of quality and consumer preference of the packaged food, both migration and flavor scalping are unfavorable. However, some applications intentionally utilize these methods of mass transfer to improve the quality of pack- aged foods. The interactions can be used in active and intelligent packaging applications (Brown and Williams 2003). Examples are off-flavor absorbing systems and beneficial volatile release systems. Besides loss of flavor in food, nonpolar flavor components loosen the polymer structure to create more amorphous polymers. This causes undesired changes in the mechanical (seal strength, loss of laminations) and barrier (to oxygen, moisture, and volatiles) properties (Linssen and others 2003). Therefore, the effect of off-flavor absorption on essential characteristics of plastic packaging materials should be investigated.

10. Advances in Food Packaging Distribution (RFID systems for packaged foods)

Radio frequency identification (RFID) is a system that uses radio waves to track items wirelessly. RFID makes use of tags or transponders (data carriers), readers (receivers), and computer systems (software, hardware, networking, and database). The tags consist of an integrated circuit, a tag antenna, and a battery if the tag is passive (most active tags do not require battery power). The integrated circuit contains a non-volatile memory microchip for data storage, an AC/DC converter, encode/decode modulators, a logic control, and antenna connectors. The wireless data transfer between a transponder/tag and a reader makes RFID technology far more flexible than other contact identifications, such as the bar- code system (Finkenzeller 2003; RFID Journal Inc. 2005), and thus makes it ideal for food packaging. The working principles of an RFID system are as follows:

1) Data stored in tags are activated by readers when the objects with embedded tags enter the electromagnetic zone of a reader;
2) Data are transmitted to a reader for decoding; and
3) Decoded data are transferred to a computer system for further processing.

Tag frequency is related to the working principles of an RFID system (for example, magnetic coupling or electric coupling) and the reading range. Frequency depends on the type of tag, reader, and cost. The typical RFID frequencies are low frequency, high frequency, ultra high frequency, and microwave frequency. Generally, low frequency systems have short reading ranges, slow read speeds, and lower cost while higher frequency RFID systems are utilized when longer read ranges and fast reading speeds are required. Microwave frequency requires active RFID tags.

11. RFID for the food industry

RFID has recently found its way into numerous applications in the food industry, ranging from food monitoring and traceability to enhancing food safety, to improving supply chain efficiency. The major benefits of RFID technology in the food industry are greater speed and efficiency in stock rotation and better tracking of products throughout the chain, resulting in improved on-shelf availability at the retail level and enhanced forecasting. The technology is well suited for many operations in food manufacturing and supply chain management. An RFID-based resource management system can help users handle warehouse operating orders by retrieving and analyzing warehouse data, which could save time and cost. The use of RFID in the food industry is currently focused on tracking and identification. When RFID technology becomes more established in the food industry, the integration of food science knowledge will be necessary to develop the intelligent food packaging application for food quality and safety (Yam and others 2005).

Some food companies have already integrated RFID into manufacturing and distribution. Retail chains such as Wal-Mart and Home Depot have been testing the technology for distribution (Joseph and Morrison 2006). In 2003, WalMart issued a mandate requiring its top 100 suppliers to use RFID tags on all cases and pal- lets entering its distribution centers by 2005. RFID compliance is a long-term project for Wal-Mart; more of its suppliers are expected to be compliant by the end of 2008. Other major players advocating RFID technology are the U.S. Department of Defense and major retailers such as Albertsons, Target, Tesco, and Marks & Spencer.

RFID technology also provides security and safety benefits for food companies through tracking the origin of supplies. For example, a small California winery uses RFID to track its barrels and to enhance wine making by streamlining data collection. The company planted RFID tags on tanks and harvesting bins, allowing better control of wine production and tracking. In addition, by attaching an RFID tag to a package, the package becomes intelligent because the stored data provide valuable information that can be stored and read by appliances. This intelligent packaging technology is also being extended to refrigeration and freezing. Appliances can communicate with the packages and identify information related to the storage of the packaged products. Despite these benefits, other factors such as cost of the technology and recycling ability need to be considered.

12. Conclusion

The food industry has seen great advances in the packaging sec- tor since its inception in the 18th century with most active and intelligent innovations occurring during the past century. These ad- vances have led to improved food quality and safety. While some innovations have stemmed from unexpected sources, most have been driven by changing consumer preferences. The new advances have mostly focused on delaying oxidation and controlling moisture migration, microbial growth, respiration rates, and volatile flavors and aromas. This focus parallels that of food packaging distribution, which has driven change in the key areas of sustain- able packaging, use of the packaging value chain relationships for competitive advantage, and the evolving role of food service pack- aging.

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