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A review on innovations in food packaging concepts

Dr. R. Rangaprasad & Dr. Y.B. Vasudeo
By Innovations Consultancy India (P) Ltd, Mumbai

An Electronic Reprint

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India today is recognized as the most happening place in the world. India is one of the emerging markets, much stronger than ever before. With the decoupling of the global economy from the US, emerging markets will continue to fuel the engine of growth. India is one of the best emerging markets & this will help control some of the global imbalances. Institutions here are stronger & economic policies are now more robust. The economic boom, arising mainly from the consuming class is causing a strain on global resources. Energy & metal prices continue to be volatile, creating a challenge for improved productivity.

Against this backdrop, it becomes imperative to recognize the immense potential of exploiting hitherto unknown product & technology applications in the polymer processing industry. To adopt high technology product innovations to service high-growth sectors like automotive, packaging, infrastructure, lifestyle products, medical & health-care, Popular Plastics & Packaging, A premier techno-commercial journal of international repute for the last 50 years, takes pleasure & pride in introducing a series of contributed papers to service the knowledge needs of its readership. In its first attempt, the objective of these knowledge papers is to bring forth scope & potential of technologies in the field of packaging.

The knowledge papers will be contributed through By Innovations Consultancy India (P) Ltd, Mumbai. It is hoped that readers will derive maximum benefit from this series. PPP welcomes inputs, suggestions, comments & criticism to make this contribution "Create Value through Fresh Thinking".

ABOUT THE AUTHORS

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Dr. Y. B. Vasudeo is the President & CEO of BY INNOVATIONS Consultancy India (Pvt.) Ltd. During an illustrious career spanning over 25 years, the innovation consultant, has conceived and developed specialized & customized plastics products & services for a wide spectrum of end-use industries including automotive, appliances and consumer durables, wires and cables, packaging ,woven sacks.etc.

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Dr. Y. B. Vasudeo has held many important positions in industry associations and currently is on the Managing Committee of PlastIndia Foundation.

Dr. Y.B. Vasudeo has traveled widely in India and across the globe. He has authored many papers, contributed chapters to books & has made presentations at many prestigious national & international conferences.

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Dr. Rangaprasad. is a qualified chemical technologist by training, from the prestigious UICT, Mumbai and holds B.Sc(Chemistry), B.Sc(Tech.), M.Sc.(Tech) & Ph.D.(Tech). Degrees.

After obtaining his doctorate degree, He began his career in the R&D department of Polyolefins Industries Limited, in 1992. During the three year stint, he worked on stabilization protocol of polyolefins, notably, HMHDPE & EVA polymers. He also gained expertise in the application areas of HMHDPE related to films, raffia tapes, and pipes. He also setup the compounding project of PIL's filled & reinforced polypropylene at R&D & was responsible for scale-up & market development of mineral –filled PP & PE & glass reinforced PP for various end-use sectors.

Between 1995 & 2007, he was associated with Product Application & Research Center of Reliance Industries Limited, where he developed expertise in stabilization of polyolefins, compounding and masterbatches for various end-use sectors. During this tenure, he published over 75 papers in journals, participated in national & international conferences, contributed chapters to books & was also involved in evolving knowledge management& training programme for polymer business.

Background Information:

THE Institute of Food Technologists (IFT) convened its fifth Research Summit in May 7-9, 2006, in Baltimore, MD. The topic for the summit was "Food Packaging Innovations: The Science, Current Research and Future Needs".

The Summit Committee chair, John Floros, Professor and Head of Pennsylvania State University's Food Science Department and IFT's President-Elect for 2006-07 opened the summit by appealing to participants to identify research needs and provide a roadmap for the future of food packaging. Dr. Floros challenged the attendees to focus on where packaging should go in the next 10 to 15 years given an unlimited world of resources. A total of 10 presentations were made by scientists and scholars during the four scientific sessions: food quality and safety needs, material science and technologies, sensing technologies and packaging in the future.

Against the backdrop of the summit & their recommendations, the present paper attempts to provide an overview of all the points mentioned earlier & prepare the base for future knowledge papers in the series.

Food quality & safety needs

Food is a complex biomaterial that is subject to many biological, chemical, and physical changes that affect its quality and shelf life. Biological changes are caused by microorganisms (spoilage and pathogenic), insects and rodents. Chemical changes result from environmental influences and include oxidation, flavor deterioration, and color loss among others. Physical changes include moisture gain or loss, breakage, textural changes and contamination by foreign materials.

Food quality refers to the degree to which a food meets expectations including sensory characteristics (taste, odor, texture, and appearance), nutritional profile, convenience, storage shelf life, safety, and other attributes related to product acceptance. Food quality is measured by several factors including microbial counts and types, nutrient content, color, appearance, and moisture content. Minimum acceptable quality can be set based on regulatory limits, noticeable differences, or customer complaints among others.

Shelf life is the time it takes for a food product to deteriorate to an unacceptable degree and is dependent on processing method, storage conditions and form of packaging. The major goals of food packaging are to reduce the rate of quality loss and to increase product shelf life to the extent required by the distribution system.

Packaging technologies have been developed to meet these goals such as high barrier packaging and modified atmosphere packaging. Further research into more advanced technologies such as active packaging (e.g. antimicrobial); indicating and sensing materials; and bio-active materials; promises to allow shelf life to be tailored to individual product and market needs.

Packaging is an essential part of preservation and quality assurance of foods. The basic functions of packaging are to protect against contaminants and environmental influences such as gases, light and moisture; to cushion against shock during transportation; and to serve as tamper-evidence devices. More importantly, packaging has the ability to hinder or minimize the growth of unwanted microbes in the food.

New trends and demands in the global food supply chain present new challenges, which create an increasing demand for safer foods. For example, global food production is tending towards bipolarization, while companies are merging and centralizing production and processing sites resulting in increased distribution of both raw materials and finished products. As a consequence, longer shelf life is demanded. At the same time numerous small niche production sites are appearing with a very different set of food safety challenges. This calls for new research in food packaging as an instrument to ensure a safer global food supply. Other trends and demands that significantly influence food safety are documentation and traceability, legislation, and consumer demand for safer, healthier, more convenient, better tasting, lower cost and environmentally friendly products.

Industry Research for Business Leaders, Strategists & Decision Makers.
(New US Industry Forecast for 2011 -2016. Study # 2236. Aug 2007)

Packaging technologies such as modified atmosphere packaging and antimicrobial active packaging based on volatile (essential oils and alcohols) or non-volatile components (chitosan and nisin) have been developed as a result of these demands. The increase in crude oil prices and the growing environmental concerns have led to increased research on alternative packaging materials from renewable or bioderived resources.

Food products have specific microorganisms associated with them. However, changes in environmental condition in the package can leave products vulnerable to other microorganisms. Therefore there is need for detailed studies on the interplay among products, related microorganisms and packaging materials. Such knowledge will form the foundation for the development of better preservation methods for new and existing products.

Food packaging in most parts of the world is governed by a mass of laws, regulations, codes of practice and guidelines. In the US, food packaging is regulated by the Food and Drug Administration (FDA) under the Federal Food, Drug and Cosmetic Act (FFDCA). Food regulations are based on prior history, standard test procedures and specific component testing. The threshold of regulation is in place for substances used in food contact materials that may exempt them from regulation as a food additive.

In Europe, a positive list of materials that can be used for food packaging is provided along with specific testing procedures. Food packaging regulations must be adhered to in the development of new and modified packaging materials. It is thus important to know the chemical composition of all new materials including, processing aids, all additives and potential breakdown products. In the final analysis, the aim is to develop new materials that do not violate food laws and regulations or impart off-flavors or odors to the packaged product.

Materials science and technologies

Novel and advanced polymeric materials are being developed for enhanced food packaging. The development of these materials is based on conventional polymer science methods, as well as newer technologies including biopolymers, nanotechnology and nanocomposites, active and intelligent packaging.

Polymer/inorganic nanocomposites: opportunities in food packaging applications

Nanotechnology is the characterization and manipulation of materials with dimensions in the nanometer range, typically 1 to 100 nanometers. Nanotechnology has great potential application in food packaging to improve properties of existing materials (for example increasing barrier properties for plastics) or develop new materials with unique properties.

Polymer/inorganic nanocomposites utilize ultra small inorganic particles to achieve non-trivial changes in the nature of a polymeric material, and when properly designed and formulated can concurrently improve mechanical, barrier, thermal, and flammability properties. Nanofillers are used in much smaller amounts (1-5 weight %) compared to traditional fillers such as silica (50%) to achieve similar performance.

There are several types of polymer/inorganic nanocomposites but the focus is on polymer/clay nanocomposites that have potential applications in food packaging. Examples of commercial polymer/clay nanocomposite ventures include: polyamide-6 film for meat packaging or for use as a coating for paperboard juice containers, and polyolefin barrier food packaging/wrapping films.

The main advantage of these systems is the opportunities that they afford to uncouple and independently improve material properties: for example these composites can be of high barrier performance and still flexible and transparent, of high stiffness and still be ductile and lightweight, of increased softening temperature but still processable and ductile. Polymer/inorganic nanocomposites are thus a viable technology for "new" materials with various functionalities for food packaging applications.

Bio-based materials for a sustainable future in packaging

Biobased materials in conjunction with nanotechnology are expected to create a major breakthrough in the plastic packaging industries. The biobased materials (polymeric blends/composites/nanocomposites) can find niche applications in both the flexible and rigid packaging sectors. The future of packaging will be sustainable if it is designed through innovative and synergistic research approaches.

New material development is now transitioning from hydrocarbon chemistry (petroleum-based) to carbohydrate chemistry (biomass derived). The switch to a bio-based economy can be a challenge to agricultural, forestry, academia, government and industrial sectors. This is due to the growing urgency to develop and commercialize natural resource-based materials and innovative technologies and to make them sustainable. The higher and unstable prices of petroleum, the growing environmental concern, and the need for national security are some of the driving forces influencing the switch.

Green polymers like poly(lactic acid), PLA; polyhydroxyalkanoates, PHAs; starch plastics; and bio-based poly(trimethylene terephthalate) show great potential in greening the packaging industry. The aim is not to develop new materials wholly from renewable resources but to develop materials containing the maximum permissible content of bio-derived materials while still maintaining cost-performance attributes. For example bio-based materials have been developed through blending of brittle PLA/PHA with biodegradable polyester.

Natural fibers like kenaf, industrial hemp, henequen, pineapple leaf fiber and even local grasses can be reinforced with Bioplastics to produce superior performance biocomposites materials with opportunities for application in rigid packaging. Organoclay reinforcement of biopolymers can be used to develop biobased materials with superior mechanical, thermal and barrier performances.

Chemistry plays a vital role and thus possesses several opportunities and challenges, such as effective chemical modification of reinforcements (fiber/clay), use of novel coupling agents, and matrix modification. Hyper branched polymer based modification of bio-plastic creates tougher materials with good stiffness properties. Besides chemistry, effective process engineering (extrusion/compression/injection/blow molding/cast film/blown film) and structure-property co-relationships also play vital roles in finding sustainable development of such new materials. Collaboration between academic and industry personnel/researchers is important to propel development of new biobased materials for a sustainable future of the packaging industry.

State- of- the- Art active and intelligent packaging

Active packaging senses change in the internal or external environment of a food package and responds by altering its properties to help better deliver the food

Active Packaging - Pic Courtesy - Active Pack International

Intelligent Packaging - Pic Courtesy - McDonalds

product. Examples of active packaging systems include: moisture control, purge or other liquids control, oxygen removal or addition, carbon dioxide addition, antimicrobial activity, adverse odor removal, desirable scent addition, content heating or cooling, ethylene removal, and microwave heating controllers.

Much of the research and development in active packaging centers on moisture control (desiccant sachets or cartridges), and purge control (absorbent pads) that have been commercial for decades. Oxygen scavengers such as sachets with ferrous iron, nylon MXD6 in beer bottles, benzoacrylates in film, and sulfites in beer bottle closures and antimicrobials such as silver salts, carbon dioxide generators and ethyl alcohol have limited commercial use. Research is underway on use of natural spices as antimicrobials. Chlorine dioxide antimicrobial and self heating technology were removed from the market in 2005 and 2006, respectively.

Intelligent packaging senses changes and signals them. It is expected that intelligent packaging signals may be upgraded to active ones to help control the environment and thus enhance the safety or quality retention of the contained product.

Intelligent packaging concepts include: maximum temperature indicators, time temperature integrators, location signalers, shelf life surrogates, spoilage and pathogen indicators, gas concentration indicators, internal gas controllers, communications links with appliances, nutritional attributes, ripeness, communications with consumers or their care givers, and compliance with medical directions.

Major research and development is underway on the following intelligent packaging: radio frequency identification (RFID), inventory controllers, theft protection devices, food safety and/or quality signaling devices and time temperature integrators.

Beyond moisture and purge control, most active packaging technologies have limited commercial application because much has centered on the active component and not on its applicability. A similar situation has prevailed in much of intelligent packaging. This Sub-section of the industry needs a single independent unbiased resource to evaluate the industry and academic offerings to measure their true value to food packaging.

The business of active & intelligent packaging

Active and intelligent packaging demand in the US is projected to exceed $1.1 billion in 2011, fueled by the development of new generations of products leading to increased competitiveness and more cost-competitive prices, which will spur greater market acceptance for many product types.

Faster growth is anticipated for intelligent packaging, for which robust expansion will be the result of the emergence of lower cost time-temperature indicator (TTI) labels as well as the growing awareness of these products as critical tools in improving food safety and reducing losses in perishable products caused by temperature abuse in the supply chain. The introduction of newer types of electronic TTIs that are integrated with RFIDs will also propel gains.

Gas scavengers were the leading single active and intelligent packaging product segment in 2006, representing over 50 percent of demand. Above-average growth will be the result of solid prospects for PET bottles in applications with higher barrier requirements, along with heightened use of less costly monolayer oxygen scavenging systems. Demand for in-package oxygen absorbers will be aided by rapid growth for packaged organic foods and the removal of trans fats from many types of processed and other foods, necessitating the need for oxygen absorbers as an alternative to direct food additives in extending shelf life.

Beverage, pharmaceutical uses are believed to be fastest growing beneficiaries. Food and beverages are the two largest markets for active and intelligent packaging, accounting for a combined 75 percent of demand in 2006. Through 2011, fastest gains are expected in beverage and pharmaceutical applications, with food uses also logging solid advances. Food packaging sector would account for 39%, Beverages 37%, Pharmaceuticals 13% & other markets would make up for the remainder 11%.

In the pharmaceutical market, the need to raise compliance and adherence levels will bode well for compliance monitoring devices and active reminder products, though product cost and cost control issues will restrain faster advances. Moisture control packaging demand will benefit from favorable pharmaceutical shipment growth and the increasing number of drugs with high moisture sensitivity.

(This data has been sourced from an internet advertisement of Industry Research for Business Leaders, Strategists & Decision Makers. New US Industry Forecast for 2011 -2016. Study # 2236. Aug 2007)

Sensing technologies

Novel sensing technologies using bio or nano materials can be used to detect quality and safety attributes in packaged foods. These sensing technologies range from rapid non-destructive and non-contact to highly specialized micro and nanobiosensing structures. Micro- and nano-based sensors that utilize a variety of transduction mechanisms to sense microbial and biochemical changes in food products are being explored. The following are examples of technologies with potential application in food quality and safety detection.

Non-contact ultrasound imaging technique can be used to detect foreign objects such as glass or bone fragments in boneless chicken or cheese. Spectroscopy methods, such as the Mid-infrared Photoacoustic, Fourier Transform Raman and possibly Near Infrared can be used for rapid assessment of microbial contamination of food surfaces or packaging films.

Biosensor technologies that are based on coupling of a ligand receptor interaction to a transducer have more specific detection capabilities. Optical biosensors such as SPR (surface plasmon resonance) based pathogen detection systems provide for selective detection of microbial species. Mid-infrared biosensors, which combine biosensing and spectroscopy capabilities, may provide improved pathogen detection specificity.

Further, research and development involving production of nano-structures such as nanorods, tubes, wires, and belts is underway. These technologies have great potential for rapid detection of microbial and biochemical activities in food. The major challenge of integrating these technologies into packaging systems is not only compounded by the complexity and varying needs of the food and package systems but also by the lack of available information on what defines quality and what defines safety.

The potential susceptibility of the food supply chain to natural or intentional contamination could result in compromised safety and quality of foods. Nano-bio sensors and integrated micro systems could play a significant role of detecting deteriorative changes in food packaging. In intelligent food packaging appropriate sensing technologies are required to detect substances in parts per trillion for food safety, quality and process control.

Development of new sensing devices may be achieved by taking advantage of miniaturization of electronics and nano-bio materials. These novel sensing systems can be used to facilitate on-line analysis of food stuffs. The devices can also be used to determine specific components in food and drinks such as sugars, proteins, vitamins and fats and to detect and quantify chemical contaminants such as pesticides, heavy metals, and antibiotics. They can also be used to detect pathogenic bacteria (E. coli, Listeria, Salmonella, Campylobacter, Vibrio), viruses, toxins (Staphylococcus Enterotoxins, Botulinum neurotoxins, mycotoxins and Paralytic/Diarrhetic shellfish toxins), and to monitor the freshness of aquatic foods including fish, and fermentation processes.

Multi-walled carbon nanotubes (MWCNTs) exhibit unique properties that make them ideal for the design of nanobio sensors for the detection of sub-femtogram quantities of target protein, DNA, and RNA. Single-crystal zinc oxide (ZnO) nanobelts/wires, silicon and gallium nitride nanowires and micro resonators open a new field of biosensor technology for the fabrication of highly sensitive biosensors. The selectivity, sensitivity and rapidity of nanobio sensors represent a vast improvement over conventional detection systems.

Integration of sensing, data storage and communication components with food packaging provides the necessary intelligence of these systems. The integration of selective multiple system functions, such as analog or RF as well as sensing and fluidic functions, into one compact, low weight, low cost unit is the concept of an integrated microsystem. The integration of biosensor with micro systems further revolutionizes the performance of these biosensors with respect to sensitivity and resolution, accuracy, repeatability, dynamic range, speed of response and cost. Research is underway at Georgia Institute of Technology to embed electronic components in ultra thin polymer substrate materials integrated with nano bio sensors and radio frequency identification components that may have beneficial application in food packaging.

The future packaging scenario

A systems approach is thought to be necessary to integrate the concepts mentioned in previous sections to present a thought-provoking perspective about the role of packaging in our future food system. The points of importance are current and future global trends ranging from social, to environmental to technological and how they affect food packaging. Specific trends include population growth and diversity, lifestyle, and health among others. The goal should be to examine these trends with emphasis on what would determine consumer needs such as convenience and what research can deliver. Another important area is exploring opportunities for use of the package as a communication tool to convey information to the consumer.

Development of new technologies including packaging innovations is often driven by consumer needs, which are directly influenced by the ever changing global trends. These major global trends include population size and growth rate, race and ethnicity, age structure, household size and structure, education, employment, income level and distribution, and obesity.

Other factors that may influence technology development include environmental issues such as global warming, water and energy shortages, land use, sustainable agriculture, globalization of the food system, emerging organic and whole foods market demands, and animal rights and compassion issues. All these global trends coupled with the worldwide obesity epidemic call for diversification of products and technologies.

Food packaging will also be influenced by important consumer needs for taste, convenience, health and safety. In addition, innovations in other areas of science and technology, biotechnology, materials science, nanotechnology, information technologies, etc., will heavily influence innovations in food packaging. It is important to carefully analyze all these trends, issues, needs and technologies in order to address the ever-changing consumer needs and advance food packaging into the future.

Future research domains

Major research and information needs are necessary to advance the field of food packaging. The following is a summary of some of the issues identified.

Materials science and technologies

Scalping and migration of components, such as flavors, presents major challenges during development of new packaging materials. Three key research areas that need to be explored.

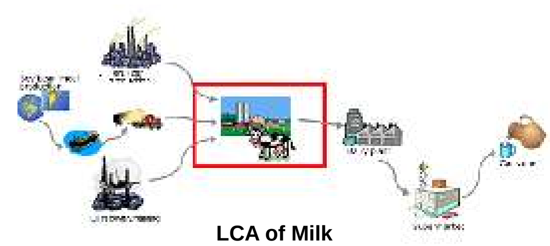
1) Kinetics of release and absorption

Kinetics is a bridge between food science and packaging. Understanding the kinetics of release and/or absorption of the various food components (such as flavors and odors) or package components (such as controlled release packaging materials, as needed for active packaging) is critical to the development of appropriate packaging materials for specific foods.

A better understanding of the kinetics of release, which varies with compounds, is necessary in order to develop materials that allow sustained delivery. Kinetic constants for each component in a multi-component system would be required in order to identify the optimum packaging materials. Development of a packaging material to minimize absorption of a food component requires knowledge of absorption kinetics to ensure that desired shelf-life of the product can be achieved.

2) Permselectivity

Permselectivity is the ratio of the permeability coefficient of carbon dioxide to that of oxygen. The general relationship is that as permeability increases, selectivity invariably decreases. The magnitude of the desired Permselectivity will vary with



LCA of Milk

product due to the unique local atmosphere (carbon dioxide/oxygen) needed to extend the shelf-life of each product. Research on development of materials with high permeability, while minimizing selectivity is needed.

Packaging materials with a range of Permselectivity magnitudes (depending on desired shelf life) are needed for improvement of shelf life of a variety of products. For example materials with high Permselectivity are desired for controlled atmosphere packaging for fresh produce such as fruits and vegetables. Development of materials with optimized permeation rates for specific food products is also desired.

3) Barrier properties.

Barrier to physical, chemical and biological influences is an important property of packaging materials. Existing materials could be modified or new materials developed with improved barrier properties. Also, materials that maintain high barrier properties with changing temperature and humidity are desired.

Bio-based materials

Bio-based materials are made from renewable resources such as starch, cellulose and soy protein. The major driving forces to develop bio-based materials are the rising prices of petroleum and environmental concerns. Bio-based materials offer an alternative for reduced dependence on oil, the source of most currently used packaging materials. Bio-materials based on poly(lactic) acid have been available for some time, but industrial application has been limited at this point in time.

Technical and economic feasibility studies such as cost-benefit analysis need to be completed in order to encourage commercial applications. Additional research on identification of appropriate additives and processing aids to improve functionality could increase utilization of bio-based materials for food packaging. For example, research should identify appropriate plasticizers for bio-based materials, since these components may differ from those currently used for petro-based materials. Other resources should be explored for development of new green polymers with properties to match conventional polymers. The use of waste materials from production of value-added products is encouraged. In addition, research to determine compatibility of these materials with food products is needed.

Nanotechnology

Nanotechnology has many potential applications to food packaging, especially in development of materials with improved mechanical, thermal and barrier properties. Although considerable research is underway, more emphasis on safety and risk assessment of nano-scale materials is needed.

Active packaging

Commercialization of active packaging technologies with the exception of moisture and purge control has been relatively slow. Furthermore some of the offerings have been poorly tested, or did not function as intended. There is a need for a single independent unbiased resource to evaluate the value of existing and upcoming food packaging technologies. Another research limitation in active packaging is associated with controlled release packaging.

The most promising opportunities involve slow release of active compounds such as antimicrobials and antioxidants from the package to food for enhancing quality and safety during prolonged storage. There is a general need to develop materials with the ability to release the active ingredient at rates suitable for various packaging applications. Considerable research has been completed on antimicrobial packaging, especially on the use of nisin to control microbial growth and extend the shelf life of food. Since cost of application seems to be prohibitive, a cost benefit analysis is needed in an effort to enhance feasibility.

Intelligent Packaging

Research on the integration of thin film electronics into food packaging (system on the package) with accurate monitoring/verification procedures and corrective actions is needed in order to have broad impact on intelligent food packaging. Low cost sensing devices that sense food status, such as volatile organics sensors, time temperature integrals, humidity sensors, and infiltrated of harmful bacteria sensors, and communicate such information to manufacturers and consumers using wireless 10 interfaces such as RFID tags are needed. Polymer compatible thin film functional electronic components (such as antenna), thin film embedded actives (reader, amplifier) and embedded nano-sensing devices will enable the convergence of low cost electronic systems into food packaging, leading to the implementation of intelligent food packaging.

Other new materials

New food processes or changes in existing processes dictate research on packaging materials to be used. For example research is needed on materials for use during microwave heating to provide a range of cooking times, uniformity of heating, improved browning and crisping during heating of heavy loads and to cater for increase in microwave wattage. Due to current concerns about obesity and in an effort to promote health and wellness, the food service sector has recognized the need to implement portion control resulting in the switch from bulk to portion packaging. New packaging materials are needed to facilitate this shift.

Life cycle assessment

Life cycle assessment for new packaging materials, such as nano-based and biobased materials is essential for their success. This is a comprehensive analysis of materials from production to disposal in order to determine their environmental impact. It involves evaluation of the materials and energy usage in product manufacture and use and evaluation of the type and amount of waste generated.

Uniform criteria or a universal model with standard inputs and outputs is needed to evaluate packaging materials. Analysis of the performance and sustainability of new materials, especially the bio-based materials, is also required to document their advantages over conventional petro-based materials. Investigations into the compatibility of new materials with food products are important.

Materials safety

Safety studies must be completed for all new materials and technologies. For example the potential release of mutagens/carcinogens needs to be evaluated. Other issues of material use and disposal include the potential safety problems of breakdown products.

Sensing technologies

Sensors need to be integrated at the processing stage of the food supply chain, as well as in bulk container packaging or storage facilities. Sensors are a critical component of packaging in order to maintain flow of information throughout the supply chain and to allow for traceability of the product.

Sensors facilitate in-plant or in-process validation as well as detection of contamination. Sensing technologies are readily available but research on mechanisms for incorporation in food packaging is needed. For example, identification of strategic locations in the sample or package for effective detection is lacking.

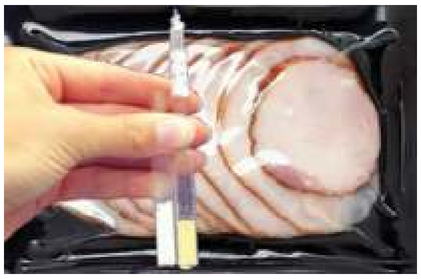
Research to establish compatibility of sensors with various packaging materials and structures should be pursued. Sensors should enhance the role of the package as a communication tool for consumers by conveying information on product usage, proper handling and storage, and as indicators for product rotation in the home pantry or refrigerator.

Food safety and quality sensors

Research on the quality and/or safety indicators to be sensed or measured in a given food needs to be conducted. Models that predict changes in terms of safety, quality and shelf life of food are important in the development of sensors.

Safety related sensors including microbiological sensors that detect specific pathogens in food are a relatively recent development. Additional research is needed in development of sensors that can detect several different microorganisms simultaneously. For example, a single sensor that could detect the most prevalent food borne pathogens in a given food would be ideal.

Research is needed on development of quality related sensors to detect metabolites or byproducts of degradation reactions in food. Other product quality attributes such as pH and staleness could be used as indicators for sensor development.



Sensors in Food Packaging

Sensing for intentional contamination

Intentional contamination or adulterants must be differentiated from accidental contamination in foods. Sensors to be used in combination with tamper evidence packaging would be useful. On-going research will develop sensors for detection of chemical contaminants. A universal sensor with the capability to detect multiple toxins would be ideal.

A better understanding of the changes (quality and shelf life) in food associated with intentional contamination is needed for sensor development. In addition, the development of software or algorithms for data gathering/collection, processing, and storage to be used in the integration and transmission of information in real-time for quick decision making, should be given elevated priority.

Collaboration

Collaboration on packaging research activities is essential to improve decision making and to advance food packaging. There is a need for material research scientists to reach out to scientists in other disciplines such as electronics, microbiology and medicine in order to create a multidisciplinary approach for technology development.

Collaboration between industry and academic research groups is also beneficial. India has well established centers of excellence to accomplish this goal. In addition, there is a need to involve nonbiased groups in research in order to help push technologies. Such a system should allow networking and collective thinking in anticipation of key research issues.

Education and communication

Consumer perception is viewed as the most significant factor in limiting the application of new packaging technologies. This is due, in part, to the lack of understanding of the technical research, or misinformation about the technologies.

Researchers need to device means to convey information to the public for better understanding of the available technologies. The need to translate technical information into a form that communicates more clearly to the consumer should help overcome resistance to new technologies.

Consumers need to gain a better understanding of the applications and safety of new technologies such as nanotechnology, and use of sensors in tamper evidence packaging. In addition, employee training is necessary in order to gain a better understanding of new technologies and to properly interpret the technology output.

It is also important to establish a mechanism for exchange of information between all stakeholders including government, industry, academia, media, consumers and groups that represent them. Formation of a consortium or forum to engage stakeholders on food packaging issues would be valuable.

Specific research areas for futuristic packaging

- Measure and publish kinetic parameters for release and absorption of key food components for packaging materials.
- Develop packaging materials for specific Permselectivity constants and permeability ratios for improved controlled/modified atmosphere packaging of foods.
- Develop food packaging materials with improved barrier properties.
- Comprehensive research on bio-

materials should focus on compatibility of materials with food products, as well as economic and technical feasibility.

- Research on nano-materials should include safety and risk assessment.
- Develop packaging materials with release rates to match reaction rates for food deterioration during active packaging.
- Research on integration of thin film electronics and sensors into food packaging and development of low cost on-package systems for intelligent packaging
- Research on packaging of foods for microwave preparation is needed in response to current trends in microwave technology.
- The concepts of life-cycle assessment should be incorporated into development of food packaging materials.
- Research on packaging materials for food contact must include migration studies and careful attention to the safety of compounds released by the materials.
- Research on food packaging sensors should focus on the compatibility between sensor and packaging material, as well as compatibility with foods.
- Sensor research for food packaging must identify specific sensors For microbiological and chemical degradation products from foods during storage.
- Development of specific sensors for intentional contamination of foods.

Ultimate goal of active & intelligent packaging

The focus of food packaging is to improve the safety, quality and shelf life of food products as well as to provide consumer convenience and satisfaction. The pressing question is "where do we go with packaging?" to meet this goal. There is a need to prioritize the identified research areas in order to come up with packaging that significantly improves the delivery of safe, high quality food to the consumer.

Part II: A Review of Active Packaging Technologies

Background

The packaging industry today is on the verge of witnessing a revolution. The world has come a long way since the days of simple brown paper bag to single polymer films and complex multilayer "barrier" structures.

With so much activity in packaging technology, it is convenient to address this area from two angles - Active packaging and intelligent packaging.

Active packaging senses environmental changes and responds by changing its properties. Intelligent packaging relatively new on the scene, measures a component and signals the result. Oxygen scavengers, antimicrobials, controllers of odor, moisture and carbon dioxide typify the former. The latter includes electronic locators, anti-theft, anti-counterfeiting devices, time-temperature integrators, signaling the presence of spoilage and / or pathogenic microorganisms in the food.

The reasons for increased interest in "active" packaging systems stems from the known limitations of "barrier" packaging in controlling the internal environments of food (and other) packages. Barrier structures can only keep out (or in) elements that are already present. To enhance the value of the packaging to the contents active agents can be incorporated to act when something is missing.

Part II looks at some of the new ideas in active packaging. The underlying chemistry of the various types of "additives", which could potentially be incorporated into conventional polyethylene or polypropylene to develop new food packaging materials, is critically reviewed.

Introduction

An ideal food package is designed to meet many requirements - than those of the food itself, processing or preservation methods, distributor and retailer needs and consumer expectations. New plastics, additives and processing technologies have created the potential for new food products and improvements in the quality and convenience of existing products.

While an obvious function of packaging is protection - to keep the "inside in" and the "outside out", the product, its preservation process and the package should be considered a unit, rather than separate entities.

The development of new polymers, polymer blends with good "barrier" properties (e.g. to oxygen) and high temperature resistances have many applications. The uses of "additives" in polymer films have opened up a new area of 'active' packaging systems. Nanocomposite technology, especially, based on nylon and polypropylene is already gaining widespread acceptance.

Concepts in active packaging

Active packaging is one of the most innovative food packaging concepts that have been introduced as a response to the continuous changes in consumer demands & market trends. Consumers are increasingly demanding mildly preserved convenience foods that have better fresh-like qualities. In addition, changes in retail & distribution practices such as centralization of activities, new trends (e.g. internet shopping) and internationalization of markets, resulting in increased distribution distances & longer storage times of a set of different products with different temperature requirements, are putting huge demands on the food packaging industry. Traditional packaging concepts are limited to prolong the shelf life of food products.

"Active packaging is an innovative concept that can be defined as a type of packaging that changes the condition of the packaging to extend the shelf life or improve safety or sensory properties while maintaining the quality of the food."

The above definition of active packaging was chosen for the European FAIR Project CT 98-4170.The European FAIR Project CT 98 - 4170, which started in January 1999 was being carried out in the framework of the EU FAIR programme by 9 research organizations & 3 industrial companies. In various countries active packaging is already successfully applied.

Active packaging does more than simply provide a barrier to outside influence. It can control and even react to

Bison Bags

events taking place inside the package. Active packaging senses environmental changes and responds by changing the properties.

The reasons for the increased interest in "active" packaging stems from the known limitations of barrier packaging in controlling the internal environments of food (and other) packages. Barrier structures can only keep out (or in) elements that are already present. To enhance the value of the packaging to the contents, active agents are incorporated to act on behalf of something that is missing.

Removal of oxygen, both residual and that entering through the plastic package walls or seals, may be achieved by affixing an oxygen-scavenger sachet to the interior of the package wall to extend the quality of the product and suppress aerobic microorganisms.

Events happening inside a package

Fresh foods just after harvest or slaughter are still active biological systems. The atmosphere inside a package constantly changes as gases and moisture are produced during metabolic processes. The type of packaging used will also influence the atmosphere around the food because some plastics have poor barrier properties to gases and moisture.

The metabolism of fresh food continues to use up oxygen in the headspace of a package and increases the carbon dioxide concentration. At the same time, water is produced and the humidity in the headspace of the package builds up. This encourages the growth of spoilage microorganisms and damages the fruit and vegetable tissue.

Many food plants produce ethylene as part of their normal metabolic cycle. This simple organic compound triggers ripening and ageing. This explains why fruits such as bananas ripen quickly when kept in the presence of ripe or damaged fruits in a container and broccoli turn yellow even when kept in the refrigerator.

Extensive studies have shown that each fresh food has its own optimal gas composition and humidity level for maximizing its shelf life. Active packaging offers promise in this area, as it is difficult with conventional packaging to optimize the composition of the headspace in a package.

The atmosphere surrounding the food also influences the shelf life of processed foods. For some processed foods, a lowering of oxygen is beneficial, slowing down discoloration of cured meats and powdered milk and preventing rancidity in nuts and other high fat foods. High carbon dioxide and low oxygen levels can pose a problem in fresh produce leading to anaerobic metabolism and rapid rotting of the food. However, in fresh and processed meats, cheese and baked goods, carbon dioxide may have a beneficial anti-microbial effect.

Controlling the atmosphere around packaged foods

Extending the shelf life of foods by controlling the gases in their immediate environment can be done by number of techniques - controlled and modified atmosphere packaging. "Controlled atmosphere" usually indicates monitoring and control of gaseous composition. This is the case with bulk stores for fruit and sometimes, with transport containers.

The term "modified atmosphere" is used when the composition of the storage atmosphere is not closely controlled. This is usually the case with wholesale or retail packs. The initial atmosphere is intentionally adjusted to give a gas mix as close that which will optimize the shelf life. Subsequent movement of gases and moisture into and out of the package is controlled only by the ability of the packaging film to act as a barrier.

Active packaging systems

Active packaging employs a packaging material that interacts with the internal gas environment to extend the shelf life of a food. Such technologies "continuously" modify the gas environment (and may interact with the surface of the food) by removing gases from or adding gases to the headspace inside a package.

The Table 1 shows some of the areas of active packaging:

Table 1: Uses of Active Packaging

Active Packaging System	Application
• Oxygen scavenging	• Most food classes
• Carbon dioxide production	• Most food affected by moulds
• Water vapor removal	• Dried and mould sensitive foods
• Ethylene removal	• Horticultural produce
• Ethanol release	• Baked foods (where permitted)

(Ci) Ethylene Absorbers / scavengers

Removal of ethylene from the plant environment can significantly retard post-harvest catabolic activity in fresh produce and complement modified-atmosphere preservation processes.

Potassium permanganate reacts with ethylene to produce eventually CO_2 and H_2O. $KmnO_4$ can be adsorbed onto inorganic substrates for incorporation into gas-permeable sachets to permit reaction with ethylene. Large capacity sachets required for small packages are awkward for consumer-size packages. Among the alternatives has been incorporation of activated carbon impregnated with palladium catalyst and blending with polymer film.

Activated earths such as zeolites or clays embedded in plastic film are employed in Japan to adsorb ethylene. A large proportion of the fresh fruits & vegetables harvested every year are lost due to fungal contamination & physiological damage. Ethylene absorber packaging concepts could possibly contribute to an increase in the export of fresh produce.

(Cii) Oxygen scavengers

The presence of oxygen in food packages accelerates the spoilage of many foods. Oxygen can cause off-flavour development, colour change, nutrient loss and microbial attack. Several different systems are available to scavenge oxygen at appropriate rates for the requirement of different foods.

One of the most important applications of oxygen scavenging systems in food packages is to control mould growth. Most moulds require oxygen to grow and in standard packages, it is frequently mould growth, which limits the shelf life of packaged baked foods such as and packaged cheese. Laboratory trials have shown that mould growth on some baked products can be stopped for atleast 30 days with active packaging.

Another promising application is the use of active packaging to delay oxidation of and therefore, rancidity development in vegetable oils.

The use of discrete

sachets containing oxygen adsorbents has already found commercial application. The scavenging material is usually finely divided iron oxide.

Mitsubishi Chemical company's "Ageless®" scavenger are regarded as the pioneers in ferrous based oxygen scavenger sachets. The oxygen concentration within the package may be reduced to below 0.01%. Among the Japanese products that contain oxygen scavenging sachets are confectionary, dried seafood snacks, processed meat, rice cake, pasta, pizza crusts, nuts, cheese and dried vegetables.

The approach of inserting a sachet into the package is effective, but is not popular with food packers. The active ingredients in most systems consist of non-toxic brown / black powder or aggregate, which is visually unaesthetic if the sachet is broken. A more attractive approach would be the use of a transparent packaging plastic as the scavenging medium.

Most of the recent published reports have been on incorporation of oxygen scavengers into plastics such as multilayer film and PET bottles. Zero2™ is one such commercial example of oxygen scavenging plastic packaging materials in which the reactive components are activated by means of UV light or related high-energy processes.

The plastics are inactive until activated and so can be subjected to conventional plastics converting processes to make films, sheets, adhesives, lacquers, and closure liners and can coatings. Test results with Zero2 materials in flexible laminations suggest that mould can be inhibited without carbon dioxide and that ham discolouration can be prevented even under visible light. Orange juice in EVOH / PE barrier laminations containing the scavenger demonstrated zero oxygen within three days at 4°C and half the loss of Vitamin C after one year, compared to conventional barrier packaging. Shelf life of wine in bag-in-box was increased by 33% using the oxygen scavenger, compared to conventional gas barrier.


Cryovac

(Ciii) Humidity control / Moisture regulators

Condensation or 'sweating' is a problem in many kinds of packaged fruit and vegetables. It is of particular concern in cartons of fresh flowers. Foods susceptible to moisture damage need to be packed in a high humidity barrier material. A certain amount of moisture, however, can be trapped in the packaging or develop during distribution. If not removed, this moisture will be absorbed by the product or condensate will be formed, causing microbial spoilage and /or low consumer appeal. Excessively high levels of water cause softening of dry crispy products such as biscuits, milk powder, instant coffee & similar products.

On the other hand, excessive water evaporation through the packaging material might result in desiccation of the packed foodstuff or it may favor lipid oxidation. To prevent this & establish the desired humidity in the package headspace, food manufacturers can use a film with the appropriate water vapor permeability or use a desiccating film or moisture controlling sachet or pad. Desiccants are successfully being used for a wide range of foods, such as cheese, meats, chips, nuts, popcorn, sweets, & spices.

The main purpose of moisture control is to lower growth of moulds, yeast, & spoilage bacteria on foods. Shelf life of packaged tomatoes at 20 deg c was extended from 5 to 15 -17 days with a pouch containing a moisture controller mainly by the retardation of surface mold growth. Another application is in the removal of melting water from frozen fish, meat or other frozen foods & blood & tissue fluid from meat to make the package more attractive to the customer. A third reason for moisture control is to prevent condensation when fresh horticultural produce respires. For dried food applications, conventional desiccants or mineral fillers can be used.

(Civ) Carbon dioxide scavengers & emitters

Carbon dioxide is formed in some foods due to deterioration & respiration reactions. The CO_2 produced has to be removed from the package to avoid food deterioration and / or package destruction. CO_2 absorbers might, therefore, be useful. Coffee, when roasted, can contain up to 15 atm dissolved CO_2 due to the Strecker degradation reaction between sugars & amines. Oxygen and carbon dioxide scavenging sachets is used in coffee to delay oxidative flavor changes & absorb occluded CO_2, which, if not removed would cause the package to burst.

In some cases, however, high CO_2 levels (10 to 80%) are desirable in some food packages because they inhibit surface growth of microorganisms & therefore extend shelf life. Fresh meat, poultry, fish, cheeses and strawberries are foods, which can benefit from packaging in a high CO_2 atmosphere. Removal of O_2 from a package by use of O_2 absorbers creates a partial vacuum that may result in collapse of flexible packages. Also, when a system is flushed with a mixture of gases, including CO_2, the CO_2 partially dissolves in the product & creates a partial vacuum. In such cases, the simultaneous release of CO_2 from inserted sachets, which consumes O_2, is desirable. Such systems are based on either ferrous carbonate or a mixture of ascorbic acid & sodium bicarbonate. The $O_2$2 absorbers / CO_2 generators are mainly used in products where package volume & package appearance are critical. e.g. peanuts or potato crisps.

So far, the problems associated with diffusion of gases, especially CO_2 through the package, have not been resolved; this remains an important research topic.

Antimicrobial food packaging systems

Interest in the development of these systems was generated due to several highly publicized cases of food-borne outbreaks. One of the most well known outbreaks occurred during December 1998, when a variety of Sara Lee products (meat and non-meat products) were recalled when they were suspected and later confirmed to contain Listeria monocyto genes.

There are two basic categories of anti-microbial films. One involves the direct incorporation of the antimicrobial additive into the packaging film, while the second type of film is coated with a material, which acts as a carrier for the additive.

The most publicized films are silver salts on Zeolite incorporated into plastic film / sheet. These structures, popular in Japan, require direct contact of the silver ion with the food surface and its microorganisms to act. The silver may preferentially react with the food itself or alter its activity as a result of pH or the presence of salt.

Food science Australia is developing systems to release sulphur dioxide to control mould growth on contained fruit. Being a gas, sulphur dioxide can permeate the product, but it can bleach the fruit and cause discomfort to sensitive individuals.

A number of Japanese organizations have commercialized the application of allylisothiocyanate as an anti-microbial in plastic films. This mustard extract is an effective anti-microbial but may not be rendered odor-free.

Some of the additives used in antimicrobial food packaging material are potassium sorbate, nisin, imzalia, triclosan (Irgasan® DP-300 of CIBA) etc.

Modification of polymers

Another way of producing anti-microbial films is through the modification of the polymer chain itself. The polymer chain can be modified before polymerization and film formation or the film can receive a surface treatment after the film is made.

Scope of active packaging

Applications of active packaging are numerous & growing. O_2-scavengers & antioxidant releasing systems can be used for most O_2 -sensitive products to extend their shelf life. Desiccants have been used extensively with dried & mould -sensitive foods. Ethylene scavengers are finding their way into the horticultural produce industry & antimicrobial release systems can be used with bakery foods, cheese & other products.

The future of active packaging

In the USA, Japan & Australia, active packaging concepts are already successfully applied. In Europe, the development & application of active packaging is limited because of legislative restrictions, fear of consumer resistance, lack of knowledge about effectiveness, economics & environmental impacts of concepts. No specific regulations exist on the use of active packaging in Europe.

The food industry's main concern about introducing active components to packaging seems to be that consumers may consider the components harmful & may not accept them. In Finland, a consumer survey conducted in order to determine consumer attitudes towards O_2 absorbers revealed that the new concepts would be accepted if consumers were well informed by using reliable information channels.

More information is needed about the chemical, microbiological & physiological effects of various concepts on the packaged foods.i.e. in regard to its quality & safety.

Furthermore, the benefits of active packaging need to be considered in a holistic approach to environmental impact assessment. The environmental effect of plastics-based active packaging will vary with the nature of the product / package combination. The additional ingredients need to be evaluated for their overall performance.

Conclusion

Active packaging is an emerging & exciting area of food preservation technology, which can offer many benefits on a wide range of foods. As industry, consumers, manufacturers become aware of the advantages of using absorbent technology, active packaging will most likely emerge as the preservation technology of the 21st century.

The next papers in the series will deal with each of the active packaging concepts in detail.

Resources

1) Proceedings of The Institute of Food Technologists (IFT) Fifth Research Summit May 7- 9, 2006, Baltimore, MD. "Food Packaging Innovations: The Science, Current Research and Future Needs".
2) Review papers of Aaron Brody on Active Packaging appearing on various internet sites
3) www.specialchem4polymers.com
4) www.omnexus.com
5) Literature survey of various internet resources. ■