Recent Advances on Intelligent and Active Packaging in Food and Beverage Technology

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ABSTRACT/INTRODUCTION

International markets are demanding packaging with increasingly sophisticated features including those for controlling food quality, for example selective diffusion of gases and moisture vapor, detection of chemical metabolites, monitoring storage temperature or accumulation of heat. Gas and moisture permeable packaging have improved substantially extending distribution channels and product shelf life. Intelligent sensors that monitor cumulative heat exposure provide shelf life predictors for individual food containers at point of sale helping to ensure safe and high quality food for consumers.

Recent concerns over intentional food contamination and widespread global recalls involving chemical and microbiological contamination have led to greater requirements for traceability on individual retail packaging. This is driving the incorporation of sensors, for example radio frequency identification devices (RFID) into food packaging with the rapid adoption of this technology driving down the cost of these sensors. Earlier difficulties with sensitivity, range and ability to use these devices in with frozen foods or in high moisture environments have been overcome. Active and intelligent packaging advances continue with the incorporation of biochemical, chemical and physical taggants and holographic features for authentication and tamper evidence into primary and secondary packaging is becoming more widely adopted as the cost of these technologies drops. Recent advances in nanomaterial technologies have led to the development of enhanced control release and adsorbent containing packaging limit microbial growth and the production of compounds that cause loss of product quality.

RESULTS AND DISCUSSION

Packaging serves many roles from simply a container for a product to a sophisticated electronic media capable of delivering customer directed advertising/information while simultaneously providing inventory control support and protection/indication of spoilage or purposeful contamination. It is integral to protecting and preserving products as well as facilitating product transportation, distribution, storage, information dissemination, sale and use. Food packaging constitutes over half of the total packaging market worldwide. Unfortunately, many companies and individuals, throughout the value chains of many products, fail to dedicate the appropriate attention to package requirements and benefits, often to their detriment.

Consumers are willing to pay more for well packaged food because of its higher perceived quality and safety. Although regulatory requirements garner much attention, the primary driving force in packaging is the market. Then net impact is an ever increasing demand upon packaging, with its integral labeling, for improvements in food packaging for protection, increased shelf life, quality, safety, inventory control and point of sale utility. Packaging also provides identification of the food item, use instructions, advertising, and additional food safety features such as tamper evidence, inventory, pricing and traceability. New printing methods and other computer based technology have reduced the cost of generating labels and graphics on packaging while simultaneously permitting greater flexibility for the producer/manufacturer at the time of packaging or labeling. This benefit has not only been realized by major manufactures but has allowed small businesses to customize packaging and enter new markets.

International markets are demanding environmentally friendly packaging and a reduction in packaging waste. This has put pressure upon the industry to develop biodegradable and recyclable packaging while at the same time minimizing the resources used in its production. Even China, which has now become the largest consumer of grocery items in the world, is finding an ever increasing number of their consumers applying pressure for recycling and reduced carbon footprints similar to the trends existing in most of the world's consumer markets.

Functionality is also an important factor in selecting the most beneficial packaging for one's products. This includes continuously innovative and sophisticated laminated wrapping to "Active Packaging" which describes that packaging resulting in changes to the characteristics of the packaged food such as extended shelf-life and employing such inclusions as sachets placed in the packaging headspace, labels attached to the inside of the container usually on the closure, and absorbent or emitting films. Intelligent features within packaging monitor the conditions of the packaged food and incorporate inventory control, pricing and traceability features. Among the most common active packaging components are absorbers or scavengers that remove undesired compounds such as oxygen, carbon dioxide, and/or ethylene). Release systems emit compounds into the headspace including carbon dioxide antioxidants and preservatives.

Another innovative and developing packaging sector includes nanoscale materials which by definition have at least one dimension in the 1 – 100 nm range. A myriad of nanoscale materials are being incorporated into packaging, providing advantageous properties because of their proportionally larger surface area compared to larger particle of identical composition. As an example, nanoscale clays, silicates and cellulose are incorporated into composites to enhance polymer performance by increasing mechanical strength, improving barrier properties such as increasing glass transition temperature. Silver and zinc oxide based nanoparticles are very effective antimicrobial agents and can be incorporated into paper, plastic and fabric based materials. Metallic nanoparticles can penetrate through the cell membrane of planktonic and sessile (biofilm intercalated) bacterial cells and are more effective against Gram^{+} bacterial cells. Titanium oxide nanoparticles improve the oxygen scavenging ability of films because of their high photo-catalytic activity following exposure to UV light which maintains low oxygen levels in product headspace. Gases produce during food spoilage can be detected by conducting polymer nano-composite or metal oxide particles embedded in an insulated polymer matrix resulting in a color change in the packaging. More sophisticated nano-biosensors for detection of pathogens and chemical contamination are not yet commercially available, but are under development many of which are based upon multiwall carbon nanotube technology. Migration of nanoparticles from the packaging into the food is a concern and many studies are underway to examine toxicological properties and predict risk from long term chronic exposure.

The passage of the Food Safety Modernization Act in the USA will not only force changes to food packaging in that country, but also internationally; first to importers of products into the USA and then to other countries as parts of the Act may become adopted by local regulatory agencies as has occurred in the past. The effects will include changes to labeling requirements, specifically coding, allergen labeling, traceability, and tamper evidence. Food defense applications for food packaging incorporate physical and chemical (including DNA based) taggants, the use of optically active materials including holographic bar codes and labeling, embedded and variable data, micro text print features, as well as increased applications of RFID technology. Other packaging features recently developed initially for covert authentication are being adopted as a control for economic fraud, including deterrence of counterfeiting in the food, beverage, and pharmaceutical industries. Unfortunately many of these applications require expensive readers or other peripheral elements, but regulatory and/or market driven demand for some such as taggants and RFIDs are driving expanded applications and development; this particularly true in the case of RFIDs.

Taggants, include a number of materials such as chemical or physical markers including microscopic or even nano-sized pieces of non-reactive materials, often multi-colored, that serve to identify the authenticity of the material or even its source of manufacture. The latter being a regulatory additive to certain explosives in many countries, adopted thru international treaties and agreements so as to permit a degree of traceability and a deterrent to terrorism. Taggants though have found limited utilization in the food industry due to a resistance of including any non-functional ingredients, but are being incorporated into labeling for some higher valued products, such as expensive beverages.

In contrast, RFIDs are finding ever increasing roles in packaging and marketing. Initially the most common use was as an electronic deterrent to shoplifting (direct, employee, and reverse), they are finding expanding applications in the food industry in many areas including traceability, inventory control, food defense, and point of sale data (pricing, size, etc.). Again, this effort is driven by market demand, particularly from major purchasing entities such as supermarket chains, large multi-line retailers like Wal-Mart and most notably by the US Department of Defense which is requiring that packaging or labeling of all products it purchases, food and non-food alike, include RFIDs. The tags can be passive or active, pre-written, or generated at time of application.
Standardization of data stored in a tag used for commerce has also been a problem, but again market demand has facilitated the establishment of EPCglobal Inc.™, a non-profit corporation formed by the merger of the former EAN (European Authority or formerly EAN International, now GS1) and the North American Uniform Code Council (now GS1 US). The organization’s stakeholders establish the standards for the application of the RFID as an Electronic Product Code (EPC). RFID’s common to the food industry contain 96 bits of information. The first 8 bits identifies the particular protocol version/application. The next 28 bits identify the data managing organization which is assigned by EPCGlobal. The next 24 bits identify the kind of product while the last 36 bit are a unique number that not only provides specific data on the product such as lot, production date/location or similar information; but further identifies the specific primary container of the product. While the RFID contains a significant amount of integral information, its utility is dynamically increased by integrating this information with data bases.

Initially commercial applications of RFIDs were plagued by high cost and closeness required for the reading/emitter device. Improved technology and increased market demand has driven the price down to a few cents and detection/reading range has increased significantly, often exceeding 15 meters. RFIDs The RFID will not be replacing the bar code in the near future, but will find more and more applications as time goes on and may well accomplish that substitution eventually.

CONCLUSIONS

Among the most interesting and cutting edge developments in packaging in recent years has been the incorporation of passive and active RFIDs for inventory control and traceability into retail food packaging. A second notable advance is bio-degradable composites with suitable barrier properties, printability features and mechanical strength for primary and secondary food packages, this has the potential to significantly reduce waste and over the long term overall packaging costs. Incorporation of nanoscale materials into packaging provides unique physical properties to food packaging and new opportunities for incorporating smart features to monitor safety and quality on individual retail containers. All stakeholders in the food industry will do well to stay on top of packaging/labeling innovations to insure that they can successfully compete in this ever expanding and competitive market.

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