Active & Intelligent Packaging Technologies: An Aspect of Food Safety Management

Saikat Mazumder¹,²*, Shalini Chanda², Amiya Bhaumik¹

¹Lincoln University College (LUC), Petaling Jaya, Malaysia; ²Department of Food Technology, Guru Nanak Institute of Technology, Kolkata, West Bengal, India.

ABSTRACT

Consumer demand for food safety is expected to be a primary driver of public policies and industry-led efforts to improve food safety through eliminating food quality information asymmetry. Food wastage in the food service industry accounts for roughly 30% of all food produced worldwide. Moreover, every year, an estimated 600 million people become unwell as a result of consuming food contaminated with germs, viruses, poisons, or chemicals, with 4,20,000 people dying as a result. The majority of waste occurs as a result of inadequate packaging. For food manufacturers, modern packaging can be a long-term option for reducing food waste. Intelligent packaging is a useful tool in the battle against food waste since it may more accurately reflect the state of food commodities. We’ve covered the many types of active and intelligent packaging, as well as their techniques for protecting food during storage and the supply chain, in this post. According to our findings, smart packaging tries to protect the product from a variety of risks. Freshness indicators, in particular, can be an effective way to get safe food to consumers. Freshness indicators, in particular, can be an effective way to get safe food to consumers. The cost of employing modern packaging technology in developing nations is a source of worry. More research is also needed, and nanotechnology could be a beneficial tool for developing low-cost smart devices that can be integrated into smart or intelligent packaging to save money.

Key Words: Active packaging, Advanced packaging, Food safety, Food waste, Intelligent packaging, Sensor

INTRODUCTION

In the early times, humans used glass and wood containers for food packaging. Packaging as a term evolved from early mankind’s basic need to store and transport their food from place to place. Although there is no record of when the very first packaging materials were used, researchers believed that leaves, animal skins, nuts, etc. were being used to store and transport goods during the nomadic era. Packaging keeps the product safe from the external environment and also performs four basic purposes such as protection, communication, convenience, and containment (fig-1). Packaging ensures the item against the external environment communicates with the customer via written texts or graphics, making the handling better and effective with different types of containers. The expectations of consumers are continually changing. When new and revolutionary products emerge, so do the packaging techniques that accompany them. There have been several different ways to package goods in human history, each of which was advancement in its own time. The emphasis on the customer has remained consistent in the evolution of product packaging. Smart packaging is still in its early stages of growth, but it has enormous potential. The advancement of smart packaging has progressed very rapidly. Just a couple of years back, smart packaging was first implemented several years ago as a powerful packaging technology, capable of performing all packaging functions. Smart packaging is one that includes both intelligent packaging as well as active packaging.
Active & intelligent packaging technologies: an aspect of food safety management

Mazumder et al:

Ligent Packaging communicates with the consumer based on the information recorded. The world of smart packaging is significantly growing and advancing in research. This period is characterized by a significant increase in the number of projects and a probable approach to overcome food preservation problems with the new technologies and improved frameworks.

Problem statement
The foodservice sector accounts for food wastage around 30% of all food produced worldwide. This waste is produced from the food sector which includes below standard packaging or improper packaging that will not stand during transportation and distribution, specifically the perishable foods making it more vulnerable to lose. According to FAO, an absence of optimized packaging is one of the main factors responsible for food loss or waste, especially in developing countries. New solutions to food packaging technology can be a promising way to fight against food wastage and to feed the increasing population.

Methodology for advanced Packaging Technologies to Reduce Food Waste

Active Packaging
Active Packaging is a concept that is characterized as a mode of packaging in which the package, the product, and the environment interact to extend shelf life, improve protection, and enhance sensory properties while preserving the quality of the product. This includes the packaging of foods with materials that provide improved functionality, such as antimicrobial, antioxidant, or bio-catalytic functions. This can be accomplished by incorporating active compounds into the packaging materials or by the application surface alteration with the required functionality. This packaging utilizes technology that is intended to discharge or assimilate compounds from the food or the headspace of food packaging, which extends the shelf life of products by slowing down the degrading reactions of lipid oxidation, microbial development, moisture loss and benefit more effectively than conventional food packaging (fig-2).

There are different types of Active Packaging available, but generally, they are categorized into three types i.e. scavengers, emitters, and adoptors.

Scavengers
Package scavengers have been in use for around many years in the shape of separate packets or sachets but presently this technology is integrated inside the packaging material. This integrated approach decreases the overall costs and makes it easily approachable for both the manufacturer and the consumer.

Oxygen scavengers
Oxygen scavengers or oxygen absorbers are included in packaging so it reduces the oxygen level within the package. They are utilized to keep up product quality and to extend shelf life. There are numerous types of oxygen absorbers available for a wide range of applications. The most commonly found substrate is iron followed by ascorbic acid and then other substances. These are incorporated into polymers as light-sensitive dyes. The shelf-life and nutritional value decrease with the increase in oxygen amount in the food packet as the oxygen react with vulnerable foods in the package, accelerating the degradation of numerous food products, rancidity in foods with high oil content, and also promoting microbial growth. The oxygen absorber scavenges this excess oxygen to slow down the oxidative reactions and also inhibits the microbial growth in the food package. Beer-cap seal contains oxygen-absorbing liners on the underside of Carlsberg FreshCap - ZerO2. This removes the headspace oxygen and extends the shelf life of beer by 15%.

Ethylene scavengers
Ethylene scavenger can be a small sachet containing a suitable scavenging agent or an ethylene scavenger incorporated directly into the packaging material and the material should be greatly permeable to ethylene gases for its functioning. This can be further sub-divided into...
scavengers and absorbers, scavengers absorb water by chemical reaction whereas, absorbers absorb the ethylene from the surrounding atmosphere.\textsuperscript{56} They increase the shelf life by slowing the aging or ripening process and senescence.\textsuperscript{18} Fruit Brite by Hazel Technologies released 1-MCP (1-methylcyclopropene)\textsuperscript{27} to diffuse ethylene blockers which extends the shelf life and the quality of the product\textsuperscript{18, 27}.

**Moisture scavengers**
Moisture scavengers regulate moisture in the headspace of any packaging and absorb the excess liquid weeping from a food product, thus increasing the shelf life of the product. High-capacity hydro-gels would be more effective in this case.\textsuperscript{18} MoistCatch film by Kyodo Printing is a moisture scavenging film that is flexible and can be molded to any form.\textsuperscript{18, 28}

**Emitters**
Emitters reduce the effect of microbial growth and activity, oxidative reactions, and even uncontrolled ripening in fruits. CO\textsubscript{2}, antimicrobial, antioxidants, etc. acts as emitters that enhance the shelf life of products.\textsuperscript{18, 29}

**Antioxidant**
Oxidation in fats and oils produces off-flavor as well as reduces the shelf life and causes spoilage in food. This can be avoided by incorporating antioxidants in food with higher fat content. They neutralize the action of harmful free radicals. Common antioxidants found in foods are Vitamin C, Vitamin E, citric acid, etc.\textsuperscript{29, 30}

**Antimicrobial Emitters**
Antimicrobial emitters would include antimicrobial macromolecules having film-forming properties, sachet, using of bioactive agents in the packaging or on the surface of the packaging material. These are used to avoid microbial contamination in food products.\textsuperscript{31} Some antimicrobial emitters are ethanol, organic acids, essential oils, and polysaccharides.\textsuperscript{29, 32}

Basil, bay leaves, and cinnamon essential oils are effective against Clostridium sporogenes and E. coli, while cinnamaldehyde essential oil inhibits L. monocytogenes. Lipid oxidation is slowed by green tea extract. E. coli, Staphylococcus aureus, and Pseudomonas spp. are all inhibited by orange essential oil.\textsuperscript{33}

**CO\textsubscript{2} Emitters**
Carbon dioxide emitters are most commonly used in combination with modified atmosphere packaging gases like nitrogen or with oxygen absorbers.\textsuperscript{18, 29}

**Intelligent Packaging**
Intelligent packaging is a system that utilizes communication to encourage decision-making for extending shelf life and overall food quality and protection.\textsuperscript{33} Intelligent packaging can carry out functions like sensing, detecting, tracing, warning about possible problems etc. Different Types of Intelligent Packaging are data carriers, Indicators and sensors.\textsuperscript{34, 35}

**Data carriers**
Data carriers assist in the effective flow of information across the supply chain. The objective of data carriers is to ensure traceability, automation, fraud prevention, not to control product quality.\textsuperscript{36} They store and transmit information about storage, delivery, and other parameters to ensure this. As a result, they’re often seen on tertiary packaging. Barcode labels and RFID (Radio Frequency Identification) tags are the most commonly used data carriers.\textsuperscript{37}

**Barcodes and QR Codes**
Barcodes are cheap, simple to use, and commonly used to deal with supply chain management, stock logging, and checkout.\textsuperscript{36} In general, barcodes can be divided into two types: one-dimensional and two-dimensional. They have different storage capacities depending on the type. A series of parallel spaces and bars make up a one-dimensional barcode. Data is encoded as a result of the various arrangements of bars and gaps. The coded information can be translated using a barcode scanner and an associated device.\textsuperscript{32}

The combination of dots and spaces arranged in an array or matrix makes the two-dimensional barcodes occupy more memory power (such as packaging date, batch number, packaging weight, nutritional details, or preparation instructions). This is very convenient for both retailers and customers. An example of 2D barcodes is QR (quick response) Codes.\textsuperscript{37}

**Radio Frequency Identification (RFID)**
RFID (Radio Frequency Identification) is a technology that uses radio waves to process data. RFID tags are advanced data carriers that can store up to 1 MB of data and capture real-time data without involving any touch or line-of-sight. These devices gather, store, and send real-time data to a user’s information system. RFID tags are more costly than barcodes and require a more efficient electronic information network.\textsuperscript{37} On the other hand, the details on these tags can be loaded electronically and updated at any time.\textsuperscript{38} RFID also has additional benefits for the entire food supply chain which include traceability, inventory control, and quality and safety promotion.\textsuperscript{39} An RFID device is made up of three parts: a tag, which is made up of a microchip linked to a tiny antenna, a reader, which sends the radio signal and collects responses from the tag, and middleware, that connects the RFID hardware to enterprise applications (fig -3).\textsuperscript{39, 40}
Indicators
The existence or absence of a substance, the magnitude of a reaction between various substances, or the concentration of a specific substance is all determined by indicators. Changes are direct, which means different color intensities are used to visualize this detail. Depending on the indicator they are placed inside or outside of the package.

Time Temperature Indicators (TTIs)
Time Temperature Indicators (TTIs) Temperature plays an important step in determining the shelf life of any food product. Deviations in the temperature profile can stimulate the development or survival of microorganisms, resulting in product spoilage. Besides, improper freezing may denature meat or other products’ proteins. Time-temperature measures may be used to determine if the cold chain or optimal temperature is adequately maintained in the food supply chain or not.

TTIs are known as user-friendly and easily accessible devices due to their easy functionality. The Fresh-Check from Lifeline technologies is an example of a TTI predictor. It works by causing a color shift in the indication range as a result of a polymerization reaction. A clear center indicates a fresh TTI. If the active center’s color matches the outer ring, the product should be consumed as soon as possible. The dark core of TTIs indicates non-fresh products. Some Commercially Available TTI are MonitorMark™, Timestrip®, Fresh-Check®, Checkpoint®.

The 3M MonitorMark® (3M Co., St Paul, Minnesota) is a diffusion-based indicator label that is based on the color change of an oxidizable chemical system regulated by temperature-dependent permeation through a filter. A blue-dyed fatty acid ester diffusing around a wick activates the action. At a temperature-dependent rate, a viscoelastic material migrates into a diffusely light-reflective porous matrix. The tag configuration, which differs by polymer concentration and glass transition temperature, controls the response rate and temperature dependence and can be set to the desired range. Timestrips® (Timestrip UK Limited, UK) are smart labels that keep track of how long a product has been open or in use. Food protection also necessitates temperature control at home. Timestrip® is a consumer-activated, single-use smart-label for tracking elapsed time on perishable items. It was created to allow customers to monitor the amount of time that had passed after activation.

Fresh-Check®TTI (Temptime Corp., Morris Plains, NJ, USA)(Fig. 4) is a solid-state polymerization reaction that produces a strong colored polymer. The TTI’s answer is a color shift that can be measured as a decrease in reflectance.

Freshness indicators
Freshness indicators track the consistency of food items as they are being stored and transported. Unfavorable conditions or a lack of durability may cause a loss of freshness. As a result, they send data on microbiological development, the presence of microbiological metabolites, and product chemical changes. Glucose, organic acids, ethanol, volatile nitrogen compounds, biogenic amines, carbon dioxide, ATP degradation products, and sulphur compounds are examples of quality indicating metabolites. Freshness indicators must be mounted within the packaging to enable interaction with the compounds. Different methods may be used to detect this information depending on the reliable indicator (Table-I).

Sensor
Sensors show the state of the food’s quality concerning the indoor environment. Although the actual indicator shows the quality status, a sensor senses and responds to changes in the environment within the packaging.

Gas sensor
The gas sensor detects carbon dioxide in the package as a sign of microbial growth, which shortens the food’s shelf life. Non-dispersive infrared (NDIR) or chemical sensors are the most common types of CO2 sensors. NDIR sensors are spectroscopic sensors that use gas absorption at a specific wavelength to test CO2 content. Although this sensor reacts to the formation of a spoilage metabolite, it does not explicitly track a quality attribute. CO2 is a useful indicator of food quality and can be used as an indicator compound; however, it is not a quality attribute because CO2 does not cause bad taste or spoilage; quality loss is caused by microorganisms. It is a colorimetric indicator label that monitors the freshness of a dessert (fig. 5).

Biosensor
Biosensors detect pathogenic bacteria on food that cause food safety issues. These are specifically monitoring the quality attribute of food. The Food Sentinel System™ (SIRA Technologies, California, USA) is an example of such a biosensor, which consists of a barcode that contains a membrane with antibodies that can bind to particular pathogens. The barcode changes color as the pathogenic bacteria develop during storage, resulting in a barcode that can no longer be scanned.

DISCUSSION
Smart packaging strives to protect products from a variety of risks while also allowing for more active and intelligent packaging applications to be commercially viable. It’s critical to keep the ultimate cost of intelligent packaging systems to a small percentage of the overall package cost, as well as to overcome the inherent challenges of transitioning laboratory trials to industrial-scale manufacturing. Multiple functionalities can be combined into a single packaging, and
single-use throwaway products can be replaced with long-lasting reusable devices.

**CONCLUSIONS**

Though the idea of intelligent packaging has not grown rapidly it is the technology of the future. Smart packaging aims to provide safety to the product from all kinds of hazards. To ensure that more active and intelligent packaging applications become commercially feasible and “into everyday packaging commodities” around the world, it is important to ensure that the final cost of intelligent packaging systems is a small fraction of the overall packaging cost and resolve the inherent difficulties in converting laboratory trials to industrial-scale production. Incorporating multiple functions to be integrated into a single package and replacing single-use disposable products with long-lasting reusable devices. Significant technical advances are still needed to realize these growth goals. Only then it will provide a safe ground for monitoring the food item and controlling the distribution correctly.

**ACKNOWLEDGEMENT**

Authors acknowledge the immense help received from the scholars whose articles are cited and included in references of this manuscript. The authors are also grateful to authors/editors/publishers of all those articles, journals and books from where the literature for this article has been reviewed and discussed

**Conflict of Interest:** Authors have no conflict of interest

**Authors’ Contribution:** Saikat Mazumder, Shalini Chanda, Dr. Amiya Bhaumik have equally contributed in the study.

**REFERENCES**


Figure 1: Different types of packaging9.

Figure 2: Working model of active packaging19.
Mazumder et al: Active & intelligent packaging technologies: an aspect of food safety management

Figure 3: The working principle of radio frequency identification (RFID) tag.

Figure 4: Principle of Lifeline’s Fresh-Check Indicator (TTI).

Figure 5: A sensor that monitors carbon dioxide as an indication for the freshness of the dessert golden drop.

Table 1: Principles of indicators and sensors based on metabolites

<table>
<thead>
<tr>
<th>Metabolites</th>
<th>Food Products</th>
<th>Indicators</th>
<th>Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose/lactic acid</td>
<td>Fermented food, meat</td>
<td>Colorimeter based on pH</td>
<td>Electrochemical sensor by redox reaction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Electrochemical sensor by silicon-based polymers</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>Fermented food, meat, seafood</td>
<td>Colorimeter based on pH</td>
<td>Electrochemical sensor, laser</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Meat, vegetable, fruits</td>
<td>Optical sensor by fluorescence, colorimeter based on pH</td>
<td>Electrochemical sensor by enzyme redox reaction</td>
</tr>
<tr>
<td>Biogenic amines</td>
<td>Fish, meat</td>
<td>Color-changing pH-sensitive dyes</td>
<td></td>
</tr>
</tbody>
</table>