




IJCRR
Section: Healthcare
ISI Impact Factor
(2020-21): 1.899
IC Value (2020): 91.47
SJIF (2020) = 7.893

Copyright@IJCRR

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

Saikat Mazumder^{1,2*}, 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 transfer 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.¹ Packaging keeps the product safe from the external environment and also performs four basic purposes such as protection, communication, convenience, and containment (fig-1).² Packaging ensures the item against the outside environment communicates with the customer via written texts or graphics, making the handling better and effective with different types of containers.⁴ 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.⁵ Smart packaging is still in its early stages of growth, but it has enormous potential.⁶ The advancement of smart packaging has progressed very rapidly. Just a couple of years back, smart packaging used to mean a label on a package with a tracking number, or even better, a barcode readable by a laser scanner. The Quick Response (QR) Code has become extremely common in recent years.⁷ This is an advancement in packaging that reflects the packaging industry's ability to adapt to customers' constantly changing expectations and concerns.^{5,7} The popularity of Active Packaging, over the years, has signaled a significant change in packaging systems shifting from passive to active. Previously, primary packaging materials were thought to be "passive," meaning they only served as an inert shield to ensure the item against oxygen and dampness. Active packaging was first implemented several years ago as powerful packaging technology, capable of performing all packaging functions.² Smart packaging is one that includes both intelligent packaging as well as active packaging. Intel-

Corresponding Author:

Saikat Mazumder, Department of Food Technology, Guru Nanak Institute of Technology, & Student, Postgraduate studies, Lincoln University College (LUC), Petaling Jaya, Malaysia, 57/1/2, South A.B.Road, Post Office-Fingapara, North 24 Parganas 743129; E-mail: saikat.23.1989@gmail.com

ISSN: 2231-2196 (Print)

ISSN: 0975-5241 (Online)

Received: 27.10.2021

Revised: 12.11.2021

Accepted: 30.11.2021

Published: 01.02.2022

ligent Packaging communicates with the consumer based on the information recorded.⁸

Literature Review

In recent times, consumers seek food that is both safe and convenient, as well as the food package should be made of recyclable or reused materials. Traditional packaging is becoming less capable of meeting all these demands, as a result of which consumers are switching to more functional packaging technology. Smart packaging is such a transformation of packaging technologies which is a combination of both active and intelligent packaging. As the consumer need is continuously changing so is the packaging technology to feed the world's growing population a safe and healthy food that will be more natural and less processed for its preservation and handling. Active packaging increases food protection as well as its shelf life by adding antimicrobial emitters or oxygen scavengers directly in food packaging film or as sachets in food packets. In the case of intelligent packaging, it functions by interacting with the food product and providing information like ripeness or indicating the freshness of the food.⁹ These new emerging technologies can also help upgrade the traceability of any food product through its packaging.

Numerous studies are continuing forward in today's world, but they are yet waiting for it to be combined into innovative solutions. The packaging technologies should be so implemented that its customer can continuously monitor the food quality until they are consumed as well as food degradation should be reduced when preserved.¹⁰ 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.¹¹

Problem statement

The foodservice sector accounts for food wastage around 30% of all food produced worldwide.¹² 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.¹³ 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.¹⁴ 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.^{15, 16, 17} 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).¹⁸

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.¹⁸

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.²⁰ There are numerous types of oxygen absorbers available for a wide range of applications.^{21, 22} The most commonly found substrate is iron followed by ascorbic acid and then other substances. These are incorporated into polymers as light-sensitive dyes.¹⁸ 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.²³ The oxygen absorber scavenges this excess oxygen to slow down the oxidative reactions and also inhibits the microbial growth in the food package.¹⁸ 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%.^{18, 24}

Ethylene scavenger

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.²⁵ 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.²⁶ They increase the shelf life by slowing the aging or ripening process and senescence.¹⁸ *Fruit Brite* by Hazel Technologies released 1-MCP (1-methylcyclopropene)²⁷ to diffuse ethylene blockers which extends the shelf life and the quality of the product^{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.¹⁸ MoistCatch film by Kyodo Printing is a moisture scavenging film that is flexible and can be molded to any form.^{18, 28}

Emitters

Emitters reduce the effect of microbial growth and activity, oxidative reactions, and even uncontrolled ripening in fruits. CO₂, antimicrobial, antioxidants, etc. acts as emitters that enhance the shelf life of products.^{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.^{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.³¹ Some antimicrobial emitters are ethanol, organic acids, essential oils, and polysaccharides.^{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.¹⁸

CO₂ Emitters

Carbon dioxide emitters are most commonly used in combination with modified atmosphere packaging gases like nitrogen or with oxygen absorbers.^{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.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.^{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.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.³⁷

Barcodes and QR Codes

Barcodes are cheap, simple to use, and commonly used to deal with supply chain management, stock logging, and checkout.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 coded 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.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.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.³⁷ On the other hand, the details on these tags can be loaded electronically and updated at any time.³⁸ RFID also has additional benefits for the entire food supply chain which include traceability, inventory control, and quality and safety promotion.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 collect responses from the tag, and middleware, that connects the RFID hardware to enterprise applications (fig -3).^{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.⁴⁰ Depending on the indicator they are placed inside or outside of the package.³²

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.^{37, 42}

TTIs are known as user-friendly and easily accessible devices due to their easy functionality.⁴³ 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.⁴⁴ Some Commercially Available TTI are MonitorMark™, Timestrip®, Fresh-Check®, Checkpoint®.

The **3M MonitorMark® (3M Co., St Paul, Minnesota)**⁴⁸ 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.^{46, 47} **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.^{49, 50}

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.⁴⁷

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.^{47, 51} Glucose, organic acids, ethanol, volatile nitrogen compounds, biogenic amines, carbon dioxide, ATP degradation products, and sulphuric compounds are examples of quality indicating metabolites.^{37, 53} 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-1).⁵⁴

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.⁵⁸

Gas sensor

The gas sensor detects carbon dioxide in the package as a sign of microbial growth, which shortens the food's shelf life.⁵³ 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.⁵⁷ 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).⁵⁸

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.⁴⁷ The barcode changes color as the pathogenic bacteria develop during storage, resulting in a barcode that can no longer be scanned.⁵⁸

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

Source of Funding: Authors have no source of funding

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

1. The history of packaging, <https://crawfordpackaging.com/automation-and-innovations/history-of-packaging>, 23rd August 2021.
2. Yam KL, Takhistov PT, Miltz J. Intelligent packaging: Concepts and applications. *J. Food Sci.* 2005; 70: 1–10.
3. Smart Packaging: Definition and Benefits, <https://impacx.io/blog/what-is-smart-packaging-and-its-benefits/>, 23rd August 2021
4. Yam KL, Lee DS. 1-Emerging food packaging technologies: An overview. In *Emerging Food Packaging Technologies*; Woodhead Publishing Series in Food Science, Technology and Nutrition; Woodhead Publishing: Sawston, UK, 2012; pp. 1–9, ISBN 978-1-84569-809-6.
5. The evolution and history of product packaging, <https://www.ptpackaging.com/blog/the-evolution-and-history-of-product-packaging/>, 25th August 2021.
6. 5 things you should know about Smart Packaging, <https://www.lead-innovation.com/english-blog/5-things-you-should-know-about-smart-packaging>, 27th August 2021.
7. The evolution of smart packaging, <http://www.sunpack.com/the-evolution-of-smart-packaging/>, 1st September 2021.
8. Smart packaging: Intelligent packaging part I, <https://www.thepackagingblog.com/smart-packaging-intelligent-packaging-part-i/>, 10th September 2021.
9. Robertson GL. *Food Packaging: Principles and Practice*. 3 Edn. Boca Raton. FL: CRC Press, Taylor & Francis Group LLC; 2013.
10. Mahmoud SF, Khaled MA, Mahmoud O. “A critical review on intelligent and active packaging in the food industry: Research and development”. *Food Research International*. 2021;141:1-24.
11. Nicoletti M, Paola Del S. Intelligent and Smart Packaging. *Future Foods:HeimoMikkola*. IntechOpen.2017; 143-159.
12. Bernhard W, Erik P, Victoria H, Manfred T. Packaging-Related Food Losses and Waste: An Overview of Drivers and Issues. *Sustainability* 2019; 11:1-15.
13. Manalili NM, Dorado MA, van Otterdijk R. *Appropriate Food Packaging Solutions for Developing Countries*; Food and Agriculture Organization of the United Nations: Rome, Italy. 2014. ISBN: 978-92-5-108235-5.
14. Ahvenainen, R. *Active and intelligent packaging: an introduction*. Cambridge, UK: Woodhead Publishing Ltd. CRC Press. 2003 ;5–21.
15. Vermeiren L, Devlieghere F, van Beest M, de Kruijf N, Debevere J. Developments in the active packaging of foods. *Trends Food Sci. Technol.* 1999; 10:77–86.
16. Suppakul P, Miltz J, Sonneveld K, Bigger SW. Active packaging technologies with an emphasis on antimicrobial packaging and its applications. *J. Food Sci.* 2003; 68:408–420.
17. Ozdemir M, Floros J. Active food packaging technologies. *Crit. Rev. Food Sci. Nutr.* 2004; 44:185–193.
18. Active and Intelligent Packaging = Longer Shelf Life, <https://www.ift.org/news-and-publications/food-technology-magazine/issues/2020/april/columns/active-and-intelligent-packaging-longer-shelf-life>, 15th September 2021.
19. Active Packaging, http://www.actinpak.eu/wp-content/uploads/2018/06/Active_packaging_English.pdf, 25th September 2021.
20. Miltz J, Perry M. Evaluation of the performance of iron-based oxygen scavengers, with comments on their optimal applications. *Packaging Technology and Science*. 2005; 18: 21–27.
21. Tewari G, Jayas DS, Jeremiah LE, Holley RA. Absorption kinetics of oxygen scavengers”. *Int. J. of Food Sci. and Tech.* 2002; 37 (2): 209–217.
22. Oxygen Absorbers, https://www.sorbentsystems.com/Oxygen_Absorber_Facts.pdf, 28th September 2021.
23. Mohan C, Ravishankar CN, Srinivasagopal TK. Effect of O2 scavenger on the shelf-life of catfish (*Pangasiussutchi*) steaks during chilled storage. *J. Sci. Food Agric.* 2008; 88: 442–448.
24. The ZerO2 bottle cap, <https://www.carlsberg.com/en-my/betterments/fresh-cap/>, 28th September, 2021.
25. Yildirim S, Röcker B, Pettersen MK, Nilsen-Nygaard J, Ayhan Z, Rutkaite R, et al. Active packaging applications for food. *Compr Rev Food Sci Food Saf.* 2018;17(1):165–199.
26. Vilela C, Kurek M, Hayouka Z, Röcker B, Yildirim S, Antunes MDC et al. A concise guide to active agents for active food packaging. *Trends Food Sci Technol.* 2018; 80:212–222.
27. Hazel's suite of technologies help extend shelf life and protect quality from field to fork, <https://www.hazeltechnologies.com/products>, 30th September 2021.

28. Moisture-absorbingdesiccant film for near-zero moisture packaging, <https://www.kyodoprnting.com/products/landi/packaging/moistcatch/>, 30th September 2021.
29. Types of Active packaging, http://www.actinpak.eu/wp-content/uploads/2018/08/Full_text_Activepackaging_download.pdf, 2nd October 2021.
30. Pereira deAbreu D, Losada PP, Maroto J, and Cruz JM. Lipid damage during frozen storage of Atlantic halibut (*Hippoglossus*) fillets packaged with an active packaging film containing antioxidants. *Food Chem.* 2010; 126: 315–320.
31. Cutter CN. Microbial control by packaging: A review. *Crit. Rev. Food Sci. Nutr.* 2002; 42: 151–161.
32. Ghaani M, Cozzolino CA, Castelli G, & Farris S. An overview of the intelligent packaging technologies in the food sector. *Trends Food Sci. Technol.* 2016; 51: 1–11.
33. Realini CE, Marcos B. Active and intelligent packaging systems for a modern society. *Meat Sci.* 2014; 98: 404–419.
34. Intelligent food packaging, https://www.logforum.net/pdf/4_4_3_2008.pdf, 3rd October 2021.
35. McFarlane D, Sheffi Y. The impact of automatic identification on supply chain operations. *Int. J. Logist. Manag.* 2003; 14: 1–17.
36. Manthou V, Vlachopoulou M. Bar-code technology for inventory and marketing management systems: A model for its development and implementation. *Int. J. Prod. Econ.* 2001; 71: 157–164.
37. Fang Z, Zhao Y, Warner RD, Johnson SK. Active and intelligent packaging in meat industry. *Trends Food Sci. Technol.* 2017; 61: 60–71.
38. Brockgreitens J, Abbas A. Responsive food packaging: Recent progress and technological prospects. *Compr. Rev. Food Sci. Food Saf.* 2016; 15: 3–15.
39. Kumar P, Reinitz HW, Simunovic J, Sandeep KP, Franzon PD. Overview of RFID technology and its applications in the food industry. *J. Food Sci.* 2009; 74: 101–106.
40. Ahmed I, Lin H, Zou L, Li Z, Brody AL, Qazi IM, et al. An overview of smart packaging technologies for monitoring safety and quality of meat and meat products. *Packag. Technol. Sci.* 2018; 31: 449–471.
41. Otles S, Yalcin B. Smart Food Packaging. *Log Forum Sci. J. Logist.* 2008; 7: 1–7.
42. Mohebi E, Marquez L. Intelligent packaging in meat industry: An overview of existing solutions. *J. Food Sci. Technol.* 2015; 52: 3947–3964.
43. Wang S, Liu X, Yang M, Zhang Y, Xiang K, Tang R. Review of time temperature indicators as quality monitors in food packaging. *Packag. Technol. Sci.* 2015; 28: 839–867.
44. Endoza TFM, Welt BA, Otwell S, Teixeira AA, Kristonsson H, Balaban MO. Kinetic parameter estimation of time-temperature integrators intended for use with packaged fresh seafood. *J. Food Sci.* 2004; 69: 90–96.
45. Pavelková A. Time temperature indicators as devices intelligent packaging. *Acta Univ. Agric. Silv. Mendel. Brun.* 2013; 61: 245–251.
46. Ahvenainen R, Hurme E. Active and Smart Packaging for Meeting Consumer Demands for Quality and Safety. *Food Additives & Contaminants.* 1997; 14: 753–763.
47. Taoukis PS. Application of Time– Temperature Integrators for Monitoring and Management of Perishable Product Quality in the Cold Chain. In: Kerry, J. and Butler, P. (ed.). *Smart Packaging Technologies for Fast Moving Consumer Goods.* John Wiley & Sons Ltd., 2008; 61–74. ISBN 978-0470028025.
48. 3m freezewatch indicators, <https://www.chemitec.co.il/Media/Uploads/3m-freeze-watch-indicators-pdf.pdf>, 5th October 2021.
49. Selman JD. 1995: Time-temperature indicators. In Rooney, M.L. (ed.), 1995: *Active food packaging.* 1st edition, London, UK: Blackie Academic & Professional, pp. 215–237, ISBN 978-0751401912.
50. Kuswandi B, Wicaksono Y, Jayus, Abdullah A, Heng LY, and Ahmad M. Smart packaging: sensors for monitoring of food quality and safety. *Sens. & Instrumen. Food Qual.* 2011; 5: 137–146.
51. The perfect on package food freshness management tool, <http://fresh-check.com/>, 7th October 2021.
52. Kuswandi B, Maryska C, Jayus, Abdullah A, Heng LY. Real time on-package freshness indicator for guavas packaging. *J. Food Meas. Charact.* 2013; 7: 29–39.
53. Nopwinyuwong A, Trevanich S, Suppakul P. Development of a novel colorimetric indicator label for monitoring freshness of intermediate-moisture dessert spoilage. *Talanta.* 2010; 81: 1126–1132.
54. Park YW, Kim SM, Lee JY, Jang W. Application of biosensors in smart packaging. *Mol. Cell. Toxicol.* 2015; 11: 277–285.
55. Meng X, Kim S, Puligundla P, Ko S. Carbon dioxide and oxygen gas sensors-possible application for monitoring quality, freshness, and safety of agricultural and food products with emphasis on importance of analytical signals and their transformation. *J. Korean Soc. Appl. Biol. Chem.* 2014; 57: 723–733.
56. Intelligent packaging in the food sector: a brief overview, <https://www.mdpi.com/2304-8158/8/1/16/htm#B36-foods-08-00016>, 10th October 2021.
57. Pandey SK, Kim K-H. The relative performance of NDIR-based sensors in the near real-time analysis of CO₂ in air. *Sensors.* 2007; 7: 1683–1696.
58. Intelligent packaging for monitoring food quality: A case study on fresh fish, <https://edepot.wur.nl/298571>, 12th October 2021.
59. RFID technology and its applications, <https://www.electronicshub.org/rfid-technology-and-its-applications/>, 15th October 2021.

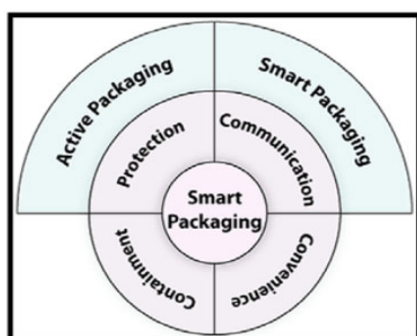


Figure 1: Different types of packaging³.

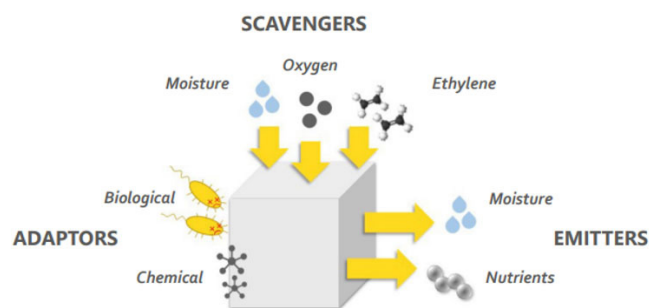


Figure 2: Working model of active packaging¹⁹.

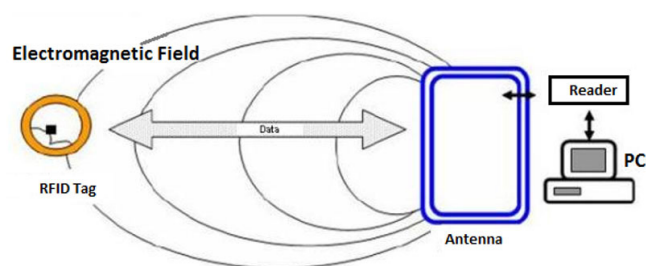


Figure 3: The working principle of radio frequency identification (RFID) tag⁵⁹.



Figure 4: Principle of Lifeline's Fresh-Check Indicator (TTI)⁴⁴.



Figure 5: A sensor that monitors carbon dioxide as an indication for the freshness of the dessert golden drop⁵³.

Table 1: Principles of indicators and sensors based on metabolites⁵³⁻⁵⁵

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