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Role of Active Packaging for Food Freshness and Quality Maintenance

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Abstract— *Active packaging is developed as a favorable method to address the challenge and prolong the shelf life of perishable foodstuffs while maintaining their freshness and quality. This abstract provides an overview of the active packaging systems and their roles in preserving food quality and safety. Active packaging incorporates various technologies, oxygen scavengers, moisture absorbers, antimicrobial agents, and flavor-release systems, within the packaging materials. These technologies actively interact with the food product to create a modified atmosphere or inhibit microbial growth, resulting in improved preservation and quality retention. Active packaging provides many benefits, including its ability to reduce food waste, enhance product safety, and meet consumer demands for convenience and sustainability. In inference, active packaging offers a favorable opportunity to enhance the shelf's life of food products and maintain their freshness and quality.*

Keywords— ***Active packaging, Shelf life, Products, Technologies, Antimicrobial agents, Atmosphere, Sustainability, Freshness.***

INTRODUCTION

The food packaging industry, on a global scale, was characterized by the active participation of developing nations, constituting approximately 50 per cent in this area (Dainelli *et al.*, 2008; Pereira *et al.*, 2020; Robertson, 2013). In the context of the food processing industry, packaging was a critical component with the primary objectives of containment, protection, and preservation of the end product to fulfill customer requirements. It should be noted that packaging served a triad of functions: firstly, safeguarding the product; secondly, conveying essential information; and thirdly, facilitating transportation (Young *et al.*, 2020). The temporal stability of packaged food was assessed through a comprehensive analysis, incorporating intrinsic factors such as water activity (Aw), pH, redox potential, nutritional composition, antibacterial agent presence, inhalation rate, and organic structure. Simultaneously, extrinsic variables include storage temperatures, relative humidity, and the compositions of the ambient gas were taken into account (Day, B. 2008). In the past, the primary objective of food packaging resided in safeguarding food items from the detrimental effects of oxygen, water vapor, UV radiation, as well as chemical and microbial pollutants. In accordance with data furnished by the World Health Organization, the United States bore witness to approximately 48 million instances of foodborne infections annually, culminating in an approximate tally of 3000 fatalities. Spain, during that timeframe, was estimated to have experienced an incidence rate of 60 cases of foodborne illnesses for every 100,000 residents yearly, thereby necessitating the emergence of biosensors engineered for pathogen detection within food matrices. Consequently, efforts were undertaken to enhance the preservation of food items and implement continuous quality control through the adoption of active packaging materials. (Pan American Health Organization, PAHO 2009). "Packaging was deemed a pivotal source of information capable of significantly influencing consumer perceptions and purchasing choices in the past." In recent years, an array of scientific publications and studies elucidating novel technologies within the realm of food packaging, particularly those pertaining to active packaging, garnered attention, driven by the increasing the consumers demand for convenient food management or prolonged product shelf-life (Jeantet *et al.*, 2016; Nur Hanani *et al.*, 2014; Rehman *et al.*, 2020) (Wyrwa & Barska, 2017). "In the earlier, active packaging constituted a system where in the packaging go through modification to enhance the preservation, sensory attributes, safety, and quality traits of the enclosed food product" (Robertson, 2013).

Food Packaging

Food packaging that is effective serves several functions. It preserves the nutritional and structural integrity of food by servings as the protective barrier against external factors like water, light, odors, dust, bacteria, and machine-driven damage. "Additionally, it functions as a receptacle for the transportation and storage of food items." Packaging may incorporate barriers to uphold stable gas composition or moisture levels within the product. Accessibility considerations are pivotal in packaging design, with a growing consumer preference for swift original, dispensing, or resealing mechanisms ensure sustained manufactured goods quality till consumption complete (Gupta, R. K. & Dudeja, P. 2017).

Materials used in the food packaging

Paper, plastic, metal, and glass have emerged as predominant materials for the packaging of food items in contemporary contexts. Glass and metal demonstrated exceptional barrier qualities and showed little contact with the contained food goods. Contrastingly, plastic materials had features that caused interactions with the packaged food products, including poor barrier properties and a lack of inertness. Nonetheless, the used of the plastics material for packaging improved exponentially in the years before then. Comparing plastics to other materials, it became clear that they were more cost-effective due to their lower energy content, reduced weight, and comparable structural robustness. (Mtolo, *et al.*, 2020).

"In numerous scenarios, the amalgamation of multiple materials was employed to attain the prescribed barrier properties of the packaging." Exemplary layers encompassed foil, diverse plastic varieties, paper, and adhesive substances. The prevalent plastics utilized in food or beverage packaging includes polypropylene, polyethylene, polyethylene terephthalate, polyamide, polystyrene, and ethylene vinyl alcohol. (Risch, S. J. 2000). Polyvinyl chloride, polyethylene (PE) emerged as the most ubiquitously manufactured plastic globally, with polypropylene (PP) ranking as the third most abundant bulk plastic

Active food packaging

It was observed that packaging played a crucial role in enhanced the shelf lives and the economic worth of food products. Along with the entire supply chain, suitable food packaging functioned mainly as a vessel for foods, safeguarding it against unfavorable biochemical and microbiological alterations (Yu *et al.*, 2019). The Active packaging systems, beyond their fundamental roles, were found to offer supplementary functionalities meant at enhancing their quality and safeties of the food products (Kra'sniewska *et al.*, 2020). In order to enhance the cleanness, quality, and safety, of the certain active packaging materials were employed in the past to impede respiration rates, hinder microbiological growth, and constrain moisture migration. The utilization of active antimicrobial treatments was explored as a means to extend the shelf's life of food products, concurrently sustaining their nutritive integrity and safeties through postponement of microbial proliferation. The incorporation of active substances abundant in antioxidants was studied for its capacity to forestall food oxidation (Realini & Marcos, 2014). The active packaging material's nature or working principle was ascertained by its active substance (AI), which exhibited properties of release, absorptions, blocking and buffering (Kuswandi & Jumina, 2019; Rehman *et al.*,2020). However, any of the active packaging material possessed either non-migratory (i.e., scavenging) and the migratory (i.e., producing) characteristics. (Kuswandi & Yu *et al.*, 2019). The Active packaging involves incorporation of additives or "freshness enhancers" across diverse packaging applications, aimed at augmenting the preservation capabilities inherent in the fundamental packaging system.

In a broader context, active packaging was divided into the two main categories: non-migratory active packaging, which refers to the scavengers considered to remove undesirable mechanisms from the internal packaging surroundings lacking intentional movement, and active discharging packaging, which is mainly concerned with emitters facilitating the controlled migration of the desired substances into the packaging milieu, thereby conferring beneficial influence upon food product. (Dainelli *et al.*, 2008; Barska *et al.*, 2017). It was observed that the majority of non-migratory active packaging systems in food products exhibited the capacity to function as oxygen scavengers, moisture scavengers, and ethylene absorbers. Conversely, active release packaging systems were found to encompass carbon dioxide-emitting mechanisms, antioxidant packaging, and antimicrobial packaging. (Yildirim *et al.*, 2018).

In the past, due to advancements in technology, active packaging systems underwent a significant expansion. The alterations engendered concomitant elevation of benchmarks pertaining to alimentary quality and safety, concomitant with an unequivocal emphasis on the imperatives of sustainability and the amelioration of waste.

Methods of Active Packaging (Mane, K. A. 2016**)**

System of active packaging	Methods	Uses for food
Oxygen scavengers	They are ascorbate, an iron-based or acid metal catalyst, and enzymes. Examples of these include platinum.	Rice that has been cooked, cake, biscuits ,cured meats and fish, pizza, pasta, cheese, and drinks, coffee, snack snacks, and dried goods.
Carbon dioxide scavengers/emitters	Sodium bicarbonate, ascorbate, and activated charcoal Calcium hydroxide ferrous carbonate, iron oxide, and calcium oxide containing metal halides.	Fresh meats, coffee and other snack food products and sponge cakes.
Ethylene scavengers	Carbon- and potassium-permanganate-activated clays and zeolites.	Fruits, vegetables, and other goods from horticulture
Preservative releasers/ Antimicrobial agents **Preservative releasers/ Antimicrobial agents**	Naturally occurring acids Herb and spice extracts in silver zeolite BHA/BHT antioxidants, vitamin E, and sulfur dioxide and volatile chlorine dioxide	Meats, seafood, cheese, breads, snacks, and fruits and vegetables
Ethanol emitters	Alcohol spray encapsulated ethanol	Cakes,bread,biscuits pizza, fish and bakery product
Moisture absorbers	Mineral silica gel and PVA blanket activated clays	Fish, cereals,sandwiches,meats,vegetables and fruits
Flavors/-odour absorbers	Ascorbate activate carbon, zeolites, ferrous salt and cellulose triacetate acetylated paper.	Dairy products,fruits,fruits juices,poultry,fried snack foods
Temperature control **Packaging**	Water ammonium nitate, non-woven plastic double walled container.	Fish,meats,poultry and beverage, ready meals

Among these developments, edible films and coatings became active packaging innovations that, at the time, showed they could meet strict criteria, were mainly made from natural sources, and had built-in biodegradability. (Han, 2005; Stoleru *et al.*, 2021).

Oxygen Scavengers

Packaged food products typically contain specific volumes of headspace gases and trapped oxygen. Additionally, there's a significant focus on preventing the ingress of oxygen into plastic containers. While it's preferred to limit the headspace gases to ensure secure sealing, it's equally vital to reduce the oxygen that could potentially act in response with the substances inside the container (C.J *et. al.*, 1985). Molecular oxygen (O2) is capable of being reduced in electron density via one to four to produce a range of intermediate species, such as superoxide, hydroxy radicals, hydrogen peroxide, and water. Notably, superoxide, hydroxy radicals, and hydrogen peroxide exhibit high reactivity, with a particular affinity for carbon-carbon double bonds. In contrast, O_2 and water display comparatively low reactivity. These reactive oxygen species are naturally free radicals, which makes the oxidative reactions they participate in autocatalytic. Assuming that products comprising complex organic constituents are likely to contain carbon-carbon double bonds and other oxygen-reactive components, the possibility of oxidative reactions increases. (Zenner, B.D. et al., 2002). Undesirable oxygen content can arise from several factors during the packaging process, including insufficient evacuation, inherent oxygen in the food or packaging materials, leakage into the headspace, permeation through the packaging, poor sealing allowing air entry, or microscopic holes in the packaging material. Elevated oxygen levels have adverse effects on food, diminishing its nutritional quality and shelf lifespan (Mohan, C. *et al.*, 2008)

Certain food yields, including meats, milk powder, and herbs and spices, can be rapidly depleted due to reactions between oxygen in atmospheric gases and sensitive food items. Furthermore, it feeds bacteria and causes rancidity in oily, fatty, and nut foods and also causes vitamin deterioration. Methods like vacuum sealing, introducing inert gases either carbon dioxide (CO2) or nitrogen (N2), even combining the two methods can all be used to remove oxygen from food packing. These approaches find applications in packaging for items like orange juice and within the brewing industry, as well as in artificial-atmosphere packaging for various food products. This technology is capable of reducing approximately 85-95% of the oxygen originally present in the surrounding appearance before or during the packaging process. However, removing the remaining traces of oxygen becomes a costly endeavor. In order to control the packaging's residual oxygen content, oxygen-absorbing materials are utilized, which helps to slow down the rate at which food goods deteriorate and degrade (Zerdin, K. *et.al.*, 2003) Promptly removing oxygen has been shown to be essential for maintaining increased ascorbic acid levels in orange juice during long storage periods. Vegetables and orange juice browning are also related to oxygen content. Additionally, using oxygen scavengers in cakes led to a substantial rise in the amount of cakes which retained their mold-free mantelshelf life. (Guynot, M.E. *et al.*, 2003).

Oxygen scavengers offer several advantages:

- They hinder oxidation processes, preventing the development of issues such as the rancidity of fats and oils, resulting in undesirable odors and flavors, as well as alterations in the natural colors of food items. They also protect substances like unsaturated fatty acids and vitamins A, C, and E that are susceptible to oxygen.
- They prevent aerobic microbes from growing.
- Buying "fresh" or "natural" things becomes increasingly desirable as they reduce or eradicate the need for preservatives and antioxidants in food.
- They provide an effective and affordable alternative for vacuum packaging and controlled environment processes.
- By impeding the metabolic processes of food, these systems facilitate preservation, consequently extending the commercial lifespan of food products, whether utilized independently or in conjunction with conventional packaging technologies.

The various mechanisms by which oxygen scavengers operate include:

1. The most common and effective process now in use is the corrosion of iron and iron salts. The oxygen scrounger methods reliant on iron rust reactions can be elucidated through the following calculation:
   $4Fe(OH)_2 + O_2 + 2H2O \rightarrow 4Fe(OH)_3$
2. Photophobic colorants undergo oxidative reactions.
3. Oxidation occurs in the unsaturated fatty acids ascorbic acid, oleic acid, and linoleic acid.
4. Enzymatic oxidation employs specific enzymes like alcohol oxidase, glucose oxidase, and catalase. For example, glucose oxidase, an oxidoreductase, catalyzes the conversion of two hydrogen atoms from glucose's CHOH group to oxygen, yielding hydrogen peroxide and glucono-δ-lactone. (Vermeiren, L *et al.*, 2000).

The process involves the oxidative transformation of iron and ferrous salts within systems, wherein interaction with aqueous food results in the hydration of iron within product packaging, leading to its irreversible conversion into a stable oxide. To prevent direct contact with the food, iron powder is encapsulated in minute, permeable pouches. In contrast to conventional residual oxygen-modified environment packaging, which typically achieves a range of 0.3–3.0%, the notable benefit of employing that kind of oxygen absorber lies in its capability to reduce oxygen levels to less than 0.01%. This diminished oxygen concentration can be sustained over prolonged durations, contingent upon the oxygen absorbency of the packing material. But, the utilization of the saccharides bags presents drawbacks, such as the introduction of additional steps in the packaging process that may compromise the visual presentation of the food. (Ohtsuka, S. *et al.*, 1984).

Ethylene Scavengers (encompassing both ethylene absorbers and emitters, serve as efficacious agents in mitigating the presence of ethylene.)

The modulation of ethylene concentrations in storage environments markedly enhances the postharvest longevity of diverse classes of perishable agricultural commodities. (Terry, L. A. *et al.*, 2007). Ethylene, a phytohormone, emanates from metabolic pathways within the living cells of climacteric fruit varieties, including but not limited to tomatoes, avocadoes, mango, banana, pears and kiwi. In contrast, non-climatic fruits like lemon, pineapples, oranges, grapes and strawberries do not exhibit similar ethylene-dependent responses (Brody, A. L. *et al.*, 2001). It has been established for an extended period that even trace amounts of ethylene elicit the hastening of ripening in all types of vegetables and fruits, encompassing both climatic and non-climatic varieties, by provoking an augmentation in their respiratory activity. For instance, ethylene is harnessed industrially to expedite the ripening of bananas and tomatoes, and also to induce the characteristic orange coloration in oranges. The mitigation of ethylene exposure within the proximate surroundings of these produce items leads to a deceleration in their respiratory rates, consequently yielding delayed ripening and thereby an extended period of postharvest viability (Vermeiren, L. *et al.*, 2003). The management of ethylene levels within storage environments assumes a pivotal role in the extension of the postharvest longevity of numerous categories of fresh agricultural produce. The majority of fruits and vegetables release ethylene following harvest, initiating and accelerating the ripening process, causing softening, and promoting the degradation of chlorophylls. Ultimately, these processes lead to the weakening of fresh and minimally handled fruit and vegetables.

Action of mechanism:

a. Different approaches depend on which materials can absorb ethylene on their own or in combination with a reactant. Palladium, for example, has shown better ethylene adsorption capability than scavengers based on permanganate, particularly under high relative humidity settings (Smith, A. W. et al., 2009). Ethylene can be adsorbed by packaging materials such polymer films made of low-density polyethylene (LDPE) and high-density polyethylene (HDPE). In the food industry, substances like ethyl acetate, hydrogen sulfide, and ethanol are employed for ethylene adsorption, providing a dual function of extending the freshness of food products and mitigating undesirable odors.

b. A primary mode of operation for ethylene scavengers involves the utilization of potassium permanganate; this makes ethylene easier to oxidize into carbon dioxide and water. These scavengers typically contain potassium permanganate concentrations ranging from 4 percent to 6 percent (ABE, K. & WATADA *et al.*, 1991). As potassium permanganate interacts with ethylene, it undergoes a visible transformation from purple to brown, thereby serving as an indicator of its remaining capacity to absorb ethylene. However, it is important to note that due to its toxicity, direct contact with food is not permissible when using potassium permanganate.

Ethanol Emitters

Ethanol finds regular application in medicinal and pharmacological packaging, underscoring its prospective role as a vapor-phase inhibitor. Its utility encompasses the prevention of microbial contamination and the mitigation of the pace at which staling and oxidative alterations occur (Seiler, 1989). Scientific studies have demonstrated that applying ethanol to the surfaces of bread, cake, and pizza prior to packaging can effectively prolong their shelf life. This can be accomplished by the use of sachets that contain ethanol that has been encapsulated. These sachets allow for the regulated release of ethanol vapor within the enclosed packaging environment, maintaining the effectiveness of the preservative. The control of sachet permeability allows for the modification of the rate at which ethanol is released into the vapor. (Smith, J. P. 1995).

Emitters of Carbon Dioxide and Scavengers

Carbon dioxide emitters and scavengers play a pivotal role in modulating the antimicrobial impact of elevated carbon dioxide concentrations within packaging, particularly on surfaces of various commodities such as meat and poultry. This modulation contributes to the extension of shelf life. But since plastics are more permeable to carbon dioxide than to oxygen, in some cases it may be necessary to intentionally add carbon dioxide to the packaging in order to preserve the expected gas composition. (Lee, D. S. 2001)

Carbon dioxide adsorption is employed as a means to mitigate pressure escalation, expansion, and potential rupture of packages containing respiring foods, thereby diminishing the overall longevity of the product. Significant endeavors have been directed towards diminishing pressure levels within kimchi packaging. (Kimchi, a fermented vegetable product predominantly consumed in Korea, continues to generate carbon dioxide even during refrigerated storage.) Zeolite has demonstrated efficacy in adsorbing carbon dioxide, consequently resulting in decreased swelling of kimchi packaging. Due to the Strecker degradation reaction occurring between sugars and amino acids, roasted coffee manifests heightened carbon dioxide levels (Floros, J. D. 2000). To counteract this, a scrounger comprised of iron powder also CaOH is employed to decrease both oxygen and carbon dioxide concentrations. The resultant reduction in carbon dioxide content prevents package rupture, while diminished oxygen levels safeguard against oxidative flavor alterations, thereby extending the shelf life of products.

To avert the collapse of packages containing oxygen-scavenging agents, it is advisable to employ carbon dioxide-generating mechanisms. The prevalent systems predominantly employ ferrous carbonate or a blend of ascorbic acid and bicarbonate. Systems integrating both oxygen-absorbing and carbon dioxide-emitting components are primarily utilized for commodities demanding substantial packaging volume and aesthetic appeal, for example potato crisps and peanuts (Smith, J. *et al.*, 1995). Microbial growth is well-documented designate inhibited by CO_2. CO_2 concentrations inside the range of 70 to 80 percents effectively curtail microbial proliferation on surfaces, thereby prolonging the shelf life of products. As a result, adding a CO2 production mechanism to the packing structure and integrating it as a sachet serves as another approach to oxygen (O2) scavenging. Since most plastic films absorb CO2 three to five times more than they do O2, a steady supply of CO2 is required to keep the anticipated amount inside the package. There are several situations where a CO2 generator can be beneficial, such as during packaging cheese, fresh meat, fish, and livestock. For food substances somewhere package volume and visual appeal are crucial considerations, the combined use of a CO2 generator and an O2 scavenger represents a viable strategy (Smith, J. P. *et al.*, 1995).To forestall package collapse resulting from oxygen (O2) absorption, measures are taken. While carbon dioxide (CO2) exhibits a microbial inhibitory effect within the context of modified atmosphere packaging, an excess of CO2 can potentially detrimentally affect the product or even negate its inhibitory properties. Consequently, multiple food preservation packaging methodologies have been devised with the objective of CO2 removal (Brody, A. L. *et al.*, 2007).

Moisture Absorbers

Water originates from the metabolic breakdown of fats and carbohydrates during food respiration. Wet food, characterized by elevated water vapor pressure, frequently undergoes condensation within packaged items, especially fruits and vegetables. Temperature differentials, either internal or external to the packaging, result in water droplet formation on package walls or food surfaces. The presence of water droplets adversely affects packaging aesthetics, diminishing consumer appeal. Additionally, surface moisture on food facilitates mold growth, ultimately reducing the product's shelf life. To address these issues, desiccating films or sachets can be employed as effective solutions.

Pads containing cellulose fiber and propylene glycol are commonly used in direct interaction with fish and meat in packaging to absorb the moisture. Current research efforts focus on enhancing methodologies for integrating desiccants into packaging materials (Hurme, E. 2002).

Over-moisture acts as the main cause of food deterioration. Excess moisture can be removed utilizing several kinds of desiccants or absorptive agents, which is an extremely efficient method to preserve food quality and increase product shelf life. This stops the growth of bacteria and stops the loss of texture and flavor caused by moisture. Permeable plastic sachets with breaking strength are used to package dried food applications and desiccants such as calcium oxide, silica gel, minerals, and activated clays. These sachets may also serve dual purposes, incorporating stimulated carbon for odor absorption and iron powder for oxygen removal.

Flavors/Odour Absorbers

Intelligent packaging principles encompass various strategies to mitigate undesirable aromas and flavors. This includes the application of scavengers to eliminate noxious odors, addressing issues such as the removal of amines from oxidized protein-rich foods, elimination of aldehydes from products like biscuits and fried foods, and eradicating bitter-taste constituents like limning in fruit juices (Vermeiren, L. et al., 2003). Porous pads, initially researched for odor mitigation in products like diapers, have found application in food packing as well (Brody, A. L. et al., 2001).

There might be positive and negative effects from removing offensive substances from food packaging. Analyzing the advantages of odor/aroma reduction is now essential in the context of active packaging. Certain foods, such as newly cooked poultry and cereals, release "confinement odors" when they break down slightly. These items can release sulfurous compounds when protein molecules and amino acids break down, or they can release ketone and aldehyde compounds when lipids oxidize and anaerobic glycolysis occurs during transportation. Despite being generally harmless, these odors can lead to product rejection, emphasizing the need to eliminate them from packaging interiors. Additionally, incorporating odor-reducing agents helps mitigate odors originating from the packaging materials themselves, which may occur during plastic processing stages, requiring the inclusion of antioxidants in polyolefin processing (Brody, A. L. et al., 2001).

Antimicrobial Agents

Antimicrobial agents applied to food have a historical precedent, yet the utilization of antimicrobial interactive packaging represents a novel methodology for managing microbial surface contamination in food products. Two distinct categories of antimicrobial systems exist: those with migratory properties and those lacking such migration. Given their shared necessity for substantial interaction among the food products and packaging material, these applications have predominantly found utility in vacuum-sealed or skin-packaged food products (Vermeiren, L. *et al.*, 2002)

The introduction of ethanol into the packaging environment is exhibited efficacy in extending the shelf life of the bakery products. By reducing the amount of water on the food's surface, ethanol inhibits the growth of bacteria, mold, and yeast in particular. Moreover, ethanol's ability to prevent bread from stagnating has been observed.

Antimicrobial agents can be incorporating into food packaging material though either immobilization or by modifying and coating the package surface to activate the antimicrobial properties. According to current approaches, it is envisaged that naturally sourced antimicrobial agents could be integrated into packaging systems designed to protect various processed foods such as cheeses, meats, and other food products. This is especially the case for products with relatively uniform food product surfaces that come into direct contact with the inner packaging surface. This strategy is becoming more popular because it is thought to pose less of a danger to the consumer (Nicholson, M. D. *et al.*, 1998).

The two various kinds of antimicrobial films that are listed below:

- Films incorporating an anti-microbial (AM) agent that exhibits migration towards the food surface.
- Films that exhibit antimicrobial efficacy against surface microbial growth without the need for migration.

Temperature-Controlled Packaging

Temperature control in the context of active packaging includes the creation of self-heating and self-cooling containers as well as novel insulating materials. These approaches serve to address specific temperature control requirements. For instance, specialized insulating materials like insulate, constructed from nonwoven plastic with numerous air pore holes, have been engineered to safeguard refrigerated products from undesired temperature fluctuations while being transported and preserved. To strengthen the food packaging's capability to resist heat in response to temperature fluctuations, an effective strategy involves augmenting its thermal mass. Employing self-heating cans and containers, a technology predominantly favored in Japan, entails leveraging exothermic reactions. In this process, the amalgamation of water and lime at the base of the container induces heat production within self-heating steel and aluminum cans. This technology is widely applied in packaging various consumables such as coffee, tea, sake, and ready-to-eat meals, as documented by Day B.P.F. in 2003.

CONCLUSION

As a result, active packaging for preserving food freshness and quality represents a potential and cutting-edge strategy in the food sector. It provides a number of benefits, including prolonging shelf life, preserving taste and texture, and improving food safety, by incorporating different technologies such as oxygen scavengers, moisture regulators, and antimicrobial agents into packaging materials. Active packaging solutions' continual development has a lot of potential for lowering food waste, preserving product integrity, and satisfying consumer needs for high-quality, long-lasting food products. Food makers must balance functionality, affordability, and sustainability as this industry develops if they are to reap the advantages of active packaging while reducing its environmental impact.

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