

Bread packaging techniques and trends

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Abstract

Bread staling and microbial growth is a complex physiochemical change that occurs during bread storage mainly reducing the quality and consumer acceptance. It is significant to understand the causes of physical, chemical, and microbial spoilage of bakery products in the food industry, to prevent quality decay and economic loss for manufacturers and consumers. Traditional packaging has limitations in protecting and preserving the final products' safety, hygiene, and quality. Effective novel strategies must be included in food packaging, especially to minimize the organoleptic losses of baked foods during their shelf life. Furthermore, owing to the spread of foodborne diseases, which directly affect the safety of the products, customer demand is increasing significantly to reduce the use of synthetic preservatives instead of natural ones. Innovative packaging is altering the way food items are packed in several ways to extend and monitor product shelf life. Traditional packaging includes packaging food in synthetic polymer film; however, modern technology allows them to interact with active/functional substances. This paper discusses innovative bread packaging strategies such as modified atmosphere packaging (MAP), active packaging (AP), intelligent packaging (IP), biosensor, and nano packaging. Furthermore, MAP and AP have received greater attention in this study due to their considerable effect in prolonging the shelf life of bread and naturally preventing fungal activity, and have gained a lot of interest among producers and consumers in recent years.

Introduction

Bread is still regarded as one of the best breakfast options worldwide, and people prefer different kinds of bread, like wheat bread with high fiber content because of its health benefits. People consume bread every day, however it only has a short shelf life due to various contaminating factors, including physical, chemical, and microbial spoilage (Salgado *et al.*, 2021; Pateras, 1998). Additionally, the product's shelf life is influenced by several extrinsic and intrinsic factors, including temperature, rainfall, humidity, and light. Intrinsic factors include oxygen availability, preservatives, environmental behavior of the pathogen in the food matrix, and water activity (Aider, 2010; Pal *et al.*, 2019). Mold formation in bakery products is a significant factor that affects shelf life since it mostly depends on environmental factors that are favorable to pathogens, mainly *Aspergillus spp.*, *Penicillium spp.*, and *Eurotium spp.* are the three most prevalent fungi that cause bread products to deteriorate (Legan, 1993). Packaging is a technical process that is used to enclose and protect finished food products to keep them fresh and safe to transport. The major goal of packaging is to safeguard food integrity and preserve sensory characteristics from microbial deterioration and staling. During the cooling process, starch crystallizes and aggregates causing, staleness in bread which is a significant source of economic loss (Fadda, Sanguinetti, Del Caro, Collar, & Piga, 2014). The other vital reasons for the decline in shelf-life are high water activity and post-baking issues resulting in the development of mold growth, which leads to mycotoxin production (Marques *et al.*, 2012). The atmospheric air is recognized as one of the primary sources of contamination in bread products, specifically after baking, due to the presence of the fungal spore in the slicing and packaging stages, resulting in high chances of contamination. Since microbial decomposition is a key concern that affects the shelf life of bread and other bakery goods, it is critical to limit its proliferation. Various measures and strategies such as good manufacturing and hygiene practices are followed, ensuring proper process control parameters, including packaging and post-storage procedures, to overcome the safety issues and critical demand of global consumption (Smith *et al.*, 2004). The food revolutionary in packaging aids in novel packaging techniques development such as active packaging (AP), and intelligent packaging (IP). It involves effective interaction between the packaging material and the antimicrobial components forming a protection layer around the food

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material and its surroundings, which increases the shelf-life, decreases sensory losses, and enhances the hygiene, safety, and security of the food product (Abdullahi., 2018).

Modified atmospheric packaging (MAP), on the other hand, works on replacing the air with a mixture of carbon dioxide (CO₂), nitrogen, and inert gas in packaging, mainly decreasing the oxygen (O₂) content to less than 1% of the surface of the packed food, commonly known as headspace. The fungistatic properties of CO₂ also inhibit the growth of mold by changing the metabolic activity of the cell membrane, resulting in a detrimental effect on growth (Pasqualone, 2019). Alternatively, another

research, stated high concentration of CO₂ increases the acidity of bakery food, affecting the taste and other sensory characteristics thereof varying conflicts of using MAP techniques many researchers conclude that MAP in bread packaging, only delays mold growth but could not prevent growth. Due to these reasons, the European Food Safety Authority (EFSA) developed new and innovative concepts for packing foods such as AP, and IP which permits intentional interaction between food and packing material by carrying the functional material and deliberately interact with the food substances and protect the food from external contamination such as light, oxygen, pathogens, chemical pollutants, and pests, resulting in enhancing food safety and quality, and extension of shelf-life of final products (Pasqualone, 2019). Table 1 lists the functional and technical understanding of active and intelligent packaging (Malhotra *et al.*, 2015; Biji *et al.*, 2015; Melini and Melini, 2018). Utilizing triple-layered high-barrier oxygen packaging with a low initial oxygen level, the bakery sector has demonstrated tremendous potential for increasing the shelf-life of white bread by up to 7 days through the implementation of the MAP and AP processes (Upasen *et al.*, 2018). Figure 1 explains the roles, functions, and advantages of packaging. In addition, a study reported that active packaging increased the shelf-life while preserving the sensory characteristics of gluten-free bread (Melini and Melini, 2018). Preserving food from internal and external contamination is the principal purpose of food packaging, however, interactions between food and packaging material can also jeopardize food quality, safety, and the integrity of food packaging (Alamri *et al.*, 2021).

The food revolutionary in packaging aids in novel packaging techniques development such as AP and IP. It involves effective interaction between the packaging material and the antimicrobial components

forming a protection layer around the food material and its surroundings, which increases the shelf-life, decreases sensory losses, and enhances the hygiene, safety, and security of the food. This review's objective is to evaluate the importance of bread packaging innovations, like modified atmospheric packaging, active packaging, intelligent packaging, and nano packaging, and their applications in increasing bread's shelf-life and enhancing sensory qualities using a combination of packaging techniques focusing on the addition of natural preservatives.

Conventional bread packaging methods and their limitations

The most common packing material used in the pre-modern era was parchment paper with paraffin wax and wax paper. In many parts of the world, wooden boxes, cane baskets, China pots, and metal cans are still used for packing bread. Today, the food industry uses low-density polyethylene and polypropylene bags for bread packaging. The primary function of packaging is to protect

food from contaminants (Pal *et al.*, 2019). The usage of multilayered packing films shows a highly effective barrier against intrinsic and extrinsic contamination factors. Traditional techniques including MAP, irradiation, aseptic packing, artificial preservatives, and organic acids like propionic acids protect baked products from microbial infection. The most common packaging material used in MAP techniques to pack bread is polyamide, Polypropylene (PP), Ethylene vinyl alcohol (EVOH), Polyvinylidene chloride (PVDC), Low-density polyethylene (LDPE), and High-density polyethylene (HDPE). Different polymer matrices such as LDPE/nylon, PVDC-coated PP, and Polyethylene (PE) are combined to produce medium and high gas barrier films, and sometimes ionomer is replaced with PE (Smith *et al.*, 2004; Jideani and Vogt, 2016). In the UK, a combination of oriented polypropylene films with the acrylic coating is used instead of LDPE films coated with aluminum for higher oxygen and water vapor barrier (Smith *et al.*, 2004). A study discussed

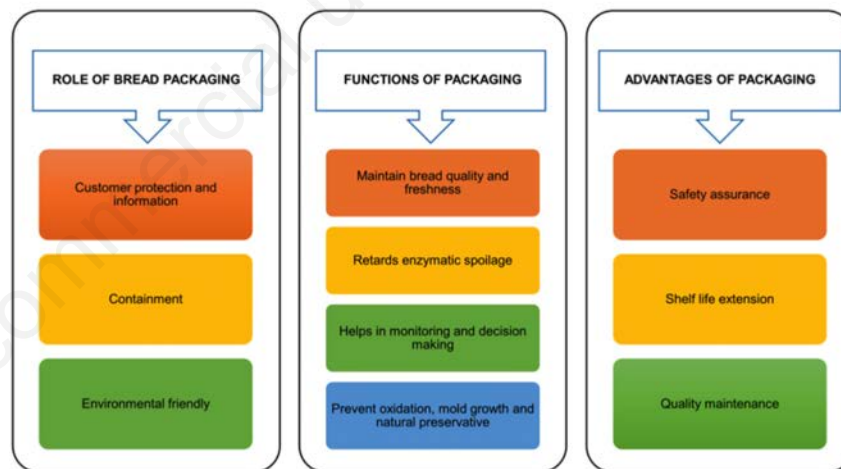


Figure 1. Role, functions and advantages of packaging.

Table 1. Main functions of Active and Intelligent packaging.

Components of Active packaging	Components of Intelligent/Smart packaging
- Consists of various chemical components that have huge anti-fungal/microbial properties, incorporated in the form of sachets/films.	- Packaging material capable of indicating time temperature for identifying contamination
- Incorporating ethylene scavengers/ethanol emitters/oxygen absorbers in packaging sachets/films	- Food products with sensors/indicators in controlling the micro spoilage.
- Packing contains inbuilt heating or cooling mechanism according to the functions and requirements.	- Shock indicators for identifying physical damage to food products
- Moisture absorbing /carbon dioxide emitters in the form of pads and sheets in food products	- Food packaging sensor that distinguishes between allergen and non-allergen
- Sachets /films made to remove/absorb odor and flavor	- Leakage indicators with microbial growth sensors.
- Contaminants causing food spoilage organisms are controlled in the form of sachets, films, and coating.	- Identification of indicators /sensors for contaminants.

the migration of chemicals from packing materials made from Perfluorooctanoic acid (PFOA), Hexafluoropropylene oxide dimer acid (PFOS), Perfluoro octane sulfonic acid (HFPO-DA), and per- and Polyfluoroalkyl substances (PFASs) to foods. These materials are primarily used in the baking industry due to their oil-repelling properties as food contact materials (FCMs) like silicon trays, paper, and boards. The research is still unclear regarding PFAS and their potential precursor's risk assessment on their exposure and quantification of the impurities which might migrate from FCM into food products, but it is clear that these chemicals are used in bread packaging material having a strongly fluorinated carbon chain, might cause a health risk and several illnesses to humans. The use of PFAS in FCMs necessitates extensive investigation, including a toxicity study to determine the danger to human health (Bokkers *et al.*, 2019).

Current trends in bread packaging

Modified atmospheric packaging

Primary gases involved in MAP are CO₂, and nitrogen, which may be utilized separately or combined in food packaging. MAP works generally by displacing air with a gas combination composed of 60% CO₂ and 40% nitrogen. CO₂ used at high levels aids in removing oxygen from the headspace and lowers the oxygen concentration in the headspace of packages to less than 1% (Smith *et al.*, 2004; Alhendi and Choudhary, 2013). CO₂ dissolved in water forms carbonic acid, which lowers the pH of food products and functions as an antimicrobial agent. It eliminates mold and yeast growth by using the combination of gases at different concentration. Nitrogen is an inert gas with no antibacterial properties; rather, it is used to avoid food package collapse and oxidative rancidity. MAP is better at retarding yeast and mold growth than bacteria. MAP can delay mold growth and extend shelf-life but cannot indefinitely prevent contamination (Upasen *et al.*, 2018). The combination of the MAP technique with mixing O₂ absorbers and mustard oil vapors inhibited the toxic organisms in wheat and rye bread by extending the shelf life to 30 days with possible implications for bread quality improvement (Suhr and Nielsen, 2005). The use of MAP in conjunction with active and intelligent packaging improves the shelf-life, nutritional characteristics, and safety of food products (Abdullahi, 2018). Alternative to MAP, Wheat dough with calcium propionate increased the shelf-life of bread to 26 days at 22 – 25 °C; storing at

low temperatures such as 15 – 20 °C increased the shelf life to 52 days; soy bread's shelf life was increased by at least four days (200%). In addition, adding 0.1% potassium sorbate produced mold-free bread, and the shelf life extended up to 21 days (Alhendi and Choudhary, 2013; Jideani and Vogt, 2016; Soltani Firouz *et al.*, 2021). Consumers are most concerned about the addition of preservatives to foods or the treatment of foods with radiation to increase their shelf life (Alhendi and Choudhary, 2013). The US Food and Drug Administration states that the gases used in MAP are thought to be natural and aren't always need to be disclosed on food product labels. However, there are several limitations in using chemical preservatives due to their health hazards in humans. In contradiction, an anaerobic neurotoxin pathogen, such as *Clostridium botulinum*, a gram-positive bacterium, poses a food safety risk to most of the bakery items and causes illness to humans when packed using MAP. Similarly increased CO₂ levels in the packaging environment had little effect on lactic acid bacteria or other anaerobic microbes. When compared to gram-positive bacteria, gram-negative bacteria have been shown to suppress bacteria at a higher degree (Alhendi and Choudhary, 2013).

Active packaging in bread

Active packaging is defined as a deliberate incorporation of unique components such as oxygen scavengers, moisture absorbers, antimicrobial agents, essential oils, sachets/films, containing spices and herbs, freshness enhancers, ethanol emitters, antioxidants etc., to a packaging material or in the package's headspace to improve the package system's quality and enhance the shelf life (Ahmed *et al.*, 2017). Active packaging preserves the food from extrinsic factors such as heat, UV rays, oxygen, water vapor, and pressure by effective packing techniques. Therefore, there should be continuous interaction between the active package material and food to control the microbial spoilage leading to increased shelf-life of bread and assured safety of the packed bread (Sharma *et al.*, 2021). Active packaging, comparing to MAP is effective in preserving flavor and sponginess while eliminating hardness and crumbliness (Gutiérrez *et al.*, 2011). It also improves the preservation process and lowers packaging costs when compared to traditional polymer packaging (Majid *et al.*, 2018). Table 2 illustrates the most common components used in MAP and active packaging techniques for extending the shelf-life of bread.

Antimicrobial packaging

Antimicrobial packaging, a type of active packaging, incorporates antimicrobial agents into packed foods to improve food quality and safety during storage and transit (Qian *et al.*, 2021). This packaging assists in the reduction or prevention of microbial development in bread by combining antimicrobial additives into packaging materials to extend shelf-life (Jideani and Vogt, 2016). Essential oils and biodegradable films enhanced with cinnamon and clove oils are often used as antimicrobial agents, providing antifungal activity against *Penicillium spp.* and *Aspergillus niger* (Sachdeva *et al.*, 2017). The traditional method of preventing bacterial development in bread is followed by adding synthetic preservatives such as calcium propionate and propionic acid to bread products according to food regulations (Lewis, 2015). However, post-baking processing steps are a source of microbial contamination in bread. Also, customer demand for natural preservatives rather than synthetic preservatives is rising mainly due to their immense range of characteristics such as antifungal, antiviral, antioxidant, and effectiveness against pathogenic organisms. Antibacterial compounds from plants and probiotic organisms are a natural source of antimicrobial agents. Many studies have revealed that infusing natural products into active packaging decreased microbial contamination. Hence, essential oils derived from clove, cinnamon, eugenol, mustard, lemon grass, oregano, thyme, garlic essential oils, grape seed extract, spices, metabolites from probiotic bacteria, and naturally occurred organic acids are used in the active packaging of food products as they show antibacterial, antifungal, antioxidant and anticarcinogenic effects (Tharmaraj and Shah, 2009; Mahmud and Khan, 2018). Similarly, probiotic bacteria, spices, and herbal extracts also have numerous health benefits (Yang *et al.*, 2014).

The increased addition of antimicrobial agents to the polymer matrix is of great concern, since it alters the attributes of packaging materials such as tensile strength, tearing strength, stiffness, and oxygen and gas permeability, which in turn affects the processing, physical, chemical, and optical properties of polymers (Jideani and Vogt, 2016). Antimicrobial and antioxidant-enhanced films and coatings on food surfaces plays a vital role in retarding fungal growth and slowing the oxidation rate. It results in preventing rancidity, increasing shelf life, enhancing the mechanical strength of the packaging and maintaining the sensory attributes of the packaged food

(Abdullahi, 2018). For instance, when used as an antimicrobial agent in rye bread, Allyl isothiocyanate inhibited the growth of *Aspergillus* and *Penicillium spp* was primarily effective against gram-negative bacteria. Active packaging containing antimicrobial-agent delivering to packed foods has the potential to significantly contribute to satisfy the demand of current needs (Rasooli, 2007).

Ethanol emitters

Ethanol emitters are effective in slowing down mold growth in baked goods such as rye bread as the sachets obtained from them have antifungal, antioxidant, and antimicrobial (Upasen *et al.*, 2018). Combining the impact of an ethanol emitter with oxygen an absorber is a replacement for chemical preservatives, has shown to prolong the shelf life of sliced bread (Latou

et al., 2010). Ethanol plasticizes the protein network of breadcrumbs, especially in combination with essential oils to prevent staling (Melini and Melini, 2018). Oxygen absorbers with ethanol vapor has an effective anti-staling and antimicrobial property by denaturing the yeast and mold's protein network in Chinese steam bread even treated at low concentrations (1% v/v) (Sheng *et al.*, 2015).

Table 2. Most commonly used MAP and active packaging techniques for shelf-life extension in different kinds of bread products.

Package types	Application	Bread types	Gas composition/ Essential oil used	Active function	Reference
Modified Atmospheric package	Oxygen, Nitrogen, Carbon dioxide	Sliced bread, soya bread, barbari bread, sangak bread, hot dog bread, gluten-free bread, prebaked pizza bread, rye bread, pita bread, barbari bread, rye wheat bread, and sangak bread. hot dog, gluten-free pizza bread, prebaked pizza dough	50% CO ₂ , 50% N ₂ 60% CO ₂ and 40% N ₂ 30% CO ₂ and 70% N ₂ 60% CO ₂ , 50% N ₂ 100 % CO ₂ CO ₂ +N ₂ +Mustard essential oil	Fungistatic activity, antimicrobial bactericidal activity retards enzymatic spoilage	(Alhendi and Choudhary, 2013; Dobrucka and Cierpiszewski, 2014; Chaste <i>et al.</i> , 2019)
	Essential Oils	Sliced bread and hot dog	Oregano, marjoram, clary sage, allyl, benzyl, and phenyl isothiocyanates oil, thyme, cinnamon, garlic, lemongrass, sodium chloride and mint oil, mustard oil+MAP, garlic oil, clove, lemongrass, citrus peel (orange)	Antifungal, Antimicrobial, Anti-aflatoxigenic, Anti-sporulation, Anti-toxicogenic, Anti-cancer, Anti-viral, Anti-inflammatory	(Suhr and Nielsen, 2005; Sachdeva <i>et al.</i> , 2017; Gavahian <i>et al.</i> , 2020)
Active packaging	Ethanol and essential oil	Bread, rolls, buns, gingerbread cake.	Ethanol and mastic oil. With essential oils <i>Pistacia lentiscus</i> (L.) var. chia (Durham)	Antioxidant, Antimicrobial, Flavoring agent, Anti-mold, Anti-staling	(Dobrucka and Cierpiszewski, 2014)
	Oxygen absorbers and ethanol emitters	Sliced wheat bread, Chinese steam bread, Ciabatta bread	ATCO commercial oxygen absorber with Ethical commercial ethanol emitter.	Antibacterial, Anti-fungal, Antioxidant	(Garcia <i>et al.</i> , 2019)
	Oxygen absorbers and essential oil emitters	Wheat and Rye bread	Iron, as well as mustard, cinnamon, garlic, and clove extracts. oregano, thyme, bay, and clove essential oils	Antioxidant, Antimicrobial, Flavoring agent, Antifungal, Antibacterial	(Carpena <i>et al.</i> , 2021)
	Moisture absorbers	Wheat bread	Polymer films, Fructose, Sorbitol, Cellulose, Calcium oxide sachets, Silica sachets and gels, Potassium chloride, Potassium carbonate, Bentonite	Antimicrobial, Antibacterial, Antifungal	(Gaikwad <i>et al.</i> , 2019)
	Antimicrobial films	Sliced bread, Gluten Free bread	Cellulose acetate containing 2-4 %sodium propionate with LDPE., PP and wax paraffin containing cinnamon EO coating., Gliadin films /cellulose polymer with 5%cinamaldehyde (Repacked with LD-PE, Mustard oil, sodium and calcium propionate, potassium sorbate, propionic acid, probiotic bacteria, spices, and herbal extract	Antioxidant, Antimicrobial, Flavoring agent, Antifungal, Antibacterial	(Tharmaraj and Shah, 2009; Dobrucka and Cierpiszewski, 2014; Yang <i>et al.</i> , 2014; Arshad and Batool, 2017)

Essential oil emitters

Essential oils are food preservatives with a wide range of antimicrobial activity due to their presence of active and natural constituents such as terpenes, terpenoids, carotenoids, coumarins, and natural curcumin. Their progress in food application is fast and enormous since it holds GRAS (Generally recognized as safe) status by regulatory bodies, which means the food additives with this status are fit for human consumption or their intended use. In addition, they are a better replacement for conventional synthetic preservatives (Pandey *et al.*, 2017). A study observed that Cinnamon-infused active packaging was a good and effective solution for preserving the sensory and micro properties of gluten-free loaves (Jideani and Vogt, 2016). Oregano essential oil inhibits yeast and mold growth in sliced bread. Essential oil from marjoram and clary sage is also effective, but due to their strong odor, it was not well-accepted (Passarinho *et al.*, 2014).

Essential oils are effective antimicrobial agents against bacteria, including *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Listeria monocytogenes*, and *Salmonella enterica*, especially when combined with factors like low water activity, low pH, chelators, mild heat, and food additives like sodium chloride, sodium nitrite, or nisin. clove, fennel, cypress, lavender, thyme, pine, and rosemary are some of the most commonly utilized essential oils (Gómez-Estaca *et al.*, 2010). A study showed that essential oils such as thyme, clove, oregano, cinnamon, and lemongrass in the vapor phase were highly efficient against *Aspergillus niger* and a safe and suitable alternative to chemical preservatives in the treatment of bread without affecting the sensory characteristics (Cisarová *et al.*, 2020).

When tested with different packaging materials to preserve the white bread *in-vitro*, incorporation of poly (3-hydroxybutyrate-co-4-hydroxybutyrate) films in thyme oil 30% w/v microencapsulated eugenol, and citral antifungal essential oil sachets showed maximum inhibition against yeast and mold. It also enhanced inhibition of the mold growth to prolong the life of bakery products considerably when compared to control (Ju *et al.*, 2020). While Essential oils have a variety of beneficial qualities, including antibacterial and antioxidant capabilities, further research is needed to determine their safety (Haro-González *et al.*, 2021). Regulations on essential oils include evaluations of their uses in flavorings, cosmetics, and animal nutritional additives (Barbieri and Borsotto, 2018).

Food producers have faced substantial challenges in producing safer foods with longer shelf life while sustaining nutritional benefits along with sensory attributes. Preserving the functional qualities of essential oils as food preservatives without affecting the taste of food or growing consumer demand remains a challenge for many food manufacturers. A bakery industry must maintain the baked goods with high safety and secured products for its consumers without compromising sensory parameters such as taste, color, flavor, texture, and overall acceptability. The addition of essential oil as a preservative over the organic acid such as sorbic and propionic acids has gained interest among consumers worldwide due to the antibacterial efficacy of essential oil against foodborne pathogens such as *Penicillium spp.*, *Aspergillus spp.*, *Escherichia coli.*, and *Staphylococcus aureus*, and extending the shelf life of the baked products (Tzortzakakis, 2009; Haro-González *et al.*, 2021).

Oxygen absorbers with ethanol and essential oil emitters

Oxygen absorbers, ethanol emitters, ethylene absorbers, and preservative releasers retard microbial growth during storage. Ethanol emitters and oxygen absorbers could replace chemical preservatives. The O₂ absorbers extend the shelf life of white bread packed in a polypropylene bag from 5 to 45 days (Smith *et al.*, 2004). Concept of integrating active packaging with a superior packaging material with effective barrier such as polyethylene terephthalate-silver oxide/ Low-density polyethylene (PET-SiOx/LDPE) has extended the shelf-life of sliced bread (Harrop, 2012). Antimicrobial properties of spice-based essential oils such as mustard oil, oregano, basil, clove, carvacrol, thymol, and cinnamon are also studied. Oregano essential oil is a moderate preservative that utilizes an O₂ absorber in conjunction with an ethanol emitter has substantially extended wheat bread's shelf life to 30 days as per sensory and microbiological data (Suhr and Nielsen, 2005).

Moisture absorbers

The accumulation of moisture inside bread can lead to bacteria and mold growth decreasing food quality and making it inedible. Therefore, moisture absorbers are used to regulate the water content and function of bread products as preservatives. These absorbers are hygroscopic, absorbing and retaining water from their external surroundings. Moisture absorbers are two types, relative humidity absorbers that

absorb water in the headspace of packaging (desiccants) and absorbers that suck the water directly from the food that is often in the shape of pads and sheets placed beneath the food products. Commercially, moisture absorbers are made using polymeric films; fructose, cellulose, sorbitol are used in organic absorbers, whereas calcium oxide sachets, silica gels and sachets, potassium chloride, potassium carbonate, and bentonite in inorganic absorbers (Gaikwad *et al.*, 2019).

Carbon dioxide emitters

High CO₂ levels in bread products (10 – 80%) can effectively arrest microbial growth to act as a food preservative. When CO₂ is flushed into a packaging system in the form of active/intelligent packaging, it creates a partial vacuum in the process of soluble gas stabilization (SGS) (Vilela *et al.*, 2018).

Future perspective of bread packing

Intelligent packaging

Intelligent packaging is a revolutionary and innovative technology that monitors changes in both the interior and exterior surroundings and transmits the status of the packed food items about the interaction of the packaging system to support decision-making. The process involved in intelligent packaging is the system that continuously monitors the integrity and effectiveness of active packaging (Ghaani *et al.*, 2016). It includes biosensors, temperature regulators, ripeness monitors, time-temperature indicators, and radio frequency tag monitors, which facilitate deciding on increasing the shelf-life and monitoring the quality and safety of the product. Intelligent packaging is so-called because it can connect with humans and warn about packaging flaws. Radio frequency identification tags are particularly promising since they employ radio waves to track food products and convey product information to consumers (Pramatari *et al.*, 2010).

Time temperature indicators

These indicators are intelligent/smart packaging that enhances the food quality and safety. They are a simple device that provides information about the time-temperature change of food products. When food packaging is tampered with or contaminated, it undergoes an irreversible physical, chemical, or biological change that manifests as physical deformation (Kuswandi and Jumina, 2020; Young *et al.*, 2020).

Radio frequency identification tags

Radio frequency identification tags incorporate tags or transponders (information carriers), readers (receivers), and computer systems (software, hardware, networking, and database) to reduce and minimize food waste, empty shelves, theft, fraud, and recalls of spoiled or harmful items in the food supply chain (Harrop, 2012), radio frequency identification (RFID) tracks goods wirelessly and provides the product information about the food quality (Pramatari *et al.*, 2010). These devices can be easily mounted on any packing commodity such as cartons, boxes, pallets, or containers and can be easily traced and readily detected. These tags are visible even from a distance of several meters. RFID tags with pH, oxygen, temperature, humidity, and gas sensors, among other sensors, are being employed in MAP and other novel packaging techniques to detect the freshness and volatile components of diverse food products (Fuertes *et al.*, 2016).

Oxygen and carbon dioxide indicators

The food, flushed with gas like carbon dioxide or nitrogen, is often applied in MAP packaging. These indicators are based on luminescence, calorimetric redox dye, and oxygen binding complexes generate a color change in contaminated food resulting in an enzymatic or chemical reaction (Chaste *et al.*, 2019; Garcia *et al.*, 2019). According to a research, the interior of ciabatta bread packets included an oxygen sensor linked with ethanol-emitting sachets before gas cleansing and sealing, monitored oxygen continuously without any disruption for a longer time (Hempel *et al.*, 2013).

Freshener indicators

Freshener indicators tracks and assess the freshness of packaged foods. If there is an undesirable change to the food's freshness, the indicators activate the following changes:

Color changes due to changes in titratable acidity, microbiological changes, such as the formation of toxic compounds, unpleasant odor, and pH changes.

Lipid and pigments oxidation produce flavors/odors, discoloration, and other adverse chemicals/biological reactions (Mills, 2005).

Biosensors

Biosensors are small devices that detect, record and transmit changes in food products via biochemical reactions. They are constructed using a two-part system: a biological recognition component (such as enzymes, nucleic acids, or other ligands) that aids in the high specificity binding of the

target analyte, and a unit for signal conversion (transducer such as calorimetric, optical, or electrochemical). Currently, existing biosensors are mostly based on the detection of pathogens and toxins, as well as contaminants (Park *et al.*, 2015).

Limitations of traditional methods are due to the expensive costs, tedious sampling procedures, long wait times, and the need for highly skilled and competent personnel. Studies have shown that biosensors were the most efficient option for accurately identifying contaminants such as toxins and pesticides with high specificity, especially when dealing with complex food matrices, at a cheap cost, and in an appropriately reliable manner (Fuertes *et al.*, 2016; Bunney *et al.*, 2017). Biosensors are most commonly used to assure product quality and safety of a food product, to detect physical, chemical, biological, and surface contamination in products and production lines, and to eliminate cross contamination-related issues. These tools may be used to separate high-quality products from low-quality ones on or at the manufacturing line, reducing the amount of time and money spent on production (Tetyana *et al.*, 2021).

Colorimetric biosensors are used mainly to detect the presence of pathogens in food products through the action of *N*-[(2-tetradecanamide)-ethyl]-ribonamide (TDER), microelectromechanical systems, heterobifunctional crosslinkers, and immobilized antibodies (Radke *et al.*, 2004; Kim *et al.*, 2015). While bacterial contamination is detected via biosensors, removal of contaminated products may require the development of a separate mechanism.

Nano packaging

Nanomaterials are effective as packaging materials due to their large surface area, they can increase barrier properties against gas permeation, ultraviolet permeation, moisture, and volatile compounds. They are used in intelligent and active packaging because of their antimicrobial activity. Challenges include removing nanoparticles from packaging materials, which might cause environmental harm, and oxidative stress in people as a result of nano components migrating from the packaging material into the food (Soković *et al.*, 2010).

Clove bud and oregano essential oil combined with methylcellulose generated a nano-emulsified edible film that lowered yeast and mold levels by a substantial amount in sliced bread (preserved for 15 days). Droplet size reduction even showed a pronounced effect in increasing the antimicrobial properties (Schifferstein *et al.*,

2021). However, a few critical attributes should be verified and validated before using nano packing techniques in foods, such as quality and safety concerns of the food, cost-effectiveness, simplicity and ease of use, reproducibility across a wide range of operations, environmental safety, easy disposal, and packaging by meeting the regulatory standards (Otoni *et al.*, 2014).

The freshness of the food is detected using a Nano sensor that is highly sensitive to gases, such as an electronic tongue attached to the food packing material. A few Nano sensors incorporated in packaging has various applications such as of pathogens and toxins detection, consumer likes and dislikes, temperature and moisture variation (Fuertes *et al.*, 2016). However, these nanoparticles, on the other hand, are dangerous and harmful to humans and the environment because of their smaller size, which allows them to infiltrate human cells and target the immune system. The smaller the particle, the faster it absorbs and distributes in the metabolic system. Several standard regulations allow the use of nano packaging techniques for food to decrease the risk of harm to consumers and the biological system. These regulations should be followed and maintained properly (Pradhan *et al.*, 2015).

Discussion and Conclusions

Improved packaging techniques have evolved significantly, providing new possibilities in the food industry's development. The area of active and intelligent packaging materials is making significant progress, and it should be developed in tandem with the search for environmentally beneficial products. To improve product safety and extend the shelf-life of bakery items, the HACCP (Hazard analysis and critical control point) system should be used in the food industry to assure food safety (Marques *et al.*, 2012). Changes in consumer preferences are increasing, particularly in using natural preservatives, which have led to new packaging innovations, developments in new technologies, and reducing bread wastage. In addition, novel packaging techniques play a vital role in the food safety management system by reducing food-borne illnesses and recalls. MAP and active packaging have long-term benefits in delaying the fungal contamination. However, the individual constituents in the essential oils are insufficient to prevent all kinds of physical, chemical, and micro contamination in the food. It is the fundamental hurdle of employing them as an alternative to the

synthetic preservative in the foods as the antimicrobial activity eliminates the fungal activity depending on the food matrix and technology employed.

Additional study is needed to assess, evaluate and analyze the synergistic and antagonistic effects of essential oils and food components in all food matrixes to assess the antimicrobial impact and, if necessary, lower the dosage of EO to achieve the desired effect when commercially administered. Currently, global food packaging standards are not defined. With considerable differences in the specifics, future food safety and security rely on integrating diverse technical advancements of novel food packaging techniques, involving a complete analysis of food-package interactions based on legislative concerns, making it critical to assess and quantify a risk-based study of various innovative food packaging strategies used across the food chain to ensure the quality and safety of food products. To achieve clean label and green technology in the future, the possible usage of MAP, active and intelligent packaging components, as well as their safety tests with diverse food matrices, must be investigated. Future considerations must include performing food safety risk assessments of all innovative packaging techniques to satisfy legal, regulatory, and statutory requirements.

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