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A Review on Nano-Food Packaging: An Untapped Revolution in Food Packaging

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Authors' contributions

This work was carried out in collaboration among all authors. Author RS designed the idea, carried out literature work, and wrote the whole manuscript. Author MC conducted an internet search for the document. Author ESC encouraged, supervised, assessed, evaluated the article, and corrected all drafts. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Spoilage of food is a worldwide concern because of poor faulty packaging material. Today the evolution of nanotechnology in the food industry provides several benefits in food preservation, food processing, and food packaging. Nano packaging has found many applications in the food industry. Nano packaging of food provides many benefits such as oxygen (O_2) scavengers, moisture scavengers, antimicrobial, gas barrier properties, strength, flexibility, keeping an eye on freshness, etc. These nanomaterials help to increase the shelf life of food, and maintaining the quality without causing any alteration is a primary concern. Nano packaging made it possible to transport food globally by increasing the shelf life of food products. Nano food packaging, however, is still in the fetal stage; therefore, this review crisps the present status and recent advancement of this technology. Furthermore, address the toxicity of nanoparticles (NPs) in food packaging and safety concerns. The pros and cons of this novel technology will describe its usefulness and appropriateness in the food packaging industry.

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1. INTRODUCTION

Food packaging is defined as the process of enclosing the food for containment, storage, transportation, distribution, retailing, and fulfilling the consumer's needs with minimal cost. Packaging plays a significant role in the preservation and marketability of any product and ensuring its safe delivery to the consumer whilst providing essential information regarding the product [1]. Packaging provides a shield to food products protecting them against damage from any physical, chemical, and biological changes like spilling, leaking, or contamination by microorganisms, or toxins (Fig. 1). In earlier times, food was consumed instantly as it was found. Natural products like leaves, shells, animal hides and organs were used when containment of food was needed. As humans started traveling to new places, their need for storing food increased. As discoveries and inventions were made, packaging also changed with that. Present packaging has changed a lot and we are using complex materials and processes in making modern packaging what we use nowadays [2]. In today's advanced commercial food industry, there are very few products that are being sold unpacked, and hence food packaging plays a major role in the handling and transporting of food products to the end of the supply chain. Packaging plays a prime role in preserving food products and beverages and minimizing the deterioration of health and quality of the packed food products caused by exposure to the external environment [3]. According to the World Packaging Organization (WPO), 25% of food products are wasted just because of faulty and improper food packaging [4]. Furthermore, around one-third of the food products all over the world are wasted and lost because of poor and inadequate food packaging [5]. Food packaging is critical for every single food industry as it is a link between producers and consumers. In today's society, people are more than ever aware of fresh, healthy, nutritious, minimally processed, and hygienic food with standard labels. Packaging is a major issue for the food industry worldwide to fulfill the rising demands for healthy, safe, and fresh food as well as meet safety standards. Hence continuous developments and innovations in the packaging sector are vital for the food industry [6].

This review highlights the active, improved, and intelligent nano packaging materials that extend the shelf life of food products. Furthermore, studying the toxicity of nanomaterials in the human body and ecosystems is a primary concern that has been discussed in this review. Moreover, this review as to bridge the gap required for the coming research opportunities in the future.

1.1 Food Packaging

Food packaging is a global concern as its internal heterogeneity affects the food product. Food quality, shelf life, and microbial contamination are the major problems faced by the food industry worldwide due to the increased interaction between food and packaging material [7]. There is an increased demand for fresh food, with a prolonged shelf life and premium quality. To maintain such applications, an emerging force for the evolution of new packaging material is required. Therefore, manufacturers are looking for packaging materials that can be transparent and tamper-resistant, compatible with the food product, provide ultraviolet (UV) protection, limit ingress of gases, extend the shelf life, be free from microorganisms, and be disposed of or recycled easily minimizing environmental damage while remaining cost-effective simultaneously [8]. [9]. Nanotechnology is emerging as a boon for the food packaging industry for such applications [10].

1.2 Nanotechnology in Food Packaging

Nanotechnology is a technique introduced by Richard Feynman in 1959 and later in 1974 term "nanotechnology" was coined by Norio Taniguchi. The term "nano" simply means tiny, micro, and very small in size. The particle size is as small as the diameter of the human hair. Nanotechnology is a de novo technique involved in the manipulation, fabrication, and characterization of molecules ranging from 1-100 nm in length [11]. In both developed and developing countries, the arrival of nanotechnology has a prominent picture in multidisciplinary areas of research such as biological, chemical, physical, and engineering [12]. In 2020, nanotechnology robust worldwide economy by $3 trillion [13]. Recently, the increased demand for nanomaterials in 2015, especially in the food industry generated revenue of $2.5 million and in 2022 it is expected to reach $9 million [14]. The advent of nanotechnology in food packaging revamps the whole food industry to create and design innovative packaging materials for the welfare of consumers [15]. In contrast with macroscale material, nanomaterials have larger surface activity, area, and volume as well as better physical, optical, electronic, and chemical properties. Just because of their nano size, nanotechnology in food packaging expanded in the last 10 years due to the boundless advantages in extending the shelf life of food products, blocking environmental stressors, heat, light, dust, volatile, and maintaining the quality and safety of food [16].

-Heterogeneity in nano packaging materials

Numerous types of nanotechnology-based food packaging materials that are used in the food industry comprise active packaging, improved packaging, and intelligent packaging.

2. ACTIVE PACKAGING

Active packaging means packaging material directly acts on the food products and their environment to extend the shelf life and certify the safety and quality of the packed food. According to European regulation (no 450/2009), active packaging means *"deliberately incorporating components that would release or absorb substances into or from the packaged food or the environment surrounding the food"* [17]. Therefore, active packaging is an excellent food packaging that can maintain the parallel relationship between the food and its surrounding, and keep the food quality simultaneously [18]. The basic fundamental principle of active packaging technology concept that could release (emitters) and absorb (scavengers) substances inside the wrapped food and its food environment [19]. However, the emitters release antioxidants, antimicrobial substances, carbon dioxide (CO_2), ethylene (C_2H_4) or ethanol (C_2H_5OH), and flavors [20]. These active compounds are helpful to maintain favorable conditions inside the packaged food. It also ensures the quality of storage and stable conditions for increases in the shelf life of food [21]. On the other hand, scavengers act to remove the unwanted substances from the surroundings of the packed food such asCO_2, moisture, oxygen(O_2), C_2H_4, and odor [22]. Additionally, there is no direct association between the food and the scavengers, but it helps to enhance the condition of food inside the packet as well as boost its shelf life [23]. Various types of active packaging are used commercially in the food industry (Fig. 2) [24], [25], [26], [27], [28]. In comparison with the traditional packaging system, active packaging extends the shelf life of the food and preserves the quality, and standard during the reaction between the environment and the food product [29]. Therefore, active packaging appraises to be exemplary packaging in the food industry [30].

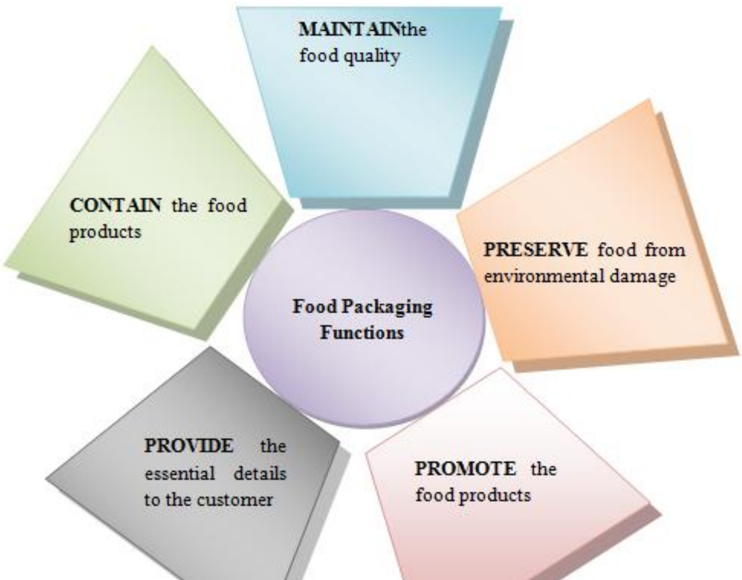

Fig. 1. Food packaging functions

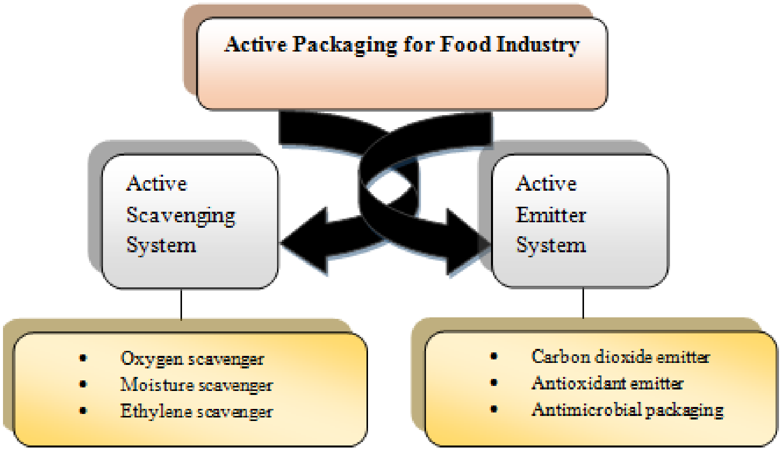

Fig. 2. Various types of active packaging used for the food industry

2.1 Oxygen Scavengers

O_2 access to the food package is most often an aspect that reduces the shelf life of food products [31], [32]. Oxidation of food results in nutrient losses, rancidity, browning, color lessening, off-odors, off-flavor, and growth of aerobic microorganisms which affects the quality [33], [34], [35], [36].O_2 scavenging agents used in food packaging are iron (Fe) powder, ferrous oxide (F_eO), ascorbic acid ($C_6H_8O_6$), tocopherol ($C_{29}H_{50}O_2$), sulfite (SO_3^{2-}), titanium oxide(TiO_2), glucose ($C_6H_{12}O_6$) oxidase, and C_2H_5OH oxidase [37], [38], [39]. O_2 scavenging mechanism based on substances absorbs O_2 based on iron compounds particularly placed on sachets. Due to the high sorption capacity of iron compounds, it is the most effective method to extend the shelf-life of food in the market. These iron compounds absorb O_2 available in the market labels present inside the packet, bottle caps, or integral parts of the packet [40]. In Japan, Germany, USA, Switzerland, and FinlandO_2 scavenger trade is presumed to gain 2.41 billion USD by 2022 and from 2017 to 2022 the compound annual growth rate (CAGR) is 5.1% [41], [42]. In addition, for example, a study conducted that $C_6H_8O_6$-basedO_2 scavenger sachets were developed by using activated carbon (C) and sodium L-ascorbate($C_6H_7NaO_6$) to increase the shelf life as well as reduce the microbial growth in meatloaf [43].

2.2 Moisture Scavengers

Moisture and humidity are major factors that are responsible for food spoilage [44]. Active moisture scavengers are moisture absorbers and desiccants and they are hydroscopic in nature or attract water molecules from the surrounding [45], [46]. The moisture absorber can be used in the form of sachet, pads, blankets, and sheets (Fig. 3) applied under fresh food products such as fish, fruits, vegetables, poultry, and meat in the various packaging system. Such absorbing pads are composed of linear low-density polyethylene, low-density polyethylene, and polyethylene-laminated [47]. On the other hand, desiccants are used in the form of sachets, bags, and pads put into the headspace of the food package. Some examples of desiccants are clays, silica (SiO_2) gel, zeolite ($Na_2Al_2Si_2O_8.xH_2O$), cellulose $(C_6H_{10}O_5)_n$ fibers, sodium chloride (NaCl), magnesium sulfate ($MgSO_4$), calcium oxide (CaO), and sorbitol ($C_6H_{14}O_6$) [48].

2.3 Ethylene Scavengers

C_2H_4 is a plant hormone that plays a key role in shortening the postharvest life of fresh food during storage. C_2H_4 accelerates the ripening resulting in softening, and chlorophyll($C_{55}H_{72}MgN_4O_5$) degradation leads to the deterioration of fruits and vegetables [49], [50].C_2H_4scavenging agents used in food packaging are$Na_2Al_2Si_2O_8$, potassium permanganate ($KMnO_4$), silver nitrate ($AgNO_3$), palladium (Pd), propylene glycol($C_3H_8O_2$), polyethylene (C_2H_4)□, activated charcoal (C), SiO_2 geland aluminum oxide (Al_2O_3) [51]. Commercially, C_2H_4scavengers are sold in the form of the C_2H_4Control Power Pellet sachet, Bio-fresh packaging system, Retarder®, Ethysorb, Profresh, EvertFresh Green Bags®, and PEAKfresh® [52]. For example, chitosan ($C_{56}H_{103}N_9O_{39}$)-TiO_2 nanocomposite film is used to extend the shelf life of tomatoes for 14 days [53].

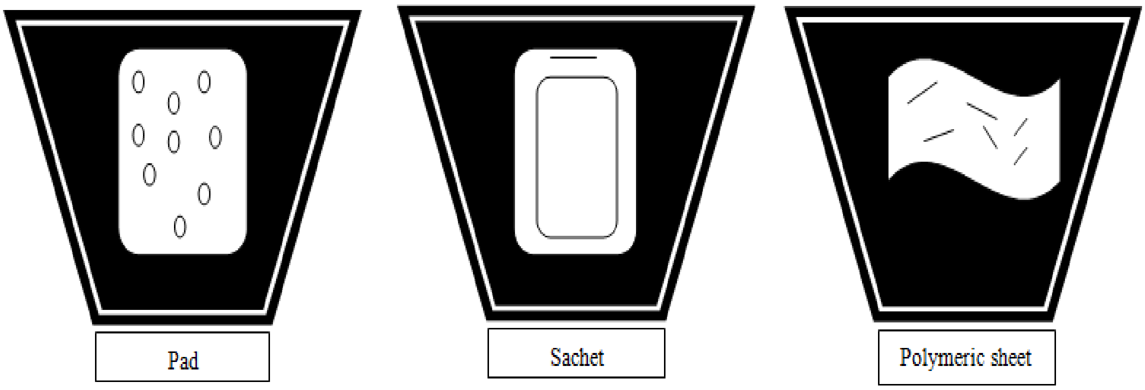

Fig. 3. Types of moisture absorbers for the active packaging system

2.4 Carbon Dioxide Emitters

CO_2 amount (60 to 80%) in the food packet inhibits microbial growth and therefore extends the shelf life of the food product [54]. Food properties such as the potential of hydrogen (pH), surface area, water, protein, and fat affect the solubility of CO_2 [55]. Generally used CO_2 emitters are sodium bicarbonate ($NaHCO_3$), sodium ascorbate ($C_6H_7NaO_6$), ferrous carbonate ($FeCO_3$), and $C_6H_8O_6$ [56]. The CO_2emitters mechanism is based onO_2 absorbed with the help of an O_2 scavenger and replaced with CO_2. In this mechanism bifunctional sachets are used which contain O_2 scavengers and CO_2emitters simultaneously which absorb O_2 and produce the same amount of CO_2 [57]. Commercially, CO_2 emitters have been sold in the form of FreshPax (India), Ageless (Japan), Freshilizer (Japan), Verifrais™ package, SARL Codimer (Paris, and France) [58]. For example, CO_2 emitters are used for the packaging of fresh food products such as meat, poultry, fish, cheese, and vegetables [59].

2.5 Antioxidant Emitters

Antioxidants in packaging material help to provide oxidative stability as well as to prevent microbial growth, discoloration, change in texture, nutritional losses, and off-flavor of the food products [60]. Antioxidant emitters used in food packaging are butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), $C_{29}H_{50}O_2$, polyphenols, essential oils (EOs), and plant extracts [61]. Furthermore, antioxidant packaging is used in the form of sachets, labels, coatings, and multilayers [62]. For example, a study conducted on natural antioxidants such as orange, lemon, and beetroot peels EOs has the potential to prevent rancidity during cold storage in sardines [63].

2.6 Antimicrobial Packaging

An antimicrobial packaging system has been designed to inhibit the growth of pathogenic microorganisms to extend the shelf life of food products [64]. Antimicrobial substances used in food packaging are bacteriocins, enzymes, natural extracts, NPs, fungicides, organic acids, and polymers [65]. Antimicrobial packaging can be used in the form of sachets or mats, incorporated, coated, immobilized, and modified on the surface of packaging material [66]. Commercially available antimicrobial packaging is AgIon®, Zeomic®, Microban®, and Irgaguard® [67]. For example, carvacrol ($C_{10}H_{14}O$) and thymol($C_{10}H_{14}O$) EOs was used to prevent the growth of *Botrytis cinerea* in strawberry without organoleptic changes [68].

3. IMPROVEDPACKAGING

The basic fundamental principle of improved food packaging by the fusion of traditional polymer materials into functional nanomaterials thus improving the packaging property [69]. It can provide great physical and mechanical properties such as high barrier quality, tough resistance to humidity, temperature, flexibility, and mechanical strength [70]. The combination of nanomaterials in food packaging has more advantages as compared to the traditional polymer packaging material [71]. The various types of nanotechnology-based packaging systems for improving quality and extend the shelf life of food products (Fig. 4) [72].

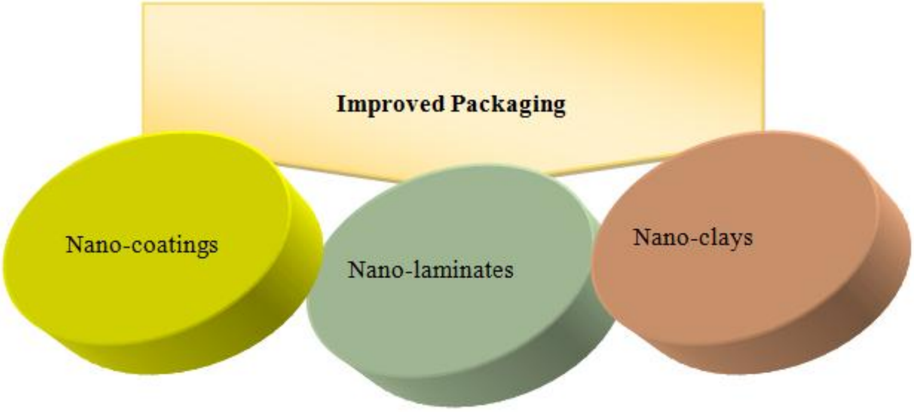

Fig. 4. Nanotechnology-based improved packaging system

3.1 Nano-Coatings

Nano-coatings or a film is a thin layers that can be used to wrap the food products and create a barrier to mass transfer. The coatings can act as a barrier to moisture, O_2, gas, etc [73], [74], [75]. Nano-coatings in food can be divided into edible and non-edible coatings. Edible coatings can be directly applied to food products, on the other hand, non-edible coatings act as a protective layer without being part of the food product [76], [77], [78]. Also, coatings in food can be applied in two ways either direct application of liquid solution or by using molten compounds [79]. NPs integrated edible coatings can be used in a variety of food products such as fruits, vegetables, bakery products, meat, fish, cheese, candies, and chocolates [80], [81], [82], [83]. Various types of packaging materials are used in edible coatings in the food industry (Fig. 5) [84], [85], [86].

3.2 Nano-laminates

Nano-laminates mean the deposition of one or more layers with materials whose dimension (D) is less than 100 nm per layer. Layer-by-layer assembly technique is the most dynamic method in which charged surfaces are attached with chemical bonding such as covalent bonding, electrostatic bonding, hydrogen bonding, charge-transfer interactions, and hydrophobic interactions. However, electrostatic bonding is the only method used in the food industry [87], [88], [89], [90]. Different types of adsorbing materials are used to create nano-laminated films such as polyelectrolytes (proteins, polysaccharides), lipids (surfactants, phospholipids), and colloidal particles (droplets, micelles, vesicles) [91], [92]. Additionally, there are two ways of using nano-laminates in the food industry that is spraying and dipping methods [93]. Also, it is possible to incorporate different active functional agents in nano-laminate films such as (antioxidants, antimicrobials, anti-browning agents, flavors, odor, enzymes, etc.) by extending the shelf life and quality of the food [94], [95].

3.3 Nano-Clays

Among the food packaging system, nano-clay was the first substance to appear on the market [96]. At present, it is the most widely used nanomaterial in the food packaging industry. Because it represents the excellent mechanical and barrier properties by embedding and incorporating the nano-clays into the polymer matrix [97], [98]. Nano-clays consist of a 2D structure, several microns long, and usually 1 nm thickness. Also, the synergism between the polymer matrix and the clays comes up with extends the shelf life, resists heat and shattering, and is lightweight [99], [100], [101]. Due to the presence of the nano-clays in a polymer matrix, the pathway of the diffused molecules is obstructed, increasing tortuosity, which results in the non-linear passage for O_2 and water vapors (Fig. 6) [102]. For example, in a study conducted by formulation of the film with agar and nano-clay (Cloisite Na^+), the result showed water vapor permeability, tensile strength, and the hydrophobic property of film due to the presence of clay [103]. One more study reported that the application of both nano-clay and silver (Ag) NPs showed antibacterial properties and extends the shelf life of shrimp (*Penaeus semisulcatus*) [104].

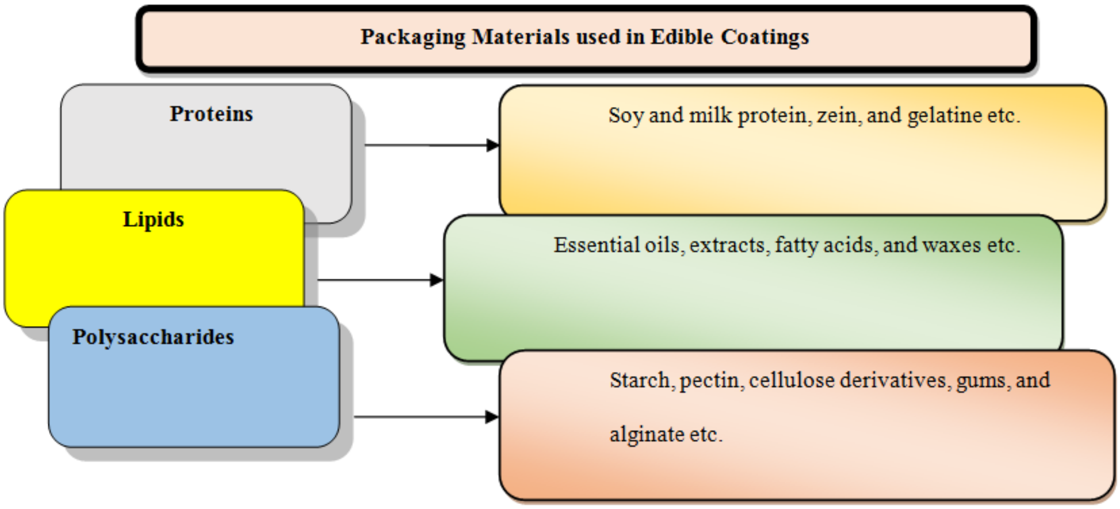

Fig. 5. Packaging materials used in edible coatings

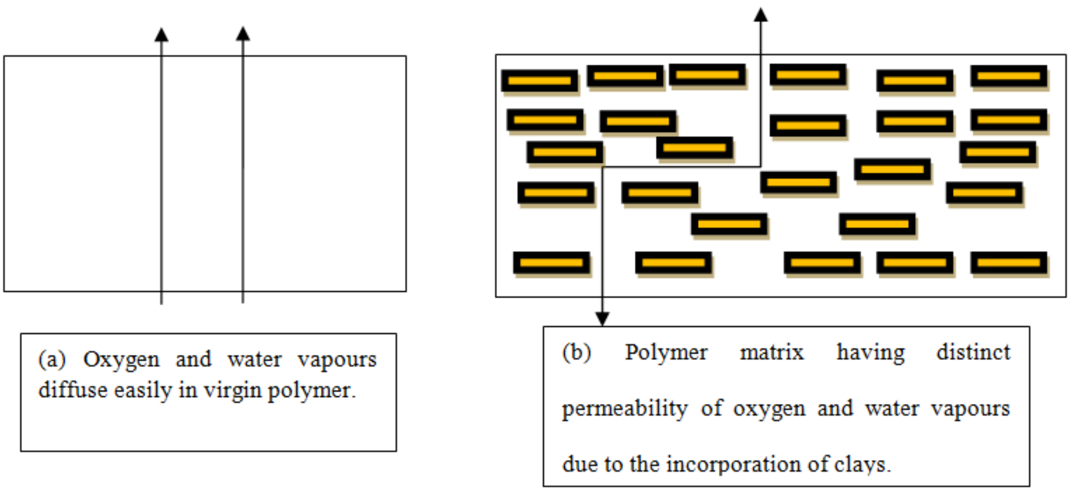

Fig. 6. Tortuous pathway of water vapor permeability created by the incorporation of clay in polymer matrix

4. INTELLIGENT PACKAGING

According to European Food Safety Authority (EFSA), intelligent packaging defines as "materials and articles that monitor the condition of packaged food or the environment surrounding the food" [105]. By using NPs, intelligent packaging sensing and communication chemical, biochemical, or microbial spoilage of the food products or their environment without direct interaction with the food products [106], [107]. The main objective of intelligent packaging is to assess and monitor the food to inform the consumer and assure its safety and quality [108]. Therefore, various types of intelligent packaging are used in the food industry (Fig. 7) [109].

4.1 Indicators

Indicators indicate the presence, absence, or concentration of the chemical substance in the food products and the degree of a chemical reaction between the two or more substances using color change [110], [111], [112].

4.1.1 Time-temperature indicators

Time-temperature indicators (TTIs) are focusing on checking food quality through visible color development that specifically correlates with food quality at a particular temperature [113], [114]. An important indicator is useful in controlling and monitoring the handling, distribution, and storage of food products [115]. TTIs are user-friendly, cost-effective, commonly used in the form of tags or labels, and fixed to food packaging [116]. For example, commercially based TTIs are 3M Monitor mark (3M Company). It has a fixed melting point of fatty acid esters melts, which indicates a color change to a blue dye [117], [118].

4.1.2 Freshness indicators

Freshness indicators **(**FIs) aim to provide actual information about the foodstuff during its storage, sale, transportation, and consumption when food became unacceptable for eating [119]. Thus, they serve or display information regarding microbial contamination, microbial growth, and chemical reaction including- biogenic amines, CO_2, organic acids, $C_6H_{12}O_6$, C_2H_5OH, sulfuric compounds, and volatile nitrogen compounds [120], [121]. FIs are used on the surface of food packaging in the form of labels to identify the quality of food products [122]. Additionally, newly developed FIs are used in the form of a smart cap to determine the freshness of the milk without opening the seal of the cap [123].

4.2 Data Carriers

Data carriers are also known as automatic identification tool that facilitates the flow of information within the whole supply chain and also maintains the traceability, protection from theft, and automatization of food products [124], [125]. The most common data carriers used in the food industry are barcode and radiofrequency identification (RFID) [126].

4.2.1 Barcode

A barcode is the most economical, cheap, and widely used optical, machine-readable, graphical representation of the data used to facilitate the recording of stocks, control the inventory, and checkouts of food products [127], [128]. In the 1970s, Universal Product Code (UPC) was introduced. The UPC was linear, 1D represents only 12 digits of the data and depicts only the manufacturer number and item number [129]. Later in 2011, a matrix code-based 2D barcode named Quick Response (QR) was introduced and used in the food industry [130], [131]. QR stores a large amount of information which is very useful to retailers and consumers. For example, batch number, nutritional information, packaging date, packaging weight, and preparation instructions [132], [133], [134], [135].

4.2.2 Radiofrequency identification

RFID tags or a label is an advanced form of wireless data transmission attached to the food packet to collect real-time information [136]. They have a 1-megabyte data storage capacity and trace the packet with the help of a radiofrequency electromagnetic field [137], [138]. As compared to barcodes, RFID is a little pricey and requires a strong electronic network [139]. Moreover, RFID provides information on the whole supply chain such as inventory management, traceability, and quality or safety of the food products [140]. RFID consists of three components (i) the RFID tag which is used to store information, (ii) the interrogator which receives information from the RFID tag, and (iii) software that manages and controls the operation [141], [142].

4.3 Sensors

A sensor is a device or tool used to measure physical energy and converts it into a signal read by the observer [143]. The excellent feature of the sensor is fast response time, high sensitivity and selectivity, long-term stability, full reversibility, good reliability, and wide dynamic range [144]. Thus, the most widely used sensor used in food packaging is biosensors and gas sensors [145].

4.3.1 Biosensors

A biosensor is an analytical device that can detect, record, and transmit information regarding biochemical reactions such as antigens, antibodies, enzymes, nucleic acids, hormones, and phages [146], [147], [148]. Furthermore, a biosensor can be used in food packaging for the detection of pathogens and microbes, especially in the meat and fish industry [149], [150]. For example, nano biosensors can be used to detect the food toxicants such as pesticides, additives, bisphenol A, and aflatoxins even in minute quantities [151].

4.3.2 Gas sensors

A gas sensor is used to assess the concentration of certain gases inside the food packet such as CO_2, and hydrogen sulfide (H_2S) [152]. Therefore, these gases indirectly monitor the spoilage status of food. A list of the gas sensor which can be used in the food industry is amperometric O_2 sensors, organic conducting polymers, potentiometric CO_2 sensors, metal oxide semiconductor field-effect transistors, and piezo-electric crystal sensors [153], [154].

Table 1. Applications of nanotechnology in food packaging (2015-2022)

Food applications	Effects	Nanomaterials	Packaging type	References
Bakery products	Slow down the growth of molds for 2 to 10 days.	Pd	O_2 scavengers	[156]
Whole-wheat breadsticks	Shelf life extension.	Rosemary extract	Antioxidant emitters	[157]
Milk chocolate cereals and dark chocolate peanuts	Improvement of oxidative stability.	Green tea extract	Antioxidant emitters	[158]
Cake	Maintains chemical and sensory quality, and also prevents fungal growth.	Zinc oxide (ZnO)	Antimicrobial packaging	[159]
Fresh pizza	Allyl isothiocyanate (AITC) inhibits the growth of *Aspergillus parasiticus* and aflatoxins after storage for 30 days.	AITC	Antimicrobial packaging	[160]
Sliced pan loaf	Garlic extract prevents the growth of mold for 30 days.	Garlic extract	Antimicrobial packaging	[161]
Dark, white, and milk chocolate	Used to assess the quality of chocolate.	Metallo porphyrin and gold (Au) NPs peptide gas sensor	Gas sensors	[162]
Strawberries and tomatoes	Regulates relative humidity below 97% at different temperatures for 7 days.	NaCl	Moisture scavengers	[163]
Guava	The shelf life of guava is extended to 32 days.	Phenols(C_6H_6O) and$C_6H_8O_6$	Moisture scavengers and C_2H_4 scavengers	[164]
Fruits and vegetables	Reduction ripening.	SiO_2, $KMnO_4$, nitrous oxide (N_2O), and1-methyl cyclopropane	C_2H_4scavengers	[165]
Peach and Nectarine	Shelf life increased with excellent sensory quality.	$Na_2Al_2Si_2O_8$ coated with $KMnO_4$	C_2H_4scavengers	[166]
Tomato	The ripening process is delayed.	TiO_2	C_2H_4scavengers	[53]
Sapodilla	Loss of vitamin C and firmness delayed. Also retarded internal and external appearance, pulp, and color changes.	$KMnO_4$	C_2H_4scavengers	[167]
Blueberry	Highly delayed both weight and firmness losses, also removed C_2H_4 and fungi.	$KMnO_4$	C_2H_4scavengers	[168]
Apples	Reduced effective respiration rate and extends the shelf life by 7 to 11 days.	$C_{56}H_{103}N_9O_{39}$-caseinate coating	Antioxidant emitters	[169]
Tomato puree	Decrease the bacterial growth: *Escherichia coli* and *Saccharomyces cerevisiae*.	Cinnamon essential oil	Antimicrobial packaging	[170]
Strawberries	Extending the shelf life and maintaining quality.	Limonene($C_{10}H_{16}$)	Nano-coatings	[171]
Fresh pineapple	Improving the shelf life of cut pineapples with anti-cancer properties.	Curcumin ($C_{21}H_{20}O_6$)	Edible nano-coatings	[172]
Cabbage	Inhibit the growth of *Escherichia coli,* and *Pichia pastoris*.	$C_{10}H_{14}O$	Edible nano-coatings	[173]
Fresh cut apple	Reduced the growth of *Escherichia coli* and bacterial growth.	Lemongrass essential oil	Edible nano-coatings	[174]
Tomato	Extending shelf life, decreasing weight loss, and microbial growth also reduced the exchange of gases and C_2H_4 production.	*Flourensia cernua* extract	Nano-laminates	[175]

Food applications	**Effects**	**Nanomaterials**	**Packaging type**	**References**
Orange	Reduced the rate of respiration and weight loss, also enhance nutritional quality and sensory acceptability.	Carnauba wax nano-clays	Nano-clays	[176]
Non-pasteurized angelica juice	*Used temperature above* 13.5°C.	Isopropyl palmitate (IPP) diffusion	TTIs	[177]
Fresh cut fruits	*The indicator works best at 18–19°C. This response is directly converted into an RFID signal and works fast as compared to critical temperature.*	Dimethyl sulfoxide (C_2H_6OS) with RFID	TTIs	[178]
Grape	*Chlorophenol red-based simple indicator impairs the filter.*	pH	Freshness indicators	[179]
Refrigerated fruits	Used to estimate energy consumption in cold storage and water loss from fruits.	RFID and wireless sensor networks.	RFID	[180]
Cabbage, and lettuce	Detection of pesticides.	C nanotubes	Biosensor	[181]
Cod loins	Initial firmness improved, also sensory and microbial shelf life extends.	CO_2, Nitrogen (N_2)	CO_2 emitters	[182]
Fresh beef	Inhibits lipid oxidation and longer the display life.	Eugenol ($C_{10}H_{12}O_2$)	Antioxidant emitters	[183]
Beef	Lowers thiobarbituric acid (TBARS), and improves oxidative stability.	Resveratrol ($C_{14}H_{12}O_3$)	Antioxidant emitters	[184]
Chicken, and fish	Reduced water vapor permeability and water solubility, also shelf life extends up to 12 days.	*Amaranthus* leaf extract (betalains) ($C_{24}H_{26}N_2O_{13}$)	Antioxidant emitters	[185]
Shrimp	Reduced the growth of *Vibrio parahaemolyticus*, *Escherichia coli*, and *Staphylococcus aureus*, alongside increased shelf life.	Nano-clays and nano-Ag	Nano-clays	[104]
Beef	*Excellent thermal insulation maintains temperature and is stored for 8 days.*	Soybean oil and tetradecane ($C_{14}H_{30}$)	TTIs	[186]
Cheese	Prevents the growth of *Listeria monocytogenes* for 14 days.	Nisin($C_{143}H_{230}N_{42}O_{37}S_7$)	Antimicrobial packaging	[187]
Cheddar cheese	Significant reduction of moisture, and microbial growth and also increased shelf life.	Alginate$(C_6H_8O_6)_n$ and $C_{143}H_{230}N_{42}O_{37}S_7$	Nano-laminates	[188]
Monterey Cheese	Decrease the moisture and acidity, further improving sensory attributes.	$(C_6H_8O_6)_n$ and turmeric	Nano-laminates	[189]
Gouda cheese	*Reduced the growth of Escherichia coli, Staphylococcus aureus, Salmonella enterica,* and *Saccharomyces cerevisiae*. Hence, shelf life increased.	Nano-clays and $C_{56}H_{103}N_9O_{39}$	Nano-clays	[190]
Kimchi	Detected CO_2 from kimchi.	CO_2	Freshness indicators	[191]
Milk	Reduced food-born microorganism growth such as *Vibrio parahaemolyticus, Salmonella, Staphylococcus aureus, Listeria monocytogenes, Shigella*, etc. Furthermore ultrasensitive, rapid, and multiplexed applications in food safety.	Au NPs amplified microcantilever array biosensor	Biosensor	[192]

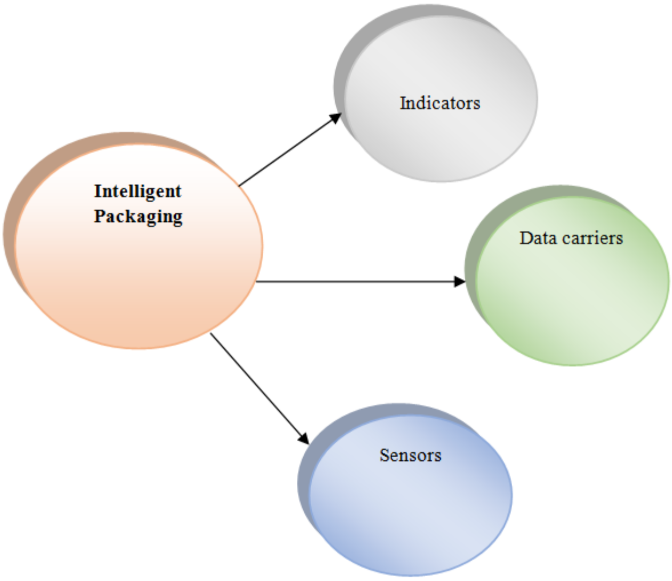

Fig. 7. Types of intelligent packaging used in the food industry

5. APPLICATION OF NANOTECHNOLOGY IN FOOD PACKAGING

Nanotechnology finds its application in several sectors of foods such as bioavailability, encapsulation, packaging, processing, fortification, food safety, pathogen detection, etc [155]. The application of nanotechnology in food packaging (Table 1) has been studied by various authors.

6. ROLE OF NANO PACKAGING IN DAIRY PRODUCTS

In the dairy industry, nanotechnology played a significant role in packaging, particulate delivery system, food safety, and shelf life. Nano packaging in dairy products involves the prevention of moisture and gas exchange, edible nano food wrappers, containing nanosensors, and anti-microbial activators that detect the spoilage of food and release anti-microbial agents to extend the shelf life of the dairy food products [193], [194].

7. TOXIC EFFECTS OF NANOMATERIALS: A PRIMARY CONCERN

Even though quality and safety are major primary concerns when using nanotechnology-based applications in the food industry. Public health and safety regarding its toxicity are equally important. As we know humans interact with NPs through foodstuff coated with nanomaterials. Therefore, researchers have focused their work on the transfer of ultrafine NPs from packaging to the human body has been increasing daily. Also, it will show negative impacts on human health and cause several diseases [195], [196].

NPs enter the human body through ingestion, inhalation, and injection [197]. Once they enter the human body, NPs interact with biological molecules such as (proteins, lipids, and sugars) [198]. In the human gastrointestinal tract, food takes 3-4 h for complete digestion in the stomach [199]. During that period, NPs produce toxic compounds in the body fluid and reach the different organs of the body such as the liver [200], brain [201], and kidney [202] and thus cause many harmful health effects and diseases. The key point for monitoring the behavior of the NPs in terms of specification, quantification, and biodistribution is crucial for hazard assessment [203]. Furthermore, the smaller the particle size, the toxicity level further increases [204]. Although not the only human body, ecosystems are also affected by NPs that are used in the food industry. These NPs accumulate in the soil or water and result in affecting the biota of that particular region and are also toxic to the species [205].

8. CONCLUSION

The favorable results that are obtained from previous research validate the use of nanotechnology in food packaging offers tremendous benefits to both consumers and the industry. NPs used in food packaging show many advantages as compared to conventional packaging. Active and improved packaging helps to improve mechanical properties, better barriers, and thermal properties, and prevent the growth of microorganisms, this will overall help to increase the shelf life and safety of food. The use of nanosensors, as intelligent packaging, helps to visualize the state of food inside the packet.

Regardless, the application of nano packaging can give numerous benefits and improves conventional packaging materials; the toxicity of the nanomaterials cannot be ignored. There is a need for more investigations and research to better understand the toxicological aspects of various types of NPs in food packaging. Also, nano packaging provides several benefits in the food industry. Still, there is doubt in the public to accept this latest technology and it is very common nature while accepting new things in the market. So, there is a need to create awareness and understanding among the common people for the novel application of nanotechnology in food packaging. In our point of view, nanotechnology is quite young and has an outstanding future, so there is a need for meticulous efforts to make it booming and flourishing in every single corner of the world. After successful popularization, demand will increase automatically which may help to reduce the market price of nano food packaging.

9. PRESENT STATUS AND FUTURE RECOMMENDATIONS

At this time, the use of nanotechnology in food packaging increased every day. Nano packaging results involves the use of NPs in different packaging composition to make them versatile for the use of the consumers. Furthermore, there is still a gap between the toxic effects of NPs in food packaging. There is a need for additional investigations and research on NPs' physicochemical characteristics, composition, shape, size, stability, and dose. Also, standardized test methods need to be developed that detect the toxicity of the NPs in food packaging. The investigation also studies the behavior, interaction, and stability of the NPs in the gastrointestinal tract and associated organs.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

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COMPETING INTERESTS

The authors have declared that no competing interests exist.

REFERENCES

1. Shin J, Selke SEM. Food packaging. In: Clark S, Jung S, Lamsal B (eds) Food processing: principles and applications. 2nd ed. USA: Wiley; 2014.
2. Prasad P, Kochhar A. Active packaging in food industry: a review. IOSR J Environ Sci Toxicol Food Technol. 2014;8(5):1-7.
3. Wyrwa J, Barska A. Innovations in the food packaging market: active packaging. European Food Research and Technology. 2017;243:1681-1692.
   Available: https://doi.org/10.1007/s00217-017-2878-2
4. Briand C. World packaging organization. 2009. Accessed 26 June 2022.
   Available:https://www.academia.edu/8711602/World_packaging_organization_2009.
5. Wikström F, Verghese K, Auras R, Olsson A, Williams H, Wever R et al. Packaging strategies that save food: a research agenda for 2030. J Ind Ecol. 2019;23(3):532-540.
   Available:https://doi.org/10.1111/jiec.12769
6. Sharma C, Dhiman R, Rokana N, Panwar H. Nanotechnology: an untapped resource for food packaging. Front Microbiol. 2017;8:1-22.
   Available:https://doi.org/10.3389/fmicb.2017.01735
7. Chen X, Chen M, Xu C, Yam KL. Critical review of controlled release packaging to improve food safety and quality. Crit Rev Food Sci Nutr. 2019;59(15):2386-2399.
   Available:https://doi.org/10.1080/10408398.2018.1453778
8. Dainelli D, Gontard N, Spyropoulos D, Zondervan-van den Beuken E, Tobback P. Active and intelligent food packaging: legal aspects and safety concerns. Trends Food Sci Technol. 2008;19(supp 1):103-112.
   Available:https://doi.org/10.1016/j.tifs.2008.09.011

9. Kubiak MS, Borowy T. Intelligent packaging within arms' reach. Opakowanie. 2013;10:51-54.
10. Echegoyen Y. Nano-developments for food packaging and labeling applications. In: Rai M, Riberio C, Mattoso L, Duran N (eds) Nanotechnologies in food and agriculture. Switzerland: Springer; 2015.
11. Enescu D, Cerqueira MA, Fucinos P, Pastrana LM. Recent advances and challenges on applications of nanotechnology in food packaging. a literature review. Food Chem Toxicol. 2019;134:1-24. Available:https://doi.org/10.1016/j.fct.2019.110814
12. Sing T, Shukla S, Kumar P, Wahla V, Bajpai VK, Rather IA. Corrigendum: application of nanotechnology in food science: perception and overview. Front Microbiol. 2017;8:1-7. Available:https://doi.org/10.3389/fmicb.2017.02517
13. Duncan TV. Applications of nanotechnology in food packaging and food safety: barrier materials, antimicrobials and sensors. J Colloid Interface Sci. 2011;363(1):1-24. Available:https://doi.org/10.1016/j.jcis.2011.07.017
14. Primožic M, Knez Ž, Leitgeb M. (Bio)nanotechnology in food science—food packaging. Nanomaterials. 2021;11(2):1-29. Available:https://doi.org/10.3390/nano11020292
15. Hoseinnejad M, Jafari SM, Katouzian I. Inorganic and metal nanoparticles and their antimicrobial activity in food packaging applications. Crit Rev Microbiol. 2018;44(2):161–181. Available:https://doi.org/10.1080/1040841x.2017.1332001
16. Hamad AF, Han JH, Kim BC, Rather IA. The intertwine of nanotechnology with the food industry. Saudi J Biol Sci. 2018;25(1):27–30. Available:https://doi.org/10.1016/j.sjbs.2017.09.004
17. European Commission. EU guidance to the commission regulation (EC) no 450/2009 of 29 May 2009 on active and intelligent materials and articles intended to come into the contact with food (version 1.0). 2009. Accessed 1 July 2022. Available:https://www.observatorioplastico.com/ficheros/legislacion/129165343guidance_active_and_intelligent_scofcah_231111_en.pdf.
18. Domínguez R, Barba FJ, Gómez B, Putnik P, Kovačević DB, Pateiro M et al. Active packaging films with natural antioxidants to be used in meat industry: A review. Food Res Int. 2018;113:93-101. Available:https://doi.org/10.1016/j.foodres.2018.06.073
19. Gaikwad KK, Singh S, Lee YS. Antimicrobial and improved barrier properties of natural phenolic compound-coated polymeric films for active packaging applications. J Coat Technol Res. 2019a;16:147–157. Available: https://doi.org/10.1007/s11998-018-0109-9
20. Momin JK, Joshi BH. Nanotechnology in foods. In: Rai M, Riberio C, Mattoso L, Duran N (eds) Nanotechnologies in food and agriculture. Switzerland: Springer; 2015.
21. Majid I, Nayik GA, Dar SM, Nanda V. Novel food packaging technologies: innovations and future prospective. Journal of the Saudi Society of Agricultural Sciences. 2018;17(4):454-462. Available:https://doi.org/10.1016/j.jssas.2016.11.003
22. Arora A, Padua GW. Review: nanocomposites in food packaging. J Food Sci. 2010;75(1):43-49. Available: https://doi.org/10.1111/j.1750-3841.2009.01456.x
23. Singh S, Ho Lee M, Park I, Shin Y, Lee YS. Antimicrobial seafood packaging: a review. J Food Sci Technol. 2016;53:2505–2518. Available: https://doi.org/10.1007/s13197-016-2216-x
24. Kapetanakou AE, Skandamis PN. Applications of active packaging for increasing microbial stability in foods: natural volatile antimicrobial compounds. Curr Opin Food Sci. 2016;12:1–12. Available: https://doi.org/10.1016/j.cofs.2016.06.001
25. Lee SY, Lee SJ, Choi DS, Hur SJ. Current topics in active and intelligent food packaging for preservation of fresh foods. J Sci Food Agric. 2015;95(14):2799-2810. Available: https://doi.org/10.1002/jsfa.7218
26. Pascuta MS, Vodnar DC. Nanocarriers for sustainable active packaging: an overview during and post COVID-19. Coatings. 2022;12(1):1-22.

Available:https://doi.org/10.3390/coatings12010102
27. Pereira de Abreu DA, Cruz JM, PaseiroLosada P. Active and intelligent packaging for the food industry. Food Reviews International. 2012;28(2):146–187. Available:https://doi.org/10.1080/87559129.2011.595022
28. Realini CE, Marcos B. Active and intelligent packaging systems for a modern society. Meat Sci. 2014;98(3):404-419. Available:https://doi.org/10.1016/j.meatsci.2014.06.031
29. 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. Available: https://doi.org/10.1016/j.tifs.2018.08.006
30. Singh S, Gaikwad KK, Lee YS. Development and application of a pyrogallic acid-based oxygen scavenging packaging system for shelf life extension of peeled garlic. Sci Hortic. 2019;256:1-8. Available:https://doi.org/10.1016/j.scienta.2019.108548
31. Arvanitoyannis IS, Oikonomou G. Active and intelligent packaging. In: Arvanitoyannis IS (ed) Modified atmosphere and active packaging technologies. 1st ed. USA: CRC Press; 2012.
32. Dey A, Neogi S. Oxygen scavengers for food packaging applications: a review. Trends Food Sci Technol. 2019;90:26-34. Available: https://doi.org/10.1016/j.tifs.2019.05.013
33. Hutter S, Rüegg N, Yildirim S. Use of palladium based oxygen scavenger to prevent discoloration of ham. Food Packag Shelf Life. 2016;8:56-62. Available:https://doi.org/10.1016/j.fpsl.2016.02.004
34. Kuswandi B. Environmental friendly food nano-packaging. Environ Chem Lett. 2017a;15(2):205–221. Available: https://doi.org/10.1007/s10311-017-0613-7
35. Mane KA. A review on active packaging: an innovation in food packaging. Int J Environ Agric Biotechnol. 2016;1(3):544-549. http://dx.doi.org/10.22161/ijeab/1.3.34
36. Van Bree I, Baetens J, Samapundo S, Devlieghere F, Laleman R, Vandekinderen I et al. Modelling the degradation kinetics of vitamin C in fruit juice in relation to the initial headspace oxygen concentration. Food Chem. 2012;134(1):207-214. Available:https://doi.org/10.1016/j.foodchem.2012.02.096
37. Gaikwad KK, Singh S, Lee YS. Oxygen scavenging films in food packaging. Environ Chem Lett. 2018c;16:523-538. https://doi.org/10.1007/s10311-018-0705-z
38. Gauthier W. Apparatus and method for extending polyolefin containing photovoltaic panel life span. 2015;U.S. Patent No. 8941006B2
39. Kasaai MR. Nanosized particles of silica and its derivatives for applications in various branches of food and nutrition sectors. J Nanotechnol. 2015;2015:1-6. Available:https://doi.org/10.1155/2015/852394
40. Pandey S, Sharma K, Gundabala V. Antimicrobial bio-inspired active packaging materials for shelf life and safety development: A review. Food Biosci. 2022;48:101730. Available:https://doi.org/10.1016/j.fbio.2022.101730
41. Anonymous. Oxygen scavengers market by type (metallic, and non-metallic), end-use industry (food and beverage, pharmaceutical, power, oil and gas, chemical, pulp and paper), and region—global forecast to 2022. 2017a. Accessed 14 July 2022. Available:https://www.marketsandmarkets.com/.
42. Anonymous. Oxygen scavenger market: global industry analysis and opportunity assessment 2017–2027. Market research report. REP-GB-3150 October 2017. 2017b. Accessed 14 July 2022. Available:http://www.futuremarketinsights.com/reports/oxygen-scavenger-market.
43. Lee JS, Chang Y, Lee ES, Song HG, Chang PS, Han J. Ascorbic acid-based oxygen scavenger in active food packaging system for raw meatloaf. J Food Sci. 2018;83(3):682-688. Available: https://doi.org/10.1111/1750-3841.14061
44. Mohan COA, Ravishankar CN. Active and intelligent packaging systems-applications in seafood. World Journal of Aquaculture Research and Development. 2019;1:10-16.
45. Day BPF. Active packaging of food. In: Kerry J, Butler P (eds) Smart packaging technologies for fast moving consumer goods. England: Wiley; 2008.

46. Suppakul P. Active and intelligent packaging. In: Alavi S, Thomas S, Sandeep KP, Kalarikkal N, Varghese J, Yaragalla S (eds) Polymers for packaging applications. Canada: Apple Academic Press; 2015.
47. Gaikwad KK, Singh S, Ajji A. Moisture absorbers for food packaging applications. Environ Chem Lett. 2018a;17(2):609-628.
Available: https://doi.org/10.1007/s10311-018-0810-z
48. Gupta A, Sahni P, Sharma S, Singh B. New insight in active packaging of fruits. In: Dar BN, Mir SA (eds) Emerging technologies for shelf-life enhancement of fruits. 1st ed. New York: Apple Academic Press; 2020.
49. Gaikwad KK, Singh S, Lee YS. High adsorption of ethylene by alkali-treated halloysite nanotubes for food-packaging applications. Environ Chem Lett. 2018b;16:1055–1062.
Available: https://doi.org/10.1007/s10311-018-0718-7
50. Zhu Z, Zhang Y, Zhang Y, Shang Y, Zhang X, Wen Y. Preparation of PAN@ TiO_2 nanofibers for fruit packaging materials with efficient photocatalytic degradation of ethylene. Materials. 2019;12(6):1-10.
Available:https://doi.org/10.3390/ma12060896
51. Wei H, Seidi F, Zhang T, Jin Y, Xiao H. Ethylene scavengers for the preservation of fruits and vegetables: a review. Food Chem. 2021;337:1-12.
Available:https://doi.org/10.1016/j.foodchem.2020.127750
52. Gaikwad KK, Singh S, Negi YS. Ethylene scavengers for active packaging of fresh food produce. Environ Chem Lett. 2019b;18:269–284.
Available: https://doi.org/10.1007/s10311-019-00938-1
53. Kaewklin P, Siripatrawan U, Suwanagul A, Lee YS. Active packaging from chitosan-titanium dioxide nanocomposite film for prolonging storage life of tomato fruit. Int J Biol Macromol. 2018;112:523–529.
Available:https://doi.org/10.1016/j.ijbiomac.2018.01.124
54. Holck AL, Pettersen MK, Moen MH, Sørheim O. Prolonged shelf life and reduced drip loss of chicken filets by the use of carbon dioxide emitters and modified atmosphere packaging. J Food Prot. 2014;77(7):1133–1141.
Available: https://doi.org/10.4315/0362-028X.JFP-13-428
55. Chaix E, Guillaime C, Gontard N, Guillard V. Diffusivity and solubility of CO_2 in dense solid food products. J Food Eng. 2015;166:1–9.
Available:https://doi.org/10.1016/j.jfoodeng.2015.05.023
56. Robertson GL. Active and intelligent packaging. In: Food packaging: principles and practice. 3rd ed. USA: Taylor and Francis Group; 2012a.
57. Alves J, Gaspar PD, Lima TM, Silva PD. What is the role of active packaging in the future of food sustainability? A systematic review. J Sci Food Agric. 2023;103(3): 1004-1020.
Available:https://doi.org/10.1002/jsfa.11880
58. Bhardwaj A, Alam T, Talwar N. Recent advances in active packaging of agri-food products: a review. Journal of Postharvest Technology. 2019;7(1):33-62.
59. Haghighi-Manesh S, Azizi MH. Active packaging systems with emphasis on its applications in dairy products. J Food Process Eng. 2017;40(5):1-13.
Available:https://doi.org/10.1111/jfpe.12542
60. Gómez-Estaca J, Calvo MM, Sánchez-Faure A, Montero P, Gómez-Guillén MC. Development, properties, and stability of antioxidant shrimp muscle protein films incorporating carotenoid-containing extracts from food by-products. LWT-Food Science and Technology. 2015;64(1):189-196.
Available:https://doi.org/10.1016/j.lwt.2015.05.052
61. Barbosa-Pereira L, Aurrekoetxea GP, Angulo I, Paseiro-Losada P, Cruz JM. Development of new active packaging films coated with natural phenolic compounds to improve the oxidative stability of beef. Meat Sci. 2014;97(2):249–254.
Available:https://doi.org/10.1016/j.meatsci.2014.02.006
62. Bolumar T, Andersen ML, Orlien V. Antioxidant active packaging for chicken meat processed by high pressure treatment. Food Chem. 2011;129(4):1406-1412.
Available:https://doi.org/10.1016/j.foodchem.2011.05.082
63. Djenane D. Chemical profile, antibacterial and antioxidant activity of algerian citrus

essential oils and their application in *Sardina pilchardus*. Foods. 2015;4(2):208-228.
Available:https://doi.org/10.3390/foods4020208
64. Kim I, Viswanathan K, Kasi G, Thanakkasaranee S, Sadeghi K, Seo J. ZnO nanostructures in active antibacterial food packaging: preparation methods, antimicrobial mechanisms, safety issues, future prospects, and challenges. Food Reviews International. 2022;38(4):537-565.
Available:https://doi.org/10.1080/87559129.2020.1737709
65. Kamarudin SH, Rayung M, Abu F, Ahmad S, Fadil F, Karim AA et al. A review on antimicrobial packaging from biodegradable polymer composites. Polymers. 2022;14(1):1-29.
Available:https://doi.org/10.3390/polym14010174
66. Coma V. Bioactive packaging technologies for extended shelf life of meat based products. Meat Sci. 2008;78(1-2):90-103.
Available:https://doi.org/10.1016/j.meatsci.2007.07.035
67. Ashfaq A, Khursheed N, Fatima S, Anjum Z, Younis K. Application of nanotechnology in food packaging: pros and cons. J Agric Food Res. 2022;7:1-14.
Available:https://doi.org/10.1016/j.jafr.2022.100270
68. Campos-Requena VH, Rivas BL, Perez MA, Figueroa CR, Sanfuentes EA. The synergistic antimicrobial effect of carvacrol and thymol in clay/polymer nanocomposite films over strawberry graymold. LWT-Food Science and Technology. 2015;64(1):390–396.
Available:https://doi.org/10.1016/j.lwt.2015.06.006
69. Pandey S, Zaidi MGH, Gururani SK. Recent developments in clay-polymer nano composites. Scientific Journal of Review. 2013;2(11):296–328.
Available:https://doi.org/10.14196/sjr.v2i11.1056
70. Nath D, Santhosh R, Pal K, Sarkar P. Nanoclay-based active food packaging systems: a review. Food Packag Shelf Life. 2022;31:100803.
Available:https://doi.org/10.1016/j.fpsl.2021.100803
71. Chausali N, Saxena J, Prasad R. Recent trends in nanotechnology applications of bio-based packaging. J Agric Food Res. 2022;7:1-14.
Available:https://doi.org/10.1016/j.jafr.2021.100257
72. Babu PJ. Nanotechnology mediated intelligent and improved food packaging. Int Nano Lett. 2021;12:1-14.
Available: https://doi.org/10.1007/s40089-021-00348-8
73. Bourtoom T. Edible films and coatings: characteristics and properties. Int Food Res J. 2008;15(3):237–248.
74. Rovera C, Ghaani M, Farris S. Nano-inspired oxygen barrier coatings for food packaging applications: An overview. Trends Food Sci Technol. 2020;97:210-220.
Available:https://doi.org/10.1016/j.tifs.2020.01.024
75. Valdes A, Ramos M, Beltrán A, Jiménez A, Garrigós MC. State of the art of antimicrobial edible coatings for food packaging applications. Coatings. 2017; 7(4):1-23.
Available:https://doi.org/10.3390/coatings7040056
76. Maringgal B, Hashim N, Mohamed Amin Tawakkal IS, Muda Mohamed MT. Recent advance in edible coating and its effect on fresh/fresh-cut fruits quality. Trends Food Sci Technol. 2020;96:253-267.
Available:https://doi.org/10.1016/j.tifs.2019.12.024
77. Paidari S, Zamindar N, Tahergorabi R, Kargar M, Ezzati S, Shirani N et al. Edible coating and films as promising packaging: a mini review. Journal of Food Measurement and Characterization. 2021;15(5):4205-4214.
Available: https://doi.org/10.1007/s11694-021-00979-7
78. Petkoska AT, Daniloski D, D'Cunha NM, Naumovski N, Broach AT. Edible packaging: sustainable solutions and novel trends in food packaging. Food Res Int. 2021;140:1-15.
Available:https://doi.org/10.1016/j.foodres.2020.109981
79. Baldwin EA, Nisperos MO, Chen X, Hagenmaier RD. Improving storage life of cut apples and potato with edible coating. Postharvest Biol Technol. 1996;9(2):151–163.
Available: https://doi.org/10.1016/S0925-5214(96)00044-0
80. Azeredo HMC, Mattoso LHC, Wood D, Williams TG, Avena-Bustillos RJ, McHugh

TH. Nanocomposite edible films from mango puree reinforced with cellulose nanofibers. J Food Sci. 2009;74(5):31–35. Available: https://doi.org/10.1111/j.1750-3841.2009.01186.x

81. Costa MJ, Maciel LC, Teixeira JA, Vicente AA, Cerqueira MA. Use of edible films and coatings in cheese preservation: opportunities and challenges. Food Res Int. 2018;107:84-92. Available:https://doi.org/10.1016/j.foodres.2018.02.013
82. Dhital R, Joshi P, Becerra-Mora N, Umagiliyage A, Chai T, Kohli P et al. Integrity of edible nano-coatings and its effects on quality of strawberries subjected to simulated in-transit vibrations. LWT-Food Science and Technology. 2017;80:257-264. Available:https://doi.org/10.1016/j.lwt.2017.02.033
83. Nile SH, Baskar V, Selvaraj D, Nile A, Xiao J, Kai G. Nanotechnologies in food science: applications, recent trends, and future perspectives. Nanomicro Lett. 2020;12(1):1-34. Available: https://doi.org/10.1007/s40820-020-0383-9
84. Kumar L, Ramakanth D, Akhila K, Gaikwad KK. Edible films and coatings for food packaging applications: a review. Environ Chem Lett. 2022;20(4):875–900. Available: https://doi.org/10.1007/s10311-021-01339-z
85. Perera KY, Sharma S, Pradhan D, Jaiswal AK, Jaiswal S. Seaweed polysaccharide in food contact materials (active packaging, intelligent packaging, edible films, and coatings). Foods. 2021;10(9):1-22. Available:https://doi.org/10.3390/foods10092088
86. Tavassoli-Kafrani E, Gamage MV, Dumée LF, Kong L, Zhao S. Edible films and coatings for shelf life extension of mango: a review. Crit Rev Food Sci Nutr. 2022;62(9):2432-2459. Available:https://doi.org/10.1080/10408398.2020.1853038
87. Acevedo-Fani A, Salvia-Trujillo L, Soliva-Fortuny R, Martín-Belloso O. Layer-by-layer assembly of food-grade alginate/chitosan nanolaminates: formation and physicochemical characterization. Food Biophys. 2017a;12:299-308. Available: https://doi.org/10.1007/s11483-017-9486-3
88. Acevedo-Fani A, Soliva-Fortuny R, Martín-Belloso O. Nanostructured emulsions and nanolaminates for delivery of active ingredients: improving food safety and functionality. Trends Food Sci Technol. 2017b;60:12-22. Available:https://doi.org/10.1016/j.tifs.2016.10.027
89. Borges J, Mano JF. Molecular interactions driving the layer-by-layer assembly of multilayers. Chem Rev. 2014;114(18):8883–8942. Available:https://doi.org/10.1021/cr400531v
90. Flores-López ML, Cerqueira MA, de Rodríguez DJ, Vicente AA. Perspectives on utilization of edible coatings and nano-laminate coatings for extension of postharvest storage of fruits and vegetables. Food Engineering Reviews. 2016;8(3):292–305. Available: https://doi.org/10.1007/s12393-015-9135-x
91. Kuswandi B, Moradi M. Improvement of food packaging based on functional nanomaterial. In: Siddiquee S, Melvin GJH, Rahman MM (eds) Nanotechnology: applications in energy, drug and food. Switzerland: Springer; 2019.
92. Weiss J, Takhistov P, McClements DJ. Functional materials in food nanotechnology. J Food Sci. 2006;71(9):107–116. Available: https://doi.org/10.1111/j. 1750-3841.2006.00195.x
93. Ramachandraiah K, Han SG, Chin KB. Nanotechnology in meat processing and packaging: potential applications—a review. Asian-Australasian Journal of Animal Sciences. 2015;28(2):290–302. Available: https://doi.org/10.5713/ajas.14.0607
94. Galus S, Arik Kibar EA, Gniewosz M, Krasniewska K. Novel materials in the preparation of edible films and coatings—a review. Coatings. 2020;10(7):1-14. Available:https://doi.org/10.3390/coatings10070674
95. Salgado PR, Ortiz CM, Musso YS, Di Giorgio L, Mauri AN. Edible films and coatings containing bioactives. Curr Opin Food Sci. 2015;5:86–92. Available:https://doi.org/10.1016/j.cofs.2015.09.004
96. Silvestre C, Duraccio D, Cimmino S. Food packaging based on polymer

nanomaterials. Prog Polym Sci. 2011; 36(12):1766-1782.
Available:https://doi.org/10.1016/j.progpolymsci.2011.02.003

97. Bumbudsanpharoke N, Ko S. Nanoclays in food and beverage packaging. J Nanomater. 2019;2019:1-13. https://doi.org/10.1155/2019/8927167

98. Majeed K, Jawaid M, Hassan A, Abu Bakar A, Abdul Khalil HPS, Salema AA et al. Potential materials for food packaging from nanoclay/natural fibres filled hybrid composites. Mater Des. 2013;46:391–410.
Available:https://doi.org/10.1016/j.matdes.2012.10.044

99. De Azeredo HMC, CapparelliMattoso LH, McHugh TH. Nanocomposites in food packaging—a review. In: Reddy BSR (ed) Advances in diverse industrial applications of nanocomposites. Croatia: In Tech; 2011.

100. Jorda-Beneyto M, Ortuño N, Devis A, Aucejo S, Puerto M, Gutiérrez-Praena D et al. Use of nanoclay platelets in food packaging materials: technical and cytotoxicity approach. Food Addit Contam Part A. 2014;31(3):354-363.
Available:https://doi.org/10.1080/19440049.2013.874045

101. Kim SW, Cha SH. Thermal, mechanical, and gas barrier properties of ethylene–vinyl alcohol copolymer-based nanocomposites for food packaging films: effects of nanoclay loading. J Appl Polym Sci. 2014;131(11):1-8.
Available:https://doi.org/10.1002/app.40289

102. Bumbudsanpharoke N, Choi J, Ko S. Applications of nanomaterials in food packaging. J Nanosci Nanotechnol. 2015;15(9):6357-6372.
Available:https://doi.org/10.1166/jnn.2015.10847

103. Rhim JW. Effect of clay contents on mechanical and water vapor barrier properties of agar-based nanocomposite films. Carbohydr Polym. 2011;86(2):691-699.
Available:https://doi.org/10.1016/j.carbpol.2011.05.010

104. Paidari S, Ahari H. The effects of nanosilver and nanoclay nanocomposites on shrimp (*Penaeus semisulcatus*) samples inoculated to food pathogens. Journal of Food Measurement and Characterization. 2021;15(4):3195-3206.
Available: https://doi.org/10.1007/s11694-021-00905-x

105. European Food Safety Authority (EFSA). Guidelines on submission of a dossier for safety evaluation by the EFSA of active or intelligent substances present in active and intelligent materials and articles intended to come into contact with food. 2009. Accessed 28 July 2022.
Available:https://www.efsa.europa.eu/en/efsajournal/pub/1208.

106. Biji KB, Ravishankar CN, Mohan CO, Srinivasa Gopal TK. Smart packaging systems for food applications: A review. J Food Sci Technol. 2015;52:6125–6135.
Available: https://doi.org/10.1007/s13197-015-1766-7

107. Madhusudan P, Chellukuri N, Shivakumar N. Smart packaging of food for the 21st century—a review with futuristic trends, their feasibility and economics. Mater Today Proc. 2018;5(10):21018–21022.
Available:https://doi.org/10.1016/j.matpr.2018.06.494

108. Müller P, Schmid M. Intelligent packaging in the food sector: a brief overview. Foods. 2019;8(1):1-12.
Available:https://doi.org/10.3390/foods8010016

109. 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.
Available:https://doi.org/10.1016/j.tifs.2016.02.008

110. Hogan SA, Kerry JP. Smart packaging of meat and poultry. In: Kerry J, Butler P (eds) Smart packaging technologies for fast moving consumer goods. West Sussex: Wiley; 2008.

111. Kuswandi B. Freshness sensors for food packaging. Reference Module in Food Science. 2017b;1-11.
Available: https://doi.org/10.1016/B978-0-08-100596-5.21876-3

112. Mohebi E, Marquez L. Intelligent packaging in meat industry: an overview of existing solutions. J Food Sci Technol. 2015;52:3947–3964.
Available: https://doi.org/10.1007/s13197-014-1588-z

113. Mihindukulasuriya SDF, Lim LT. Nanotechnology development in food packaging: a review. Trends Food Sci Technol. 2014;40(2):149–167.
Available:https://doi.org/10.1016/j.tifs.2014.09.009

114. Pavelkova A. Time temperature indicators as devices intelligent packaging. Acta

Universitatis Agriculturae Et SilviculturaeMendelianaeBrunensis. 2013;61(1):245–251. Available:http://doi.org/10.11118/actaun201361010245

115. Ranjan S, Dasgupta N, Chakraborty AR, Melvin Samuel S, Ramalingam C, Shanker R et al. Nanoscience and nanotechnologies in food industries: opportunities and research trends. Journal of Nanoparticle Research. 2014;16(6):1-23. Available: http://doi.org/10.1007/s11051-014-2464-5
116. Kuswandi B, Jumina. Active and intelligent packaging, safety, and quality controls. Fresh-Cut Fruits and Vegetables. 2020;243-294. Available: https://doi.org/10.1016/B978-0-12-816184-5.00012-4
117. Gregor-Svetec D. Intelligent packaging. In: Cerqueira MA, Lagaron JM, Castro LMP, Vicente AA (eds) Nanomaterials for food packaging: materials, processing technologies, and safety issues. 1st ed. Elsevier; 2018.
118. Kuswandi B, Wicaksono Y, Jayus, Abdullah A, Heng LY, Ahmad M. Smart packaging: sensors for monitoring of food quality and safety. Sens Instrum Food Qual Saf. 2011;5(3-4):137–146. Available: https://doi.org/10.1007/s11694-011-9120-x
119. Lee SJ, Rahman ATMM. Intelligent packaging for food products. In: Han JH (ed) Innovations in food packaging. 2nd ed. USA: Academic Press; 2014.
120. Siracusa V, Lotti N. Intelligent packaging to improve shelf life. In: Galanakis CM (ed) Food quality and shelf life. England: Academic Press; 2019.
121. Sohail M, Sun DW, Zhu Z. Recent developments in intelligent packaging for enhancing food quality and safety. Crit Rev Food Sci Nutr. 2018;58(15):2650–2662. Available: https://doi.org/10.1080/10408398.2018.1449731
122. Fuertes G, Soto I, Carrasco R, Vargas M, Sabattin J, Lagos C. Intelligent packaging systems: sensors and nanosensors to monitor food quality and safety. J Sens. 2016;2016:1–8. Available:https://doi.org/10.1155/2016/4046061
123. Lu M, Shiau Y, Wong J, Lin R, Kravis H, Blackmon T et al. Milk spoilage: methods and practices of detecting milk quality. Food Nutr Sci. 2013;4(7):113-123. Available: https://doi.org/10.4236/fns.2013.47A014
124. Chowdhury EU, Morey A. Intelligent packaging for poultry industry. J Appl Poult Res. 2019;28(4):791-800. Available: https://doi.org/10.3382/japr/pfz098
125. McFarlane D, Sheffi Y. The impact of automatic identification on supply chain operations. International Journal of Logistics Management. 2003;14(1):1-17. Available:https://doi.org/10.1108/09574090310806503
126. Robertson GL. Food packaging: principles and practice. USA: CRC Press; 2012b.
127. Magasura M. The role of packaging in supply chain management. Global Vision. 2018. Accessed 1 August 2022. Available: https://www.pharmaceuticalonline.com/doc/the-role-of-packaging-in-supply-chain-management-0001.
128. 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(1-3):157–164. Available: https://doi.org/10.1016/S0925-5273(00)00115-8
129. Mirza Alizadeh A, Masoomian M, Shakooie M, ZabihzadehKhajavi M, Farhoodi M. Trends and applications of intelligent packaging in dairy products: a review. Crit Rev Food Sci Nutr. 2020;62(2)1–15. Available:https://doi.org/10.1080/10408398.2020.1817847
130. Hakola L, Vehmas K, Smolander M. Functional inks and indicators for smart tag based intelligent packaging applications. Journal of Applied Packaging Research. 2021;13(2):1-19.
131. Liu Y, Yang J, Liu M. Recognition of QR code with mobile phones. Chinese Control and Decision Conference. 2008;203-206. Available:https://doi.org/10.1109/CCDC.2008.4597299
132. Cata T, Patel PS, Sakaguchi T. QR code: a new opportunity for effective mobile marketing. Journal of Mobile Technologies, Knowledge and Society. 2013;2013:1-7. Available:https://doi.org/10.5171/2013.748267
133. Cipriani J. Apple hid a QR code scanner in ios 11 - here’s how to use it. 2017. Accessed 5 August 2022.

Available:https://www.cnet.com/tech/mobile/how-to-use-ios-11s-hidden-qr-code-reader/.

134. Drobnik O. Barcodes with ios: bringing together the digital and physical worlds. New York: Manning Publications; 2015.
135. Gao JZ, Prakash L, Jagatesan R. Understanding 2D-barcode technology and applications in m-commerce - design and implementation of a 2D barcode processing solution. 31st Annual International Computer Software and Applications Conference. 2007;49-56. Available:https://doi.org/10.1109/COMPSAC.2007.229
136. Bibi F, Guillaume C, Gontard N, Sorli B. A review: RFID technology having sensing aptitudes for food industry and their contribution to tracking and monitoring of food products. Trends Food Sci Technol. 2017;62:91-103. Available:https://doi.org/10.1016/j.tifs.2017.01.013
137. Abad E, Palacio F, Nuin M, De Zárate AG, Juarros A, Gómez JM et al. RFID smart tag for traceability and cold chain monitoring of foods: Demonstration in an intercontinental fresh fish logistic chain. J Food Eng. 2009;93(4):394–399. Available:https://doi.org/10.1016/j.jfoodeng.2009.02.004
138. Aguzzi J, Sbragaglia V, Sarriá D, García JA, Costa C, Del Río J et al. A new laboratory radio frequency identification (RFID) system for behavioural tracking of marine organisms. Sensors. 2011;11(10):9532-9548. Available:https://doi.org/10.3390/s111009532
139. Brockgreitens J, Abbas A. Responsive food packaging: recent progress and technological prospects. Compr Rev Food Sci Food Saf. 2016;15(1):3–15. Available: https://doi.org/10.1111/1541-4337.12174
140. 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(8):101–106. Available: https://doi.org/10.1111/j.1750-3841.2009.01323.x
141. 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. Packaging Technology and Science. 2018;31(7):449–471. Available: https://doi.org/10.1002/pts.2380
142. Dabbene F, Gay P, Tortia C. Traceability issues in food supply chain management: a review. Biosyst Eng. 2014;120:65–80. Available: https://doi.org/10.1016/j.biosystemseng.2013.09.006
143. Vanderroost M, Ragaert P, Devlieghere F, De Meulenaer B. Intelligent food packaging: the next generation. Trends Food Sci Technol. 2014;39(1):47–62. Available:https://doi.org/10.1016/j.tifs.2014.06.009
144. Hanrahan G, Patil DG, Wang J. Electrochemical sensors for environmental monitoring: design, development and applications. J Environ Monit. 2004;6(8):657–664.
145. Adley CC. Past, present and future of sensors in food production. Foods. 2014;3(3):491–510 Available: https://doi.org/10.3390/foods3030491
146. Chaudhary V, Punia Bangar S, Thakur N, Trif M. Recent advancements in smart biogenic packaging: reshaping the future of the food packaging industry. Polymers. 2022;14(4):1-23. Available: https://doi.org/10.3390/polym14040829
147. Thakur MS, Ragavan KV. Biosensors in food processing. J Food Sci Technol. 2013;50:625–641. Available: https://doi.org/10.1007/s13197-012-0783-z
148. Yam KL, Takhistov PT, Miltz J. Intelligent packaging: concepts and applications. J Food Sci. 2006;70(1):1–10. Available: https://doi.org/10.1111/j.1365-2621.2005.tb09052.x
149. Alocilja EC, Radke SM. Market analysis of biosensors for food safety. Biosens Bioelectro. 2003;18(5-6):841–846. Available: https://doi.org/10.1016/S0956-5663(03)00009-5
150. Sobhan A, Muthukumarappan K, Wei L. Biosensors and biopolymer-based nanocomposites for smart food packaging: challenges and opportunities. Food Packag Shelf Life. 2021;30:1-12. Available: https://doi.org/10.1016/j.fpsl.2021.100745
151. Raja IS, Vedhanayagam M, Preeth DR, Kim C, Lee JH, Han DW. Development of two-dimensional nanomaterials based electrochemical biosensors on enhancing

the analysis of food toxicants. Int J Mol Sci. 2021;22(6):1-24.
Available:https://doi.org/10.3390/ijms22063277

152. Matindoust S, Baghaei-Nejad M, Zou Z, Zheng LR. Food quality and safety monitoring using gas sensor array in intelligent packaging. Sensor Review. 2016;36(2):169-183.
Available: https://doi.org/10.1108/SR-07-2015-0115

153. Firouz MS, Mohi-Alden K, Omid M. A critical review on intelligent and active packaging in the food industry: research and development. Food Res Int. 2021;141:1-24.
Available:https://doi.org/10.1016/j.foodres.2021.110113

154. Kalpana S, Priyadarshini SR, Leena MM, Moses JA, Anandharamakrishnan C. Intelligent packaging: trends and applications in food systems. Trends Food Sci Technol. 2019;93:145-157.
Available:https://doi.org/10.1016/j.tifs.2019.09.008

155. Thangadurai D, Sangeetha J, Prasad R (eds). Nanotechnology for food, agriculture, and environment. India: Springer; 2020.

156. Ruegg N, Rocker B, Yildirim S. Application of palladium-based oxygen scavenger to extend the mould free shelf life of bakery products. Food Packag Shelf Life. 2022;31:1-7.
Available:https://doi.org/10.1016/j.fpsl.2021.100771

157. Alamprese C, Cappa C, Ratti S, Limbo S, Signorelli M, Fessas D et al. Shelf life extension of whole-wheat breadsticks: formulation and packaging strategies. Food Chem. 2017;230:532-539.
Available:https://doi.org/10.1016/j.foodchem.2017.03.092

158. Carrizo D, Taborda G, Nerin C, Bosetti O. Extension of shelf life of two fatty foods using a new antioxidant multilayer packaging containing green tea extract. Innov Food Sci Emerg Technol. 2016;33:534–541.
Available:https://doi.org/10.1016/j.ifset.2015.10.018

159. Sahraee S, Milani JM, Ghanbarzadeh B, Hamishehkar H. Development of emulsion films based on bovine gelatin-nano chitin-nano ZnO for cake packaging. Food Sciences and Nutrition. 2020;8(2):1303–1312.
Available:https://doi.org/10.1002/fsn3.1424

160. Quiles JM, Manyes L, Luciano F, Manes J, Meca G. Influence of the antimicrobial compound allyl isothiocyanate against the *Aspergillus parasiticus* growth and its aflatoxins production in pizza crust. Food and Chemical Toxicology. 2015;83:222–228.
Available:https://doi.org/10.1016/j.fct.2015.06.017

161. Heras-Mozos R, Muriel-Galet V, Lopez-Carballo G, Catala R, Hernandez-Munoz P, Gavara R. Development and optimization of antifungal packaging for sliced pan loaf based on garlic as active agent and bread aroma as aroma corrector. Int J Food Microbiol. 2019;290:42–48.
Available:https://doi.org/10.1016/j.ijfoodmicro.2018.09.024

162. Compagnone D, Faieta M, Pizzoni D, Di Natale C, Paolesse R, Van Caelenberg T et al. Quartz crystal microbalance gas sensor arrays for the quality control of chocolate. Sensors and Actuators B: Chemical. 2015;207(2015):1114-1120.
Available:https://doi.org/10.1016/j.snb.2014.10.049

163. Rux G, Mahajan PV, Linke M, Pant A, Sangerlaub S, Caleb OJ et al. Humidity-regulating trays: moisture absorption kinetics and applications for fresh produce packaging. Food Bioproc Tech. 2016;9:709–716.
Available: https://doi.org/10.1007/s11947-015-1671-0

164. Murmu SB, Mishra HN. Selection of the best active modified atmosphere packaging with ethylene and moisture scavengers to maintain quality of guava during low-temperature storage. Food Chem. 2018;253:55-62.
Available:https://doi.org/10.1016/j.foodchem.2018.01.134

165. Sadeghi K, Lee Y, Seo J. Ethylene scavenging systems in packaging of fresh produce: a review. Food Reviews International. 2021;37(2):155–176.
Available:https://doi.org/10.1080/87559129.2019.1695836

166. Emadpour M, Ghareyazie B, Kalaj YR, Entesari M, Bouzari N. Effect of the potassium permanganate coated zeolite nanoparticles on the quality characteristic and shelf life of peach and nectarine. Journal of Agricultural Technology. 2015; 11(5):1263-1273.

167. Álvarez-Hernández MH, Martínez-Hernández GB, Avalos-Belmontes F, Castillo-Campohermoso MA, Contreras-Esquivel JC, Artés-Hernández F. Potassium permanganate-based ethylene scavengers for fresh horticultural produce as an active packaging. Food Engineering Reviews. 2019a;11:159-183. Available: https://doi.org/10.1007/s12393-019-09193-0
168. Álvarez-Hernández MH, Martínez-Hernández GB, Avalos-Belmontes F, Rodríguez-Hernández AM, Castillo-Campohermoso MA, Artés-Hernández F. An innovative ethylene scrubber made of potassium permanganate loaded on a protonated montmorillonite: A case study on blueberries. Food Bioproc Tech. 2019b;12:524-538. Available: https://doi.org/10.1007/s11947-018-2224-0
169. Volpe S, Cavella S, Torrieri E. Biopolymer coatings as alternative to modified atmosphere packaging for shelf life extension of minimally processed apples. Coatings. 2019;9(9):1-12. Available:https://doi.org/10.3390/coatings9090569
170. Gherardi R, Becerril R, Nerin C, Bosetti O. Development of a multilayer antimicrobial packaging material for tomato puree using an innovative technology. LWT-Food Science and Technology. 2016;72:361–367. Available:https://doi.org/10.1016/j.lwt.2016.04.063
171. Dhital R, Mora NB, Watson DG, Kohli P, Choudhary R. Efficacy of limonene nano coatings on post-harvest shelf life of strawberries. LWT-Food Science and Technology. 2018;97:124-134. Available:https://doi.org/10.1016/j.lwt.2018.06.038
172. Ghosh T, Nakano K, Mulchandani N, Katiyar V. Curcumin loaded iron functionalized biopolymeric nanofibre reinforced edible nanocoatings for improved shelf life of cut pineapples. Food Packag Shelf Life. 2021;28:1-12. Available:https://doi.org/10.1016/j.fpsl.2021.100658
173. Sow LC, Tirtawinata F, Yang H, Shao Q, Wang S. Carvacrol nanoemulsion combined with acid electrolysed water to inactivate bacteria, yeast in vitro and native microflora on shredded cabbages. Food Control. 2017;76:88–95. Available:https://doi.org/10.1016/j.foodcont.2017.01.007
174. Salvia-Trujillo L, Rojas-Graü MA, Soliva-Fortuny R, Martín-Belloso O. Use of antimicrobial nanoemulsions as edible coatings: impact on safety and quality attributes of fresh-cut *Fuji* apples. Postharvest Biol Technol. 2015;105: 8–16. Available:https://doi.org/10.1016/j.postharvbio.2015.03.009
175. Salas-Méndez EdeJ, Vicente A, Pinheiro AC, Ballesteros LF, Silva P, Rodríguez-García R et al. Application of edible nanolaminate coatings with antimicrobial extract of *Flourensiacernua* to extend the shelf-life of tomato (*Solanum lycopersicum* L.) fruit. Postharvest Biol Technol. 2019;150:19-27. Available:https://doi.org/10.1016/j.postharvbio.2018.12.008
176. Motamedi E, Nasiri J, Malidarreh TR, Kalantari S, Naghavi MR, Safari M. Performance of carnauba wax-nanoclay emulsion coatings on postharvest quality of Valencia orange fruit. Sci Hortic. 2018; 240:170–178. Available:https://doi.org/10.1016/j.scienta.2018.06.002
177. Kim JU, Ghafoor K, Ahn J, Shin S, Lee SH, Shahbaz HM et al. Kinetic modeling and characterization of a diffusion-based time-temperature indicator (TTI) for monitoring microbial quality of non-pasteurized angelica juice. LWT-Food Science and Technology. 2016;67:143–150. Available:https://doi.org/10.1016/j.lwt.2015.11.034
178. Lorite GS, Selkälä T, Sipola T, Palenzuela J, Jubete E, Viñuales A et al. Novel, smart and RFID assisted critical temperature indicator for supply chain monitoring. J Food Eng. 2017;193:20-28. Available:https://doi.org/10.1016/j.jfoodeng.2016.06.016
179. Kuswandi B, Murdyaningsih EA. Simple on package indicator label for monitoring of grape ripening process using colorimetric pH sensor. Journal of Food Measurement and Characterization. 2017;11(4):2180–2194. Available: https://doi.org/10.1007/s11694-017-9603-5
180. Badia-Melis R, Ruiz-Garcia L, Garcia-Hierro J, Villalba JIR. Refrigerated fruit storage monitoring combining two different

wireless sensing technologies: RFID and WSN. Sensors. 2015;15(3):4781-4795. Available:https://doi.org/10.3390/s150304781

181. Griesche C, Baeumner AJ. Biosensors to support sustainable agriculture and food safety. Trends in Analytical Chemistry. 2020;128:1-16. Available:https://doi.org/10.1016/j.trac.2020.115906

182. Hansen AA, Moen B, Rødbotten M, Berget I, Pettersen MK. Effect of vacuum or modified atmosphere packaging (MAP) in combination with a CO_2 emitter on quality parameters of cod loins (*Gadus morhua*). Food Packag Shelf Life. 2016;9:29–37. Available:https://doi.org/10.1016/j.fpsl.2016.05.005

183. Navikaite-Snipaitiene V, Ivanauskas L, Jakstas V, Rüegg N, Rutkaite R, Wolfram E et al. Development of antioxidant food packaging materials containing eugenol for extending display life of fresh beef. Meat Sci. 2018;145:9-15. Available:https://doi.org/10.1016/j.meatsci.2018.05.015

184. Busolo MA, Lagaron JM. Antioxidant polyethylene films based on a resveratrol containing clay of interest in food packaging applications. Food Packag Shelf Life. 2015;6:30–41. Available:https://doi.org/10.1016/j.fpsl.2015.08.004

185. Kanatt SR. Development of active/intelligent food packaging film containing *Amaranthus* leaf extract for shelf life extension of chicken/fish during chilled storage. Food Packag Shelf Life. 2020;24:1-9. Available:https://doi.org/10.1016/j.fpsl.2020.100506

186. Singh S, Gaikwad KK, Lee M, Lee YS. Temperature sensitive smart packaging for monitoring the shelf life of fresh beef. J Food Eng. 2018;234:41-49. Available:https://doi.org/10.1016/j.jfoodeng.2018.04.014

187. Divsalar E, Tajik H, Moradi M, Forough M, Lotfi M, Kuswandi B. Characterization of cellulosic paper coated with chitosan-zinc oxide nanocomposite containing nisin and its application in packaging of UF cheese. Int J Biol Macromol. 2018;109:1311-1318. Available:https://doi.org/10.1016/j.ijbiomac.2017.11.145

188. Khairi SR, Al-Mosowy AJ. Preparation of a nanolaminate of alginate and nisin in LBL method and its use in prolonging shelf life of cheddar cheese. Curr Res Microbiol Biotechnol. 2018a;6(2):1550-1561.

189. Khairi SR, Al-Mosowy AJ. Preparation of a nanolaminate of alginate and turmeric in LBL method and its use in prolonging shelf life of monterey cheese. Journal of Kerbala for Agricultural Sciences. 2018b;5(5):717-726.

190. Mohammadzadeh-Vazifeh M, Hosseini SM, Mohammadi A, Jahanfar M, Maleki H. Investigation of the antimicrobial properties of nanoclay and chitosan based nanocomposite on the microbial characteristics of gouda cheese. Iran J Microbiol. 2020;12(2):121-126.

191. Meng X, Lee K, Kang TY, Ko S. An irreversible ripeness indicator to monitor the CO_2 concentration in the headspace of packaged kimchi during storage. Food Sci Biotechnol. 2015;24(1):91–97. Available: https://doi.org/10.1007/s10068-015-0014-2

192. Zheng F, Wang P, Du Q, Chen Y, Liu N. Simultaneous and ultrasensitive detection of foodborne bacteria by gold nanoparticles-amplified microcantilever array biosensor. Front Chem. 2019;7:1-12. Available:https://doi.org/10.3389/fchem.2019.00232

193. Radha K, Thomas A, Sathian CT. Application of nano technology in dairy industry: prospects and challenges—a review. Indian Journal of Dairy Science. 2014;67(5):367-374.

194. Pushparaj K, Liu WC, Meyyazhagan A, Orlacchio A, Pappusamy M, Vadivalagan C et al. Nano-from nature to nurture: A comprehensive review on facets, trends, perspectives and sustainability of nanotechnology in the food sector. Energy. 2022;1:122732. Available:https://doi.org/10.1016/j.energy.2021.122732

195. Golja V, Dražić G, Lorenzetti M, Vidmar J, Ščančar J, Zalaznik M et al. Characterisation of food contact non-stick coatings containing TiO_2 nanoparticles and study of their possible release into food. Food Addit Contam Part A. 2017;34(3):421–433. Available:https://doi.org/10.1080/19440049.2016.1269954

196. He X, Hwang HM. Nanotechnology in food science: functionality, applicability, and safety assessment. J Food Drug Anal. 2016;24(4):671–681.

Available:https://doi.org/10.1016/j.jfda.2016.06.001

197. Maisanaba S, Pichardo S, Puerto M, Gutiérrez-Praena D, Cameán AM, Jos A. Toxicological evaluation of clay minerals and derived nanocomposites: A review. Environ Res. 2015;138:233–254. Available:https://doi.org/10.1016/j.envres.2014.12.024
198. Farhoodi M. Nanocomposite materials for food packaging applications: characterization and safety evaluation. Food Engineering Reviews. 2016;8(1):35-51. Available: https://doi.org/10.1007/s12393-015-9114-2
199. Hu W, Wang C, Gao D, Liang Q. Toxicity of transition metal nanoparticles: a review of different experimental models in the gastrointestinal tract. Journal of Applied Toxicology. 2022;43(1)32-46. Available: https://doi.org/10.1002/jat.4320
200. Choi K, Riviere JE, Monteiro-Riviere NA. Protein corona modulation of hepatocyte uptake and molecular mechanisms of gold nanoparticle toxicity. Nanotoxicology. 2016;11(1):64–75. Available:https://doi.org/10.1080/17435390.2016.1264638
201. Yin Y, Hu Z, Du W, Ai F, Ji R, Gardea-Torresdey JL et al. Elevated CO_2 levels increase the toxicity of ZnO nanoparticles to goldfish (*Carassius auratus*) in a water-sediment ecosystem. J Hazard Mater. 2017;327:64–70. Available:https://doi.org/10.1016/j.jhazmat.2016.12.044
202. Kononenko V, Repar N, Marušič N, Drašler B, Romih T, Hočevar S et al. Comparative in vitro genotoxicity study of ZnO nanoparticles, ZnO macroparticles and $ZnCl_2$ to MDCK kidney cells: size matters. Toxicol In Vitro. 2017;40:256–263. Available:https://doi.org/10.1016/j.tiv.2017.01.015
203. Hardy A, Benford D, Halldorsson T, Jeger MJ, Knutsen HK, More S et al. Guidance on risk assessment of the application of nanoscience and nanotechnologies in the food and feed chain: part 1, human and animal health. European Food Safety Authority. 2018;16(7):5327-5395. Available:https://doi.org/10.2903/j.efsa.2018.5327
204. Schrand AM, Rahman MF, Hussain SM, Schlager JJ, Smith DA, Syed AF. Metal-based nanoparticles and their toxicity assessment. Wiley Interdiscip Rev Nanomed Nanobiotechnol. 2010;2(5):544–568. Available:https://doi.org/10.1002/wnan.103
205. Pradhan N, Singh S, Ojha N, Shrivastava A, Barla A, Rai V et al. Facets of nanotechnology as seen in food processing, packaging, and preservation industry. Biomed Res Int. 2015;2015:1-17. Available:https://doi.org/10.1155/2015/365672

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