Asian Journal of Chemistry; Vol. 34, No. 10 (2022), 2499-2510

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2022.23917

REVIEW

Trends in Food Packaging: A Comprehensive Review

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Received: 18 May 2022; *Accepted*: 18 August 2022; *Published online*: 19 September 2022; AJC-20950

Food packaging is one of the fastest developing components of the food industry and the one where innovations are constantly happening according to the ever-evolving needs of the market. Food market is responsible for global food packaging approximately to 35%. Food packaging is conventionally required to have many functions like containing and protecting the food, having a specific space for nutrition facts labels, shelf life, adding a distinct brand identity and packaging the food in a way that consumers are attracted to it. However, focus on solely packaging can only address the symptoms of the problem, but does not cater the underlying systemic causes for the rapid growth and dependance on packaging. The deleterious effects of conventional packaging materials on environment and human health and the public awareness about the same, have prompted food industry to transit towards sustainable packaging. Packaging material, these days, is being manufactured using green technology and various practices to optimize the use of materials and energy. There is a growing demand for packaging through the use of edible or biodegradable materials, plant extracts and nanomaterial. Consumers are interested in packaging that increases shelf-life, tells them about the food it contains and uses technology to enhance the quality and safety of food packed within. Therefore, a completely new generation of packaging material is now being developed to monitor the property of packed food as well as their environmental sustainability. This article gives an overview of conventional packing, critically evaluates its environment and health impacts and discusses current trends and advances in the food packaging industry including active, intelligent and green technologies like edible and nanomaterial-based packaging. It is evident that the development of novel technologies using biodegradable nano based composite material have enhanced shelf life and passive properties (mechanical, thermal and barrier performance) of food but still there is need to research the migration, toxicity and environmental implications of the existing ingredients used for packaging and work towards searching novel renewable resources to prepare the biocompatible packaging materials, their processing to improve performance and finally their up-scale production.

Keywords: Food packaging, Chemicals, Environment impact, Edible packaging, Active packaging, Nanomaterials.

INTRODUCTION

Food packaging is the packaging of the food product to protect it from contamination and damage besides conserving taste and quality during its shelf life. It is one of the essential steps of preparation processes in the food industry to preserve the quality of food products for long term storage, export and final utilization. Food packaging assists in the protection of food from biochemical deterioration while ensuring hygiene. It can also be helpful in reducing the food waste [1-3] generated due to the spoilage during food transportation [2] (Fig. 1). Growing population, convenience of packaged food and hectic lifestyle have increased the demand of packaged food. At the same time, a consumer gets attracted to fancy packaging. This is why the food packaging industry has grown exponentially in recent years. The global food packaging market was estimated to be approximately US $ 394 billion in 2018 and will reach US $ 606 billion by 2026 as reported by research report of Fortune Business Insights [4].

There are three subsequent levels of food packaging. Primary packaging first envelops the product and remains in direct contact with contents, followed by secondary packaging

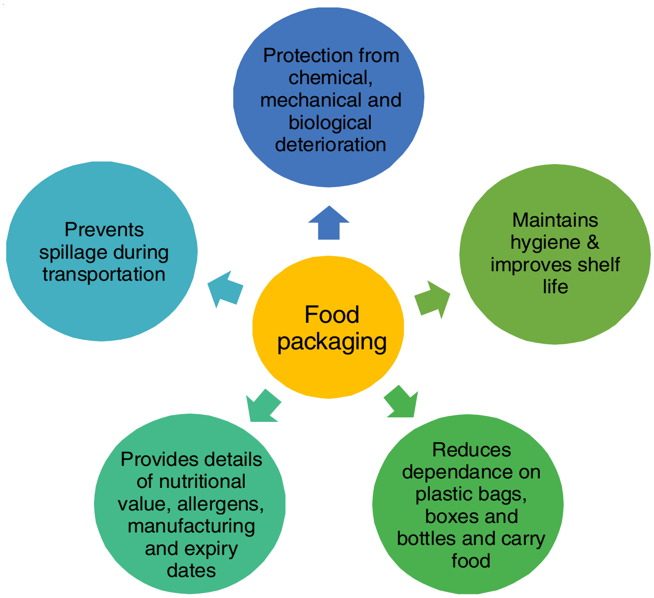

Fig. 1. Applications of food packaging

which groups the primary packaging together. Finally, tertiary packaging is done for bulk handling, shipping and warehouse storage. A packaging material should provide an impervious and non-toxic physical barrier between food and the external environment besides being antimicrobial and thermally, mechanically and physico-chemically stable [5].

Conventionally used materials for packaging of food includes paper, metal, glass and some natural materials owing to their wide availability and low cost [6]. Plastic use has become very popular due to its merits like affordability, light-weight, versatile nature, easy processing, impermeability and better physical properties. Despite their numerous advantages they could have adverse effect on environment, with most of them not being biologically degradable/renewable. Few of them like paper, which is mild to the environment and has a sufficient recycling rate. Their incineration also causes the generation of toxic gases like phosgene, carbon monoxide, vinyl chloride, formaldehyde posing serious health issues *viz.* cancer, eye/skin irritation/damage, problems of central nervous system, respiratory organs, liver, spleen, *etc.* Other gases are CO_2 and oxides of nitrogen and sulphur, giving rise to global warming and acid rains, respectively [7].

At the same time, the nonbiodegradability of the short usage plastics has also become a significant cause of concern worldwide because 95% of its packaging material cost is lost to economy every year [8]. Plastics are derivatives of fossil feed-stocks, which is non-renewable. Non-degradable small plastic pieces leak into the ocean and affect marine lives. Mostly low and medium density polymers like polyethylene (PE), polypropylene (PP) , polyvinyl chloride (PVC), polyethylene terephthalate (PET), polystyrene, polyethylene are used in the plastic packaging. PVC, polystyrene, polypropylene, *etc.* are non-recyclable and unsafe because they can permeate and contaminate the food leading to serious health consequences such as endocrine disruption or carcinogenicity (Table-1). Plastic used in the juice and milk cartons contain polyolefins, which interfere with female reproductive system as it mimics estrogen [9]. Recycling of plastic also has limitations. Their sorting, segregation and recovery also affect recycling and may contaminate recycled product. Chemicals generated during their production, handling or recycling may migrate into the food through packaging. A substantial amount of packaging is made of multilayer plastic packaging comprising different layers of plastic polymers. This multi-layer has benefits like higher barrier properties, low volume, extended shelf life, *etc.* with limitations like non biodegradability and incapability to recycle mixture of polymers/plastics [8]. Beer cans are made of aluminium containing *o*-phenylphenol which is carcinogenic in nature [10]. Although glass is considered safest packaging material but it has been found out that few types of glass contain lead, which can cause food poisoning, vomiting and liver and kidney damage [11]. Its production also releases CFCs, causing ozone layer depletion [12].

Therefore, selecting an appropriate food packaging material is one of the significant aspects of the food supply industry. Thus, there is a shift to change the packaging material to more sustainable ones like polysaccharides, edible proteins and lipids. The idea of this technology is driven by the consumer's inclination for food safety and waste reduction. The food packaging industry has come a long way in today's consumer-driven market and in recent years research on intelligent and active packaging methods and tools incorporating nanotechnology has accelerated to fabricate food packs to attain enriched physical/chemical and biological properties with better communication and environment compatibility [21,22].

Nanomaterials, due to their versatile properties and exceptionally small size, are in high demand across various industries ranging from medicine, agriculture, lubricant and electronics to the food and nutrition industry [23]. These nano-based substances are capable of designing specialized materials to meet specific goals depending upon their applications. Food packaging incorporating nanomaterials is advantageous over traditional packaging as it provides an efficient and cost-effective system, which improves temperature, chemical, biological resistance and shelf life of packaging with reducing its influence on the environment [24,25]. However, disadvantages related to their toxicity and migration (in food and environment) are needed to be addressed. The future of food-packaging technology lies in the scientific innovations where biodegradable, edible materials, plant extracts, biologically derived nanomaterial along with the benefits of active and intelligent systems, work symbiotically to develop a cost-effective, multifunctional, completely green packaging system with all the benefits. This will involve a lot of technology and planning, since bio-based/edible nanomaterials are not as cheap and readily available as the current conventional materials and research in this field is new and limited. Their action, compatibility with different food types and processing techniques have to be studied for their upscale production to make them an industrial and global food packaging.

The present article summarizes the impact of conventional packaging materials on human health and the surroundings, followed by the recent explorations and developments in this

TABLE-1
CONVENTIONAL FOOD PACKAGING AND ITS ENVIRONMENTAL IMPACT

Material	Uses	Impact	Ref.
Paper used for primary packaging	Kraft paper- is made by a sulfate treatment process and is used for packaging flour, sugar, dried fruits and vegetables *etc*. Sulfite paper - Paper is glazed to enhance its looks and its ability to resist water and oil. Small bags or wrappers for packaging biscuits and confectionary are made from this paper. Grease proof paper - is prepared using a technique called beating. In this, the strands of cellulose filaments separate and become thick. This paper is used to wrap oily foods like snacks, cookies, candy bars *etc*. Parchment paper - The pulp is given a wash of sulphuric acid that modifies the cellulose to render it smooth and impermeable to water and oil, giving it some wet strength. Butter and other solid fats are packed in this paper. Paper board - It is made in multiple layers and is usually used to make containers like boxes, cartons, and trays for shipping.	Paper production uses harmful chemicals like surfactants, bleaching agents, inks, phthalates *etc*., which ultimately become part of the food chain and environment through leaching and water discharge. Chlorine dioxide used for bleaching depletes the ozone cover. While landfills cause the leaching of harmful substances, incineration releases ash, slag, and other inorganic chemicals like gypsum.	[13]
Glass	Glass jars and bottles	Production of glass uses non-renewable sources, produces CFCs, HCFCs, and free radicals hence depletes the ozone layer. More dangerous than PET, HDPE and Al. In landfills, it takes more than 4000 years to decompose. Glass is fragile and heavier than other packaging materials; therefore, it needs heavy and careful transportation and consumes more fuel. More fuel more emission of air pollutants.	[12,14]
Laminates	Used for primary packaging and in making flexible pouches like potato chip bags and as laminates for plastic bottles and polypropylene (PP) trays	Containing more than one polymer type makes them non-recyclable	[15,16]
Metals	Aluminium is largely used for making foils, beverage cans and laminates.	Nonbiodegradable but infinitely recyclable. Environmentally effective if recycled. If not, then it majorly contributes to landfills; may choke waste streams	[17,18]
Plastics	Single service plates, cups, bottles, jars, cans	Non-recyclable and non -degradable plastic are a cause of concern. Undecomposed Plastic pieces (5mm) accumulated in sea bed for years are a threat to the marine ecosystem. Although PET and RPET bottles are recyclable, recycled plastics release carcinogenic heavy metals, viz. Cr, Ni, Pb and Cd into the atmosphere.	[7,19,20]

direction to provide a sustainable, healthy, more informative packaged product with increased shelf life and added nutritional values. This review will help the researchers to design and develop smart and green food packaging material by continuous monitoring the food properties like microbial contamination and protection against physical, chemical and mechanical deterioration.

Conventional packaging: Conventional food packaging has been in use for years. The technique is of vital importance in the modern-day food industry. This packaging has to perform some basic functions like containment of food, its protection/preservation from atmospheric and microbial degradation, providing ease and convenience, communication of information regarding spoilage/shelf-life/ingredients, *etc.* and finally, its marketing. Packaging is done in different sizes, shapes and materials to provide a passive covering around food to keep them away from environmental (heat/light/oxygen/moisture/dirt), biological (bacteria, fungi/mould) deterioration and to facilitate their logistic performance. It also involves marketing and communication for consumers to know the manufacturing/expiry date, shelf life, ingredients, nutritional facts, *etc.* Any new development in this technology needs to fulfill consumers' and industrial demands.

Conventional packaging materials: Paper, paperboard, glass, metal, laminates and plastics have largely been used as packing material in conventional packaging. Paper is the oldest packaging material and primarily used for the temporary containment and protection of dry foods but chemical treatment like coating with wax, resin and lacquer make it capable of packing wet/fatty foods by enhancing its functional and protective characteristics. It has various types, *viz.* Kraft, greaseproof, sulphite, parchment *etc.*, depending upon their production and packaging demand (Table-1). Paperboard, on the other hand, is a secondary packaging material which is not in direct contact with the food. Being thicker and heavier than the paper, it is used for shipping in the form of boxes, trays and cartons. Another type is paper laminate, which has better barrier properties [11].

Glass is another important and common packing material that has been used for centuries. Its unique characteristics like inertness, transparency, impermeability, heat resistance, hygiene, ability to be recycled infinitely without losing properties made it widely used as bottles and jars to contain soft drinks, water, alcoholic drinks, *etc*. Glass is basically manufactured from natural substances like soda, lime and silica after giving them heat, surface and annealing treatment. However, its production uses non-renewable sources, emits chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and free radicals hence depletes the ozone layer. Its decomposition takes several years. It is fragile and heavier than other packaging materials; therefore, it needs heavy and careful transportation and consumes more fuel. More fuel means more emission of air pollutants [12,14].

Plastic is the most common and popular packaging material. This is owed to its lucrative properties like light-weight, durability, convenience, ease to process, low cost, reformability, resistance towards moisture, reshaping and designing, *etc*. The broad use of plastics includes trays, bags, foil, cups, pouches, bottles, jars, cans, single serve plates, *etc*. The remouldability of thermoplastics renders it as the perfect choice for packaging. These can be fabricated into several shapes, recycled and reused. Polyethylene (PE) and polypropylene (PP) belong to this class. PE is used in milk/juice/bottles, grocery containers, garbage bags, bread and frozen food bags, whereas PP is heat resistant and used in yoghurt, margarine, ice cream tubs, tea-coffee cups, *etc*. Another member of this class is polyethylene terephthalate (PET/PETE), which finds its use in bottles and containers for beverages, foods and many other consumer and personal care products. It is chemically inert, light in weight, yet strong and economical, making it a valued packaging material [7].

Metals like tin, aluminum, steel, stainless steel, in the form of pouches, wraps, cans and foil, are generally used for food packaging. These packagings provide a great barrier towards moisture, light and gases. These are transport friendly, rigid and can bear high temperature. Aluminium, ~8.8% of the earth crust, is chiefly used as light weight material for cans of seafood and soft drinks, making wrapping foil, lamination of paper and plastics. It is easily recyclable material but already recycled aluminium, due to its non-magnetic nature can pose problems in segregation. Further, in order to improve barrier properties and overall appearance of the pack lamination technology is employed in which two or more primary packagings (paper, films, 'Al' foil, *etc.*) are joined together using a binding agent/ adhesive. This technology is used in making flexible food bags, pouches and as a laminate for PP and PET bottles/trays/cups, *etc*. [17,18].

Impact of conventional packaging materials on the environment: Conventional packaging is largely made from either non-biodegradable material like plastics or a combination of different materials having different recycling rates. These materials are a threat to health and sustainability. Table-1 depicts the environment impact of these poor traditional packaging materials. Packaging material damages the environment and even leads to serious ecological problems. The menace of packaging materials results in many environmental issues such as soil degradation, water pollution and decrease in resources, waste disposal and toxic chemical pollution and global warming [26]. Apart from these, flooding is also a major consequence as the hotter temperature will cause the sea level to rise. Instead of groundwater draining out to the sea, the water stays inland. Insect and pest infestation is also caused if plastic containers and packaging are not disposed of properly, which can cause dengue fever and leptospirosis.

Water pollution arises from wastewater discharge of some packaging material manufacturing or related activities. One of the basic water-polluting activities is paper production which is adversely affecting biological oxygen demand (BOD), chemical oxygen demand (COD), volatile suspended solids (VSS) and total suspended solids (TSS) [27]. Also, the manufacture of miscellaneous materials used in packagings, such as adhesives, coatings and inks, are a source of hydrocarbon pollution [28].

The packaging material manufacturing process is the primary source of air pollution. Accidental fires or waste incineration activities can emit harmful chemicals such as vinyl chloride, chlorofluorocarbons (CFC), hexane, *etc.* [12,13]. Solid waste related to packaging turns up at the point in production when raw materials are extracted and processed. These wastes end up in landfill sites quite often [17,18].

Litter constitutes only a minor part of total waste, but it is an issue of grave concern. It is a displeasing sight and constitutes a hazard to many animals, such as cows, *etc.* Packaging materials are the main constituents of litter. Even in our daily lives, what we see thrown away are the packets of chips and gutka, plastic bottles of cold drinks and paper packets made out of newspapers, which we get from the small hawkers. This is partly because single-use food packaging wastes are a very visible part of environmental problems but also due to our negligence and laziness.

There are a few more cases of poor packaging which are commonly used these days, for example, potato chips bag, popular among children, have multiple layers of plastic and foil are not recyclable. Single serving food packets like yoghurt and coffee cups, coming in small packaging, are a cause of concern as their small size makes it difficult to recycle them. Take-away packagings like pizza, burger and other fast food products boxes are recyclable, but due to the foodstuff left adhered to them, they no longer remain recyclable. Therefore, the selection of right kind of packaging material and technology is important because packaging technology must balance food safety with other issues, including material expenses, increased social and environmental awareness, alternative energy resources, regulations related to pollutants and solid waste disposal.

Impact of conventional packaging materials on human health: Conventional food packaging systems are mainly limited to fulfill consumer's and industry's demands without paying attention towards health and environment consequences. These packagings are not safe and sometimes they are further subjected to various chemical treatments to improve the appearance, functional and protective properties of the material used for the packaging. Though these chemicals are regulated, the exposure is low, but chronic, as many of us eat packaged or processed foods throughout our lives. The various environmental implications, as well, directly or indirectly affect our well-being. The health consequences of the chemicals present/produced by traditional packaging materials are tabulated in Table-2.

TABLE-2
CHEMICALS PRESENT IN COMMON PACKAGING MATERIALS ARE ASSOCIATED WITH HEALTH HAZARDS [Ref. 29-34]

Chemicals	Health hazards
Lead	Some of the glass bottles used for storing liquids have a high possibility of containing lead. Long term exposure to lead in high concentration results in damage of liver and kidney. As it is a known neurotoxin, it causes poisoning and vomiting as well.
Phthalate	This chemical contaminant can be released from the metal caps of bottles or jars. It is linked to several disturbances in the hormonal (endocrine) system.
ortho-Phenylphenol	Thin aluminium and tin cans used to store refreshing beverages contain this chemical. It is a pesticide used to kill bacteria and fungus; it is known to be carcinogenic.
Bisphenol A (BPA)	• Polycarbonate plastics and epoxy resins have BPA. These are used in containers storing food and beverages, coating the inside of metal products such as food cans and bottle tops and in some dental sealants. • Exposure to BPA results in negative health impacts, especially on the health of infants and children
Di-isobutyl phthalate and di-*n*-butyl phthalate	Recycled paper boxes may be contaminated by these chemicals. They can cause digestion problems and severe toxicity.
Perfluoroalkyl chemicals (PFCs)	They are used in greaseproof food packaging and could reduce immunity, birth weight and fertility.
Perchlorate	It is added in dry food packaging to control static electricity and is known to disrupt thyroid function and affect early brain development.
Nitrates and nitrites	These are used to preserve food and are found in processed meats, which can interfere with thyroid hormone production.
Styrene and associated compounds	Styrene is present in some plastics, resins and styrofoam. It is used in the manufacture of CD cases, catering service products and some luggage. Styrofoam which is derived from polystyrene, is used for making disposable plates and cups. As a result, these cups and plates contain carcinogens that can leach into the hot food and drinks they hold. So, in general, they are unsafe for the users.
Formaldehyde	Beverages are packaged in plastic bottles, which generally contain small levels of formaldehyde that can trigger cancer.
Per- and polyfluoroalkyl substances (PFAS)	It has commonly been used in a wide range of products to make them stain-resistant or waterproof. PFAS is associated with developmental problems in children, decreased fertility and increased cancer risk.

Advanced packaging technologies: Advanced or smart packaging incorporating active and intelligent packaging systems is a novel and emerging field in food industry. These technologies are capable of sensing spoilage of contained food in real time besides extending its shelf life. Not only do they ensure food safety by retarding oxidative reactions and growth of microorganism but also provide required information for consumers [35].

Active packaging: This is one of the smart packaging techniques to improve product quality, shelf life, freshness, data quality and consumer convenience. Active packaging needs to perform active functions beyond the inert passive containment and product safety. The requirement for natural, reusable and biologically decomposable packaging material led to the development of this technique. The technique uses some common tools like the introduction of antioxidants, antimicrobials, dehumidifiers, scavengers, emitters, ethylene/CO_2 absorbing systems, *etc.* to increase the shelf life and efficiency of the product [36]. The presence of ethylene, oxygen and humidity may initiate and accelerate food deterioration and corruption. To scavenge them, various packaging systems have been developed. The existence of CO_2, SO_2 and ethanol have a positive impact on food preservation. While carbon dioxide helps remove foul odour, sulphur dioxide and sulphates act as allergens, prevent oxidative decays and enzymatic browning, ethanol being antimicrobial [36]. Therefore, the presence of these substances is desirable in food headspace and it is done by means of the diffusion/emitting systems using different mediators to produce/carry them. Active edible films are also being prepared incorporating essential oils possessing oxygen scavenging and antimicrobial properties [37]. A few examples of the active packaging tools have been listed in Table-3.

Intelligent packaging: Traditional packaging only protects the food from the outer environment without providing any information about freshness. Physical and chemical methods of detection of freshness, sensory glands and study of microbial properties are not convenient and rapid evaluation methods. Intelligent packaging performs active functions within the conventional passive containment. It can smartly sense and detect the internal and external changes of products in real-time to give information regarding the quality and safety of food [38]. Freshness indicators sense the substances that release during the microbial and enzymatic degradation of food. The freshness of fruits and some other foods can be detected by the increase in CO_2 concentration [39]. Volatile nitrogen compounds produced after the microbial action on animal food products increase the pH of the packaged food environment, which can easily be detected using a pH indicator showing different colours at different stages of deterioration of animal food [40]. Corruption of some fruits and poultry meat items can also be detected by the release of volatile sulphides [41].

Intelligent packaging technology has emerged to introduce the communication device to the existing food packaging science to provide better traceability, enhanced quality and safety to the packaged food. For communicating with stakeholders about the various factors and properties of food, this technique uses three different smart devices, namely, indicators, sensors and identification tools [21]. Classification of freshness indicator devices (Table-4) is based on the way the measurement of freshness is to be reported.

Sustainable packaging (need of the hour): Although smart packages have excellent potential to ensure safety and freshness of food by means of variety of active ingredients and detecting devices but it is also required at the same time

TABLE-3
VARIOUS ACTIVE PACKAGING SYSTEMS AND THEIR APPLICATIONS [Ref. 36]

Active packaging systems	Intermediators
Scavengers	
Ethylene scavengers	$KMnO_4$ alone or on a silica support, silica gel, zeolite, activated carbon, kieselguhr, aluminium oxide, aluminium oxide
Oxygen scavengers	Unsaturated hydrocarbon, tocopherol, ascorbic acid, enzyme, iron, platinum and palladium catalysts
Moisture absorber	Organic compounds like fructose, sorbitol and cellulose pads, sodium carboxymethylcellulose (CMC) films, Inorganic material like silica gel, CaO minerals like potassium chloride, potassium carbonate (K_2CO_3), calcium chloride ($CaCl_2$) and bentonite sachets, polypropylene films with NaCl
Diffusion/emitter systems	
CO_2 emitter	$NaHCO_3$ and citric, ferrous carbonate in an acidic environment,
SO_2 emitter	Calcium sulphite and moisture, Metabisulphite and moisture
C_2H_5OH emitter	• Direct adsorption of ethanol on adsorbents such as silica to give emitter • For controlled release to prevent off flavour- Ethanol is mixed with sodium stearate and heated to form translucent ethanol gel + diatomite. This on cooling afforded ethanol emitter as a white powder. A controlled release ethanol emitter
Antioxidant emitting	• Synthetic antioxidants like Butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT), • Natural antioxidants like Tocopherol and ascorbic acid are integrated into polymer films like cellulose acetate for controlled release.
Antimicrobial emitting	Direct addition, Multilayer antimicrobial films • Lauramide arginine ethylester (LAE) films, Metals like gold, silver, copper, titanium dioxide and zinc oxide are antimicrobial. Silver zeolite, triclosan, glucose oxidase, chlorine dioxide, natamycin, and allyl isothiocyanate are widely used as active compounds in commercially available antimicrobial AP. • ZnO- Polylactic acid (PLA) nanocomposite coated paper as antimicrobial packaging material. • Essential oils extracted from coriander, clove, rosemary, oregano, lemongrass, tea tree, basil, and fennel are active antimicrobial additives. • Polypeptide based antibacterial substance for meat packaging • Chitosan alone or in addition with polyphenols, Vit-C and Vit-E, proanthocyanins with improved properties**.** • Carboxymethyl cellulose (CMC) and polyvinyl alcohol (PVA) films containing zeolite doped with silver or gold. • Lauroyl-L-arginine ethyl ester monohydrochloride (LAE)-zein based antimicrobial coating

TABLE-4
DIFFERENT TYPES OF FRESHNESS INDICATOR SYSTEMS AND THEIR APPLICATIONS

Indicator system	Advantage	Types	Ref.
Colour changing chemical indicator Food spoilage release reacts with the indicator, which changes its colour accordingly in real-time *e.g.*, bromophenol blue/red, phenol red, bromocresol green/violet, methyl red, polyaniline *etc*.	• Quick response • Distinct colour change • High stability • Indicators don't have contact with the food item.	**Single:** It contains a single pH indicator, which is highly sensitive to the wide pH range. **Hybrid:** They have more than one indicator to improve the sensitivity of the transition of colour from one stage of spoilage to another. Time Temperature Indicator (TTI): Keeps history of temperature maintained throughout, from packaging to consumption. Useful for cold storage chains. Attached on the surface of the packed product and accumulate the information about its exposure with temperature, change in colour shows food spoilage	[42-48]
Data-carrier indicator system They have optical readers, which read the saved information related to the freshness of the food and pass it on to the consumer.	• Enhanced data storage • no-contact type • non-metallic materials for data acquisition, Automatic identification of single/multiple products	**Sensors:** It can be a sensitive element, biological or chemical sensor. **Barcode:** A machine-readable optical symbol. It may be a sensory ink print base, Colorimetric indicator base or biological base like DNA attached to nanomaterials. Sensory tags for radiofrequency identification (RFID): It is a 'chip' technology, which can monitor the freshness level of food.	[48-52]
Natural colour indicator	• Safe and environment friendly because most of the chromogenic agents are natural and edible. • Direct contact with food is possible • Natural polymers are widely available, have low cost, are stable chemically, and are adaptable to different storage conditions.	**Natural pigment:** These are natural indicators like Anthocyanin, betaine chlorophyll, curcumin carotenoids *etc*. They are unstable but safer to use. Some of them viz. Polyvinyl alcohol, tara gum and curcumin, increase the shelf life of food owing to their antioxidant properties **Natural polymer carrier:** They mainly use polysaccharides, protein and composite membrane carriers.	[53-59]

to ascertain toxicological effect of the ingredients of active and intelligent food packagings. Natural products are biodegradable, safe, compatible with biological tissues. Therefore, the recent trend is to use these natural products to develop sustainable packings having natural pH sensing ingredients to monitor microbial action, polyphenols to provide antioxidant properties [60,61].

The increasing awareness towards environment and health has placed pressure on companies to transit to sustainability. It is nowadays, a global need in the packaging industry. Sustainability is the ability to maintain change in a balanced environment, in which resource exploitation, investment direction, technology development orientation and institutional change are all in the same patterns and help to satisfy present and future human needs and ambitions. In view of the need for the sustainable development, researchers have to work for reshaping the demand of the food packaging industry. Food spoilage and wastage have always been a big challenge for food supply chains. The need to reduce food waste has gained momentum after having experienced the scarcity of food during the Covid-19 pandemic. Also, pre-consumer and post-consumer wastes have to be distinguished. Consumer's demand for fresh, safe, hygienic and high-quality food having an extended shelf life with reduced waste of resources subsequently created the need for modernized packaging technologies like edible and nanocomposite based packagings [62,63].

Edible packaging: Edible packaging perfectly replaces the harmful synthetic polymer-based films by naturally occurring biopolymer (lipids, polysaccharides, proteins, *etc.*) based films. A lot has been done in the area of edible food packaging science, in the recent times [1,64]. The technique makes use of highly sustainable edible material as a coating or film around the food item, aiming to generate zero waste. This is a highly versatile method to provide safe and high-quality packaged food with some added value. The edible coating material is natural, mainly polymer derived and safe for human consumption. While edible films can be of different thicknesses, the coatings are an inherent part of the food component [1]. Choice of packaging material depends on the type of food to be packaged and its compatibility with the food items [64]. Edible coatings and layers are made of biodegradable materials, which may be derived from proteins, polysaccharides, lipids [2] microorganisms, from the biological monomers [65,66]. While polysaccharides are hydrophilic, lipids are hydrophobic and act as moisture barriers, whereas proteins enhance the mechanical strength. These materials have excellent property of forming films and can be used as it is or in the integration with other packaging materials. Composite materials have the advantages of two or more materials, one overcoming the limitation of the other. Additives, like colour, flavour or antimicrobial, antioxidant, nutraceuticals and prebiotic substances can also be added to improve functional properties, nutritive value and the shelf life of the product [67-70] (Table-5).

Nanotechnology in food packagings: Due to their dimensional features, adaptable mechanical, physical and chemical functions, the use of nanomaterials has also been explored in food industries. These smart materials possess a plethora of benefits over traditional materials by modifying and enhancing their temperature and heat resistance, barrier properties, antimicrobial spectrum, shelf life and providing safer delivery systems for active components in an affordable and sustainable way [81-84]. Nano-emulsions, nano-liposomes, nanoparticles and nano-fibers are usually reported as nano-carriers [85].

Of all nanomaterials, nanocomposites are the most popular and dependable nanomaterials for food packaging. These are a combination of nanomaterial with the traditional packaging materials, mostly polymeric, used to improve their packaging properties keeping safety and environmental issues into consideration [86]. They are being developed in different shapes and dimensions depending upon the type of nanomaterial used.

Organic and inorganic nanomaterials like clay, silica, carbon nanotubes and graphene are being used as fillers in combination with polymeric materials (synthetic/biological) yielding polymeric nanocomposites, a new class of packaging system [86]. Metal/metal oxide/hybrid metal-metal oxide/organic molecules (fat/protein/starch) have been integrated into polymer matrix to enrich their functional properties. Table-6 represents various inorganic/organic/hybrid nanomaterials with their applications when incorporated with synthetic and natural polymer matrix.

Silver, gold, iron, gallium, palladium, copper, TiO_2, Al_2O_3, iron oxide and copper oxides have been widely used to improve the physico-chemical and barrier properties of edible coatings/films and as an encapsulation to deliver active ingredients [110,111]. Silver nanoparticles, a well-known antibacterial

TABLE-5
ADDITIVES AND THEIR FUNCTION

Additives	Function	Ref.
Plasticizer: Monosaccharides, oligosaccharides, polyphenols and lipids	Enhances flexibility and resilience	[1,71]
Emulsifier: Lecithin, sugar esters, glycerol monooleate, acetylated monoglyceride, glycerol mono-palmitate/stearate, polysorbates, sodium lauryl sulfate, and sorbitan mono-oleate/stearate	Helps in the emulsification of the composite films to provide better adhesion to the coating	[65,72,73]
Texture enhancer: Calcium salts	Improves texture	[74,75]
Antioxidant: Plant extracts, essential oils, α-tocopherol, ascorbic and citric acid	Reduces the rate of oxidation of food	[76-79]
Antimicrobial: Lactic acid bacteria (LAB) or yeasts like *Saccharomyces cerevisiae* var. boulardii, *Debaryomyces hansenii*, *Torulaspora delbrueckii*, *Kluyveromyces lactis*, *Yarrowia lipolytica, S. cerevisiae, Kluyveromyces marxianus* or *Kluyveromyces lodderae*, essential oils	Kills microbes	[2,80]
Nutraceutical: Omega-3 fatty acids (anti-inflammatory), casein (anti-atherosclerotic), pectin (cardiovascular-support), polyphenols, ascorbic acid (antioxidant), capsaicin (anticarcinogenic), β-carotene (immunity enhancer)	Provides nutritional and health benefits	[70]

TABLE-6
RECENT EXAMPLES OF SOME POLYMER NANOCOMPOSITES AND THEIR APPLICATIONS AS PACKAGING FILMS

Nanomaterial and its properties	Polymer matrix used/food item tested	Properties of the developed film	Ref.
Metal-polymer nanocomposites			
Gold nanoparticles: Catalytic, oxidative, medicinal and antimedicinal, oxidative catalytic, and antibacterial properties, as well as their inert and non-toxic nature which can fix defects of other nanoparticles But not Cost effective	Lignocellulose-fiber / Cavier	Improved antioxidant activity by radical scavenging	[87]
Silver nanoparticles: Excellent and broad-spectrum antimicrobial agent against a variety of fungi, viruses, bacteria and moulds	Polylactic acid and oligomeric Lactic acid matrix/ Not given	Boost in antimicrobial activity, mechanical and thermal properties of the packaging material with enhanced and visible degradation of the film after ~ 1 month	[88]
	Chitosan/ grapes	Shelf life was extended while restoring the quality of grapes. Substantial inhibition in microbial growth.	[89]
Copper nanoparticles: Antimicrobial, catalytic, surface active, sensors, antifouling properties But toxicity effect, specially on aquatic animals, limits its use	CuS nanoparticles-Carrageenan Matrix/ Packaged beef	Film with increased transparency, sufficient mechanical properties and thermal stability, reduction in bacterial population.	[90]
Sulphur nanoparticle: Bectericidal against variety of species, non-toxic for human cell.	Alginate matrix/Not given	Better tensile and water- vapor barrier properties, Significant increase in UV barrier characteristics and antimicrobial activity.	[91]
Metal oxide-polymer nanocomposites			
Zinc oxide nanoparticles: Posses unique catalytic, electrical, optical, photochemical and anti-fungal /bacterial properties.	Chitosan-gelatin matrix/not given	Wide spectrum antimicrobial activity against with improved thermal stability and elongation at break. Although tensile strength decreased slightly.	[92]
	Starch-PVA matrix/not given	Better mechanical, water resistant and antimicrobial properties along with pH sensing capability.	[93]
	Starch and Xyloglucan/ Tomato	They exhibited strong antimicrobial action, improved water vapour barrier and mechanical strength properties.	[94]
Ag-ZnO nanoparticles: (Hybrid metal/metal oxide)	Starch/ PBAT (poly -butylene-co-terephthalate)/Peach, nectarines	Better antimicrobial efficiency, improvement in mechanical and barrier properties	[95]
Magnesium oxide nanoparticles: Low cost, more surface area, low toxicity, and excellent reactivity making them a good catalyst and antimicrobial agent.	Carboxy-methyl Chitosan matrix- Not given	Increased tensile power, UV, O_2 shielding and antimicrobial action, water resistance	[96]
Silicon dioxide nanoparticles: Great adhesion, catalytic, reinforcing, anti-binding/foaming, viscosity control and desiccant properties	Chitosan D-α-tocopheryl PEG 1000 succinate/ Soyabean oil	Increased tensile strength, lowered moisture content, water vapour and oxygen permeability. It also showed enhanced free radical scavenging. Prevented rancidity of soyabean oil during its storage while increasing antimicrobial activity	[97]
Titanium dioxide nanoparticles: Economical, abundant and safe to use. Traditional food colouring additive, photocatalytic, non-toxic, ecofriendly.	Chitosan-cymbopogon citrus essential oil bio-nanocomposite film / minced meat for refrigeration	Increased water vapour permeability reducing elongation at break. Prevents growth of total bacteria in minced meat during storage.	[98]
	PVA and locust bean gum containing betacyanins/ Shrimp	This double layer film indicated freshness by colour change. Excellent antioxidant properties owed to betacyanin. Enhanced barrier and mechanical properties due to TiO_2 nanoparticles.	[99]
Zeolites: Available in abundance, having excellent catalytic, adsorption, ion exchanging and medicinal properties. Presence of impurities limit their usage.	Cassava starch matrix containing polybutylene adipate terephthalate and citric acid/ Brocolli fresh florets	Active film which restored the Vit- C and color and reduced the metabolism of broccoli florets for a week; enhanced its elongation at break.	[100]

Nanoclay (montmorillonite): Their easy adaptability with other polymers, better diffusion into the polymeric layers, cost effectiveness.	β-carotene matrix containing capsicum essential oil/ Butter	This colour indicating (due to the presence of β-carotene) smart packaging film had good flexibility, and firmness with enhanced antibacterial and antioxidant activity capable of detecting oxidation with time.	[101]
Graphene oxide nanoparticles: Owing to their own unique chemical (large surface area having many functional groups like carbonyl, hydroxy, epoxy *etc.*), thermal, electrical and mechanical characteristics, they are used as nanofillers in bionanocomposites.	Chitosan matrix/ Melon fruit	Films were prepared and then bags were made out of them to store melon. It Improved shelf-life of melons, reduced bacterial growth and water vapor permeability. These bags were biodegradable and had better tensile strength.	[102]
Biomolecules-organic based nanocomposites			
Nanocellulose fiber: Non-toxic, abundantly available, biologically compatible, sustainable.	Chitosan-curcumin matrix/Not given	Film had high crystallinity, oxidation and UV- rays resistance along with the excellent antibacterial action.	[103]
	Anthocyanine (from purple colored sweet potato- oregano oil matrix/ Not given	This film also showed improved activity against microbes, ultraviolet and visible light with improved elasticity and tensile strength.	[104]
Chitosan nanoparticles/Nanofibers: Widely available, biodegradable, antimicrobial, non-toxicity.	Starch matrix/cherry tomatoes	Efficient antimicrobial action. Action was more effective in the case of Gram-positive bacteria.	[105]
	Zein matrix- pomegranate peel extract encapsulation-/Pork storage	The film manifested better thermal properties and inhibited the growth of bacteria L. (monocytogenes) throughout storage due to the prolonged and uniform release of pomegranate polyphenols which was achieved through cold plasma therapy.	[106]
	Methyl cellulose-anthocyanine (from saffron petals/berberry) / Meat/sea food	This pH-sensitive membrane showed Increased mechanical, antimicrobial, antioxidant, water barrier and UV–vis barrier properties besides prolonging the shelf life of food.	[107,108]
Starch nanocrystals: Renewable, non-toxic, cheap biocompatible/degradable, better solubility and absorptivity, reaction surface and biological penetration.	Starch matrix-Not given	Increase in tensile strength, decrease in water vapour permeability.	[109]

agent, has been employed with artificial as well as biological polymer matrix to yield food packaging with improved qualities [88,89]. Titanium dioxide nanoparticles are efficient photocatalysts, non-toxic, ecofriendly and excellent UV-rays barrier when have been found to provide antimicrobial action, better barrier properties and photodegradation of oxygen and ethylene gas from packaging thus increasing shelf life [112,113]. Nanoclays (multilayered mineral silicates) mimic thermoplastics therefore, they are widely used in packaging [114]. These silica nanoparticles are cost-effective and easily accessible. Their blend with polymer imparts the excellent barrier properties, mechanical and physical strength and impermeability for released atmospheric gases and vapours. With additives, these nanocomposites behave as active and smart materials [115-117]. Carbon nanotubes, because of their versatility and in-built bactericidal activity, when integrated with polymeric materials, have exhibited improved properties, making them suitable for storing and preserving cooked food [115].

Food grade biological nano-polymers like nano-starch, nano-protein, curcumin and nano-chitosan, protein nanoparticles have also been researched due to their low cost, stability, non-toxicity, ease of availability, non-persistence and degradability (Table-6). Nano-starch is used as nanofillers/crystals in combination with clay to improve water-resistant properties, flexibility, barrier and thermal features of polymeric matrix; titanium oxide nanoparticles and carboxymethyl cellulose concentration (CMC) as stabilizers to further improve water permeability along with the tensile strength [118,119]. Nanocelluloses are the plant polysaccharide derived nanomaterials, used as nanofibers, hydrophilic in nature and impart excellent barrier properties to matrix [111]. Protein nanoparticles are responsible to increase strength, moisture and temperature resistance [120] Chitosan nanoparticles are antimicrobial, non-toxic, ecofriendly, renewable, hydrophobic and capable of forming covalent bond with biopolymer film to prevent diffusion of moisture into the packaging [111].

Incorporation of nanomaterial into active and intelligent packaging further enhances the communication system of the packaging [121,122]. Nanosensors/indicators can be used to provide real-time information about the leakage, microbial action, temperature and humidity exposure, ensuring safety and preventing food spoilage and waste generation [123-128]. Antimicrobial agents and vitamins have been introduced as active ingredients using nanoencapsulation made of natural nanopolymers like chitosan and zein [87,129].

Besides the tremendous applications, nano-based packaging has some limitations too. Nanoparticles, because of their enormous surface-to-volume ratio, may migrate into the food through packaging material and impose serious health problems depending upon their nature, exposure time and body's immunity [130]. Silver nanoparticles slowly release, through packaging, to impart action against microbes [131]. Their migration into food may cause neurotoxicity, brain, liver and kidney disfunction. Nanoclays, due to better diffusion properties, may also migrate into food leading to cytotoxicity [132]. The field of migration into food as well as environment and toxicological effect of nanomaterial is still not sufficiently explored. It needs urgent attention.

Conclusion

Sustainability is a major area of concern, especially after the recent pandemic of COVID-19. We often come across pictures of plastic packets of chips, chocolates and other polyethylene packaging clogging drains and populating landfills. This mostly impacts the low- and middle-income countries and the low- and middle-income areas within them. Thus, it affects the poorest of the poor the most. This makes it imperative that the material used for most of the food packaging is replaced by more sustainable alternatives. In furtherance of the same need, this review article looks at the various trends in food packaging as they have emerged over the years, starting with conventional packaging to active packaging, intelligent packaging and sustainable packaging, including edible packaging and bio-nano based packaging. Reusable and refillable containers are the classic solution to the problem of unsustainable packaging, which will help decrease the carbon footprint and improve the brand image. Wishes of consumers influence product sales and the packaging is a powerful sales tool. Thus, it is necessary that consumers, too, leverage such a position for the end goal of sustainability. It has to be a holistic approach while adopting sustainability as a virtue. This virtue needs to be adopted in the place we live, to the products we use in our daily life.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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