PROSPECT OF NANOTECHNOLOGY IN FOOD PACKAGING

Abstract

Nanotechnology is a revolutionary technology that has the power to transform our lives in countless ways. It's potential to improve health, wealth, products, and food is immense. However, it is surprising that food nanopackaging, an area with immense possibilities, has not been explored to its full potential yet in the fields of nanoscience and food science. This chapter covers bio-based packaging technology with potential applications in the industry. The utilization of bio-based packaging as an alternative to conventional packaging has emerged as an effective solution to mitigate the environmental hazards posed by non-degradable plastic polymers. Bio-based packaging offers the ability to reduce waste, extend the shelf life of products, and improve their quality. Further, enhancing its properties, nanomaterials can be employed to improve the packaging's barrier properties, mechanical strength, flexibility, and stability. Its implementation could enhance food quality, safety, and sustainability.

Keywords: Nanotechnology, nanopackaging, nanoscience, bio-based packaging

Author

Richa Singh
Department of Food Science and Nutrition
Chandra Shekhar Azad University of Agriculture and Technology
Kanpur, Uttar Pradesh, India
richa81196@gmail.com

I. INTRODUCTION

Nanotechnology has undoubtedly revolutionized the food industry in recent years. It involves harnessing the power of particles that measure between 1-100 nm to create materials with exceptional properties. The size of the nanometers facilitated the examination and handling of materials at the nanoscale. Nanomaterials have unique properties because of their high surface-to-volume ratio, making them a fascinating area of study. These unique physiochemical features set them apart (Gupta *et al.,* 2016). The economic revolution driven by nanotechnology has sparked global interest and investment. The implementation of nanotechnology has the potential to enhance food processing, resulting in better nutrient stability and increased bioavailabilty. Nanoparticles possess outstanding mesoscopic properties, including remarkable surface area, reactivity, strength, quantum effects, and ductility. They are extensively utilized innumerous industries (Omerović *et al.,* 2021). The field of science has benefited greatly from research on nanomaterials, including their synthesis, categorization, applications, and assessment. Nanomaterials have revolutionized the agri-food industry with their exceptional physicochemical and biological properties, enabling them to carry out diverse functions. Nanomaterials have proven to be valuable asset to the field of science, particularly in the realm of agri-food industry. Their unique properties have enabled them to effectively perform key function such as synthesis, categorization, applications, and assessment, ultimately transforming the industry (Bouwmeester *et al.,* 2018). The utilization of nanotechnology holds immense potential in the areas of detecting food-related illnesses, developing nutritional plans for seniors, and achieving sustainable food production through nanoencapsulation. Various food additives such as preservatives, flavoring agents, encapsulated food ingredients, antimicrobial sensor, packaging compounds, and nanoparticles are employed to enhance the nutritional value, aroma, texture, and keeping qulaity of food products.

II. NANOTECHNOLOGY'S ROLE IN ENHANCING FOOD PACKAGING

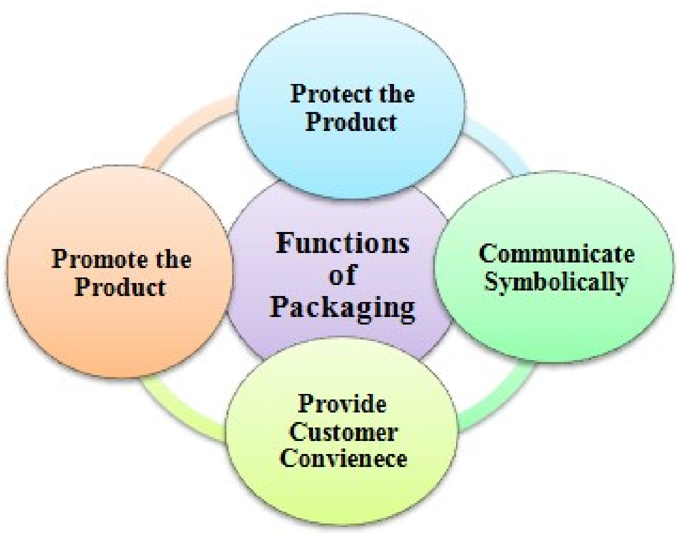

Figure 1: Functions of the Packaging

Packaging plays a vital role in safeguarding, systematizing, conveying, and identifying goods across the complete supply chain, starting from the initial materials to the final consumers (Figure 1). When it comes to packaging and preserving item, it is essential to take into account the mechanical, thermal, and barrier specification. These requirements are crucial to ensure that the items remain intact and protected throughout the packaging and transportation process.

Ensuring food safety heavily relies on appropriate packaging. It must be recognized that all packaging substances are susceptible to certain degree of penetration by natural elements, atmospheric gases, and water vapor. To ensure the preservation of fresh fruits and vegetables during cellular respiration, it is imperative to avoid any gas migration and permeability. For the preservation of carbonated beverages, it is imperative that the packaging is designed to obstruct the passage of oxygen and CO 2. The regulation of CO_2, oxygen, and water vapor flow in food packaging can be effectively managed with the use of nanocomposite materials like polymers. Such materials possess the capability to tackle the numerous complexities that surface during this process (Abbaspour *et al.,* 2015). To increase the time that products can be stored, it is advisable to produce nanopackaging that can dispense antimicrobials, antioxidants, enzymes, flavors, and nutraceuticals (Figure 2).

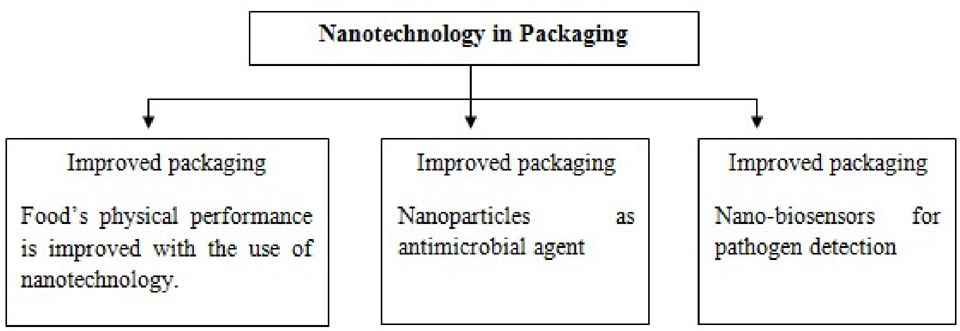

Figure 2: Application of Nanotechnology in Food Packaging

The majority of current food packaging materials are comprised of non-biodegradable plastic polymers derived from petroleum, which presents a significant environmental threat. Employing bio-based packaging made from renewable resources is a crucial step towards reducing packaging waste and enhancing food quality. Edible and biodegradable films can effectively extend the shelf life of food products, making it easier for us to enjoy fresh and nutritious food for longer periods. This innovative approach has immense potential and must be implemented to achieve a significant and lasting improvement in our environment and food industry.

Nanoparticles are becoming increasingly prevalent in food packaging due to their enhanced functional capabilities. Presently, there are 500 nano-packaging items commercially available, and it is a fact. A recent study has revealed that within the next decade, 25% of all food packaging will be manufactured using nanotechnology (Reynolds. 2007). Nanotechnology is a highly effective method for increasing the longevity of products. By releasing antimicrobial, antioxidants, enzymes, flavors, and nutraceuticals, this technology ensures that product remain fresh and safe for use for an extended period of time.

The packaging industry overwhelmingly relies on non-biodegradable plastic polymers that are derived from petroleum, which pose a environmental threat. It is important to recognize that non-biodegradable food packaging materials have infected considerable damage to the environment (Kirwan and Strawbridge. 2003). The utilization of biodegradable packaging materials can be an effective solution to address this problem. Using bio-based packaging materials, like edible and biodegradable films made from renewable resources, can help reduce packaging waste and increase keeping quality of the food products. There exists a potential solution to address the issue of waste and enhance the quality of food.

III. BIO-BASED PACKAGING

Bio-based packaging offers a safeguard against various environmental factors that could compromise the quality and freshness of food products. By creating a barrier that shields against bacterial growth, humidity, and gas conditions, this type of packaging effectively protects the contents within. Although biodegradable materials are the ideal option for packaging, they must be improved due to their poor mechanical and thermal resilience, low gas and water barrier properties. The limitations of biopolymer have been overcome through the incorporation of nanofillers, which has led to the creation of bio-nnocomposites (Sharma *et al.,* 2017). The nanoreinforceent of biopolymers has been done using nanofillers such as nanoclay and layered silicate nanoparticles (montmorillonite (MMT)) (Fortunati *et al.,* 2018). To enhance the durability and effectiveness of polymer packaing, the technique of nanoreinforcement is employed to fill the gaps between the polymer molecules with nanofillers. Bio-based materials can be derived from renewable or non-renewable sources, and while certain types possess the property of biodegradability, others do not exhibit this characteristic.

In accordance with their sources, bio-based polymers can be divided into three types

- Naturally produced polymers (proteins, polynucleotides, polysaccharides etc.)
- Polymers produced from bio-monomers or chemical synthesis from bio based monomers (bio-polyesters, PLA,PBS,PVA,PGA (polyglycolic acid))
- Polymers extracted from microorganisms or genetically modified organism (GMOs) (PHB, xantha, PHA (polyhydroxyalkonoates)) (Reddy *et al.,* 2013)

Bionanocomposites: Bio-nanocomposites, such as PLA, PHB, and PBS, among others, that are based on chitosan, proteins, cellulose, and starch have lately come under notice for their improved performance in food packaging. Antioxidants, oxygen scavengers, antibacterial activity, scent, color, and other biologically active substances may be added to bio-nanocomposites to increase biochemical packing and active functionalities.

1. **Natural Bio-Nanocomosites:** Sustainable packaging applications have acknowledged the potential of numerous natural polymers including starch, chitosan, cellulose, and proteins, along with naterials like nanoclay and zein. These polymers have been recognized for a number of uses in food packaging, which are thoroughly covered in the sections below.

   - **Nanocomposites based on Starch:** The most popular polysaccharide used for biodegradable packaging is starch. It is a plentiful, affordable, recyclable, and environmentally beneficial polymer for packaging. However, starch-based polymers have several key limitations, including poor mechanical and barrier qualities, sensitivity to UV and moisture, and low durability (Flores et al., 2007). Starch has been modified to have better mechanical and barrier qualities by adding nanoparticles like ZnO, TiO2, Graphene, and poly (methyl methacrylate-co-acrylamide).

The rle of starch and other bio-based nanocomposites in improving polymer properties is highlighted in table 1, which contains the latest reserach.

Table 1: Starch based Bionanocompsites for Packaging and their Application in Food Industry

Polymer matrix	Source	Properties	Nanomaterial	Refrences
Starch & PVA	-	Antimicrobial,mechnical, tensile strength	Nano TiO_2	Liu *et al.,* 2015
Starch	Potato	Mechanical thermal	Starch nanocrystals	Sessini *et al.,* 2016
Starch	Pea	Mechanical barrier	Starch-PVA blend	Cano *et al.,* 2015
Starch	Cassava	Mechanica,watervapor permiability	Starch nanocrystals	Garcia *et al.,* 2009
Starch	-	Thermal mechanical, hydrophobicity, water vapor permeability	Starch/TiO_2 nanocomposites	Goudarzi *et al.,* 2017
Starch	Corn	Hydrophobicity	Poly vinyl chloride (PVA)loaded with anao size poly (methyl methacrylate-acrylamide)	Yoon *et al.,* 2012

- **Chitosan based Nanocomposites:** Another natural polysaccharide, chitosan, is produced by deacetylating chitin, a plentiful biopolymer. It is a polymer that is both biocompatible and biodegradable and has antibacterial qualities. Biocompatible and biodegradable films, coatings, compostie materials, and nanocomposites have been produced using chitosan and chitosan-based systems (Wang *et al.,* 2018).

Table 2: Chitosan based Bionanocompsites for Packaging and their Application in Food Industry

Polymer matrix	Source	Properties	Nanomaterial	Refrences
PVA-chitosan	Marine source	Mechanical gas barrier	TiO_2 NPS	Lian *et al.,* 2016
Chitosan	Marine sources	Mechnical transparency	Cellulose micro/nano fibers	Fernandes *et al.,* 2009
		Tensile strength, mechanical, water permeability	Cellulose nanocrystals (CNC)	Khan *et al.,* 2012
		Mechnical, water vapor permeabilty, antibacterial	BC micro/nano fibers	Fernandes *et al.,* 2009
		Mechanical water vapor pemeability	Chitin whiskers	Rubentheren *et al.,* 2015

- **Cellulose based Nanocomposites:** The environment is abounding in cellulose, a natural polymer made of glucose monomers. Because pure cellulose lacked the desirable properties for packaging applications, cellulose derivatives like CNC (Cellulose nanocrystals) have been most frequently used as fillers for the reinforcement of polymer matrices (Brinchi *et al.,* 2013). Thus, CNC increased the polymeric matrix's mechanical, barrier, and thermal properties as a result (Duran *et al.,* 2011). As shown in Table 3, numerous nanocomposites have been created utilizing CNC and various metals/metal oxides (such as Fe3O4, TiO2, etc.), metal nanoparticles (such as Ag), MMT, and nanoclay to provide enhanced or modified packaging.

Table 3: Cellulose based Bionanocompsites for Packaging and their Application in Food Industry

Polymer matrix	Source	Properties	Nanomaterial	Refrences
Cellulose		Antimicrobial, antioxidant	Ag NPs, grapes seed extract (GSE), 2,6,6-tetranethylypiperidine-1-oxyly (TEMPO)-oxidised nano-cellulose (TNC)	Wu *et al.,* 2019
Cellulose	-	Water permeability, oxygen barrier	Surfactant modified CNC	Fortunati *et al.,* 2012
Cellulose	Mango leaf	UV-light protection and antioxidant properties	Nanobrillated cellulose films with mango leaf extract (NFC-MLE)	Bastante *et al.,* 2021
Carboxymethyl cellulose	-	Water vapor and UV barrier, mechanical, antioxidant, extended the shelf-life of high-fat meats	ZnO NPs and grape seed extract (CMC/ZnO/GSE)	Priyadarshi *et al.,* 2023
Cellulose		Mechanical, thermal, barrier, migration	PHBV-CNC-me (Functionalized methyl ester)	Yu *et al.,* 2014

- **Protein based Nanocomposites:** Bio-based packaging and bionanocomposite have been made using wheat gluten, lectins, corn zein, soy, and sunflower protein (Table 4). Because they have weak mechanical and barrier qualities, protein-based packaging other than maize zein and keratin is less common. Consequently, plasticizers are typically utilized to enhance protein- based polymer matrices. Zein is a potential reinforcement agent because of its hydrophobic properties, and the Food and Drug Administration (FDA) has deemed it safe for packaging (Chuacharoen *et al.,* 2016).

Table 4: Protein based Bionanocompsites for Packaging and their Application in Food Industry

Polymer matrix	Source	Properties	Nanomaterial	Refrences
Protein	Whey protein isolate	Mechanical, water vapor permeability	Nanoclay	Sothornvit *et al.,* 2009
	Soyabean	NPs	ZnO	Tang *et al.,* 2019
	Gelatin	Mechanical, hydrophobicity	Bacterial CNC	George *et al.,* 2012
	Soy protein isolate (SPI)	Mechniacl water vapor permeability	Exfoliate MMT (montmorillonite)	Kumar *et al.,* 2010
	Wheat gluten (WG)	Uv resistance, water senstivity, mechnaical	Lignin NanoParticles (LNPs)	Yang *et al.,* 2015
	Whey protein isolate (WPI)	Mechnaical, water vapour permeability	Nanoclay	Sothornvit *et al.,* 2009

- **Nanoclay based Nanocomposites:** Since they are made of layered phyllosilicate clays, nanoclays, notably MMT, are widely employed as nanofiller. A material called nanoclay can greatly enhance the properties of polymeric matrices, including young's modulus, elastic modulus, thermal stability, and barrier properties. Nanoclay can be added to polymeric materials through various methods, including in situ polymerization, melt intercalation, and solution intercalation. Several studies have shown that incorporating nanoclay into polymer matrices, such as polyactic acid (PLA) and ethylene vinyl alcohol (EVOH) improves the oxygen barrier and increases the shelf life of food. Due to the tortuous path of diffusion that clay reinforcement creates, nanoclay-based composites typically contain 5% weight-weight nanoclay particles, resulting in a drop in permeability of 80–90% (Cui *et al.,* 2015).

2. **Synthetic Bio-Nanocomposites:** Since plastic usage has led to major health risks and environmental contamination, many researchers have been interested in bioplastics. Therefore, biodegradable or renewable polymers became popular as a replacement for plastic that was based on petroleum. Through the process of microbial activity, bioplastics and biopolymers have the ability to decompose into organic substances such as carbon dioxide, hydrogen, and water (Peelman *et al.,* 2013).

Table 5: Synthetic Bio-Nanocomposites and their use in Bio-Based Packaging

Synthetic bio-nanocomposites	Nanomaterial/Nanoparticles (NPs)	Polymer matrix	Properties
Polylactic acid (PLA) based nanocomposites	Ag-chitosan NPs	PLA (polylactic acid)	Antimicrobial
	Nanoclay		Antibacterial
	Cellulose nanowhiskers		Water vapor, oxygen barrier
	Ag-zeolite NPs		Antimicrobial
	Ag NPs		Antimicrobial
Polyhydroxyalkonoates (PHA)	ZnO NPs	PHBV (poly 3-hydroxybutyrate-co-3-hydroxyvalerate)	Mechanical, thermal, crystallization, antimicrobial
	Ag NPs	PHBV	Antimicrobial
Mixed polymers	Organomodified clay	PLA/PCL (polcaprolactone) blend	Biodegradation rate, oxygen permeability, thermal, rheological
	CNC and surfactant modified CNCs	PLA-PHB blend	Mechanical, film stretchability, oxygen and water barrier

Source: Chausali *et al.,* 2022

IV. CONCLUSION

In food science and research, there have been enormous advancements in the use of nanotechnology. Bio-based packaging is a sustainable and biodegradable alternative to traditional plastic packaging. The next generation of packaging provides a solution to the issues of persistent material degradation and the need to reduce plastic waste. There are different types of biodegradable and biocompatible packaging materials that fall into four main categories. These categories include biopolymers derived from microorganisms or genetically modified organisms such as PHA, PHB, PHBV, and xanthan. Another category is synthetic biopolymers such as bio-polyesters, PVA, PBS, PLA, PGA, and others. Natural biopolymers such as polysaccharides, polynucletides, protein, and other fall into a third category. Lastly there are biopolymers that are made from a combination of these substances. Therefore, to create the perfect packaging, it is important to improve bio-based packaging materials through research and development.

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