**Prospect of Nanotechnology in Food Packaging**

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**Introduction:**

Nanotechnology is now widely recognized as a revolutionary technology in the food industry, gaining popularity over the past few decades. Nanotechnology is the study of using particles that measure between 1-100nm to create materials with outstanding properties. The size of the nanometers, facilitated the examination and handling of materials at the nanoscale. Nanomaterials possess distinct characteristics when compared to their macroscale counterparts due to their surface-to-volume ration and diverse properties properties. These unique physiochemical features set them apart (Gupta *et al.,* 2016). The new economic revolution that is being driven by nanotechnology has caught the attention of both developed and developing countries, and they are eager to invest in it. Nanotechnology provides alternative methods to enhance the physicochemical properties of food processing, as well as increase nutrient stability and bioavailability. 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. In recent years, nanomaterials have been utilized to enhance and transform the entire agri-food industry, with their unique physicochemical and biological properties enabling them to perform a wide range of important 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). Nanotechnology plays a crucial role in the detection of food-related illnesses, devising nutritional plans for the elderly, and ensuring 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 shelf life of food products. Additionally, these additives can also aid in the identification of food pathogens, which is crucial for maintain high food quality standards.

**Application of Nanotechnology in Food Packaging:**

Packaging system is essential for protecting organizing, transporting, and labeling products across the entire supply chain, from raw materials to end users (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.

**Figure 1: Functions of the Packaging**

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. It is imperative to avoid blocking the migration and permeability of gases when packaging fresh fruits and vegetables that undergo cellular respiration. 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 CO2, 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). Nanopackaging must be deigned to release antimicrobials, antioxidants, enzymes, flavors, and nutraceuticals in order to extend the shelf life (Figure 2).

**Figure 2: Application of Nanotechnology in Food Packaging**

**Nanotechnology in Packaging**

Improved packaging

Nano-biosensors for pathogen detection

Improved packaging

Nanoparticles as antimicrobial agent

Improved packaging

Food’s physical performance is improved with the use of nanotechnology.

*Source*: Singh *et al.,* 2017

The majority of current food packaging materials are comprised of non-biodegradable plastic polymers derived from petroleum, which presents a significant environmental threat. Utilizing bio-based packaging materials, such as edible and biodegradable films derived from renewable resources, is crucial in reducing packaging waste and enhancing food quality by extending its shelf life. 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. In particular, non-biodegradable food packaging materials have had a devastating impact on the planet (Kirwan and Strawbridge. 2003). However, the solution to this problem lies in the use of biodegradable packaging materials, which can effectively mitigate this issue. As a result, the adoption of bio-based packaging material, such as edible and biodegradable films made from renewable resources, might, at least in part, solve the waste problem by lowering packaging waste and increasing shelf life, which in turn would improve food quality.

# Bio-Based Packaging:

Bio-based packaging works similarly to other types of packaging by establishing a barrier between a food product and its surroundings, protecting it from pollutants such as bacterial growth, ambient relative humidity, and gas conditions. 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. To overcome these limitations, bio-nanocomposites were produced by the incorporation of nanofillers into biopolymer (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). In order to increase the strength and viability of polymer packaging, nanoreinforcement involves filling the space between polymer molecules with nanofillers. Bio-based materials can be produced using renewable or non-renewable resources, and although some exhibit biodegradability, others do not.

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

1. Polymers produced from natural sources (proteins, polynucleotides, polysaccharides etc.)
2. Polymers produced from bio-monomers or chemical synthesis from bio based monomers (bio-polyesters, PLA,PBS,PVA,PGA (polyglycolic acid))
3. 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.

### Natural bio-nanocomosites:

Applications for sustainable packaging have been recognized for natural polymers such starch, chitosan, cellulose, proteins, and materials like nanoclay and zein. These polymers have been acknowledged for a number of uses in food packaging, which are thoroughly covered in the sections below.

**1.1 Starch based nanocomposites:**

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 most current studies on starch and other bio-based nanocomposites and their role in enhancing polymer properties are shown in Table 1.

**Table 1: Starch based bionanocompsites for packaging and their application in food industry**.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Polymer matrix** | **Polymer source** | **Nanomaterial** | **Improved proerties** | **Refrences** |
| Starch | Cassava | Starch nanocrystals | Mechanica,watervapor permiability | Garcia *et al.,* 2009 |
| Starch | Corn | Poly vinyl chloride (PVA)loaded with anao size poly (methyl methacrylate- acrylamide) | Hydrophobicity | Yoon *et al.,* 2012 |
| Starch | Pea | Starch-PVA blend | Mechanical barrier | Cano *et al.,* 2015 |
| Starch | Potato | Starch nanocrystals | Mechanical thermal | Sessini *et al.,* 2016 |
| Starch | - | Starch/TiO2 nanocomposites | Thermal mechanical, hydrophobicity, water vapor permeability | Goudarzi *et al.,* 2017 |
| Starch & PVA | - | Nano TiO2 | Antimicrobial,mechnical, tensile strength | Liu *et al.,* 2015 |

**1.2 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. Chitosan and chitosan based systems have been used for producing biocompatible or biodegradable films, coatings, composite materials, and nanocomposites (Wang *et al.,* 2018).

**Table 2: Chitosan based bionanocompsites for packaging and their application in food industry**.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Polymer matrix** | **Polymer source** | **Nanomaterial** | **Improved proerties** | **Refrences** |
| Chitosan | Marine sources  | Chitin whiskers | Mechanical water vapor pemeability | Rubentheren *et al.,* 2015 |
| Cellulose micro/nano fibers | Mechnical transparency | Fernandes *et al.,* 2009 |
| BC micro/nano fibers | Mechnical, water vapor permeabilty, antibacterial | Fernandes *et al.,* 2009 |
| Cellulose nanocrystals (CNC) | Tensile strength, mechanical, water permeability  | Khan *et al.,* 2012  |
| PVA-chitosan | Marine source | TiO2 NPS | Mechanical gas barrier | Lian *et al.,* 2016 |

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

**3.4 Protein based nanocomposites:**

Bio-based packaging and bionanocomposite have been made using wheat gluten, lectins, corn zein, soy, and sunflower protein. 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** | **Polymer source** | **Nanomaterial** | **Improved proerties** | **Refrences** |
| Protein | Whey protein isolate (WPI) | Nanoclay | Mechnaical, water vapour permeability | Sothornvit *et al.,* 2009 |
| Soy protein isolate (SPI) | Exfoliate MMT (montmorillonite) | Mechniacl water vapor permeability | Kumar *et al.,* 2010 |
| Gelatin | Bacterial CNC | Mechanical, hydrophobicity | George *et al.,* 2012 |
| Whey protein isolate | Nanoclay | Mechanical, water vapor permeability | Sothornvit *et al.,* 2009 |
| Wheat gluten (WG) | Lignin NanoParticles (LNPs) | Uv resistance, water senstivity, mechnaical | Yang *et al.,* 2015 |
| Soyabean | ZnO | NPs | Tang *et al.,* 2019 |

**3.5 Nanoclay based nanocomposites:**

Since they are made of layered phyllosilicate clays, nanoclays, notably MMT, are widely employed as nanofiller. A potential reinforcement agent known as nanoclay has been shown to significantly increase the properties of polymeric matrixes (such as young's modulus, elastic modulus, thermal stability, water and gas barrier, etc.). Numerous methods, including in situ polymerization, melt intercalation, and solution intercalation, can be used to incorporate nanoclay into polymeric materials. Numerous researches have revealed that adding nanoclay to polymer matrices like PLA (polyactic acid) and ethylene vinyl alcohol (EVOH) increases the oxygen barrier and, as a result, extends 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. By the action of microorganisms, bioplastics and biopolymers can breakdown into organic compounds, carbon dioxide, hydrogen, and water (Peelman *et al.,* 2013).

**Table 5 : Synthetic bio-nanocomposites** **and their use in bio-based packaging:**

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

**Source:** Chausali *et al.,* 2022

**Conclusion:**

 In food science and research, there have been enormous advancements in the use of nanotechnology. A sustainable substitute for traditional plastic or non-biodegradable packaging materials is bio-based packaging, which is the next generation of packaging. A sustainable solution to the problems of persistent material degradation and plastic waste reduction is provided by the next generation of packaging. The main categories of biocompatible or biodegradable packaging materials include biopolymers extracted from microorganisms or genetically modified organisms (PHA, PHB, PHBV, xantha, etc.), synthetic biopolymers (bio-polyesters, PVA, PBS, PLA, PGA, etc.), natural biopolymers (polysaccharides, polynucleotides, proteins, etc.), and biopolymers made from these substances. Therefore, in order to achieve the desired qualities of an ideal packaging, substantial research and development is needed for the upgrading of bio-based packaging materials.

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