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Developing Food Packaging with Nanomaterials: In-Depth Examination Based on Electromagnetic and Optical Radiations

P. William[1,]*, Pravin B. Khatkale[2], Harshal P. Varade[3], Santosh Kumar Sharma[4], N. Yogeesh[5]

Abstract

Problems with food degradation, infection, and environmental compatibility are driving constant innovation in the food packing sector. Nanomaterials (NM) are investigated as possible solutions to the problem to improve the effectiveness of food packaging by means of their exceptional optical and electromagnetic characteristics. Several factors, such as the need to analyze capacity, cost-effectiveness, and possible environmental implications, prohibit the use of NM in food packing. This review summarizes the optical radiations, electromagnetic, Nanoparticles (NPs), and NM properties in food packaging. The optical and electromagnetic characteristics of NP used in food packing are examined using a methodical empirical approach. Research indicates that NM enhances barrier characteristics when added to food packaging, which in turn increases the market visibility of packaged foods. An important step toward creating efficient and eco-friendly food business goods has been the development of food packaging based on NM. This development attempts to create a harmonious balance between maximizing efficiency and taking into regard environmental and health factors.

Keywords: Nanomaterials, electromagnetic, optical radiations, food packaging, nanoparticles

INTRODUCTION

Integrating NPs into food packaging is a significant step forward in the ever-evolving field of food manufacturing. These two factors, when combined and it can revolutionize food processing and strengthen safety measures. For problems including spoilage, contamination, and environmental effects, experts and companies are working on new packaging methods at the nanotechnology (NT) level [1]. Using NT in food development has many potential benefits and drawbacks, which this advanced, anticipated attempt to explore. The ground-breaking approach has far-reaching alternatives and potential effects [2]. Traditional packing techniques could be modified by an interdisciplinary effort that combines NT, plastics technology, and food manufacturing. NM has special features that make them useful for improving barrier capacities, prolonging product shelf life, and allowing for real-time assessment of food quality [3]. Responsible package products that reduce waste and economic damages can be created with the incorporation of NM, making these innovations ecologically important. Table1. Shows the abbreviations.

*__Author for Correspondence__
P. William
E-mail: william160891@gmail.com

[1]Assistant Professor, Department of Information Technology, Sanjivani College of Engineering, Kopargaon, India
[1]Faculty of Information Technology, Victorian Institute of Technology, Australia
[2]Assistant Professor, Sanjivani University, Kopargaon, Maharashtra, India
[3]Assistant Professor, Department of Mechanical Engineering, Sanjivani College of Engineering, Kopargaon, Maharashtra, India
[4]Professor, Department of Mechanical Engineering, Chhatrapati Shivaji Institute of Technology, Durg, Chhattisgarh, India
[5]Assistant Professor, Department of Mathematics, Government First Grade College, Tumkur, Karnataka, India

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Table 1. Overall abbreviations.

	Abbreviations
Nanoparticle	(NP)
Nanotechnology	(NT)
Nanomaterial	(NM)
Nanocomposite	(NC)
Electromagnetic radiations	(EMR)
polymer nano-materials for food packaging	(PNFPs)
biodegradable	(BD)
non-biodegradable	(N-BD)
polyvinyl alcohol	(PA)
polyhydroxy butyrate	(PHB)
Nonbiodegradable polymers (NBP)	(NBP)
polyurethane	(PU)
Biodegradable polymers	(BP)
“polyolefin	(PF)
Fourier spectroscopy	(FS)
Zinc oxide-nanorods	(ZnO-nr)
Silver-copper	(Ag-Cu)
lightness	(L)
Short-wavelength	(SW)
long-wavelength	(LW)
Radio wave	(RW)
ultraviolet	(UV)
visible light	(VL)
infrared	(IR)
microwave	(MW)
Electron beam	(EB)
mycotoxins	(MX)
nano-cellulose	(nc)
nano-composite multiple layers	(NCML)
hybrid organic and inorganic nano-coatings	(HOINC)
European Union	(EU)
European Food Safety Authority	(EFSA)
Food & Drug Administration	(FDA)
graphene oxide	(GO)

Regarding NM, The tackle important problems with food packaging, including making it easier to maintain, it endure longer, secure, and making more environmentally friendly [4]. The evaluates potential of a wide range of NMs used in packaging, including NPs and NC, to change the industry. NP incorporation guarantee that food efficiency is preserved, but it also provides the way for the invention of tools for real-time observation of produced output.

A growing collection of evidence suggests that EMR including photons and radioactive waves can enable more precise heating methods. This improves pasteurization and sterilization methods, in the food packaging industry lengthen the shelf life of delicate goods [5]. A natural and beneficial item can be made through the systematic deployment of EMR, which helps destroy unwanted microbes and reduces dependency on chemical protection. The food packaging business makes extensive use of optical radiations. Packing elements that incorporate integrated optical technology can evaluate and communicate data in real time regarding the state and health of the food contained. By enhancing

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supplies administration and decreasing the probability of products going harmful technology assists reduce food consumption while providing customers with up-to-date information [6].

Implementation of optical and EMR technologies in food packing requires careful risk assessment, including consideration of radiation's impact on nutritional significance, and the development of appropriate, code-compliant design features. If optical and EMR technologies are used effectively in food package, a suitable medium between their advantages and disadvantages must be found. There are several benefits to using optical and EMR in food presentation, such as a longer preserving period and the capacity to detect elements in real-time. It's a considerable movement towards. To make more informed packaging judgments in this domain, research on radiation's impacts on food ingredients is essential [7, 8]. This article provides a concise overview of the NM, optical, and electromagnetic characteristics of food packing.

VARIOUS NMS

Polymer NM

Individual molecules known as polymer NM can include energy substances either inside or externally. Improved efficiency, safety, and market life are purposes of food package. In addition to improving physical and microbiological resistance, this strategy is economical and good for the environment. It is mostly employed in the production and packing sectors because of its exceptional efficiency in advanced economies. Polymer NM offers improved performance in terms of barrier properties against ultraviolet rays, as well as increased elasticity, endurance, and temperature tolerance as compared to conventional gas packing materials such as O_2 and CO_2. Utilizing Polymer NM dynamic packaging, intelligence packaging, and biopolymer decomposition. This can be utilized in the context of commercial packaging for a wide range of items such as beverages, fizzy drinks, baked foods, and livestock products. The Polymer NM used in food packaging can be produced using two methods prepolymerization and postpolymerization. While PNFPs offer numerous benefits, they have drawbacks, including the potential to cause various health problems such as respiratory troubles, skin penetration, and ingestion [9].

Polymers can be classified into two categories BD and N-BD. BD materials are categorized as natural biopolymers, which consist of carbohydrates such as starches from wheat, maize, and potatoes, as well as proteins derived from animals and plants.BP can be categorized into two types of chemically manufactured polymers, such as polyglycolide and PA, and microbiological polymers, such as PHB. NBP are categorized as nylons, PU, and PF. NM can be classified into two distinct categories organic and inorganic. The category of organic materials can be further subdivided into nanofibers, which consist of cellulose, starch, and chitin. The classification of inorganic materials consists of two categories nano clay, which includes hectorite, saponite, and transformed ceramics, and conductive NPs, such as silver, copper, and gold. NPs have the ability to disperse the human body through three routes inhalation, skin contact, and oral consumption. The evaluation of their toxicity and particle size (small or large) can be used to assess their impact. It is worth noting that smaller particles are more rapidly consumed [10].

Biopolymer NCs

Most non-natural and manufactured polymers are harmful to ecosystems. Biopolymers have the potential to replace synthetic polymers. To set it simply, biopolymers are manufactured polymers that are both kind to the environment and capable of decomposing efficiently in ground. However, biopolymers generally exhibit minimal heat and structural properties. It is necessary to improve the characteristics by altering the ceramic composition of montmorillonite through the introduction of organic ammonium ions, the biopolymer demonstrates a significant enhancement in its mechanical characteristics. This renders a structure reusable, biodegradable, cost-effective, and user-friendly. This altered organic structure demonstrates significant antibacterial characteristics, particularly against (common bacteria found in food). These qualities are further observed and evaluated using X-ray reflection, FS, and SEM [11].

Antimicrobial NMs

This involves the implementation of dynamic material. Antimicrobial NM inhibits microbial activity, hence reducing food spoiling and the risk of foodborne illnesses. Antimicrobial NM such as TiO_2, Ag, $Fe3O_4$, ZnO, and CuO are some examples. Various antibacterial nanostructures are employed in food packaging for their diverse processes and varying levels of deployment. Although NT has great promise for food packaging, several issues must be addressed, including toxicity stages, migration, and preservation, while prioritizing the safety of individuals and the environment. Prior to granting market approval [12], it is imperative to provide an explanation for ensuring the continuous improvement of the packing material's quality is vital. Certain active packaging preserves the shelf life of food by releasing distinct substances. Additionally, specific intelligent packages inform consumers about the safety of the food for consumption. Additionally, there exist antibacterial packages that incorporate probiotics, which represents a novel approach to bio-preservation. Considering these factors, it is reasonable to anticipate that future active packages may include additional features such as antimicrobial characteristics, atmospheric control, a protective barrier for food preservation, resilient barrier characteristics to reduce material requirements and enable lightweight manufacturing, and biodegradability to minimize environmental impact, within a limited package [13].

EFFECTS OF METALLICNPS ON THE OPTICAL CHARACTERISTICS OF COMPOSITES USED IN THE FOOD PACKAGE

The optical qualities of packing materials, including color, transparency, and UV transmission/absorption, are crucial for preserving food quality because they shield it from harmful UV rays and light. Additionally, packaging should shield contents from ultraviolet light to avoid lipid oxidation, maintain nutritional value, and avoid food deterioration. Color is one of the most critical material qualities that could impact their application affects consumers' approval of food packaging [14]. Despite the fact that pristine semolina coatings appear colorless and completely transparent, the addition of ZnO-nrsubstantially lowered the L and A values, indicating an increase in the amount of NPs, leading to diminished propagation from productions [15]. According to [16]. adding Ag-Cu NPs to fish gelatin material drastically changed their appearance by decreasing their L and dramatically increasing their and b values. According to [17] these outcomes were line with those of agar NC coatings combined with nano-silver. In addition, the inclusion of nano-clay appears to lower the transparency of productions, in contrast to the very translucent control gelatin material. Using nano-silver in NC productions reportedly made them less transparent and gave them a brownish surface pigment [18]. The inclusion of TiO_2 reduced the transparency of NC kefiran-WPI material, according to [19]. and the degree to which this drop depended on the quantity of NP.

UV-vis spectroscopy is used to determine the reflection and retention spectra of NC materials. The UV region has been divided into three zones “UVA (320–400 nm)”, “UVB (280–320 nm)”, and “UVC (180–280 nm)”. The NC materials containing ZnO-nr exhibited a distinct maximum of elimination, while the inclusion of ZnO-nr resulted in even higher absorbance concentrations at UVA [14]. Furthermore, [20] and [21] documented a decrease in UV transmission when “(Ag-clay and ZnO-nr)” were added to gelatin material [14]. Table 2 displays the results of light penetration through biopolymers incorporating different NPs. Evidently, the incorporation of metal NP led to a decrease in the amount of light that passed through all NC biopolymer layers.

Table 2. The impact of various metallic nanoparticles on the optical characteristics.

Metallic NPs	Biopolymers	Installation degree (wt%)	Source	Optical characteristics
Zinc oxide-nanorods (ZnO-nr)	Tapioca starch, Bovine gelatin, Semolina	0-5	[14]	ZnO-nr integration with tapioca starch sections facilitates their complete absorption of UV radiation. The creation of gelatin from bovine sources, namely ZnO–nr, showed extremely minimal UV transmission and had the ability to absorb more than 50% of the near-IR spectrum. The integration of ZnO–nr to the semolina

				NC coatings led to a ultraviolet absorbance rate of 90%.
Copper oxide (CuO)	Kefiran-carboxymethyl cellulose	1-2	[23]	When the amount of CuO NPs was increased, the transmission of radiation in the visible (400-800 nm) and ultraviolet (200-400 nm) bands was significantly reduced.
Silver-copper (Ag-Cu)	Fish skin gelatin	0-2	[17]	A direct correlation between the amount of nanoparticles (NPs) and the decrease in manufacturing visibility over the optical and ultraviolet (UV) spectrums was observed.
Gold (Au)	Quinoa starch	0-5	[22]	Elevated concentrations of gold NPs (Au NPs) resulted in higher transparency. Biopolymer coatings that contained Au NPs showed a significant increase in UV absorption.
Titanium dioxide (TiO_2)	Potato starch	0.5-2	[24]	The addition of 0.5% wt of TiO2 resulted in the effective blocking of over 90% of UV radiation, while also improving the transparency and white indices of the materials.

ELECTROMAGNETIC RADIATION(EMR)

In EMR the power carrier particles travel across a medium with a constant electric and magnetic field strength but a sinusoidal variation in the force strength [25]. From SW gamma radiation to LW RW, EMR encompasses a continuous range of various energy. Other types of radiation, such as X-ray, UV, VL, IR, and MW are located between these two ends. Ionizing radiation is EMR with a frequency greater than 2500×10^1 MHz, which has the power to disrupt the chemical bonds of substances [25]. Shorter wavelengths and greater penetrating power characterize high-frequency radiation. Some examples of ionizing radiation are γ-irradiation, X-rays, and EB. The low frequency of non-ionizing radiation makes incapable of breaking chemical bonds. In this group are the RW, MW, IR, and UV rays [26]. Many sectors, including healthcare, pharmaceuticals, and food manufacturing, utilize ionizing radiation as the most effective sterilizing treatment. For surfaces to be safe to use in the food industry, non-ionizing radiations are preferred [27].

The use of EMR in the food industry to guarantee high-quality and safe products has been investigated in recent years [28]. Food products can be rendered storage stable through the use of radiation in food manufacturing. This is achieved by eradicating insects and infections, blocking enzyme operation, and reducing the number of bacteria, fungi, germs, and MX that can be found in food [29]. The most expanding methods for successfully removing MX and fungi from food are ultraviolet light, MW, and electrostatic filters. Variations in the energy levels of ionizing and non-ionizing radiations cause their inactivation mechanisms for microbes to change. To kill microbes, ionizing radiation releases free radicals that damage their DNA and other cell components [29]. In contrast, non-ionizing radiation causes cell breaking by the heat breakdown of DNA, proteins, and lipids, killing microbes [30]. “Cereals, nuts, dried fruits, vegetable juices, herbs, and oil” are some of many products that employ EMR to decrease MX and fungi [26]. Using EMR to decontaminate MX and fungi has been the focus of substantial investigation.

The nutritional and taste features of food are changed by irradiation, significantly by many other techniques of food processing. Irradiation of food at dosages exceeding 10 kGy damages proteins in a manner analogous to heat processing, such as canning, heating, blanching, or pasteurization, however, nutrient effects are regarded insignificant at levels below 1 kGy. Irradiation of food causes vitamin reduction, the most serious nutritional problem. Vitamins B and C, which are water-soluble, are particularly susceptible to irradiation's oxidative effects. During irradiation at doses below 10 kGy, the denaturation of carbohydrates and proteins is not impacted [27]. Table 3 shows the EMR Food-borne fungus.

Table 3. Research on the use of non-ionizing EMR to eliminate food-borne fungus.

Medication technique	Source	Amount of degradation	Fungi classification	Medication requirements	Food production
MW	[33]	1.06 log reduction	A. flavus	2450 MHz,	Brown rice
IR	[31]	88%	Fungal colony	254 nm for 3h	Red rice
	[32]	7.2- log reduction	A. flavus	60degree Celsius in <1 minute then 60 minutes of heating	Rough Rice

Note: Fungal colony –"(Aspergillus spp., Penicillium spp., and Fusarium spp.,)"

MANUFACTURINGVALUE

The use of NT in food manufacturing raises concerns regarding the cost-effectiveness of producing such materials. One possible immediate explanation is that the production of polymers comprising NP is not viable due to their high value. Nevertheless, the issue is subject to debate. There are two distinct cases that can be identified. In the initial scenario, substances that have been introduced into the market offer enhanced packaging characteristics. These materials are composed of polymers that either contain nano clay or have metallic (or metal oxides) incorporated at the nano-scale or contain nc. These NPs can be included in traditional packaging components including buildings or structures, enhancing the material's characteristics. The augmented expense of these materials is minimal, as traditional techniques are employed for their production, but the enhanced packaging characteristics lead to an extended lifespan of the food products. Conversely, it is possible to create intriguing packaging with significant production requirements. Illustrations include the implementation of NCML and the utilization of HOINC. Nevertheless, these materials are not feasible for implementation on a large commercial level [34].

The discernible influence of NT in the food sector is evident through market investigations, patent functions, and the increasing array of items accessible in the market. Based on the market investigation conducted by the Helmut Kaiser Consultancy, US emerged as the leading country in importing NT for the food sector. Asian nations, led by China, are at the forefront of this field, and it is projected. The NT market in the food industry was valued at approximately 7 billion US $ in 2006, and experienced significant growth, reaching 20 billion US $ in 2015 [35]. According to the consulting firm Cientifica, the anticipated value of NT technologies in the food industry is approximately 410 million Indian rupees. NC packaging components dominate the market, accounting for over 50% (210 million US $). Food preparation and the use of food ingredients follow closely, each with (200 million US $). Approximately 400 businesses are involved in the application of NT in the field of food science.

SAFETY EVALUATION

The utilization of NT in food packages is a revolutionary method. Hence, it is imperative to evaluate the potential migration of NM to safeguard consumers against detrimental health consequences. The EU and India mandate that their respective responsible agencies, the EFSA and the FDA, must grant special certification for each packaging material before it may be sold on the market [36]. The risk evaluation relies on the chemical and toxicity data provided and must correspond to the standards of the regulation. Until there were no specifications regarding the dimensions of the packaging supplies. As a result, NM was authorized without undergoing any specific risk evaluation. In 2011, the FDA implemented amended regulations that prompted the evaluation of the specific dimensions of materials utilized in food manufacturing [34]. The EFSA released a report in 2009 outlining the possible hazards associated with the application of NT conclusions that are typically aligned with the legislation established in the European Parliament. It is imperative that a public authority conducts risk assessment in every instance, and the categorization of NM designed for packaging cannot be discretionary. This is in conformity with Regulation EC/1935/2004, which states that each item that comes into touch with food or livestock nutrition must be evaluated independently to determine its safety. [37] Provides a comprehensive and informative evaluation of the current situation in many locations globally.

The concerns of regulatory organizations regarding the efficacy of NMs stem from the contentiousness observed in published investigations [38]. This assertion is supported by two specific instances GO and inorganic NPs, specifically “silver (Ag) and “gold (Au)”NPs)”. The investigation demonstrated the little sensitivity of GO against specific gut bacteria [39]. Cell viability remained unaltered across all tested concentrations of GO for a duration of 24 hours, and no dose-dependent toxicity of GO was found. Conversely, [40] reported the in vitro cytotoxicity of GO on cultivated 8226 cells. The cytotoxic impact observed exhibited a direct correlation with the dosage administered and it was accompanied by heightened oxidative stress. Although Au, NP is taken up by human cells, they do not appear to be innately harmful to these cells [41]. The data presented by [42] showed that even small amounts of Ag and NP had harmful effects on human macrophages. An article distributed in the scientific journal Nature [43] asserts while many NM is unlikely to cause harm to human health, there is evidence suggesting that certain NM may indeed have detrimental consequences. Consequently, further investigation is necessary to understand the potential risks. Given the aforementioned facts, it is evident that the safety evaluation of NM is its nascent phase and requires further dedication and attention.

CONCLUSION

The ever-changing food packaging sector is constantly determined by the need to tackle issues such as food deterioration, pollution, and ecological reliability, resulting in persistent development. The incorporation of NP into food packaging has arisen as a possible pathway, capitalizing on their unique electromagnetic and optical characteristics. Nevertheless, the investigation recognizes possible drawbacks such as flexibility, cost-effectiveness, and environmental implications, underscoring the significance of a comprehensive evaluation. The investigation conclusively shows that the inclusion of NM improves the protective qualities of food packaging, resulting in a significant extension of the market life of packaged food. This article provides an overview of the significance and impact of metal NPs in the alteration of the various characteristics of NC material and NT technique in food packaging. Regarding its efficiency, in food packaging materials the investigation utilizing NM is a significant breakthrough, that has the potential to enhance package techniques and their impact on creating a durable and environmentally responsible food production system. It was essential to guarantee that mass production is possible and to tackle concerns regarding economic sustainability and ecological effects to achieve general acceptance. NM-based food package has significant possibilities for future developments in scalability manufacturing, affordability, and environmental compatibility.

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