

# Application of Nanomaterials for Food Packaging

Cang Li\*

Faculty of Art and Science, Queen's University, Kingston, Canada

\*Corresponding author: 17cl93@queensu.ca

**Abstract.** Nanomaterials have been widely used in a diverse of different fields because of their excellent physicochemical properties, such as food functional materials and food safety testing and analysis. For this reason, nanotechnology in the food business is rising in popularity since it provides numerous new possibilities in this dynamic sector. Applying nanotechnology to the food sector can improve flavor and color, increase barrier characteristics, and boost food safety by detecting bacteria in packaging. In addition, nanofoods have numerous potential advantages, but there are also risks that should be considered. Contents of the piece using a combination of journal and online resources, this article explores the features and benefits of nanotechnology in food packaging, discusses its application in other areas of the food industry, and discusses the potential health risks that food nanotechnology may pose. The article concludes with predictions about the future of nanotechnology, and it is expected to provide a new idea for the application of nanomaterials in the food field.

**Keywords:** Nanotechnology, Food Packaging, Food Additives.

## 1. Introduction

Nanotechnology, which involves making, manipulating, characterizing, and producing materials on a nanoscale (1-100 nm), is one of the most worrisome developments in recent years. The physical and chemical properties of the material considerably deviate from those of macroscale materials composed of the same component when the particle size is below this threshold. With the improvement and progress of nanotechnology, more and more fields begin to try to use nanomaterials. Nanotechnology has a wide range of potential applications in the food business, including farming, processing, and packaging. Nanotechnology will usher in new ways to analyze and improve the quality of food in ways previously unimaginable, including in terms of taste, texture, processing speed, heat resistance, shelf life, traceability, safety, nutritional bioavailability, and the bottom line. However, because of the lack of information regarding their impacts on the environment and human health, the use of nanotechnology in the production of organic food should be approached with caution. The main issue with nanoparticle exposure in humans is several entrance routes, including ingestion, inhalation, and skin absorption. Following absorption, nanoparticles may enter the bloodstream, where they may settle in various regions like the brain or cause immunological reactions. These particles exhibit behaviors reminiscent of asbestos. Some researchers have investigated the possibility of genetic modification due to food nanoparticles or food nanoengineering [1]. The public is looking for government and food producer assurances of safety. Despite all these disputes, nanotechnology has already permeated food packaging, farm technologies, food processing, and the food itself.

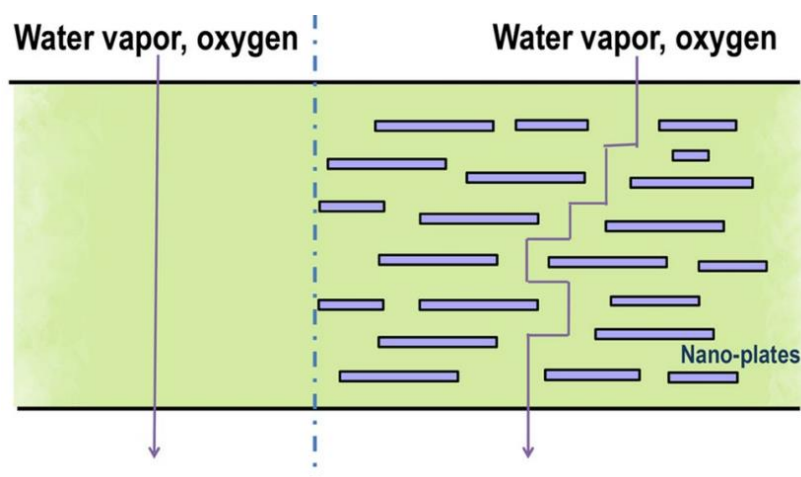
The likelihood of food spoilage is high, making the quality of service provided to clients intolerable. Food packaging is the most important part of safe food handling and storage. The primary goals of common food packaging are preservation, containment, convenience, and information transfer. Flavor and texture can be enhanced, fat content reduced, and minerals like vitamins encapsulated to prevent loss over time thanks to nanotechnology's use in the food industry. Nanomaterials can also be used to create packaging that extends the shelf life of its contents. Nano-sensor-equipped intelligent food packaging may even advise customers about the condition of the food within. Traditional conventional food packaging is being replaced by intelligent, interactive, and responsive packaging made possible by nanotechnology. Moreover, consumers can learn more about the true quality of food goods thanks to packaging created with nanotechnology. In addition, the controlled release of antimicrobials and preservatives via nanotechnology has been studied with the

aim of elongating the shelf life of the product contained within the packaging. Thanks to some promising preliminary findings, nanotechnology in food packaging has emerged as a topic worthy of its own study.

By analyzing recent advances in nanotechnology for food packaging and related systems, this paper fills this information gap, focusing on the applications that are most likely to be accepted by consumers and gain regulatory attention in the near future. The use of organic and inorganic nanocomposites for improved strength and quality in food packaging, as well as sensors that monitor changes in packaging integrity or conditions, are among the topics covered. Health concerns specific to each use are also briefly discussed. In this paper's conclusion, it can provide a high-level summary of the commercial and regulatory prospects of nanoparticles in the food industry and food packaging.

## 2. Application of different nanomaterials for food packaging

Storage of food in a way that preserves its nutritional and organoleptic qualities is a critical element of the food industry, and this is where food packaging comes in. Packaging for food does more than just prevent spoilage. And it also protects perishables by preserving their freshness and preventing environmental and physical damage to sensitive bioactive compounds. Improvements in food packaging using nanotechnology are the subject of extensive study. The addition of functional nanoparticles to food packaging has been found to increase the package's barrier properties, thermal stability, strength, and durability, hence extending the food's shelf life [2], as shown in Figure 1.



**Figure 1.** The added nanoplates extend shelf life by reducing gas permeability [2]

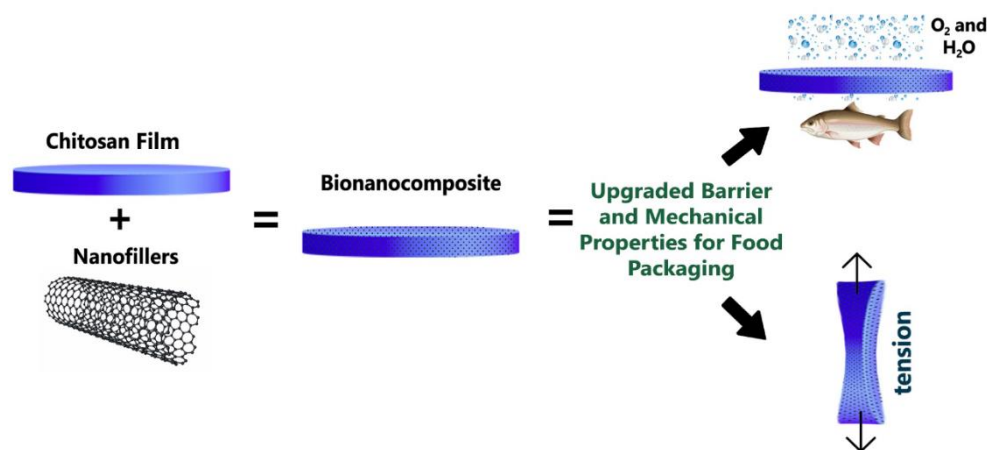
### 2.1. Improved properties of food packaging

Improved food packaging often incorporates nanoparticles to increase its mechanical, physical, and chemical features such durability, malleability, biodegradability, thermal resistance, UV blocking abilities, water vapor permeability, and barrier qualities against gases and moisture. Polymers' mechanical, barrier, and light-transmittance properties can be improved by including metal oxides.

The mechanical qualities impact resistance, Young's modulus, and flexural modulus are all areas where nanomaterials (NPs) show potential for improvement. Nanocrystals of starch or cellulose, for instance, or silica, or calcium carbonate, or clay, or titanium nitride, or even smaller sized silica particles are just a few examples [3]. There are a wide variety of carbon-based NPs that are giving increased mechanical strength for packaging applications; nevertheless, whether or not they are appropriate for food packaging is still a matter of some discussion. Sanchez-Garcia acknowledges that because of their dramatic black coloration, issues with accidental migration, and likely toxicity, these NMs are best used in specialist applications [4].

Many of the found NPs are oriented in a way that enhances the barrier properties of the matrices into which they have been included. Because natural polymers exhibit poor barrier qualities and weak mechanical capabilities, bio-based plastics are employed in this situation. The barrier characteristics

can be improved by adding NPs [5], as shown in Figure 2. Nanoclays, which include different varieties of kaolinite, montmorillonite, and vermiculite, are the most exciting NPs for increasing barrier properties (some of which are already commercially available). Clays are not natively nanoscale materials, as should be highlighted in [6]. They are converted into nanocomposites by being dispersed in a polymer matrix and having their layers exfoliated [7]. Furthermore, better barrier properties have been shown for starch nanocrystals, micro fibrillated cellulose (MFC), and cellulose nanocrystals.



**Figure 2.** Applications of various nanofillers for food packaging [5]

There are many different kinds of polymer nanocomposites that use metal or metal oxide nanoparticles for their diverse features, such as “active” packaging that kills bacteria, resistance to abrasion and UV light, and/or strength. Polystyrene (PS), polyethylene (PE), and polyvinyl chloride (PVC) can be preserved using nanomaterials like titanium dioxide as UV absorbers, and similar results have been reported using copper, magnesium oxide, and zinc oxide nanoparticles. Certain metals and metal oxides are used in nanotechnology, including zinc oxide (ZnO), silica (SiO<sub>2</sub>), titanium dioxide (TiO<sub>2</sub>), alumina (Al<sub>2</sub>O<sub>3</sub>), and iron oxides (Fe<sub>3</sub>O<sub>4</sub> and Fe<sub>2</sub>O<sub>3</sub>). Nanocomposites have also been made with cadmium telluride/gallium arsenide and other semi-conductor nanoparticles [8]. Food packaging made from PHBV and PLA matrices has been found to have some UV/visible light-blocking properties.

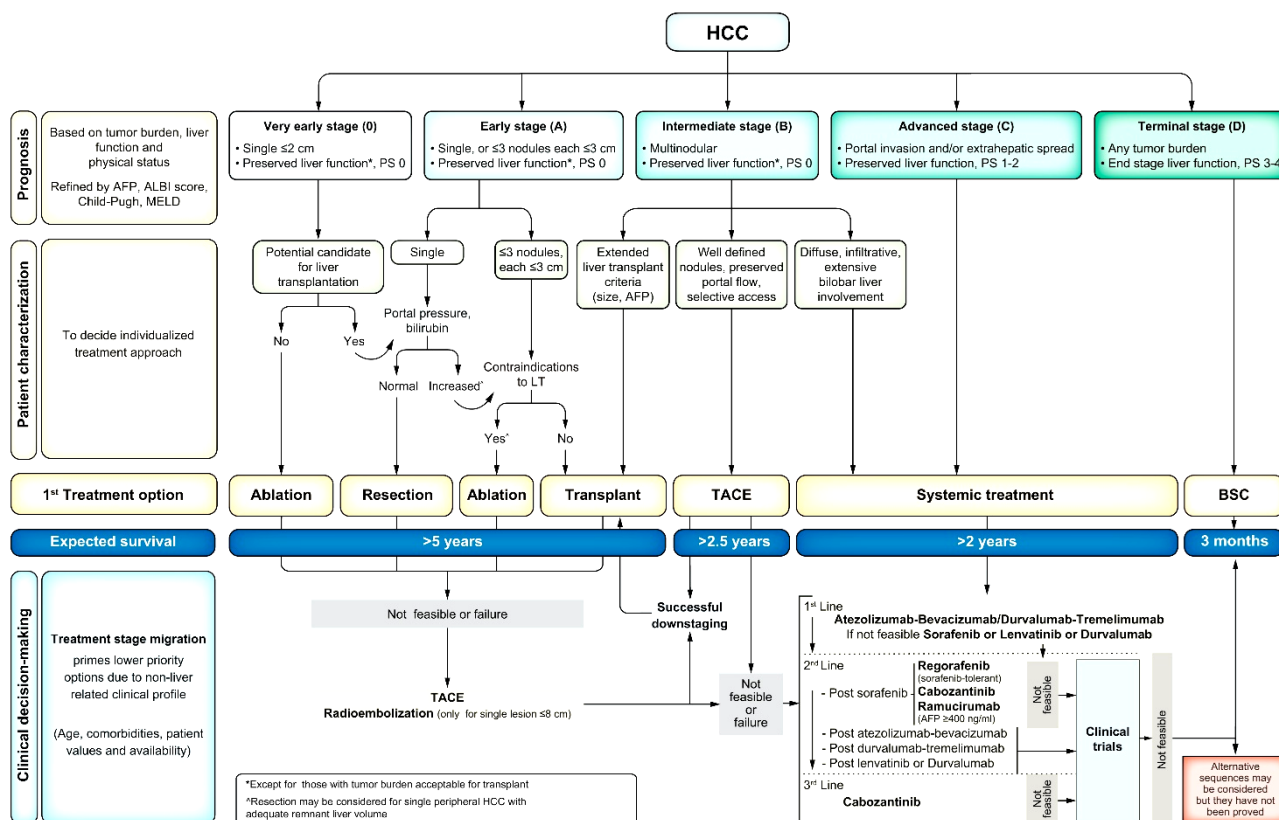
## 2.2. Active properties of food packaging

Active packaging is a new way to keep perishable items fresh for longer by neutralizing the effects of oxygen, moisture, heat, and other spoiling factors. Improve the effectiveness of the packing polymer by adding components to the packing material or the package headspace, which is what active packaging does. Antibacterial, carbon dioxide emitters, carbon dioxide scavengers, antioxidants, and ethylene absorbers are only a few of these substances’ many uses. Antimicrobial agents either weaken microorganisms’ cellular structure or disrupt their metabolic route to stop future growth. Reactive oxygen species, which are produced in part by nanoparticles and stop DNA replication and ATP generation, harm or kill cells.

Active packaging is made possible by the extrusion production of recyclable and biodegradable polymers. Environmentally friendly polymeric matrices like low-density polyethylene (LDPE), polylactic acid (PLA), and polycaprolactone were extruded to create the active films (PCL). Antibacterial action was achieved by utilizing the lemon extract, thymol, and lysozyme. According to the results, the processing temperatures significantly influence the antimicrobial efficacy of the examined active films. After being subjected to higher processing temperatures, the antimicrobials added to PLA and LDPE revealed just a minor remnant of their original antimicrobial action. The antibacterial properties of PCL were less affected by heat treatment. Among the natural compounds studied, lysozyme has the highest heat stability. Pea starch laced with lysozyme was likewise subjected to extrusion, and the results were published [9]. The same extrusion procedure commonly

employed in the packaging film preparation sector can be utilized to prepare chitosan-based active films.

Cellulose acetate (CA) nanocomposites have been studied [10]. They were made via extrusion and then compressed or injected to form the final product. Incorporating clay at a concentration of 5% (w/w) increased the tensile strength and tensile modulus of the resulting cellulose acetate plastic matrix by approximately 38% and 33%, respectively. The nanocomposites' mechanical and thermal properties are anticipated to improve with the addition of a tiny amount of the appropriate compatibilizer, which will increase the miscibility of the clay nanofillers and CA matrix. Edible films or bio-based nanocomposites based on cellulose have been used extensively to prevent quality degradation in various perishable foods. The scientific literature indicates that cellulose derivatives such as hydroxypropyl cellulose, carboxyl methylcellulose, and ethyl cellulose are commonly used in edible films and coatings [10]. Active films based on chitosan can be made in a number of ways.



**Figure 3.** The BCLC staging and treatment strategy [11]

Due to the wide variety of antimicrobial nanostructures, methods of action, and levels of deployment, they find widespread use in food packaging. Many issues, such as nanoparticles' toxicity, migration, and storage, need to be resolved before nanotechnology may be widely used in food packaging without posing serious risks to humans and the environment. This must be clarified prior to the product's release into the market. The means by which the packaging's quality is kept up also need to improve. Some dynamic packaging keeps food fresh by releasing particular compounds, and other smart packaging alerts buyers if the item they're considering buying is unsafe to eat. Moreover, a new method of biopreservation employs antimicrobial packaging coated in probiotics. The next generation of active packaging may include qualities such as biodegradability, antimicrobial protection, high barrier capabilities, and the ability to prevent the growth of microorganisms that could spoil the food (the most crucial feature to ensure it does not harm the environment).

The creation of nanosensors to monitor the quality of both raw and cooked foods is among the most promising uses of nanotechnology. To monitor the condition of stored items, a range of indicators can be utilized, including time-temperature indicators, pH indicators, and leak indicators. A noticeable change in hue indicates if the product is still edible after a certain period of time has

passed after it was opened, while time and temperature sensors reveal how much time has passed after the product was opened before it goes bad. Nanoparticles with intelligent qualities go beyond the NMs by allowing them to be used to notify users and customers of aspects of the packed food. For instance, oxygen-sensing inks containing  $\text{TiO}_2$  and other metal NPs may be used to discourage tampering, whereas nanocarbon black and modified carbon nanotubes may be utilized as a biosensor to detect whether food is spoiling [11]. Nano barcodes are the “gold standard” for capturing critical product quality requirements in the food business, as shown in Figure 3.

### 3. The use of nanotechnology in food-related systems

Improvements in ingredient texture, encapsulation of ingredients or additives, creation of novel flavors and sensations, regulation of flavor release, and enhanced bioavailability are just some of the ways in which nanotechnology has aided the food industry. Due to these advancements, new materials are available for use in food packaging that boast enhanced mechanical, barrier, and antibacterial qualities. Other than food packaging, the following are the most prominent areas where nanotechnology is expected to be used in the food industry in the near future: food ingredients and additives.

The food nanotechnology sector is now focused on developing nanostructured food ingredients and vitamin and supplement delivery methods. Reverse micelles, nano-emulsions, surfactant micelles, and emulsion bilayers are some of the few techniques used for this purpose [12]. Improved flavor, texture, and consistency are just some of the benefits touted for the nanostructured food ingredients currently in research. Low-fat mayonnaise, spreads, and ice cream with nanostructures, for instance, claim to taste equally as “creamy” as their higher-fat versions. Introducing Bioral™ nanocochleate micronutrient and antioxidant delivery technology is BioDelivery Sciences International. Soybean phosphatidylserine, the carrier used to make nanocochleates, is widely recognized as safe. Calcium ions are incorporated into tiny vesicles of phosphatidylserine to stimulate the formation of discs, which are subsequently connected to form huge sheets of lipid before being folded into nanocrystalline structures. The name “cochleate” comes from the Greek word for a snail with a spiral shell. Nanocochleate technology, it is claimed, keeps antioxidants and micronutrients from deteriorating during processing and storage [13].

As a result of their high absorbability, ultrastructure, and dispersibility, nanomaterials can be used to boost the activity and bioavailability of food. The prolonged release of nanoparticles allows for sustained efficacy in the body and reduces the risk of side effects from functional components. Incorporating nanotechnology into the additive’s application process has the potential to reduce the required dosage and maximize efficiency. On the other hand, nanoparticles can be used for long-term food preservation because of their slow-release action, which improves both stability and safety. One of the two main categories of nanofood additives is natural food additives, which are generally sourced from plants and animals. For instance, carotenoids are used as a nutritional supplement. The radish is good for you for many reasons, including its nutritional value and its immune-suppressing and antioxidant properties. Carotenoids are essential nutrients that the human body does not make on its own, but fortunately, they are found in low concentrations in many plants and at relatively moderate levels in most diets. This has led to the extraction of nano-carotenoid additions from natural plants, which have increased the carotenoid content of food. Here, the nanoscale carotenoids produced by German company BASF will be used as an example. As a form of food additive, it is advantageous in that humans easily absorb it and it successfully extends the freshness of food by a factor of. There is a second type of nanofood additive, which is synthesized chemically. The main purpose of food processing is to improve the shelf life of food, decrease the likelihood of spoilage, and improve the food's appearance, flavor, texture, and even nutritional value. Antioxidants and other preservatives, for example, can keep food from going bad without reducing its nutritional value. As shown in Figure 4, titanium dioxide ( $\text{TiO}_2$ ) is a popular culinary additive that is utilized in many kinds of cuisine, from cheeses and sweets to baked goods and even surimi-based candies and meat products [14].

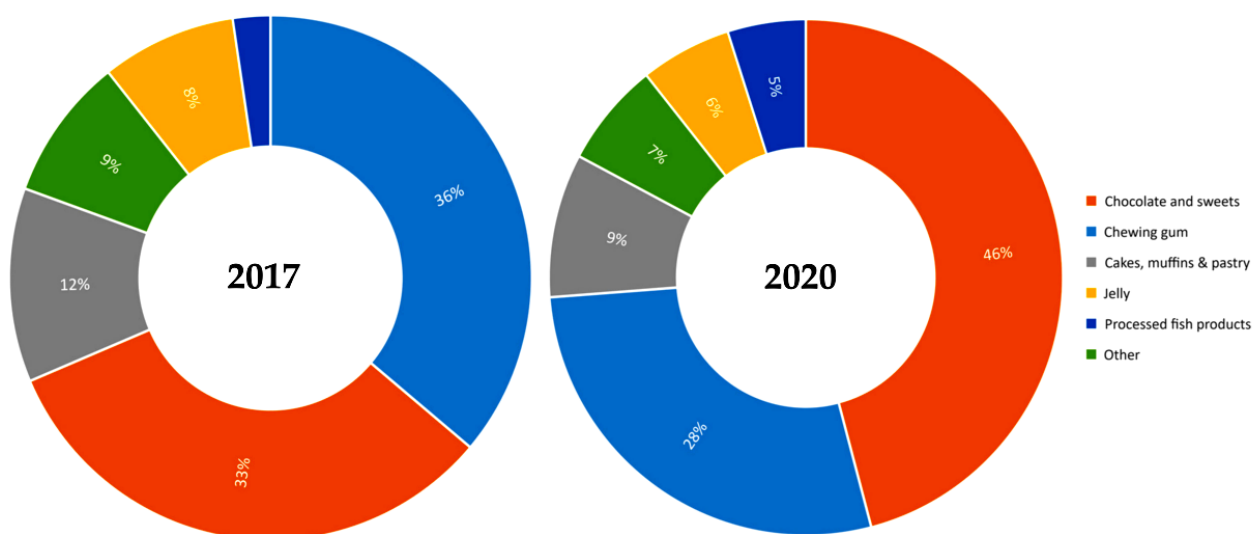


Figure 4. Distribution of foods containing TiO<sub>2</sub> [14]

#### 4. Toxicological concerns of nanoparticles in food packaging

Nanoparticles may be harmful because of the separation between their large surface area and their small volume, both of which occur as a result of nanoparticles' migration into food. The sort, concentration, length of exposure, and personal susceptibility of nanoparticles all influence their toxicity. The dangers of nanoparticles and how they affect living things are little understood at the moment. Since they are biodegradable and transient, organic nanoparticles like proteins, lipids, starch, and chitosan are typically regarded as non-toxic. Organic nanoparticles, with a much greater surface area to volume ratio than their bulk counterparts, may be digested and absorbed in a different way and have different nutritional characteristics. Producing safe food items necessitates *in vivo* and *in vitro* studies to determine if organic nanoparticles improve the bioavailability of specific substances, which can in some cases lead to toxicity. Many recent researches have examined the movement of nanoparticles in food products, with a focus on silver nanoparticles. The characteristics that silver nanoparticles can add to packaging materials are constrained by their ability to produce toxicity. Up to this level in food, silver nanoparticle movement is quite normal. Silver nanoparticles can accumulate in the liver, kidney, testicles, and brain and can be neurotoxic and genotoxic. Positively charged hydrophilic nanoparticles have the potential to significantly increase blood circulation and pose a risk to organs, according to data; nevertheless, they have not been properly explored and need further investigation in this area. Nanoclay migration is dependent on temperature, direct food contact, and nanoclay-polymer interactions. Long-term exposure to particular nanoclay promotes cytotoxicity [15]. However, the possibility of nanoparticles migrating into a food product is low if they are adequately enclosed in a polymer matrix; however, migration can be brought on by outside factors. Significant investigation into nanoparticle movement, toxicity, and interaction with polymer is required before any nanocomposite that will meet food can be created.

#### 5. Potential future changes and improvements in food packaging

While studies on using nanoparticles to improve quality have been undertaken, studies on the particles' impact on freshness and toxicity are just getting started. The potential of nanomaterials cannot be fully realized without more research. Beginning with techniques, nanomaterial properties must be described and assessed in order to determine their biotransformation in food. Rarely utilized due to their expense, inability to determine a large number of tests, and the complexity of the dietary matrix. Regardless of whether NPs are regarded an edible ingredient or are exposed to food, more research is needed to examine the dangerous consequences of NPs.

For its deployment to be successful, costs, biocompatibility, and scalability issues must also be addressed. Future work should centre on validating the sensor's technology and making sure it can be stored reliably and indefinitely within its environmental limits. The release of NPs from food packaging into the environment is another area in need of investigation. Such issues require a developmental lens for analysis. Without a set of rules governing the use of nanotechnology in the food industry, consumers are wary about consuming nanofoods. The nanoproductions' greater quality and improved analysis necessitate their classification and naming in order to satisfy consumer demand, address administrative problems, and expedite the financial clearance process. Topics must frequently organize special meetings to examine the potential uses of nanotechnology; in the near future, this effort will increase.

Innovation in improved manufacturing, preservation, and food analysis is aided by nanotechnology. However, given their toxicity, both the health effects and the environmental effects may be questioned. This research outlines current advancements and future uses, highlighting the dangers and benefits associated with these techniques. Future efforts should ensure that nanotechnology is used safely and effectively.

## 6. Conclusions

Food packaging based on nanotechnology has a lot of potential to replace conventional food packaging, even though this field of application is still in its infancy. Food packaging has improved properties, such as water vapor permeability and UV protection. In addition, nanotechnology can be used for food additives and food ingredients. This article discusses the health issues related to nanofoods. Even Nevertheless, the topic of food nanotechnology is still in its infancy, and it is difficult to predict where it will go in the future. No matter how the public is ultimately exposed to, deals with, or understands the uses of nanotechnology in the food sector, it seems inevitable that the manipulation of matter at the nanoscale will continue producing new and astonishing products.

## References

- [1] Amini, S. M., Gilaki, M., & Karchani, M. (2014). Safety of Nanotechnology in Food Industries [J]. *Electronic Physician*, 6(4), 962-968.
- [2] Shukla, P., Chaurasia, P., Younis, K., Qadri, O. S., Faridi, S. A., & Srivastava, G. (2019). Nanotechnology in sustainable agriculture: Studies from seed priming to post-harvest management [J]. *Nanotechnology for Environmental Engineering*, 4, 11.
- [3] Amjady N. Short-term hourly load forecasting using time series modeling with peak load estimation capability [J]. *IEEE Transactions on Power Systems*, 2001, 16(4), 798-805.
- [4] Sanchez-Garcia, M. D., Lopez-Rubio, A., & Lagaron, J. M. (2010). Natural Micro and nanobiocomposites with enhanced barrier properties and novel functionalities for Food Biopackaging Applications [J]. *Trends in Food Science & Technology*, 21(11), 528-536.
- [5] Pires, J., Paula, C. D., Souza, V. G., Fernando, A. L., & Coelho, I. (2021). Understanding the barrier and mechanical behavior of different nanofillers in chitosan films for Food Packaging [J]. *Polymers*, 13(5), 721.
- [6] Cohen, J. D., Li, L., Wang, Y., Thoburn, C., Afsari, B., Danilova, L., . . . Papadopoulos, N. (2018) [J]. Detection and localization of surgically resectable cancers with a multi-analyte blood test. *Science*, 359(6378), 926-930.
- [7] Franco-Urquiza, E. A. (2021). Clay-based polymer nanocomposites: Essential work of fracture [J]. *Polymers*, 13(15), 2399.
- [8] Manikantan, M. R., Sharma, R., Kasturi, R., & Varadharaju, N. (2012). Storage stability of banana chips in polypropylene based nanocomposite packaging films [J]. *Journal of Food Science and Technology*, 51(11), 2990-3001.

- [9] Wang, Y., Li, S., Jin, M., Han, Q., Liu, S., Chen, X., & Han, Y. (2020). Enhancing the thermo-stability and anti-bacterium activity of lysozyme by immobilization on chitosan nanoparticles [J]. *International Journal of Molecular Sciences*, 21(5), 1635.
- [10] Miteluț, A. C., Popa, E. E., Drăghici, M. C., Popescu, P. A., Popa, V. I., Bujor, O., . . . Popa, M. E. (2021). Latest developments in edible coatings on minimally processed fruits and vegetables: A review [J]. *Foods*, 10(11), 2821.
- [11] Reig, M., Forner, A., Rimola, J., Ferrer-Fàbrega, J., Burrel, M., Garcia-Criado, Á, . . . Bruix, J. (2022). BCLC strategy for prognosis prediction and treatment recommendation: The 2022 update [J]. *Journal of Hepatology*, 76(3), 681-693.
- [12] Salvia-Trujillo, L., Artiga-Artigas, M., Molet-Rodríguez, A., Turmo-Ibarz, A., & Martín-Belloso, O. (2018). Emulsion-based nanostructures for the delivery of active ingredients in foods [J]. *Frontiers in Sustainable Food Systems*, 2, 79.
- [13] Chaudhry, Q., Scotter, M., Blackburn, J., Ross, B., Boxall, A., Castle, L., . . . Watkins, R. (2008). Applications and implications of nanotechnologies for the Food Sector [J]. *Food Additives & Contaminants: Part A*, 25(3), 241-258.
- [14] Blaznik, U., Krušič, S., Hribar, M., Kušar, A., Žmitek, K., & Pravst, I. (2021). Use of food additive titanium dioxide (E171) before the introduction of regulatory restriction due to concern for genotoxicity [J]. *Foods*, 10(8), 1910.
- [15] Bandyopadhyay, J., & Ray, S. S. (2018). Are nanoclay-containing polymer composites safe for food packaging applications?—an overview [J]. *Journal of Applied Polymer Science*, 136(12), 47214.