CHAPTER 6

Biomediated Synthesis of Nanomaterials for Packaging Applications

P. Sivaranjana*[, 1], N. Rajini[2], V. Arumugaprabu[3], S. O. Ismail[4]

[1]Department of Chemistry, Kalasalingam Academy of Research and Education, Krishnankoil 626126, Tamil Nadu, India.

[2]Centre for Composite Materials, Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil 626126, Tamil Nadu, India.

[3]Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil 626126, Tamil Nadu, India.

[4]Department of Engineering, School of Physics, Engineering and Computer Science, University of Hertfordshire, Hatfield, AL10 9AB, Hertfordshire, England, United Kingdom.

*Corresponding author: P. Sivaranjana, E-mail: psivaranjana@gmail.com

Abstract

Change in lifestyle of humans in this present generation with huge dependence on packaging materials has encouraged several studies on development of new variety of packaging materials. Emphasis on replacement of existing non-biodegradable packaging materials with biodegradable materials paved the way for the use of biopolymers. Lack of properties, such as thermal stability and mechanical strength in biopolymers led to the development of biopolymer nanocomposites by adding metal/metal oxide nanoparticles as fillers into the biopolymers. Metal/metal oxide nanoparticles improve mechanical/tensile strength, thermal stability as well as antimicrobial properties of the binding and receiving polymer matrix. Biomediated synthesis of metal/metal oxide nanoparticles result to development of novel packaging materials at a low cost and without releasing hazardous wastes into the environments. Novel packaging materials with metal/metal oxide nanoparticles as additives are capable of increasing the shelf life of food stuffs, in certain cases they act as indicators of quality food inside the package. Summarily, this present chapter focuses on biomediated synthesis of various metal/metal oxide nanoparticles and their applications in food packaging.

Keywords: biosynthesis, filler, additive, packaging material, antimicrobial, metal nanoparticles.

Introduction

The use of non-biodegradable packaging materials has been restricted in several countries to ensure environmental safety. Therefore, there is a need for development of alternative packaging materials with enhanced properties. The development of eco-friendly green packaging materials has potentials to reduce environmental impacts caused by synthetic packaging materials [1]. The biopolymers have been used as new alternative packaging materials, they include, but are not limited to, polysaccharides (starch and cellulose derivatives, chitosan and alginates), lipids (bees and carnauba wax, and free fatty acids), proteins (casein, whey and gluten), poly hydroxyl butyrate (PHB), poly lactic acid (PLA), poly caprolactone (PCL), poly vinyl alcohol (PVA), poly butylene succinate and their biopolymer blends [2]. Considering environmental safety, the biodegradable natural or biopolymers are preferred. However, the inherent properties and mechanical strength of natural polymers limit them from being utilized as packaging materials, especially on an industrial scale. It is often essential to have their surface modification or physical cross linking or even modified as a composite material [3].

The nanometals have potential to overcome certain limitations in properties of the biodegradable materials. The nanometals have exhibited preferable properties, such as high surface area, fine particle size, high reactivity, high strength and ductility, which make them suitable to be employed frequently in a diversified range of industrial fields [4]. The available vacuum sealed food packaging polymeric materials are permeable to oxygen and moisture, which leads to spoiling of foods. To prevent this situation, polymer packaging materials are coated with nanometal, which inhibits the penetration of oxygen and moisture, thereby preserves the food materials from spoiling [5]. These nanometals also act as antimicrobial agents by preventing growth of harmful microbes, thereby prevent food spoilage and extend their shelf life [6]. Beyond these, nanometals in food packaging also act as smart indicators of change in the chemical composition, pH, gas composition, among others, inside the package that contains food stuff. These changes are communicated to the consumers by change in colour of the tag attached to them. Therefore, the role of nanometals in the food packaging include prevention of shelf life, fighting against the microbial growth and acting as smart indicators for the exact condition of the food stuff to the consumers. Metal and metal oxide (silver, gold, zinc oxide, silica, titanium dioxide, alumina and iron oxides), carbon based nanometals and nano-sized polymers are most commonly used as nanofillers in food packaging applications [7].

Furthermore, the nanometals improves functionalities, such as durability, flexibility, temperature and flame resistance, barrier properties, optical and recycling properties of the recipient packaging materials [8]. Nanometals are added to polymeric packaging materials, such as polyamides (PA), nylons, polyolefin, ethylene-vinyl acetate copolymer, polystyrene (PS), epoxy resins, polyurethane, polyvinyl chloride (PVC) and polyethylene terephthalate (PET) [9]. Development of packaging materials using nanoparticles can be broadly classified into two categories/types: (I) biocomposite materials with inorganic metal nanoparticles as fillers [10, 11], (II) biocomposite materials with plant extracts/agro wastes as fillers [12]. Type I materials possess appreciable strength and shelf life and they are best suitable for packaging applications, whereas type II lacks shelf life and strength. The responses of the type II materials towards the environmental factors, such as humidity, temperature and pressure are higher, when compared with type I. The conventional methods of synthesis and distribution of nanometals into the matrix of the packaging materials results to generation and deposition of hazardous chemicals into the environments. In recent years, studies have been focusing on bioreduction process for the synthesis of nanometals. This is very simple, efficient and cost effective, but it consumes time [13]. In this method, the choice of bioreductant includes plant extracts, which contains flavonoids capable of reducing the metal to its nano state [14]. In this chapter, specific discussion on nanometals synthesized via bioreduction process and utilized as nanofiller in packaging materials is presented.

In spite of the advantages of utilization of nanometals in food packaging materials, most of studies on these materials are still on the stage of demonstration, and their real time applications are yet to receive approval concerning their safety issues, which could be caused by the migrations of nanomaterials from packaging to food stuffs [15] . Additionally, the absorption, distribution, metabolism, excretion and toxicological assessment of nanoparticles in food in humans are to be assessed [16]. Therefore, the use of nanometals in food industry provokes various assessment methodologies to ensure usage as well as the real-time analysis of nanometals in the environment and their impact on various levels of organisms [16]. This is an emerging and evolutionary area involving multidisciplinary studies and provides scope for interdisciplinary research.

Metal nanoparticles as fillers in packaging materials

The unique behaviors of metal nanoparticles have attracted researchers to employ them in many different types of matrices [17]. Though, these nanometal particles are added as nano fillers in a minimum quantity, they do not lose their properties, such as antimicrobial nature, thermal resistivity and/or tensile strength [18]. They usually enrich the properties the matrices to which they are added. The antimicrobial activity of metal nanoparticles varies accordingly with their methods of synthesis; either physical, chemical or biological [19]. Interest on biosynthesized metal nanoparticles increases incredibly, owing to their reliability and cost effectiveness [20]. The most preferred and commonly used metal nanoparticles are zinc, iron, copper, gold, aluminium, nickel and silver. In addition, certain metal oxides include titanium, zirconium, iron and zinc are also used as nanofillers in packaging applications. Among various aforementioned metal nanoparticles (MNPs), silver nanoparticles (AgNPs) is observed to be most appropriately employed in packaging materials, biomedical appliances, cosmetics, pharmaceuticals and textile sectors [21]. The toxicity of AgNPs is found to be very minimum in animal cells. Certain inorganic metal nanoparticles are also recognized as safe materials by US Food and Drug Administration (FDA).

Biosynthesized AgNPs

Biological synthesis of AgNPs using bacterial strains

Biosynthesis of AgNPs includes bioreduction of silver salts with various plant extracts and biological synthesis of AgNPs with bacteria, fungi and biomolecules [22]. Biological synthesis of AgNPs can be via either intracellular or extracellular mechanisms [23]. Comparatively, the extracellular mechanism is observed to be simpler and more economical. Though, the mechanism is not yet completely understood, it is predicted to take place by the presence of nitrate reductase enzymes released by microorganisms, which reduces metallic ions to metallic nanoparticles. Among the biological syntheses of AgNPs, the bacterial synthesis has been identified to be most convenient [24], owing to its availability and vulnerability for genetic modification. The shape, size and nature of AgNPs determine method of synthesis. Hence, many variety of bacterial strains are used for the biological synthesis of AgNPs. These include *Bacillus spp.* [25], *Streptomyces spp*. [26], *Acinetobacter spp*. [27], *Pseudomonas spp*. [28], to mention but a few. Minimum quantity of AgNPs synthesized by biological method using bacterial strains shows a good activity towards major strains of microbes from attacking food stuffs. Amongst them are *S. aureus*, *P. aeruginosa, B. subtilis* and *E. coli.*

Biological synthesis of AgNPs using fungi species

The biological synthesis of AgNPs using fungal species is observed to be efficient with extracellular mechanism. The fungal species extracted from plants are more efficient than other species [29]. The following species of fungi are most prominently tested for the biological synthesis of AgNPs, *Fusarium oxysporum* [30], *Guignardia spp.* [31], *Penicillium aculeatum* [32], *Alternaria spp.* [33], *Phenerochaete chrysosporium* [34]. AgNPs synthesized via biological method using fungi have antimicrobial activity against a variety of fungal species as well as bacterial strains; both Gram-positive and negative. Therefore, the AgNPs synthesis using fungal species is an effective process to be employed in packaging material, since it effectively attacks microbes attacking the food stuffs.

Bioreduction of AgNPs using plant extracts

The plant extracts with flavonoid contents are mainly reported bioreductants for the synthesis of AgNPs [35]. Almost all the parts of a plant with flavonoids are been used. The experimental condition and active flavonoid contents play major roles in geometry and activity of the AgNPs. In most cases, capping agents are not used during bioreduction of AgNPs with plant extracts, which results in aggregation of the reduced AgNPs. The agglomeration of AgNPs may lead to reduced behavior of AgNPs. In this case, certain researchers generated the AgNPs *in-situ*; inside the polymer films directly, using plant extract as a reducing agent [36-38].

Anti-microbial activity of AgNPs

AgNPs have a wide spectrum of antimicrobial activity, including Gram-positive and negative bacteria, fungi and viruses. The mechanism of antibacterial activity of AgNPs have been studied based on its ability to release Ag^+ ions [39] and their potential to inhibit the growth metabolism of bacterial cells [40]. The mechanism of action of AgNPs against bacteria is proposed in three ways [41]: (1) penetration of AgNPs in the range of 1 to 10 nm into the cell membrane and interfere with its respiration, (2) interaction of AgNPs with the compounds of sulphur and phosphorus, such as DNA and (3) release of active silver (Ag^+) ions, which reacts with negatively charged cell membrane and damages them.

Moreover, the release of Ag^+ ions are influenced by availability of oxygen atmosphere. In anaerobic condition, the antibacterial effect is almost nil even with higher concentration [40]. The antimicrobial activity of AgNPs is also influenced by the shape and size of the synthesized AgNPs, the symmetry of the particles which offers greater contact surface have greater antimicrobial activity.

Packaging materials with AgNPs

The addition of nanoparticles into the already existing packaging materials provides improved physical-chemical properties, reduces hydrophilic behavior and induces biodegradability and antimicrobial activity. AgNPs are added as fillers in both biodegradable and non-biodegradable polymers. Few examples of food packaging material with AgNPs are presented in Table 1.

Table 1: Food packaging materials with AgNPs as additives.

Packaging material	Type of food material	Preferred storage period	References
PVC/AgNPs	Beef	Up to 14 days; 4 ± 2 ^oC	[42]
	Dried fruits and nuts	Up to 21 days; 4 ± 2 ^oC	[43]
LDPE/AgNPs	Meat, pork and chicken	Up to 21 days; 4 ± 2 ^oC	[44]
	Cheese	Up to 28 days; 4 ± 2 ^oC	[45]
PLA/AgNPs	Cheese	Up to 25 days; 4 ± 2 ^oC	[46]
	Mangoes	Up to 15 days; room temperature	[47]

Biosynthesized ZnNPs/ ZnONPs

Among various inorganic metal oxide nanoparticles available, Zinc oxide nanoparticles (ZnONPs) are more preferred, because they are inexpensive and easy to prepare. The US FDA has enlisted ZnONPs as part of safe materials [48]. As mentioned in the previous sub-sections, similar to AgNPs, the ZnNPs/ZnONPs can also be synthesized via bioreduction process, using plant extracts as well as biological synthesis with microorganisms. The following strains of bacteria have been effectively utilized for the biological synthesis of Zn/ZnONPs: *Aspergillus strain, Aspergillus fumigatus, Aspergillus terreus* [49], *Candida albicans* [50]. In addition, few used algal strains include *Chlamydomonas reinhardtii* [51], *Sargassum muticum* [52] and *S. myriocystum*.

Moving forward, biosynthesized Zn/ZnONPs possess appreciable antimicrobial activity against broad spectrum of bacteria and fungi. ZnNPs/ZnONPs also possess antitumor activity, it is cytotoxic and genotoxic towards certain types of human cells [53]. Further large scale production of ZnONPs by bioreduction process is possible [54], by coating the synthesized ZnONPs over cotton fabric, which possesses antimicrobial activity and washing durability. The biosynthesized ZnNPs/ZnONPs show a better catalytic activity than those ZnNPs/ZnONPs obtained from chemical methods. ZnONPs synthesized from the fungal strain, *Aspergillus fumigatus* is stable up to 90 days, while ZnONPs obtained from seaweed, *Sargassum myriocystum* is stable up to 6 months [55]. In case of bioreduction of Zn/ZnONPs using plant extracts, the carboxylic and phenolic groups present in the extract act as bioreductants as well as capping agents [56].

Packaging materials with ZnNPs/ ZnONPs

Zn/ZnONPs are well known for their stability under extreme conditions. They are effective against a wide spectrum of microbial strains, more specifically the food born microbes at a lower concentration [53, 57]. ZnONPs possess a unique property of filtering ultraviolet (UV) rays [58]. Addition of Zn/ZnONPs to both biodegradable or non-biodegradable polymer matrices increases the mechanical properties of the polymer, such as tensile strength, Young’s modulus and thermal resistance [59]. ZnONPs coated packaging materials are suitable for storing fish samples [60]. Zn/ZnONPs coated packaging materials also act as a good scavenger of oxygen. All the aforementioned characteristics qualify Zn/ZnONPs to be used as potential additives for packaging applications [61].

Table 2: Food packaging materials with ZnNPs as additives.

Packaging Material	Type of food material	Preferred storage period	References
PVC/ZnNPs	Cheese	30-40 days	[62]
	Sliced apples	Decay rate decreased by 60%	[63]
PLA/ZnONPs	Sliced apples	Decay rate decreased by 65%	[64]
OBG/ZnONPs	Spinach	Up to 7 days	[65]
PU/ZnONPs	Sliced carrot	Up to 9 days	[66]
PVA/ZnONPs	Aqueous food stuffs	pH indicator	[67]

Biosynthesized CuNPs/ CuONPs

Copper metal is well known for its antimicrobial activity from the ancient days. This is the reason behind the use of copper vessels for storing water. Even now, copper nanoparticles (CuNPs) are used for water treatment. CuNPs/CuONPs have commendable antimicrobial activity against a variety of bacteria, fungi and viruses [68]. The mechanism of interaction of CuNPs/CuONPs with microbes is through their cell membranes, thereby making them inactive. The bioreduction of CuNPs is successful with extracts of various plant species, such as, *Citrus medica Linn*. [69], *Ziziphus spina-christi* [70], *Asparagus adscendens Roxb*. Used root and leaf [71] include *Eclipta prostrata* leaves [72], *Ginkgo biloba Linn.* [73], *Plantago asiatica* leaf [74], *Thymus vulgaris L.* [75], black tea leaves [76], to mention but a few. Biological synthesis of CuNPs can be carried out with the following bacterial strains: *Escherichia coli*, *M. psychrotolerans* and *M. morganii RP42*. Biomediated synthesis of CuNPs/CuONPs is an economical as well as simple method, which can be executed with minimum infrastructures. In certain cases, CuNPs synthesized are observed to be more efficient than those synthesized via commercial chemical methods.

Packaging materials with CuNPs/ CuONPs

CuNPs are effective materials against both Gram-positive and negative organisms [77], which make them more suitable for packaging applications. The antimicrobial effect of CuNPs/ CuONPs more specifically towards *E.coli* in food stuffs and ability of CuNPs/CuONPs to be blended into polymer suggest them to be good additives in food packaging materials [78]. Impregnation of CuNPs/CuONPs into polymer films or biopolymer films [79] enhances their tensile strengths, transparency, thermal stability, mechanical strengths [80]. More also, it adds to the antimicrobial activity, UV barrier property and prolonged shell life, which make the material suitable for food packaging applications [81]. CuNPs coated packaging materials act as freshness indicator in case of meat, by turning dark by reacting with the volatile sulfide released during the spoilage of meat [82]. Currently, researchers are interested in examining the CuNPs/CuONPs impregnated films for electronic as well as catalytic applications.

Table 3: Food packaging materials with CuNPs/CuONPs as additives.

Packaging Material	Type of food material	Preferred storage period	References
Cellulose/CuNPs	Fruit juices	Decay rate decreased by 60%	[83]
Hydroxypropyl methylcellulose/CuNPs	Meat	Up to 15 days	[84]
Polylactic acid/CuNPs	All types of food stuffs	Expected to decrease the decay rate by 45%	[85]
Agar/CuNPs	All types of food stuffs	Expected to decrease the decay rate by 40%	[86]
HDPE/CuNPs	All types of food stuffs	Expected to decrease the decay rate by 30%	[87]

Titanium dioxide nanoparticles used as additives in food packaging

Titanium dioxide nanoparticles (TiO_2NPs) are effective additives in food packaging, due to their thermal stability, economical, non-toxic and stability properties towards UV light. TiO_2NPs are extensively employed as promising photo catalysts in various types of reactions [88]. They are also used in water treatment and self-cleaning applications. Due to the antimicrobial property of TiO_2NPs, the interest of several researchers have increased towards using them in food packaging. Unlike previously discussed metal nanoparticles, TiO_2NPs are more prone to agglomeration; therefore, ionic surfactants are used as capping agents to prevent agglomeration. TiO_2NPs are also synthesized from various plant extracts [89] and microbes [90]. TiO_2NPs can be fabricated with biodegradable fish skin gelatin [91], potato starch [92], pectin [93], super hydrophobic paper [94], poly vinyl chloride [95], polyethylene [96] and PLA [97]. Besides, TiO_2NPs as additives in packaging materials improve the mechanical strength, tensile strength, hydrophobicity, thermal stability, transparency, water vapour permeability, UV transmittance and antimicrobial properties. More specifically, application of TiO_2NPs has been effectively analyzed for foodstuffs, such as bread [98] and strawberry [99] for their nutritional values and decay periods. Also, TiO_2NPs are used for controlling hematophagous fly and sheep-biting louse [100]. Biosynthesized TiO_2NPs are employed in solar cells [101].

Other metal and metal oxide nanoparticles used as additives in packaging

The magnesium oxide nanoparticles (MgONPs) are recognized as safe materials by the US FDA. MgONPs are added as additives to PLA, poly ethylene (PE) and biodegradable polymers. MgONPs improve oxygen barrier, tensile strength and antibacterial property of polymer packaging materials [102], but they have poor water barrier property. Similarly, iron oxide nanoparticles (FeONPs) additives to polypropylene (PP), PVA and biopolymers show good gas barrier and improved thermal stability [103]. Also, silicon dioxide nanoparticles (SiO_2NPs) provide good insulation, low toxicity and stability to polymer, when they are used in packaging materials [104].

Conclusions

The use of biosynthesized metal/metal oxide nanoparticles as additives in packaging materials has been elucidated. It is evident that they increase shelf life of foodstuffs by inducing water vapour permeability, UV barrier, gas barrier and antimicrobial properties. Metal/metal oxide nanoparticles also increase thermal stability and mechanical/tensile strength of the receiving polymers used in packaging materials.

Besides, metal/metal oxide nanoparticles are found to be compatible with both synthetic as well as biopolymers. Biomediated synthesis of metal/metal oxide nanoparticles result to manufacturing of intelligent packaging materials in an economical and eco-friendly manners. Most metal/metal oxide nanoparticles are recognized as safe materials by US FDA. Therefore, biomediated synthesis of metal/metal oxide nanoparticles and their application in food packaging are important research areas to be explored and promising field to satisfy our day-to-day needs.

List of abbreviations

AgNPs	Silver nanoparticles
CuNPs	Copper nanoparticles
CuONPs	Copper oxide nanoparticles
FDA	Food and Drug Administration
FeONPs	Iron oxide nanoparticles
HDPE	High density polyethylene
LDPE	Low density polyethylene
MgONPs	Magnesium oxide nanoparticles
MNPs	Metal nanoparticles
NPs	Nanoparticles
OBG	Olive flounder bone gelatine
PA	Poly amides
PE	Poly ethylene
PET	Poly ethylene terephthalate
PHB	Poly hydroxyl butyrate
PLA	Poly lactic acid
PP	Polypropylene
PS	Poly styrene
PU	Polyurethane
PVA	Poly vinyl alcohol
PVC	Poly vinyl chloride
SiO_2NPs	Silicon oxide nanoparticles
TiO_2NPs	Titanium oxide nanoparticles
UV	Ultraviolet
ZnNPs	Zinc nanoparticles
ZnONPs	Zinc oxide nanoparticles

References

[1] J.-W. Han, L. Ruiz-Garcia, J.-P. Qian, and X.-T. Yang, “Food Packaging: A Comprehensive Review and Future Trends,” *Compr. Rev. Food Sci. Food Saf.*, vol. 17, no. 4, pp. 860–877, Jul. 2018.

[2] O. M. Koivistoinen, “Catabolism of biomass-derived sugars in fungi and metabolic engineering as a tool for organic acid production.” 2013.

[3] J. Vartiainen, M. Vähä-Nissi, and A. Harlin, “Biopolymer Films and Coatings in Packaging Applications—A Review of Recent Developments,” *Mater. Sci. Appl.*, vol. 05, no. 10, pp. 708–718, Aug. 2014.

[4] “Nanomaterial advantage | Nature.” [Online]. Available: https://www.nature.com/articles/419887a. [Accessed: 01-May-2020].

[5] N. Peelman *et al.*, “Application of bioplastics for food packaging,” *Trends in Food Science and Technology*, vol. 32, no. 2. Elsevier, pp. 128–141, 01-Aug-2013.

[6] M. Pal, “Nanotechnology: A New Approach in Food Packaging,” 2017.

[7] “Nanomaterials | Food Packaging Forum.” [Online]. Available: https://www.foodpackagingforum.org/food-packaging-health/nanomaterials. [Accessed: 01-May-2020].

[8] C. Buzea, I. I. Pacheco, and K. Robbie, “Nanomaterials and nanoparticles: Sources and toxicity,” *Biointerphases*, vol. 2, no. 4, pp. MR17–MR71, Dec. 2007.

[9] M. Cushen, J. Kerry, M. Morris, M. Cruz-Romero, and E. Cummins, “Migration and exposure assessment of silver from a PVC nanocomposite,” *Food Chem.*, vol. 139, no. 1–4, pp. 389–397, Aug. 2013.

[10] E. Fortunati *et al.*, “Multifunctional bionanocomposite films of poly(lactic acid), cellulose nanocrystals and silver nanoparticles,” *Carbohydr. Polym.*, vol. 87, no. 2, pp. 1596–1605, Jan. 2012.

[11] H. Y. Yu, X. Y. Yang, F. F. Lu, G. Y. Chen, and J. M. Yao, “Fabrication of multifunctional cellulose nanocrystals/poly(lactic acid) nanocomposites with silver nanoparticles by spraying method,” *Carbohydr. Polym.*, vol. 140, pp. 209–219, Apr. 2016.

[12] B. Iamareerat, M. Singh, M. B. Sadiq, and A. K. Anal, “Reinforced cassava starch based edible film incorporated with essential oil and sodium bentonite nanoclay as food packaging material,” *J. Food Sci. Technol.*, vol. 55, no. 5, pp. 1953–1959, May 2018.

[13] N. Mude, A. Ingle, A. Gade, and M. Rai, “Synthesis of silver nanoparticles using callus extract of Carica papaya - A first report,” *J. Plant Biochem. Biotechnol.*, vol. 18, no. 1, pp. 83–86, Jan. 2009.

[14] K. Vasudeo, S. Sampat, and K. Pramod, “Biosynthesis of copper nanoparticles using aqueous extract of Eucalyptus sp . plant leaves,” *Curr. Sci.*, vol. 109, no. 2, pp. 255–257, 2015.

[15] “Nanomaterials in food contact materials; considerations for risk assessment - Annals of the National Institute of Hygiene - Volume 68, Number 4 (2017) - AGRO - Yadda.” [Online]. Available: http://agro.icm.edu.pl/agro/element/bwmeta1.element.agro-ed369718-d0fb-47ff-a249-10e3a56ee46b. [Accessed: 01-May-2020].

[16] Z. Piperigkou *et al.*, “Emerging aspects of nanotoxicology in health and disease: From agriculture and food sector to cancer therapeutics,” *Food and Chemical Toxicology*, vol. 91. Elsevier Ltd, pp. 42–57, 01-May-2016.

[17] C. M. Ramakritinan *et al.*, “Synthesis of chitosan mediated silver nanoparticles (Ag NPs) for potential antimicrobial applications,” *Front. Lab. Med.*, vol. 2, no. 1, pp. 30–35, 2018.

[18] M. Cruz-Romero, “Crop-based biodegradable packaging and its environmental implications.,” *CAB Rev. Perspect. Agric. Vet. Sci. Nutr. Nat. Resour.*, vol. 3, no. 074, 2009.

[19] N. Durán, P. D. Marcato, R. De Conti, O. L. Alves, F. T. M. Costa, and M. Brocchi, “Potential use of silver nanoparticles on pathogenic bacteria, their toxicity and possible mechanisms of action,” *Journal of the Brazilian Chemical Society*, vol. 21, no. 6. Sociedade Brasileira de Quimica, pp. 949–959, 2010.

[20] X. Wei *et al.*, “Synthesis of silver nanoparticles by solar irradiation of cell-free Bacillus amyloliquefaciens extracts and AgNO 3,” *Bioresour. Technol.*, vol. 103, no. 1, pp. 273–278, Jan. 2012.

[21] K. AbdelRahim, S. Y. Mahmoud, A. M. Ali, K. S. Almaary, A. E. Z. M. A. Mustafa, and S. M. Husseiny, “Extracellular biosynthesis of silver nanoparticles using Rhizopus stolonifer,” *Saudi J. Biol. Sci.*, vol. 24, no. 1, pp. 208–216, Jan. 2017.

[22] T. Yurtluk, F. A. Akçay, and A. Avcı, “Biosynthesis of silver nanoparticles using novel

Bacillus sp. SBT8," *Prep. Biochem. Biotechnol.*, vol. 48, no. 2, pp. 151–159, Feb. 2018.

[23] H. Singh, J. Du, P. Singh, and T. H. Yi, "Extracellular synthesis of silver nanoparticles by Pseudomonas sp. THG-LS1.4 and their antimicrobial application," *J. Pharm. Anal.*, vol. 8, no. 4, pp. 258–264, Aug. 2018.

[24] E. K. F. Elbeshehy, A. M. Elazzazy, and G. Aggelis, "Silver nanoparticles synthesis mediated by new isolates of Bacillus spp., nanoparticle characterization and their activity against Bean Yellow Mosaic Virus and human pathogens," *Front. Microbiol.*, vol. 6, no. MAY, 2015.

[25] V. L. Das, R. Thomas, R. T. Varghese, E. V. Soniya, J. Mathew, and E. K. Radhakrishnan, "Extracellular synthesis of silver nanoparticles by the Bacillus strain CS 11 isolated from industrialized area," *3 Biotech*, vol. 4, no. 2, pp. 121–126, Apr. 2014.

[26] D. Manikprabhu and K. Lingappa, "Antibacterial activity of silver nanoparticles against methicillin-resistant Staphylococcus aureus synthesized using model Streptomyces sp. pigment by photo-irradiation method," *J. Pharm. Res.*, vol. 6, no. 2, pp. 255–260, Feb. 2013.

[27] B. A. Chopade *et al.*, "Synthesis, optimization, and characterization of silver nanoparticles from Acinetobacter calcoaceticus and their enhanced antibacterial activity when combined with antibiotics," *Int. J. Nanomedicine*, p. 4277, Nov. 2013.

[28] V. Gopinath *et al.*, "Biogenic synthesis, characterization of antibacterial silver nanoparticles and its cell cytotoxicity," *Arab. J. Chem.*, vol. 10, no. 8, pp. 1107–1117, Dec. 2017.

[29] L. Devi and S. Joshi, "Ultrastructures of silver nanoparticles biosynthesized using endophytic fungi," *J. Microsc. Ultrastruct.*, vol. 3, no. 1, p. 29, Mar. 2015.

[30] S. M. Husseiny, T. A. Salah, and H. A. Anter, "Biosynthesis of size controlled silver nanoparticles by Fusarium oxysporum, their antibacterial and antitumor activities," *Beni-Suef Univ. J. Basic Appl. Sci.*, vol. 4, no. 3, pp. 225–231, Sep. 2015.

[31] M. D. Balakumaran, R. Ramachandran, and P. T. Kalaichelvan, "Exploitation of endophytic fungus, Guignardia mangiferae for extracellular synthesis of silver nanoparticles and their in vitro biological activities," *Microbiol. Res.*, vol. 178, pp. 9–17,

Sep. 2015.

[32] L. Ma *et al.*, "Optimization for extracellular biosynthesis of silver nanoparticles by Penicillium aculeatum Su1 and their antimicrobial activity and cytotoxic effect compared with silver ions," *Mater. Sci. Eng. C*, vol. 77, pp. 963–971, Aug. 2017.

[33] K. Siegel-Hertz, V. Edel-Hermann, E. Chapelle, S. Terrat, J. M. Raaijmakers, and C. Steinberg, "Comparative microbiome analysis of a Fusarium wilt suppressive soil and a Fusarium wilt conducive soil from the Châteaurenard region," *Front. Microbiol.*, vol. 9, no. APR, p. 568, Apr. 2018.

[34] M. Saravanan, S. Arokiyaraj, T. Lakshmi, and A. Pugazhendhi, "Synthesis of silver nanoparticles from Phenerochaete chrysosporium (MTCC-787) and their antibacterial activity against human pathogenic bacteria," *Microb. Pathog.*, vol. 117, pp. 68–72, Apr. 2018.

[35] S. Kumar, A. Shukla, P. P. Baul, A. Mitra, and D. Halder, "Biodegradable hybrid nanocomposites of chitosan/gelatin and silver nanoparticles for active food packaging applications," *Food Packag. Shelf Life*, vol. 16, 2018.

[36] S. Paramasivan, N. E.R., R. Nagarajan, V. R. Anumakonda, and H. N., "Characterization of cotton fabric nanocomposites with in situ generated copper nanoparticles for antimicrobial applications," *Prep. Biochem. Biotechnol.*, vol. 0, no. 0, pp. 1–8, 2018.

[37] V. Sadanand, N. Rajini, B. Satyanarayana, and A. V. Rajulu, "Preparation and properties of cellulose/silver nanoparticle composites with in situ-generated silver nanoparticles using Ocimum sanctum leaf extract," *Int. J. Polym. Anal. Charact.*, vol. 21, no. 5, pp. 408–416, 2016.

[38] P. Sivaranjana, E. R. Nagarajan, N. Rajini, M. Jawaid, and A. V. Rajulu, "Cellulose nanocomposite films with in situ generated silver nanoparticles using Cassia alata leaf extract as a reducing agent," *Int. J. Biol. Macromol.*, vol. 99, pp. 223–232, 2017.

[39] A. C. S. Almeida, E. A. N. Franco, F. M. Peixoto, K. L. F. Pessanha, and N. R. Melo, "Aplicação de nanotecnologia em embalagens de alimentos," *Polimeros*, vol. 25, no. spe, pp. 89–97, Dec. 2015.

[40] A. S. Asger, K. Jannick, K. Jørgensen, M.-L. Knop, L. Martin, and O. Mikkelsen,

"Bactericidal Effect of Silver Nanoparticles Determination of size and shape of triangular silver nanoprisms and spherical silver nanoparticles and their bactericidal effect against Escherichia coli and Bacillus subtilis."

[41] J. R. Morones *et al.*, "JN2005," *Nanotechnology*, vol. 16, no. 10, pp. 2346–53, 2005.

[42] S. Soltani and R. Nourdahr, "Study on the Antimicrobial Effect of Nanosilver Tray Packaging of Minced Beef at Refrigerator Temperature," *Glob. Vet.*, vol. 9, no. 3, pp. 284–289, 2012.

[43] H. Tavakoli, H. Rastegar, M. Taherian, M. Samadi, and H. Rostami, "The effect of nano-silver packaging in increasing the shelf life of nuts: An in vitro model," *Ital. J. Food Saf.*, vol. 6, no. 4, pp. 156–161, Jan. 2017.

[44] L. Kuuliala *et al.*, "Preparation and antimicrobial characterization of silver-containing packaging materials for meat," *Food Packag. Shelf Life*, vol. 6, pp. 53–60, Dec. 2015.

[45] F. Beigmohammadi, S. H. Peighambardoust, J. Hesari, S. Azadmard-Damirchi, S. J. Peighambardoust, and N. K. Khosrowshahi, "Antibacterial properties of LDPE nanocomposite films in packaging of UF cheese," *LWT - Food Sci. Technol.*, vol. 65, pp. 106–111, 2016.

[46] W. Li, L. Li, H. Zhang, M. Yuan, and Y. Qin, "Evaluation of PLA nanocomposite films on physicochemical and microbiological properties of refrigerated cottage cheese," *J. Food Process. Preserv.*, vol. 42, no. 1, p. e13362, Jan. 2018.

[47] H. Chi *et al.*, "Effect of PLA nanocomposite films containing bergamot essential oil, TiO 2 nanoparticles, and Ag nanoparticles on shelf life of mangoes," *Sci. Hortic. (Amsterdam).*, vol. 249, pp. 192–198, Apr. 2019.

[48] J. Pulit-Prociak, J. Chwastowski, A. Kucharski, and M. Banach, "Functionalization of textiles with silver and zinc oxide nanoparticles," *Appl. Surf. Sci.*, vol. 385, pp. 543–553, Nov. 2016.

[49] R. Raliya and J. C. Tarafdar, "ZnO Nanoparticle Biosynthesis and Its Effect on Phosphorous-Mobilizing Enzyme Secretion and Gum Contents in Clusterbean (Cyamopsis tetragonoloba L.)," *Agric. Res.*, vol. 2, no. 1, pp. 48–57, Jan. 2013.

[50] Shamsuzzaman, A. Mashrai, H. Khanam, and R. N. Aljawfi, "Biological synthesis of

ZnO nanoparticles using C. albicans and studying their catalytic performance in the synthesis of steroidal pyrazolines," *Arab. J. Chem.*, vol. 10, pp. S1530–S1536, May 2017.

[51] M. D. Rao and P. Gautam, "Synthesis and characterization of ZnO nanoflowers using *C hlamydomonas reinhardtii* : A green approach," *Environ. Prog. Sustain. Energy*, vol. 35, no. 4, pp. 1020–1026, Jul. 2016.

[52] S. Azizi, M. B. Ahmad, F. Namvar, and R. Mohamad, "Green biosynthesis and characterization of zinc oxide nanoparticles using brown marine macroalga Sargassum muticum aqueous extract," *Mater. Lett.*, vol. 116, pp. 275–277, Feb. 2014.

[53] A. Król, P. Pomastowski, K. Rafińska, V. Railean-Plugaru, and B. Buszewski, "Zinc oxide nanoparticles: Synthesis, antiseptic activity and toxicity mechanism," *Advances in Colloid and Interface Science*, vol. 249. Elsevier B.V., pp. 37–52, 01-Nov-2017.

[54] R. Yuvakkumar, J. Suresh, A. J. Nathanael, M. Sundrarajan, and S. I. Hong, "Novel green synthetic strategy to prepare ZnO nanocrystals using rambutan (Nephelium lappaceum L.) peel extract and its antibacterial applications," *Mater. Sci. Eng. C*, vol. 41, pp. 17–27, Aug. 2014.

[55] S. Nagarajan and K. Arumugam Kuppusamy, "Extracellular synthesis of zinc oxide nanoparticle using seaweeds of gulf of Mannar, India," *J. Nanobiotechnology*, vol. 11, no. 1, pp. 1–11, Dec. 2013.

[56] L. Xiao, C. Liu, X. Chen, and Z. Yang, "Zinc oxide nanoparticles induce renal toxicity through reactive oxygen species," *Food Chem. Toxicol.*, vol. 90, pp. 76–83, Apr. 2016.

[57] H. Esmailzadeh, P. Sangpour, F. Shahraz, J. Hejazi, and R. Khaksar, "Effect of nanocomposite packaging containing ZnO on growth of Bacillus subtilis and Enterobacter aerogenes," *Mater. Sci. Eng. C*, vol. 58, pp. 1058–1063, Jan. 2016.

[58] A. Babaei-Ghazvini, I. Shahabi-Ghahfarrokhi, and V. Goudarzi, "Preparation of UV-protective starch/kefiran/ZnO nanocomposite as a packaging film: Characterization," *Food Packag. Shelf Life*, vol. 16, pp. 103–111, Jun. 2018.

[59] V. K. Kotharangannagari and K. Krishnan, "Biodegradable hybrid nanocomposites of starch/lysine and ZnO nanoparticles with shape memory properties," *Mater. Des.*, vol.

109, pp. 590–595, Nov. 2016.

[60] M. Mizielińska, U. Kowalska, M. Jarosz, and P. Sumińska, “A Comparison of the Effects of Packaging Containing Nano ZnO or Polylysine on the Microbial Purity and Texture of Cod (Gadus morhua) Fillets,” *Nanomaterials*, vol. 8, no. 3, p. 158, Mar. 2018.

[61] S. V. Calderon, B. Gomes, P. J. Ferreira, and S. Carvalho, “Zinc nanostructures for oxygen scavenging,” *Nanoscale*, vol. 9, no. 16, pp. 5254–5262, Apr. 2017.

[62] X. Li, Y. Xing, Y. Jiang, Y. Ding, and W. Li, “Antimicrobial activities of ZnO powder-coated PVC film to inactivate food pathogens,” *Int. J. Food Sci. Technol.*, vol. 44, no. 11, pp. 2161–2168, Nov. 2009.

[63] “Effects of Nano-ZnO Power-Coated PVC Film on the Physiological Properties and Microbiological Changes of Fresh-Cut ‘Fuji’ Apple | Scientific.Net.” [Online]. Available: https://www.scientific.net/AMR.152-153.450. [Accessed: 18-May-2020].

[64] W. Li, L. Li, Y. Cao, T. Lan, H. Chen, and Y. Qin, “Effects of PLA Film Incorporated with ZnO Nanoparticle on the Quality Attributes of Fresh-Cut Apple,” *Nanomaterials*, vol. 7, no. 8, p. 207, Jul. 2017.

[65] S. Beak, H. Kim, and K. Bin Song, “Characterization of an Olive Flounder Bone Gelatin-Zinc Oxide Nanocomposite Film and Evaluation of Its Potential Application in Spinach Packaging,” *J. Food Sci.*, vol. 82, no. 11, pp. 2643–2649, Nov. 2017.

[66] S. S. K., M. P. Indumathi, and G. R. Rajarajeswari, “Mahua oil-based polyurethane/chitosan/nano ZnO composite films for biodegradable food packaging applications,” *Int. J. Biol. Macromol.*, vol. 124, pp. 163–174, Mar. 2019.

[67] A. Jayakumar *et al.*, “Starch-PVA composite films with zinc-oxide nanoparticles and phytochemicals as intelligent pH sensing wraps for food packaging application,” *Int. J. Biol. Macromol.*, vol. 136, pp. 395–403, Sep. 2019.

[68] H. Almasi, P. Jafarzadeh, and L. Mehryar, “Fabrication of novel nanohybrids by impregnation of CuO nanoparticles into bacterial cellulose and chitosan nanofibers: Characterization, antimicrobial and release properties,” *Carbohydr. Polym.*, vol. 186, pp. 273–281, Apr. 2018.

[69] S. Shende, A. P. Ingle, A. Gade, and M. Rai, “Green synthesis of copper nanoparticles

by Citrus medica Linn. (Idilimbu) juice and its antimicrobial activity," *World J. Microbiol. Biotechnol.*, vol. 31, no. 6, pp. 865–873, Apr. 2015.

[70] R. Khani, B. Roostaei, G. Bagherzade, and M. Moudi, "Green synthesis of copper nanoparticles by fruit extract of Ziziphus spina-christi (L.) Willd.: Application for adsorption of triphenylmethane dye and antibacterial assay," *J. Mol. Liq.*, vol. 255, pp. 541–549, Apr. 2018.

[71] S. Thakur, S. Sharma, S. Thakur, and R. Rai, "Green Synthesis of Copper Nano-Particles Using Asparagus adscendens Roxb. Root and Leaf Extract and Their Antimicrobial Activities," *Int. J. Curr. Microbiol. Appl. Sci.*, vol. 7, no. 04, pp. 683–694, Apr. 2018.

[72] I. Chung *et al.*, "Green synthesis of copper nanoparticles using eclipta prostrata leaves extract and their antioxidant and cytotoxic activities," *Exp. Ther. Med.*, vol. 14, no. 1, pp. 18–24, Jul. 2017.

[73] M. Nasrollahzadeh and S. Mohammad Sajadi, "Green synthesis of copper nanoparticles using Ginkgo biloba L. leaf extract and their catalytic activity for the Huisgen [3+2] cycloaddition of azides and alkynes at room temperature," *J. Colloid Interface Sci.*, vol. 457, pp. 141–147, Nov. 2015.

[74] M. Nasrollahzadeh, S. S. Momeni, and S. M. Sajadi, "Green synthesis of copper nanoparticles using Plantago asiatica leaf extract and their application for the cyanation of aldehydes using K 4 Fe(CN) 6," *J. Colloid Interface Sci.*, vol. 506, pp. 471–477, Nov. 2017.

[75] Z. Issaabadi, M. Nasrollahzadeh, and S. M. Sajadi, "Green synthesis of the copper nanoparticles supported on bentonite and investigation of its catalytic activity," *J. Clean. Prod.*, vol. 142, pp. 3584–3591, Jan. 2017.

[76] M. A. Asghar *et al.*, "Iron, copper and silver nanoparticles: Green synthesis using green and black tea leaves extracts and evaluation of antibacterial, antifungal and aflatoxin B1 adsorption activity," *LWT - Food Sci. Technol.*, vol. 90, pp. 98–107, Apr. 2018.

[77] A. F. Jaramillo *et al.*, "Comparative Study of the Antimicrobial Effect of Nanocomposites and Composite Based on Poly(butylene adipate-co-terephthalate) Using Cu and Cu/Cu2O Nanoparticles and CuSO4," *Nanoscale Res. Lett.*, vol. 14, no. 1, pp. 1–17, May 2019.

[78] M. Grigore, E. Biscu, A. Holban, M. Gestal, and A. Grumezescu, “Methods of Synthesis, Properties and Biomedical Applications of CuO Nanoparticles,” *Pharmaceuticals*, vol. 9, no. 4, p. 75, Nov. 2016.

[79] V. Sadanand, N. Rajini, A. Varada Rajulu, and B. Satyanarayana, “Preparation of cellulose composites with in situ generated copper nanoparticles using leaf extract and their properties,” *Carbohydr. Polym.*, vol. 150, pp. 32–39, Oct. 2016.

[80] Y. A. Arfat, J. Ahmed, N. Hiremath, R. Auras, and A. Joseph, “Thermo-mechanical, rheological, structural and antimicrobial properties of bionanocomposite films based on fish skin gelatin and silver-copper nanoparticles,” *Food Hydrocoll.*, vol. 62, pp. 191–202, Jan. 2017.

[81] A. Eivazihollagh *et al.*, “One-pot synthesis of cellulose-templated copper nanoparticles with antibacterial properties,” *Mater. Lett.*, vol. 187, pp. 170–172, Jan. 2017.

[82] C. Sharma, R. Dhiman, N. Rokana, and H. Panwar, “Nanotechnology: An untapped resource for food packaging,” *Frontiers in Microbiology*, vol. 8, no. SEP. Frontiers Media S.A., 12-Sep-2017.

[83] A. Llorens, E. Lloret, P. Picouet, and A. Fernandez, “Study of the antifungal potential of novel cellulose/copper composites as absorbent materials for fruit juices,” *Int. J. Food Microbiol.*, vol. 158, no. 2, pp. 113–119, Aug. 2012.

[84] S. Ebrahimiasl and A. Rajabpour, “Synthesis and characterization of novel bactericidal Cu/HPMC BNCs using chemical reduction method for food packaging,” *J. Food Sci. Technol.*, vol. 52, no. 9, pp. 5982–5988, Sep. 2015.

[85] D. Longano *et al.*, “Analytical characterization of laser-generated copper nanoparticles for antibacterial composite food packaging,” in *Analytical and Bioanalytical Chemistry*, 2012, vol. 403, no. 4, pp. 1179–1186.

[86] S. Shankar and J. W. Rhim, “Effect of copper salts and reducing agents on characteristics and antimicrobial activity of copper nanoparticles,” *Mater. Lett.*, vol. 132, pp. 307–311, Oct. 2014.

[87] D. N. Bikiaris and K. S. Triantafyllidis, “HDPE/Cu-nanofiber nanocomposites with enhanced antibacterial and oxygen barrier properties appropriate for food packaging

applications," *Mater. Lett.*, vol. 93, pp. 1–4, Feb. 2013.

[88] H. M. Yadav, J. S. Kim, and S. H. Pawar, "Developments in photocatalytic antibacterial activity of nano TiO2: A review," *Korean Journal of Chemical Engineering*, vol. 33, no. 7. Springer New York LLC, pp. 1989–1998, 01-Jul-2016.

[89] G. Rajakumar, A. A. Rahuman, B. Priyamvada, V. G. Khanna, D. K. Kumar, and P. J. Sujin, "Eclipta prostrata leaf aqueous extract mediated synthesis of titanium dioxide nanoparticles," *Mater. Lett.*, vol. 68, pp. 115–117, Feb. 2012.

[90] A. Vishnu Kirthi *et al.*, "Biosynthesis of titanium dioxide nanoparticles using bacterium Bacillus subtilis," *Mater. Lett.*, vol. 65, no. 17–18, pp. 2745–2747, Sep. 2011.

[91] Q. He, Y. Zhang, X. Cai, and S. Wang, "Fabrication of gelatin-TiO2 nanocomposite film and its structural, antibacterial and physical properties," *Int. J. Biol. Macromol.*, vol. 84, pp. 153–160, Mar. 2016.

[92] S. A. Oleyaei, Y. Zahedi, B. Ghanbarzadeh, and A. A. Moayedi, "Modification of physicochemical and thermal properties of starch films by incorporation of TiO2 nanoparticles," *Int. J. Biol. Macromol.*, vol. 89, pp. 256–264, Aug. 2016.

[93] A. Nešić *et al.*, "Pectin-based nanocomposite aerogels for potential insulated food packaging application," *Carbohydr. Polym.*, vol. 195, pp. 128–135, Sep. 2018.

[94] H. Li, J. Yang, P. Li, T. Lan, and L. Peng, "A facile method for preparation superhydrophobic paper with enhanced physical strength and moisture-proofing property," *Carbohydr. Polym.*, vol. 160, pp. 9–17, Mar. 2017.

[95] C. López de Dicastillo, C. Patiño, M. J. Galotto, J. L. Palma, D. Alburquenque, and J. Escrig, "Novel antimicrobial titanium dioxide nanotubes obtained through a combination of atomic layer deposition and electrospinning technologies," *Nanomaterials*, vol. 8, no. 2, Feb. 2018.

[96] Y. Xing *et al.*, "Effect of TiO 2 nanoparticles on the antibacterial and physical properties of polyethylene-based film," *Prog. Org. Coatings*, vol. 73, no. 2–3, pp. 219–224, Feb. 2012.

[97] D. Roilo, C. A. Maestri, M. Scarpa, P. Bettotti, and R. Checchetto, "Gas barrier and optical properties of cellulose nanofiber coatings with dispersed TiO2 nanoparticles,"

Surf. Coatings Technol., vol. 343, pp. 131–137, Jun. 2018.

[98] A. Mihaly-Cozmuta *et al.*, “Preparation and characterization of active cellulose-based papers modified with TiO2, Ag and zeolite nanocomposites for bread packaging application,” *Cellulose*, vol. 24, no. 9, pp. 3911–3928, Sep. 2017.

[99] D. Li, Q. Ye, L. Jiang, and Z. Luo, “Effects of nano-TiO $_2$ -LDPE packaging on postharvest quality and antioxidant capacity of strawberry (*Fragaria ananassa* Duch.) stored at refrigeration temperature,” *J. Sci. Food Agric.*, vol. 97, no. 4, pp. 1116–1123, Mar. 2017.

[100] K. Velayutham *et al.*, “Evaluation of Catharanthus roseus leaf extract-mediated biosynthesis of titanium dioxide nanoparticles against Hippobosca maculata and Bovicola ovis,” *Parasitol. Res.*, vol. 111, no. 6, pp. 2329–2337, Dec. 2012.

[101] N. A. Órdenes-Aenishanslins, L. A. Saona, V. M. Durán-Toro, J. P. Monrás, D. M. Bravo, and J. M. Pérez-Donoso, “Use of titanium dioxide nanoparticles biosynthesized by Bacillus mycoides in quantum dot sensitized solar cells,” *Microb. Cell Fact.*, vol. 13, no. 1, pp. 1–10, Jul. 2014.

[102] C. Swaroop and M. Shukla, “Nano-magnesium oxide reinforced polylactic acid biofilms for food packaging applications,” *Int. J. Biol. Macromol.*, vol. 113, pp. 729–736, Jul. 2018.

[103] M. J. Khalaj, H. Ahmadi, R. Lesankhosh, and G. Khalaj, “Study of physical and mechanical properties of polypropylene nanocomposites for food packaging application: Nano-clay modified with iron nanoparticles,” *Trends in Food Science and Technology*, vol. 51. Elsevier Ltd, pp. 41–48, 01-May-2016.

[104] S. Mallakpour and H. Y. Nazari, “The influence of bovine serum albumin-modified silica on the physicochemical properties of poly(vinyl alcohol) nanocomposites synthesized by ultrasonication technique,” *Ultrason. Sonochem.*, vol. 41, pp. 1–10, Mar. 2018.