OPEN ACCESS Plant Health 01 (01) 2022. 17-24 DOI: 10.33687/planthealth.01.01.4535

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Available Online at EScience Press
Plant Health
ISSN: 2305-6835
https://esciencepress.net/journals/planthealth

A Comprehensive Review of the Synthesis and Antimicrobial Properties of Food Nanopackaging

[a]Muniba Zahid, [a]Momna Abbasi, [b]Tanzila Zahid, [a]Tayyaba Tariq, [c]Shazia Erum, [c]Shabana Irum, [a]Arifa Khan*, [d]Wajeeha Hassan

[a] Department of Zoology, Govt. Viqar-un-Nisa Post Graduate College, Rawalpindi, Pakistan.
[b] Healthcare Management, Riphah International University, Pakistan.
[c] National Agriculture Research Centre Islamabad, Pakistan.
[d] Solid State Physics Department, The University of Punjab Lahore, Pakistan.

ARTICLE INFO

Article History
Received: July 26, 2022
Revised: Septemner 13, 2022
Accepted: November 16, 2022

Keywords
Eco-friendly
Food packaging
Nanoparticles
Nanotechnology
Foodborne pathogens

ABSTRACT

Nanotechnology is a vast field of science that plays a significant role in our daily life by providing a lot of advantages. It improves our feeding habits by preventing a lot of microbiological infections. Nanotechnology promises interesting changes for a better environment, for a better life. It provides a lot of advantages to improve health and wealth. Biosynthesis of nanoparticles is the green approach for the eco-friendly environment. It plays an important role in improving quality of products and life, for eco-friendly environment. Foodborne pathogens such as bacteria, viruses and parasites cause foodborne illness by ingesting the food contaminated by foodborne pathogens. This article reviews uses of different materials in advance field of smart nanotechnology, including bio-based packaging, improved packaging, intelligent packaging and active packaging. Silver, gold, zinc oxide, silicon dioxide are the inorganic nanoparticles which improve and extend the shelf life of fruits, vegetables and meat because of their unique properties such as oxygen exchange and retains the moisture and freshness in the food for a long period of time. It prevents the foodborne pathogens and thus providing eco-friendly packaging.

Corresponding Author: Arifa Khan
Email: arifa.phdbt55@iiu.edu.pk

INTRODUCTION

Foodborne infection occurs when food which is contaminated with pathogen is ingested and multiplies itself in the human host. Storage food and other beverages are contaminated by foodborne pathogens including the bacteria, viruses and parasites causing serious foodborne diseases that are classified into foodborne intoxication and infection. Today, nanotechnology presents effective applications against food pathogenic microorganisms. Nanotechnology presents the novel food packaging technology that produces and uses nanomaterials including the nano particles and nanocomposites with novel antimicrobial and physiochemical properties. Microbiological or microbial quality of the raw and processed food is important to considered during food safety. Packaging and storage of food is a critical step to prevent foodborne infection and foodborne intoxication. At present, nonconventional packaging is becoming the most important application to prevent foodborne illness and extend and improves the shelf life of packaged foods. Nanotechnology provide novel opportunities for the bactericidal effect of nanomaterials including the nanoparticles and nanocomposites with a marked bioactivity (Singh *et al.*, 2017). Nanotechnology is defined as a study of nanoparticles and nanocomposites and use of matter and structures sizes ranges from 1 to 100nm (Sujithra & Manikkandan, 2019). Nanotechnology has become one of the most auspicious technology to transfigure conventional food science and the food manufacturing and packaging industry. Nanotechnology develops the particles of nano size which improves the food quality, color, texture and taste of food and imparts perfect flavor also. nanomaterials are particles having nanoscale dimension. They are nano sized particles with thermal conductivity, enhanced catalytic reactivity, and chemical steadiness owing to its large surface area to volume ratio (Tabrez *et al*., 2016). nanoparticles are also called as nano antibiotics because they have antimicrobial properties (Ahmad *et al*., 2003). nanoparticles have been homogenized into various industrial, health, food, feed, cosmetics, and chemical industry which calls for a green and eco-friendly approach to their synthesis (Rao & Gautam, 2016).

There are many benefits of nanotechnology in food manufacturing and packaging industry. Nanoparticles like tio_2 and sio_2 and amorphous silica are used as food additives. Tio_2 is used as a coloring in the confectioner sugar coating on biscuits, doughnuts and breads. Nanotechnology plays an important role in packaging of frozen food and storage food for the purpose of long-lasting freshness and moisture without contaminated by pathogens.

Synthesis of nanoparticles

There are two methods of nanoparticle synthesis: Bottom side up and topside down method. The topside–down method involves crunch or attenuation of large macroscopic particle. It initially involves synthesizing of large-scale particles and then reducing it to nanoscale dimension level through the process of plastic deformation. This technique cannot be used for large scale production of nanoparticles because it is a costly and it is very slow process (Arasu *et al*., 2010). One of the techniques involved in synthesis of nanoparticles is Interferometric Lithographic (IL). It is the most common technique. It employs the role of topside–down approach for nanoparticle synthesis (Vitor *et al*., 2015). This technique of synthesis of nanomaterials involves the synthesis of nanomaterials from already miniaturized atomic source through self-assembly of particles. This includes formation of nanomaterials through chemical and physical means. It is a comparatively inexpensive approach (Rashid *et al*., 2017). It is based on the kinetic and thermodynamic equilibrium. It involves molecular beam epitaxy.

Biosynthesis of nanoparticles

Microorganisms plays a major role in our daily life. They are involved in the synthesis of nanoparticles. This approach is an eco-friendly, biocompatible, cost effective and most important is that it is green approach (Salam *et al*., 2014). Green approach means synthesis through bacteria, plants, algae, fungi etc. It allows large scale production of zinc oxide nanoparticles. This process is free of additional impurities (Yuvakkumar *et al*., 2014). Nanoparticles synthesized from this method exhibit more catalytic activity and it also limit the use of most expensive and toxic chemicals.

The major advantage is that these natural plant extract and microorganism's strains are able to secrete some phyto chemicals that act as both stabilization agent and reducing agent. For example, *B.licheniformis* involved in synthesis of ZnO nanoflowers of uniform size showed enhanced photo stability and photocatalytic activity clearly portrait by 83% degradation of methylene blue pollutant dye in the presence of Zinc oxide nanoflowers showed that the self-degeneration of pollutant dye was null and through the series of experiments, it was found that degeneration is 74% which clearly depicted photo stability of Zinc Oxide nanoflowers (Auld, 2001). Fungal strain *Aspergillus fumigates* is involved in synthesis of hexagonal and spherical shaped ZnO nanoparticles and these synthesized nanoparticles showed stability for about 90 days. It showed the higher stability of nanoparticles synthesized from fungal strain. (Holmes *et al*., 2003).

Antimicrobial activity of nanomaterials

Pathogenic infections are because of microbial contamination and poor nutrition associated with weaning foods. In the production, processing, transport and storage of food, dealing with microbial activity including the microbial interaction and bacterial deterioration is the most critical task. Nanotechnology advanced applications ensures the prevention of bacterial spoilage and deterioration. It has safeguarding effects on food spoilage and deterioration, thereby improves and extend the shelf life of food. A number of metal and metal oxide particles of nano scale dimension are effective in preservation of food and long lasting freshness and moisture because they act as antimicrobials. These nano scale dimension particles have unique intrinsic physiochemical properties allowed them to form excessive reactive oxygen species (ROS), Leading to subsequent cell damage and oxidative stress (Wu *et al*., 2014; Fu *et al*., 2014).

One of the used nanomaterials are the nanoparticles and nanocomposites because they are antimicrobials, in the food manufacturing and packaging industry. A number of silver-containing zeolites or other substances have been approved by the U.S. FDA as food materials involved in disinfection (FDA, 2015).

Silver nano particles have the ability to bind with the membrane proteins because they are likely serving as a source of Agþ ions, forming pits, producing other structural changes (Morones *et al*., 2005).Catalyzing and multiplication of ROS in bacterial cells, succeeding the cell death through the process of oxidative stress. In addition, nanocomposites offer more stability for sustaining antimicrobial activity and reduces the incidence of transferring of metal ions into preserved foods. For food application, polymers play an important role in engineering of nanomaterials. Some of the important polymers involved in engineering of nanocomposites are the Ag/LDPE (Kim *et al*., 2007) (Becaro *et al*., 2015), CuO/LDPE (Beigmohammadi *et al*., 2016), TiO2/LDPE (Bodaghi *et al*., 2015), and ZnO/LDPE (Beigmohammadi *et al*., 2016; Esmailzadeh *et al*., 2016). In addition, ZnO/gelatin (Shankar *et al*., 2015; Umamah eswari *et al*., 2015; Arfat *et al*., 2016), Ag/OMteLDPE (Savas & Hancer, 2015), Ag/poly (3-hydroxybutyrate-co-18mol% -3-hydroxyvalerate)(Castro-Mayorga *et al*., 2016), ZnO/polycarbonate Dhapte *et al*., 2015), ZnO/isotactic polypropylene (Cimmino *et al*., 2015) ZnO/polylactic acid (Marra *et al*., 2016; De Silva *et al*., 2015), ZnO/graphene oxide/polylactic acid (Huang *et al*., 2015), are targeted specifically for the purpose of food packaging applications. Nanocomposite including the Polystyrene, polyvinylpyrrolidone, and poly(vinyl chloride) are reported as nanocomposite films that bind to Copper or ZnO nanomaterials of nanoscale dimension in order to inactivate food pathogens (Cárdenas *et al*., 2009; Jin *et al*., 2009; Li *et al*., 2009).

Physical properties of nanomaterial

Food color additive: For the purpose of food safety and health hazards, it is necessary to approved the color additives by the office of color and cosmetics for food safety and health. With the help of nanotechnology, a number of color additives have manufactured that are suitable for heath and food safety. The certain color additives are approved which play an important role in the psychological appeal of consumer products. TiO_2 is approved by U.S FDA as a food color additive with the limit that food color additive should not be exceed 1% w/w (FDA, 2002). Food color additive mixture used for food are made with TiO_2 may also contain SiO_2 and AI203. One of the food color additives is carbon black is no longer authorized (FDA, 2015).

Anticaking agents: In powdered products, the flow properties are maintained by using SiO_2 in order to thick paste because it acts an anticaking agent. It also acts as a carrier of fragrances or flavors in food products. Food additive (e551) is registered and widely been use in food products.

Food packaging

The application of nanotechnology is to protect the food from microbial contamination and to improve food quality and mechanical and physical barriers. Nano-silver is used as a nanoparticle in order to improve the food freshness and to extend it and to prevent microbial contamination Nano materials involved in Nanotechnology packaging application can also be used to boost the packaging barrier properties to synchronize the passage of gases and moisture of food fibers. It is also involved in increasing and improving the shelf life and maintain the quality and freshness of food through the packaging.

Nano packaging is divided into three main categories.

- Improved packaging: These packages are resistance to humidity and temperature and contain nanoparticles.
- Second is active packaging: it contains inorganic nanoparticles, it interacts directly with food particles and provide anti-microbial properties.
- Intelligent packaging: it has the ability to sense biochemical and microbial changes and the specific pathogens producing and developing in food (Anvar *et al*., 2021).

The basic goal of packaging is to increase and improves the physical and mechanical properties of packages. A number of nanocomposites are manufactured for different types of food products such as oil and beverages to regulate and reduce the carbon dioxide and oxygen gases for upto 80-90%. One of the most well-liked nanoparticles used in food packaging is nanoclay. Nanoclay play an important role in food packaging, it incorporates into the polymer and can prevent the penetration of various gases, most important oxygen up to 50% and also water vapors up to 90% (Kim and Cha, 2014). Improved packaging does not include the antimicrobial packaging (Anvar *et al.*, 2021). The manufacturing of nanomaterials including the nanoparticles and nanocomposites leads to development of antimicrobial active packaging. It is capable to preserve storage food and extending the shelf life of food. (Fig. 1)

Figure 1. Types Of Nano Packaging.

Silver nanoparticles

The most common nanoparticle is nanosilver used in food packaging because it offers high stability and it is toxic to wide range of pathogens. Silver nanoparticles has to ability to release silver ions which have the capability to adhere the cytoplasmic membrane and enhances permeability. Silver ions enters into bacterial cells inactivates respiratory enzymes and generates ROS but disturb the ATP synthesis. ROS can cause DNA damage and cause bacterial death (Yin *et al*., 2020). A number of studies have improved and extended the shelf life of packaged food with the help of antimicrobial activity of silver nanoparticles. It has been reported that the trays coated with silver nanoparticles could extend the shelf life of minced meat to 7 days at refrigerator temperature compared with other common packaging. (Lima *et al*., 2013).

Gold nanoparticles

Other important nanoparticles are gold nanoparticles. Gold nanoparticles have a great antimicrobial property against broad range of pathogens or microorganisms depend on their shape and size (Lima *et al*., 2013). The biofilms or bio coatings containing gold nanoparticles are very beneficial to be used as active food packaging for the extension and improvement of the shelf life of food. (Lima *et al*., 2013) showed that 5nm gold nanoparticles are capable for the elimination of 90-95% of *E. coli* bacteria and *s.typhi* bacterial colonies in short time. Active biofilms of quinoa starch (*Chenopodium quinoa*) exhibit strong action of antibacterial activity against *E. coli* bacteria and *S. aureus* foodborne bacteria. The inhibition % is 99 and 98% (Pagno *et al*., 2015). Gold nanoparticles have the ability to affect respiratory enzymes which lead to cell death (Zawrah *et al*., 2011). Bacteriocin in combination with Gold nanoparticles has increased anti-microbial properties and activities against food spoiling organism of *Bacillus cereus, Micrococcus luteus, S.aureus and E.coli* (Thirumurugan *et al*., 2013).

Silicon dioxide nanoparticles

Nanoparticle SiO_2 possess unique properties and offer several advantages such as thermal stability, high strength and high abundance.it is lowly cost and used in inorganic polymer composites (Hou *et al*., 2019) (GC)-SiO_2 film and GC SiO_2-octadecyldimethyl-(3-trimethoxysilylpropyl)- ammonium. Chloride are the nanocomposites showed the antimicrobial activities against *Bacillus cereus, S.aureus, Salmonella enteric and e.coli.* Results showed that GC-SiO_2/Chitosan Complex film plays very beneficial role in extending shelf life of tomatoes and in preservation of food especially tomatoes. GC-SiO_2-ODDMAC coating film had a broad spectrum of antimicrobial activities for both gram-negative and gram-positive bacteria (Rukmanikrishnan *et al*., 2020). Advanced Nano film slow the moisture loss from packaged food and gas exchange and also respiration rates.It is also involved in limiting bacterial growth and decrease malondialdehyde and total polyphenol content present in food. In post-harvested tomatoes, nano SiO_2/Chitosan complex film is proposed for packaging (Zhu *et al*., 2019).

Zinc oxide nanoparticles

Zinc oxide is generally recognized as a safe nanoparticle listed by FDA (Espitia *et al*., 2012). For the fruits like mango, black grape, apple, tomato etc, chitosan and zinc oxide nanoparticles with gallic-acid filmshas been used for active food packaging of these fruits (Yadav *et al*., 2021). Kalia *et al., (2021)* fabricated chitosan-based nanomaterial particularly nanocomposite for extending the shelf life of guava (Kalia *et al*., 2021). This film contains CuO and ZnO nanoparticles synthesized from nettle leaf extract. The antimicrobial and antioxidant properties of biologically synthesized nanoparticles is in order of CuO NPs > ZnO NPs > nettle extract (Kalia *et al*., 2021). In white brined cheese. Foodborne pathogens can easily grow such as *E. coli*. The initial number of *E. coli* can be reduced by using Chitosan and chitosan-ZnO NPs coating films (Al-Nabulsi *et al*., 2020). C.jejuni present in raw chicken meat can be controlled by using absorbing pads containing ZnO nanoparticles (Hakeem *et al*., 2020) They reduced to the undetectable level by using immobilized zinc oxide nanoparticles.

CONCLUSION

The synthesis of nanomaterials by using microorganism's strains and plants extract is the green approach that has been the area of interest in the last decade. Nanoparticles synthesized in this way are eco-friendly and act as both reducing agent and stabilizing agent. The shape and size of the nanoparticles can be easily control by the use of this eco-friendly approach. The vegan-based nanoparticles have the huge application in the field of cosmetics, food and pharmaceutical industries. To avoid the foodborne illness, nanopackaging is the advance science for the synthesis of nanoparticles as preservatives. Nanopackaging plays an important role in reducing the risk of foodborne pathogens, retains the freshness and moisture and extending the shelf life of food. This review represents the capability of nanoparticles as antimicrobial agents against the foodborne pathogens. Thus, nanopackaging plays a major role in food safety, preventing foodborne pathogens and illness, improves the quality of food and extends the shelf life of food.

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CONFLICT OF INTEREST

The authors have not declared any conflict of interests.

ACKNOWLEDGMENTS

The authors would like to thank Department of Zoology, Govt. Viqar un Nisa college Rawalpindi Pakistan for providing technical assistance of this work.