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Green synthesis of nanoparticles the importance of use in food packaging: an overview

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Abstract

Studies focusing on food quality and shelf life continue on the packaging of food products. Food industry professionals often find it challenging to preserve food that is tasty, practical, shelf-stable, and of excellent quality. Active antibacterial packaging technologies that can handle these difficulties have been developed through research and the development of antimicrobial materials for food applications. New development technological solutions such as biodegradable materials, antimicrobial packaging edible films, smart packaging, nanocomposite packaging, and nanosensors can be used to improve food safety and shelf life. An important research area that offers new perspectives and solutions for the food industry is nanotechnological applications. Although there are many physical and chemical ways of making nanomaterials, green synthesis is also the most acceptable method as environmentally friendly materials are used. The use of green synthetic nanoparticles (NPS) in food packaging has been extensively researched. It is estimated that green synthetic NPs used in packaging will minimize the damage to the environment while simultaneously affecting and increasing its performance. In addition, the synthesis of nanoparticles has gained great importance with the use of plant extracts, non-toxicity, and non-hazardous to the environment. In an effort to lessen the detrimental effects of technological practices on environmental and human health, society is concentrating on a greener future. Another innovative synthesis used to achieve safe and active packaging is called "green synthesis," and it is mentioned here. Using such environmentally friendly active packaging can minimize product losses, enhance food safety and quality, lower the risk of foodborne pathogen outbreaks, and reduce waste all while preserving sustainability. Food packaging that is both antimicrobial and ecologically friendly has the potential to greatly benefit from the new and developing field of nanotechnology. In this article, the importance of using nanomaterials in food packaging with the green synthesis method, the role of Au, Ag, ZnO, Cu, and TiO_2 metal nanoparticles on packaging due to their biological and antibacterial properties, and their therapeutic application areas are discussed.

Keywords: Antimicrobial; food packaging; green synthesis; nanoparticles.

1. Introduction

The chemical reaction of ambient oxygen and the growth of aerobic microbes determine the shelf life of perishable products. The quality of the food decreases due to the color, taste, and odor changes that occur when any of these element's act alone or together [1]. In addition to keeping the food cold to prevent or delay deterioration, different techniques in food packaging are solutions to protect food quality and ensure human safety [2]. According to, antimicrobial packaging for the food industry is a reliable technique to meet the above-mentioned needs. The bacteria grow stopped and the shelf life of foods is significantly increased by the application of antimicrobial agents to food contact materials [3]. Today, it is possible to make printing materials or devices with a length of 1 to 100 nm using nanotechnology. Food safety and shelf life can be increased by using nanomaterials [4], [5]. Nanoparticles (NPs) have a large antimicrobial activity due to their physical and chemical properties [6], [7], [8], [9]. Despite the more widespread use of NPs in food packaging, there are still concerns about customer perception and acceptability, toxicity, and potential health risks [10]. Some studies have shown that nanoparticles can migrate from packaging or containers to food. However, the movement of nanomaterials and the number of migration reports have also been proven in several experimental studies to be quite low compared to other migration rates. Established procedures for the synthesis of nanoparticles, also known as "green synthesis", are more effective and economical than conventional materials. As a result, researchers and manufacturers can create nanoparticles using a variety of ways. They also focus on environmentally friendly production as no harmful chemicals are used and do not require high pressure, or temperature [11], [12]. Green plant extracts, microorganisms, and bioactive molecules, which are natural resources, are used in green synthesis studies, so therefore, experts are turning to green synthesis technology to produce low-hazard syntheses. They have turned to developing environmentally friendly, clean, and non-toxic materials. In general, antimicrobial substances are divided into two classes organic and inorganic materials. Recently, quaternary ammonium salts, phenols, halogenated compounds, and chitosan are some of the commonly used organic materials [5]. When considering inorganic materials, metal oxides, metals, and metals bound to phosphates are mentioned. Many nanoparticles, including CaO, MgO, ZnO, and, TiO_2 have attracted attention because they can withstand difficult machining conditions with inorganic agents and have strong antibacterial effects on pathogens found in foods [13], [14]. Consumers are frequently exposed to microorganisms in packaged products that can cause allergies and other health problems. Therefore, it is necessary to seek safe antibacterial agents for coating food packaging surfaces. Agents used as antimicrobials include gold, magnesia, copper, titania, silver, zinc oxide, and selenium. These nanoparticles are widely used in medical equipment, food packaging, synthetic fabrics, water treatment, and other fields. Many industries can also benefit from its use as antimicrobial compounds coated on surfaces. In many studies, plant extracts have been used as natural reductants in the production of these nanoparticles and have been identified as an effective green synthesis method. Recently, when the studies in the literature are examined, there are many studies on the use of NPs as antimicrobials and antioxidants in active food packaging [15]. Silver nanoparticles were synthesized by using *Cymbopogan Citratus* plant leaf extract [16]. Besides having antifungal properties against *C. albicans* and *A. niger* it was determined that the synthesized NPs had a conventional structure that allowed them to penetrate the wall of fungi. Ag NPs showed antibacterial activity against *E. coli*, *S. aureus*, *S. typhi*, and *K. pneumoniae* bacteria. In another study, copper and silver nanoparticles were formed from cassia occidentalis leaf extract, characterized using various spectroscopic methods, and evaluated for antibacterial and antioxidant activity. According to study, the nanoparticles considered as a reducing agent for nitro compounds [17], due to this, a new category of packaging-based nanoparticles was developed. The aim of the study is to develop a green and environmentally friendly method for the synthesis of Ag and Cu nanoparticles using *Cassia occidentalis* extract.

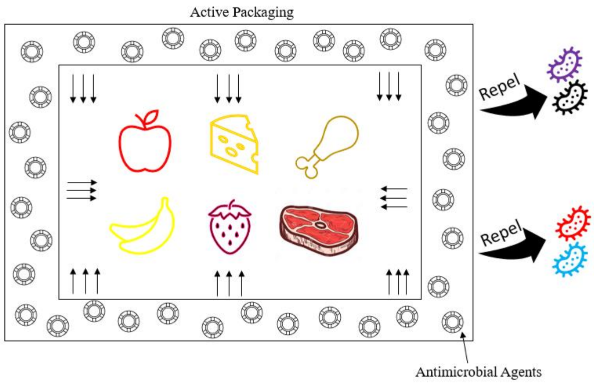

Fig. 1. Active packaging diagram

2. Active food packaging

Food packaging protects the safety and quality of food by interacting with a food product and the food ecosystem [18], [19]. Active packaging is a new concept aimed at providing consumers with high-quality, safe food goods that have an extended shelf life [19]. The active packaging scheme for food packaging in line with the needs of consumers is shown in Fig. 1.

2.1. Using nanomaterials in food packaging and preservation

The creation of foods packaging is currently one of the key areas where nanomaterials are being used in the food industry. Nanomaterials can be utilized to preserve food in addition to producing lighter, more robust materials like plastic bottles and containers. Plastic is typically used to make materials for food packaging. Their biggest drawback is that they can't stop gases like oxygen and other tiny molecules from getting into food. Nanomaterials can stop light and gases from penetrating packaging and deteriorating food. They might also possess antibacterial qualities, which keep food safe from hazardous microorganisms and preserve its freshness over extended periods of storage. In the food packaging sector, innovation is being applied to produce more sustainable materials. The majority of metal nanoparticles (gold, copper, selenium, copper oxide, silver, titania, zinc oxide, and selenium) utilized in active packaging have potent biocidal capabilities [20]. Nanomaterials like nanocluster, titanium nitride, or titanium dioxide can be added to materials to change their qualities, such as making them lighter and stronger. Since the synthesis of NPs using physicochemical methods requires strong acidic chemicals and high temperatures, toxicity problems arise in the use of food packaging. Alternatively, green synthesis methods using microorganisms or plant extracts have recently attracted attention and started to be used [21]. Chemical pollutants are not present in the nanoparticles created using biological processes, which are regarded as secure, simple, and affordable. Because the use of nanoparticles in food packaging is still relatively new, there is little information on potential NP migration from food packaging to food [22], [23]. One of the most prevalent substances in nature is cellulose, which may be obtained from both plants and trees. From cellulose nanoparticles, scientists have created biodegradable composite membranes. According to research, these bio-based coatings can shield fresh food from dangerous bacteria, prevent water from entering packaging, and perhaps increase product shelf life. Bio-based nanomaterials may have uses in the food packaging industry to reduce food waste and the amount of foodborne diseases. Additionally, scientists are creating "smart" packaging that keeps track of food quality using nanometer-sized sensors. To find contaminants in food, a variety of nanoparticle-based detectors have been created. When pollutants come into contact with the nanosensor, a reaction occurs between the nanomaterial and the pollutant, and pollutant detection can be achieved in this way [23].

3. Green synthesis of NPs

Conventional methods for obtaining NPs are not expensive, dangerous, and environmentally friendly. To circumvent these problems, a green method or naturally occurring sources and their byproducts are used for the synthesis of NPs. Green or biological synthesis of nanoparticles provides many positive properties by allowing the synthesis of NPs at low pressure, temperature, and pH levels and most importantly at a cheaper cost [15]. In the context of green nanotechnology, plant extracts such as nettle, linden, aloe vera, tea, and coconut are used [24]. Figure 2 shows the synthesis scheme of Pd-ZnO NPs using grapefruit extract. Previous studies on "green" nanoparticle production, methodologies, and benefits are reviewed in this section.

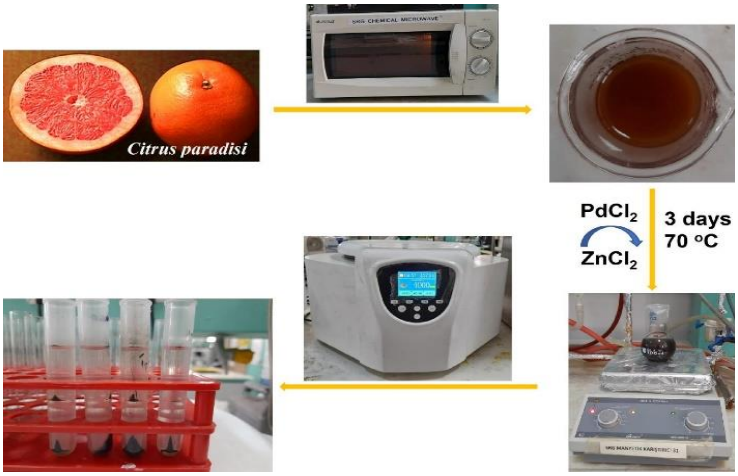

Fig. 2. Scheme of green synthesis of Pd@ZnO NPs from grapefruit extract (Reprinted with permission from [25], Copyright Elsevier).

3.1. Role of plant in green synthesis of nanoparticles

According to research, biomolecules found in plant extracts such as alkaloids, sugars, phenolic acids, polyphenols, and terpenoids serve as reducer and stabilizer agents during the formation of NPs [26]. Many plant parts, including whole plants, leaves, roots, fruits, blooms, seeds, bark, and stems, have the capacity to make NPs in an environmentally friendly manner. The use of plant extracts provides a simple, affordable, environmentally friendly, and virtually pollution-free process [27]. Plant extracts in NPs obtained by green synthesis contain many functional groups for example –COOH, –CHO, –COOR, -OH, and –NH. Therefore, these phytochemicals participate in NP formation and have a dual role in the morphology and composition of the produced NPs [28]. The use of plant extracts for the green synthesis of nanoparticles provides more benefits than the use of microorganisms because it is non-pathogenic and cost-effective. The size and applications of NPs produced via plant-mediated synthesis are listed in Table 1.

Table 1. Green synthesis and applications of metal nanoparticles in the literature.

NPs	Synthesized by	Size (nm)	Applications	References
Ag	Mulberry fruit	80-150	Antibacterial activity	[29]
Au	Nigella arvensis	3-37	Antibacterial, antioxidant	[30]
Cu	Clove	15-20	activities	[31]
Fe	Tea leaves extract	30-100	Antimicrobial properties	[32]
Mn	Cinnamomum	50-100	Wastewater remediation	[33]
ZnO	Olive leaves	40-124	Photocatalytic activities	[29]

3.2. The role of bacteria and fungi in obtaining nanoparticles by green synthesis method

The UV photo reduction process, and physical, chemical, and biological techniques are some of the ways to make nanoparticles; each has advantages and downsides. In comparison to chemical and physical methods, biological strategies for producing nanoparticles have many advantages. Because no hazardous reducing agent or stabilizing agent is employed in the synthesis of biologically generated nanoparticles, they are "eco-friendly". Bacteria are able to produce nanoparticles both intracellularly and extracellularly, making them a biofactory for the production of gold, silver, and cadmium sulphide. According to several studies, the enzyme NADH-dependent nitrate reductase is essential for transforming metal ions into nanoparticles [24], [26]. These environmentally friendly and safe particles have a wide range of uses in biochemical sensors, industry cosmetics, agriculture, medicine, and other fields. On the other hand, algae are a rich source of secondary metabolites, simple to grow, quick to scale, and known for their ability to hyper-accumulate heavy metal ions and re-modulate them into more pliable forms [34]. For the biogenic production of nanoparticles, fungi are desirable because they have a high metal tolerance and are simple to control. They also release a lot of extracellular proteins, which help the nanoparticles stay stable. Microscopically small filamentous fungi have been found to produce about 6,400 bioactive compounds. The fact that fungi produce a lot of proteins and enzymes, some of which can be employed for the quick and sustainable synthesis of nanoparticles, gives them an advantage over other microbes [35]. Table 2 mentions different microorganisms used in NPs synthesis and their applications.

Table 2. Recent advances in the use of microorganisms in the production of nanostructured materials.

Source	NPs Produced	Applications	References
Escherichia sp.	Cu	Dye degradation	[36]
Aspergillus niger	ZnO	Antimicrobial	[37]
Bacillus sp.	Ag	Anticancer effect	[38]
Penicillium oxalicum	Fe	Penicillium oxalicum	[39]

Streptomyces spp	Fe	Biomedical application	[40]
Periconium sp.	ZnO	Antimicrobial applications	[41]

Enzymes, and other organic components are essential for the green production of NPs [24], [26]. After release into suspensions or growing media, the biomolecules are what cause mono- and polydisperse NPs with various sizes and morphologies to form. Furthermore, the proteins that bacteria secrete may act as stabilizing substances to increase the stability of NPs. As a result, nanomaterials are created using a variety of natural extracts, including those from plants, bacteria, fungi, yeasts, and plant extracts. For the synthesis of controlled materials, the plant extract is the most efficient among them as reducer agents and stabilizing agents. A green nanoparticle is mass-producible and chemical-free, environmentally friendly, and less expensive. Therefore, nanoparticles made from 'green' materials and biocomponents are expected to be widely used in varied fields such as the cosmetic industries, environmental, food, and pharmaceutical [24].

3.3. Applications of green synthetic carbon dots used in food packaging

Investigated the effect of aqueous chitosan (CH) solution and green synthetic CDs (produced from banana) on the stability and shelf life of soy milk. Different concentrations of chitosan solution, banana-based CDs and soymilk samples were made to assess shelf life. The results obtained showed that CDs obtained by green synthesis would stop the growth of *S. aureus* bacteria. Soymilk containing 0.16% chitosan and 8% CD was stored at room temperature for 4 days and bacteria of *Bacillus subtilis, E. coli* was visibly reduced. As a result, it can be said that soy milk has a long shelf life. It was observed that bacterial growth decreased as CD concentration increased. On the other hand, bacteria such as *B. subtilis, E. coli, S. aureus* were grown in the medium, but as the CD concentration increased, the number of visible colonies decreased. On solid plates with 8% CD, only a small number of bacteria could grow (61, 11, and 8 for *B. subtilis*, *E. coli* and *S. aureus* respectively). Plates with a CD level of 10% have almost no bacterial colonies [42]. After waiting for 2 days, the control and the other samples have a better appearance. The control and the sample containing 0.16% CH showed a color change after 4 days of waiting, while the other samples containing 0.16% CH + 8% CD did not. Based on this information, it has been shown that the chitosan solution and CDs can be used for shelf-life extension applications in foods. The stability and shelf life of soy milk can be effectively extended by CDs and a chitosan aqueous solution [42]. A different study [43] reported employing soy protein isolate to successfully create nitrogen-doped CDs and then incorporated them into an anthocyanin-containing starch matrix extracted from the flower of *Clitoria ternatea* to produce a smart and economical biopolymer matrix used to monitor the freshness of packaged products. Scientists claim that the inclusion of CDs reduces the film's susceptibility to water and increases its mechanical strength. The termal stability of the starch film is also improved by the inclusion of green sythetic CDs. In another study [44], created CDs using polyvinyl alcohol and tea residues to create a very flexible. They discovered that the UV light blocking capacity of composite films increased with increasing WTR-CD (tea waste residue powder) content in PVA films. They discovered that the UV light blocking ability of composite films increased with the concentration of tea waste residue powder-CDs in PVA films. The composite films of PVA@WTR(tea waste residue powder)-CDs can block 100% of the UV-B and UV-C areas and 20-60% of the UV-A regions when the CD concentration is adjusted. Reviews claim that adjusting the transparency and thickness of the PVA@WTR-CD composite films allowed for the highest UV blocking to be attained. In addition, changes in the tensile strength and mechanical properties of PVA films were observed with the gradual introduction of UV blocker. Only when the grapes were exposed to UV light did significant, noticeable changes in fruit color and effect occur. After exposure to UV light for up to 30 hours, the grapes in the 2 different containers turned brown and shriveled more than the grapes in the other container.

Composite film (PVA@WTR-CDs) used to wrap the grapes in the container, which covers all information, shows the prevention of UV radiation harmful. By using waste, by-products and ecologically viable (green syntheses) resources as raw materials to produce CDs, it is possible to improve sustainability, bring costs in the food supply chain, and perhaps achieve various new uses [42].

4. Role of some metal nanoparticles in food packaging

In the realm of industry, reduction in food spoilage has been provided by the use of appropriate packaging materials and processes. With the introduction of nanotechnology in food packaging, solutions have been found to many packaging-related problems, including the short shelf life of some foods. Metal matrix nanocomposites, which are created by mixing biopolymer layers with metal-based nanoparticles, are a part of antimicrobial active packaging. When a nano-scale agent is created, the substance produced has entirely different physical and chemical properties than its macro-scale equivalent because a nanoparticle's size can range from 1 to 100 nm. By preventing the growth of food spoilage agents, different metals like (Cu) copper, (Zn) zinc, (Au) gold, (Ag) silver and (TiO_2) titanium dioxide are used to protect and package food products [19].

4.1. Au-NPs

Due to their remarkable biocompatibility and ability to conjugate with proteins, AuNPs are receiving a lot of attention these days. AuNPs have been shown to be capable of identifying a large variety of food pathogens. Food packaging and the medical industries have both become interested in AuNPs because of their oxidative catalytic qualities, inert and non-toxic nature, and therapeutic potential [45]. Milk is rich in nutrients and incredibly prone to microbial attack. For example, methylene blue is an organic color used to measure the amount of microbes in milk. Au-NPs can be used as an alternative to MB dye to identify the anionic component of microbials in milk. Au-NPs are used in combination with propidium monoazide-asymmetric PCR to find emetic Bacillus cereus. Milk containing long fragments of genomic DNA conjugated to Au-NPs is stabilized by the addition of NaCl. Visual detection by spectrophotometer or UV can be achieved after a short time. In addition, Au-NPs can be used to detect meat spoilage [46].

4.2. Ag-NPs

One of the most promising nanoparticles is silvers nanoparticle, which is a good fit for the food industry due to its advanced functional properties. Because of their potent antimicrobial activity against a variety of pathogens, silver nanoparticles that are produced using a variety of biological sources are frequently utilized. When it comes to cost, benefits, and environmental friendliness, biologically produced silver nanoparticles made with microorganisms are superior to chemically synthesized nanoparticles [47]. Ag-NPs are a better option than Au-NPs despite their chemical stability. Sharper damping bands, larger damping coefficients, higher scattering-extinction ratio and greater area improvement contribute to this. However, recent research has focused on optical properties to improve chemical stability. Additionally, Ag-NPs can be used to detect milk spoilage. For instance, in one of the published articles, Ag-NPs incorporated with cysteine and histidine were used to detect lactic acid in fresh milk without causing a color shift. Ag-NPs were bonded to lactic acid by the imidazole group of histidine and the thiol group of cysteine, which caused NPs to aggregate and cause a color change that was observed. [48], [49]. The polyphenols gallic, pyrogallic acids, rutin and quercetin have been used to make green synthesized silver nanoparticles. All AgNPs produced showed activity against harmful bacteria tested and the nanocomposite film showed strong antimicrobial properties. Using AgNPs as fillers [50], an agar-based nanocomposite film was made with the extract of *Lagerstroemia speciosa*, a medicinally used plant in northeast India, to form AgNPs. According to the findings, the addition of silver nanoparticles reduced the TS (tensile strength) while improving the EB (elongation break), thermal stability, antibacterial qualities, and appearance of the nanocomposite films. has improved. Also, the orange and brown color of the compound layers could protect packaged foods from UV rays. Formed sodium alginate films doped with green-produced silver nanoparticles from the plant extract of Nymphae odorata and then tested the antibacterial activity of both the films and green-synthesized Ag NPs. The results showed that *S. aureus* and *E. coli* completely lost all their bacterial activities at very low Ag nanoparticle concentrations and similar effects were also shown in the films, supports the antibacterial activity of Ag NPs and films. In a different study [51], looked at the effect of thyme essential oil and green synthesis Ag NPs on polyvinyl alcohol-starch film. According to their findings, NPs and films containing 5% by weight essential oil exhibited the lowest activity against *E. coli* and *S. aureus*. Ag NPs containing thyme essential oil were also added, which improved the mechanical qualities and water resistance of the films. This study indicated how the addition of green synthetic Ag nanoparticles and essential oil improves the performance of nanocomposite bioactive film used in food packaging [52]. In another study by [53], a cellulose acetate-based nanocomposite film containing green synthetic silver nanoparticles was made for use as antibacterial packaging for some foodborne bacteria.

4.3. ZnO-NPs

ZnO NPs have excellent catalytic and photocatalytic activities and relatively high chemical reactivity. Additionally, they show a strong resistance to heat, UV light, and infrared light, which is useful for some food applications. Furthermore, zinc is a necessary micronutrient that the body uses for the biosynthesis of nucleic acids and proteins. ZNPs can thus be used in the food industry as long as they are taken at the right dosage[54][55].Because of its UV inhibition and being less expensive than Ag-NPs, ZnO-NPs are used to create effective food packaging, which also shows increased antibacterial activity. The absorption of ZnO-NPs into films, the mechanical strength of the packaging, the properties such as clogging resistance can significantly improve the packaging properties. ZnO-NPs produced from Catharanthus roseus showed significant antibacterial activity against B. thuringiensis, *P. Aeruginosa, P. aeruginosa, S. Aureus, E. coli, C. Jejuni,* and *B. Subtilis.* In conclusion, ZnO-NPs showed antibacterial activity on both gram (+) and gram (-) bacteria [56]. In a study on nanocomposite film, ZnO NPs produced by green synthesis method were produced from fruit pulp called cassia fistula. The results showed that the heat stability and density of ZnO nanoparticle films synthesized by the green synthesis method were improved. The produced films containing 4% and 2% ZnO NP exhibited a compact, smooth, and heterogeneous surface morphology compared to the control films. A nanocomposite film against *E. coli* showed impressive antibacterial activity [57].

4.4. Cu-NPs

As other nanofillers, copper-based nanofillers are crucial for enhancing the mechanical and barrier qualities of bio-based packaging films, among other performances. Biodegradable food packaging films are made using a variety of copper-based nanofillers, including copper or copper oxide nanoparticles, copper sulfide nanoparticles, and copper-doped alloys. When utilized as food packaging materials, copper-based nanofillers have strong, all-around antibacterial activity that can successfully slow the growth of foodborne pathogens[58]. Extracts of biological waste can be used as a green synthesis source to produce copper nanoparticles since it is easily accessible, affordable, environmentally friendly, and free of any byproducts that could be detrimental. All first through fourth instar Aedes aegypti larvae were destroyed by copper nanoparticles from Artocarpus heterophyllus at a concentration of 10 mg/L, according to a study by Sharon et al. According to Phang and Almade, CuO nanoparticles using environmentally friendly, non-toxic papaya peel aqueous extract show a high photocatalytic activity with low phytotoxicity in waste photocatalytic degradation of palm oil. Din et al. produced copper nanoparticles using (i) cranberry waste residues from fruit juice processing and (ii) aqueous extracts of unusable "false cranberry" berries.

These extracts are excellent candidates for the green synthesis of Cu-NPs due to the abundance of phenolic chemicals, especially anthocyanins, which are potent reducing agents. In another study, the formation of stable nanoparticles was investigated by transmission electron microscopy, and the oxidation state of copper in these aggregates was monitored by X-ray photoelectron spectroscopy. Gram (+) and Gram (-) bacteria were both successfully treated by the method the generated Cu-NPs antibacterial activity [59].

4.5. TiO_2-NPs

TiO_2 NPs are a suitable compound for the production of active food packaging because of their high compatibility with most biopolymers, excellent antimicrobial, ethylene scavenging, and UV protection properties [60]. Titanium dioxide, its high chemical stability and non-toxicity makes it an environmentally beneficial substance.The most effective component for shielding skin from ultraviolet (UV) rays is titanium dioxide nanoparticles, which are used in toothpastes, medicines, food colorants, and papers. Strong antibacterial capabilities can be seen in TiO_2 NPs. Using a methanolic extract of fruit peel agricultural wastes, Ajmal et al. produced inexpensive, environmentally friendly TiO_2 nanoparticles. It was found that nanocrystalline titanium dioxide NPs were present based on the X-ray diffraction spectrum. The production of TiO_2 NPs involves the reactions C-H, C-O, C=O and O-H. The functional groups were found in the fruit peel when the Fourier transform infrared was used to detect them. In SEM images, it was discovered that the TiO_2 NPs mediated by Plum, Kiwi and Peach were cylindrical, and all of the TiO_2 NPs had antibacterial and antioxidant properties that varied depending on their size and dosage [61].

5. Therapeutic application of nanoparticles

5.1. Anticancer activities

Cancer disease is expressed by uncontrolled cell division. There are about 200 different types of cancer. 8.2 million people die from cancer every year. The cancer treatment method known as nano-immune-chemotherapy was created by combining nanotechnology and immunology [27]. Different metal and metal oxide nanoparticles effectively inhibit the growth of cancer by showing cytotoxicity against malignant cells without harming normal cells. Ag NPs were created from pineapple peel waste extract by Das et al and have demonstrated antibacterial, anti-diabetic and cytotoxic activities against HepG2 cancer cells. It has been instrumental in both the treatment of serious diseases and the creation of drugs that can treat conditions such as cancer and diabetes. Additionally, it can be used to treat bacterial infections and repair wounds [62] .

5.2. Antibacterial activities

Metal and metal oxides provide benefits against inhibiting bacterial growth. As an example, Basumatari et al. produced ZnO NPs using *Musa balbisiana Colla* extract at sizes between 45 and 65 nm. By releasing Zn^{2+} ions from ZnO nanoparticles that bind to the cell membrane and form reactive oxidative species, including *Bacillus, S. aureus* and *E. coli* showed significant antibacterial effect against both gram (+) and gram (-) bacteria [63].

5.3. Antioxidant activities

Antioxidants, being the top protectors of antioxidant cells, delay cell damage by stopping it. Carbon quantum dots (CQDs) made from biowaste pineapple comosus using a straightforward hydrothermal technique, according to Rajamanikandan et al., have antioxidant action. Determining the antioxidant activities of the synthesized nanoparticles is done in 3 different ways. It is known as radical scavenging activity, antioxidant capacity activity and iron reducing capacity. In a study in the literature, it was determined that Ag NPs made from fruit pulp showed antioxidant activity due to DPHH ability. The -H groups and metal ions in this fruit give the essence of this fruit an antioxidant function [64].

6. Health risks and toxicity of nanoparticle applications used in the food industry

Although nanotechnology is a very promising technology with great potential in many industrial sectors, there are concerns regarding its use in the food industry. There are serious concerns that adverse effects may occur if particulate nanomaterials come into controlled or uncontrolled contact with the human body. It is simpler for these foreign compounds to enter the human body and alter the biochemical and physiological processes in the body thanks to the reduction in particle size of materials acquired with nanotechnology. It is becoming more and more likely that the use of nanomaterials in the food sector will result in particle nanomaterials entering tissues in the human body, accumulating hazardous contaminants, and negatively harming human health [65]. As a result of the lack of conclusive scientific evidence regarding the hazards and toxicity of nanomaterials, preventive measures are envisaged if serious doubts exist when placing nanofood products on the market. Nanotechnology promises to produce better packaging and healthier foods with the claim that it is an innovative technology that will break new ground in the field of food production. It has been shown that concerns about the health and environmental impacts of products produced with a new technology can seriously hinder public acceptance of those products or technologies [66].

7. Conclusion and future perspective

In the food industry, nanotechnology creates innovative food and intelligent packaging technologies. Inorganic nanoparticles are now well recognized as some of the most widely employed antibacterial substances across a variety of industries, particularly in the food packaging sector. It has been demonstrated that these inorganic nanoparticles have broad-spectrum antibacterial action, which can offer defence against a variety of pathogens, including systems like antibacterial coatings and edible films, and foodborne illnesses. As a result, there is now more research being done on these recently developed packages. Their use is still not particularly widespread, though. Zinc oxide, silver, copper, gold, selenium, titanium oxide, and other antimicrobial materials are utilized in food packaging. Since these antimicrobial agents exhibit strong activity at incredibly low concentrations and can effectively replace traditional chemical antibacterial materials, they are ideal agents. Finally, more study is required to establish safe methods of utilizing these nanoparticles in materials of food contact packaging systems and to manufacture non-toxic goods because it is still unknown whether inorganic nanoparticles are harmful and whether they can be mass-produced in the near future. One of the key objectives in the field of antimicrobial nanoparticles, according to study, is the environmentally friendly production of these cutting-edge materials. The use of microorganisms and plant extracts to make affordable, ecologically friendly antibacterial nanoparticles has been the subject of numerous investigations. They can also be employed in a wide range of industries, such as food packaging, medicines, and medical applications. Another intriguing advancement in the creation of food packaging polymers is the use of various types of nanocomposites in the beverage production industry that can be simply placed in glass bottles. It might serve as an alternative to antibiotics, which must be used more frequently and eventually lose their efficacy due to bacterial resistance. Before these chemicals may be employed in food packaging materials to properly limit microbial growth and safeguard consumers' health, further study must be conducted. In line with the studies, this article contains metal After nanoparticles (Au, Ag, ZnO, Cu, TiO_2) are obtained with green synthesis, they will have antibacterial, antifungal and antioxidant properties and will also contribute to green synthesis being an environmentally friendly synthesis.

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The authors dedicated this publication to the 100th anniversary of the Republic of Türkiye. As scientists raised by Türkiye, they are proud to be citizens of this country.

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