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Green Synthesis of Zinc Oxide Nanoparticles by Using Pomegranate Peels: An Overview †

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Abstract: Zinc oxide (ZnO) is a crucial material for industries such as rubber production, biomedical applications, and metal surface treatment areas. ZnO exhibits semi-conductivity, antimicrobial activity, and UV absorption capability. This material is regarded as a vulcanization activator. Transforming this material to a nanoparticle is preferred because increasing the particle size of the material decreases the surface area. In the scientific literature, researchers have attempted to increase the features of ZnO nanoparticles to use them as photocatalysts and antimicrobial agents. Besides that, there are also studies aimed at improving the properties of this nanomaterial for use in energy cells and sensors. The synthesis of ZnO nanoparticles in a biological way is accepted as an eco-friendly process. Since hazardous chemicals and high energy are not used, the biological method is called green synthesis. In the synthesis of ZnO nanoparticles via the green route, zinc nitrate or zinc acetate is the source of zinc salt added to biological extracts. These extracts can be obtained from algae, plants, and bacteria. The reaction between the salt and extract occurs, and then a thermal treatment is applied to reach the nanoparticle.

Keywords: ZnO nanoparticles; green chemistry; pomegranate peels

1. Introduction

Nanotechnology refers to the control and restructuring of a material at the size of between 1 and 100 nm [1]. There are two approaches to Nanotechnology: top-down and bottom-up. The aim is to create nanoscale structures from large ones in the top-down approach. This approach endeavors to obtain a nanomaterial that preserves its initial properties. The purpose is to produce nanomaterials by assembling atoms or molecules in a bottom-up approach [2]. Nanomaterials are classified as carbon-based, metal-based, dendrimer, composite, and ceramics in terms of their structure. Besides that, they can be in several forms, such as nanowires, nanotubes, quantum dots, etc. Because nanomaterials have many crucial features, such as electronic, optical, mechanical, and thermo-physical, they have many applications. One of the application areas of nanomaterials is environmental waste management. Thanks to their high surface area/volume ratio, nanomaterials can be used in water treatment as adsorbents. Metallic and metal oxide nanomaterials and carbon nanotubes can be utilized to clean water from contaminants. Besides that, nanomaterials have been used in biomedical areas. For example, carbon-based nanomaterials can be utilized in drug delivery, bio-sensing, bio-imaging, and immobilization of enzymes. In addition, nanomaterials can be used in the food sector to detect food quality. Thanks to nano-sensors, it is possible to define pathogens and identify microorganisms in food. However, nanomaterials can be toxic to humans. Therefore, nowadays, researchers have developed green synthesis routes to overcome this situation. The green synthesis of nanomaterials is based on using biological extracts instead of hazardous chemicals for surface functionality [3].

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This study aimed to show the synthesis, properties, and applications of biomass-based nanoparticles specific to pomegranate-based ZnO nanoparticles.

2. Biomass-Based ZnO Nanoparticles (ZnONPs): Synthesis and Applications

Green synthesis is an environmentally friendly and non-expensive method to produce nanoparticles (NPs). Via this method, it can be possible to obtain ZnONPs with high yield and no impurities [4].

Several kinds of inorganic metal oxides like Titanium Dioxide (TiO_2), Copper (II) Oxide (CuO), and ZnO are popular in scientific research. Among them, ZnO has the most eminent inorganic metal oxide because it is considered a safe material. ZnONPs have many features. Firstly, its band gap, 3.37 eV, is high. Therefore, the material has high semi-conductivity. Secondly, it has a high exciton binding energy of 60 meV. The applications of ZnONPs are wide. They are used in the cosmetic sector due to their UV-protective properties. Besides that, they are also suitable for biomedical applications. They are utilized in anti-cancer and anti-diabetic treatments and drug delivery systems. They have great antibacterial properties. In addition, they can be used in several sectors like rubber production, painting, and for the adsorption of arsenic from water [4].

Biological synthesis is accepted as a green way to produce ZnONPs in a laboratory because the synthesis route is based on a few principles of green chemistry that use renewable feedstocks and safer solvents and obtain safer chemicals. Generally, the synthesis procedure is carried out by adding a zinc salt like zinc nitrate or zinc acetate to a biological extract prepared from fungus, plants, algae, or bacteria. Then, the solution is exposed to a thermal treatment. Thus, ZnONPs are obtained. The parameters that affect the reaction are temperature, time, pH, and the concentration of zinc salts [5].

Table 1 shows various biomass types and applications for ZnONPs.

Table 1. Current biomass based ZnONPs and their applications published in the literature.

Biomass	Application	Reference
Spirogyra hyalina sp. algae	antioxidant and antimicrobial agent	Hameed et al. (2023) [6]
thymus syriacus plant	optoelectronic materials and antibacterial agents	Şahin et al. (2022) [7]
*Scoparia Dulcis*plant	antioxidant and antimicrobial agent	Sivasankarapillai et al. (2022) [8]
*Malva Parviflora*plant	preserving food quality for a long time, increasing shelf-life	Iqbal et al. (2022) [9]
mushroom fungus *Cordyceps militaris*	antidiabetic, antioxidant, and antibacterial	Dias et al. (2022) [10]
*Dictyotadichotoma*endophytic fungi	photocatalytic degradation of fast green dye and antibacterial applications	Kumar et al. (2022) [11]
Orange peels	antibacterial	Thi et al. (2020) [12]

3. Pomegranate-Based ZnO Nanoparticles (ZnONPs): Outstanding Features and Applications

The pomegranate is a crucial fruit in the biotechnology field. Its seeds, juice, and peels are under investigation for use in many applications in this area. The importance of this fruit comes from its phenolic composition. Extracts of pomegranate peels have antioxidant, antibacterial, anti-inflammatory, anti-ulcer, and anticancer activity [13]. Besides that, it is known that after it is consumed, two-thirds of the pomegranate fruit is thrown away as waste [14]. Therefore, selecting pomegranate peel as a feedstock for the synthesis of NPs is crucial to waste management. Currently, pomegranate peels can be used for the synthesis of several metallic nanoparticles: Zirconium (Zr) [15], Silver (Ag) [16], Selenium (Se) [17], Gold (Au) [18], Iron (Fe) [19], and Platinum (Pt) [20]. Besides that, much research about pomegranate-based ZnO nanoparticles has been conducted. Table 2 shows the applications and zinc salt types used in the synthesis of these materials. In Figure 1, the synthesis process of pomegranate-based ZnONPs is displayed. Phenolic compounds in pomegranate peel extract (PPE), like gallic acid, ellagic acid, and punicalagin, change the color of the zinc salt solution. This color change occurs due to the reduction effect of these phenolics.

Table 2. Current pomegranate-based ZnONPs and their applications published in the literature.

Zinc Salt	Application	Reference
zinc acetate dihydrate ($C_4H_6O_4Zn{\cdot}2H_2O$)	UV-protective properties of a cotton textile	Verbič et al. (2021) [21]
zinc nitrate hexahydrate ($Zn(NO_3)_2{\cdot}6H_2O$)	antibacterial, antifungal, cytotoxicity, and anticancer activity	Hashem and El-Sayyad (2023) [22]
zinc acetate dihydrate ($C_4H_6O_4Zn{\cdot}2H_2O$)	antibacterial activity	Abdelmigid et al. (2022) [23]
Zinc chloride ($ZnCl_2$)	removal of cephalexin (CEX) from aqueous solutions	Rashtbari et al. (2020) [24]

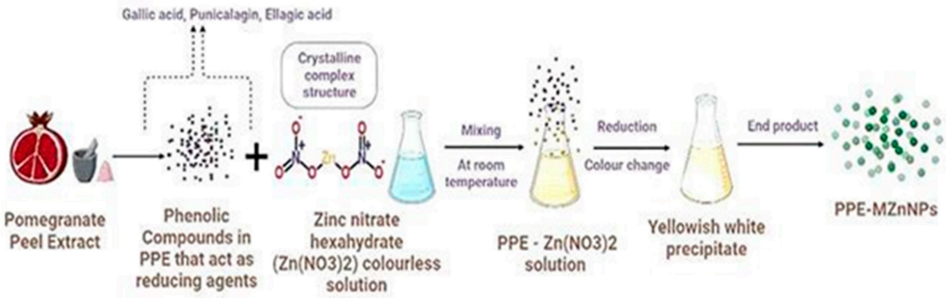

Figure 1. Synthesis of ZnONPs by using pomegranate peel extract. Reprinted with permission from Ref. [13]., 2022, Taylor & Francis.

4. Conclusions and Remarks

Green chemistry has gained importance due to global warming issues. Biological synthesis is a green and feasible way to synthesize metallic nanoparticles. ZnO nanoparticles have semi-conductivity and UV-filtering properties. According to the literature, the synthesis of ZnO nanoparticles through the use of pomegranate peels is a novel topic. Pomegranate peels have importance mainly in the biomedical area. This research concluded that researchers could try several fruit peels to synthesize ZnONPs. In addition, several metallic salts can be used in relation to pomegranate peels to obtain NPs. In addition, there is scarce information concerning the computational studies on this topic. Also, the catalytic activity in several reactions can be modified with pomegranate-derived ZnONPs.

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