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Burdock-Derived Composites Based on Biogenic Gold, Silver Chloride and Zinc Oxide Particles as Green Multifunctional Platforms for Biomedical Applications and Environmental Protection

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Abstract: Green nanotechnology is a rapidly growing field linked to using the principles of green chemistry to design novel nanomaterials with great potential in environmental and health protection. In this work, metal and semiconducting particles (AuNPs, AgClNPs, ZnO, AuZnO, AgClZnO, and AuAgClZnO) were phytosynthesized through a "green" bottom-up approach, using burdock (*Arctium lappa* L.) aqueous extract. The morphological (SEM/TEM), structural (XRD, SAED), compositional (EDS), optical (UV–Vis absorption and FTIR spectroscopy), photocatalytic, and bio-properties of the prepared composites were analyzed. The particle size was determined by SEM/TEM and by DLS measurements. The phytoparticles presented high and moderate physical stability, evaluated by zeta potential measurements. The investigation of photocatalytic activity of these composites, using Rhodamine B solutions' degradation under solar light irradiation in the presence of prepared powders, showed different degradation efficiencies. Bioevaluation of the obtained composites revealed the antioxidant and antibacterial properties. The tricomponent system AuAgClZnO showed the best antioxidant activity for capturing ROS and ABTS$^{\bullet+}$ radicals, and the best biocidal action against *Escherichia coli*, *Staphylococcus aureus* and *Pseudomonas aeruginosa*. The "green" developed composites can be considered potential adjuvants in biomedical (antioxidant or biocidal agents) or environmental (as antimicrobial agents and catalysts for degradation of water pollutants) applications.

Keywords: "green" synthesis; burdock (*Arctium lappa* L.); biogenic metal and semiconducting nanoparticles; composites; antioxidant activity; antibacterial action; photocatalytic properties

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1. Introduction

Metal nanoparticles (MNPs) are widely used in engineering, and more in biomedical field (e.g., biosensors, diagnostic imaging, and drug delivery applications) [1,2]. They have attracted the interest of the scientific community due to their great potential in nanoscience [3].

MNPs (Ag [4], Cu [5], Au [6], Pt [7], Zn [8]) have received increasing attention in various fields such as electronics [8–11], optics [12] and biomedicine [6,13], due to their properties, e.g., the very large specific surfaces of MNPs that determine their catalytic properties [14]. This has led to the active use of MNPs as catalysts for a variety of industrial processes, e.g., environmental cleaning [15,16]. However, MNP use is difficult because they are complicated to handle and tend to agglomerate easily. This has the effect of reducing their specific surface area. Through aggregation, the excellent functionalities

TEM). The EDS spectra, SAED, and XRD patterns of the samples were well-correlated and showed the presence of potassium chloride in the burdock extract, and also in the AuNPs and AgClNPs. Moreover, the XRD results were well-correlated with the SAED and FTIR data, regarding the particles' phase. The DLS results were in good agreement with the SEM and TEM analyses related to the dimensions of the obtained materials.

The optical characterization (FTIR and UV-Vis) of phytoderived materials demonstrated the key role played by proteins, flavones, polyphenols, ethers, and other phytocompounds arising from *A. lappa* extract in the development of prepared particles. The presence of these phytomolecules gives the antioxidant and antibacterial properties and also the physical stability of our developed materials. The phytometallic and semiconducting materials presented good physical stability with zeta potential values between −18 and −35 mV. The most stable samples proved to be AgClNPs and AuAgClZnO.

The novel material AuAgClZnO showed an ability to inhibit both kinds of short-life oxygenated radicals (ROS) and long-life cationic radicals ($ABTS^{\bullet+}$), and an inhibition capacity of 50.5% $ABTS^{\bullet+}$ was determined, while the ability to capture ROS radicals was of 65%. This tricomponent system showed excellent antimicrobial properties against *Escherichia coli* (ZOI = 20 ± 0.57 mm), *Pseudomonas aeruginosa* (ZOI = 27.5 ± 0.41 mm), and *Staphylococcus aureus* (ZOI = 15 ± 0.14 mm). Additionally, the bicomponent material, AgClZnO, showed good photocatalytic properties demonstrated by the degradation of 97.02% of RhB, and antibacterial activity against the tested Gram-negative and Gram-positive bacteria. The ZnO-containing samples presented photocatalytic activity, but the most efficient system proved to be AgClZnO which can be used as an efficient catalyst in wastewater treatment for dye pollutant degradation.

The "green" developed composite particles combine the properties of all the components they are made of. Due to a synergic action of all components, the trimetallic AuAgClZnO particles presented the best bioperformance (good antioxidant and antibacterial activities) as compared to the bi- and monometallic components.

Our developed burdock-derived composites based on phytogenic gold, silver chloride, and zinc oxide particles could be used as green multifunctional platforms in various applications in the biomedical field (as antioxidant and antibacterial agents) or in environmental protection (as antimicrobial agents and catalysts for dye degradation).

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ma16031153/s1, Table S1: FT-IR band assignment for vegetal extract and phytosynthesized materials. Refs. [78,79] are cited in the supplementary materials.

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