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Biosynthesis protocols for colloidal metal oxide nanoparticles

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ABSTRACT

Metal oxide nanoparticles (MO-NPs) have attracted great attention among nanomaterials in many fields including environmental remediation, catalysis, drug delivery, agriculture, molecular sensing and medicine. This has led to the development of different synthetic pathways for these nanostructures. Currently, the synthesis of MO-NPs largely depends on chemical methods where synthetic routes involve toxic chemicals and harsh reaction conditions that have been identified as a major contributor to environmental pollution. As an alternative, synthesis based on green chemistry principles has recently gained a large audience because they are eco-friendly, cost-effective and minimize waste. In this review, we focus on the green synthetic approaches to metal oxide nanoparticles such as ZnO, TiO_2, Fe_3O_4. The synthesis based on microbes such as bacteria, fungi, algae and plant-mediated route are given major attention. In addition, the possible mechanisms for some of the syntheses and, the merits and demerits of green synthesis of metal oxide nanoparticles are also discussed.

Contents

1. Introduction

Nanoparticles (NPs) have attracted tremendous attention in the last three decades due to their unique properties such as thermal, optical, chemical, magnetic, mechanical [1,2] which are different from their bulk counterparts. As a result of these special properties, NPs have found applications in various fields such as catalysis, electronics [3], optical sensing and bioimaging [4–6]. NPs have a considerable advantage when applied in life science because their size is comparable with that of cells and organelles which allows them to attach to biological entities without changing their functions. The small size of the particles coupled with their large surface area to volume ratio, enables them to interact with contaminants for degradation and detection applications [2]. According to

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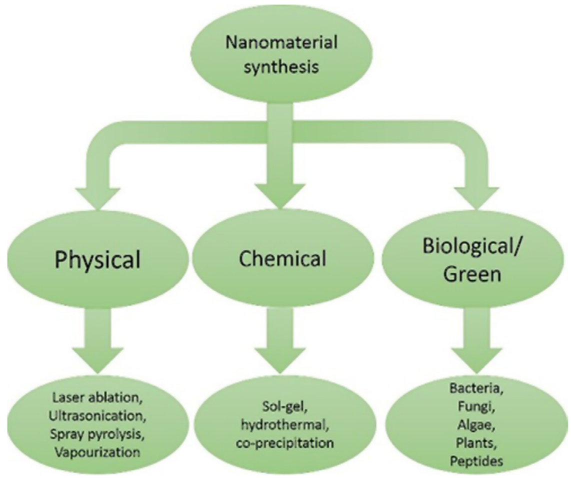

Fig. 1. Various methods of synthesizing metal oxide nanoparticles.

Khan et al., [7] nanoparticles can be subdivided into carbon-based, metallic, metal oxides, ceramics, semiconductors, polymeric and lipid-based.

Among these nanomaterials, metal oxide nanostructures have been popular in various fields ranging from the biomedical field, water treatment and so on [4–6]. Metal oxide nanoparticles (MO-NPs) have been synthesized majorly by using physical and chemical methods. Physical methods include spray pyrolysis [8], ultrasonication [9] chemical vaporization e.t.c [10]. However, physical methods suffer many limitations such as non-uniformity in particle size and high instrumentation cost. Metal oxide nanoparticles can be chemically synthesized through oxidation–reduction reaction, or by the precipitation of the necessary metal ion precursor in an aqueous solution phase [11,12]. Despite its success in the preparation of various inorganic nanoparticles with myriad morphologies, conventional chemical methods generally make use of toxic chemicals which are a threat to human health and the environment. This has led to the development of new synthetic methods which are environmentally friendly.

Fig. 1 depicts general methods that can be used to synthesize metal oxide nanoparticles. This review provides a comprehensive study of the biological synthesis of metal oxide nanoparticles using different biomaterials.

Although the synthesis of nanoparticles has been mainly dominated by chemical and physical methods, a green chemistry-based method of preparing nanoparticles is gaining a profound attention especially in this era of protecting human being and the environment [11]. Green synthesis of nanoparticles involves the use of milder synthesis condition such as sol–gel techniques [12,13], biomolecules i.e. amino acids [3] proteins [14], carbohydrates [15,16], microorganism, plants and living cells.

Green synthesis has attracted tremendous interest as it is a cost-effective and environmentally friendly method to produce nanoparticles by reducing or eliminating the use of toxic reaction precursors. It is an emerging technique for remediation of nanoparticle toxicity usually associated with conventional chemical and physical methods of synthesis. It uses non-hazardous reagents, simple protocols and mild reaction conditions. Green synthesis methods include synthesis through different biomaterials such as bacteria, fungi, algae and plants (Fig. 2) e.t.c. as either stabilizing agents or reducing agents or both in some cases. Synthesis of nanoparticles using microorganisms and plants is referred to as biosynthesis. The term biosynthesis can be used interchangeably with green synthesis. Biosynthesis of nanoparticles is not extraordinary with nature since many organisms of both prokaryotic and eukaryotic had been identified to produce nanomaterials via extra or intra-cellular processes [17]. The term ‘nano’ is native to the biological systems because many biological reactions make use of biological molecules within the nanometre-sized range. These natural strains and plant extracts produce some proteins, enzymes and other phytochemicals that can act as reducing and stabilizing agents during the synthesis of nanoparticles.

2. Microbial synthesis

Microbial organisms possess an incredible capability of fabricating extremely specialized inorganic nanostructures. These magnificent skills of the living creatures have caught the attention of many material scientists towards these biological systems to acquire knowledge and recuperate the skills for the precise formulation of nanostructures. Generally, synthesis of inorganic nanomaterials by living organism has been categorized as biologically controlled and biologically induced synthesis. Biologically controlled synthesis is well-known to occur naturally in a few organisms. During this type of synthesis, the organisms are able to modulate the particle size, composition and surface area of the produced particles. Though biologically controlled synthesis of metal oxide nanoparticles exhibits high control over the morphology and composition of the nanoparticles, it occurs only in a few numbers of organisms and is restricted to the synthesis of a limited number of nanoparticles. On the other hand, material scientists have successfully induced micro-organism to synthesize different inorganic nanomaterial such as metal oxide nanoparticles from simple metal ions precursors [19]. It has been established that biologically induced synthesis of metal oxide nanomaterials can be as a result of bioremediation of metal ions toxicity [19]. Compared to controlled biological synthesis, induced biological synthesis of inorganic nanomaterial has a wide range of composition. Micro-organisms with the ability to synthesize inorganic nanomaterials such as metal oxides have been identified to date [20]. Both prokaryotic such as bacteria and eukaryotic organisms such as fungi and plants can be utilized as nanofactories for the synthesis of different nanoparticles.

2.1. Bacterial synthesis

Bacteria are abundant in the environment, they easily adapt to severe conditions, multiply and grow very fast, inexpensive to cultivate and easy to manipulate hence they can serve as green precursors for the metal oxide synthesis. Moreover, growth conditions such as temperature, oxygenation and incubation time can be easily controlled. Controlling such properties is important, as varying sizes of NPs are required for different applications such as optics, catalysts or antimicrobials [1].

Bacteria are a large group of prokaryotic microorganisms, with various shapes namely, bacilli (rods), cocci (spheres) and spirochaetes (spiral) in the size range of microscale. They can be found anywhere; in the soil, water and land. The use of bacteria for the synthesis of nanoparticles as an alternative to conventional chemical and physical methods has increased tremendously as an emerging research area in green nanotechnology [21]. In the past decade, bacteria have been successfully utilized in commercial biotechnology process including bioremediation and bioleaching [22].

Recently, biomass or cell extracts of different bacterial strains have been used by researchers for the synthesis of different metal oxide nanoparticles with a variety of morphologies. Magnetotactic bacteria and S-layer bacteria whose cell walls are wrapped by a proteinaceous are some of the widely used bacteria for the synthesis of these nanoparticles [21].

Most metal ions are toxic to bacteria, and as a defence mechanism, bacteria transform these metal ions to nanoparticles in