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Seaweeds: A resource for marine bionanotechnology

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ABSTRACT

Marine bionanotechnology is one of the most promising areas of research in modern science and technology. Although there are multitude methods for the synthesis of nanoparticles (NPs), there is an increasing attention in developing high-yield, low-cost, non-toxic and eco-friendly procedures. The vital advantages of greener synthesis are cost-effective, reduced usage of toxic chemicals and abundant availability of resources. During the last ten years, there have been many biological entities used to elevate novel, greener and affordable methods for the metal NPs synthesis. Rate of synthesis and stability are higher for plant material mediated NPs. However, in comparison with terrestrial resources, marine resources have not been fully explored for synthesis of noble metal NPs. Our present review is designed to speculate the importance of usage of vast marine resources and its mediated NPs synthesis, in particular seaweed-mediated NPs synthesis to overcome the limitations involved in physical and chemical methods. Finally, recent advancements in greener synthesis of metal NPs, their size, distribution, morphology and applications such as antimicrobial, antifouling and anticancer potentials are briefly described along with portraying the prospective scope of research in this field without any negative impact on the environment.

1. Introduction

Nanotechnology is one of the most vibrant areas of research in modern material science and burgeoning day by day, making an impact in all spheres of human life. Nanotechnology is the engineering of the functional systems of matter at the atomic and molecular scale to synthesize particles of ≤100 nm using top-down and bottom-up strategies. Advancements in nanotechnology lead to the synthesis of nanoparticles, nanowires and nanotubes that have extensive applications in disease diagnosis/treatment, fabrication of medical devices and in various fields of biotechnology.

Nanoparticles (NPs) are of great interest because of their extremely smaller size and higher surface area to volume ratio that leads to the difference in both chemical and physical properties compared to its bulk composition [1,2]. NPs exhibit size and shape-dependent properties, and play a significant role in applications ranging from biosensing, antimicrobial activity, anticancer activity, computer transistors, electrometers, chemical sensors, wireless electronic logic and memory schemes. The metal NPs have many applications in the field of medicine, pharmacy, environmental monitoring and electronics [3–5].

1.1. Types of NPs and their importance

NPs are classified into organic (Carbon-based NPs) and inorganic NPs. Magnetic NPs (Iron), noble metal NPs (Silver, Gold and Platinum) and semiconductor NPs (Silica, Titanium oxide, Zinc oxide, Zinc sulphite, Cadmium, etc) are grouped as inorganic NPs. Indeed special properties of NPs such as biocompatibility, large scale production, simple usage and functional efficiency made them to use in drug delivery. Gold (Au) and silver (Ag) NPs have multiple applications in diverse fields. Owing to their distinctive surface plasmon resonance (SPR) AuNPs are widely used in biomedical sciences including drug delivery, tissue/tumour imaging, photothermal therapy, immunochromatographic identification of pathogens in clinical samples, immunoassay, protein

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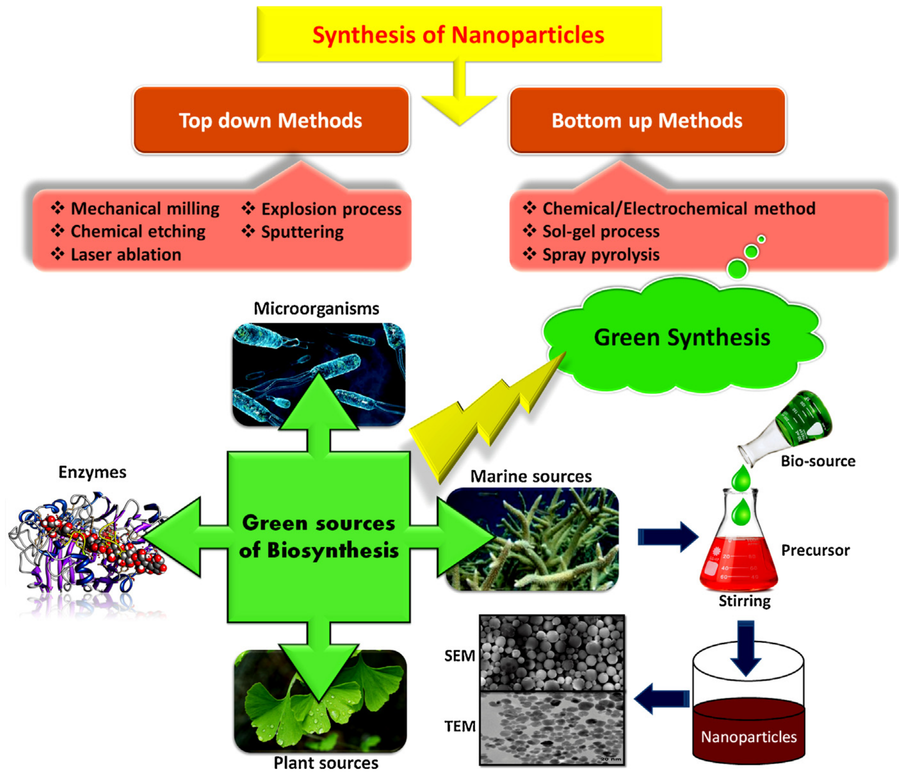

Fig. 1. Various approaches and protocols for the synthesis of nanoparticles.

assay, capillary electrophoresis and nano oncology and in biosensors. Usage of AuNPs is beneficial in biological labelling, as visible light can be used to detect the colour shift from red to blue when it forms conglomerations. Furthermore, oligonucleotide capped AuNPs are used for polynucleotide or protein detection, using atomic force microscopy, gel electrophoresis, scanometric assay, surface plasmon resonance imaging, amplified voltammetric detection, chronocoulometry and Raman spectroscopy [6].

On the other hand, AgNPs have received greater attention due to their antimicrobial properties. Clothes fabricated with AgNPs are found to be sterile and used in hospitals to prevent or minimize infections due to pathogenic bacteria [7,8]. AgNPs coated on glass slide acts as an excellent substrate for Surface Enhanced Raman Scattering (SERS) to probe even a single molecule, and acts as an excellent catalyst to accelerate few chemical reactions. AgNPs are used in integrated circuits, sensors, biolabelling, filters, nonlinear optics, selective coating for solar energy absorption, intercalation materials for electrical batteries, cell electrodes and antimicrobial deodorants. NPs of noble metals are used for water purification, environmental cleaning, pollution control, material chemistry and so on [9]. Moreover, NPs are also used in the formulation of pesticides and insecticides, insect repellents, pheromones and fertilizers [10].

1.2. *Methods of NPs synthesis*

NPs can be synthesized by physical, chemical and biological methods. In chemical synthesis (traditional wet methods), hazardous substances like sodium borohydride, tetrakis (hydroxymethyl) phosphonium chloride (THPC), poly-N-vinyl pyrrolidone (PVP) and hydroxylamine, etc. is used for the synthesis. Usages of these toxic chemicals are the subject of paramount concern and the mechanism of synthesis limits their application in clinical fields. Physical methods like laser ablation, UV irradiation, evaporation condensation, aerosol and lithography are mostly used for synthesis of NPs but the limitations are costly, requires high energy input, vacuum and expensive equipment's which makes these techniques as uneconomical. Biological synthesis comes up with the need of environmentally benign technologies, facile, economical and convenient entry to produce multiple NPs [11] and different methods of NPs synthesis are clearly depicted in Fig. 1. Green synthesis provides an advancement over physical and chemical methods as it is cost effective, eco-friendly, easily scaled up for large scale synthesis and there is no need to use higher pressure, energy, temperature and toxic chemicals. Therefore, the synthesis of clean, biocompatible, non-toxic and eco-friendly NPs produced by both extracellular and intracellular substances deserves merit [12]. A vast array of biological resources gleaned from nature including plants and plant products, algae, fungi, yeast, bacteria, actinobacteria and viruses are employed to synthesize advanced nanomaterials [13–16].

2. Biological agents in NPs synthesis

2.1. *Synthesis of NPs using microorganisms*

Narayanan and Sakthivel [17] reviewed the synthesis of nanomaterials using microorganisms, which is compatible with the green chemistry principles, resulting in a surge of interest for scientists towards biological systems. Many microbes are known to produce highly fascinating structured metal NPs with similar properties of chemically synthesized materials and have precise control over uniform size and shape. For instance, magnetic NPs synthesized by the magnetotactic bacteria in nature since long back, is an excellent biosystem to learn the basic principles of biofabrication [18,19]. Klaus et al. [20] reported that prokaryotes like *Pseudomonas stutzeri* AG259 produce AgNPs within their periplasmic space. In addition, the reduction of Pd(II) using sulphate reducing bacteria *Desulfovibrio desulfuricans*, the reductive power from electron donors such as formate or hydrogen to form crystalline Pd(0) from Pd(II) on the cell surface [21] and synthesis of semiconducting CdS