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Bio-inspired nanomaterials in agriculture and food: Current status, foreseen applications and challenges

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ABSTRACT

Nanotechnology is a potential area that revolutionizes almost every sector of life and is predicted to become a major economic force in the near future. Recently, nanomaterials have received great attention for their properties at nanoscale regime and their applications in many areas primarily, agriculture and food sectors. The Nanomaterials are dispersed or solid particles, with a size range of 1–100 nm. In recent times, there has been an increased research work in this area to synthesize nanomaterials using various approaches. The use of natural biomolecules using 'green' approach play key role in the synthesis of nanomaterials having different shapes and sizes. Further this 'green synthesis' approach not only minimize the cost but also limit the need of hazardous chemicals and stimulates synthesis of greener, safe and environmentally friendly nanoparticles. The present review focus on studies based on the biosynthesis of nanoparticles using biomolecules such as plants, bacteria, fungi, etc. The text summarizes the recent work done globally by renowned researchers in area of biosynthesis of nanomaterials. It also discusses the potential applications of biologically mediated nanomaterials in the areas of agriculture and food and a critical evaluation of challenges within this field.

1. Introduction

Nanotechnology is a cutting-edge technology that deals with nanosized materials [1]. It is a multidomain field, which covers diverse domains from engineering, biology, physics and chemistry which together display unique properties of nanomaterials with wide-range of applications [2]. The building blocks of nanotechnology are nanoparticles (NPs), whose particles dimensions ranged between 1 and 100 nm [3,4]. Due to the small size and bigger surface area NPs are different from bulk materials. Moreover, NPs and bulk materials also differs from each other in parameters such as physical strength, reactivity, electrical conductivity, optical features and magnetism [4,5]. These properties make the use of NPs in diverse fields such as energy, pharmaceutics, biomedical, cosmetics, textiles, food, and agriculture [6,7]. Studies in the past several years showed that nanotechnology has the ability to bring revolution in the field of agriculture, food and health sectors with the application of biosensors [8], plant growth regulators/promoters [9], food supplements [10], enhancement of plants and animals by genetic means [11,12], smart delivery agents for drugs, pesticides and fertilizers [13,14] and nanopesticides [15].

The nanoparticles are synthesized by chemical, physical and biological methods [16]. Although the synthesis of nanoparticles by physical and chemical ways is quite frequent but the use of toxic chemicals limits their applications in agriculture, food and health related applications [17]. However, the NPs synthesized by biogenic approach showed good polydispersity, dimension as well as stability. In addition, biological methods also allow the synthesis of NPs at physiological pH, temperature and pressure along with that, it is cost effective and ecofriendly [18,19].

The research in the area of nanotechnology is advancing, mainly due to valuable properties of nanomaterials and the products have been influencing all the major areas (Fig. 1). In this review, we have explored

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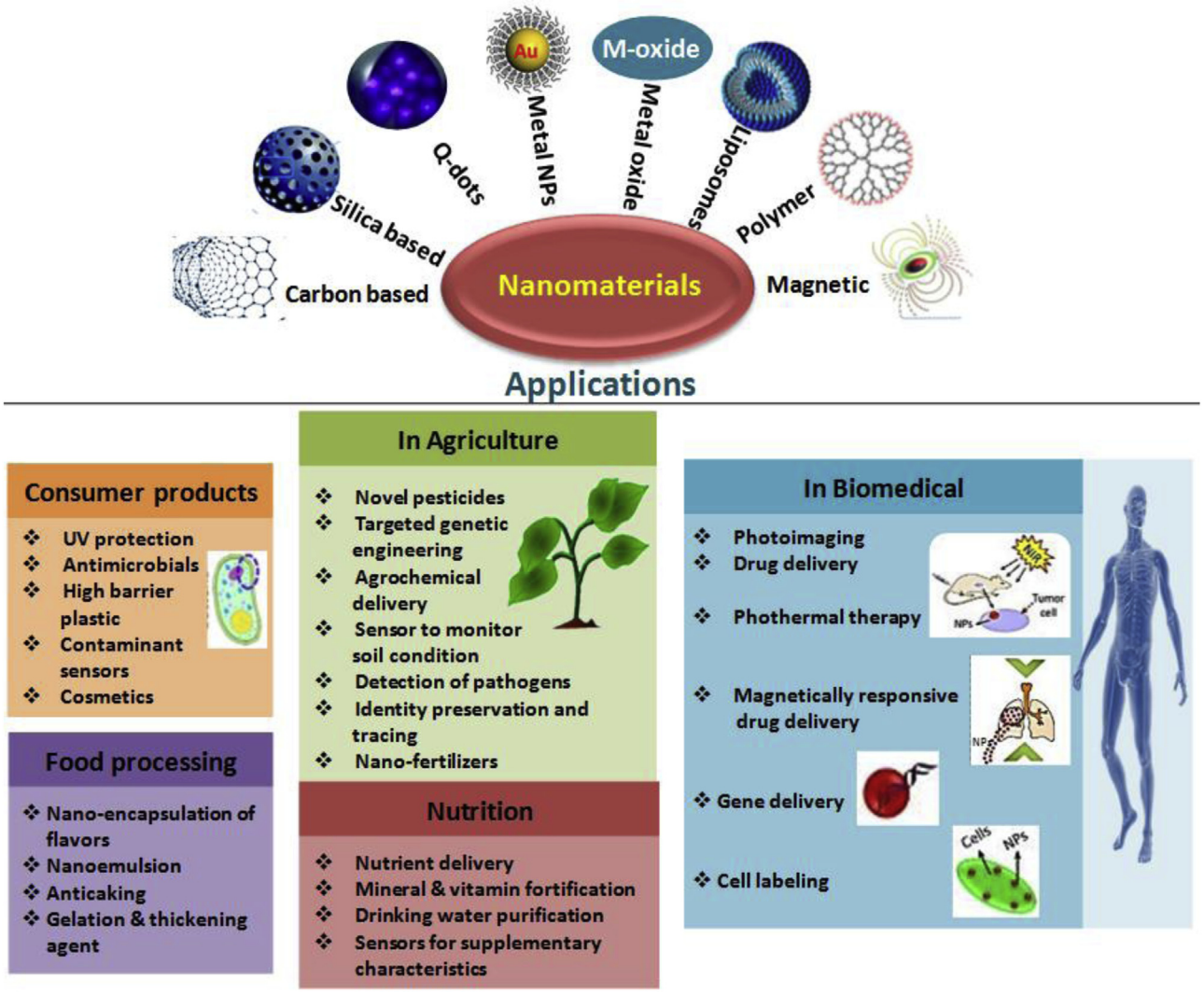

Fig. 1. Applications of bioinspired nanomaterials in agriculture, food and biomedicine.

and discussed approaches to the synthesis of NPs by biological methods, their applications and the challenges in food and agriculture sectors.

2. Biological synthesis of nanoparticles

A large number of microorganisms have the potential to synthesize nanoparticles, either intra or extracellularly. Due to their unique properties, nanoparticles have gained importance in many fields, such as agriculture, food, health care etc. in the recent years. There are number of chemical free sources for nanoparticle synthesis such as plants, microorganisms (fungi, yeast, bacteria) etc. The synthesis of inorganic nanoparticles intracellularly and extracellularly by various sources are enlisted in Table 1.

2.1. Nanoparticle synthesis by plant extracts

The synthesis of nanoparticles by plants has drawn interest to the researchers because of its one step biosynthesis procedure. To prepare the extract for synthesis, plants parts such as the root, leaf, shoot, fruit and peel are used by the researchers. Plants are considered as effective alternative for synthesis of nanoparticle, as the plant extracts are free from toxicants. Moreover, plants also provide both reducing and capping agents needed to synthesis and stabilize the nanoparticles [20].

There are several reports in literature describing the role of different plant extracts in nanoparticle synthesis. Some of the reports described in literature shown the production of gold and silver nanoparticles using extracts from Geranium [21], Aloe vera [22], sundried *Cinnamomum camphora* and *Azadiracta indica* leaf [23,24]. Furthermore, eugenol and carbazoles from extracts of *Szyygium aromaticum* and *Murraya koenigii* were also utilized as a reducing agent for the synthesis of nanoparticles [25]. In addition to this, biosynthesis of gold nanoparticles was also performed and analyzed using the leaf extract of *Mirabilis jalapa* [26].

2.2. Nanoparticle synthesis by microorganisms

Microorganisms mediated nanosized materials synthesis has come out as promising approach that have great potential as environment-friendly and cost-effective methods, avoiding the need of toxic chemicals for their synthesis. Microorganisms due to the presence of reductases are known to accumulate and reduce metal salts into metal nanoparticles with small size range and less polydispersity [27].

In the past years, microorganisms such as bacteria (also actinomycetes), fungi, and yeasts, have been reported to synthesize metal nanoparticles both intracellularly and extracellularly. There are number of protocols in literature for biological way of synthesis of nanoparticles by using proteins, peptides, enzymes, and cofactors as reducing agents. All these factors also provided the capping to synthesize nanoparticles as well as to prevent aggregation and overall stability of nanoparticles.