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A Comprehensive Review of the Parameters and Factors Affecting the Morphology of Cobalt Nanoparticles Synthesized Using Green Methodology and their Applications

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ABSTRACT

Green mediated transition metal nanoparticles have received great attention in scientific and technological fields due to their catalytic and magnetic properties. Currently, cobalt oxide is gaining interest in the environmental and biomedical fields because of its high exciton binding energy and magnetic properties. In the nano technological area, researchers always prefer the physical and chemical approach to the biological approach due to the uncontrollable morphological changes during the synthesis of particles. But biologically mediated nanoparticles are considered to have a synergistic effect with phytochemicals, which can reduce toxic chemicals as well as high energy requirements. Functional molecules of phytochemicals involve and act as reducing, stabilizin and capping agents in the synthesis of cobalt oxide and can modify the nature of nanoparticle features. This review summarizes the factors and parameters affecting the morphological changes during the synthesis of cobalt nanoparticles and their optimization parameters for the desired size and shape of cobalt nanoparticles. In addition, the reaction processes of cobalt nanoparticle formation and their various applications are especially focused on in this review.

Keywords: Green nano chemistry; Cobalt oxide; pH; Temperature; Concentration; Biological applications

INTRODUCTION

Green nano chemistry is a very limited and developed area in the modern scientific area, which draws attention to the size of constituent elements (1 nm-100 nm) and the synthesis of the morphology of various miniaturization materials. Furthermore, it has many unique surface and physicochemical properties, such as high exciton binding energy, various oxidative states, catalytic reactions, thermal resistivity and chemical cohesion, in a large area of volume. This efficacy draws interest in nanomaterials, which are suitable for technology; chemistry and nanomedicine therapy and so can be synthesized using both natural and engineered methods. Specifically, the property of large surface volume and increased crystalline structure provides the specific proposition of diverse fields such as nanomedicines, biomaterials, nano electronics, imaging, solar cells and crop growing. Nanoparticles will proceed to mediate synthesis through the use of physical force, chemical inducing and biologically mediated and this nano size provides physical, structural, magnetic and optical properties. In nanotechnology, the top down approach is a complex technique where materials are disrupted into diminished micron size particles. This limiting size makes the particles under permanently applied stress eventually irreversible and this procedure is economical, time valid and a high yield synthesis method whereas, bottom up method is constructive, uses subatomic building blocks to create bulk nanomaterials and is the scaled version of a top down method. This is a cost effective and time-consuming process. Everyone desires nanoparticles these days because the elemental dimension can change the physio chemical properties of a unique function. At present, several techniques and methods are accessible, but researchers are familiar with selecting non-hazardous, cost effective, time feasible and convenient procedures. Hence, researchers focus on the environmental non-toxicant for that biology. Arbitrate synthesis is a commercially viable alternative to physical and chemical mediating methods. Bio-nanoparticles synthesized by organisms such as microbes, bio waste and plant mediated metal oxide contain efficient biomolecules and phytochemicals that vigorously reduce the metal ions. Green synthesis nanomaterials have a wide range of applications in the biomedical field, including nanomedicines, drug delivery, tissue engineering, catalysis, etc. This photo nanomedicine increases solubility, stability and functionality, as well as induces membrane transport and extends the drug circulating period [1].

Transition metal nanomaterials, including nickel, iron and cobalt, attract interest with their catalytic, mechanical, optical and biological properties. Transition metals with intoxicant green chemistry enhance opportunities in the biomedical field. There are several metal oxide nanoparticles available that commendably promote their goal due to their recognizable metal potential. This cobalt is a transitional, p-type, d-block transition magnetic metal that is less expensive than noble metal and has health benefits as well as specific electromagnetic properties [2].

Cobalt has several oxidation states, such as tetrahedral, pyramidal and octahedral and this redox property attracts nanomaterials. Cobalt exists in two forms; the Hydroxide Co (OH) structure of cobalt metal has an α and β polymorphic form that has been used in supercapacitors and the cobalt oxide structure has magnetic materials whose oxidative state increases the electro-catalytic and optic electronic applications. Cobalt plays a major role in catalytic and magnetic dependencies including, that it possesses magnetostrictive properties to achieve greatness in the domains of nano electronics, optical devices and sensors and magnetic cooling system. Cobalt has been used in nano sensing diagnostic devices which reduces the device size in the clinical area. In addition, cobalt, which acts as a cofactor in the catalytic process, has a large surface area that can conveniently stimulate and regulate functional molecules, proteins and enzymes. In the living system, cobalt is an essential cofactor 46 that is involved in the vitamin B_{12} (hydroxocobalamin) and some enzymes that stimulate the RBC that are treated for iron deficiency anemia [3].

Some researchers proved that this green-mediated cobalt oxide nanoparticle has antioxidant, antimicrobial, anticancer, larvicidal, enzyme inhibition and anticholinergic, wound healing and anti-diabetic properties. Researchers must also realize the negative aspects of effort, time and risk to the environment, as well as the impact of cobalt metal. Cobalt nanoparticles are progressively used by size and shape with physiochemical and magnetic properties. Metal oxide with sensitive bio macromolecules remains an issue in synthesizing and achieving the target nanoparticle. This present review aims to highlight cobalt oxide nanoparticles made with green chemistry and factor that involve and modify the morphology and properties of nanoparticles and their various applications. As a result, researchers can develop a deeper understanding of cobalt oxide and expand its applications in various nano biomedical fields [4].

LITERATURE REVIEW

Synthesis of cobalt oxide nanoparticles

Synthesizing and stabilizing the desired metal nanoparticle requires an optimized protocol. During nucleation and stabilization periods, researchers can regulate the reaction through some important factors to eliminate clustering and agglomeration. Undesired morphological features can modify the solubility, plasmon resonance band, dispersion and refractive index. A cobalt metal nanoparticle should fulfill the criteria of being 1 nm to 10 nm in size, having a defined composition, being monodisperse, having a target shape, being bottle able and having a good surface volume. These desired properties increase the high catalytic activity of the target.

Chemical approach: Chemical mediated synthesis is a clear and simply updated method. In this case, compounds are used to bind the nanoparticles and form the nanostructure. Solve thermal method, sol-gel method, co-precipitation method 96, sono chemical process, hydrothermal synthesis, as well as other methods, are used to the chemical mediating cobalt oxide. This process, with a mixture of cobalt (II) metal ion salt solution as a precursor and sodium borohydride as a reducing agent reduces the metal precursor through an oxidation reduction reaction by the reduction of metallic salt. Polyvinyl alcohol acts as a capping agent for the stabilization and crystallization processes. Finally, inorganic, surfactant and polymer coatings lead the electronic forces. The chemical mediated method requires the use of solvents and hydrocarbons to synthesize and some of these substances and solvents can be harmful and cause health complications. Consequently, in chemical mediated synthesis on a large scale, final by-products produce more toxicants all through the discharge into lakes and rivers. This chemically mediated process, in particular, disrupts the marine ecosystem. However, this chemical mediated synthesis is simple, effective and produces well-defined morphological nanoparticles.

Physical approach: The physical method is a continuous kinetic and thermodynamic approach used for the synthesis of nanoparticles with optoelectronic characteristics. The physical force that attracts nanoparticles defines the nanostructure and this method necessitates high tech equipment and costly, complicated, high temperature, high pressure and time consuming processes. Amorphous crystallization, colloidal dispersion, laser fragmentation, vapor condensation, plasma method, laser ablation, sputtering and thermal evaporation are all frequently employed in physically mediated methods. This method necessarily requires the use of expensive equipment, more energy, high temperatures and pressures and special large machinery.

Biological approaches: Green chemistry and nanotechnology integration provide features such as being eco-friendly, cost efficient, biocompatible, lasting and reliable. Green sources use biocompatible chemicals and also don't require any toxic precursors or specialized technology. Plants, bacteria, fungi, algae, enzymes and bio waste are used to produce nanoparticles, but we should consider most of the disadvantages of concentrating this green mediated method which is outdated, limited and complicated to synthesize target features. In plants, nanoparticles have been synthesized using nucleation, reduction and stabilizing the organic molecules with metal oxide nanoparticles. Biological mediators synthesized using a biomimetic approach exhibit catalytic activity and act as a stabilizing agent, reducer and capping agent to prevent nanoparticle accumulation during the particle phase. Some factors, such as metal resistance genes, enzymes and reducing transcription factors are required for the biologically mediated synthesis of nanoparticles [5].

DISCUSSION

Mechanism of cobalt oxide from plant extract

Plants are the right alternative for nanoparticle synthesis, although biogenic compounds have the potential to reduce metal ions. Green nanoparticles have quite a few desirable properties because primary and secondary metabolites of plants such as antioxidants, polyphenols, catechins, flavones, isoflavones, anthocyanidins, isothiocyanates, carotenoids, polyphenols and glycosidase, are important for bio-reduction. Constituents enriched in alkaloids, flavonoids and terpenoids are primarily responsible for the reduction of metal to metal oxides. This process, with a mixture of cobalt (II) metal ion salt solution as a precursor and plant extract methoxy group, initiates the nucleation process for crystallization through interaction and reduction reactions. In following that precursor with plant bio macromolecules, phytochemicals and NADH dependent reductase, the metal ions are converted for growth by metal precursor through an oxidation reduction reaction. Bio active phytochemical with metal nanoparticles stabilized by functionally active groups. Carbonyl and amine functional molecules act as a capping agent for the crystallization process through electrostatic force and this coating leads the electronic forces for applications. During coating, nanoparticles attract and repel through electrostatic interaction and Vander Waals bonds that can modify the attraction and repulsion effects on surface area and cause aggregation in synthesis. Compared to a chemical and physical mediated method, some significant parameters affecting the plant mediated nanoparticles including a concentration of plant extract, pH, temperature, duration and revolution per minute can modify the morphology [6]. These factors and parameters optimized are sufficient to synthesize the desired distribution of size, the desired shape and the maximum yield of nanoparticle which is major factors involved in the purpose of synthesis (Figure 1).

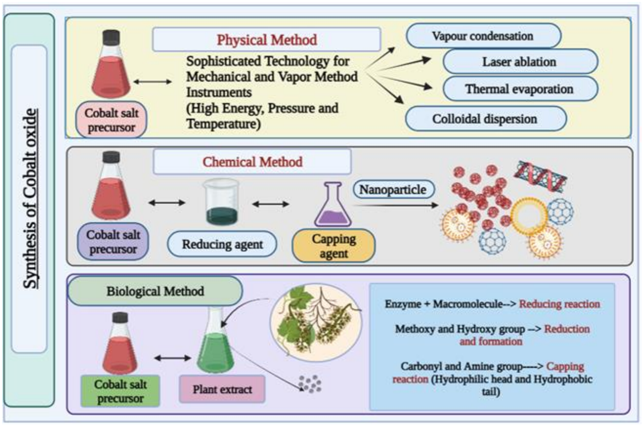

Figure 1: Schematic illustration depicting the different methods of synthesizing cobalt nanoparticles.

Mechanism of cobalt oxide from microbes

In biological methods, not only plants but microbes including bacteria, viruses, actinobacteria, fungi and algae are also used to synthesize the metal nanoparticle in intracellular and extracellular methods. In intracellular methods, some ion channels and cell wall components play a crucial role. Negatively charged proteins trap ions by electrostatic interaction, which is already reduced by the NADH dependent electron carrier enzyme in the cell wall. This microbial method undergoes the processes of bio reduction and oxidation, trapping, growth and capping to synthesize the metal nanocluster into nanoparticles. When compared to physical and chemical methods, microbial mediated synthesis is a good conventional method. But to identify and isolate organisms, culture preparation, maintaining pure culture, media preparation and growth optimization are difficult to control [7].

Effects of experimental parameters on cobalt oxide synthesis

A biologically mediated technique is a one pot protocol that does not require a lot of energy, pressure, temperature and chemical because it is non-toxic. To obtain nanoparticles, optimization of factors and parameters including pH, temperature, pressure, time duration, plant concentration, pore size, proximity and environmental conditions must be considered to achieve the size and shape of the nanoparticle. The transition process is regulated by shape and size, which entrap drug ability. The significant effect of proximity on particle charging, substrate interaction and magnetic properties of nanoparticles. People conclude that factors and parameters determine the nature and targeted quality of nanoparticles based on these modifications.

Effect of pH on surface charge: pH and buffer play significant roles in factors affecting and influencing the stability of nanoparticles. Moderation of pH may improve the surface charge, purity, crystallinity and size of nanoparticles, as well as their properties and yield. Acidic pH is the positive charge on the surface of nanoparticles that minimizes target interaction and nanoparticle quantity and acidic pH can lead to particle surface protonation and repulsion. In alkaline pH, the protonated surface charge of cobalt nanoparticles was compromised and deteriorated more. Increased pH reduces the size and increases the binding energy of the cobalt nanoparticle due to confinement effects. As a result, the crystallization rate is lower than the particle growth rate at pH, which is the optimal pH for the synthesis of cobalt oxide nanoparticles. Astonishingly, the size, shape and stability of nanomaterials improve catalytic reactions, heat conduction, optical performance and chemical stability. The pH and buffer solution has a significant effect on the ions on the surface, which greatly influences the stability of the nanoparticle [8].

Effect of plant extracts and concentrations: Plant category, growing conditions, polyphenols, based on the extraction concentration, subcellular and extracellular enzyme, extraction methodology, centrifugation and chromatography separation ion are several physiologically active components that effectively influence the formation of nanostructures. Plant category, growing conditions, polyphenols, based on the extraction concentration, subcellular and extracellular enzymes, extraction methodology, centrifugation and chromatography separation ions are several physiologically active components that effectively influence the formation of nanostructures. For plant concentration, around 1 gram to 10 grams of dried plant material and 1 gram to 5 grams of fresh plant material in 100 mL of aqueous solvent extract give a maximum yield rate [9].

Effect of incubation interval: Time and short intervals play an important role in the formulation and development of metallic nanoparticles with synergistic bioactive components, which give nanocrystals their efficiency. The duration and photoperiod have a significant impact on nanoparticle properties; however, function, yield and morphological characteristics may be compromised subsequently. Metal nanoparticle formation, particularly cobalt, necessitates an increase in incubation time up to a certain point. Following that, a sharp decrease in cobalt nanoparticle yield was observed. The acidic post synthesis incubation for 24 hours precipitated a coating effect, which reduced the size and size variation. As a result, the rate and incubation period influence the determination of the kinetic rate constant for cobalt oxide synthesis [10].

Effect of temperature on physical property: High temperature and calcination are critical parameters in the formation of pure, aggregated nanoparticles with a granular structure. High temperatures denature molecules and modify chemical and physical processes, whereas low temperatures modify the quantity and quality of nanoparticles. To control the persistence of nanoparticles, the magnetic stirring temperature and calcination must be precise. Aggregation can result in the loss of natural physical properties such as size and shape, decreasing the rate of crossing barriers in drug delivery. Researchers prefer moderate temperatures, preferably below 500°C, for cobalt oxide nanoparticles to achieve the best outcomes (Figure 2).

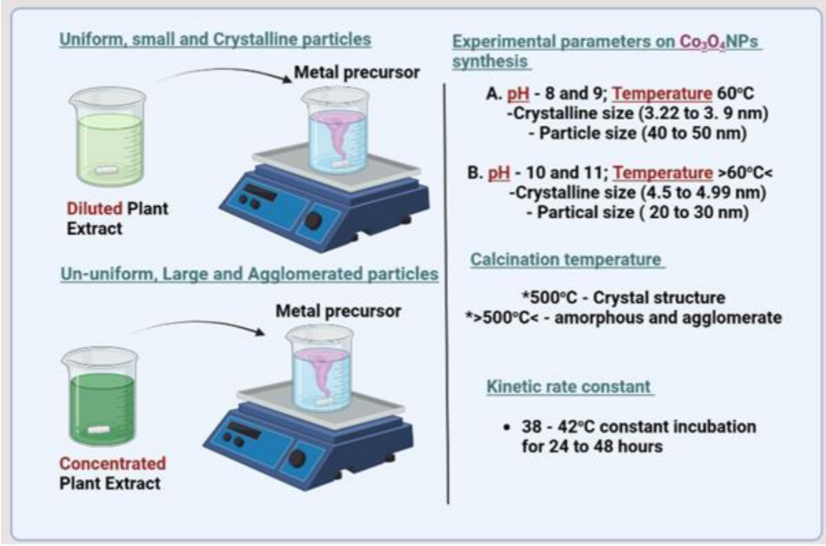

Figure 2: Optimized temperature, plant concentration and pH factor steps in the synthesis of cobalt oxide nanoparticle.

Applications of cobalt oxide: Diverse research and different elements have indeed been accomplished to synthesize metallic nanoparticles using various organisms due to the increased emphasis on green synthesis. Nevertheless, eco-friendly influenced metallic nanoparticles are relatively rare in science and engineering. Particularly in comparison to other transition metal ions, the above mentioned infrequent cobalt with intoxicant green synthesis has quite limited availability. To broaden the application of biomedical research, some studies reported nanoparticles synthesized in herbal medicines. Furthermore, cobalt metal oxide has metallic properties that help in antimicrobial, electrochromic, heterogeneous catalysis and energy storage devices. Cobalt nanoparticles have a wide range of applications, including catalysts, composite materials, magnetic devices, bio sensing, bio separation, drug delivery, magnetic resonance imaging and magnetic hyperthermia treatment [11-13].

Cobalt oxide has a cytotoxic activity that has gained attention in cancer biology and it has been used for targeted drug delivery. In the molecular mechanism, cobalt nanoparticles increase the ROS in cells and induce cytotoxicity through the downstream transcriptional factors NF-kB, VEGF in AKT and the ERK1 signaling pathway, which affect the angiogenesis process in cancer. However, cobalt stimulates intracellular stress, genotoxicity, skin allergic and inflammatory responses and acute toxicity limitations that are about to be resolved (Table 1) [14,15].

Table 1: Plant mediated cobalt nanoparticles and their activities.

S. No	Plant	Nanoparticle	Activity
1	*Murraya koenigii*	Cobalt doped nickel	Antibacterial activity in gram-negative and gram-positive bacterial strain
2	*Catharanthus roseus*	Cobalt	Antioxidant, antibacterial, haemolytic and catalytic activity
3	*Sesbania sesban*	Cobalt oxide	Antioxidant and antibacterial strain
4	*Geranium wallichianum*	Cobalt oxide	Cytotoxic and enzyme inhibition
5	*Sageretia thea*	Cobalt oxide	Antioxidant, anti-diabetic, cytotoxic, anti-leishmanial activity
6	*Ziziphus oxyphylla*	Cobalt oxide	Antimicrobial activity
7	*Tinospora cordifolia*	Cobalt doped titanium oxide	Photocatalytic degradation
8	*Phoenix dactylifera*	Cobalt oxide	Antimicrobial and photocatalytic activity
9	*Psidium guajava*	Cobalt co-doped tin oxide	Anticancer property

10	*Coriandrum sativum*	Nickel-dopped cobalt ferrite	Apoptosis and gene expression in breast cancer MCF-7 cell.
11	*Momordica charantia*	Cobalt oxide	Photocatalytic activity
12	*Parkia biglobosa*	Cobalt oxide	Antibacterial activity
13	*Euphorbia heterophylla*	Cobalt oxide	Photocatalytic activity

CONCLUSION

This review summarizes the cobalt oxide nanoparticle research studies in the field of green chemistry with nanotechnology. This literature survey of parameters and factors involved in the synthesis of cobalt nanoparticles is exhibited in the major portion of the work. Various application responses indicate cobalt metal oxide nanoparticle properties in the biomedical and therapeutic fields. This conventional synthesis with ethno medicinal plants and microbes can improve various applications in the clinical and environmental fields. Even though some plant mediated nanoparticles have some limitations, including plant concentration, duration, pH and temperature, that is evidence of the bioactive component's presence and synergistic effect in the nanoparticle. On the other hand, major bioactive compounds play a vital role in the interaction and reduction processes, which adds value for synergistic effects in applications. These factors can easily control the synthesis of cobalt nanoparticles with the desired size, shape, monodispersing and maximum yield without sophisticated lab equipment and chemicals.

AUTHOR CONTRIBUTION

All authors contributed to the manuscript design and study conception. Menaka Priya Balaji collected the data and wrote the manuscript. Devi Rajeswari V contributed to the drafting of the manuscript. All authors approved the final version of the manuscript.

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CONFLICT OF INTEREST

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the study reported in this paper.

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