
**METFORMIN-BASED COBALT (III) NANOPARTICLES: ADVANCES
IN SONOCHEMICAL SYNTHESIS, CHARACTERIZATION, AND
APPLICATIONS – A REVIEW**

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Email Id: Shrutidumale60@gmail.com.**ABSTRACT**

Nanoparticle research has rapidly advanced due to the unique physicochemical properties of materials at the nanoscale, including high surface-to-volume ratios, tunable morphologies, and improved solubility. Among synthetic strategies, sonochemical methods have emerged as green, efficient, and scalable routes for preparing nanomaterials. Metformin, a widely prescribed antidiabetic drug, has recently gained attention as a chelating agent for transition-metal complexes due to its multiple donor nitrogen sites and high aqueous solubility. This review summarizes recent developments in the synthesis and characterization of metformin–cobalt(III) nanoparticles, with emphasis on the role of sonication in particle size reduction and improved morphology. We further discuss comparative studies on copper, nickel, and iron nanocomplexes synthesized via sonication and their biomedical and catalytic applications. Finally, challenges such as toxicity, agglomeration, and scalability are examined, with future perspectives on clinical translation and industrial potential.

KEYWORDS: Metformin, cobalt (III), sonication, nanomaterials, nanomedicine, transition-metal complexes.

1. INTRODUCTION

Nanotechnology plays a pivotal role in modern chemistry, biology, and materials science due to the exceptional structural and functional properties of nanoscale systems [9]. Multiple synthesis methods have been reported in literature, including ball milling, electrospinning, sputtering, arc discharge, chemical vapor deposition, sol–gel, and reverse micelle techniques. Among these, sonication has emerged as a preferred approach because it reduces particle size,

accelerates reaction time, and provides a greener aqueous-based synthesis [9–12].

Sonochemistry, driven by ultrasonic waves (>20 kHz), produces cavitation bubbles that collapse violently, generating localized hotspots with extreme temperatures and pressures. This results in rapid nucleation and uniform particle formation [1–3]. In recent years, sonochemical synthesis of coordination complexes has been reported for Cu(II), Ni(II), Fe(II), Pb(II), and Co(III), leading to nanoscale materials with improved solubility, stability, and biological activity [18–23].

Metformin hydrochloride (Hmet·HCl), with its two imino and one amino groups, is an effective ligand for transition metals [13–15]. Stable complexes of metformin with Ni, Co, Cr, Nd, and Cu have been reported, with cobalt-based complexes demonstrating enhanced biological relevance [16–17]. This review focuses on metformin–cobalt(III) nanocomplexes synthesized by sonication, evaluating their structural characterization, applications, and comparative position among transition-metal nanomaterials.

2. Sonochemical Synthesis of Nanoparticles

Sonication offers several advantages over conventional synthetic methods

1. Reduction in reaction time [4–7]
2. Formation of nanosized particles with narrow distribution [18–20]
3. Greener medium (aqueous, fewer organic solvents) [11–12]
4. Improved crystallinity and morphology [21–22]

For example, Hojaghani et al. (2015) reported sonochemical synthesis of Cu(II) complexes, which upon calcination yielded CuO nanoparticles (60–75 nm) [18]. Ghanbari et al. (2024) prepared Cu(II) complexes with pyridine-2,6-dicarboxylic acid ligands using ultrasound, producing crystalline nanomaterials with significant antioxidant and anticancer potential [19]. Similarly, Abdel-Rahman et al. (2016) reported Cu(II), Ni(II), and Co(II) complexes that formed nano- metal oxides (16–46 nm) after calcination [20].

These studies highlight the universality of sonochemistry for preparing nanostructured complexes, which has been extended to cobalt(III)–metformin nanoparticles.

3. Metformin and Its Metal Complexes

Metformin (C₄H₁₁N₅·HCl) is widely used as an oral hypoglycemic drug. Its donor nitrogen atoms form stable coordination complexes with transition and lanthanide metals [13–15].

Literature reports confirm antimicrobial, anticancer, and antioxidant activities of cobalt(III)–metformin complexes [16–17].

Recent work by Kumar et al. (2024) demonstrated sonochemical synthesis of cobalt(III) complexes with various phenolate ligands, producing nanostructures ranging from 7–140 nm [23]. These results support the role of ultrasound in generating bioactive cobalt(III) nanocomplexes with tunable morphologies.

4. Characterization of Metformin-Co(III) Nanoparticles

4.1 UV–Vis Spectroscopy

Bulk and nano complexes of tris(metformin)cobalt(III) chloride monohydrate exhibit one LMCT band at 275 nm and two d–d transitions at 345 and 477 nm [24]. Importantly, molar absorptivity values were higher for the nano-complex, indicating enhanced electronic transitions due to reduced particle size.

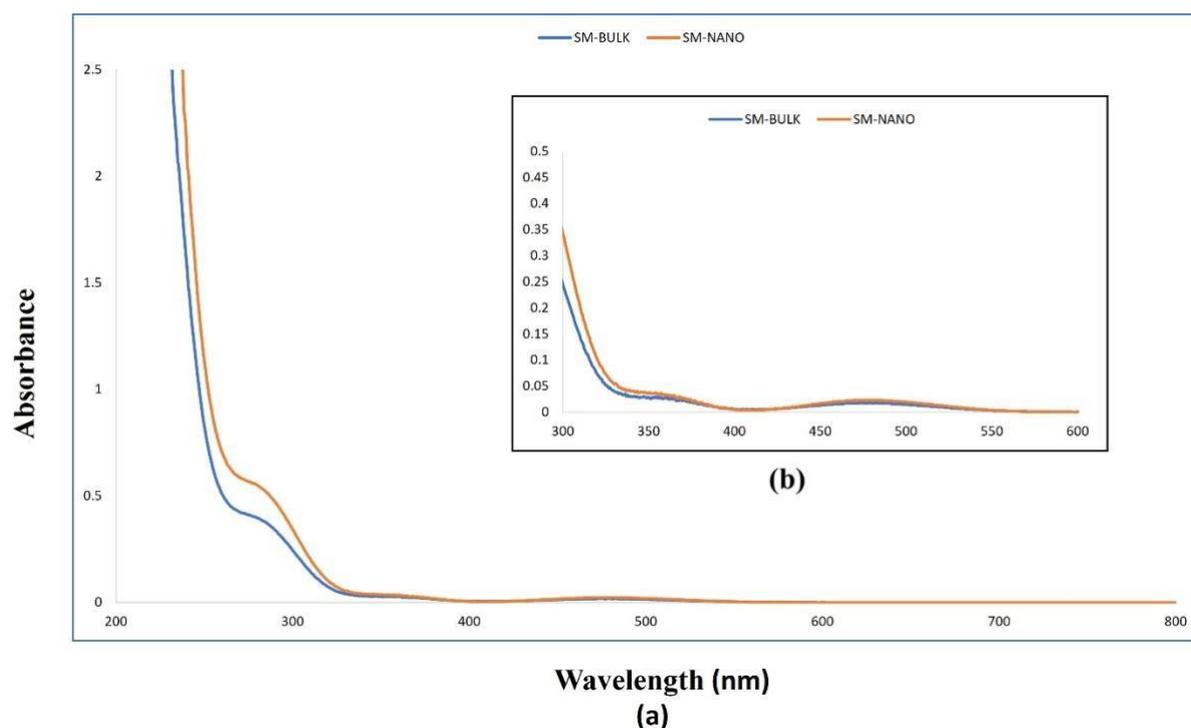


Figure 1: UV-Visible spectra of Bulk and Nano Co(III) complexes.

4.2 NMR Spectroscopy

^1H NMR spectra of bulk Co(III) complexes showed signals at δ 9.01–9.02 (–C=N–H), δ 6.99–7.35 (–C–N–H), and δ 3.10–3.40 (–CH₃), confirming ligand coordination. ^{13}C NMR peaks for –C=N were observed at δ 154.56–152.07 ppm, further validating complex

formation [29].

4.3 Morphology and Size Analysis

AFM analysis revealed spherical-to-semi-spherical nanoparticles with rough surface topologies ranging from 10–80 nm. This morphology is attributed to rapid nucleation during sonochemical synthesis.[25–26]

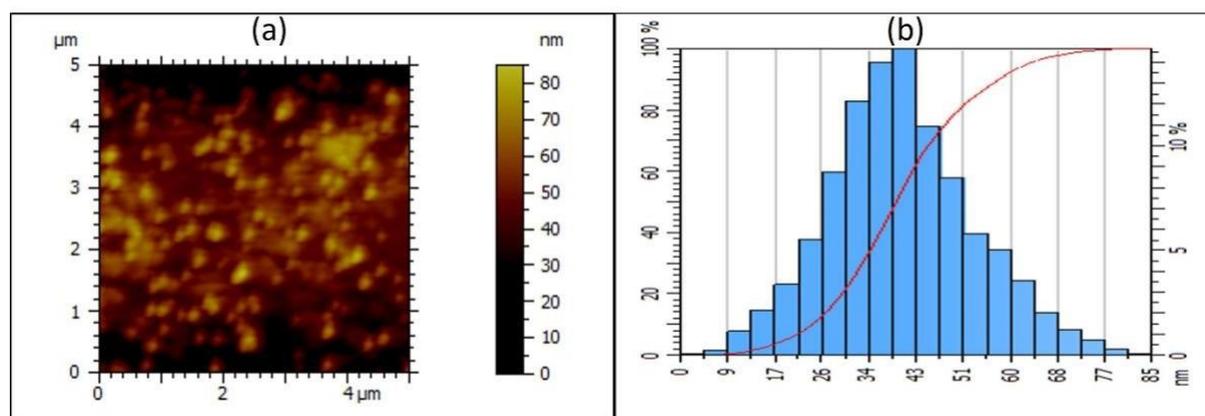


Figure 3: (a) AFM micrograph of SM (Nano-sized) and (b) height distribution in nm.

4.4 X-ray Diffraction (XRD)

PXRD confirmed crystallinity with broadened peaks in nanoforms, yielding an average crystallite size of ~66 nm (Debye–Scherrer equation) [27–28].

5. Applications of Metformin-Co(III) Nanoparticles

5.1 Biomedical Applications

Antimicrobial activity: Sonochemically synthesized complexes inhibit bacterial and fungal growth due to high surface area [20–23].

Antioxidant potential: Effective scavenging of free radicals and peroxy nitrates [19].

Anticancer activity: Cobalt and copper nanocomplexes have demonstrated cytotoxicity against cancer cells with minimal fibroblast toxicity [19–20].

Drug delivery: Hydrophilicity and coordination chemistry of metformin allow its use as a potential nanocarrier [16–17].

5.2 Environmental Applications

Dye degradation: Fe_3O_4 , CuO , and Co_3O_4 nanoparticles have been shown to degrade methylene blue, suggesting similar potential for metformin–Co(III) complexes [20–21].

Heavy metal adsorption: Functional nitrogen atoms in metformin enhance affinity for toxic metals, making these complexes potential candidates for wastewater treatment [9–12].

6. Comparative Insights from Literature

- Copper complexes: Effective antioxidants but limited antibacterial effects [19].
- Nickel complexes: Stable octahedral nanostructures, with applications in catalysis [20].
- Iron complexes: Rough and porous nanomorphologies with strong antimicrobial potential [21].
- Cobalt complexes: Superior in solubility, stability, and wide-ranging biomedical activity [16,23].

This comparative evidence suggests cobalt–metformin nanocomplexes provide the most balanced properties for both biomedical and environmental applications.

7. Challenges and Future Perspectives

Despite their promise, cobalt(III)–metformin nanoparticles face several challenges:

Limited toxicity and biosafety data [19–20] Particle agglomeration reducing stability [25–26]
Scale-up issues for industrial synthesis [4–7] Lack of in vivo and clinical validation [16–17]

Future research should emphasize:

1. Green synthesis using plant extracts or biotemplates.
2. Surface modification to reduce agglomeration.
3. Toxicological studies for clinical translation.
4. Industrial-scale sonochemistry for consistent nanoparticle production.

8. CONCLUSION

Sonochemical synthesis offers a promising route to metformin–cobalt(III) nanoparticles, producing stable, water-soluble, and bioactive nanostructures with enhanced physicochemical properties compared to bulk complexes.

Literature evidence confirms their potential in antimicrobial, antioxidant, anticancer, and environmental applications. Although challenges remain, advances in sonochemistry and nanomedicine make cobalt–metformin complexes strong candidates for future biomedical and environmental technologies.

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