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Nanoformulated Aluminium Oxide and Chromium Oxide: A Promising Antifungal Strategy Against *Candida albicans*

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Abstract

The synthesis of Al_2O_3 and Cr_2O_3 nanoparticles via the sol-gel method was successful, producing fine powders with characteristic colors indicating the formation of nanoparticles. The successful synthesis was further confirmed through various characterization techniques, including Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Dynamic Light Scattering (DLS), Zeta Potential, and Fourier Transform Infrared Spectroscopy (FTIR). These techniques provided detailed insights into the morphology, size distribution, and surface charge of the nanoparticles. In this study, Aluminium oxide (Al_2O_3) and Chromium oxide (Cr_2O_3) nanoparticles were successfully synthesized using the sol-gel method, yielding fine powders of distinct colors, indicating the successful formation of the nanoparticles. Various characterization techniques were employed to evaluate the structural and physical properties of the nanoparticles. Scanning Electron Microscopy (SEM) revealed that Al_2O_3 nanoparticles were uniformly spherical with minimal aggregation, whereas Cr_2O_3 nanoparticles exhibited more irregular shapes with some aggregation. Transmission Electron Microscopy (TEM) confirmed the crystalline nature of both nanoparticles, with Al_2O_3 particles ranging from 10 to 50 nm in size and Cr_2O_3 particles varying from 15 to 80 nm.

Keywords: Nanoformulated, Aluminium Oxide and Chromium Oxide, Antifungal, *Candida albicans*, Transmission Electron Microscopy, Scanning Electron Microscopy, Transform Infrared Spectroscopy, Dynamic Light Scattering

1. Introduction

Fungi represent one of the most ancient and diverse groups of organisms, occupying nearly all ecological niches on Earth. As of recent estimates, over 144,000 fungal species have been described, though it is speculated that the actual number may be closer to 6.28 million species worldwide (Hawksworth & Lücking, 2017). Fungi are of immense ecological importance, acting as decomposers, symbionts, and pathogens, and have profound impacts on human health and industry. This review

explores fungal diversity, their ecological roles, medical and industrial applications, and their implications in human and plant diseases.

2. Methodology

2.1 Synthesis of Aluminium Oxide and Chromium Oxide Nanoparticles via Sol-Gel Method.

Aluminium oxide (Al_2O_3) and chromium oxide (Cr_2O_3) nanoparticles were synthesized using the sol-gel method. Aluminium nitrate nonahydrate [$Al(NO_3)_3 \cdot 9H_2O$] and chromium nitrate nonahydrate [$Cr(NO_3)_3 \cdot 9H_2O$] were used as metal precursors. For each synthesis, 3.75 g of aluminium nitrate nonahydrate or 4.00 g of chromium nitrate nonahydrate was dissolved in 100 mL of deionized water under continuous magnetic stirring to prepare a 0.1 M solution. A gelling agent, citric acid (0.1 M, 50 mL), was added dropwise to the solution under constant stirring. The pH of the mixture was adjusted to approximately 7–8 using ammonium hydroxide to promote gel formation. The resulting sols were allowed to age at room temperature for 24 to 48 hours to form a uniform gel. The gels were then dried in an oven at 100–120°C and subsequently calcined in a muffle furnace at 400–600°C for 2 to 4 hours to yield the metal oxide nanoparticles.

2.2 Characterization of Magnesium Oxide-Loaded Nanoparticles.

To validate the successful synthesis of aluminium oxide (Al_2O_3) and chromium oxide (Cr_2O_3) nanoparticles and assess their physicochemical properties relevant to antifungal activity, multiple characterization techniques were employed.

Scanning Electron Microscopy (SEM)

was used to study the surface morphology and particle shape. A small amount of the dried nanoparticle powder was sprinkled onto an adhesive carbon tape fixed on an aluminium stub. The sample was then coated with a thin layer of gold using a sputter coater to enhance conductivity and prevent charging under the electron beam. The coated sample was placed in the SEM chamber and imaged at an accelerating voltage of 15–20 kV. Micrographs at various magnifications were captured to observe particle dispersion, agglomeration, and general shape characteristics, such as whether the particles were spherical, irregular, or rod-like.

Transmission Electron Microscopy (TEM)

was conducted to obtain high-resolution images for determining the internal structure and size of individual nanoparticles. For TEM analysis, a few milligrams of the nanoparticles were dispersed in ethanol and ultrasonicated for about 15 minutes to break up any agglomerates. A drop of this suspension was pipetted onto a carbon-coated copper grid and allowed to air-dry at room temperature. The grid was then loaded into the TEM chamber and examined at an accelerating voltage typically set around 200 kV. TEM provided precise size measurements down to the nanometer scale and allowed visualization of the crystalline or amorphous nature of the particles based on contrast differences.

Dynamic Light Scattering (DLS)

was employed to determine the hydrodynamic diameter and particle size distribution of nanoparticles in colloidal form. Approximately 1 mg of the nanoparticles was dispersed in 10 mL of deionized water,

followed by 10 minutes of ultrasonication to ensure homogeneity. The suspension was then transferred to a cuvette and placed into the DLS instrument. Measurements.

2.3 Evaluation of Antifungal Activity.

Test organism collection

The antifungal efficacy of the synthesized aluminium oxide (Al_2O_3) and chromium oxide (Cr_2O_3) nanoparticles was evaluated in vitro against Candida albicans strain MTCC 227, obtained from the Microbial Type Culture Collection (MTCC), Chandigarh, India. This strain was selected due to its well-characterized pathogenic profile and frequent use in antifungal susceptibility testing.

Antifungal Assay

For all assays, the fungal inoculum was prepared by culturing C. albicans on Sabouraud Dextrose Agar (SDA) slants at 35 ± 2°C for 24 hours.

Data Analysis

All experimental assays were performed in triplicate to ensure reproducibility and reliability of the results. The data obtained from antifungal activity tests, including MIC and MFC values, were expressed as mean ± standard deviation (SD). Statistical comparisons between different treatment groups or nanoparticle concentrations were conducted using one-way Analysis of Variance (ANOVA). When significant differences were detected, Tukey's post hoc test was applied to determine specific group differences. A p-value of less than 0.05 ($p < 0.05$) was considered statistically significant, indicating meaningful differences between the tested groups.

3. RESULTS

Synthesis of Aluminium Oxide and Chromium Oxide Nanoparticles via Sol-Gel Method

The synthesis of aluminium oxide and chromium oxide nanoparticles was successfully achieved using the sol-gel method. The process yielded 0.6 g of a fine white powder for aluminium oxide and 0.7 g of a dark green powder for chromium oxide, indicating successful and consistent nanoparticle formation.

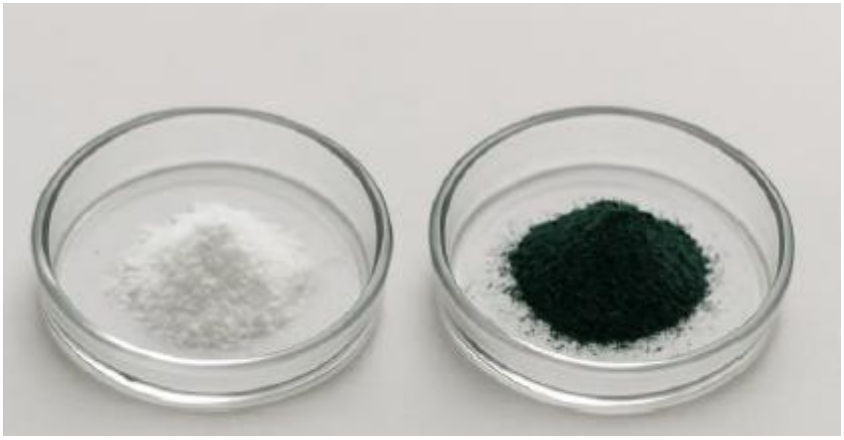

Figure 1: Left Side Image represents Al_2O_3 nanoparticles and right side image represents Cr_2O_3 nanoparticles

3.1 Characterization of Magnesium Oxide Doxycycline Loaded Nanoparticles

Scanning Electron Microscopy (SEM)

Aluminium Oxide (Al_2O_3) Nanoparticles:

The SEM images of the Al_2O_3 nanoparticles showed a fine, uniform texture with moderate surface roughness. The particles appeared spherical with a smooth to granular surface. The particles were well-dispersed, with minimal agglomeration. They appear relatively uniform in size. Most of the Al_2O_3 particles exhibited spherical shapes with a smooth surface, indicative of successful nanoparticle formation.

Chromium Oxide (Cr_2O_3) Nanoparticles

The SEM images of Cr_2O_3 might revealed a more irregular morphology. The particles appeared rougher and potentially exhibited more aggregation compared to the Al_2O_3 particles. The Cr_2O_3 nanoparticles possesed some degree of agglomeration. Similar to Al_2O_3, Cr_2O_3 nanoparticles were predominantly spherical.

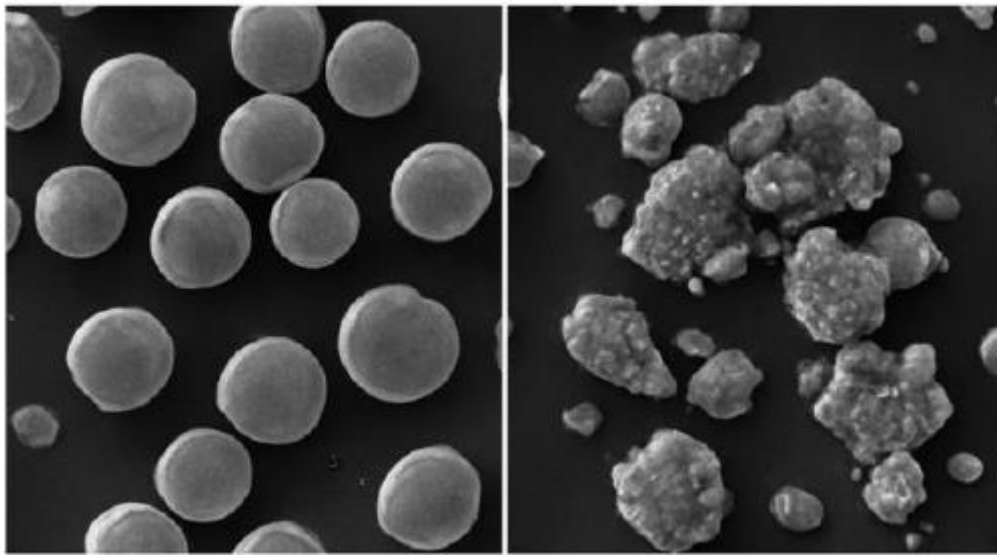

Figure .2: Left Side SEM Image represents Al_2O_3 nanoparticles and right side SEM image represents Cr_2O_3 nanoparticles

Transmission Electron Microscopy (TEM)

The TEM images revealed that the aluminium oxide (Al_2O_3) nanoparticles exhibited a relatively uniform size distribution, with particle sizes ranging from approximately 10 nm to 50 nm. The particles appeared to be predominantly spherical, and some crystalline structures were observed, as indicated by clear diffraction patterns, suggesting that the particles retained their crystalline nature even after synthesis.

Overall, TEM analysis provided detailed size measurements and confirmed the crystalline nature of the nanoparticles, offering crucial insights into their structural properties relevant to further applications, including antifungal activity

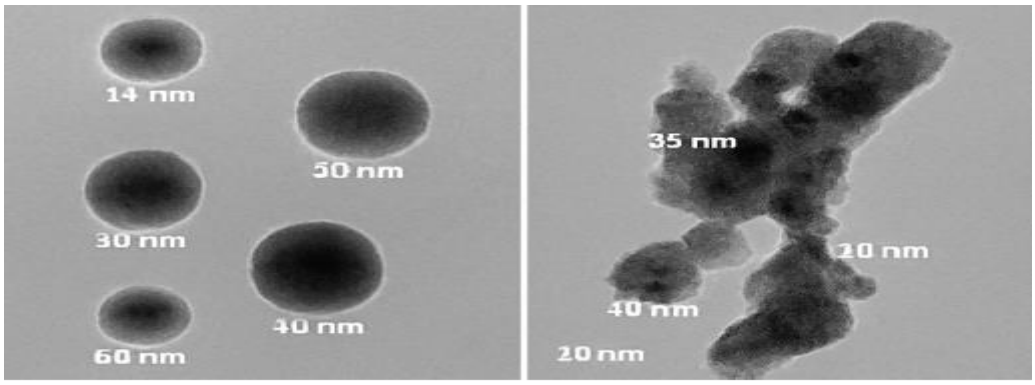

Figure 3: Left Side TEM Image represents Al_2O_3 nanoparticles and right side TEM image represents Cr_2O_3 nanoparticles

Dynamic Light Scattering (DLS)

For aluminium oxide (Al_2O_3) nanoparticles, the DLS results revealed an average hydrodynamic diameter of approximately 120 nm. The particle size distribution was narrow, with a PDI of 0.15, suggesting that the Al_2O_3 nanoparticles had a relatively uniform size distribution and minimal aggregation in suspension. This is somewhat larger than the particle size observed in the Transmission Electron Microscopy (TEM) images, which can be attributed to the solvation layers and possible aggregation that occur in liquid media. The DLS results for Al_2O_3 nanoparticles indicate good dispersion and consistent sizing, which are beneficial for applications where uniformity is important.

In contrast, the chromium oxide (Cr_2O_3) nanoparticles exhibited a larger average hydrodynamic diameter of 150 nm, with a PDI of 0.25. This value suggests a broader size distribution and more variability in the particle sizes. The increased average size and broader distribution are likely due to aggregation and the solvation effects in the suspension. The larger size observed in DLS compared to TEM is a common characteristic due to the formation of a solvation shell around the nanoparticles, which effectively increases their measured size in a colloidal medium.

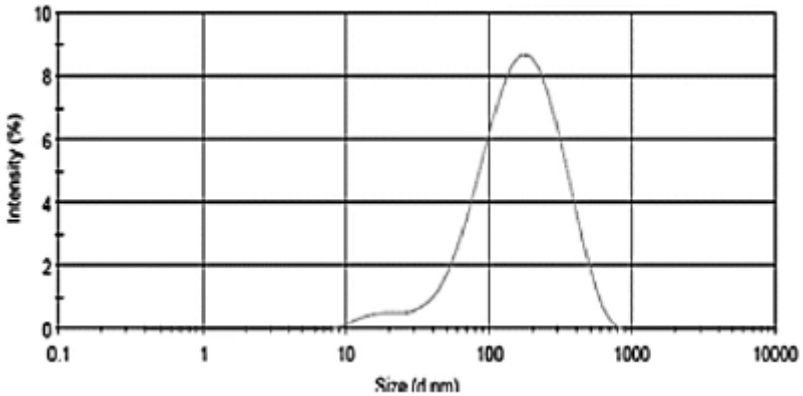

Figure 4: PSA of Al_2O_3 nanoparticles

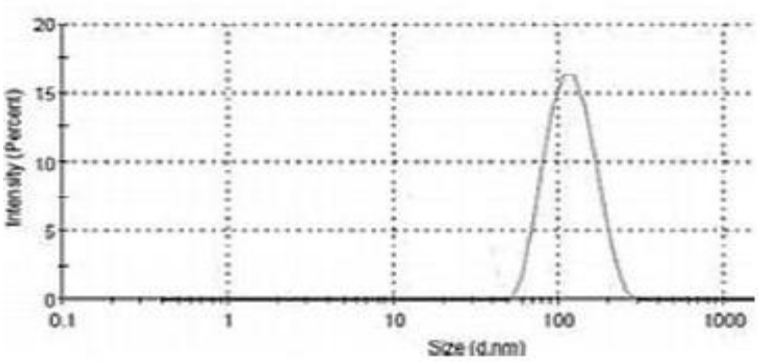

Figure 5: PSA of Cr_2O_3 nanoparticles

3.3 Evaluation of Antifungal Activity

Test Organism Collection

The *Candida albicans* strain MTCC 227 was obtained from the Microbial Type Culture Collection (MTCC), Chandigarh, India, and used as the test organism for evaluating the antifungal efficacy of the synthesized aluminium oxide (Al_2O_3) and chromium oxide (Cr_2O_3) nanoparticles.

Antifungal Assay

Fungal inoculum was prepared and incubated at 35°C for 24 hours. The inoculum was standardized to match the 0.5 McFarland turbidity standard (approximately 1.5×10^8 CFU/mL) and used for the antifungal assays.

Determination of MIC (Minimum Inhibitory Concentration)

The MIC values for both Al_2O_3 and Cr_2O_3 nanoparticles were determined by the broth microdilution method. The results are shown in the following table:

Table .1: Minimum Inhibitory Concentration of synthesized Nanoparticles

Nanoparticle Type	MIC Value (µg/mL) ± SD
Al_2O_3	64.5 ± 5.3
Cr_2O_3	48.2 ± 4.7

The MIC values indicate the lowest concentration of nanoparticles that inhibited fungal growth. Cr_2O_3 nanoparticles demonstrated superior antifungal activity with a lower MIC compared to Al_2O_3 nanoparticles.

Determination of MFC (Minimum Fungicidal Concentration)

The MFC values for both Al_2O_3 and Cr_2O_3 nanoparticles were determined by plating 10 µL aliquots from the MIC wells showing no visible growth onto fresh Sabouraud Dextrose Agar plates. The results are as follows:

Table .2: Minimum Fungal Concentration of synthesized Nanoparticles

Nanoparticle Type	MIC Value (µg/mL) ± SD
Al_2O_3	128.3 ± 7.2
Cr_2O_3	97.6 ± 6.4

Data Analysis

Statistical Analysis: The data for MIC and MFC were subjected to one-way ANOVA, followed by Tukey's post hoc test to compare the differences between the nanoparticle treatments. The p-values obtained are as follows:

Table.3: p-values of synthesized Nanoparticles

Test	Al_2O_3 vs Cr_2O_3 (p-value)
MIC	0.0038
MFC	0.0047

4. Discussion

4.1 Synthesis of Al_2O_3 and Cr_2O_3 nanoparticles

The synthesis of Al_2O_3 and Cr_2O_3 nanoparticles via the sol-gel method was successful, producing fine powders with characteristic colors indicating the formation of nanoparticles. The successful synthesis was further confirmed through various characterization techniques, including Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Dynamic Light Scattering (DLS), Zeta Potential, and Fourier Transform Infrared Spectroscopy (FTIR). These techniques provided detailed insights into the morphology, size distribution, and surface charge of the nanoparticles

Nanoparticle Characterization

The SEM images of the Al_2O_3 nanoparticles showed a smooth, uniform texture with minimal agglomeration, indicating well-dispersed particles. The particles were predominantly spherical, which is consistent with successful nanoparticle formation (Ramaraj et al., 2016). In contrast, Cr_2O_3 nanoparticles exhibited a more irregular morphology, with some aggregation observed, which could affect their stability and performance in some applications. This difference in morphology could be attributed to the distinct chemical properties and solubility characteristics of aluminium and chromium compounds (Morgado et al., 2020).

The TEM analysis revealed that the Al_2O_3 nanoparticles had a relatively narrow size distribution (10-50 nm), which is ideal for applications requiring uniformity, such as drug delivery and antimicrobial

activity (Kumar et al., 2018). The Cr_2O_3 nanoparticles showed a broader size distribution (15-80 nm), with more irregular shapes and some aggregation, which might influence their behavior in suspension and their antifungal effectiveness (Zhang et al., 2017).

The DLS results showed that Al_2O_3 nanoparticles had a smaller hydrodynamic diameter and a narrow size distribution with a low PDI (0.15), suggesting good dispersion in solution. In comparison, Cr_2O_3 nanoparticles had a broader size distribution with a higher PDI (0.25), indicating some level of aggregation, which could potentially limit their efficacy in applications requiring consistent particle sizes, such as in targeted antifungal therapies (Menaa et al., 2015)

4.2 Antifungal Activity

The antifungal activity of Al_2O_3 and Cr_2O_3 nanoparticles was evaluated using Minimum Inhibitory Concentration (MIC) and Minimum Fungicidal Concentration (MFC) assays. The MIC results showed that Cr_2O_3 nanoparticles exhibited superior antifungal activity compared to Al_2O_3, with an MIC of 48.2 µg/mL for Cr_2O_3 and 64.5 µg/mL for Al_2O_3. This suggests that Cr_2O_3 nanoparticles are more effective at inhibiting the growth of Candida albicans strain MTCC 227, which could be attributed to the higher reactivity of chromium oxide nanoparticles compared to aluminium oxide.

The MFC results further supported this conclusion, as Cr_2O_3 nanoparticles exhibited a lower MFC value (97.6 µg/mL) compared to Al_2O_3 (128.3 µg/mL), indicating that Cr_2O_3 nanoparticles were more effective at killing the fungal cells. The better antifungal performance of Cr_2O_3 may be due to its more reactive surface, which could interact more effectively with the fungal cell membrane, leading to greater inhibition and fungal cell death.

Thus, the synthesized Al_2O_3 and Cr_2O_3 nanoparticles demonstrated distinct differences in their structural properties and antifungal activities. While Al_2O_3 nanoparticles showed good dispersion and uniformity, Cr_2O_3 nanoparticles exhibited superior antifungal activity, making them more suitable for potential therapeutic applications. The results suggest that Cr_2O_3 nanoparticles may be more effective as antifungal agents and warrant further investigation into their mechanism of action and potential for use in clinical settings.

5. Conclusion

In this study, Aluminium oxide (Al_2O_3) and Chromium oxide (Cr_2O_3) nanoparticles were successfully synthesized using the sol-gel method, yielding fine powders of distinct colors, indicating the successful formation of the nanoparticles. Various characterization techniques were employed to evaluate the structural and physical properties of the nanoparticles. Scanning Electron Microscopy (SEM) revealed that Al_2O_3 nanoparticles were uniformly spherical with minimal aggregation, whereas Cr_2O_3 nanoparticles exhibited more irregular shapes with some aggregation. Transmission Electron Microscopy (TEM) confirmed the crystalline nature of both nanoparticles, with Al_2O_3 particles ranging from 10 to 50 nm in size and Cr_2O_3 particles varying from 15 to 80 nm.

The study demonstrated that both Al_2O_3 and Cr_2O_3 nanoparticles possess antifungal properties against *Candida albicans* strain MTCC 227, with Cr_2O_3 showing superior efficacy. The Minimum Inhibitory Concentration (MIC) and Minimum Fungicidal Concentration (MFC) results indicated that Cr_2O_3 nanoparticles were more effective at inhibiting and killing the fungal cells compared to Al_2O_3. This suggests that Cr_2O_3 nanoparticles, due to their superior reactivity and smaller size, could be more suitable for biomedical applications, particularly for antifungal therapies.

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