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ANTIMICROBIAL ACTIVITY STUDIES OF MESOPOROUS MCM-41, METAL INCORPORATED MCM-41, AND MCM-41 MATERIALS WITH ACID-FUNCTIONALIZATION

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ABSTRACT

The antimicrobial activity of the synthesized mesoporous materials was presented. The antibacterial activity was conducted against E.Coli and S. Aureus bacteria, whereas the antifungal activity was examined against Candida albicans, and Candida rugosa. In these studies, the antimicrobial activity of the phosphotungstic acid functionalized MCM-41 material was found to be the highest among all the materials. The antimicrobial activity studies of the synthesized mesoprous MCM-41, metal incorporated MCM-41 (Mn/Al-MCM-41) and there was a discussion of the acid functionalized MCM-41 (SA/PA-MCM-41) materials. After conducting the literature review, the aim of the work was designed and it was conducted with the experimentation and the results were presented.

Keywords: Antimicrobial Activity; E.Coli; S.Aureus; Phosphotungstic Acid; MCM-41.

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INTRODUCTION

The literature was presented based on the existing works, which report the biological activity of the various mesoporous MCM-41 materials. Noria Bouchikhi*et al.*.have reported the antibacterial and antifungal activities of 8-hydroxyquinoline 5-sulfonic acid-impregnated MCM-41 materials. These materials were used from the spent glass, which is the source of Silicon and Aluminium. The mesoporous materials were synthesized in various percentage compositions to study and optimize the appropriate composition in the material. The antibacterial activity of these materials was evaluated against the bacterial strains Gram-negative (E. coli ATCC 25922, P. aeruginosa ATCC 27853), Gram-positive (Staphylococcusaureus1 ATCC 25923, S.aureus2 ATCC 43300).Furthermore, the antifungal activity was examined against the Candida albicans ATCC 10231. The materials were reported to be efficient inhibitors of these organisms. Bhuvaneswari *et al.*. has presented their work on the antibacterial activity studies on Tetracycline containing MCM-41 materials against the Escherichia coli bacteria. The efficacy of these mesoporous silica nanomaterials (MSNs) was examined with two different-sized materials namely, TC-MCM-41 at 41± 5 nm and TC-MCM-41 at 406 ± 55 nm. These materials were named MCM-41A and MCM-41B respectively. Both the materials were observed to be efficient in inhibiting the growth of the bacteria at a concentration of 1.0 µg/mL. Sohrabnezhad Sh. *et al.*. have synthesized mesoporous MCM-41 and silver-containing MCM-41 nanofibers (Ag-MCM-41) and their antibacterial activity was investigated against Gram-negative E.coli, Gram-positive Staphylococcusaureus (S. aureus). The Ag-MCM-41 composites were calcined at 500ºC and 600ºC, respectively, and based on these temperatures, the samples are labeled as 500Ag/MCM-41 and 600Ag/MCM-41 materials. The minimum inhibitory concentration (MIC) was determined with the nutrient broth solution of 8g/L. In the experimental studies, E.Coli was completely inhibited (99.9%) with 60µg/mL (6.31 µg/mL of Ag)

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concentration of the 500Ag/MCM-41 nanofiber. Whereas, the bacteria S.aureus was inhibited at 120 µg/mL (12.63 µg/mL of Ag) concentration of the 500Ag/MCM-41 nanofiber. This shows the bacteria S.aureus required more content of Ag than for the E.Coli. With 600Ag/MCM-41 composite, the optimal concentrations were observed to be 120 µg/mL and 250 µg/mL for the inhibition of E.Coli and S.aureus bacteria respectively. The bacterial activity of the pure MCM-41 nanofibers was almost negligible when compared with the above composites. Oliveira *et al.*. have synthesized Red propolis-loaded mesoporous MCM-41 nonmaterial's and the materials were evaluated for antibacterial activity using well diffusion method against the Staphylococcus aureusATCC 25923 strain. Among the conducted experiments, higher inhibition of the bacteria was observed at 500 µg/mL in a dimethyl sulphoxide (DMSO) medium.Tian*et al.*. have demonstrated the antibacterial activity of silver-containing mesoporous MCM-41 nanomaterials (Ag-MCM-41 MNMs).E. coliandS. Aureus were selected as model bacteria for the studies. When the optical density was measured at 600 nm, it was observed that at 80 µg/mL of the MNMs, the E.colibacteria was completely inhibited, whereas the S.aureus was inhibited to the maximum at 320 µg/mL concentration.

The Ag-MCM-41 MNMs were found to be highly efficient in exhibiting antibacterial activity than the other examined compounds, $AgNO_3$ and Ag NPs. Suman *et.al* have synthesized various metal-incorporated MCM-41 nanomaterials (Metal= Ti, V, and Pd)through the sol-gel method and these MNMs were evaluated for their antibacterial and cytotoxic studies. The antibacterial studies were conducted against E.Coli, S. aureus, Salmonella paratyphi, and Bacillus subtilis. The zone of inhibition (ZOI) was determined in millimeters (mm). It was observed that the ZOI was obtained as 15 mm for E. coli, and 16 mm for S. paratyphi with Ti-MCM-41 MNM (900 µg/mL). With V-MCM-41 MNM (900 µg/mL), the ZOI was obtained as 13 mm E. coli and 22 mm S. paratyphi. These materials were successful in the inhibition of the gram-negative bacteria.

The Pd-MCM-41 MNM (900 µg/mL), inhibited the gram-positive bacteria B. subtilis and S. aureus with 17 and 18 mm of ZOI respectively. The studies were conducted with Streptomycin as the standard drug. Assessment of drug release from structured three-dimensional silica constructs[1], mesoporous silica nanoparticles: fabrication techniques and practical uses[2], tailoring SBA-15-type silicates with oleo chemical attachments: controlling nanostructure, surface chemistry, and biological effects[3], enhanced antibacterial performance through synergistic action of three-dimensional mesoporous carbon-lysozyme composite[4], Mesoporous Silica Materials in Drug Delivery: Addressing Challenges in Combatting Bacterial Infections[5], functionalized porous nanomaterials as green catalysts for sustainable organic conversions[6], silica-based mesoporous materials: innovative adsorbents for water remediation[7], custom synthesis of antimicrobial polymer-grafted mesoporous silicas[9], insights into the synthesis and applications of hydrophobic solid catalysts[9], heterogeneous catalysts for perfumery chemical synthesis: isomerization, acetalization, and hydrogenation[10], mesoporous silica nanospheres for targeted delivery of natural anticancer agents[11], carbon-based nanocomposites for eco-friendly remediation of emerging environmental pollutants[12], selective monolaurate esterification using zro2/mcm-41 catalysts: comparison of impregnation and precipitation methods[13], biomass-derived materials for catalysis and adsorption: advancements since 2010[14], mononuclear cu-complex-embedded nano-porous silica hybrid catalysts for benzyl alcohol oxidation[15], review of mesoporous silica-based catalysts for biodiesel synthesis[16],revisiting carboxylic group functionalization of silica sol-gel materials.[17]

EXPERIMENTAL

Based on the above literature reports, it was strongly supported that the mesoporous MCM-41 materials can exhibit antimicrobial activity. Therefore, it was aimed to conduct antibacterial and antifungal activities against selected microorganisms, so as to evaluate the antimicrobial functions of the synthesized MCM-41, Mn&SA-MCM-41, PA-MCM-41, and Al-MCM-41 materials. In the present studies, the antibacterial activity was conducted against the Gram-positive Staphylococcus aureus (ATCC6538) and the gram-negative E. coli (ATCC29181), with Streptomycin as the standard drug. Further, the antifungal activity was conducted against microorganisms yeast and filamentous fungi namely Candida albicans, and Candida rugosa (ATCC10231) concerning the standard Amphotericin B.

Experimental

The lyophilized cultures were obtained from the Microbial Type Culture Collection and Gene Bank at MTCC IMTECH, located in Chandigarh, India. For a whole day, the lyophilized cultures of S. aureus and E. coli were maintained at 27 °C in their corresponding growth conditions. For duration of 24 hours, E. Coli was cultured on nutritional agar (NA) at 27°C, whereas S. aureus was grown on yeast extract peptone dextrose agar (YPDA) medium at the same temperature. After that, the cultures were subcultured to produce live bacteria. In addition, glycerol stocks were created in order to store the microorganisms for later use.

General Procedure of Anti-Bacterial Activity Studies

In this experimentation, 0.5 mL of the already existing bacterial culture (24 h) was slowly spread on a petri plate and in wells filled with 200 mg/mL and 600 mg/mL of each of the synthesized MCM-41, Al-MCM-41, and Mn, SA & PA- MCM-41 mesoporous materials. The entire setup was kept under incubation for over period of 24 h at 27°C. After a proper diffusion was observed, the anti-microbial activity was determined by measuring the zone of inhibition (in mm) using the HI antibiotic zone scale.

General Procedure of Anti-Fungal Activity Studies

The antifungal activity of the mesoporous materials was determined using the method adopted in section 5.4.3 (potato dextrose agar, PDA medium).[7]

RESULTS AND DISCUSSION

In the antibacterial studies, the zone of inhibition in the *E.Coli* bacteria was observed to be almost less with the PA-MCM-41 material at 600 µg/mL. At 200 µg/mL concentration of the material, the zone of inhibition (ZOI) was observed to be nominal. Among the metal-incorporated MCM-41 materials, Mn-MCM-41 has shown enhanced inhibition than Al-MCM-41 material at 600 µg/mL concentration of the materials. The bacteria *S. aureus was* almost inhibited similarly. Moreover, the inhibition tendency was observed to more at higher concentrations of the mesoporous materials. The inhibition trend of the *E.Coli* bacteria was observed as PA-MCM-41 (ZOI=18 mm) >Mn-MCM-41 (ZOI=15mm) >SA-MCM-41 (ZOI= 12 mm)>Al-MCM-41 (ZOI= 10 mm). For the *S.aureus* bacteria, the trend was observed as PA-MCM-41 (ZOI=17 mm)>SA-MCM-41 (ZOI= 15 mm) >Mn-MCM-41 (ZOI= 13 mm) >Al-MCM-41 (ZOI= 10 mm). The above results were compared with the activity of the standard drug *Streptomycin* (Control) and were displayed in Fig.-1 and Table-1.

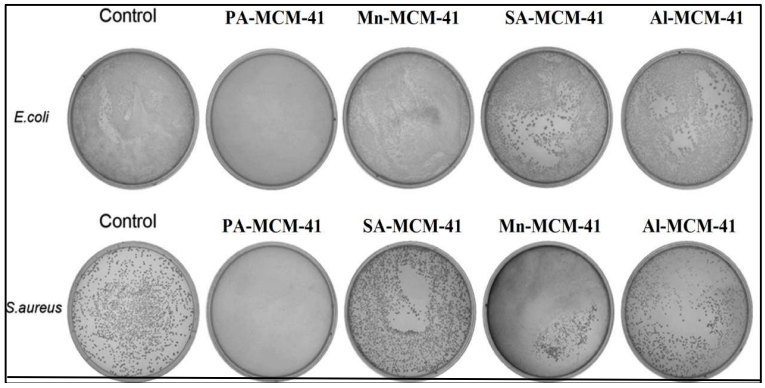

Fig.-1: Images of the Antibacterial Activity of the Mesoporous Materials (at 600 µg/mL)

Table-1: Zone of Inhibition of the Bacteria with Respect to the Composition of the Mesoporous Materials

Mesoporous material	Concentration(µg/mL)	Zone of inhibition, (mm)	
		E.Coli	*S.aureus*
MCM-41	200	7	7
	600	8	8
PA-MCM-41	200	10	9
	600	18	17

SA-MCM-41	200	8	8
	600	12	15
Mn-MCM-41	200	11	9
	600	15	13
Al-MCM-41	200	8	9
	600	10	10
Streptomycin (Standard)	50	18	18
	100	26	26

In the antifungal activity studies, the percentage zone of inhibition was determined using an equation. It was observed that the fungal strain *Candida albicans* was inhibited majorly by the PA-MCM-41 and Mn-MCM-41 mesoporous materials than the other materials, as compared with the standard drug *Amphotericin* B. The fungal strain *Candida rugosa* was inhibited majorly by the three Mn-MCM-41, Materials for SA-MCM-41, and PA-MCM-41. In these investigations, the activity of the Al-MCM-41 material was found to be almost less (Table-2). Further, the activity of the mesoporous materials was higher at 150 μg/mL concentration as compared to 100 μg/mL concentration.

Table-2: % Zone of Inhibition of the Fungi with Respect to the Composition of the Mesoporous Materials

Mesoporous material	Concentration (μg/mL)	Zone of inhibition (%)	
		Candida albicans	*Candida rugosa*
MCM-41	100	0	0
	150	15	15
PA-MCM-41	100	25	50
	150	75	75
SA-MCM-41	100	25	25
	150	40	75
Mn-MCM-41	100	50	25
	150	75	50
Al-MCM-41	100	15	15
	150	15	15
Amphotericin* B *(Standard)	100	75	75
	150	100	100

CONCLUSION

The paper presents the antimicrobial applications of the various acid-functionalized and metal-incorporatedMCM-41 mesoporous materials.Compared to the SA-MCM-41 material, the PA-MCM-41 mesoporous material was found to have higher antibacterial activity. Among the ingredients for Mn and Al-MCM-41, Mn-incorporated MCM-41 material has shown superior activity against the selected bacterial strains. Similar trend was observed in the antifungal activity against the selected fungal strains and therefore, it was concluded that the synthesized MCM-41 with acid fictionalization and metal incorporation mesoporous. The materials were biologically active in nature.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest

AUTHOR CONTRIBUTIONS

All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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