processes

MDPI

Article

Extraction of Carbon Nanodots from Benzoin Resin Soot for Multifaceted Antibacterial Applications

Pranesh Thangavel [1,†], Nazim Hasan [2,3,†], Gnanadeepam Raja [4], Ahmed Hussain Jawhari [2] and Judy Gopal [4,*]

[1] Saveetha Medical College, Saveetha Institute of Medical and Technical Sciences (SIMATS), Thandalam, Chennai 602105, Tamil Nadu, India; pranesht0805@gmail.com
[2] Department of Physical Sciences, Chemistry Division, College of Science, Jazan University, P.O. Box 114, Jazan 45142, Saudi Arabia; hhasan@jazanu.edu.sa (N.H.); ahjawhari@jazanu.edu.sa (A.H.J.)
[3] Nanotechnology Research Unit, College of Science, Jazan University, P.O. Box. 114, Jazan 45142, Saudi Arabia
[4] Department of Research and Innovation, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences (SIMATS), Thandalam, Chennai 602105, Tamil Nadu, India; gnanadeepamofficial@gmail.com
* Correspondence: jejudy777@gmail.com
† These authors contributed equally to this work.

Abstract: Antimicrobial compounds have been gaining paramount importance in recent years since there has been a lot of concern over the increasing threats from microbial infections. Medicinal smoke has always been received with warmth and positivity, and being an age-old traditional process, it has been practiced down the generations. Nanomaterials have become highly promising when it comes to antimicrobial applications, and carbon nanomaterials have also gained preeminence. In the following study, carbon nanodots were extracted and characterized from benzoin resin smoke and tested for their antibacterial, anti-oral bacterial, and anti-biofilm properties. 2–15 nm-sized carbon nanodots were isolated, and their antibacterial activity was validated. Carbon coatings were made on glass using the benzoin resin-extracted carbon nanodots using a simple dip–dry technique. These coatings were confirmed to possess antibiofilm activity against pathogenic *Staphylococcus aureus* biofilms. With rising concerns over chemically synthesized nanomaterials, green extraction of carbon nanodots from benzoin smoke will come in handy for multiple biomedical applications.

Keywords: benzoin smoke; carbon nanodots; coliforms; antibiofilm; oral bacteria

check for updates

Academic Editors: Nicola Gargiulo, Mike Barbeck, Stevo Najman and Sanja Stojanović

Received: 27 September 2024
Revised: 22 November 2024
Accepted: 27 January 2025
Published: 10 February 2025

Citation: Thangavel, P.; Hasan, N.; Raja, G.; Jawhari, A.H.; Gopal, J. Extraction of Carbon Nanodots from Benzoin Resin Soot for Multifaceted Antibacterial Applications. *Processes* **2025**, *13*, 484. https://doi.org/10.3390/pr13020484

Correction Statement: This article has been republished with a minor change. The change does not affect the scientific content of the article and further details are available within the backmatter of the website version of this article.

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

With benefits like chemical inertness, low toxicity, functionalization, and resistance to photobleaching, carbon nanodots (CNDs) have been put to extensive use in diverse fields, such as tissue engineering, gene therapy, wound healing, cancer treatment, bioimaging, biosensors, and photothermal cancer therapy. The family Styracaceae is where the tree *Styrax benzoin*, which is the source of benzoin resin, belongs to. There are more than 150 species under the genus *Styrax*. The fragrant resin that this tree produces is burned as incense in various ceremonies, especially in Asian rites. When physically damaged, the resins are expelled from the trunks and barks of *Styrax* spp. [1,2]. These resins start off yellowish but eventually turn reddish-brown as they thicken and solidify.

Although benzoin resin's historical use in fragrance and incense manufacturing is well known, it has also obtained its own reputation from the medicinal context. The substance is versatile, as seen by its usage in over-the-counter medications as a mild yet effective antiseptic. Cuts, wounds, sores, and abrasions on the skin may all be effectively cleaned

with it, whether it is prepared as an alcoholic solution or as a benzoin tincture. Because of its bactericidal, germicidal, antiviral, and fungicidal qualities, benzoin resin smoke, also known as "Sambrani", has been popularly used for a very long time. Being a natural product, benzoin resin has been intuitively acknowledged and accepted in various cultural and medical traditions for decades.

Currently, antimicrobial resistance (AMR) threatens successful treatment of infectious diseases across the globe [3]. Uncontrolled prescription of antimicrobials, as well as their use in agriculture, results in the spread of AMR. Scientific and economic challenges have brought about a steady decline in the pipeline of new drugs [4,5]. For counteracting the lack of new antibacterials and combating the phenomenon of antibiotic resistance, plants apparently seem to offer a potentially better solution. Plants are equipped with secondary metabolites in order to cater to their defense against pests and pathogens. Throughout history, people have looked up to plants as a source of medicine; in many geographical locations of the developing world, people continue to rely on plants as the primary form of medicine, with several countries integrating traditional plant-based medicines through regulations into mainstream healthcare systems [6–8]. The burning of plant/plant parts to release their volatile components for harnessing their medicinal attributes results in medicinal smoke, which has been gaining paramount interest [9]. The antimicrobial effect of this medicinal smoke has been demonstrated [10].

Apart from the pathogenic aspects of microbes, microbes are also involved in various dental problems; common oral bacterial strains, including *Porphyromonas gingivalis* and *Streptococcus mutans* [11,12], have proven to be problematic. Biofilms, where colonies of microbes become embedded in an extracellular polymeric matrix on various surfaces, are a grave problem when it comes to dental caries, medical implants, and industrial equipment (biofouling). Coliforms, such as *Escherichia coli* (*E. coli*), are well-known for causing food- and waterborne illnesses, necessitating the employment of efficient countermeasures [13,14].

CDs are nanoparticles smaller than ≈10 nm, typically composed of carbon, oxygen, nitrogen, and hydrogen. Their most important hallmark is bright fluorescence, tunable across the visible range, which has revolutionized the traditional paradigm of carbon as a black material unable to emit light [15]. Their luminescence is accompanied by many additional benefits, such as low cost, ease of synthesis, high water solubility, biocompatibility, non-toxicity, high sensitivity to the external environment, and marked electron-donating and -accepting capabilities. From a structural viewpoint, CDs are a relatively wide family of nanomaterials with a range of possible structures and variable optical properties. Their morphology is mostly quasi-spherical, and the structure can be graphitic [16], amorphous [17], or characterized by a C3 N4 crystalline core [18–20]. Ray et al. have reported the successful extraction of CNDs from smoke and have characterized the nanomaterial [21].

The objective of the present work was to isolate CNDs from benzoin resin smoke and characterize the extracted nanomaterial. The antibacterial credentials of the extracted CNDs was proven against coliforms and oral bacteria. The benzoin resin-extracted CNDs were then used to make coatings on glass, and the antibiofilm activity of these coatings was demonstrated. This study is the first investigation in this direction.

2. Materials and Methods

2.1. Collection of Turmeric Soot

Benzoin resin was sourced from a nearby provision store and ignited, with the resulting smoke collected in a glass beaker. This process was repeated multiple times to gather highly concentrated soot. The accumulated benzoin resin soot (BRS) was then transferred from the beaker by subjecting it to ultrasonication for 10 min in 50 milliliters of sterile water. The

suspended carbon from the BRS was subsequently extracted by centrifuging the mixture at 10,000 rpm for 10 min [8,22]. The supernatant, containing the benzoin resin-derived carbon nanodots (BRS-CNDs), was collected and stored for further experimentation.

2.2. Characterization of the BRS-CNDs

The morphology and size distribution of the BRS-CNDs were examined using a scanning electron microscope (JSM –IT800 NANO SEM). The particle size distribution of the various NPs was obtained using OPTIMAS 6.1 software based on the SEM images. A UV-visible spectrophotometer (Thermo Fisher Scientific, Waltham, MA, USA, NanoDrop Lite Plus UV) was employed to assess the optical properties and absorbance of the BRS-CNDs. Fourier-transform infrared spectroscopy (FTIR) (Bruker, Billerica, MA, USA, Compact FT-IR Spectrometer ALPHA II) was utilized to identify the functional groups and chemical composition of the BRS-CNDs.

2.3. Anti-Coliform Assay

The effectiveness of BRS-CNDs against coliform bacteria, specifically *E. coli* and *Enterococcus faecalis*, was evaluated. Various concentrations of BRS-CNDs were administered to cultures of *E. coli* and *E. faecalis*, which were then incubated overnight at 37 °C. The total viable count (TVC) of the coliform bacteria after exposure to BRS-CNDs was determined using the plate count method on nutrient agar, and results were expressed as colony-forming units per milliliter (cfu/mL) [23]. The reported data represent the average value plus or minus the standard deviation, based on three independent experiments. Statistical analysis was performed using IBM SPSS for Windows version 12.0 (SPSS Inc., Chicago, IL, USA). A one-way analysis of variance (ANOVA) with Duncan's multiple-range test was used to determine the statistical significance of multiple comparisons. p-values of less than 0.05, 0.01, and 0.001 were considered statistically significant. The three cultures used for the antimicrobial and antibiofilm testing, namely Escherichia coli (ATCC 8739-0483-CRM), Enterococcus faecalis (ATCC 29212-0366-CRM), and Staphylococcus aureus (ATCC 6538-0485-CRM), were procured from microbial culture collections at HiMedia Laboratories Private Ltd., Maharashtra, India.

2.4. Anti-Oral Bacterial Assay

The effectiveness of the extracted BRS-CNDs against oral bacteria was evaluated. Oral samples were collected from a human volunteer (one of the authors). Samples were collected using a sterile brush and suspended in 20 mL phosphate buffer and stored in the refrigerator in 50 mL falcon tubes. Samples were collected on three consecutive mornings and labeled OS1, OS2, and OS3.

An antibacterial assay was conducted by adding various concentrations of carbon nanomaterial (100 uL, 500 uL, and 1000 uL) to 10 mL aliquots of OS1, OS2, and OS3. Following carbon nanomaterial interaction overnight in a shaker cum incubator, the surviving bacteria were enumerated using the TVC method by plating on Mitis Salivarius Agar Base (HiMedia M259). After 48 h the colonies were counted, and the total viable bacteria were calculated using standard microbiological formulae.

2.5. Anti-Biofilm Assay

Nanocoatings of carbon were created on glass surfaces by submerging them in a BRS-CND solution for 24 h. After removal, the glass slides were dried in a hot air oven overnight. To grow biofilm, the carbon-coated slides were immersed in nutrient broth cultures of *Staphylococcus aureus* and incubated for 24 h. The slides were then gently rinsed in sterile water to eliminate loosely attached biofilm components. A 0.1% acridine orange fluorescent dye was applied to the biofilm, incubated for 2 min, washed off, and

air-dried. The biofilm on both coated and uncoated glass surfaces was observed using an Olympus CKX53 fluorescence microscope, with the orange fluorescing cells indicating actively metabolizing cells [23]. The fluorescence emitted by the cells was quantified using ImageJ software (Version 1.45k). Five areas on each surface were imaged, and the average values from three samples are reported here. Figure 1 gives the overall scheme behind the workflow of this study.

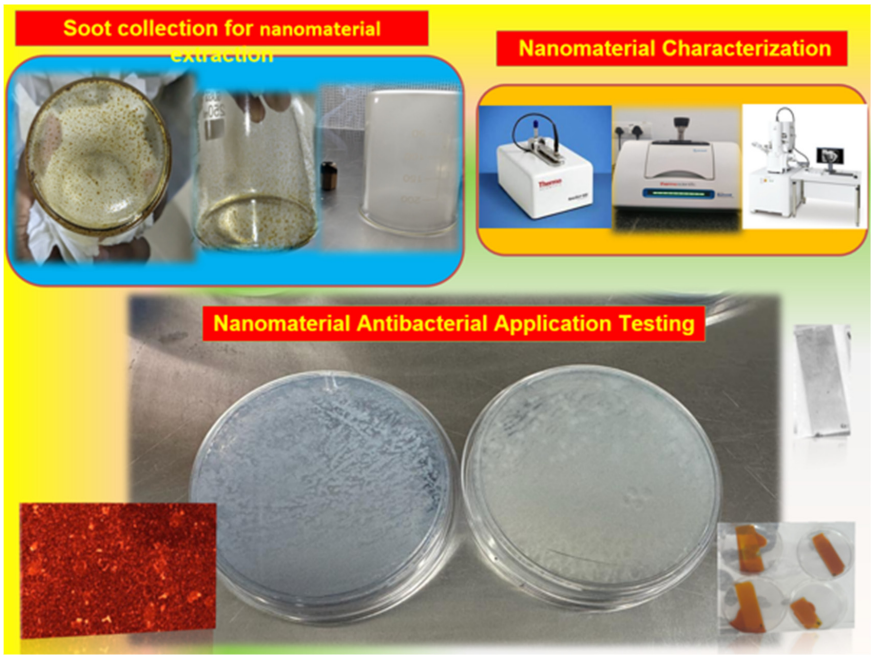


Figure 1. Scheme showing workflow involved in the study.

3. Results

Characterization of Turmeric BRS-CNDs

The morphology and size of the BRS-CNDs were confirmed using NanoSEM. Figures 2 and 3 display the SEM micrographs and size distribution histogram of the BRS-CNDs, respectively. It was confirmed that their size regimes were in the range of 2–15 nm. Earlier reports [24,25], also document the successful extraction of small-sized CNDs from smoke/soot as well.

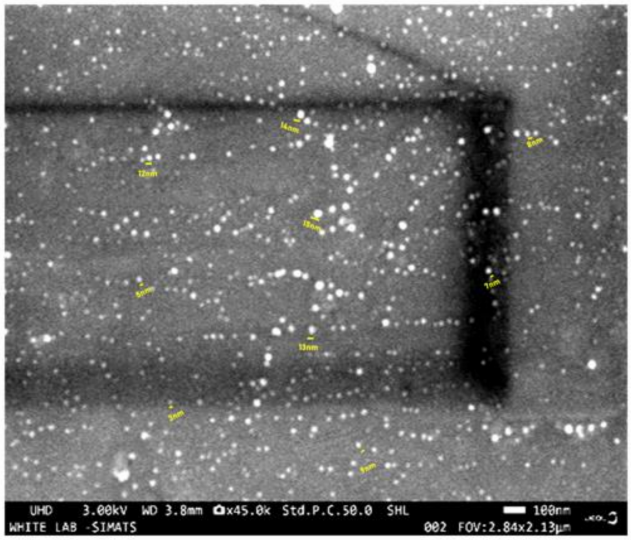


Figure 2. NanoSEM micrographs of the BRS-CNDs in the size regime of 2–15 nm.

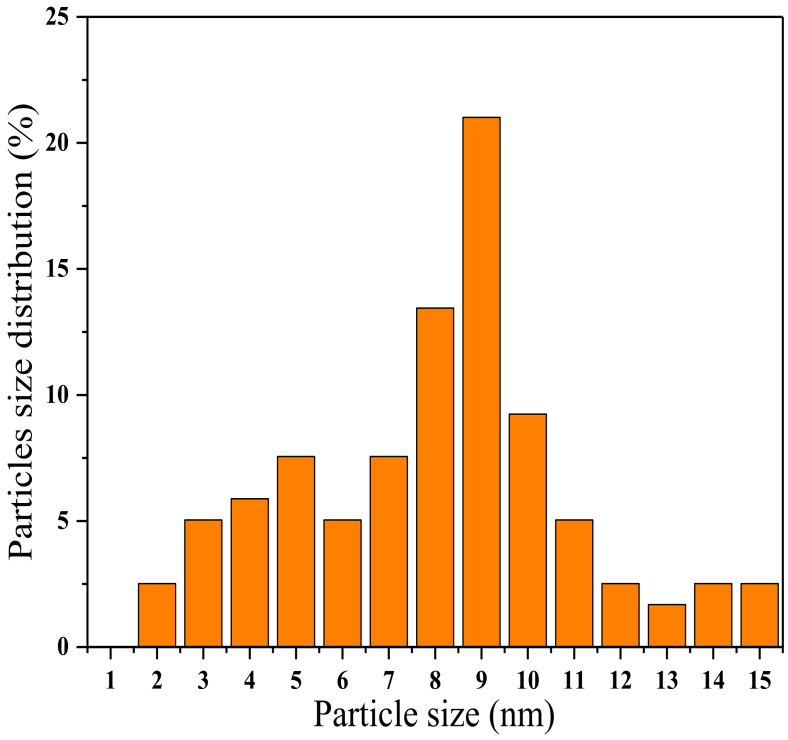


Figure 3. Size distribution histogram of BRS-CNDs.

The chemical characterization of the extracted nanocarbon to ascertain the chemical nature of the nanodots was carried out using FTIR and UV-Vis spectrophotometry (Figure 4A). The FT-IR spectrum of BRS-CNDs shows two significant peaks merged with small weak vibrations located in the 3400–2800 cm^{-1} region. The broad and merging peaks at around ~3497 and ~3295 cm^{-1} correlate with the −NH and −OH stretching vibrations, respectively. The peaks at around ~2920 and 2869 cm^{-1} belong to (−C−H) stretching vibrations. A weak peak at ~3080 cm^{-1} is characteristic of (=C−H) stretching vibration. A sharp peak at around ~1644 cm^{-1} is used to recognize the presence of (C=O/C=N) stretching vibrations of the nitrogenous amide group; the peak at 1532 cm^{-1} represents (O=C−NH/C=C) stretching vibrations. The smaller peaks at ~1454 and ~1350 cm^{-1} help to correspond to the (−C−N) stretching vibration and −C−NH stretching vibration, respectively [26]. These are characteristic of carbon nanomaterials. The UV-Vis spectroscopic results showing absorption peaks from 206 nm to 280 nm confirm the presence of carbon nanoparticles as well (Figure 4B).

The results of the antimicrobial tests confirmed the anti-coliform activity of the BRS-CNDs. Figure 5 displays the results of the plate count method, where a statistically extremely significant inhibition of the coliform bacteria *E. faecalis* was observed, while *E. coli* inhibition rates were relatively lesser than that of *E. faecalis* but still were statistically significant.

The results of the anti-oral bacterial tests proved the antibacterial activity of BRS-CNDs. As observed from Figure 6A,B, significant inhibition of oral bacteria was evidenced, confirming the anti-oral bacterial activity of CNDs.

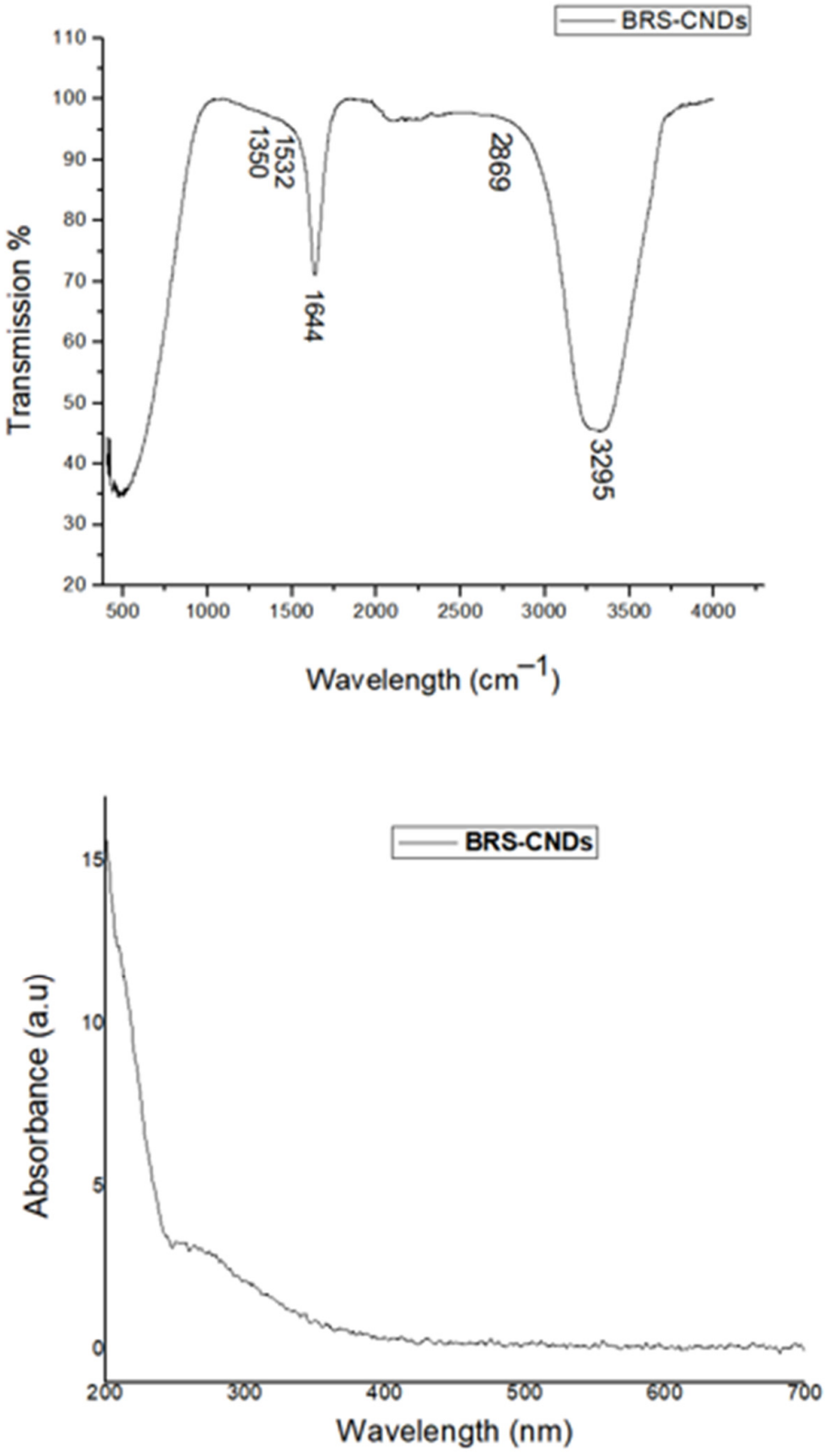


Figure 4. Results of the chemical characterization of BRS-CNDs. (**A**) FTIR spectraand (**B**) UV-Vis spectra of the BRS-CNDs.

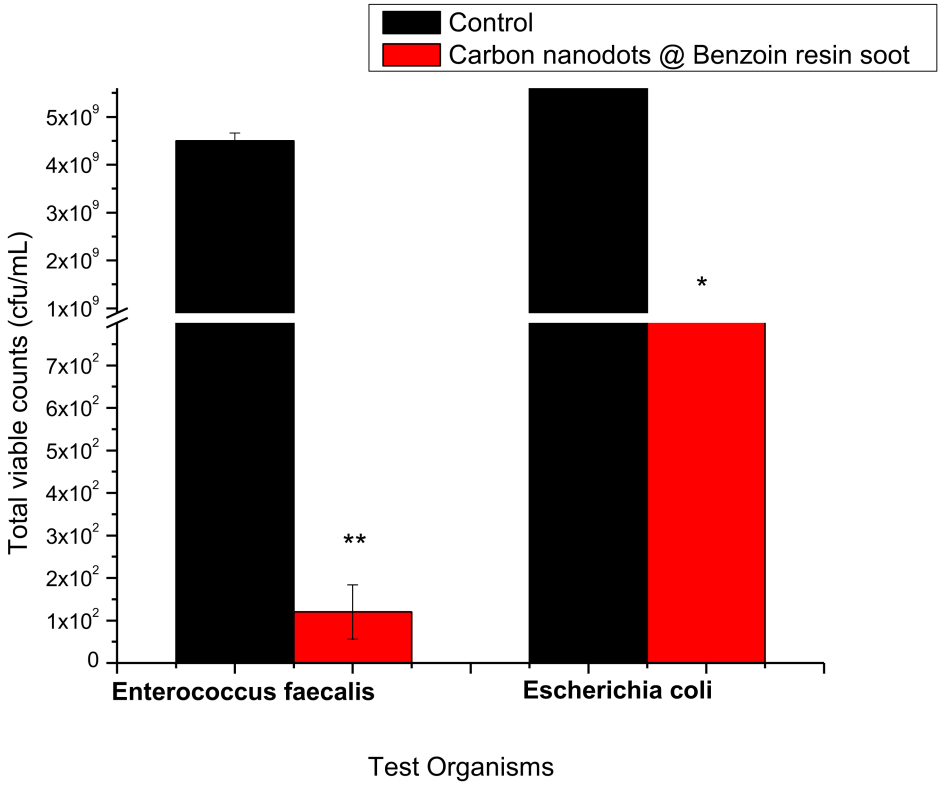


Figure 5. Graph showing results of anti-coliform activity of BRS-CNDs. The inset shows the distinct inhibition of viable colonies on agar plates owing to the carbon nanodot interaction. * significant; ** highly significant based on statistical analysis using paired *t*-tests. Error bars = SD of mean.

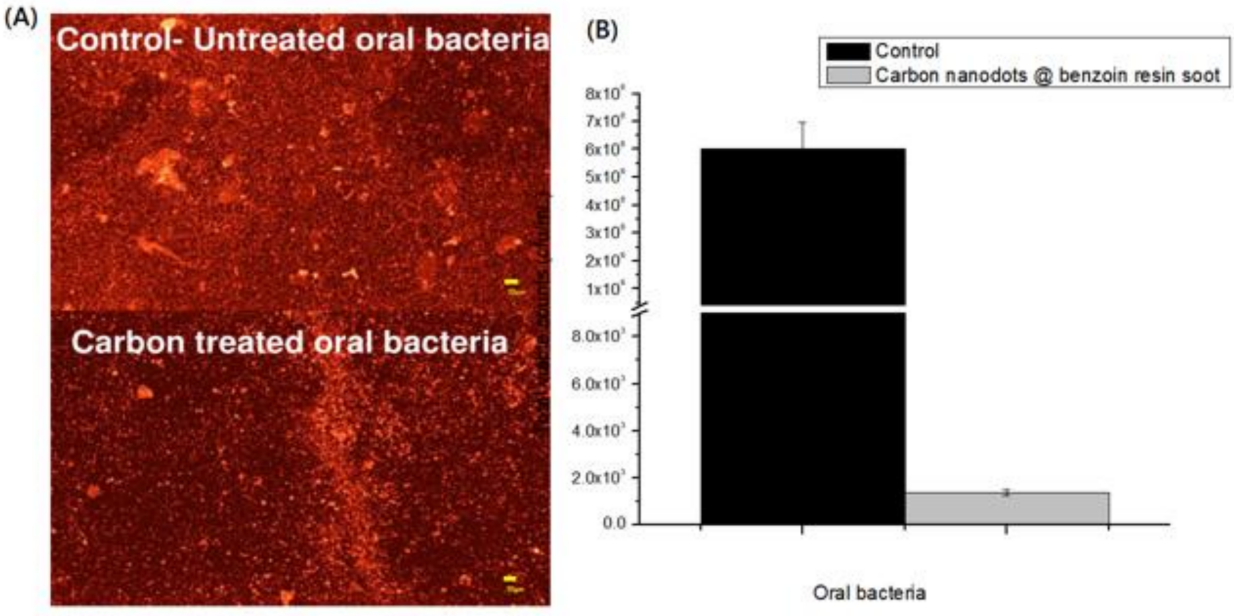


Figure 6. Results of (**A**) TVC counts showing inhibition of oral bacteria following incubation with BRS-CNDs and (**B**) Epifluorescence images showing fluorescing live oral bacteria post-interaction with turmeric smoke-derived BRS-CNDs. Error bars = SD of mean.

The coatings made from dip-coating BRS-CNDs on glass slides were exposed to Staphylococcus aureus cultures, and the anti-biofilm ability of the coatings was evaluated. Figure 7A shows the carbon coating on the glass slide. The control surface is the uncoated glass surface. As observed from Figure 7B, the epifluorescence imaging of the bacterial

culture-exposed surfaces confirmed the antibiofilm ability of the BRS-CNDs coatings. The biofilm was quantified using ImageJ analysis, and these results also confirmed significant inhibition of biofilm formation on the BRS-CNDs-coated surfaces compared to the control (Figure 7C).

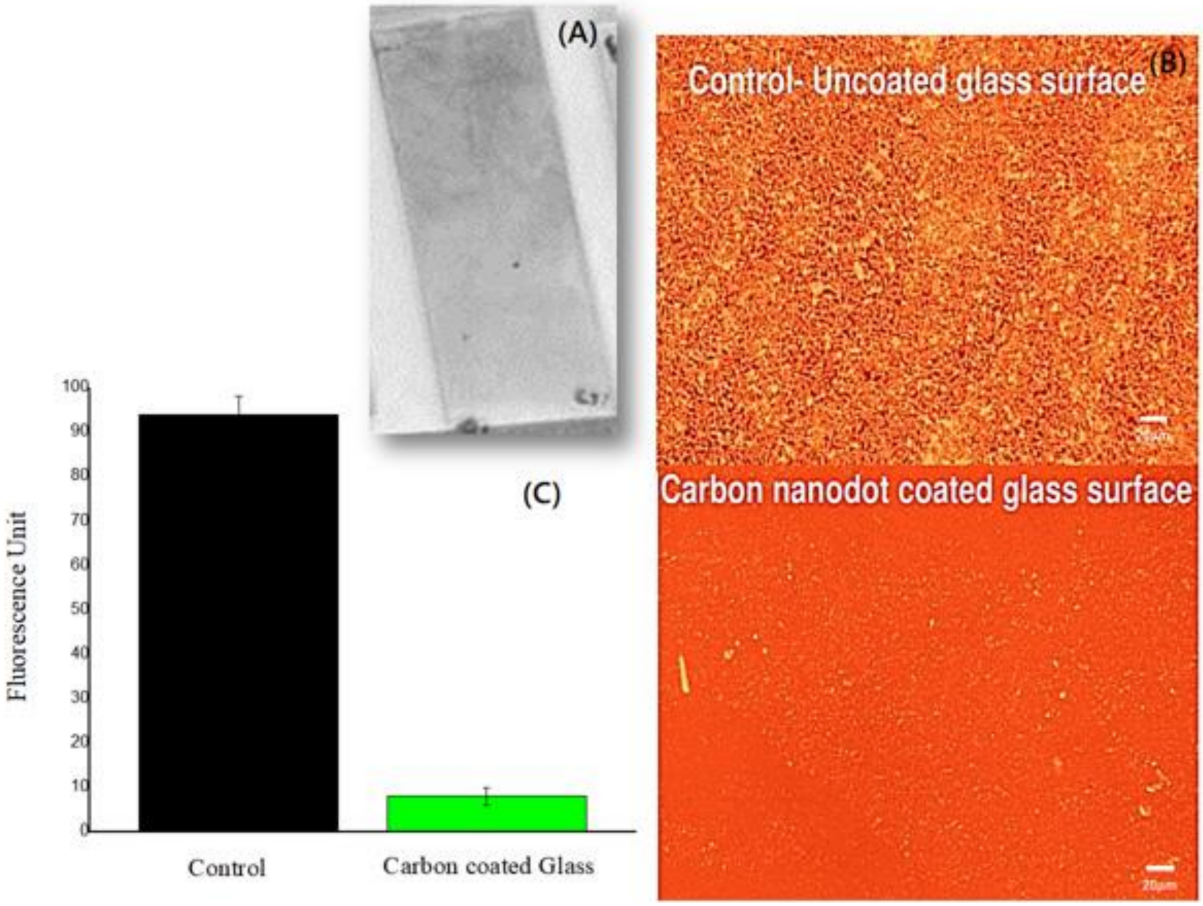


Figure 7. (**A**) Photograph showing carbon coating on glass. Epifluorescence images of biofilm on (**B**) carbon-coated and control glass surfaces and (**C**) a graph showing the results of image analysis to quantify fluorescing cells on control and coated glass surfaces. Error bars = SD of mean.

4. Discussion

The results of the investigation showed how effective the BRS-CNDs were against coliform bacteria, especially against *E. faecalis*. The results further demonstrated the successful inhibition of oral bacteria by BRS-CNDs. Strong antibiofilm activity was also shown by the carbon coatings that were made from the BRS-CNDs. These findings support the anti-bactericidal properties of the benzoin resin smoke extracted carbon nanodots. These findings suggest that carbon nanoparticles derived from benzoin smoke may find application as potent antimicrobials. The antibacterial properties of medicinal smoke have been documented by earlier writers [9,10,25]. Airborne microbes were reported to be significantly decreased on exposure to medicinal smoke. Chun et al. [26] have documented the antimicrobial properties of CNDs extracted from turmeric smoke [26]. To pinpoint the exact mechanisms by which these CNDs function as antibacterial agents, more investigation is required. Nonetheless, it is reported that the mechanism of antibacterial activity of CNDs is usually via the rupturing of bacterial cell membranes, with eventual interaction with the cellular organelles and metabolic activity through reactive oxygen species (ROS) production. Figure 8 gives the speculated scheme showing the plausible mechanism behind the antibacterial activity of BRS-CNDs based on published reports [26].



Figure 8. Schematic representation of the plausible mechanism behind the antibacterial activity of CNDs that leads to the inactivation of microbes.

BRS-CNDs probably have antibacterial qualities because they are functionalized with the volatile bioactive components of benzoin resin. The functionalization of bioactive chemicals derived from turmeric on carbon nanodots was verified by our previous investigation [26]. Vanillin, cinnamic acid, benzaldehyde, benzoic acid, and benzyl benzoate

are the main ingredients of *Styrax benzoin* [27]. The chemicals found in *styrax benzoin*, such as benzyl benzoate, benzaldehyde, and benzoic acid, have fungicidal, bactericidal, and germicidal properties [28]. The antibacterial activity of carbon nanomaterials is well documented by diverse authors as well [29–31]; what is lacking is mechanistic studies as well as in vivo studies with life cycle assessments of these nanomaterials.

Our group has previously isolated carbon nanodots from turmeric smoke to create coatings on glass [24]. The smoke-extracted carbon nanodots provide antibiofilm coatings that are economic, cost-effective, and obtained via a simple and straightforward energy-efficient technique. This is the first investigation in this direction; more research in this area may produce authoritative answers that meet the sustainability mandate.

5. Conclusions

The results indicated that the nanomaterials extracted from the burning of benzoin resin were confirmed to be BRS-CNDs. The BRS-CNDs were tested against pathogenic coliforms, *E. faecalis* and *E. coli*. The antibacterial effect was greater on *E. faecalis*. The BRS-CNDs were also active against oral bacteria and Staphylococcus biofilms. These nanomaterials will prove to be useful for biomedical applications such as antimicrobials as well as for the surface sterilization of biomedical equipment. The results are promising; more intensive investigations and in vivo testing will aid in the maximum utilization of these naturally acquired nanomaterials.

Author Contributions: P.T.—data curation, writing—original draft; N.H.—writing—review, funding acquisition, revision and editing; G.R.—writing—original draft, visualization, analysis, review, revision and editing; A.H.J.—writing—review, funding acquisition, revision and editing; J.G.—conceptualization, data curation, formal analysis, supervision, resources, validation, writing—original draft writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Informed Consent Statement: Not applicable.

Institutional Reviewer Board Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Li, Q.L.; Li, B.G.; Qi, H.Y.; Gao, X.P.; Zhang, G.L. Four New Benzofurans from Seeds of Styrax Perkinsiae. *Planta Med.* **2005**, *71*, 847–851. [CrossRef]
2. Coppen, J.J. Benzoin: Production, uses and international trade. *Perfum. Flavorist* **1999**, *24*, 11–24.
3. McEwen, S.A.; Collignon, P.J. Antimicrobial Resistance: A One Health Perspective. In *Antimicrobial Resistance in Bacteria from Livestock and Companion Animals*; American Society for Microbiology: Washington, DC, USA, 2018; pp. 521–547.
4. World Health Organization. *Antibacterial Agents in Clinical Development: An Analysis of the Antibacterial Clinical Development Pipeline, Including Tuberculosis*; No. WHO/EMP/IAU/2017.11; World Health Organization: Geneva, Switzerland, 2017.
5. World Health Organization. *Antibacterial Agents in Preclinical Development: An Open Access Database*; No. WHO/EMP/IAU/2019.12; World Health Organization: Geneva, Switzerland, 2019.
6. Thorn, J.P.R. *Royal Botanic Gardens Kew: State of the World's Plants*; Royal Botanic Gardens Kew: Richmond, UK, 2016.
7. Vandebroek, I. Intercultural Health and Ethnobotany: How to Improve Healthcare for Underserved and Minority Communities? *J. Ethnopharmacol.* **2013**, *148*, 746–754. [CrossRef] [PubMed]
8. Chassagne, F.; Samarakoon, T.; Porras, G.; Lyles, J.T.; Dettweiler, M.; Marquez, L.; Salam, A.M.; Shabih, S.; Farrokhi, D.R.; Quave, C.L. A Systematic Review of Plants with Antibacterial Activities: A Taxonomic and Phylogenetic Perspective. *Front. Pharmacol.* **2021**, *11*, 586548. [CrossRef]

9. Mohagheghzadeh, A.; Faridi, P.; Shams Ardakani, M.; Ghasemi, Y. Medicinal Smokes. *J. Ethnopharmacol.* **2006**, *108*, 161–184. [CrossRef] [PubMed]
10. Nautiyal, C.S.; Chauhan, P.S.; Nene, Y.L. Medicinal Smoke Reduces Airborne Bacteria. *J. Ethnopharmacol.* **2007**, *114*, 446–451. [CrossRef] [PubMed]
11. Klimek, H.I.; Moczulska, H.; Sieroszewski, P. Streptococcus Mutans in the Oral Cavity as a Risk Factor for Threatened Miscarriage. *Ginekol. Pol.* **2024**, *95*, 123–125. [CrossRef] [PubMed]
12. Lin, H.; Zhou, R.; Zhang, M.; Huang, R.; Fan, C.; Zhou, S.; Qiu, J.; He, J. In Vitro Antibacterial Activity of a Novel Acid-Activated Antimicrobial Peptide against Streptococcus Mutans. *Curr. Protein Pept. Sci.* **2023**, *25*, 83–93. [CrossRef]
13. Kang, Z.; Yang, B.; Prato, M. Carbon Nanodots: Nanolights Illuminating a Bright Future. *Small* **2023**, *19*, e2304703. [CrossRef]
14. Da Ros, T.; Martín, N.; Nierengarten, J.F. (Eds.) *Carbon Nanostructures for Biomedical Applications*; Royal Society of Chemistry: Cambridge, UK, 2021.
15. Sciortino, A.; Cannizzo, A.; Messina, F. Carbon Nanodots: A Review—From the Current Understanding of the Fundamental Photophysics to the Full Control of the Optical Response. *C J. Carbon Res.* **2018**, *4*, 67. [CrossRef]
16. Sun, Y.P.; Zhou, B.; Lin, Y.; Wang, W.; Fernando, K.A.S.; Pathak, P.; Meziani, M.J.; Harruff, B.A.; Wang, X.; Wang, H.; et al. Quantum-Sized Carbon Dots for Bright and Colorful Photoluminescence. *J. Am. Chem. Soc.* **2006**, *128*, 7756–7757. [CrossRef]
17. Cayuela, A.; Soriano, M.L.; Valcárcel, M. Photoluminescent Carbon Dot Sensor for Carboxylated Multiwalled Carbon Nanotube Detection in River Water. *Sens. Actuators B Chem.* **2014**, *207*, 596–601. [CrossRef]
18. Zhou, J.; Yang, Y.; Zhang, C. A Low-Temperature Solid-Phase Method to Synthesize Highly Fluorescent Carbon Nitride Dots with Tunable Emission. *Chem. Commun.* **2013**, *49*, 8605–8607. [CrossRef] [PubMed]
19. Rong, M.; Song, X.; Zhao, T.; Yao, Q.; Wang, Y.; Chen, X. Synthesis of Highly Fluorescent P,O-g-C3N4 Nanodots for the Label-Free Detection of Cu^{2+} and Acetylcholinesterase Activity. *J. Mater. Chem. C* **2015**, *3*, 10916–10924. [CrossRef]
20. Sciortino, A.; Mauro, N.; Buscarino, G.; Sciortino, L.; Popescu, R.; Schneider, R.; Giammona, G.; Gerthsen, D.; Cannas, M.; Messina, F. β-C3N4 Nanocrystals: Carbon Dots with Extraordinary Morphological, Structural, and Optical Homogeneity. *Chem. Mater.* **2018**, *30*, 1695–1700. [CrossRef]
21. Ray, S.C.; Saha, A.; Jana, N.R.; Sarkar, R. Fluorescent Carbon Nanoparticles: Synthesis, Characterization, and Bioimaging Application. *J. Phys. Chem. C* **2009**, *113*, 18546–18551. [CrossRef]
22. Guo, Y.; Zhang, L.; Cao, F.; Leng, Y. Thermal Treatment of Hair for the Synthesis of Sustainable Carbon Quantum Dots and the Applications for Sensing Hg^{2+}. *Sci. Rep.* **2016**, *6*, 35795. [CrossRef]
23. Gopal, J.; George, R.; Muraleedharan, P.; Khatak, H. Photocatalytic Inhibition of Microbial Adhesion by Anodized Titanium. *Biofouling* **2004**, *20*, 167–175. [CrossRef]
24. Gopal, J.; Muthu, M.; Chun, S. Autochthonous Self-Assembly of Nature's Nanomaterials: Green, Parsimonious and Antibacterial Carbon Nanofilms on Glass. *Phys. Chem. Chem. Phys.* **2016**, *18*, 18670–18677. [CrossRef]
25. Bipin, R.; Ujjwal, M. A review on characterization of carbon quantum dots. *Vietnam. J. Chem.* **2023**, *61*, 693–718.
26. Chun, S.; Muthu, M.; Gansukh, E.; Thalappil, P.; Gopal, J. The Ethanopharmacological Aspect of Carbon Nanodots in Turmeric Smoke. *Sci. Rep.* **2016**, *6*, 35586. [CrossRef] [PubMed]
27. Pastorova, C.; De Koster, J.B. Analytical study of free and ester bound benzoic and cinnamic acids of gum benzoin resins by GC–MS and HPLC–frit FAB–MS. *Phytochem. Anal.* **1997**, *8*, 63–73. [CrossRef]
28. Atia Sharif, H.N.; Rehman, R.; Mushtaq, A.; Rashid, U.A. Review on bioactive potential of Benzoin Resin. *Int. J. Chem. Biochem. Sci.* **2016**, *10*, 106–110.
29. Selvaraju, N.; Ganesh, P.S.; Palrasu, V.; Venugopal, G.; Mariappan, V. Evaluation of Antimicrobial and Antibiofilm Activity of Citrus medica Fruit Juice Based Carbon Dots against Pseudomonas aeruginosa. *ACS Omega* **2022**, *7*, 36227–36234. [CrossRef]
30. Ramasundaram, S.; Manikandan, V.; Vijayalakshmi, P.; Devanesan, S.; Salah, M.B.; Ramesh Babu, A.C.; Priyadharsan, A.; Oh, T.H.; Ragupathy, S. Synthesis and investigation on synergetic effect of activated carbon loaded silver nanoparticles with enhanced photocatalytic and antibacterial activities. *Environ. Res.* **2023**, *233*, 116431. [CrossRef] [PubMed]
31. Saravanan, A.; Maruthapandi, M.; Das, P.; Ganguly, S.; Margel, S.; Luong, J.H.; Gedanken, A. Applications of N-doped carbon dots as antimicrobial agents, antibiotic carriers, and selective fluorescent probes for nitro explosives. *ACS Appl. Bio Mater.* **2020**, *3*, 8023–8031. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.