Bio-fabrication of Bio-inspired Silica Nanomaterials from *Bryophyllum pinnatum* Leaf for Agricultural Applications

M. Sankareswaran1 · Rajiv Periakaruppan2 · M. Sasivarnam2 · Jeyapragash Danaraj3 · Sugapriya Dhanasekaran4 · Mosleh Mohammad Abomughaid4

Accepted: 27 May 2022 / Published online: 6 June 2022
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2022

Abstract

A green chemistry approach was employed to synthesize silica nanoparticles (SiNPs) using aqueous extract of *Bryophyllum pinnatum* leaf as capping agents. The novelty of this study was to produce silica nanoparticles using the biological method. An analysis of the physicochemical properties of formed nanoparticles was successfully completed through sophisticated characterization methods, such as UV–Visible absorbance spectroscopy, Fourier transform infra-red spectroscopy, X-ray diffraction, scanning electron microscope, energy dispersive X-ray, zeta potential analysis, and thermo-gravimetric analysis. All the characterization results indicated their spherical morphology and amorphous nature with an average size of 24 nm. FT-IR results highlighted the key bioactive compounds that could be responsible for capping and reducing the formation of SiNPs. Synthesized SiNPs show excellent stability with a negative zeta potential value of −32 mV. The biomolecules from *B. pinnatum* were successfully working for the formation of SiNPs with spherical shapes. Moreover, to assess the agricultural application, green-synthesized SiNPs were carried out by seed germination assay on *Vigna radiata*. The seed germination assay confirms that a low concentration of SiNPs enhances seed germination. Meanwhile, a higher concentration of the SiNPs inhibits seed germination and shoot, and root formation. SiNPs at optimum concentration could be used in the agriculture field as nano growth promoters.

Keywords Silica · Nanoparticles · *B. pinnatum* · Green synthesis · Seed germination

Introduction

The field of nanoscience and nanotechnology has the potential to create revolutionary methods to produce novel materials. It will have a significant impact on biological sciences and increase their values exponentially in the future [1]. These unique nanomaterials have wide-ranging physicochemical properties and are extensively used in food packaging industries, agricultural industries, biosensors, and biomedical, textile, and environmental applications [2].
Among all the available nanoparticles, inorganic mesoporous SiNPs are the newcomers to the field, contributing with their unique and excellent physical and chemical properties (small size, strong surface energy, high scattered performance, and thermal resistance) [3; 4]. SiNPs have numerous applications, including drug delivery, biosensing, catalysis, bioimaging, and energy storage [5, 6]. Silicon plays a vital role in increasing plant tolerance against pests and diseases. Mesoporous SiNPs were used as solid adsorbents for the removal of lindane pesticides from aqueous solutions [7]. The synthesis, properties, and applications of SiNPs have become a fast-expanding field of research [6]. The SiNPs have been produced from agricultural wastes [8]. The Stober process is used for the preparation of monodispersed silica colloids “white carbon black” by hydrolysis of alkyl silicates and silicic acid in alcoholic solutions using ammonia as a catalyst [9].

Synthesis of metal/metal oxides nanomaterials, hybrid materials, and bioinspired materials using plants and microbes/other natural resources has received significant attention as a reliable, sustainable, cost-effective, and eco-friendly technology—a nanoscience alternative to chemical and physical methods [10, 11]. The capping agents such as polymers, phytochemicals, surfactants, and organic ligands are basic components in the synthesis of nanomaterials with controlled size and well-defined shape [12].

*Bryophyllum pinnatum* (Fig. 1) is commonly known as *Pattharcat*ta. It belongs to the Crassulaceae family. The herb contains a wide range of valuable chemicals that could be responsible for its various pharmacological effects [13]. It is mainly used as a natural anti-inflammatory agent [14]. It is used in ethnomedicinal practices to treat kidney stones,
jaundice, skin diseases, hypertension, and urinary problems [15, 16]. The leaves of B. pinnatum possess both sedative and muscle relaxant properties [17].

This study focused on the green synthesis of SiNPs using an extract of B. pinnatum by a sustainable approach in a simple, cheap, and environment-friendly manner. In addition, the current research aimed to investigate the effect of SiNPs on seed germination of Vigna radiata and its development of root and shoot after the germination.

Materials and Methods

Analytical grade chemicals (99% of purity) and reagents were used in the experimental studies. Tetraethyl orthosilicate (TEOS), hydrochloric acid, ethanol, and double distilled water (DDW) were obtained for this investigation and purchased from Sigma Aldrich, Mumbai. All the glassware was soaked in acid and washed with distilled water.

Preparation of Plant Extract and Phytochemical Screening

Fresh and healthy leaves were collected from villages south of Coimbatore (District), Tamil Nadu, India, on January 2021. The leaves were cleaned with running tap water to remove debris. The aqueous extract was made by mixing and macerating 10 g of fresh B. pinnatum leaves with 200 ml of double-distilled water. The mixture was boiled for 20 min at 50 °C. The extract was cooled and filtered by Whatman filter paper, and the extract was stored at 4 °C for further analysis. The phytochemicals of B. pinnatum were screened by the methods of Harborne [18].

Synthesis of SiNPs

Tetraethyl orthosilicate (TEOS) is a precursor to the production of SiNPs. Twenty milliliters of plant extract was mixed with 12 mL of precursor solution and allowed continuous stirring at 50 to 65 °C for 10 min. Then, 1 M HCl was mixed with the above mixture to reduce impurities and attain highly purified silica nanomaterials. After 20 min, jelly-like precipitation was formed. Next, the precipitation was dried in a hot air oven at 150 °C. Finally, a white-colored powder was obtained, and it was stored in a sterile air-tight container for further analysis.

Characterization of Synthesized SiNPs

Various techniques were used to characterize the synthesized biogenic SiNPs. The optical property of biogenic SiNPs was determined by the UV–Visible double beam spectrophotometer. The nature of biogenic SiNPs was determined by the X-ray diffractometer. The atomic percentage of elements present in the biogenic silica nanomaterials was determined by EDX. The surface morphology of SiNPs was assessed by the SEM analysis. The functional group of SiNPs and aqueous plant extracts were identified by the FT-IR spectrometer. The charge of SiNPs was determined using a Malvern particle size analyzer. The thermal stability of synthesized SiNPs was analyzed by Mettle-Toledo TGA.
Agricultural Applications

Seed Germination Analysis

Seeds of *Vigna radiata* were used for this investigation. Four different concentrations (5, 10, 15, and 20 μg/mL) of SiNPs were prepared using distilled water. The seeds were surface-sterilized using distilled water. Meantime, sterile Petri plates were taken, and cotton was placed on them. Then, 15 different seeds were placed on plates. A 15 mL of biogenic SiNPs at various concentrations was poured on seeds in corresponding plates. Positive control (distilled water) was maintained. Next, the plates with seeds were incubated in a dark condition at 37 °C for 5 days. After incubation, the germinated seeds were counted, and the length of the root and shoot was measured. Five replications were used for this analysis.

Results and Discussion

Phytochemical Analysis

Table 1 determined the phytochemicals analysis of *B. pinnatum* (aqueous extract). Steroids, alkaloids, flavonoids, tannins, saponins, and reducing sugar were found in *B. pinnatum* leaf extract. Terpenoids and glycosides were absent in the extract. Kavit et al. [19] reported the presence of medicinally active phytoconstituents like tannins, alkaloids, terpenoids, steroids, and saponins in the leaves of *Phyllanthus fraternus*.

Characterization of SiNPs

UV–Visible absorbance spectroscopy is broadly used as a technique to determine the optical properties of nanosized particles. The result obtained from the analysis of UV–Visible spectroscopy of the sample is presented in Fig. 2. The SiNPs formation was confirmed by the peak occurrence in the range between 230 and 300 nm in UV spectra because of the surface plasmon resonance nature of silica nanoparticles in the reaction medium. The optical feature is similar to that in an earlier report [20] and indicated a Si–O–Si bond approving the existence of silica nanoparticles. Babu et al. [21] analyzed the optical properties of *Cynodon dactylon*-assisted silica nanoparticles

| Table 1 | Screening of phytochemicals in *B. pinnatum* extract |
|-------|-----------------------------------------------|
| S.No  | Qualitative test   | Color obtained          | Aqueous extract (*B. pinnatum*) |
|-------|--------------------|-------------------------|-------------------------------|
| 1     | Steroids           | Blue green              | Presence                      |
| 2     | Alkaloids          | Orange to red           | Presence                      |
| 3     | Flavonoids         | Yellow                  | Presence                      |
| 4     | Terpenoids         | Red, pink, or violet    | Absence                       |
| 5     | Tannins            | White precipitate       | Presence                      |
| 6     | Saponins           | Foam formation          | Presence                      |
| 7     | Glycosides         | Blue or green           | Absence                       |
| 8     | Reducing sugar     | Yellow to orange        | Presence                      |


using UV–Visible spectroscopy and obtained the peak at a wavelength at 350 nm in UV spectra.

The nature of biogenic SiNPs was evaluated from the X-ray diffraction pattern. The most substantial peaks at 2theta values of 22.01 correspond to the amorphous nature of SiNPs, and are shown in Fig. 3. The average size of the SiNPs was calculated by Debye–Scherrer’s formula. The size of the *B. pinnatum* leaf extract-mediated SiNPs is 24 nm. This finding is similar to the one by Patil et al. [22], and they produced amorphous silica nanoparticles from rice husk. Mohd et al. [23] carried out the XRD analysis to find out the nature and size of the sugarcane bagasse-mediated nanomaterials. The XRD was used to confirm the formation of amorphous silica nanoparticles from palm kernel shell ash by the modified sol–gel extraction method [24].

The elemental composition and purity of *B. pinnatum* leaf extract-mediated SiNPs were determined by the EDAX analysis. Figure 4 shows the EDAX spectrum for phyto-genetic mediated SiNPs. The atomic percentage of the presence of carbon was 21.68%, oxygen 50.95%, and silica 27.37% in green-synthesized SiNPs. The carbon was derived
from plant extracts. The SiNPs were synthesized by [25], who assessed the level of their composition. They reported the presence of silica and oxygen with no other impurities.

The shape or morphology of the synthesized SiNPs was determined by the SEM analysis. The microscopic images of *B. pinnatum* leaf extract-mediated SiNPs are presented in Fig. 5, and it clearly shows the distribution and spherical shape of the SiNPs. The synthesized silica nanoparticles were spherical and agglomerated because of the existence of biomolecules from *B. pinnatum* leaf extract. Similarly, Patil et al. [22] produced spherical-shaped silica nanoparticles from rice husk. [8] reported the production of biogenic SiNPs using maize stalk and determined their morphology using the SEM analysis. It is worthy to note that the outcome of SEM analysis is compared to the one by Zamani et al. [26], and spherical shaped silica nanoparticles have been produced using the extract of *Saccharomyces cerevisiae*, which is again confirmed by SEM analysis.
FT-IR spectra of plant extract and SiNPs are shown in Fig. 6a and b. The peaks such as 3348, 2970, 2885, 1921, 1658, 1442, 1087, 879, 671, and 555 cm$^{-1}$ are in Fig. 6b and correspond to the hydroxyl, amide, and carboxyl functional groups. The spectrum of SiNPs shows peaks such as 2978, 2893, 1589, 1396, 1143, 1072, 956, 678, and 555 cm$^{-1}$. Conforming to the result of FT-IR (Fig. 6a), the chemical bonding of silicon and oxygen was detected in the biogenic silica nanoparticles. The peaks of 1072, 956, 678, and 555 cm$^{-1}$ refer to the Si–O–Si bonds. The intense peaks of 2978, 2893, 1589, 1396, and 1143 cm$^{-1}$ were corresponding to C–H stretching, hydroxyl, amide, and carboxyl functional groups, which were derived from B. pinnatum leaf extract. FT-IR study determined the functional groups of capping, reducing, and stabilizing agents from B. pinnatum leaf extract to form the nanomaterials. Anuar et al. [27] found that the functional groups or chemical groups, namely Si–O–Si, CH$_2$, -OH, and Si–OH, form the FT-IR spectrum of coconut husk ash-mediated silica nanomaterials.

Zeta potential analysis is a traditional method to determine the stability of the nanomaterials. The SiNPs from B. pinnatum show negative charges and the zeta potential value of $-32.4$ mV (Fig. 7). The high value of zeta potential refers to the stability of the suspension due to the increased force of electrostatic repulsion between the particles. The low zeta potential value indicates the aggregation of the nanomaterials [28]. The SiNPs with antibacterial properties were produced by Joni et al. [29], who also reported the zeta potential value of $-24.69$ mV for the SiNPs.

![FT-IR spectrum of a) Silica nanoparticles and b) plant extract](image-url)
The thermal stability of synthesized SiNPs was performed to determine the weight loss of green synthesize SiNPs at different temperatures (the ranging between 30 and 1000 °C (Fig. 8a and b). It was observed that the mass of the SiNPs decreased in two stages at different temperatures ranging between 30 and 800 °C. In the first stage, 53.8% of mass loss was acquired up to 250 °C due to the decomposition of phytomolecules on the surface of silica nanoparticles. In the second stage, about 7.6% of mass loss was obtained at temperatures ranging between 300 and 800 °C due to the vaporization of the remaining residue of the phytocompounds. The mass reduction of bio-synthesized silica nanomaterials was assessed by the exothermic peak in the DTA curve. Similar results were reported by Maroušek et al. [30] and Sankareswaran et al. [31].

**Agricultural Applications**

**Seed Germination Assay**

Different concentrations (5, 10, 15, and 20 μg/mL) of SiNPs were used in the present investigation. The maximum level (100%) of seed germination was achieved on 5 μg/mL SiNPs treated treatment, and meanwhile, the minimum level (40%) of seed germination was observed on 20 μg/mL of SiNPs treated treatment. An increased shoot length of 4.3 cm was observed on the treatment of 5 μg/mL SiNPs, and a decreased shoot length of 1.8 cm was achieved with a concentration of 20 μg/mL of SiNPs. The highest root length (1.0 cm) was observed on T2 treatment (5 μg/mL of SiNPs), and the lowest root length (0. 2 cm) was recorded on T4 treatment (20 μg/mL of SiNPs) (Table 2). The results have shown that SiNPs have a significant effect on seed germination, and the length of the shoot and the root. Roohizadeh et al. [32] observed that SiNPs improved seed germination on *Vicia faba*.

**Conclusion**

This investigation was focused to produce highly stable silica nanoparticles by a simple, bio-based, less toxic, and environment-friendly method. The aqueous extract of *B. pinnatum* leaf was used as a capping and reducing agent for the green synthesis of SiNPs.
The phytoconstituents, namely steroids, alkaloids, flavonoids, tannins, saponins, and glycosides, were present in the leaf extract. Bio-synthesized silica nanomaterials were characterized by various techniques. The spherical and amorphous biogenic SiNPs were characterized by various techniques. The spherical and amorphous biogenic SiNPs were analyzed using TGA/DTG/DTA analysis.

**Fig. 8**  a TGA/DTG/DTA analysis of Silica nanoparticles. b TG analysis of Silica nanoparticles

The phytoconstituents, namely steroids, alkaloids, flavonoids, tannins, saponins, and glycosides, were present in the leaf extract. Bio-synthesized silica nanomaterials were characterized by various techniques. The spherical and amorphous biogenic SiNPs were
produced with an average size of 24 nm. The green-synthesized SiNPs enhanced seed germination and shoot, and root formation at low concentrations of SiNPs. So, SiNPs could be used to improve seed germination and crop production in agriculture.

Acknowledgements The authors are thankful to the Karpagam Academy of Higher Education for providing the laboratory facilities to conduct the experiments and the authors acknowledge the DST-FIST for infrastructure facility (SR/FST/LS-1/2018/187).

Author Contribution SM: Conceptualization
PR: Supervision, funding acquisition and project administration
MS: Investigation
JD: Methodology
SD: Data curation and writing—original draft preparation
MMA: Data curation and writing—original draft preparation

Data Availability Not applicable.

Declarations

Ethics Approval Not applicable.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Informed Consent Not applicable.

Research Involving Human Participants and/or Animals Not applicable.

Conflict of Interest The authors declare no competing interests.

References

1. Hulla, J. E., Sahu, S. C., & Hayes, A. W. (2015). Nanotechnology: History and future. Human & Experimental Toxicology, 34(12), 1318–1321.
2. Nguyen, N. H., Padil, V. V. T., Slaveykova, V. I., Černík, M., & Ševců, A. (2018). Green synthesis of metal and metal oxide nanoparticles and their effect on the unicellular alga Chlamydomonas reinhardtii. Nanoscale Research Letters, 13(1), 1–13.
3. Ma, X., Lee, N. H., Oh, H. J., Hwang, J. S., & Kim, S. J. (2010). Preparation and characterization of silica/polyamide-imide nanocomposite thin films. Nanoscale Research Letters, 5(11), 1846–1851.
4. Wang, Y., Zhao, Q., Han, N., Bai, L., Li, J., Liu, J., Che, E., Hu, L., Zhang, Q., Jiang, T., & Wang, S. (2015). Mesoporous SiNPs in drug delivery and biomedical applications. *Nanomedicine: Nanotechnology, Biology and Medicine, 11*(2), 313–327.

5. Kordasht, H. K., Pazhuhi, M., Pashazadeh-Panahi, P., Hasanzadeh, M., & Shadjou, N. (2020). Multifunctional aptasensors based on mesoporous SiNPs as an efficient platform for bioanalytical applications: Recent advances. *TrAC Trends in Analytical Chemistry, 124*, 115778.

6. Nandanwar, R., Singh, P., & Haque, F. Z. (2013). Synthesis and properties of SiNPs by sol–gel method for the application in green chemistry. *Material Science Research India, 10*(1), 85–92.

7. El-Said, W. A., Fouad, D. M., Ali, M. H., & El-Gahami, M. A. (2018). Green synthesis of magnetic mesoporous silica nanocomposite and its adsorptive performance against organochlorine pesticides. *International Journal of Environmental Science and Technology, 15*(8), 1731–1744.

8. Adebisi, J. A., Agunsoye, J. O., Bello, S. A., Haris, M., Ramakokovhu, M. M., Daramola, M. O., & Hassan, S. B. (2019). Green production of SiNPs from maize stalk. *Particulate Science and Technology*.

9. Ibrahim, I. A., Zikry, A. A. F., & Sharaf, M. A. (2010). Preparation of spherical SiNPs: Stober silica. *Journal of American Science, 6*(11), 985–989.

10. Parveen, K., Banse, V., & Ledwani, L. (2016). Green synthesis of nanoparticles: Their advantages and disadvantages. In *AIP conference proceedings* (Vol. 1724, No. 1, p. 020048). AIP Publishing LLC.

11. Singh, J., Dutta, T., Kim, K. H., Rawat, M., Samddar, P., & Kumar, P. (2018). ‘Green’ synthesis of metals and their oxide nanoparticles: Applications for environmental remediation. *Journal of Nanobiotechnology, 16*(1), 1–24.

12. Campisi, S., Schiavoni, M., Chan-Thaw, C. E., & Villa, A. (2016). Untangling the role of the capping agent in nanocaltis: Recent advances and perspectives. *Catalysts, 6*(12), 185.

13. Latif, A., Ashiq, K., Qayyum, M., Ashiq, S., Ali, E., & Anwer, I. (2019). Phytochemical and pharmacological profile of the medicinal herb: Bryophyllum pinnatum. *Journal of Animal and Plant Sciences, 29*(6), 1528–1534.

14. Fernandes, J. M., Cunha, L. M., Azevedo, E. P., Lourenço, E. M., Fernandes-Pedrosa, M. F., & Zucolotto, S. M. (2019). Kalanchoe laciata and Bryophyllum pinnatum: An updated review about ethnopharmacology, phytochemistry, pharmacology and toxicology. *Revista Brasileira de Farmacognosia, 29*(4), 529–558.

15. Oufir, M., Seiler, C., Gerodetti, M., Gerber, J., Füurer, K., Mennet-von Eiff, M., Elsas, S. M., Brenneisen, R., von Mandach, U., Hamburger, M., & Potterat, O. (2015). Quantification of bufadienolides in Bryophyllum pinnatum leaves and manufactured products by UHPLC-ESIMS/MS. *Planta Medica, 81*(12/13), 1190–1197.

16. Yadav, M., Gulkari, V. D., & Wanjarri, M. M. (2016). Bryophyllum pinnatum leaf extracts prevent formation of renal calculi in lithiatic rats. *Ancient Science of Life, 36*(2), 90.

17. Von Manitius, S., Flügel, D., Steinlein, B. G., Schnelle, M., von Mandach, U., & Simões-Wüst, A. P. (2019). Bryophyllum pinnatum in the treatment of restless legs syndrome: A case series documented with polysomnography. *Clinical Case Reports, 7*(5), 1012.

18. Harborne, J. B. (1998). Textbook of Phytochemical Methods. A Guide to Modern Techniques of Plant Analysis. 5th Edition, Chapman and Hall Ltd, London, 21–72.

19. Kavir, M., Patel, B. N., & Jain, B. K. (2013). Phytochemical analysis of leaf extract of Phyllanthus fraternus. *Research Journal of Recent Sciences ISSN, 2277, 2502.*

20. Djangang, C. N., Mlowe, S., Njopwouo, D., & Neerish, R. (2015). One-step synthesis of silica nanoparticles by thermolysis of rice husk ash using nontoxic chemicals ethanol and polyethylene glycol. *TrAC Trends in Analytical Chemistry, 124*, 2298–2306.

21. Babu, R. H., Yugandhar, P., & Savithramma, N. (2018). Synthesis, characterization and antimicrobial studies of bio silica nanoparticles prepared from Cynodon dactylon L.: A green approach. *Bulletin of Materials Science, 41*(3), 1–8.

22. Patil, N. B., Sharanagouda, H., Doddagoudar, S. R., Ramachandra, C. T, & Ramappa, K. T. (2018). Biosynthesis and characterization of silica nanoparticles from rice (Oryza sativa L.) husk. *International Journal of Current Microbiology and Applied Sciences, 7*(12), 2298–2306.

23. Mohd, N. K., Wee, N. N. A. N, & Azmi, A. A. (2017) Green synthesis of SiNPs using sugarcane bagasse. In *AIP conference proceedings* (Vol. 1885, No. 1, p. 020123). AIP Publishing LLC.

24. Imoni, P. E., Ukoba, K. O., & Jen, T. C. (2020). Green technology extraction and characterization of silica nanoparticles from palm kernel shell ash via sol–gel. *Journal of Materials Research and Technology, 9*(1), 307–313.

25. Dubey, R. S., Rajesh, Y. B. R. D., & More, M. A. (2015). Synthesis and characterization of SiO2 nanoparticles via sol–gel method for industrial applications. *Materials Today: Proceedings, 2*(4–5), 3575–3579.
26. Zamani, H., Jafari, A., Mousavi, S. M., & Darezereshki, E. (2020). Biosynthesis of silica nanoparticle using *Saccharomyces cerevisiae* and its application on enhanced oil recovery. *Journal of Petroleum Science and Engineering*, 190, 107002.

27. Anuar, M. F., Fen, Y. W., Zaid, M. H. M., Matori, K. A., & Khaidir, R. E. M. (2020). The physical and optical studies of crystalline silica derived from the green synthesis of coconut husk ash. *Applied Sciences, 10*(6), 2128.

28. Wang, J., Zheng, S., Shao, Y., Liu, J., Xu, Z., & Zhu, D. (2010). Amino-functionalized Fe3O4@ SiO2 core–shell magnetic nanomaterial as a novel adsorbent for aqueous heavy metals removal. *Journal of Colloid and Interface Science, 349*(1), 293–299.

29. Joni, I. M., Vanitha, M., Panatarani, C., & Faizal, F. (2020). Dispersion of amorphous SiNPs via beads milling process and their particle size analysis, hydrophobicity and anti-bacterial activity. *Advanced Powder Technology, 31*(1), 370–380.

30. Maroušek, J., Maroušková, A., Periakaruppan, R., Gokul, G. M., Ambukumaran, A., Bohatá, A., Kříž, P., Bárt, J., Černý, P., & Olšan, P. (2022). Silica nanoparticles from coir pith synthesized by acidic sol-gel method improve germination economics. *Polymers, 14*(2), 266.

31. Sankareswaran, M., Vanitha, M., Rajiv, P., & Ambukumaran, A. (2021). *Phyllanthus emblica* mediated silica nanomaterials: Biosynthesis, structural and stability analysis. *Silicon*. https://doi.org/10.1007/s12633-022-01724-5

32. Roohizadeh, G., Majd, A., & Arbabian, S. (2015). The effect of sodium silicate and SiNPs on seed germination and growth in the *Vicia faba* L. *Tropical Plant Research*, 2(2), 85–89.

**Publisher’s Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

### Authors and Affiliations

M. Sankareswaran¹ · Rajiv Periakaruppan² · M. Sasivarnam² · Jeyapragash Danaraj³ · Sugapriya Dhanasekaran⁴ · Mosleh Mohammad Abomughaid⁴

M. Sankareswaran
sankarsankar87@gmail.com

M. Sasivarnam
saidiya.1127@gmail.com

Jeyapragash Danaraj
pragashdb@gmail.com

Sugapriya Dhanasekaran
sughaphd@gmail.com

Mosleh Mohammad Abomughaid
moslehali@ub.edu.sa

1 PG & Research Department of Microbiology, Muthayammal College of Arts & Science, 637408 Rasipuram, Namakkal, Tamil Nadu, India

2 Department of Biotechnology, Karpagam Academy of Higher Education, Coimbatore 641021, Tamil Nadu, India

3 Centre for Ocean Research (DST-FIST Sponsored Centre), MoES - Earth Science and Technology Cell (Marine Biotechnological Studies), Sathyabama Institute of Science and Technology, Col. Dr. Jeppiaar Research Park, Chennai 600 119, Tamil Nadu, India

4 Medical Laboratory Sciences Department, College of Applied Medical Sciences, University of Bisha, Bisha, Saudi Arabia