IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

“Synthesis of carbon Dots on papaya leaves, its characterisation and fluorescence.”

Mrs. Preeti Nitin Joshi[1*], Dhruvi M. Tabiyar[2*], Archita Bhattacharyya[3*]

1* Assistant Professor, Parul University, Gujarat, India
2,3* Students, Parul University, Gujarat, India

1.ABSTRACT

Since carbon dot particles (or CDs) have differentiated optically, electronic, and chemistry characteristics, scientists from all over the world have been very interested in these manufactured carbon nanoparticles, which are smaller than 10 nm. Carbon sources are cheap and fall under the category of resources from nature that are renewable. The low toxic effects, improved solubility in water, excellent biocompatibility, and sustained the photoluminescence of carbon dots [CDs] make them a popular choice for researchers. The easy techniques for making Carbon Dots are hydrothermal, requiring little equipment, little energy, easy handling, and a single-step preparation. Researchers have employed CDs for a variety of purposes since their discovery, including medication delivery, bioimaging, sensing, and catalysis. Carbon sources are cheap and fall under the category of natural resources that are renewable. Using a sand bath technique, fluorescence carbon-dot particles (CDs) are made from Carica papaya leaves, a natural resource. Ultra Violet-Visible, FT-IR, and fluorescence analysis were used to investigate the optical and structural features of the as-synthesised CDs. Using the technique of transmission electron microscopy, the dimensions, forms, and distributions of the particle sizes were also examined. These CDs were tested for biomedical uses, such as in vitro anti-inflammatory action using membrane stabilization technique, antioxidant capability using phosphomolybdate method, and free radical scavenging ability using DPPH assay. The CDs demonstrated significant half-maximum effective concentration (EC50) and good biological activity at lower concentration.

KEYWORDS; Nanoparticles, carbondots, papaya leaves, carica papaya.

2.INTRODUCTION

The plant, which is most commonly found in most nations, is a member of the caracca family's Carica papaya., choosing renewable precursors for CDs with high availability is crucial.[1] As a result, a number of regulatory agencies use traditional lab-based methods with its identification, speciation, and tracking in water resources, including atomic absorption spectroscopy and ion chromatography, ICP-MS, and ICP-OES [2]. It is currently shown that carbon-based nanomaterials with strong adsorption and photocatalytic degradation capabilities can efficiently lower the levels of organic pollutants in both water and air Graphene oxygen (GO) and carbon dots (CDs) are two carbon-based nanomaterials that are good choices for photocatalytic applications. Little particles of carbon with exceptional water dissolution, minimal cytotoxicity, and high quantum yield, superb biological compatibility, are known as CDs [3].

The tree is indigenous to Africa and the Indian the Indian Ocean. Parts of medicinal plants, such as roots, bark, leaves, and fruits and vegetables, are particularly useful in India for treating a variety of illnesses. The active ingredients in neem leaves specifically have the following properties: antibacterial, anti-microbial, anti-inflammatory, anti-gastric, anti-ulcer, antiarthritic, spermicidal, antifungal properties, antimalarial, hypoglycaemia, immune-modulating, diuretic, and antitumor23[4]. Created in 2004 by the researchers Xu et al., carbon dot particles (CDs) are bright round nanomaterials made of carbon with a single particle size of less than 10 nm [5]. As a result, many techniques are developed to create CDs, such as alkali oxidation, high water solubility greater choice & sensitivities for the intended analytical substances, simple functioning, and so forth.[6],[7],[8],[9].

Medical facilities face a significant threat from infection by bacteria. All of these techniques have certain disadvantages as well, a high temperature, and severe synthetic conditions; as a result, these techniques are quite costly. [10],[11]. The precursors and method of synthesis affect CD characteristics. Furthermore, research has shown that heteroatoms can simply adjust the characteristics of CDs' cores as well as surfaces in order to modify chemical capabilities [12]. Because of their unique qualities, such as their superior optical qualities, the CDs were employed in a variety of applications, such as medical diagnosis, photocatalysis, fluorescence detection, Different compounds can improve all of the chemical, physical, and optical properties of CDs by surface passivating them.[13][14] The scientific community is paying close attention to carbon dots (CDs), a relatively new class of nanomaterials, because of their exceptional qualities. These qualities include higher chemical resistance, outstanding biocompatibility, low level of toxicity, a catalytic characteristic, conductivity of electricity, excellent visibility, and minimal picture bleaching occurs [15].

Several synthesis methods, such as arc exit, the combustion process, thermodynamic preparing, electromagnetic pyrolysis, or laser sterilization, and plasma therapy, can be used to create CDs. It is able to made utilizing numerous processes etc. [16][17] Researching CDs with a high level of sensitivity and selectivity for Fe3+ detection is therefore essential. These investigators believe that using plant extract to produce metallic nanoparticles is the best option because it is easier to cultivate plants than bacterial or fungal cells, which need complex growth and preservation conditions. [18][19] This includes reduced overall reflection, a type of Raman spectroscopy, and diffraction of X-rays (XRD). like veggies, plants, and leaves, as well as milk and hair. The goals of a strategy for sustainable growth are aligned with the utilization of green, profitable, or recyclable materials in the creation of CDs. Green synthesizers for CDs has been chosen over other conventional processes due to its low cost, environmental friendliness, and ability to recycle and reuse organic waste products. [20][21]

As a result, CDs are used in a variety of activities, medication administration, water filtering, and farming, which spread more readily in water. and bio imaging employing fluorescent. Functional groups on the surface of CDs have different energy levels and produce a sequence of emissive traps according to the surface state mechanism. A red-shifted emission can result from greater surface flaws caused by a greater level of surface corrosion or other significant alteration. Hu et al. produced a number of CDs by altering the reagents and came to the conclusion that the PL red shift that resulted was mostly caused by some unique oxygen or nitrogen contained group on the surfaces of the molecules. [22][23][24] Fluorescence carbon dots (also known as CDs) are a type of monodisperse, spherical-looking carbon tiny material that has numerous functions on its surface and a length of below ten nm. Heteroatom doping is a common method of adjusting the electrical structure of CDs and a significant means of increasing output. [25] Owing to CDs' advantageous optical and chemical characteristics, using them like a signal source to create optical Nano sensors is becoming a popular area of study. Presently available CD-based sensing platforms are built using the fluorescence "on-off" concept. CDs' original carbon sources can originate from either natural or synthetic items. In actuality, natural products offer a few benefits over synthetic carbon sources when it comes to generating biomass CDs, including their abundance as well as minimal cost. [26][27]

This investigation looked into the growing use of C-dots made from extracts of leaves in beauty products. Skincare can find creative solutions that satisfy customer needs and fit with the modern standards for environmentally friendly and ethical production by utilizing the intrinsic qualities of these nanoparticles.[28] Because these invasive plants have the potential to seriously disrupt the balance between the economy and our natural surroundings, this work offers a method for turning carica papaya leaves into extremely useful and adaptable material. [29] gave an overview of the most recent research on the utilization of CDs for storing power and electrochemical processes, such as the creation of supercapacitors and power sources, H2/O2, and CO2 reduction. Transformed polymer dots, or CPDs, have garnered a lot of interest because they are inexpensive, have great optical properties, and need straightforward synthesis processes. [30][31][32]

Effective and targeted anticancer drugs with minimal damage toward normal cells remain a challenge of multiple anticancer drugs for cancer therapy. To create new nanomaterials with improved physical and chemical activities, different natural-based compounds are still being synthesized.[33] [34]The rapid advancement of nanomaterials, such as oxides of graphene, pure graphite, energy storage, and diodes that produce light, because of their special optical qualities and ease of preparation.[35][36][37] The Fourier transform for infrared (FTIR), the X-ray diffraction meter (XRD), ultraviolet–visible absorption (UV–vis), and X-ray photoelectron spectroscopy (XPS) were used to evaluate the composition and structure of FCDs. 38[39][40]

3.EXPERIMENTAL;

MATRIALS;

Fresh carica papaya leaves
Dilute hydrochloric acid [HCl]
Sodium hydroxide solution [NaOH]
Ethanol [CH_3CH_2OH]

SYNTHESIS;

1.Preparation of papaya Leaves: - Harvest fresh papaya leaves. Wash them thoroughly with distilled water to remove any dirt or contaminants. - Cut the leaves into small pieces or strips

2. Carbonization: - Place the papaya leaf pieces on a clean, heat-resistant surface, like a ceramic dish. - Carbonized the leaves by heating them in an oven at around 250-300°C for several hours. Alternatively, you can microwave the leaves in short intervals, checking until they become carbonized (blackened). - Allow the carbonized leaves to cool to room temperature.

3. Grinding: - Use a mortar and pestle to grind the carbonized banana leaves into a fine powder. This will increase their surface area.

4. Acid Treatment: - Mix the powdered carbonized papaya leaves with hydrochloric acid (HCl) to create a slurry. The concentration of HCl will depend on the desired results, but typically a dilute solution will suffice. - Stir the mixture and let it sit for a while to allow the acid to interact with the carbonized material.

5.Neutralization: - Gradually add sodium hydroxide (NaOH) to the slurry to neutralize the acidic solution. This will result in the formation of carbon dots.

6.Washing and Drying: - Wash the carbon dots thoroughly with distilled water to remove any residual acid or base. - Optionally, you can use a centrifuge to separate the carbon dots from the liquid.

7. Collecting Carbon Dots: - After washing, collect the carbon dots by filtering or centrifuging them. - Allow the collected carbon dots to air-dry or use a desiccator to remove any remaining

Figure 1 papaya leaf

Figure 2 Grinding

Figure 3 Washing and Drying

4. RESELT AND DISCUSSION

4.1 FT-IR

The powerful and popular technique known as Fourier transform infrared spectroscopy, or FTIR, is used to examine a wide range of substances particularly their functional groups. FTIR analyses infrared light absorption, producing an absorption sample absorbs incident radiation. FTIR's frequency range usually extends over 4000-600 cm. The analysis of the FTIR data for the papaya leaf carbon dots is as follows

Graph 1 graph of FTIR of carbon dots of papaya leaves

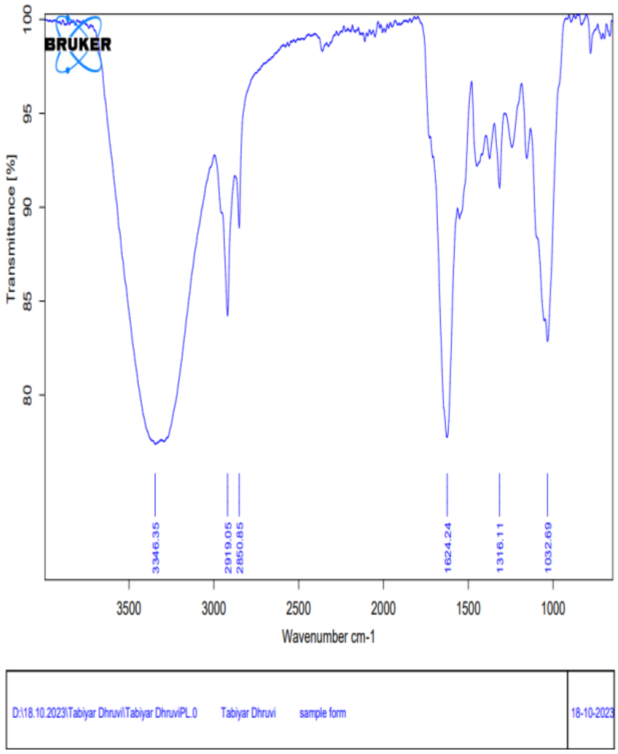


Table 1 data obtained by interpretating FTIR graph

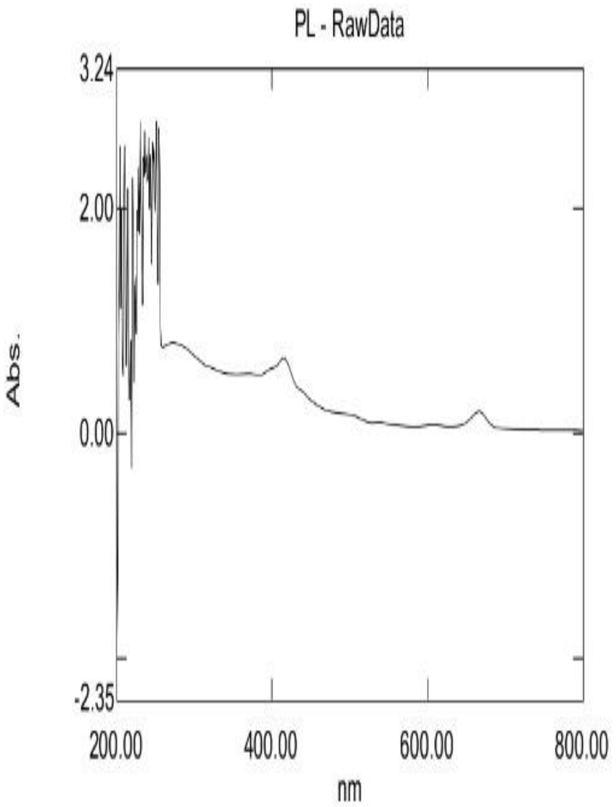
SR.No	Wavelength [cm^{-1}]	Bands/functional group
1	1032.69 cm^{-1}	-NH_2
2	1316.11 cm-1	-No_2
3	1624.24 cm-1	-AR
4	2850.85 cm-1	-CHO
5	2919.05 cm-1	-CH
6	3346.35 cm-1	-OH

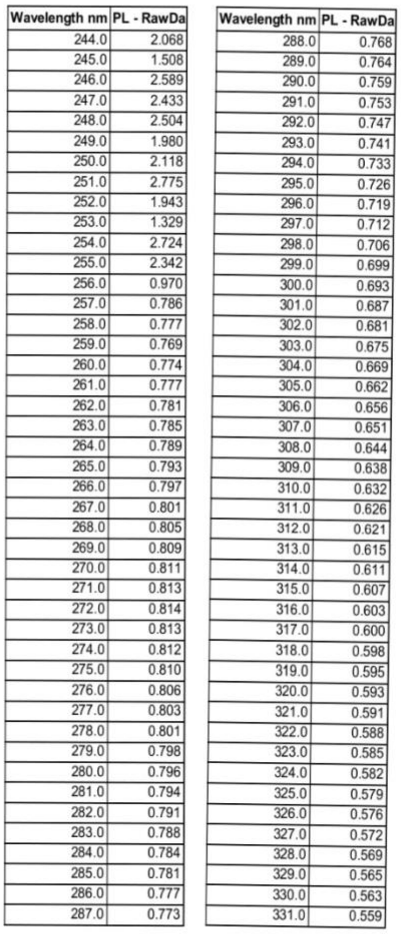
The FTIR spectrum of carbon dots reveals distinct picks, including -NH_2 band at 1032.69 cm^{-1} , NO_2 band 1316.11 cm^{-1}, -AR band at 1624.24 cm^{-1}, -CHO band at 2850.85 cm^{-1} ,-CH band at 2919.05 cm^{-1},-OH band at 3346.35 cm^{-1}. These peaks helpfor relative quantification of functional group.

4.2 UV SPECTROSCOPY

The UV sp synthesized from papaya leaves was seen in between the range of 200-300nm at absorbance of 2.5. this indicates absorption of light in ultra violet regain of the electromagnetic spectrum attributed to electronic transition within the molecule. the peak around 200-300nm indicates the presence of conjugation, chromophore group resulting in fluorescence.

This specific wavelength and intensity of the peaks provide information about the structure and composition of the sample.

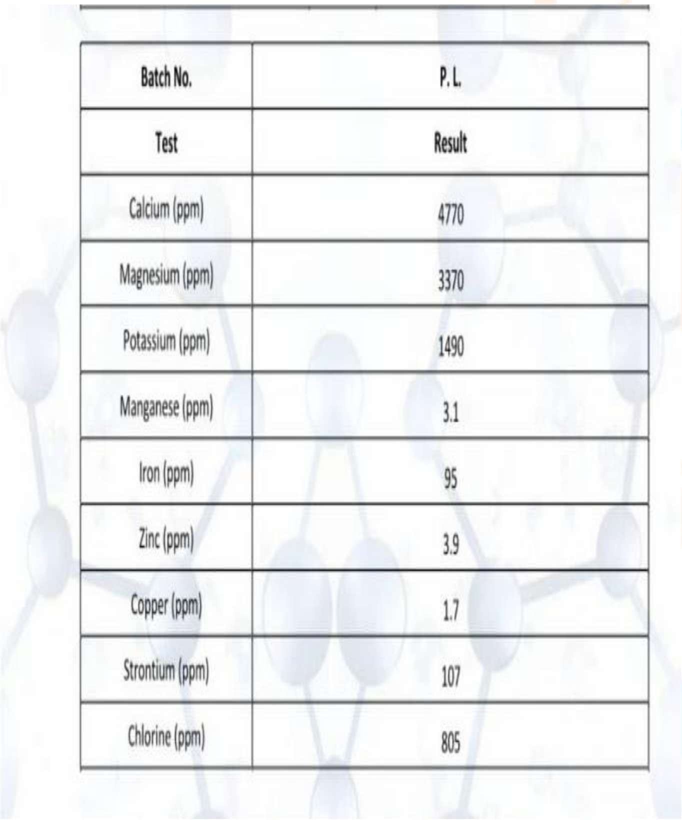




Wavelength nm	PL - RawDa
244.0	2.068
245.0	1.508
246.0	2.589
247.0	2.433
248.0	2.504
249.0	1.980
250.0	2.118
251.0	2.775
252.0	1.943
253.0	1.329
254.0	2.724
255.0	2.342
256.0	0.970
257.0	0.786
258.0	0.777
259.0	0.769
260.0	0.774
261.0	0.777
262.0	0.781
263.0	0.785
264.0	0.789
265.0	0.793
266.0	0.797
267.0	0.801
268.0	0.805
269.0	0.809
270.0	0.811
271.0	0.813
272.0	0.814
273.0	0.813
274.0	0.812
275.0	0.810
276.0	0.806
277.0	0.803
278.0	0.801
279.0	0.798
280.0	0.796
281.0	0.794
282.0	0.791
283.0	0.788
284.0	0.784
285.0	0.781
286.0	0.777
287.0	0.773
288.0	0.768
289.0	0.764
290.0	0.759
291.0	0.753
292.0	0.747
293.0	0.741
294.0	0.733
295.0	0.726
296.0	0.719
297.0	0.712
298.0	0.706
299.0	0.699
300.0	0.693
301.0	0.687
302.0	0.681
303.0	0.675
304.0	0.669
305.0	0.662
306.0	0.656
307.0	0.651
308.0	0.644
309.0	0.638
310.0	0.632
311.0	0.626
312.0	0.621
313.0	0.615
314.0	0.611
315.0	0.607
316.0	0.603
317.0	0.600
318.0	0.598
319.0	0.595
320.0	0.593
321.0	0.591
322.0	0.588
323.0	0.585
324.0	0.582
325.0	0.579
326.0	0.576
327.0	0.572
328.0	0.569
329.0	0.565
330.0	0.563
331.0	0.559

4.3 CHARACTERISATION BY FLUORESCENCE SPECTROSCOPY

Chemical compounds can be quantitatively measured using fluorescence spectroscopy, which depends on the fluorescence characteristics of the material under investigation. Fluorescence spectroscopy analyses a molecule's fluorescence based on its fluorescent properties. Fluorescence is one type of luminescence that happens when photons excite a molecule and bring it to an electrically excited state. Fluorescence spectroscopy involves the employment of a laser beam to excite electrons that are in particular compounds' molecules, resulting in the production of light. By passing the light via the filter & onto a detector, it is intended for measurement and identify the molecules or modification of the molecule. Calcium (4770 ppm), magnesium (3370 ppm), potassium (1490 ppm), manganese (3.1 ppm), iron (11 ppm), iron (95ppm) , zinc (11 ppm), copper(1.7ppm),strontium(107ppm) & Chlorine(805ppm) are all found in papaya leaves.



Batch No.	P. L.
Test	Result
Calcium (ppm)	4770
Magnesium (ppm)	3370
Potassium (ppm)	1490
Manganese (ppm)	3.1
Iron (ppm)	95
Zinc (ppm)	3.9
Copper (ppm)	1.7
Strontium (ppm)	107
Chlorine (ppm)	805

5.CONCLUSION

The growing development of nano particles, in this research the novel method of development of simple, cost effective, eco-friendly technique for synthesis of carbon dots from carica papaya leaves is shown. The carbon dots synthesised using papaya leaves In a single step green proses The carbon dots exhibited in a good nano size, its characteristics were also studied by FT-IR technique to interpreted its functional groups this word also provided insight that under UV light blue fluorescence was observed.

6. REFERENCES

1. Gudimella, K. kanthi, Gedda, G., Kumar, P. S., Babu, B. K., Yamajala, B., Rao, B. V., Singh, P. P., Kumar, D., & Sharma, A. (2022). Novel synthesis of fluorescent carbon dots from bio-based Carica Papaya Leaves: Optical and structural properties with antioxidant and anti-inflammatory activities. *Environmental Research*, *204*, 111854.
2. D., P., Singh, L., Thakur, A., & Kumar, P. (2019). Green synthesis of glowing carbon dots from Carica papaya waste pulp and their application as a label-freechemo probe for chromium detection in water. *Sensors and Actuators B: Chemical*, *283*, 363–372. https://doi.org/10.1016/j.snb.2018.12.027
3. Hesam Salimi Shahraki, Rani Bushra, Shakeel, N., Ahmad, A., None Quratulen, Ahmad, M., & Christos Ritzoulis. (2023). Papaya peel waste carbon dots/reduced graphene oxide nanocomposite: From photocatalytic decomposition of methylene blue to antimicrobial activity. *Journal of Bioresources and Bioproducts*, *8*(2), 162–175.
4. Archana Johny, Silva, Pereira, C. M., & Silva. (2024). Sustainability Assessment of Highly Fluorescent Carbon Dots Derived from Eucalyptus Leaves. *Environments*, *11*(1), 6–6.
5. Iravani, S., & Varma, R. S. (2020). Green synthesis, biomedical and biotechnological applications of carbon and graphene quantum dots. A review. *Environmental Chemistry Letters*, *18*(3), 703–727.
6. Jayanthi, M., Megarajan, S., Subramaniyan, S. B., Kamlekar, R. K., & Veerappan, A. (2019). A convenient green method to synthesize luminescent carbon dots from edible carrot and its application in bioimaging and preparation of nanocatalyst. *Journal of Molecular Liquids*, *278*, 175–182
7. Kurian, M., & Paul, A. (2021). Recent trends in the use of green sources for carbon dot synthesis–A short review. *Carbon Trends*, *3*, 100032.
8. Meng, W., Bai, X., Wang, B., Liu, Z., Lu, S., & Yang, B. (2019). Biomass-Derived Carbon Dots and Their Applications. *ENERGY & ENVIRONMENTAL MATERIALS*, *2*(3), 172–192.
9. De, B., & Karak, N. (2013). A green and facile approach for the synthesis of water soluble fluorescent carbon dots from banana juice. *RSC Advances*, *3*(22), 8286.
10. Wang, Z., Sheng, L., Yang, X., Sun, J., Ye, Y., Geng, S., Ning, D., Zheng, J., Fan, M., Zhang, Y., & Sun, X. (2023). Natural biomass-derived carbon dots as potent antimicrobial agents against multidrug-resistant bacteria and their biofilms. *Sustainable Materials and Technologies*, *36*, e00584–e00584.
11. De, B., & Karak, N. (2013). A green and facile approach for the synthesis of water soluble fluorescent carbon dots from banana juice. *RSC Advances*, *3*(22), 8286.

12. Lin, X., Xiong, M., Zhang, J., He, C., Ma, X., Zhang, H., Kuang, Y., Yang, M., & Huang, Q. (2021). Carbon dots based on natural resources: Synthesis and applications in sensors. *Microchemical Journal*, *160*, 105604–105604.
13. Atchudan, R., Edison, T. N. J. I., Perumal, S., Muthuchamy, N., & Lee, Y. R. (2020). Hydrophilic nitrogen-doped carbon dots from biowaste using dwarf banana peel for environmental and biological applications. *Fuel*, *275*, 117821.
14. Salimi Shahraki, H., Ahmad, A., & Bushra, R. (2022). Green carbon dots with multifaceted applications– Waste to wealth strategy. *FlatChem*, *31*, 100310.
15. Atchudan, R., Edison, T. N. J. I., Chakradhar, D., Perumal, S., Shim, J.-J., & Lee, Y. R. (2017). Facile green synthesis of nitrogen-doped carbon dots using Chionanthus retusus fruit extract and investigation of their suitability for metal ion sensing and biological applications. *Sensors and Actuators B: Chemical*, *246*, 497–509.
16. Vandarkuzhali, S. A. A., Jeyalakshmi, V., Sivaraman, G., Singaravadivel, S., Krishnamurthy, K. R., & Viswanathan, B. (2017). Highly fluorescent carbon dots from Pseudo-stem of banana plant: Applications as nanosensor and bio-imaging agents. *Sensors and Actuators B: Chemical*, *252*, 894–900.
17. Komalavalli, L., Amutha, P., & Monisha, S. (2020). A facile approach for the synthesis of carbon dots from Hibiscus sabdariffa & its application as bio-imaging agent and Cr (VI) sensor. *Materials Today: Proceedings*, *33*, 2279–2285.
18. Venkatesan, G., Rajagopalan, V., & Sarada Nallani Chakravarthula. (2019). Boswellia ovalifoliolata bark extract derived carbon dots for selective fluorescent sensing of Fe3+. *Journal of Environmental Chemical Engineering*, *7*(2), 103013–103013.
19. Jain, A., Ahmad, F., Gola, D., Malik, A., Chauhan, N., Dey, P., & Tyagi, P. K. (2020). Multi dye degradation and antibacterial potential of Papaya leaf derived silver nanoparticles. *Environmental Nanotechnology, Monitoring & Management*, *14*, 100337.
20. Kanwal, A., Bibi, N., Hyder, S., Muhammad, A., Ren, H., Liu, J., & Lei, Z. (2022). Recent advances in green carbon dots (2015–2022): synthesis, metal ion sensing, and biological applications. *Beilstein Journal of Nanotechnology*, *13*, 1068–1107.
21. Atchudan, R., Jebakumar Immanuel Edison, T. N., Perumal, S., & Lee, Y. R. (2018). Indian Gooseberry-Derived Tunable Fluorescent Carbon Dots as a Promise for In Vitro/In Vivo Multicolor Bioimaging and Fluorescent Ink. *ACS Omega*, *3*(12), 17590–17601.
22. Sun, X., & Lei, Y. (2017). Fluorescent carbon dots and their sensing applications. *TrAC Trends in Analytical Chemistry*, *89*, 163–180.
23. Barzinjy, A. A., & Azeez, H. H. (2020). Green synthesis and characterization of zinc oxide nanoparticles using Eucalyptus globulus Labill. leaf extract and zinc nitrate hexahydrate salt. *SN Applied Sciences*, *2*(5).
24. Liu, H., Ding, J., Zhang, K., & Ding, L. (2019). Construction of biomass carbon dots based fluorescence sensors and their applications in chemical and biological analysis. *Trends in Analytical Chemistry*, *118*, 315–337.
25. Wang, T., Luo, H., Jing, X., Yang, J., Huo, M., & Wang, Y. (2021). Synthesis of Fluorescent Carbon Dots and Their Application in Ascorbic Acid Detection. *Molecules (Basel. Online)*, *26*(5), 1246–1246.
26. Luo, X., Zhang, W., Han, Y., Chen, X., Zhu, L., Tang, W., Wang, J., Yue, T., & Li, Z. (2018). *N,S co-doped carbon dots based fluorescent "on-off-on" sensor for determination of ascorbic acid in common fruits*. *258*, 214–221. https://doi.org/10.1016/j.foodchem.2018.03.032
27. Liu, H., Ding, J., Zhang, K., & Ding, L. (2019). Construction of biomass carbon dots based fluorescence sensors and their applications in chemical and biological analysis. *Trends in Analytical Chemistry*, *118*, 315–337.
28. Thi, L., Moon, J.-Y., & Lee, Y.-C. (2023). Plant Extract-Derived Carbon Dots as Cosmetic Ingredients. *Nanomaterials*, *13*(19), 2654–2654.
29. Torres Landa, S. D., Kaur, I., & Agarwal, V. (2022). Pithecellobium dulce Leaf-Derived Carbon Dots for 4-Nitrophenol and Cr(VI) Detection. *Chemosensors*, *10*(12), 532.
30. Pundi, A., & Chang, C.-J. (2022). Recent Advances in Synthesis, Modification, Characterization, and Applications of Carbon Dots. *Polymers*, *14*(11), 2153.
31. Meng, W., Wang, B., Ai, L., Song, H., & Lu, S. (2021). Engineering white light-emitting diodes with high color rendering index from biomass carbonized polymer dots. *Journal of Colloid and Interface Science*, *598*, 274–282.
32. Jacinth Gracia, K. D., Thavamani, S. S., Amaladhas, T. P., Devanesan, S., Ahmed, M., & Kannan, M. M. (2022). Valorisation of bio-derived fluorescent carbon dots for metal sensing, DNA binding and bioimaging. *Chemosphere*, *298*, 134128.
33. Ghosal, K., Ghosh, S., Ghosh, D., & Sarkar, K. (2020). Natural polysaccharide derived carbon dot based in situ facile green synthesis of silver nanoparticles: Synergistic effect on breast cancer. *International Journal of Biological Macromolecules*, *162*, 1605–1615.

34. Ngafwan Ngafwan, Marwan Effendy, Gatot Supangkat Samidjo, I. Gusti Ketut Puja, & I.N.G. Wardana. (2023). The role of Carica papaya latex bio-catalyst and thermal shock in water on synthesizing rice husk. *Arabian Journal of Chemistry*, *16*(4), 104568–104568.
35. Ngafwan Ngafwan, Marwan Effendy, Gatot Supangkat Samidjo, I. Gusti Ketut Puja, & I.N.G. Wardana. (2023). The role of Carica papaya latex bio-catalyst and thermal shock in water on synthesizing rice husk. *Arabian Journal of Chemistry*, *16*(4), 104568–104568.
36. Hou, X., Xu, J., Zhou, P., Dai, L., Zhang, J., Xiao, X., & Huo, K. (2023). A shining transmutation of lignin into multicolor carbon dots via the dynamic solvent-fractionation engineering. *Chemical Engineering Journal*, *478*, 147363–147363.
37. Zhou, P., Xu, J., Hou, X., Dai, L., Zhang, J., Xiao, X., & Huo, K. (2023). Heteroatom-engineered multicolor lignin carbon dots enabling bimodal fluorescent off-on detection of metal-ions and glutathione. *International Journal of Biological Macromolecules*, *253*, 126714–126714.

38. Wan, S., Chen, H., Liao, B., & Guo, X. (2021). Adsorption and anticorrosion mechanism of glucose-based functionalized carbon dots for copper in neutral solution. *Journal of the Taiwan Institute of Chemical Engineers*, *129*, 289–298.
39. Zhu, M., Guo, L., He, Z., Riadh Marzouki, Zhang, R., & Elyor Berdimurodov. (2022). Insights into the newly synthesized N-doped carbon dots for Q235 steel corrosion retardation in acidizing media: A detailed multidimensional study. *Journal of Colloid and Interface Science*, *608*, 2039–2049.
40. Niu, F., Zhou, G., Zhu, J., Zhang, X., Shi, Y., Lu, G., & Liu, Z. (2021). Inhibition behavior of nitrogen-doped carbon dots on X80 carbon steel in acidic solution. *Journal of Molecular Liquids*, *339*, 117171.