Anchor University Journal of Science and Technology (AUJST)
A publication of the Faculty of Science Applied and Health Science, Anchor University Lagos

URL: journal.aul.edu.ng

In AJOL: https://www.ajol.info/index.php/aujst

Vol. 6 No 2, November 2025, Pp. 187-192

ISSN: 2736-0059 (Print); 2736-0067 (Online)

Conversion of Plastic Polymeric Wastes into Carbon Dots: A Sustainable Approach

[1,2,3] B. H. Akpeji, [1,3] L.O Okhuarobo, [4] A.O. Akakabota, [1] J.O. Okologume , [1] O.L Osio,

[1] Department of Science Laboratory Technology, Federal University of Petroleum Resources, P.M.B 1221, Effurun, Delta State, Nigeria

[2] Centre of Sustainable Development Goals, Federal University of Petroleum Resources, P.M.B 1221, Effurun, Delta State, Nigeria

[3] Centre for waste Management and Sustainable Resources, Federal University of Petroleum Resources, P.M.B 1221, Effurun, Delta State, Nigeria

[4] Department of Chemical Engineering, Federal University of Petroleum Resources, P.M.B 1221, Effurun, Delta State, Nigeria

***Corresponding author Email**: akpeji.honesty@fupre.edu.ng.

Submitted 25, June 2025

Accepted 04, August 2025

Competing Interests.

The authors declare no competing interests.

ABSTRACT

Plastic polymeric materials pose significant waste and environmental hazards, creating widespread environmental concerns. In this study, carbon dots (CDs) were synthesized from plastic wastes by hydrothermal carbonization technique and their reactions and morphology were investigated. The prepared carbon dots were characterized using the UV-Visible spectrophotometer, Fourier Transform Infrared (FTIR) Spectrophotometer, Energy Dispersive X-ray spectrophotometer (EDX), Powder X-ray Diffraction (PXRD), Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM). UV-Visible spectrum revealed that carbon dot showed maximum absorption peak at 286 nm. FTIR analysis indicated the presence of reactive functional groups at peak bands of 3399 cm^{-1}, 2975 cm^{-1}, 1743 cm^{-1}, 1652 cm^{-1}, 1165 cm^{-1} representing -OH Stretch of alcohol, -C-H Stretch of alcohol, C=O Stretch of carbonyl, N-H bending of amide and C-O stretch of ether. EDX result provided the elemental composition and percentage distribution of the elements in the carbon dot, showing C (89.65%) and O (10.35%) respectively depicting its successful synthesis. SEM images showed that the synthesized carbon dots had a spherical morphology with porous surface, while TEM analysis revealed an average particle size of 3.54 nm. PXRD spectra confirmed that the carbon dots have band peaks at the miller index of (002) and (101) with broad and non-intense peaks which characterized them to contain no crystalline substances.

Keywords: Carbon dot, characterization, plastic waste, synthesis

1. Introduction

The increased usage and disposal of plastics has become the actual environmental problem of the twenty- first century. From the current production level of more than 368 million metric tons of plastics per year and where only 9% of the plastics produced is recycled, there is need to find more efficient and sustainable solutions to the management of plastic waste (Thompson *et al*., 2023). The recycling process, especially those that create valuable products like carbon dots (CDs) from plastic waste, can be considered as among the best solutions to two problems at once. Carbon dots are nanoscale carbon particles that were synthesized accidentally during the repossession of single-walled carbon nanotubes in the year 2004 and became a research focus because they exhibit unique optical properties, high biocompatibility, and Multiple application areas. These fluorescent carbon nanoparticles, with a mean size of below 10 nm, have properties such as photostability, biocompatibility, and photo luminescence that can be easily tuned (Akpeji *et al.,* 2024b; Elemike *et al*., 2021; Wang & Hu, 2021). The idea of obtaining these irreplaceable nanomaterials from plastic wastes suggests the application of modern notions on circular economy. Carbon dots generated from plastics were produced through several synthetic strategies, which include hydrothermal treatment, microwave radiation, and pyrolysis. These processes of the template-assisted synthesis are capable of reducing large polymer macromolecules into smaller carbonaceous structures from which quantum-sized carbon dots with distinct physicochemical characteristics are generated (Gusain *et al.,* 2020 Bibekananda and Niranjan, 2013). Utilizing various plastic waste kinds, such as polyethylene terephthalate (PET), polyethylene (PE), and polypropylene

https://dx.doi.org/10.4314/aujst.v6i2.2

(PE), and polypropylene (PP), shows how adaptable and widely applicable this strategy is.

Carbon dots derived from plastic waste conversion possess tremendous prospects in different fields such as bioimaging, sensing, catalysis, and optoelectronic application. Some of the exceptional features that have made them more suitable for biomedical applications include; high fluorescence intensity, good photostability, and low toxicity. Moreover, its application in the recovery of polluted sites and energy conversion makes another outstanding contribution to sustainability aspect. Due to the possibility of generating economic returns, the conversion of plastic waste to carbon dots has received interest from academic and industrial communities (Akpeji *et al.,* 2024a; Shen *et al.,* 2018). The process also presents a chance to turn an expensive problem into valuable resources and generate income in the process to handle environmental woes of waste disposal. The use of converting plastic waste into carbon dots is therefore a feasible method that complies with circular economy as well as sustainable development goals. In addition to helping solve the problem of the accumulation of plastic waste, this technological development may contribute to the creation of improved materials for numerous uses to show that there are ways of turning environmental threats into technological benefits (Wang *et al*., 2020; Zheng *et al*., 2004).

2. Materials and Methods

2.1 Materials

The procedure used in the synthesis of carbon dots in the Department of Science Laboratory Technology, Federal University of Petroleum Resources at Effurun involved the following apparatus; chemical balance (JJ623BC), which operates by electromagnetic force restoration; muffle furnace (GWL-XAD), which utilizes resistance heating and thermal decomposition; drying oven (LD-201-E, Vision Scientific), which uses convective heating and evaporation of water; heating mantle (HH-W420) which functions by contact heat generation; UV-Visible spectrophotometer (Perkin Elmer Lambda 40) using the Beer Lambert principle, UV-lamp for photoluminescence (CAMAG-30003), retort stand, magnetic stirrer (78-1), centrifuge (DL-1042R) and water distiller (LZ 76-1) with principles of centrifugal force and distillation process respectively.

2.2 Methods

2.2.1 Collection of Plastic Wastes and Hydrothermal carbonization for Carbon dot Synthesis

Figure 1 is the flow process diagram that describes the hydrothermal carbonization method employed in the synthesis of carbon dot from plastic wastes as described by Rifat *et al.,* (2021) and Akpeji *et al.,* (2024). The plastic wastes which include the Polyethylene Terephthalate (PET) bottles were gathered from the university environment and shop locations where drinks are sold in the school premises. These plastic wastes were cut into smaller pieces using a pair of scissors, after which, the were washed with distilled water to removes dirts, sand and liquids that are entrapped. In a murfle furnace 250 g of these shrielded plastic trash was weighed and carbonized for 2 hours. After the furnace was allowed to cool, the solid carbon was removed grinded using a mortar and pestle. The powdered carbon obtained was left in a 1000 mL beaker and 500 mL of distilled water was poured into it to obtain a mixture. This mixture was left under a homogenizer under a heating element left at 400 ^{o}C to induce motion on the molecular level the mixture was for two hours monitored under UV-Visible spectrophotometer. Finally, the resultant combination was centrifuged and the supernatant is kept in a waste bucket for neutralization to avoid environmental hazard. Meanwhile, the residue was poured on a petri dish which was dried in an oven at 105 ^{o}C. After drying, 1 g of the carbon dot dissolved in distilled water was placed under a UV lamp to determine that the prepared carbon dot has green luminescence.

2.2.2 Instrumental Characterization of the Synthesized Carbon dot

UV-visible spectrophotometry followed by

https://dx.doi.org/10.4314/aujst.v6i2.2

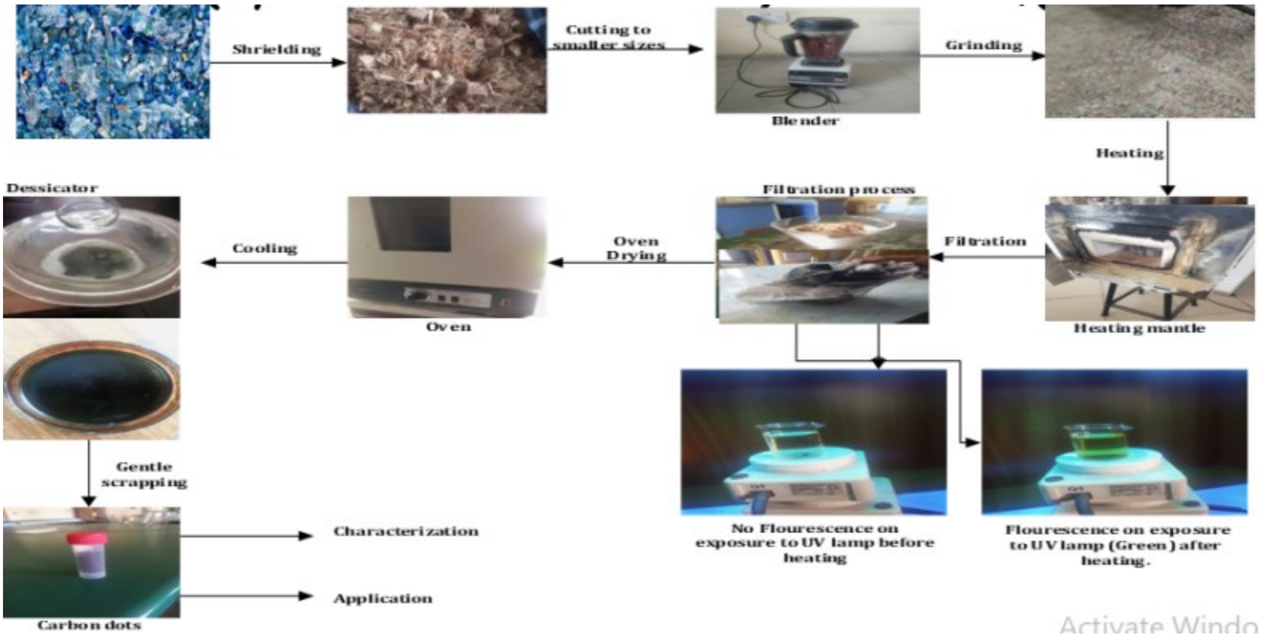


Figure 1: Flow Process in Synthesis of carbon dot from Plastic wastes

Fourier Transform Infrared Spectrophotometry (FTIR), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Powder X-ray Diffractometry (PXRD), pH meter (PHS-115), and Energy Dispersive X-ray techniques were further employed in order to characterize the synthesized carbon dot so as to elucidate their optical properties, reactivity, morphology, particle size, crystallography and elemental constituents and acidity or alkalinity respectively.

3. Results and Discussion

3.1 Optical Property with UV-Vis Spectrophotometer

UV-Vis spectrum of the synthesized carbon dot is presented in figure 2. The UV-visible absorption characteristic peaks in the CDs synthesized from plastic waste give a clear indication of their optical features. The absorption at 286 nm is common and is normally associated with the π-π* transition of the aromatic C=C bonds within the carbon core structure (Li *et al*., 2020). This absorption feature can be attributed to the formation of sp^2 hybridized carbon domains which are characteristic when plastic waste is converted into carbon dots. The extended absorption band in the UV to visible region of course indicates the presence of multiple chromophoric groups and surface states; the oxygen-containing functional groups on the carbon dot surface (Zhang *et al*., 2022). These surface functionals are particularly significant in defining the optical properties and usability of the synthesized carbon dots. Wang *et al*., (2020) suggested that this distinct absorption characteristic is desirable for optoelectronic applications profiting from light absorption over a wide range of wavelengths, including photocatalysis and solar energy conversion. The above results demonstrate that the synthesized carbon dots possess a relatively high absorption coefficient in the UV region where the absorption intensity is greater than 2.0 a.u. Due to this property they are suitable especially for use in UV protection and photocatalytic processes. A progressive reduction on the absorption intensity at wavelengths larger than 500 nm points to a decrease on its interaction with visible light, which is expected for carbon dots produced from plastic waste precursors (Chen & Liu, 2023). The observed optical characteristics show that the carbon dots derived from the selected plastic waste has similar absorption capabilities to the carbon dots prepared with conventional precursors. The clear sharp peak at 286 nm along with the broader work of the spectrum ensures the basic conversion of plastics into functional C-dots for opto-electronics, sensing, and environmental remediation (Park *et al*., 2023). These optical properties confirm that plastic waste can be

https://dx.doi.org/10.4314/aujst.v6i2.2

used effectively to synthesize carbon dots while making it a sustainable precursor.

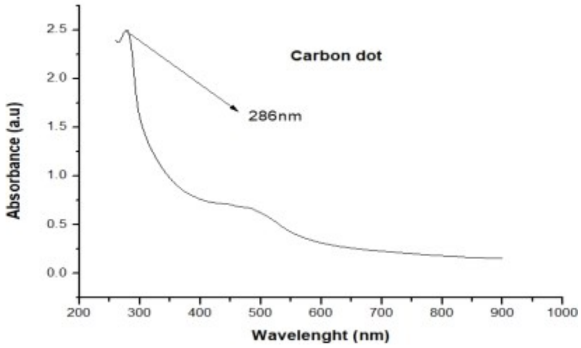


Figure 2: UV-Vis Spectrum of Carbon dot

3.2 Functional Group Properties by FTIR Spectrophotometer

The functional properties of the carbon dots is presented in Figure 3 with band peaks within the range of 800-4000 cm^{-1}. FTIR analysis revealed that the material contain some reactive functional groups relative to the peak bands at 3399 cm^{-1}, 2975 cm^{-1}, 1743 cm^{-1}, 1652 cm^{-1}, 1165 cm^{-1} corresponding to –OH of alcohol, –C -H of alcohol, C=O of carbonyl, N-H bending of amide and C-O stretch of ether. The presence of these functional groups implies that the synthesized carbon dots are electron rich which has several uses in the removal of pollutants in water, the control of microbial activity and other uses in industries. The presence of these functional groups suggest that the synthesized carbon dots are electron rich which can have several applications in remediation of pollutants in water, inhibition of microbial activities and other industrial applications. Furthermore, previous studies of Akpeji *et al.,* (2024) showed that the carbon dots with these reactive functional moieties exhibited good solubility in water.

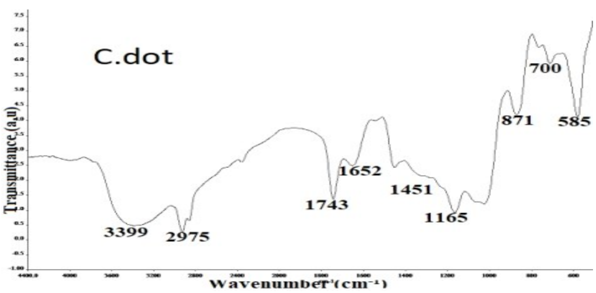


Figure 3: FTIR Spectrum of Carbon dot

3.3 Morphology and Shape of Carbon dot by SEM

The SEM image of carbon dot made from plastic trash is shown in figure 4. Upon analyzing the image, it was seen that the carbon dot is surrounded with a spherical molecules as illustrated in the morphology of the material. Likely also, in SEM image analysis, the team observed that the carbon dots have porous surfaces, which the author described their high reactivity in the adsorption of molecules. The author definitely rightly attributed similar observations regarding its morphology and aspect in application as pointed out by (Junjun *et al.,* 2020).

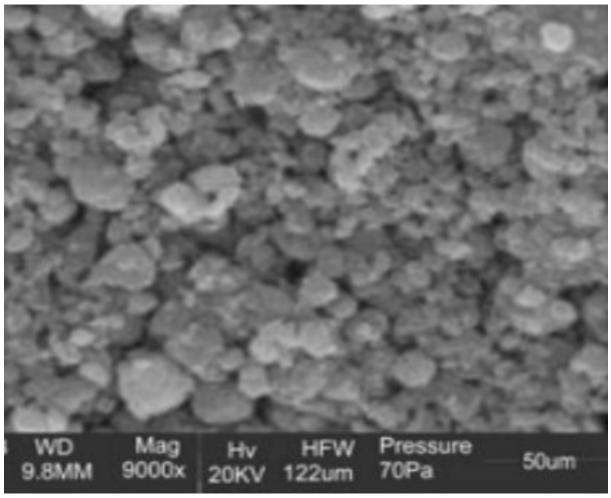
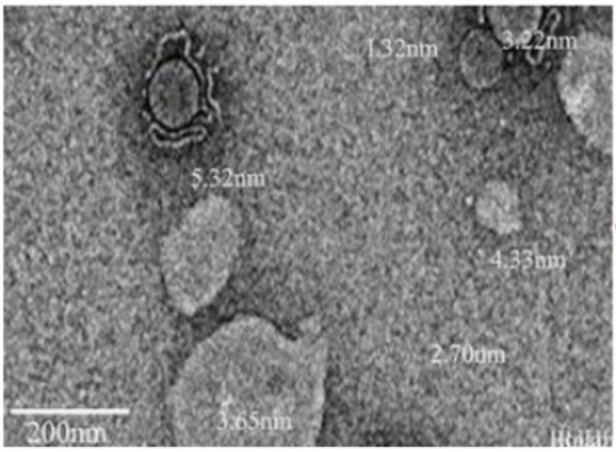


Figure 4: SEM Image of Carbon dot

3.4 Average Particle Size by TEM

The particle size of the synthesized carbon dot as derived from the discussion on figure 5 is as follows: In the micrographs, it was confirmed that the carbon dots are almost spherical in shape, uniformly separated and there is no sign of agglomeration between them. The morphology described in this case agreed with the SEM image. The average particle size of the synthesized carbon dot from plastic wastes was therefore determined using origin lab and image J softwares to be 3.54nm which is within the nano range of 1-10nm. This actually demonstrated that there was a successful formation of the carbon dot. This research found out that the particle size of the carbon dot was very high, and the surface area of the

https://dx.doi.org/10.4314/aujst.v6i2.2



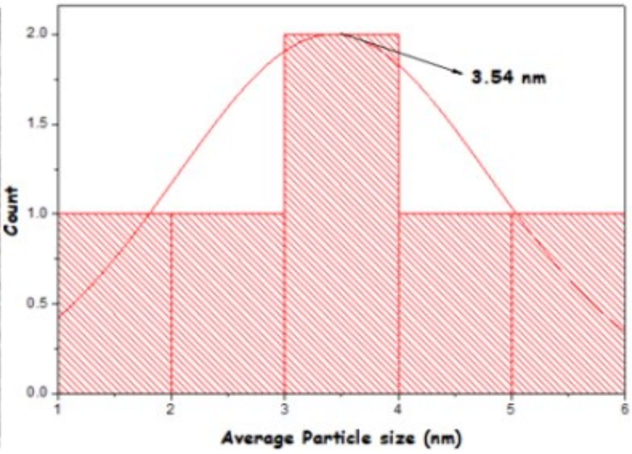


Figure 5: TEM Micrograph of Carbon dot

particle could be utilized in several ways in the adsorption purposes as proposed by (Tratnyek *et al*., 2006).

3.5 Crystallography State of Carbon dot by PXRD

The Powdered X-ray Diffraction (PXRD) spectrum of carbon dot synthesized from plastic waste is presented in Figure 6. The studied pattern has sharp maxima at the two theta angles of 22 and 43 degrees indicative of the miller index of (002) and (101) respectively. The wide, blunt and low intensity of the peaks further supports the non-crystalline nature of the carbon dots. Rifat *et al.,* (2021) in their earlier research study observed a different observation where they experienced peak of 21 degree which corresponds to (002) in the two theta plane and in addition broad peaks all over the spectrum. This is the reason behind non-crystalline nature of the synthesized carbon dot.

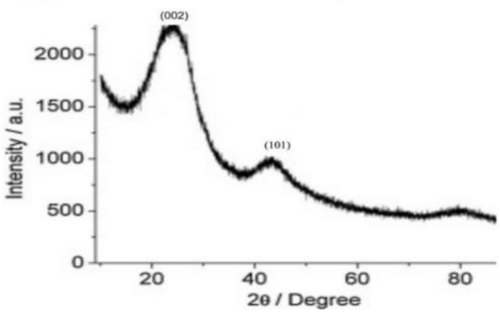


Figure 6: PXRD Spectrum of Carbon dot

3.6 Acidity and Alkalinity of carbon dot by pH meter

The pH result is presented in figure 7. The synthesized carbon dots underwent analysis of pH, using the pH meter of model PHS-25. The pH of the carbon dot solution as obtained was 8.93 which implies that the solution has alkaline properties. The obtained pH value of 8.93 is moderately alkaline that may benefit some biological and environmental uses such as the disposal of acidified water through enhancing its pH to standard. The alkalinity revealed by the presence of nitrogen-containing functional groups and hydroxyl moieties at the surface of the carbon dots, which can affect their photoluminescence properties and colloidal stability (Gusain *et al.,* 2020).

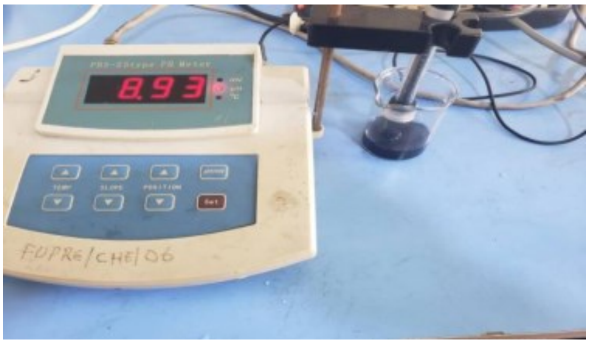


Figure 7: pH of Carbon dot

3.7.Elemental Constituents by EDX

Energy Dispersive X-ray (EDX) analysis of the synthesized carbon dots as shown in figure

https://dx.doi.org/10.4314/aujst.v6i2.2

8 provides elemental composition of the material. According to the analysis, the carbon content is high at a weight percentage of 89.65, whereas oxygen content is low at a weight percentage of 10.35. The efficiency and quality control of the synthesis process confirm successful production of carbon-rich nanomaterials as evident by this elemental distribution. These results are in line with previous publications that also stated that the most predominant element in the structure of carbon dots is carbon (Bibekananda & Niranjan, 2013; Chauhan et al., 2020; Dong et al., 2020; Ghirardello et al., 2021). The high carbon content not only confirms the integrity of the synthesis method but it also implies the possibility of use in energy storing, bioimaging, environmental cleaning and environmentally friendly optoelectronic devices. At the end, it leads to the emergence of nanomaterials that are affordable and environmentally friendly and can help in providing both the environmental and technological answers in the society.

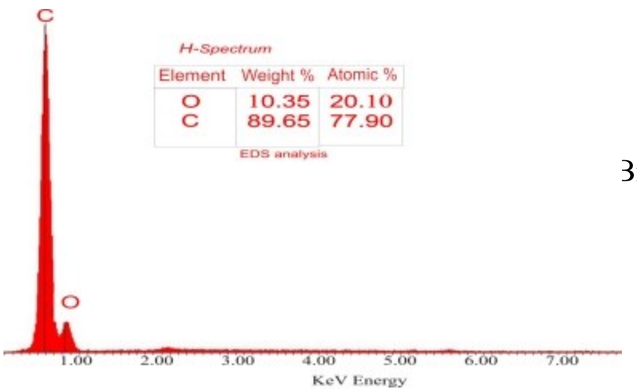


Figure 8: EDX of Carbon dot

4. Conclusion

This work involves conversion of plastic polymeric wastes into carbon dots. These wastes are found everywhere and has brought menace to the environment especially to drainages blocking the water ways. The carbon dot synthesized was characterized for their optical properties, functional reactivity, morphology, crystallography, particle size, acidity or alkalinity and elemental composition using several instrumental techniques like the UV-Visible spectrophotometer, FTIR, SEM, PXRD, TEM, pH meter and EDX respectively. The result showed quality and successful synthesis of carbon dots and their potentials in the industries to solving problems of water contamination, drug delivery, sensors, bioimaging, medicine owing to their various properties shown in the course of discussion of results.

References

Akpeji, B.H., Akusu, P. O., Emegha, M.C., Onyenue, E.E., Elemike, E.E. (2024a) Synthesis and Characterization of Carbon Dot from Plastic Waste for Remediation of Fe^{3+} in Wastewater. International Journal of Research and Innovation in Applied Science (IJRIAS), 9 (6) DOI: 10.51584/ IJRIAS.

Akpeji, B. H., Emegha, M. C., Onyenue, E. E., Meshak, O. Q., Elemike, E. E (2024b). Synthesis and characterization of nanoparticles of ZnO, carbon dot and ZnO-Carbon dot Nanocomposite from groundnut shell waste. J. Appl. Sci. Environ. Manage. 28 (6) 1771-1780.

Bibekananda, D.E and Niranjan K. (2013). A green and facile approach for the synthesis of water soluble fluorescent carbon dots from banana juice. Journal of the Royal Society of Chemistry. DOI: 10.1039/c3ra00088e. Vol 3, page 8286–8290.

Chauhan, P., Dogra, S., Chaudhary, S., Kumar, R. (2020). Usage of coconut coir for sustainable production of high-valued carbon dots with discriminatory sensing aptitude toward metal ions. Today Chem, 16, 100247.

Chen, X., & Liu, Y. (2023). Sustainable synthesis of carbon dots from plastic waste: A comprehensive review of optical properties and applications. Advanced Sustainable Systems, 7(3), 2200429.

Dong, X., Liang W., Meziani M.J., Sun Y.P., Yang L. (2020). Carbon dots as potent antimicrobial agents. Theranostics2020, 10, 671–686.

Elemike, E.E., Adeyemi, J., Onwudiwe, D.C., Wei, L., Oyedeji, A.O. (2022). The Future of energy materials; A case of Mxenes-carbon dots Journal of Energy storage. 50(104711).

Ghirardello, M., Ramos-Soriano, J., Galan, M.C. (2021). Carbon dots as an emergent class of antimicrobial agents. Nano Mater.2021, 11, 1877. 11.

Gusain, R., Kumar, N., Ray, S.S (2020). Recent advances in carbon nanomaterial-based adsorbents for water purification. Coord. Chem. Rev., 405.

Junjun L, Rui L, Bai Y. (2020). Carbon dots; A new type of carbon-based Nanomaterial with wide Applications. ACS Central Science. 6(12), 2179-2195.

Li, Y., Zhang, B., & Liu, X. (2020). Optical properties and applications of carbon dots derived from waste materials. Chemical Engineering Journal, 395, 125025.

Park, S., Kim, J., & Lee, H. (2023). Recent advances in plastic waste-derived carbon dots for environmental applications. Environmental Science: Nano, 10(4), 1089-1112.

Rifat, M.d., Nepu, S., Thomas, Q., Toufiq R. (2021). Formation of Carbon Quantum Dots via Hydrothermal Carbonization: Investigate the Effect of Precursors. Energies MDPI, Vol 14, 986. https://doi.org/10.3390/en14040986.

Shen, C.L.; Zang, J.H.; Lou, Q.; Su, L.X.; Li, Z.; Liu, Z.Y.; Dong, L.; Shan, C.X. (2018). In-situ embedding of carbon dots in a trisodium citrate crystal matrix for tunable solid-state fluorescence. Carbon2018, 136, 359–368.

Thompson, R. C., Swan, S. H., Moore, C. J., & vom Saal, F. S. (2023). Plastics, the environment and human health: Current consensus and future trends. Philosophical Transactions of the Royal Society B, 364(1526), 2153-2166. https://doi.org/10.1098/rstb.2009.0053

Zheng, X., Chen, G., Li, Z., Deng, S., Xu, N. (2004). Quantum-mechanical investigation of field emission mechanism of a micrometer-long single-walled carbon nanotube. Rev. Lett.2004, 92, 106803.

Wang, Y., & Hu, A. (2021). Carbon quantum dots: Synthesis, properties and applications. Journal of Materials Chemistry C, 9(15), 5578-5597.https://doi.org/10.1039/C4TC00988F

Wang, L., Li, W., Yin, L., Liu, Y., Guo, H., Lai, J., Han, Y., Li, G., Li, M., Zhang, J., Vajtai, R., Ajayan, P.M., Wu, M. (2020). Full-color fluorescent carbon quantum dots. Sci Adv. 6(40): doi:10.1126/sciadv.abb6772.

Ye, H.G., Lu, X., Cheng, R., Guo, J., Li, H., Wang, C.F., Chen S. (2021). Mild bottom-up synthesis of carbon dots with temperature-dependent fluorescence. J. Lumin., 238

Zhang, M., Sun, Y., & Yang, D. (2022). Surface chemistry and optical properties of carbon dots: From waste plastics to functional materials. ACS Sustainable Chemistry & Engineering, 10(15), 4789-4801.