International Journal of Engineering Research and Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 21, Issue 8 (August 2025), PP 43-52

Fabrication of Nanocrystals from Banana Plant Waste Residue: Comprehensive Structural, Spectroscopic Characterization and Impact in Soil pH Improvement.

Sumit Sarkar[1†], Anjan Sengupta[1], Ratan Das[2],Darsu Chakma[1], Krishna Deb[3],Bimal Das[1]

[1]*Directorate of Biotechnology, Department of Science, Technology & Environment, Agartala, Tripura, India*
[2]*Department of Physics, Tripura University (A Central University), Suryamaninagar, Tripura, India*
[3]*Department of Physics, National Institute of Technology, Jirania, Tripura, India*
[†]*Email:sarkarsumit07phy@gmail.com*

Abstract:
The banana plant is abundant in subtropical regions, leading to considerable waste production from its various parts. Utilizing this waste is economically significant, given its availability. This study presents an experimental method for repurposing banana plant waste.X-ray diffraction analysis confirms the purity and crystalline structure of the resulting materials. Scanning Electron Microscopy (SEM) reveals that the average size of the nanocrystals ranges from 50 to 80 nm, exhibiting a spherical morphology. Additionally, Energy Dispersive X-ray Spectroscopy (EDAX) analysis highlights the presence of multiple elements, notably a high concentration of magnesium.Our findings indicate that using 0.25 g to 0.30 g of the banana plant waste material positively impacts soil health, particularly in low pH conditions. This method shows great promise as a rapid solution for improving soil pH, contributing to sustainable agricultural practices.
Keywords: *Banana Plant Waste; Nanocrystals; SEM; EDAX; Soil pH.*

Date of Submission: 27-07-2025 Date of Acceptance: 05-08-2025

I. Introduction:

In tropical and subtropical regions, banana (Musa paradisiaca)—a member of the Musaceae family—is among the most widely cultivated fruit crops, occupying approximately 8.8 million hectares worldwide [1]. It is believed to be one of the earliest crops domesticated by humans [2]. Around 300 banana cultivars are grown globally, with the majority found across tropical Asia [3]. Each year, banana cultivation results in the generation of substantial waste materials. Due to their abundant availability and rich biochemical composition, there is growing interest in utilizing banana plant residues for both economic and environmental purposes.Economically, banana waste holds potential as a low-cost feedstock for producing value-added products. From an environmental perspective, the proper utilization of these materials could help mitigate pollution problems linked to improper waste disposal. The main agricultural residues from banana cultivation are the pseudostem and leaves. The pseudostem comprises concentric layers of leaf sheaths and stalks, both of which are abundant in lignocellulosic compounds [4]. Certain bacteria are capable of breaking down these materials and, in doing so, release cellulolytic enzymes, which are widely used in industrial sectors such as textiles, detergents, and laundry products.Despite these potential applications, much of the banana biomass is discarded, leading to environmental burdens and waste management issues. Presently, large quantities of banana pseudostems are left to decay in fields, causing considerable disposal challenges for farmers.On a related note, soil pH is heavily influenced by land use patterns and vegetation types. For instance, forest soils generally tend to be more acidic compared to grassland soils. When land is converted from forest or grassland to cropland, significant shifts in soil pH can occur over time. These changes are often the result of declining organic matter, nutrient depletion due to crop harvesting, topsoil erosion, and fertilizer usage.

Assessing soil pH and nutrient content is thus a critical step prior to agricultural experimentation. Soil acidity is mainly determined by the concentration of hydrogen ions (H^+) in the soil solution and is influenced by various climatic, biological, and geological factors. For example, soils that originate from granite tend to acidify more rapidly than those formed from limestone. Similarly, sandy soils with low clay content acidify faster because of their limited alkaline cation reserves and higher leaching capacity. High rainfall accelerates this process, particularly where water percolates quickly through the soil profile. Additionally, the decomposition of organic matter contributes weak organic acids, which can increase soil acidity over time. While these factors may have only minor short-term effects, their cumulative impact over the years can become significant [5].In the current study, the banana plant waste as raw materials have been prepared after drying the waste of banana plant parts. The prepared raw materials have been investigated by X-ray diffraction (XRD)techniques. Subsequently, the prepared materials have been incorporated into the soil in calculated proportions to examine its potential for improving soil pH.

II. Materials and Methods:

2.1 Preparation of Raw Materials:

Banana plant wastes have been collected and then it has been dried in sunlight for 8-10 days. Further, the dried products have been burnt (temperature ~ 600°C)and prepared in powder form which is shown in figure-1. Therefore, 5 gm of collected soil having low pH is diluted in water to measure the soil pH and after that the prepared materials of 0.25 gm (T_1), 0.50 gm (T_2) and 01 gm (T_3) have been mixed with the above-mentioned solution. The prepared solution has been vigorously stirred by rotator shaker for 10 to 15 min.

Figure 1: Powder form of the banana plant waste material

III. Characterization:

X- ray diffraction (XRD) studies of the prepared banana stem powder have been carried out using a D8-Advance Bruker system equipped with Cu Kα radiation (λ= 0.1541nm). UV/vis measurements have been carried out with the Perkins Elmer spectrophotometer Lambda 11, where light source is the deuterium tungsten halogen lamp. Further, Fourier Transform Infra-Red (FTIR) spectra of the prepared samples, have been recorded on a Perkin Elmer FTIR Spectrophotometer in 800–4000 cm−1 range in the form of KBr pellets. The size and elemental analysisof the prepared samples have been investigated using a Scanning Electron Microscope, Model - Sigma 300, Carl Zeiss. Energy dispersive X-ray analysis measurements have been performed under standard conditions.

IV. Result & Discussion:

4.1 X-ray Diffraction Study:

In solid state physics, material science and solid-state chemistry, X-ray diffraction is one of the most important characterization techniques used [6-9] for the estimation of the average grain size as well as the confirmation of crystalline nature. XRD measurement has been performed on a D8-Advance Bruker system equipped with Cu Kα radiation (λ= 0.1541nm). The diffracted intensity was measured in a 2θ range. The XRD pattern of the prepared sample is shown in figure: 2. All the detectable reflection peaks (2θ) at 14.85^0, 29.80^0, 40.47^0 and 49.05^0have been clearly indicated the crystallinity of the prepared sample (standard JCPDS-ICDD card number: 00-056-1718& 00-041-1476) [10-13].

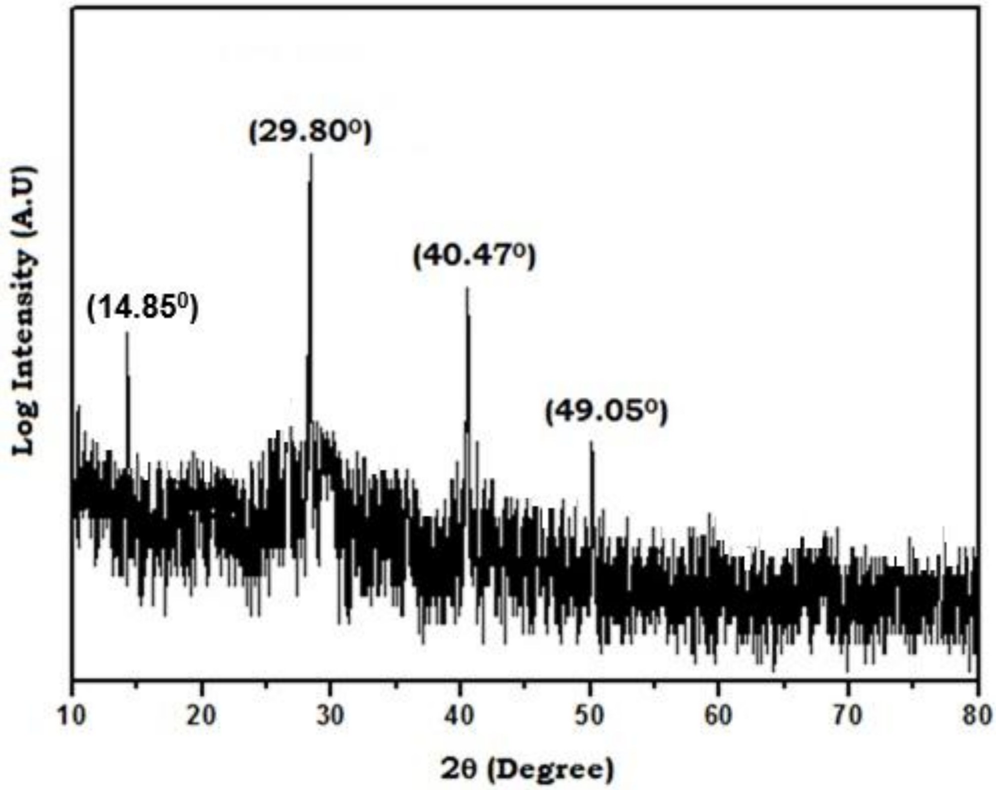


Figure 2: X-ray diffraction pattern of the banana waste powder

The detectable high intense peak for the prepared material is observed at 29.80^0. The prominent diffraction peaks, their corresponding miller indices and the interplanar spacings are provided belowin table-1

Table 1: Crystallographic parameters derived from XRD analysis.

Sl No.	Peak Position (2θ)	Corresponding (hkl)	Specific 'd' values	Lattice Parameter 'a'
1	14.85^0	(110)	0.59nm	0.83 nm
2	29.80^0	(200)	0.31nm	0.62 nm
3	40.47^0	(220)	0.22nm	0.62 nm
4	49.05^0	(222)	0.18 nm	0.623 nm

4.2 Spectroscopic Analysis of Constituents:

Infrared spectroscopy is basically connected with vibrational energy spectrum of atoms or cluster of atoms in a material that is extremely helpful for the analysis of molecules or compounds. As, IR spectra, in general, show several bands, two different compounds or molecules cannot have the similar infrared spectrum and for this reason, IR spectrum provides the "finger print" of a molecule [14]. Here, fig. 3 shows the FTIR spectra of banana stem powder. In the FTIR spectrum, the band observed around 875 cm^{-1} corresponded to β-1, 4 glycosidic linkages while the band around 1030 cm^{-1} corresponded to ring vibrations and C-O-C links [15-16]. The band in the region around 1428–1315 cm^{-1}has been assigned to C-H in plane deformation of CH_2 groups [17]. Further, C=C stretching bond in the lignin component can be observed from peaks inthe range of 1450–1590 cm^{-1}[17-18]. The FTIR spectra clearly indicate the presence of functional groups such as glycosidic bonds, ether groups, alkynes groups and alkenes in the selected adsorbents.

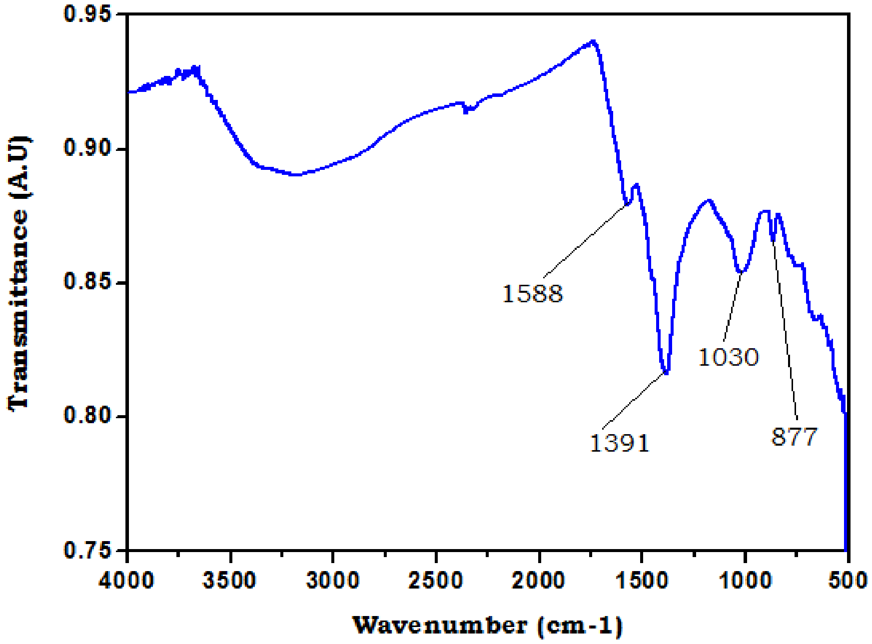


Figure 3: FTIR spectrum of banana plant waste powder

The presence of these functional groups is crucial for improving the effectiveness of the nanomaterials in various soil applications. Specifically, these groups contribute to key soil benefits, including enhanced water retention, nutrient adsorption, biodegradability, and overall soil quality improvement. These properties are essential for boosting plant growth and promoting long-term soil health, making banana waste-derived nanomaterials a promising and sustainable solution for agricultural enhancement [19-23].

4.3 Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDX) analysis: SEM images of the prepared banana plant waste powder are shown in fig. 4, and the energy-dispersive X-ray spectrum is shown in fig.5. The SEM images confirm the formation of nanocrystalsand mostly spherical in nature, whereas energy-dispersive X-ray analysis confirmed the presence of the elements K, C, N, Fe, Na, Mg in atomic proportions.

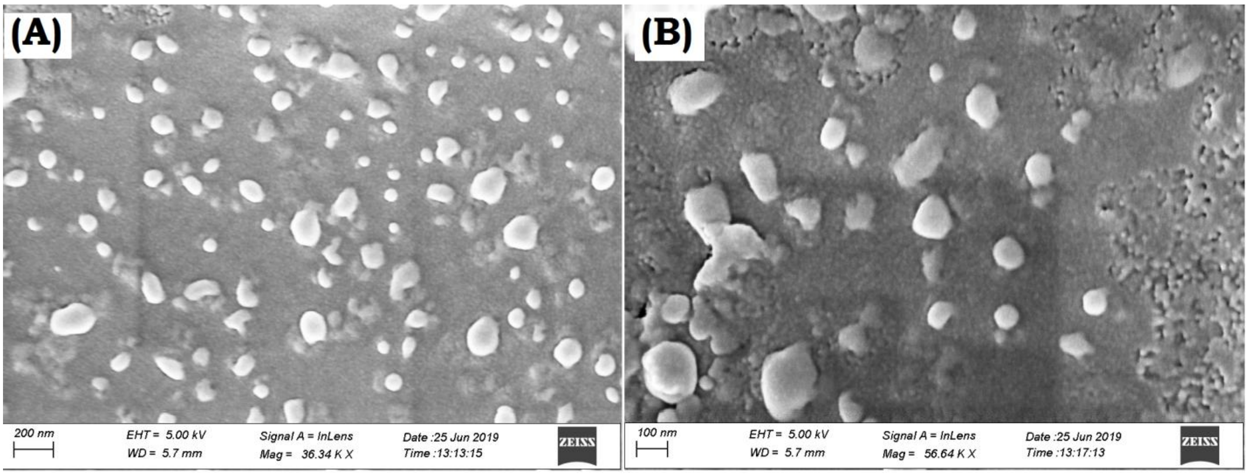
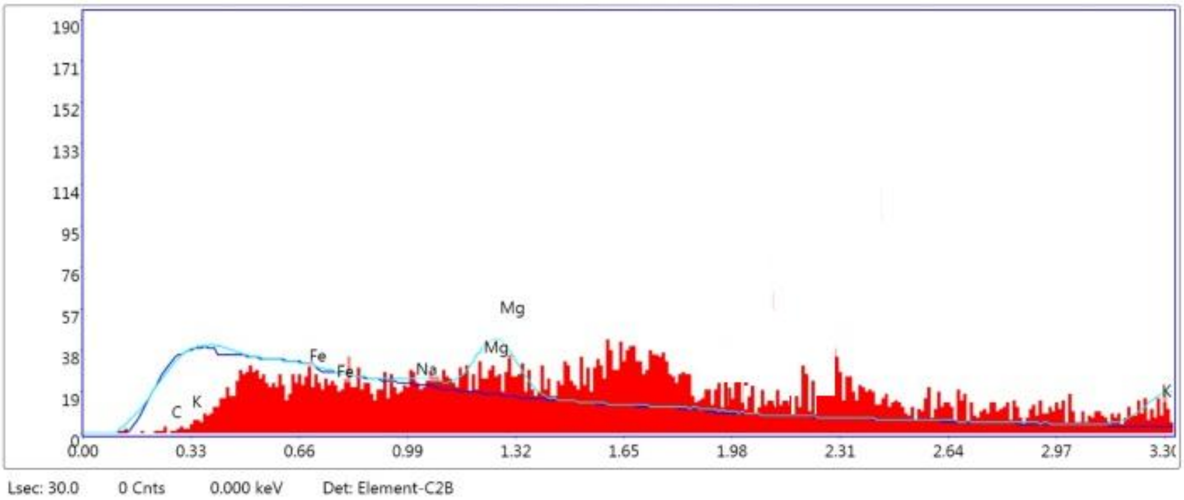


Figure 4: (A) & (B) SEM images of the prepared banana plant waste powder

It is clear from these images that acommon characteristic of the particles is theirsphericalshape.It is also visible that particles are mutuallydifferentin size varying between 30 to 100 nm.Therefore, the analytical results of EDX analysis are obtained from the specimen as it exists in the electron microscopy, which is shown in figure: 5.



eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	A	F
K L	0.00	0.00	0.00	99.99	0.0000	0.8910	0.6563	1.0000
C K	0.21	0.42	0.03	99.99	0.0011	1.2024	0.4448	1.0000
FeL	1.25	0.54	0.13	99.99	0.0109	0.7959	1.0971	1.0000
NaK	10.42	11.01	1.67	76.01	0.1026	0.9939	0.9846	1.0062
MgK	88.12	88.03	14.37	19.33	0.8623	1.0034	0.9752	1.0000

Figure 5: Energy dispersive X-ray (EDX) analysis spectrum of Banana Plant waste powder

EDAX spectrum of banana plant waste powder in fig. 5 clearly showed the presence of various elements viz. K, C, Fe, Na and Mg present in the banana plant waste powder along with a high amount of magnesium. Further, the different nutrients present in the sample are also identified from the elemental mapping analysis which is shown in figure: 6. Here, different colour shows different nutrients to distinguish the presence of different nutrients.

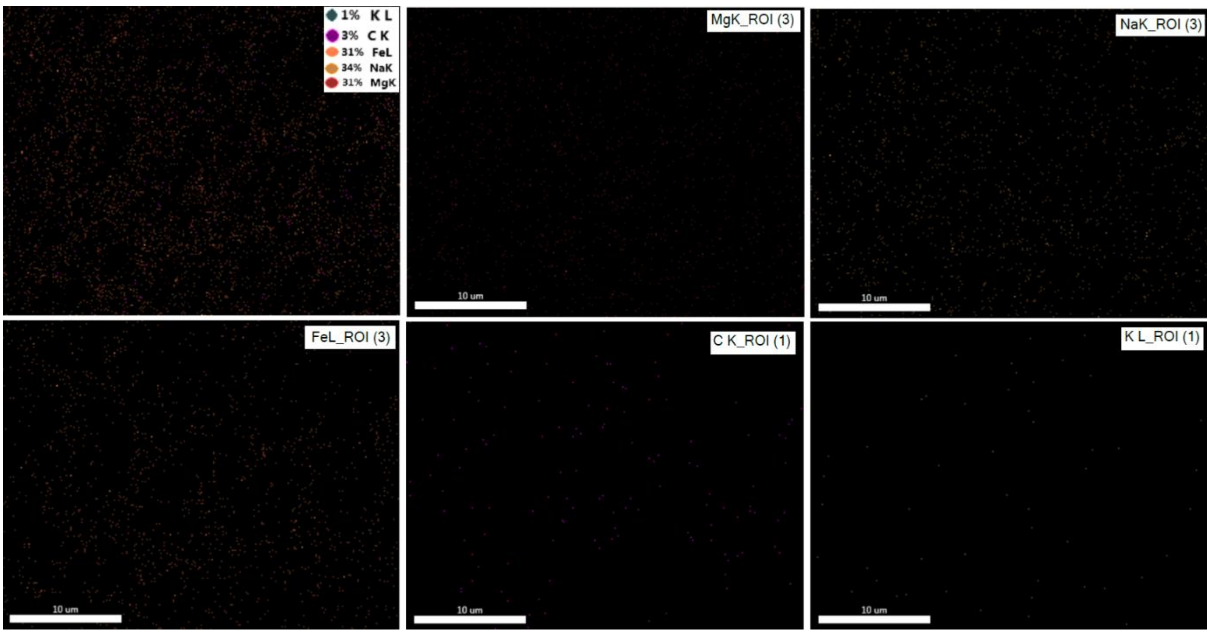


Figure 6: Elemental mapping for different nutrients presents in Banana Plant waste powder

V. Application of Banana Plant Waste Powder for Enhancement of Soil pH:

"Soil acidity" is the term used to express the quantity of hydrogen (H) and aluminum (Al) cations (positively charged ions) in soils. When the levels of hydrogen or aluminum become too high—and the soil becomes too acid—the soil's negatively charged cation exchange capacity (CEC) becomes "clogged" with the positively charged hydrogen and aluminum, and the nutrients needed for plant growth are pushed out. This is why root growth and plant development suffer when soils become too acid.

Soil pH is an indicator of "soil acidity" and a relationship between soil pH and acidity is shown in figure-7. A pH of 7.0 is defined as neutral. Values below 7.0 are acidic, and values above 7.0 are basic or alkaline. Small changes in numbers indicate large changes in soil acidity. A soil with a pH of 5 is 10 times more acidic than a soil with a pH of 6 and 100 times more acidic than a soil with a pH of 7.

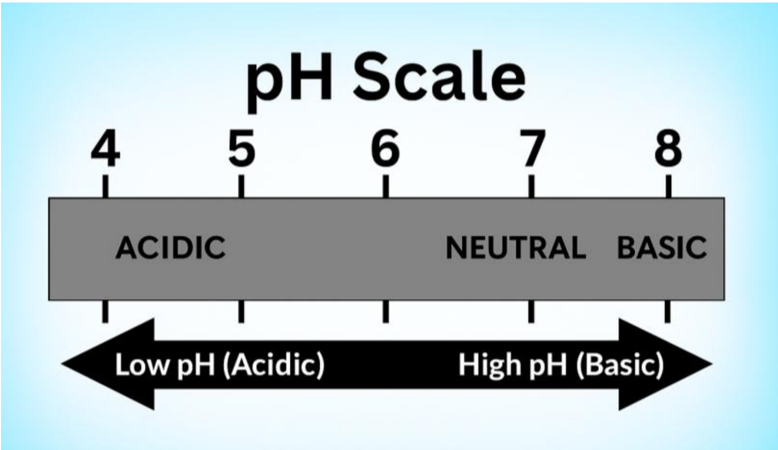


Figure 7: Relationship between soil pH and acidity

Soil acidity involves intensity and quantity aspects. The intensity aspect is universally characterized by the measurements of H+ ion activity, expressed as pH. The quantity aspect is characterized, directly or indirectly, by the quantity of alkali required to titrate soil to some arbitrarily established endpoint. Soil acidity is a major problem in relation to plant growth and therefore, acid soils are called a problem soil. Hence, we are interested to prepare the banana plant waste powder for the enhancement of soil pH.The soil used in this study was collected from the tea cultivation regions of Sepahijala District, Tripura, India (Latitude: 23.685712 &Longitude: 91.310729) known for its favorable conditions for tea growth. The region experiences a tropical climate with abundant rainfall and moderate temperatures, ideal for tea cultivation. The soils in these areas are primarily red soils, derived from the weathering of crystalline rocks such as granite and gneiss. These red soils are well-drained, slightly acidic, and moderately fertile, properties that support healthy tea plant growth. The soil texture is typically loamy or sandy loam, ensuring good drainage and aeration, which prevents waterlogging—an essential factor for tea cultivation. The pH of the soils in Sepahijala ranges from 4.8 to 5.8, falling within the optimal range for tea cultivation, which is slightly acidic to moderately acidic.For this study, the pH of banana plant waste powder has been measured by a suitableratioand it has been observed that the pH value of the powder product is 9.55. For the enhancement of soil pH, some soil sample has been collected from tea garden and it is found thatpH value is 5.60. In different conical flask, the soil sample has been merged in water containing banana plant extract powder of different concentration, which is shown in figure-8.

Figure 8: Colloidal solution of soil having different concentration of the banana plant waste burnt powder.

These conical flasks are kept for more than 5 days at room temperature, in a room where sufficient light can enter during the daytime, so that the pH value has been measured. The three different conical flasks have different concentration and following results are shown in table-2.

Table 2: Effective pH values of different concentration of powder sample& soil.

Sl No	Water (ml)	Soil Sample (gm)	Powder Sample (gm)	pH value
01.	50	Nil	01	9.55
02.	50	05	Nil	5.60
03.	50	05	0.25	8.47
04.	50	05	0.50	8.80
05.	50	05	01	9.07

After a few trials with different concentration of banana plant waste powder, it has been found that enhancement rate of pH value of soil gets significantly or linearly increased after treatment with banana plant waste powder, as shown in the figure-9.

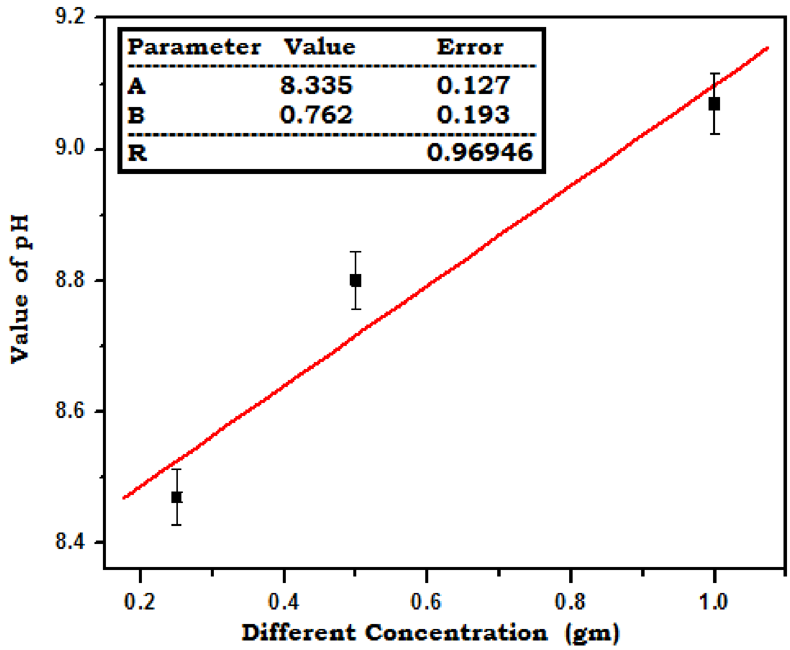


Figure 9: Plotting of pH value against the different concentration of prepared powder sample

Figure: 9, clearly showing the effects of banana plant waste powder of different concentration, on the enhancement of pH.Further, more studies have been performed to find out the suitable concentration dose for the enhancement of pH. Experimental study indicate that suitabledosebanana plant waste powder for better wealth of soil is 0.30 gm for 50 gm soil diluted in 150 ml of water. The following results are shown in table-3.

Table 3: Influence of powder sample concentration on acceleration of soil pH

Sl No	Water (ml)	Soil Sample (gm)	Powder Sample (gm)	pH value
01.	150	50	Nil	5.60
02.	150	50	0.15	5.82
03.	150	50	0.25	6.20
04.	150	50	0.30	6.35
05.	150	50	0.35	6.70

A plot of pH value for different solution against the different concentrations of banana plant waste powder is shown in figure-10, which confirms that the concentration of powder sample i.e 0.25 gm and 0.30 gm are effective for the good wealth of soil.

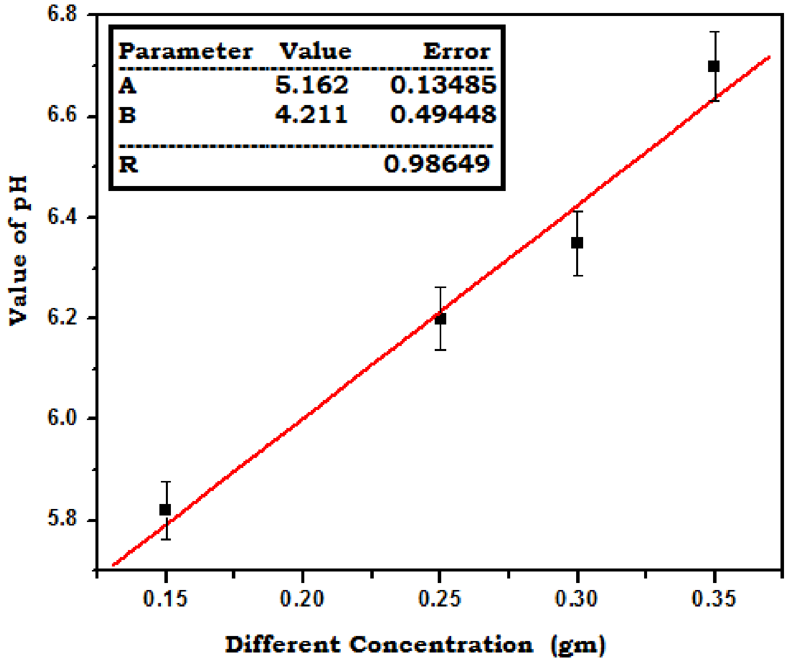


Figure 10: Plotting of pH value for different solution against the different concentration of prepared powder

After carefully examining the experiment, it has been observed that at the combination of 150 ml mixed with 50 gm of soil having 0.25 gm of powder sample and 150 ml mixed with 50 gm of soil having 0.30 gm of powder sample are suitable for obtaining the pH value at 6.20 to 6.35. In this regard, R. Gentili et al. [24], H. Ireri Gitari et al. [25] and A. Sutradhar et al. [26] have reported that at pH 6.00 to 6.50 plant leaves seemed to grow more quickly than the other values of pH.The proton activity (pH) in soil is one of the most essential physicochemical properties and is closely related to the availability of soil nutrients, microbial activity and plant growth and development [27]. The highest percentage of Mg present in nanomaterials prepared from banana waste can contribute to the observed increase in soil pH primarily through cation exchange and dissolution mechanisms. Due to their high surface area, these nanoparticles interact more effectively with the soil's cation exchange sites, allowing magnesium ions (Mg^{2+}) to replace acidic hydrogen ions (H^+) that contribute to soil acidity. This ion exchange reduces the concentration of hydrogen ions in the soil, raising the pH.

In addition, magnesium can release magnesium ions into the soil solution over time. These magnesium ions act as a base, neutralizing excess hydrogen ions (H^+) and further raising soil pH. The dissolution of magnesium compounds, such as magnesium oxide or magnesium carbonate, within the nanoparticles also produces hydroxide ions (OH^-), which neutralize additional acidity in the soil [28-30]. This dual mechanism—ion exchange and hydroxide production—makes these nanocrystals an effective tool for ameliorating acidic soils. Further, many authors [31-34] reported that in addition to ion exchange and dissolution, soil buffering capacity plays a role in how magnesium affects soil pH. Magnesium can interact with other soil minerals, potentially modifying the buffering capacity of the soil and contributing to a more gradual or sustained increase in pH. This process results in the formation of different ions, ultimately leading to an increase in soil pH. This effect can be particularly beneficial in soils where acidity inhibits plant growth, helping to create a more favorable environment for nutrient uptake and overall soil health.

VI. Conclusion:

Here, in this work the banana plant waste materials have been prepared in powder form. The materials have been characterized by XRD, SEM with EDAX and FTIR. X-ray diffraction study clearly indicates the banana plant wastes material are crystalline in nature, whereas Scanning Electron Microscopy confirms the formation of nanocrystals and Energy Dispersive X-ray Analysis also gives the presence of various elements viz. K, C, Fe, Na and Mg present in the banana plant waste powder along with a high amount of magnesium. Further, the functional groups identified in the FTIR spectra—glycosidic bonds, ether groups, alkynes, and alkenes—are indeed crucial for enhancing the properties of banana waste-derived nanomaterials. These functional groups play a pivotal role in improving the effectiveness of these materials as soil amendments. Here, in this study banana plant waste materials were applied in varying concentrations to evaluate their effectiveness in enhancing soil pH. Among the tested combinations, the mixture containing 50 g of soil diluted in 150 ml of water with 0.30 g of the powdered banana plant waste was found to be the most effective, resulting in a pH range of 6.20 to 6.35. This indicates a favorable shift toward neutral pH levels, suggesting the material's suitability for amending acidic soils. Furthermore, X-ray Diffraction (XRD) analysis revealed the presence of alkaline mineral phases within the prepared samples. These mineral constituents are likely responsible for the observed pH improvement, as they contribute to the neutralization of soil acidity. Overall, the findings emphasize the potential of banana plant waste as an eco-friendly and sustainable solution for managing soil pH and improving soil health.

Acknowledgement:

The authors express their sincere gratitude to the scientific staff of the Directorate of Biotechnology for their valuable support during the experimental work. The authors also acknowledge Dr. Babli Debnath, Research Scholar at the Nano-Physics & Nanotechnology Research Lab, Department of Physics, Tripura University, India, for her assistance in conducting the SEM and FTIR analyses.

Declarations

Conflict of interest: The author confirms that there are no financial interests or personal relationships that could be perceived as influencing the research presented in this paper.

References:

[1] D. Mohapatra, S. Mishra, N. Sutar, Journal Scientific & Industrial Research, 69 (2010) 323-329
[2] K. P. S. Kumar, D. Bhowmik, S. Duraivel, and M. Umadevi, Journal Pharmacognosy and Phytochemistry 1 (2012) 51-63
[3] N. W. Simmonds, The evaluation of bananas. Tropical Science Series (Longmans, London) (1962)
[4] G. V. Reddy, P Babu Ravindra, P. Komaraiah, K.R.R.M Roy, I. L. Kothri, Process Biochem 38 (2003) 1457-62
[5] Nanda K. Fageria, Adriano S. Nascente, in Advances in Agronomy, Management of Soil Acidity of South American Soils for Sustainable Crop Production, Advances in Agronomy 128 (2014) 221-275
[6] N.W. Ashcroft, N.D. Mermin, Solid State Physics, Saunders College, 1976
[7] R. Das, S. Sarkar, Materials Chemistry and Physics 167 (2015) 97-102
[8] S. Sarkar, R. Das, Journal of Nondestructive Evaluation 38 (2019) 1-8
[9] S. Sarkar, R. Das, Micro & Nano Letters 13 (2018) 312 – 315
[10] M. M. Rahmana, M. E.HosenPk.,M.Waliullah,M. I. Hossain,M.Maniruzzaman,B.C. Ghos, Carbohydrate Polymer Technologies and Applications 8 (2024) 100607
[11] L. Hadisoewignyo, K. Foe and R.R Tjandrawinata, International Food Research Journal 24 (2017) 1324-1330
[12] S. Mishra, B. Prabhakar, P. S. Kharkar, A. M. Pethe, ACS Omega 8 (2023) 1140−1145
[13] G. Kataya, M. Issa, M. Jeguirim and A. Hijazi, Eng. Proc. 37 (2023) 105
[14]J. Celio Pasquini, Braz. Chem. Soc. 14 (2003) 198–219.
[15] R. Kumar, R. Verma, International Journal of Environmental Science and Technology, 11 (2014) 155-161.
[16]Y.Li& W. Li, Journal of Agricultural and Food Chemistry, 65 (2017) 2289–2297
[17] M K Murigi, E S Madivoli, M MMathenyu, P G Kareru, A N Gachanja, P K Njenga, G Nowsheen, P N Githira& Mercy Githua, Journal of Polymer and Textile Engineering, 1(2014) 53-63.
[18] B. Dan-asabe, A.S. Yaro, D.S. Yawas, S.Y. Aku, I.A. Samotu, U. Abubakar, D.O. Obada, Tribology in Industry 38 (2016) 255-266
[19] X. Kong, H.Zhang& L. Li, Journal of Environmental Science, 45 (2017) 543-550.
[20] A. Sharma, R. Gupta & P. Mishra, Environmental Nanotechnology, 22 (2020) 312-325.
[21] W. Elkhatib, H. Omar &S. Ali, Sustainable Agriculture Reviews, 15(2021) 89-103.
[22] R. Singh, S. Kumar, &P. Verma, Soil Science and Plant Nutrition, 65 (2019) 256-272.
[23] M. González, E. García&S. Ramírez, Agricultural Innovations, 37(2022) 1015-1028.
[24] R. Gentili, R. Ambrosini, C. Montagnani, S.Caronni and S.Citterio, Front. Plant Sci., 2018. Doi:10.3389/fpls.2018.01335
[25] H. Ireri Gitari, B. Evans Mochoge and B. Oginga Danga, J. Soil Sci. Environ. Manage, 6(2015) 275-283
[26] A. Sutradhar, R. P. Lollato, K. Butchee and D. B. Arnall, International Journal of Agronomy, 2014, 13 pages, Doi:10.1155/2014/894196
[27] A. Voegelin, S. Pfister, A.C. Scheinost, M. A. Marcus, R. Kretzschmar, Environ. Sci. Technol. 39 (2005)6616–6623
[28] W. Raza, G. M. Shah, Journal of Nanoscience and Nanotechnology, 21 (2021) 5645-5655.

[29] P. K. Samal, S. Sahoo, International Journal of Agricultural Science and Research, 12 (2022) 123-134.
[30] A. Chaturvedi, P. Khare, Environmental Nanotechnology, Monitoring & Management, 13 (2020) 100303.
[31] H. Marschner, (2012). Mineral Nutrition of Higher Plants (3rd ed.). Elsevier Publisher. ISBN: 978-0-12-384905-2, DOI: https://doi.org/10.1016/C2009-0-63043-9
[32] M. Senbayram, A. Gransee, V. Wahle, and H. Thiel,Crop& Pasture Science, 66 (2015) 1219–1229
[33] P. S. Hooda, L. E. Naylor (2013) Soil Acidification and Liming Practices in Agriculture, Wiley-Blackwell Publisher, ISBN: 978-0470667241
[34] S. L. Tisdale, W. L. Nelson, &J. D. Beaton(1985) Soil Fertility and Fertilizers. Macmillan Publisher, ISBN: 0024201002