AN EXPERIMENTAL STUDY ON BIOCHAR PRODUCED FROM PISTACHIO SHELLS

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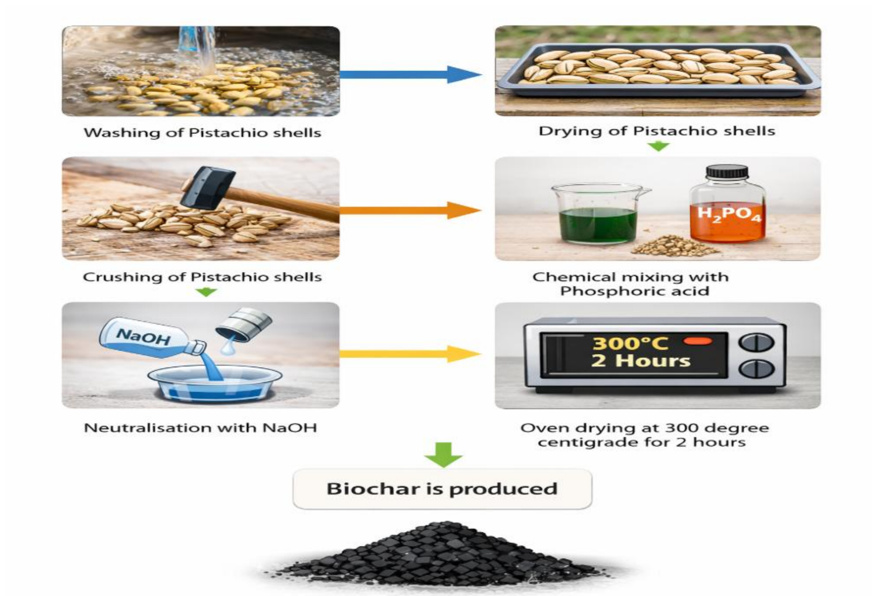
ABSTRACT

The growing accumulation of agricultural biomass waste has intensified the need for sustainable waste management strategies. This study investigates the production and characterization of biochar derived from pistachio shells through chemical activation and thermal treatment at 300°C. Proximate analysis and Fourier Transform Infrared Spectroscopy (FTIR) were conducted to evaluate carbon stability and surface functional groups. The fixed carbon content was found to be 24.20%, indicating moderate carbonization. FTIR analysis revealed aromatic structures and oxygen-containing functional groups, suggesting potential suitability for soil amendment and nutrient retention. However, comparison with published studies indicates that higher pyrolysis temperatures are required to enhance fixed carbon content and structural stability. The findings support pistachio shell biochar as a sustainable, low-cost material with scope for optimization in environmental applications.



KEYWORDS

Biochar, Pistachio shells, Pyrolysis, Fixed carbon, FTIR analysis, Biomass valorization, Soil amendment, Carbon sequestration

1. INTRODUCTION

The increasing generation of agricultural and food-processing waste presents significant environmental challenges. Improper disposal contributes to greenhouse gas emissions and resource loss. In this context, biochar has emerged as a promising approach for converting biomass residues into stable carbon-rich materials.

Biochar is produced through pyrolysis under limited oxygen conditions. It is characterized by porous structure, surface functional groups, and environmental stability. These properties make it useful in soil amendment, nutrient retention, contaminant immobilization, and carbon sequestration.

Pistachio shells are an abundant lignocellulosic waste generated by the food industry. Their high carbon content and structural rigidity make them suitable precursors for biochar production. This study aims to produce pistachio shell biochar using chemical activation and moderate thermal treatment, evaluate its physicochemical properties, and compare its quality with findings reported in published literature.

2. LITERATURE REVIEW

Previous research has demonstrated that pistachio shell biochar possesses promising structural and adsorption characteristics. Studies published in the *Journal of Composite Sciences (MDPI)* report that controlled pyrolysis enhances porosity and structural stability, making pistachio shell biochar suitable for environmental remediation.

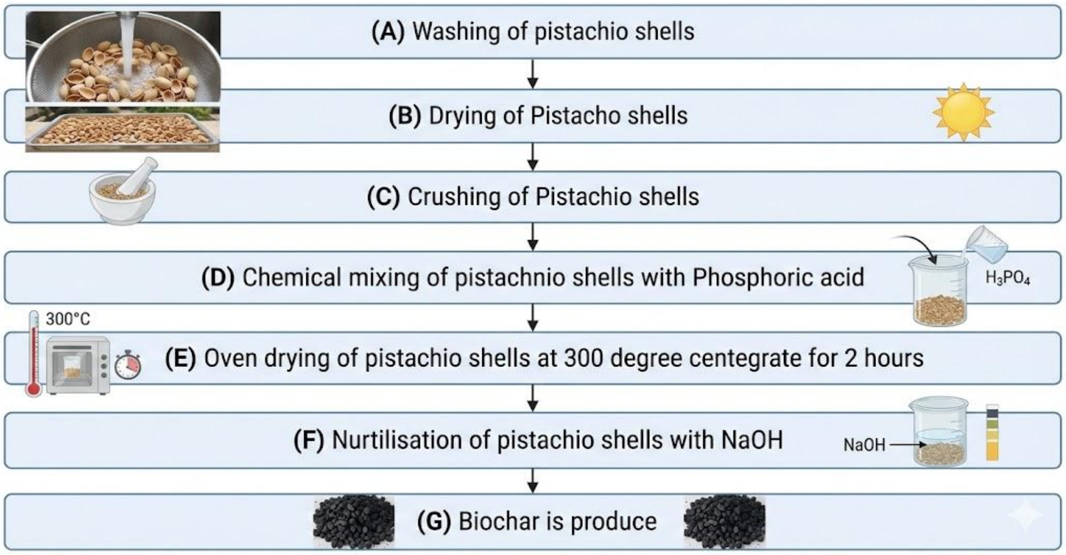
Research available on *ScienceDirect* indicates that biochar produced at elevated temperatures (500–700°C) achieved BET surface areas exceeding 300 m^2/g and demonstrated efficient adsorption of dyes such as Congo Red and Methylene Blue. The primary mechanisms included π–π interactions, hydrogen bonding, electrostatic attraction, and pore filling.

Similarly, studies in *Waste and Biomass Valorisation (Springer Nature)* show that higher-temperature biochars typically exhibit fixed carbon content ranging from 50–80%, enhanced aromaticity, and improved heavy metal adsorption capacity.

However, lower pyrolysis temperatures (below 400°C) generally result in reduced carbonization, higher volatile matter, and lower structural stability. This highlights the critical influence of temperature on biochar quality.

Therefore, while pistachio shell biochar is recognized as a sustainable and low-cost adsorbent, optimization of pyrolysis parameters remains essential for achieving high-grade performance.

3. METHODOLOGY



Procedure for the Preparation of Chemically Activated Pistachio Shell Biochar

3.1 Raw Material Preparation

Pistachio shells were collected and thoroughly washed with demineralized water to remove impurities. The material was sun-dried for four hours to eliminate surface moisture.

Picture 1: Washing of Pistachio Shells followed by sun drying

3.2 Size Reduction and Sieving

The dried shells were crushed into approximately 1 cm pieces and sieved to obtain uniform particle size.

Picture 2: Crushing of Pistachio Shells & determination of the weight

3.3 Chemical Activation

The crushed shells were mixed with phosphoric acid (H_3PO_4) and stirred for 10 minutes using a magnetic stirrer to ensure uniform impregnation.

Picture 3: Chemical Activation Process with Phosphoric Acid

3.4 Thermal Treatment

The chemically treated material was heated at 300°C for 2 hours in a laboratory drying oven to promote carbonization.

Picture 4: Thermal treatment at 300 degree C

3.5 Neutralization and Washing

The carbonized product was washed with sodium hydroxide (NaOH) solution to neutralize residual acid and further rinsed with hot water to remove impurities.

3.6 Final Processing

The material was sun-dried and ground into fine powdered biochar for analysis.

3.7 Characterization Techniques

Biochar characterization included:

- Proximate analysis for fixed carbon determination
- Fourier Transform Infrared Spectroscopy (FTIR)

All measurements were conducted in triplicate to ensure reproducibility. Mean values were calculated, and variation was maintained within ±5%.

Picture 5: Final Product: Biochar

4. RESULTS AND DISCUSSION

4.1 Proximate Analysis

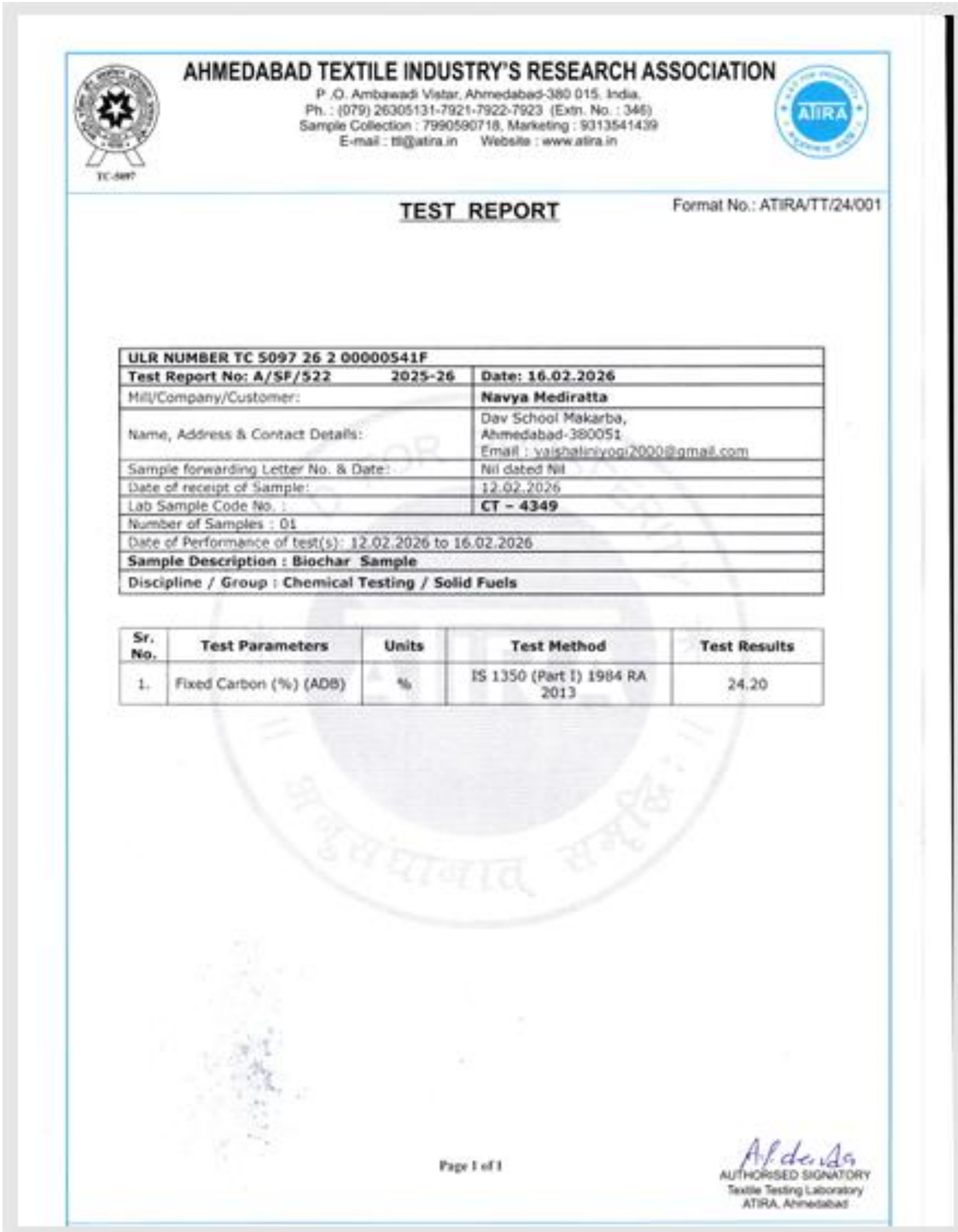
The fixed carbon content was determined to be 24.20%. High-quality biochar intended for carbon sequestration typically exhibits 50–80% fixed carbon when produced at 500–700°C. The relatively low fixed carbon content observed in this study can be attributed to the moderate pyrolysis temperature of 300°C. At lower temperatures, incomplete devolatilization occurs, resulting in higher volatile matter and reduced aromatic carbon formation.
Additionally, chemical activation may contribute to mineral residue retention, further affecting carbon percentage.

Comparative Analysis:

Published pistachio shell biochars produced at 500–600°C report fixed carbon values between 55–75%. The present study's value is significantly lower, indicating incomplete carbonization.

Improvement Strategies

- To enhance fixed carbon content in future studies:
- Increase pyrolysis temperature to 500–600°CExtend residence time beyond 2 hours
- Conduct carbonization under inert atmosphere (nitrogen)
- Optimize acid impregnation ratio



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TC-5097

TEST REPORT

Format No.: ATIRA/TT/24/001

ULR NUMBER TC 5097 26 2 00000541F	
Test Report No: A/SF/522 2025-26	**Date: 16.02.2026**
Mill/Company/Customer:	**Navya Mediratta**
Name, Address & Contact Details:	Dav School Makarba, Ahmedabad-380051 Email : vaishaliniyogi2000@gmail.com
Sample forwarding Letter No. & Date:	Nil dated Nil
Date of receipt of Sample:	12.02.2026
Lab Sample Code No. :	**CT – 4349**
Number of Samples : 01	
Date of Performance of test(s): 12.02.2026 to 16.02.2026	
Sample Description : Biochar Sample	
Discipline / Group : Chemical Testing / Solid Fuels	

Sr. No.	Test Parameters	Units	Test Method	Test Results
1.	Fixed Carbon (%) (ADB)	%	IS 1350 (Part I) 1984 RA 2013	24.20

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Textile Testing Laboratory
ATIRA, Ahmedabad

Picture 6: Test Report for Fixed Carbon

4.2 FTIR Analysis

FTIR analysis revealed the following functional groups:

- ~1560 cm^{-1}: Aromatic C=C bonds
- ~1693 cm^{-1}: Carbonyl (C=O) groups
- ~1112 cm^{-1}: C–O stretching
- ~970 and 876 cm^{-1}: Aromatic ring structures
- ~468 cm^{-1}: Mineral-related vibrations

The presence of aromatic C=C bonds confirms partial graphitization and structural stability. Carbonyl and C–O groups indicate oxygenated surface chemistry, which enhances adsorption of heavy metals through complexation mechanisms.

Aromatic ring structures support π–π interactions, beneficial for adsorption of organic dyes. Mineral peaks suggest ash content, which may contribute nutrients when applied to soil but may reduce adsorption selectivity.

Overall, the FTIR results indicate that the produced biochar is more suitable for soil amendment and nutrient retention rather than high-efficiency industrial adsorption applications.

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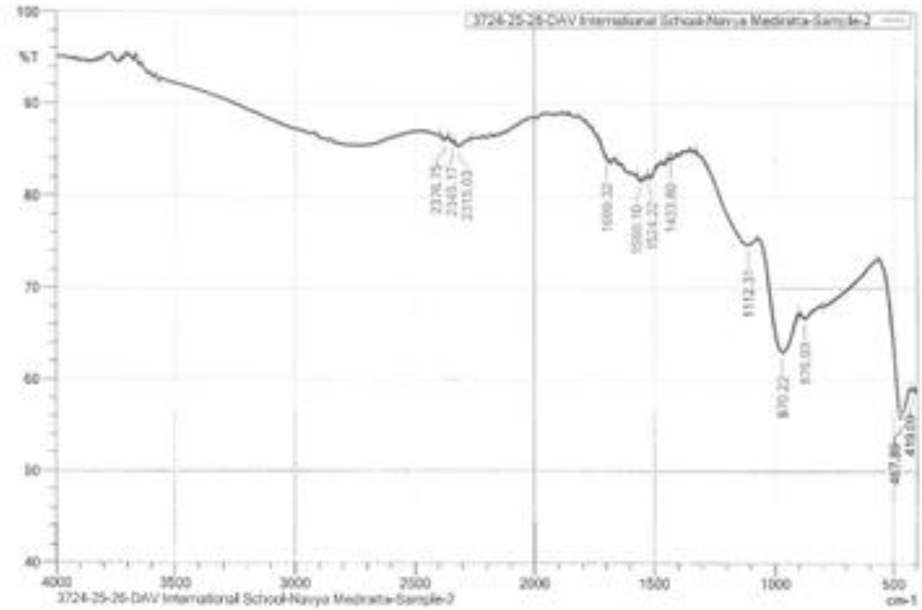

E:¥DHARA¥DATA¥2025-26¥February 2026¥3724-25-26-DAV International School-Navya Mediratta-Sample-2.ispd
3724-25-26-DAV International School-Navya Mediratta-Sample-2

	Item	Value
2	Sample name	Sample-2
3	Sample ID	3724-25-26
4	Option	
5	Intensity Mode	%Transmittance
8	Apodization	Happ-Genzel
9	No. of Scans	45
10	Resolution	4 cm-1

	Peak	Intensity	Corr. Intensity	Base (H)	Base (L)	Area	Corr. Area	Comment
1	419.39	58.92	0.14	421.96	411.91	411.662	0.824	
2	467.89	55.79	7.33	564.05	430.57	4833.210	326.919	
3	876.93	66.75	0.83	899.89	800.86	3220.123	30.527	
4	970.22	63.07	7.65	1072.12	899.89	5605.877	689.684	
5	1112.31	74.80	2.20	1327.59	1072.12	5393.480	344.480	
6	1433.80	84.05	0.03	1436.67	1430.93	91.489	0.074	
7	1524.22	82.10	0.21	1529.96	1519.91	176.700	1.058	
8	1560.10	81.67	0.39	1571.58	1552.92	337.788	4.090	
9	1699.32	84.06	0.12	1730.89	1687.66	494.078	4.915	
10	2315.03	85.37	0.70	2336.56	2263.36	1040.704	24.360	
11	2345.17	85.81	0.38	2362.39	2336.56	359.761	5.259	
12	2376.75	86.04	0.55	[illegible]	2362.39	489.813	8.886	

Charutar Vidya Mandal SICART V.V. Nagar-388120

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Picture 9: Test Report for Fourier Transform Infrared Spectroscopy (FTIR).

5. LIMITATIONS

Chemical activation requires energy input and may generate wastewater containing residual chemicals. The moderate pyrolysis temperature limited carbonization and structural stability. Absence of BET surface area and SEM analysis restricts complete structural characterization. Regeneration of activated biochar may also reduce mechanical strength over repeated cycles.

6. RECOMMENDATIONS FOR FUTURE WORK

Future studies should:

- Optimize pyrolysis temperature (500–700°C)
- Employ inert atmospheric conditions
- Conduct BET surface area analysis
- Perform CHNS elemental analysis
- Include SEM imaging for pore morphology
- Apply adsorption isotherm modeling (Langmuir and Freundlich)
- Incorporate detailed statistical tools such as ANOVA

These improvements will enhance structural stability and adsorption performance.

7. CONCLUSION

This study demonstrates that pistachio shells can be converted into biochar through chemical activation and thermal treatment at 300°C. The produced biochar exhibited functional surface groups and partial aromatic structure; however, the fixed carbon content of 24.20% indicates moderate carbonization compared to high-temperature biochars reported in literature.

The material shows potential for soil amendment and nutrient retention. Nevertheless, optimization of pyrolysis temperature and processing conditions is essential to enhance structural stability and adsorption efficiency. With improved thermal parameters, pistachio shell biochar can serve as a sustainable and effective material for environmental remediation and carbon management.

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