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Development and Performance Evaluation of Hybrid Solar Cells Using Biochars from Agricultural Waste

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ABSTRACT

This study investigates the potential of biochar derived from agricultural waste—specifically plantain peels, groundnut shells, and rice hulls—for enhancing solar cell performance. Key findings reveal that biochar exhibits significant elemental composition, including high silicon concentrations (up to 100% in some samples) and oxygen levels (up to 68.30%), which are essential for improving charge transport and energy conversion efficiency. Thermal stability assessments show favorable temperature profiles, with peak temperatures reaching 47.55℃, indicating that biochar can maintain integrity under varying environmental conditions. Preliminary performance comparisons suggest that biochar-based solar cells can achieve efficiencies comparable to or exceeding those of traditional silicon-based models, which typically operate above 20% efficiency. Additionally, utilizing agricultural waste for biochar not only provides a sustainable alternative but also reduces production costs, addressing environmental concerns associated with waste disposal while promoting renewable energy solutions. These findings collectively highlight the viability of biochar-based solar cells as an innovative and sustainable alternative to conventional solar technologies, hence, setting the stage for future research into advanced hybrid solar cell systems.

1. INTRODUCTION

Sustainable hybrid solar cells, developed using biochar from agricultural waste, offer significant contributions to Nigeria's energy landscape. By providing a renewable energy source, these cells reduce dependence on fossil fuels and promote waste valorization, addressing both waste management and circular economy principles in agriculture. Utilizing locally sourced materials can lower production costs, enhancing accessibility to renewable energy for communities and small industries. Hence, it is essential that we find and use other sources of renewable energy. One energy source that has been identified as a prospective renewable energy source that will contribute more to halting the depletion of the current energy source is solar energy. Therefore, it seems quite likely that photovoltaic technology and panels will be utilized to fulfill both the existing energy needs and lower carbon emissions [1].

The consumption of energy in big areas is quite high and this is expected to keep rising for many years to come. The major supply of power is the thermal power plants, thus, the use of solar energy may be an alternative substitute for power plants where clean energy is generated without much noise [1]. Based on the study conducted by Kerr et al. [2], on Mars, solar energy has been installed as a power source for the Mars surface mission. In order to compare the ideal orientation of static tilted solar panels with those that rely on sun-tracking around the earth, the study employed a one-dimensional radiative transfer method. Based on the surface position, the study found that the slanted solar panel can capture up to 8.5 times as much solar energy as a horizontal static panel. Furthermore, it was said that the static panels could gather minimum of about 53% of the total solar radiation accessible to the sun-tracking panel at the ideal elevation and azimuthal pointing for the area. Additionally, it was shown that the polar regions benefited more from the benefits of both inclined and sun-tracking solar panels [2]. Therefore, more power can be accessed by implementing a system that can change direction for a portion of a year. Consequently, this study's insight shown that it is feasible to harvest the energy available for various solar panel orientations for use in cost-benefit assessments of sun-tracking panels and power calculation for surface missions to Mars in the mission's planning stages.

Khalil et al. [3] stated the utilization of solar dryers in drying agricultural goods has gained ground in various sectors. However, there are bottlenecks to the use of open sun drying. Based on the latest technologies, photovoltaic/thermal (PVT) panels have been found to be very effective in solving these limitations. Patil et al. [4] revealed that an increase in the temperature of photovoltaic solar cells is usually caused by increased levels of solar radiation which has an adverse effect on the efficiency and life span of the photovoltaic cells. The study performed an experimental investigation on how to minimize the photovoltaic cells operating temperature using an air-cooling system. This experiment was developed and integrated at the panel back. Additionally, an equal amount of research was done on the impact of air mass flow rate on heat transfer from PV panels to the surrounding air. The findings demonstrated that the PV's operating temperature had dropped and its electric performance had increased. Thus, the temperature of the PV cells was dropped to about 9 degrees Celsius. Also, the air mass flow rate was recorded as 0.08 kg/s while the mean optimal temperatures with and without air cooling were recorded respectively as 45.60°C and 50.24°C. The effect of reducing the temperature resulted in an increase in the efficiency of the energy conversion from 7 to 12.6%. Thus, using air-cooling systems could be a solution for preventing cells from excessive temperature. In the study of Zhang et al. [5], the numerical investigation of solar energy for heating purposes was done using Energy Plus and Multiphysics by using a solar panel of size 0.51 m × 1 m for the simulation process. The rectangular chamber which contains $CaCl_{26}H_2O$ as a phase transiting element was located below the solar panel while a pipe containing Al_2O_3-water as nanofluid was deployed for the hot water supply in a residential building. Furthermore, the temperature of the panel and the melted phase change material below the panel were investigated using varying nanofluid velocities of flow. It was observed that an increased flow velocity of 20 mm/s resulted in a decreased temperature of the lower panel when compared to a velocity of 5 mm/s. Hence, an increase in the nanofluid velocity will result in an increase in the fraction of energy demand which was generated via the solar system in the daytime period.

Senthil [6] disclosed that the sustainability of global energy can be improved via the effective utilization of solar energy. While the use of photovoltaic solar installations is on the increase globally, the focus should be on the effective management of solar cells. Integration of solar collectors into photovoltaic cells is very important as it helps the energy requirements. The use of photovoltaic solar cooling helps in improving electrical life and productivity, hence using solar water/air heating mechanism in PV finds application in drying, space heating, solar desalination, heating process, and hot water. One of the fastest-growing energy sources that has brought an enormous decrease in the carbon footprint is in the use of solar photovoltaic panels. In fact, in the mid-century, there are probabilities that it could become the largest source of renewable energy [7]. Additionally, the word total energy is becoming a very great area in the world, especially in developed regions, energy need is becoming an unavoidable factor in economic growth, and the advance in industry is not possible where reliable energy resources are absent. The activities of the industries are dependent on energy [8]. The aim of countries worldwide is to decrease carbon emissions via the use of environmentally friendly materials. To be able to achieve environmental sustainability, the use of renewable energy technologies is playing a big role. It was established that solar energy has achieved great interest in accessing the untapped potentials in solar cells and solar cell thermal collectors. Abid et al. [9] proposed an incorporation of copper-reinforced metal-organic frameworks (Cu-MOFs) in solving pressing challenges that includes instability, suboptimal power conversion efficiency and inefficient light absorption in Perovskite solar cells (PSCs). They anticipated that the incorporation of Cu-MOFs into PSCs will lower energy usage and greatly increase the solar cells' efficiency. Widhiyanuriyawan et al. [10] investigated the influence of carrying out precoating on $TiCl_4$ in the cause of producing a semiconductor that is TiO_2 based for a two-layered TiO_2/ZnO Dye-Sensitized Solar Cell. According to the findings, TiO_2 nanoparticles treated with $TiCl_4$ for 60 minutes had greater inter-particle connection than those treated for shorter periods of time. It has been established that the use of solar cell thermal regulators via hybrid cooling of flat heat pipe integrated with phase change materials with and without the integration of hybrid nanoparticles has yielded tremendous results. The heat pipe with phase change material incorporated cooling system was observed to have excellent performance when compared to the natural solar cooling panel which was boosted using hybrid nanoparticles [11]. In the study of Alamayreh and Alahmer [12], it was reported that direct thermal energy storage can be improved in the solar dish technology using a steady supply of heat source even in the presence of low or intermittent solar radiation. Biochar formed from agricultural waste has shown promise as a material for eliminating environmental toxins due to its many functional groups, broad pore size distribution, high heat stability, and large surface area. In addition to efficiently adsorbing pollutants from gas, catalysis, composting and anaerobic digestion, biochar derived from agricultural waste has the potential to improve soil fertility [13-15]. But because of their affordability, large surface area, and extraordinarily high electronic conductivity, scientists have lately begun working on producing supercapacitor electrodes from agricultural waste [16, 17].

While solar cells have gained significant traction as a viable renewable energy source, they still face limitations such as relatively low efficiency, high energy loss due to high temperature, and high manufacturing costs. As reported by Soonmin et al. [18], crystalline silicon was used to create the first generation of solar cells. They were rather effective, but because they needed a lot of energy to purify the silicon, they were highly costly. The manufacturing of solar cells has advanced since the first generation, and now includes thin-film, dye-sensitized, perovskite, and organic solar cells.

These challenges hinder the widespread adoption of solar energy and its potential to significantly reduce greenhouse gas emissions and reliance on fossil fuels. Hence, the current study aims to explore the utilization of agro waste products suitability in the production of hybrid solar cells with a view to minimize temperature of the solar cells, energy loss and enhance the energy generation efficiency of the solar cells with a reduced cost.

2. MATERIALS AND METHODS

2.1 Materials selection justification

The selection of agricultural wastes such as peanut shells, groundnut shells, rice hulls, and plantain peels for solar cell production is grounded in several compelling reasons. First, these materials are abundantly available due to widespread cultivation, ensuring a sustainable and consistent feedstock. Peanut and groundnut shells, in particular, are rich in carbon, making them ideal for biochar production, which enhances solar cell performance. Rice hulls, often regarded as waste from rice production, contain silica that improves the electrical properties of solar cells, thereby increasing efficiency. Similarly, plantain peels are nutrient-rich and help reduce food waste, promoting sustainability in agricultural practices.

2.1.1 Collection and preparation of plantain

The peel of plantain was sourced from a local market stall in Ikire, Nigeria. The peels were dehumidified at 50 degrees centigrade for eight hrs. using a drying oven. After drying, the materials were transferred to a laboratory ball mill for grinding. Before milling the pieces, the inside of the ball mill was wiped clean with a wet cloth and left to dry. A five-hour rotational period at 330 rpm and 2000 revolutions was used in milling the peel. A sieve was used to separate the finer particles away from the unmashed peel materials. Pulverisation and sieving were required to expand the area of their surfaces and let the ingredients to thoroughly bond while being blended. For further examination, the recovered pulverized hulls were kept in a bag with a zipper. Figure 1 is a representation of the sieved plantain peels.

2.1.2 Collection and processing of peanut shells

Equal amounts of freshly picked and roasted peanuts were used in this investigation and groundnuts in shells were sourced from a market in Ado Ekiti, Ekiti State, Nigeria. The peanuts were shelled manually at the mechanical engineering laboratory at Afe Babalola University, Ado Nigeria. Following segregation, the shells were cleaned with water to get rid of any contaminants that had stuck to them. After being cleaned, the shells were left to air dry at room temperature until all of the moisture had been removed, and then they were dried for eight hours at 10 degrees in an electric oven. The entire shells that were dehumidified was grounded in a single batch using the similar ball mill utilized in grinding the Plantain peel shells and then separated. The pulverised shells were stored in a zip-lock bag for further characterisation. Figure 2 is a sample of the sieved peanut shell.

Figure 1. Milled and sieved plantain

Figure 2. Milled and sieved peanut shells

Figure 3. Pulverized rice hulls

2.1.3 Collection and preparation of rice hulls

Already milled rice hulls were purchased from Bodija market in Ibadan Oyo State, Nigeria. The rice hulls were filtered after being left unaltered and unprocessed in order to create porosity in the filtered material. The Kaolin material was used as a binder. Figure 3 is a representation of the pulverized rice hulls used for the experiment.

2.1.4 Preparation of biochar

Pyrolysis, akin to charring, involves a chemical reaction (thermal decomposition) that eliminates all atoms that are not carbon from the feedstock. The pyrolysis process is typically conducted in an inert atmosphere (with the presence of nitrogen and the absence of oxygen) at temperatures between 600 and 1200. This research used biomass (Plantain, Rice hulls, peanut and groundnuts shells) as the precursors for biochar preparation. Before pyrolysis, the materials were weighed and recorded in grams.

The groundnut and powdered peanut shells were each separately added to four mediums in size ceramic crucibles. The ceramic crucibles were then moved into a muffled furnace. The carbonisation procedure was carried at a carbonisation temperature of 600 degrees centigrade, carbonisation time of 3 hrs. A rate of heating at about 10 per minutes in an atmosphere where air is not circulated. As shown in Figure 4, following the pyrolysis process, the resultant biochars were left to cool. To get rid of ash and other contaminants, the biochar granules were carefully cleaned with distilled water. Following a 24-hour drying process at 105 degrees, the filtrates were sieved and then placed in an airtight container for later utilization.

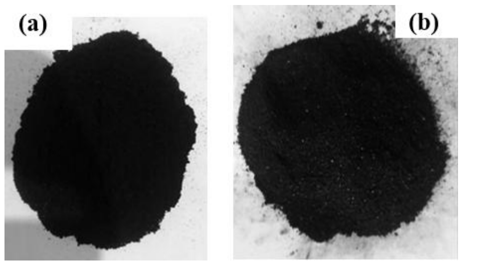


Figure 4. Produced biochar

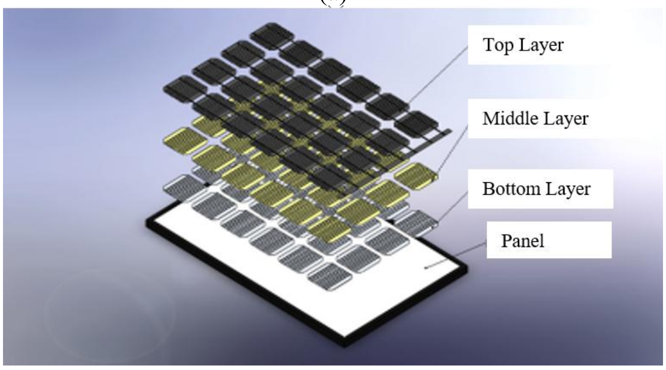
2.2 Design and modelling of solar cell prototype hybrid solar panel system

2.2.1 Design optimization

As a result of the findings from the literature review, the design of the hybrid solar cell was optimized to maximize its energy efficiency. The design was carried out using AutoCAD and other relevant tools as shown in Figures 5 (a) and (b).

A prototype of the hybrid solar cell was fabricated using the optimized design. The fabrication process will involve depositing organic and inorganic layers onto a suitable substrate, followed by the application of transparent conductive electrodes. The fabricated device was characterized to evaluate its performance parameters, such as temperature, power output characteristics, external quantum efficiency, and stability under different environmental conditions.

(a)



(b)

Figure 5. (a) Solar cell prototype (b) Solar cell exploded view

2.2.2 Preparation of materials using design expert

Design expert was used to prepare the materials using the formulated ratio at proportioned percentage ratio for an optimal mixing ratio of the materials used as shown in Table 1. The mixing ratios of peanut shells, groundnut shells, rice hulls, and plantain peels for solar cell production are strategically designed to leverage their unique properties while ensuring sustainability. Peanut and groundnut shells, with high carbon content, are included to enhance the energy density of the biochar, typically in ratios of 20% for peanut shells and 10-15% for groundnut shells. Rice hulls, contributing significant silica, are often included at higher percentages to improve the electrical properties and overall efficiency of the solar cells. Plantain peels, containing nutrient-rich organic matter, are incorporated at varying ratios to enhance the structural integrity and porosity of the biochar. The variations in these ratios allow for a balanced optimization of mechanical strength, thermal stability, and electrical conductivity, which is crucial for performance.

2.3 Development of hybrid solar cell

The biochar particles of the selected agro-wastes comprise of 2 kg each of peanut shell, rice hull, plantain peel and groundnut shell were mixed with adhesive materials at different mixing ratio as showed in Table 1. Ten samples of solar cell were developed with different aggregate ratio of the materials which were randomised using design expert for optimized mixing ratio. The design also considered scalability and manufacturability. In order to achieve the aims and objectives of this study, as well as to develop a hybrid solar cell system, a careful selection of materials and sample 8 with the same proportion of mixing ratio gave the best maximum power of solar cell. Figures 6 (a)-(d) describe the weighing of biochar to their respective ration-percentages. Figure 7 shows samples of cupper conductors used for the cell production while Figure 8 presents samples of the developed hybrid solar cells.

Table 1. Mixing ratio for the materials

S/N	Peanuts Shell	Groundnut Shell	Rice Hulls	Plantain Peel
1	20	10	50	20
2	25	15	40	20
3	20	10	45	25
4	10	15	55	20
5	30	20	40	10
6	25	15	30	30
7	10	20	40	30
8	25	25	25	25
9	20	20	30	30
10	20	30	30	20

(a) (b) (c) (d)

Figure 6. Weighing of the biochar's to their respective ratio-percentages

Figure 7. Cupper conductors for the production

(a) (b)

(c) (d)

Figure 8. Developed solar cells samples

Figure 9. JSM-7600F Schottky field emission scanning electron microscope

2.4 Performance evaluation

2.4.1 Temperature measurement from temperature sensor

The temperature sensor was connected to Arduino and displays the critical temperature of each solar cell. The temperature of all the cells were measured every hour on different days between 10:00 am to 04:00 pm per day.

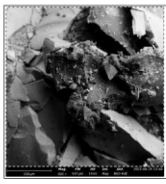
2.4.2 Scanning electron microscopy (SEM)

The morphology of the surface for the specimen of solar cell, developed solar cells and materials such as Rice hulls, Plantain peel, peanut shells and groundnut shells, and composite blend were studied using an SEM analyser as shown in Figure 9. SEM is a type of microscope used to visualise the porous structure of a material, using a beam of highly energetic electrons to scan a sample or specimen and create its image. The magnification was adjusted for getting a clear picture. The results of the SEM of the groundnuts shell, peanut shells, rice hulls, plantain peel and composite blend samples are shown in the result section.

3. RESULTS AND DISCUSSION

3.1 SEM and EDX results of the materials used

As shown in Table 1, the elemental composition of materials significantly influences the performance of solar cells, particularly in the context of hybrid solar cells enhanced by biochars derived from agricultural waste. The control sample demonstrated a substantial presence of essential elements: 54.00% oxygen, 24.00% silicon, and notable amounts of sodium, carbon, and calcium. In contrast, agricultural waste materials such as rice hulls, groundnut shells, and plantain peels exhibited higher concentrations of silicon and oxygen, crucial for photovoltaic efficiency. For instance, rice hulls contained 61.98% silicon and 56.07% oxygen, while groundnut shells showcased 85.32% oxygen alongside 14.68% carbon. These high levels of silicon and oxygen can enhance charge transport and light absorption, vital for energy conversion efficiency. Furthermore, the carbon content in groundnut shells and plantain peels (14.68% and 18.38%, respectively) suggests improved conductivity, which can reduce resistive losses within the solar cell architecture (Figure 10).



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
8	O	Oxygen	64.60	54.63
14	Si	Silicon	16.16	24.00
11	Na	Sodium	8.60	10.45
6	C	Carbon	7.82	4.97
20	Ca	Calcium	2.81	5.96

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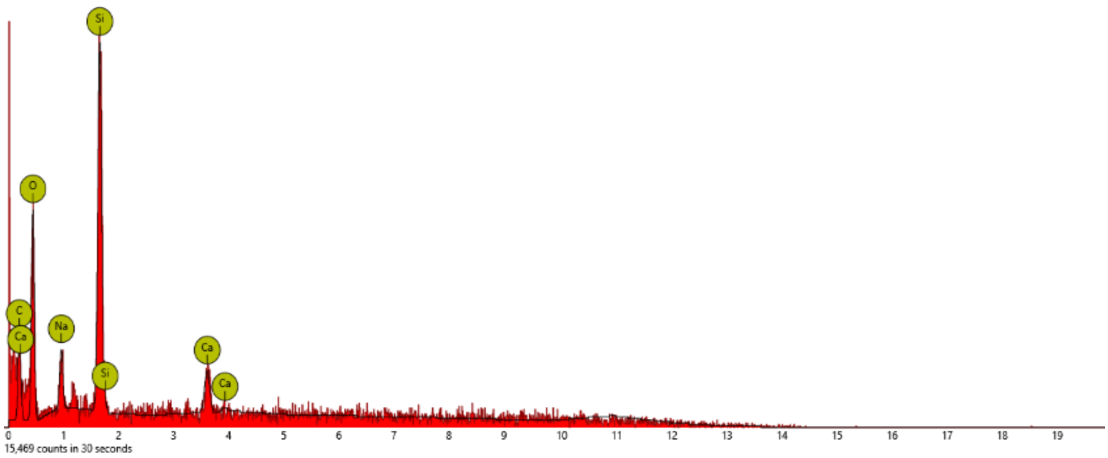

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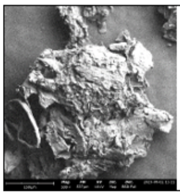
Figure 10. SEM and EDX of the control solar cell

When compared to traditional silicon-based solar cells, which typically achieve efficiencies above 20%, biochar-enhanced solar cells may initially exhibit lower performance levels due to their varying elemental compositions and the challenges associated with processing agricultural waste. However, the advantages of utilizing these biochars include cost-effectiveness and sustainability, as they not only provide a viable source of materials but also contribute to carbon sequestration and improved soil health. While biochar-derived solar cells may currently lag behind in efficiency, their environmental benefits and potential for innovation present a promising avenue for the future of renewable energy technologies, warranting further research to optimize their performance and integration into the solar energy landscape.

3.1.1 Plantain-based hybrid solar cell results

Figures 11-13 present the elemental analysis of plantain samples reveals significant insights into their potential application in solar cell technology. The results from the SEM and energy-dispersive X-ray spectroscopy (EDX) provide a detailed breakdown of the elemental composition. In plantain spot 1, oxygen constituted 80.15% of the atomic concentration, while carbon comprised 19.85%. Meanwhile, in plantain spot 2, oxygen slightly decreased to 76.92%, with carbon increasing to 23.08%. This high oxygen content is particularly advantageous, as oxygen plays a crucial role in enhancing the electrical properties of solar cells by facilitating charge transport and light absorption.



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
8	O	Oxygen	80.15	84.32
6	C	Carbon	19.85	15.68

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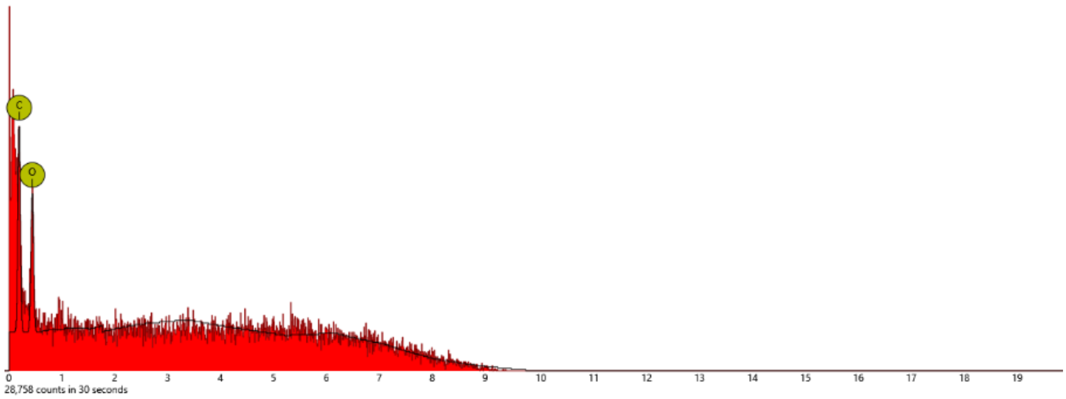

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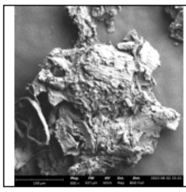
Figure 11. SEM and EDX of plantain-spot 1



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
8	O	Oxygen	76.92	81.62
6	C	Carbon	23.08	18.38

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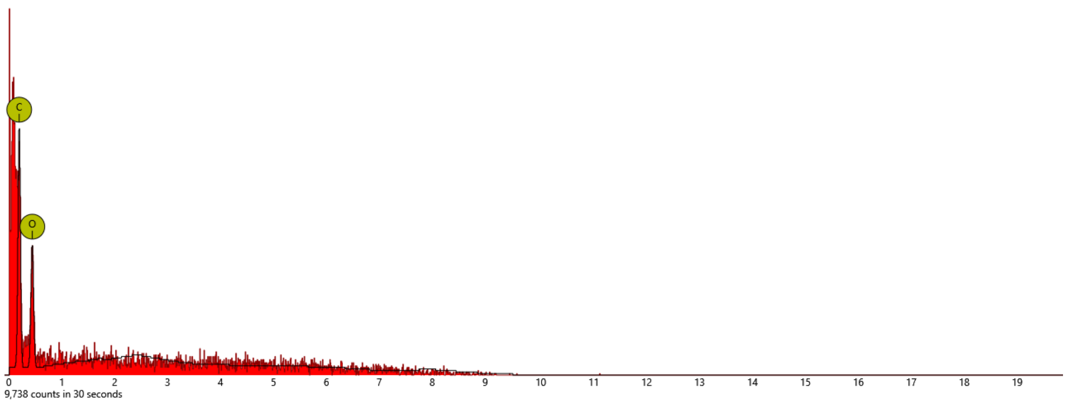

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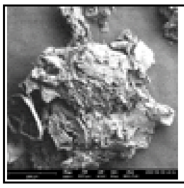
Figure 12. SEM and EDX of plantain-spot 2



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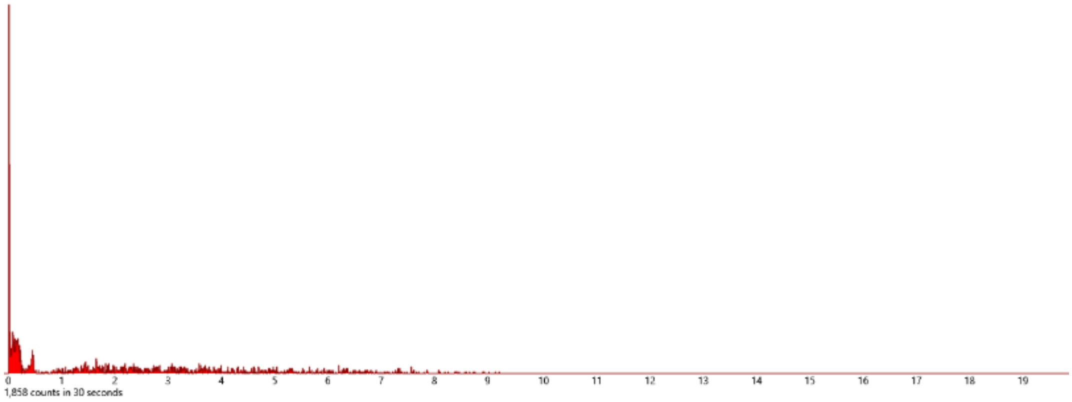

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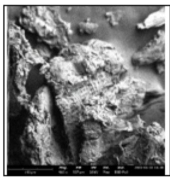
Figure 13. SEM and EDX of plantain-spot 3

Comparatively, the carbon content in these plantain samples indicates a notable capacity for conductivity, which is essential for minimizing resistive losses in solar cell applications. Although traditional silicon-based solar cells typically achieve efficiencies above 20%, the biochar derived from plantain, with its high oxygen and carbon concentrations, presents a viable alternative that could offer a sustainable and cost-effective method for energy production. While the initial performance levels of biochar-enhanced solar cells may not match those of conventional cells, the environmental benefits and potential for further optimization make them a promising area for future research in renewable energy technologies.

3.1.2 Groundnut hybrid solar cell results

The analyses presented in Figures 14-16 describe the elemental composition analysis of groundnut and peanut shells provides valuable insights into their potential for enhancing solar cell performance. In the SEM and EDX results for groundnut shell spot 1, oxygen was the predominant element, accounting for 79.64% of the atomic concentration, with carbon at 20.36%. This high oxygen content is beneficial as it aids in improving the charge transport properties essential for effective energy conversion in solar applications. In groundnut shell spot 2, the oxygen content was slightly lower at 75.35%, with carbon at 14.27% and silicon at 10.39%. The presence of silicon is particularly relevant, as it is a key element in traditional photovoltaic cells, potentially allowing for improved structural integrity and conductivity in hybrid solar cells.



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
8	O	Oxygen	79.64	83.90
6	C	Carbon	20.36	16.10

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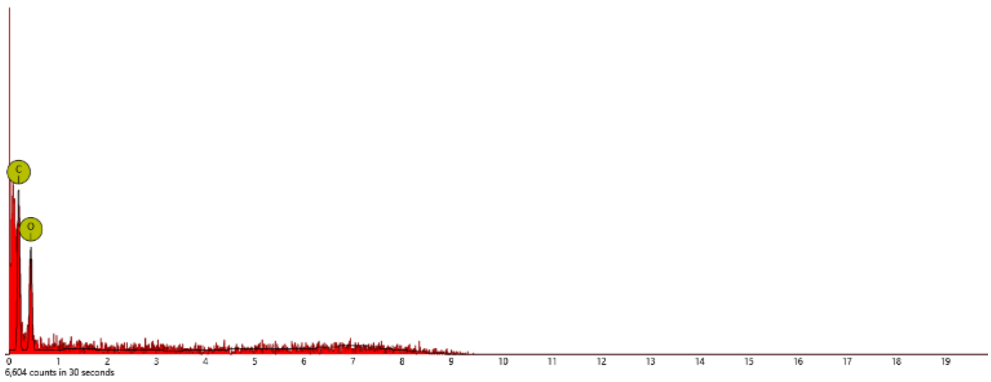

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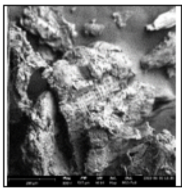
Figure 14. SEM and EDX of groundnuts shell-spot 1



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
8	O	Oxygen	75.35	72.25
6	C	Carbon	14.27	10.27
14	Si	Silicon	10.39	17.48

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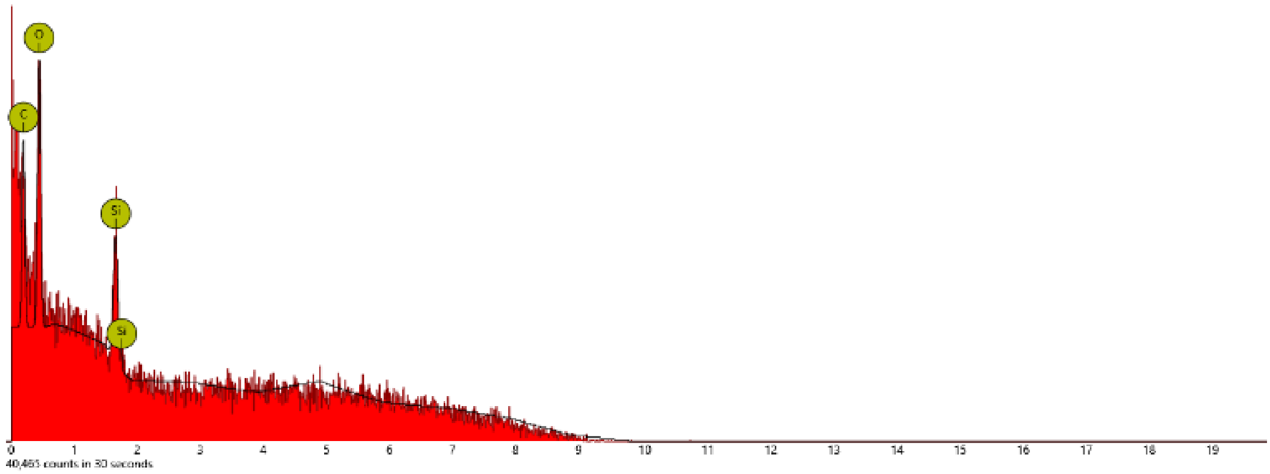

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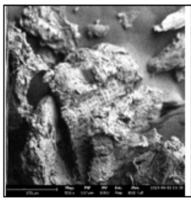
Figure 15. SEM and EDX of groundnuts shell-spot 2



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
8	O	Oxygen	81.35	85.32
6	C	Carbon	18.65	14.68

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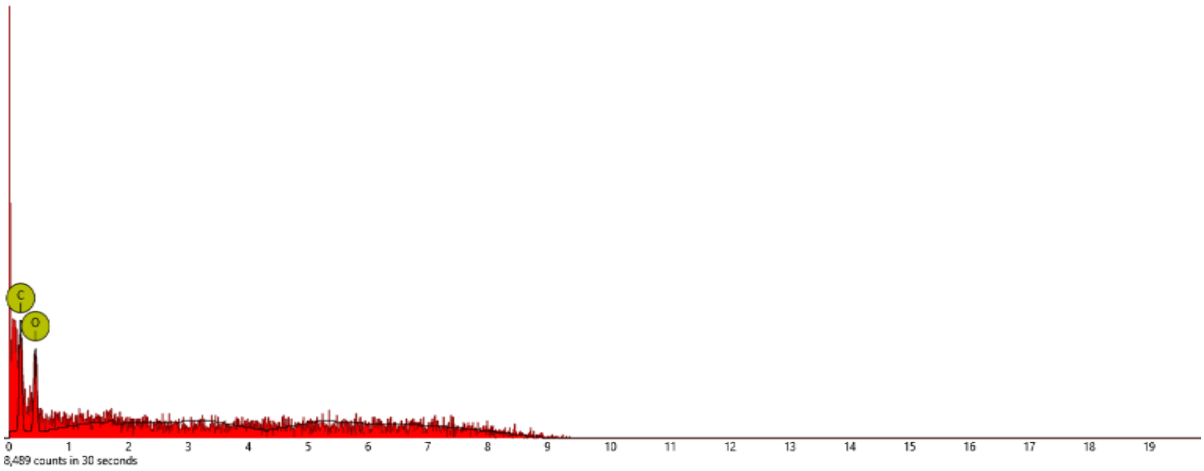

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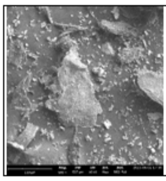
Figure 16. SEM and EDX of groundnuts shell-spot 3

Further analysis of groundnut shell spot 3 revealed an oxygen concentration of 81.35% and a carbon content of 18.65%, reaffirming the material's conductivity potential. In contrast, the peanut shell analysis indicated a more diverse elemental composition with 59.32% oxygen, 18.37% potassium, and 15.10% silicon. The potassium content may enhance ionic conductivity, providing additional pathways for charge transport.

3.1.3 Peanut hybrid solar cell results

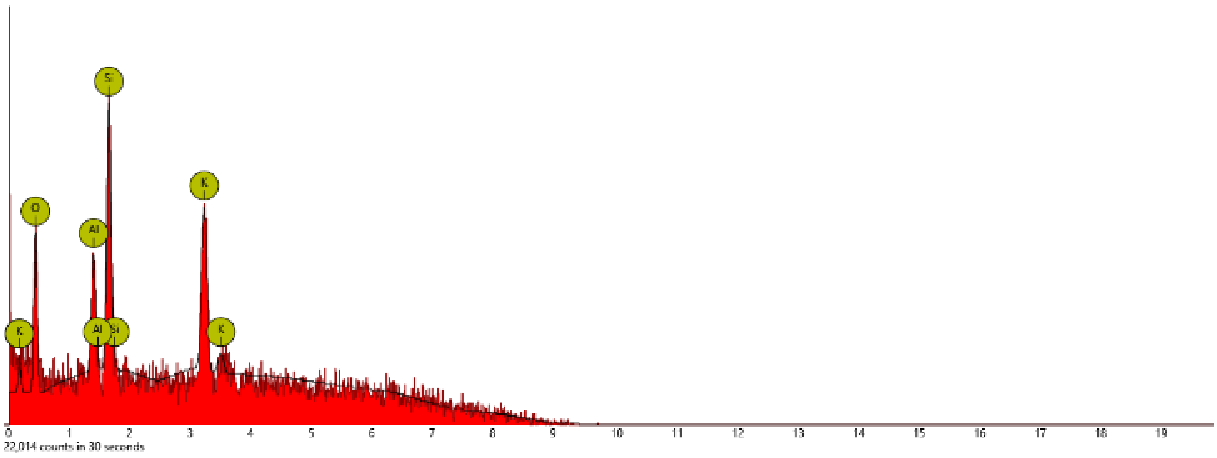
Figures 17-19 provides insightful data regarding their potential use in enhancing solar cell performance. In the results from peanut shell spot 2, calcium emerged as the dominant element, constituting 68.51% of the atomic concentration, while potassium accounted for 31.49%. The high calcium content is particularly noteworthy as it may contribute to structural stability and enhance the mechanical properties of biochar-derived materials. Potassium, with its significant presence, can improve ionic conductivity, facilitating charge transport within the solar cell architecture, which is crucial for efficient energy conversion.

While the third spot of peanut shell did not yield specific elemental data, the previous results indicate a promising compositional profile for integrating these agricultural byproducts into hybrid solar cells. Compared to traditional silicon-based solar cells, which typically achieve efficiencies exceeding 20%, the initial performance of biochar-enhanced solar cells may be lower due to the variability in elemental compositions and processing techniques. However, the advantages of utilizing agricultural waste—such as sustainability and cost-effectiveness—position these biochar materials as a viable alternative in renewable energy solutions. Further research focusing on optimizing processing methods and enhancing the properties of biochar from peanut shells could lead to significant advancements in the efficiency and performance of solar energy technologies, making them a compelling option for future development.



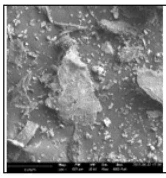
Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
8	O	Oxygen	59.32	41.52
19	K	Potassium	18.37	31.42
14	Si	Silicon	15.10	18.55
13	Al	Aluminum	7.21	8.50

FOV: 537 µm, Mode: 10kV - Map, Detector: BSD Full, Time: JUN 2 2023 17:36



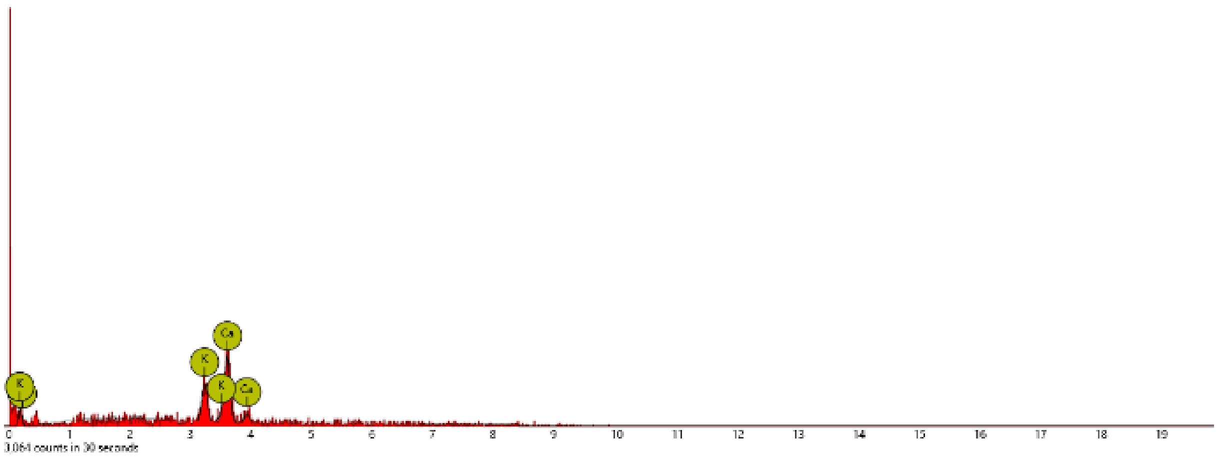
Disabled elements: B

Figure 17. SEM and EDX of peanuts shell -spot 1



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
20	Ca	Calcium	68.51	69.04
19	K	Potassium	31.49	30.96

FOV: 537 µm, Mode: 10kV - Map, Detector: BSD Full, Time: JUN 2 2023 17:36

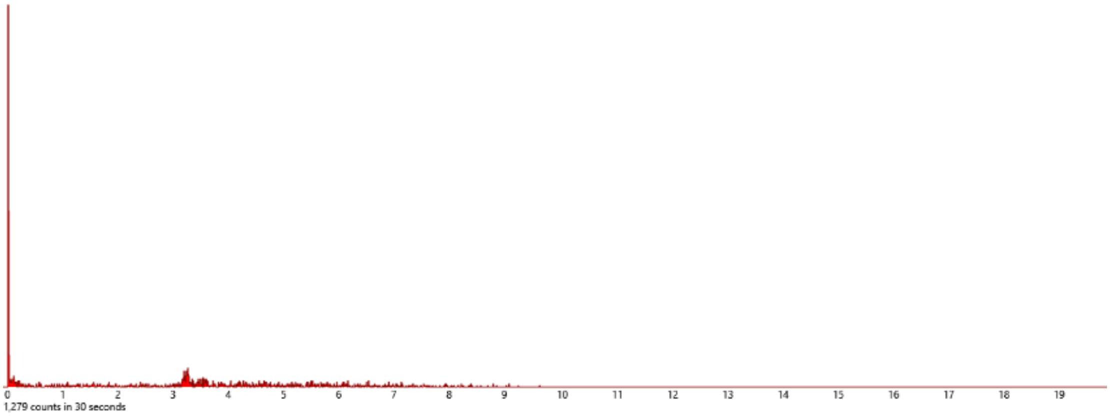


Disabled elements: B

Figure 18. SEM and EDX of peanuts shell-spot 2

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.

FOV: 537 µm, Mode: 10kV - Map, Detector: BSD Full, Time: JUN 2 2023 17:36



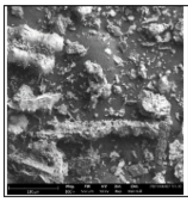
Disabled elements: B

Figure 19. SEM and EDX of peanuts shell-spot 3

3.1.4 Rice hull hybrid solar cell results

Figures 20-22 present the elemental composition of rice hulls reveals promising characteristics for their application in enhancing solar cell performance. In the results from rice hull spot 1, oxygen comprised 68.30% of the atomic concentration, with silicon at 18.43%, nitrogen at 8.50%, and smaller amounts of carbon, sulfur, and tellurium. The high oxygen content is beneficial for charge transport and light absorption, both critical for the efficiency of photovoltaic cells. Silicon's presence is particularly noteworthy, as it is a fundamental element in conventional solar cells, which can enhance the structural and electrical properties of biochar-derived materials.

In contrast, rice hull spot 2 demonstrated a remarkable 100% silicon concentration, indicating a homogenous composition that could provide excellent conductivity and stability in solar cell applications. Rice hull spot 3 revealed a balanced composition of 51.89% oxygen and 48.11% silicon. This equilibrium between oxygen and silicon is advantageous, as it optimizes both the absorptive and conductive properties necessary for effective energy conversion. The improvement in performance is as related to work carried by Sait et al. [19] who reported an optimal increase Biochar performance using statistical and AI-based modeling technique.



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
8	O	Oxygen	68.30	56.07
14	Si	Silicon	18.43	26.56
7	N	Nitrogen	8.50	6.11
6	C	Carbon	2.17	1.34
16	S	Sulfur	1.42	2.34
52	Te	Tellurium	1.04	6.83

FOV: 537 µm, Mode: 10kV - Map, Detector: BSD Full, Time: JUN 2 2023 17:30

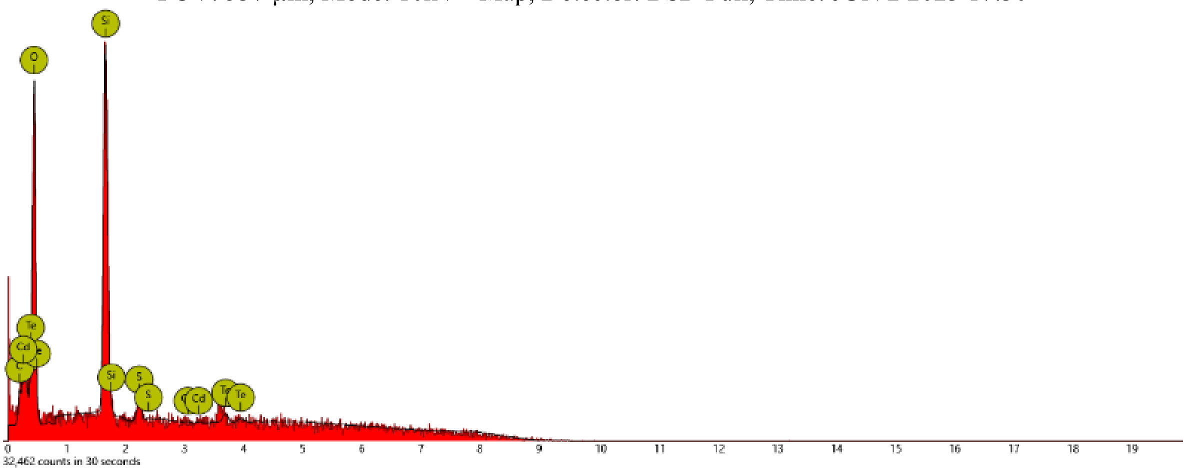


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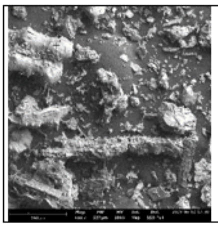
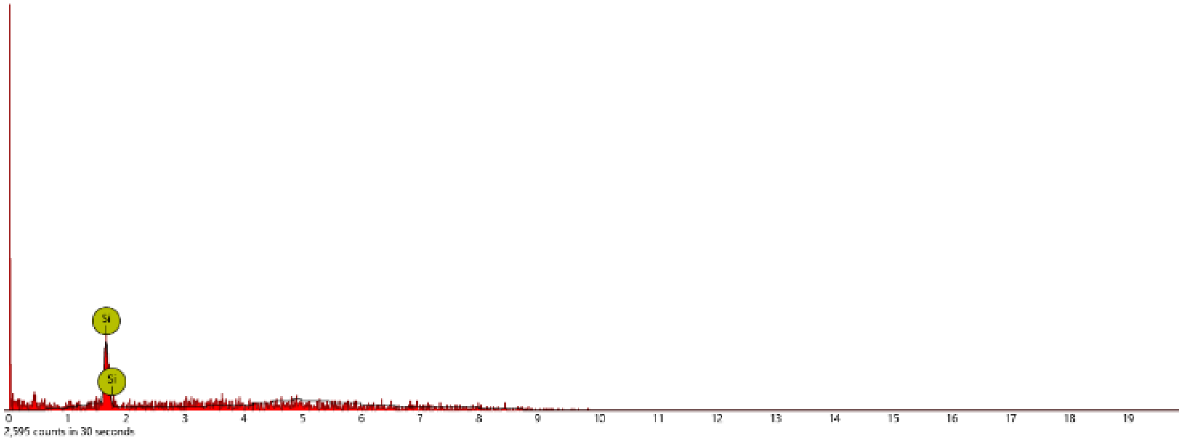
Figure 20. SEM and EDX of rice hulls-spot 1



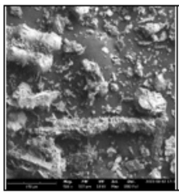
Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
14	Si	Silicon	100.00	100.00

FOV: 537 µm, Mode: 10kV - Map, Detector: BSD Full, Time: JUN 2 2023 17:30



Disabled elements: B

Figure 21. SEM and EDX of rice hulls-spot 2



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
8	O	Oxygen	51.89	38.05
14	Si	Silicon	48.11	61.95

FOV: 537 µm, Mode: 10kV - Map, Detector: BSD Full, Time: JUN 2 2023 17:30

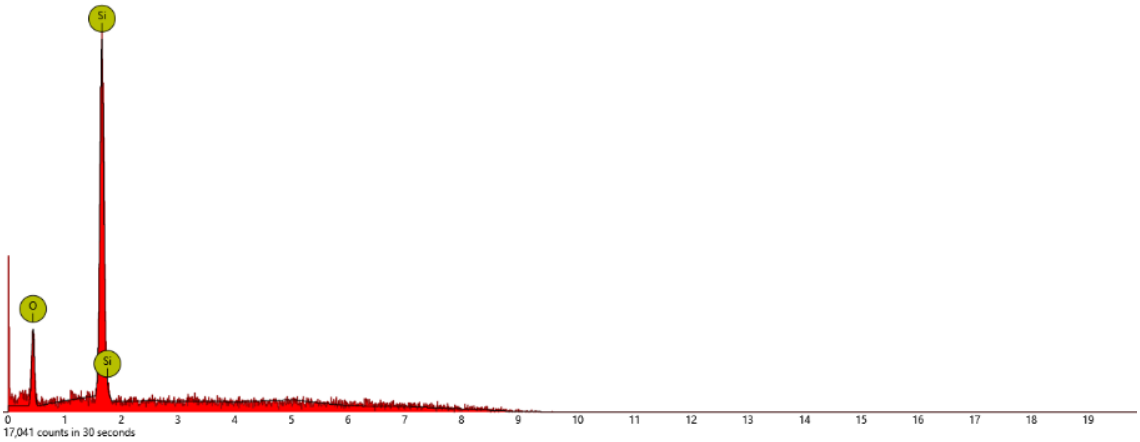


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Figure 22. SEM and EDX of rice hulls-spot 3

When comparing these biochar materials to traditional silicon-based solar cells, which typically achieve efficiencies above 20%, the initial performance of rice hull-derived solar cells may be variable due to the complexities in processing and the diverse elemental compositions. However, the sustainability and cost-effectiveness of utilizing agricultural byproducts like rice hulls position them as a viable alternative in renewable energy technologies. Continued research into optimizing the processing and enhancing the functional properties of rice hull biochars could lead to significant advancements in solar energy applications, making them an attractive option for future development in the field.

3.2 Temperature measurement variance

The analysis starts with measurement of temperature variances for Samples 1-11 between 10:00 am and 5:00 pm of ranges 10:00-11:00, 11:00-12:00, 12:00-1:00, and 1:00-2:00, 2:00-3:00, 3:00-4:00 and 4:00-5:00 pm. The analysis helps to identifies and quantifies exergy flows and losses in the hybrid solar system, thereby identifying areas in which the heat concentrated via using thermocouple. The analysis integrates data into the exergy framework, this enables the value of ambient temperature to exergy streams and losses. This synthesis of analysis provides a more detail of the system's efficiency. Hybrid solar cell is particularly well-suited for exergoeconomic analysis. In these systems, maximizing energy output is imperative, given the inherently intermittent nature of solar radiation.

The hybrid solar cell developed has really shown significant tendency in heat absorption resulting to temperatures rises at respective time. As shown in Tables 2 and 3, readings were taken using thermo-couple to measure the response of the solar cell to heat resulting to temperature taken on each sample 1 to 11 including the control sample, the sample 11. From the readings as shown in Figures 23 and 24, we observed an increase order of temperatures of samples; 2, 1, 4, 5 and 3 in Figure 23. Also increase order of temperatures of samples 8, 7, 6, 9, 10 and 11. Validating the analysis of the temperature responses, samples 3-39.4℃, sample 9-40.45℃ and sample 10-41.45℃ have relatively higher temperature but not up to the control sample 11 with 47.55℃. This shows a relative improvement on the heat absorption using agro-waste of this nature for solar cell as compared to the analytical study carried out by Satter et al. [20] who recorded a maximum cell temperature of 38.810℃. It may seem counter-intuitive, but solar cells efficiency is negatively affected by temperature increases.

Table 2. Samples 1-5

Time (Hr)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
	TEMP (℃)	TEMP (℃)	TEMP (℃)	TEMP (℃)	TEMP (℃)
10:10	15.2	13.3	16.2	15.1	17.2
11:00	19.1	17.2	21.3	20.2	20.3
12:00	25.02	23.12	25.32	22.1	25.2
13:00	31.5	28.3	33.5	35.5	34.4
14:00	35.4	33.3	39.4	36.3	37.4
15:00	34.2	30.2	32.2	30.2	32.2
16:00	33	29	27	24.3	20.3

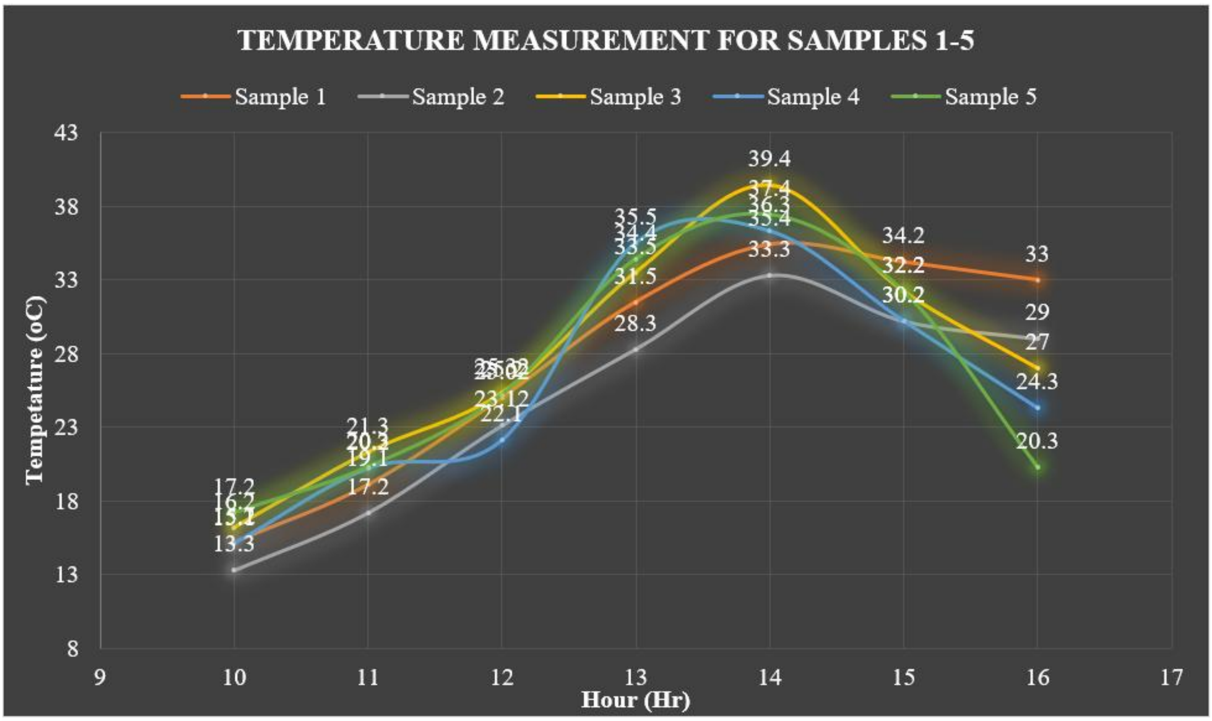

Figure 23. Graph of temperature measurement for samples 1-5

Table 3. Samples 6-11

Time (Hr)	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11
	TEMP (℃)	TEMP (℃)	TEMP (℃)	TEMP (℃)	TEMP (℃)	TEMP (℃)
10.00	12.1	15.3	14.25	15.15	12.15	20.15
11.00	23.2	23.2	22.12	20.22	26.32	25.22
12.00	30.2	30.2	32.21	35.41	37.22	35.4
13.00	37.4	36.3	33.21	40.35	41.45	47.55
14.00	38.4	39.4	33.32	35.42	39.40	40.32
15.00	27.5	22.5	25.54	22.55	27.30	28.38
16.00	18.3	17.3	19.35	17.55	17.65	16.25

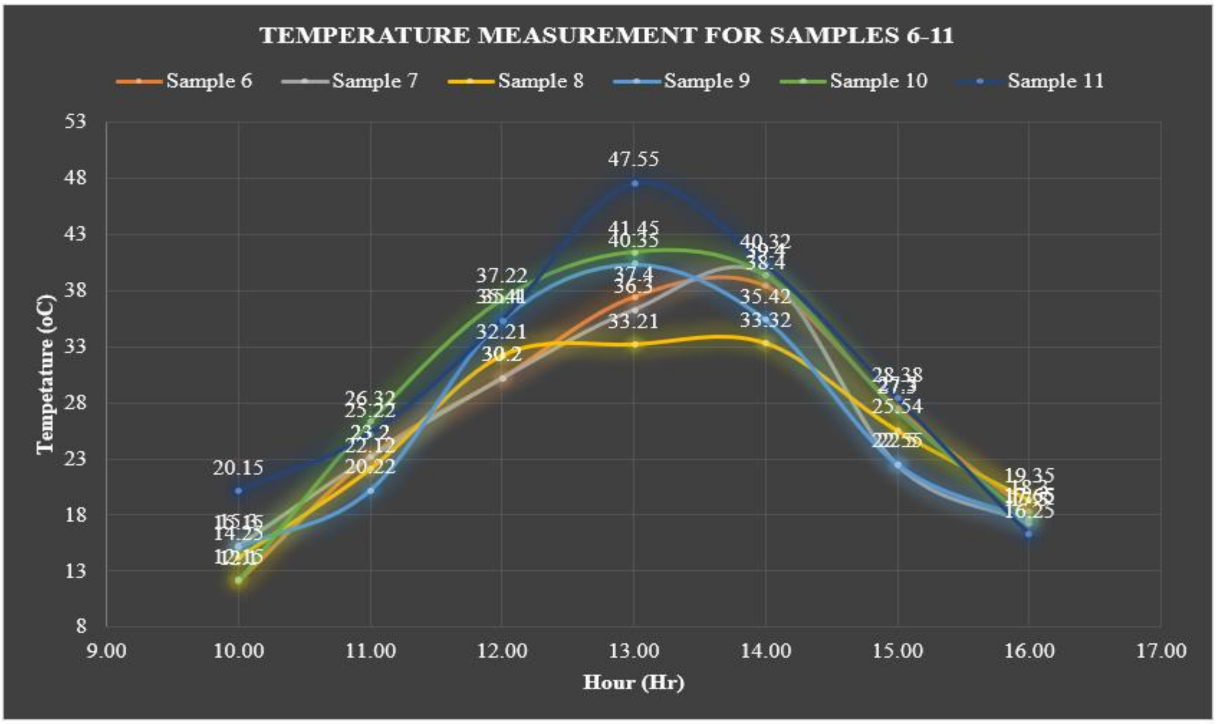

Figure 24. Graph of temperature measurement for samples 6-11

4. CONCLUSIONS

The study presents a comprehensive analysis of the elemental compositions and thermal behaviors of various agricultural waste materials, including plantain peels, groundnut shells, and rice hulls, regarding their potential application in enhancing solar cell performance. The findings indicate that these materials possess significant concentrations of key elements, such as oxygen, silicon, and carbon, which are critical for improving charge transport and energy conversion efficiency in hybrid solar cells. Notably, the high silicon content in rice hulls, the structural stability offered by calcium in peanut shells, and the conductivity provided by carbon in groundnut shells highlight the diverse advantages these biochar materials can offer.

Thermal measurements further reveal distinct temperature profiles across the samples, illustrating the materials' responses to environmental conditions. The observed trends of increasing and subsequently decreasing temperatures suggest a typical diurnal pattern. This thermal behavior is essential for understanding how these materials might perform under varying operational conditions, particularly in applications related to renewable energy.

In conclusion, the results underscore the potential of utilizing agricultural waste materials as sustainable and cost-effective alternatives in solar energy technologies. While further research is needed to optimize processing techniques and enhance the performance of biochar-enhanced solar cells, the promising elemental compositions and favorable thermal characteristics indicate a viable pathway for developing innovative solutions in renewable energy. The integration of these materials not only contributes to energy sustainability but also addresses environmental concerns associated with agricultural waste disposal.

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NOMENCLATURE

SEM	Scanning Electron Microscope
EDX	Energy Dispersive X-ray
FOV	Field of View
kg	Kilogram