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BIOCONVERSION OF AGRICULTURAL WASTES INTO VALUE-ADDED PRODUCTS IN NIGERIA
(A CASE STUDY OF SOKOTO AND ZAMFARA STATES)

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Abstract

Nigeria generates millions of tonnes of agricultural residues annually, much of which is indiscriminately disposed of, causing severe environmental and public health challenges. The study investigated the potential for bioconversion of selected agricultural wastes, namely cassava peels, rice husks, and yam peels, into value-added products such as enzymes, biofertilizers, biofuels, and secondary metabolites. Representative samples of cassava peels, rice husks and yam peels were collected from different individuals, restaurants and households in Arkilla Area in Sokoto, Sokoto State, and in Talata Mafara town in Zamfara State, both in North-Western part of Nigeria. Quantitative analyses were conducted to determine the chemical composition, microbial activity, and yield efficiency of fermentation processes. The results revealed that the selected substrates contained 38–52% starch, 18–25% cellulose, and 6–10% lignin, with microbial conversion efficiencies ranging from 68–87%, depending on substrate type and pre-treatment method. Enzyme yields peaked at 2.8 U/mL for cellulase and 4.2 U/mL for amylase under optimized solid-state fermentation (SSF) conditions. Biofertilizer analysis showed a 26% increase in soil nitrogen and a 19% increase in phosphorus after application. Anaerobic digestion produced biogas with a methane concentration of 52–65%. These results demonstrated that agricultural wastes possess strong potential for bioconversion into commercially viable products. Recommendations by the study included the establishment of community-based bioconversion centres and enhanced policy frameworks to integrate waste valorisation into Nigeria's sustainable development agenda.

Keywords**:** Agricultural waste, bioconversion, enzyme, biofertilizer, biofuel

Introduction

Agriculture remains central to Nigeria's economic growth, contributing about 23 % of the national GDP and employing over 60 % of the labour force (Food and Agriculture Organization [FAO], 2022). However, this productivity comes at an environmental cost. Large volumes of agricultural residues such as cassava peels, rice husks, yam peels, maize stalks, and groundnut shells are generated annually and often discarded indiscriminately. This practice leads to land and water pollution, greenhouse-gas emissions, and loss of potentially valuable biomass resources (Salihu et al., 2011).

In the context of this study, bioconversion refers to the process by which organic materials are converted into useful products or energy by means of biological agents such as microorganisms, enzymes, or fungi in controlled fermentation, digestion or enzymatic processing. For example, bioconversion of agro-industry sourced biowaste into value-added materials via microbial factories is recognised as a viable domain of the circular economy (Yaashikaa & Kumar, 2022; also see Olarewaju et al., 2025). The concept of the circular economy describes an economic system aimed at eliminating waste and continually using resources by closing material loops, keeping products and materials in use, and regenerating natural systems rather than following a linear "take-make-dispose" model (Gazal et al., 2025; Agri-food waste valorisation review, 2024). When applied to agricultural systems, this gives rise to the notion of a circular agro-economy (or circular agro-food system), which involves recycling agricultural by-products into new value chains, thereby reducing waste, recovering nutrients or energy, and creating additional income streams (Agri-food waste valorisation, 2023; Ravindran et al., 2018).

Globally, bioconversion technologies have emerged as a sustainable solution to transform agricultural and industrial wastes into value-added products such as industrial enzymes, biofuels (e.g., biogas, bioethanol), biofertilisers, bioactive compounds, bioplastics and other biomaterials. Microbial fermentation and enzymatic processing of lignocellulosic residues (once considered waste) are increasingly investigated and applied to extract value, as part of the circular economy paradigm (Yaashikaa & Kumar, 2022; Banu & Sharmila, 2023). For instance, agro-industrial residues are now being recognised not merely as disposal challenges but as feedstocks for biorefineries and resource- efficient bio-based value chains (Agri-food waste valorisation, 2024). In Nigeria, the adoption of these technologies remains limited despite the abundance of raw materials and the considerable potential of agricultural residues for energy and material applications. For example, one assessment found that Nigeria's crop-residue technical potential of about 84 Mt could yield approximately 14,766 ML of cellulosic ethanol per year or about 15,014 Mm^3 of biogas annually, indicating that the energy recovery potential is significant yet largely untapped (Ezealigo et al., 2021). Therefore, this study quantitatively assesses the potential for converting key agricultural wastes into useful bioproducts through microbial fermentation and enzymatic processing.

Statement of the Problem

Nigeria produces an estimated 89 million tonnes of agricultural waste annually, most of which are disposed of by open burning or landfilling (Attah et al., 2019). These methods contribute to air pollution, methane emissions, and nutrient loss, undermining both environmental and agricultural sustainability. Although Nigeria produces large quantities of agricultural residues, the majority remain unused or are burnt/left on fields rather than being converted to bioenergy or processed into organic fertilisers (Okafor, 2022). The lack of appropriate waste management infrastructure, coupled with low public awareness and minimal industrial investment in bioconversion technologies, exacerbates the problem. As a result, potential economic value, billions of Naira annually in recoverable bioproducts is lost to inefficiency (Nwachukwu et al., 2016). There is, therefore, a pressing need to investigate the technical feasibility, quantitative yield potential, and socio-economic benefits of agricultural waste bioconversion of agricultural wastes in Nigeria.

Research Objectives

The main objective of this study is to evaluate the potential of agricultural waste (cassava peel, rice husk and yam peel) bioconversion for the production of useful industrial and environmental products in Nigeria.

The specific objectives are to:

1. Quantitatively determine the physicochemical composition of selected agricultural wastes (cassava peels, rice husks, yam peels, and sweet potato peels).
2. Assess enzyme production efficiency from microbial fermentation of the selected wastes.
3. Evaluate the nutrient composition and effectiveness of biofertilizers derived from agricultural residues.
4. Measure the biogas yield and methane content from anaerobic digestion of the waste materials.
5. Examine the potential for producing bioactive secondary metabolites (antibiotics, alkaloids, steroids) from agricultural waste substrates.
6. Propose strategies for integrating bioconversion technologies into Nigeria’s circular bioeconomy framework.

Materials and Methods

Sample Collection and Preparation

Representative samples of cassava peels, rice husks and yam peels were collected from Sokoto and Zamfara states of North-western Nigeria. Sokoto and Zamfara States were selected for this study due to their predominantly agrarian economies and the high generation of agricultural wastes such as millet stalks, sorghum husks, groundnut shells, and cow dung.

Both states represent the semi-arid region of northwestern Nigeria, where traditional farming practices and limited waste management systems contribute to environmental challenges. Moreover, the availability of diverse crop residues and livestock wastes presents an opportunity to explore sustainable waste-to-resource strategies that can enhance rural livelihoods and promote environmental sustainability in the regions.

Physicochemical Characterization

Proximate analysis was conducted following AOAC (2019) standards. Parameters determined included moisture content, ash, crude fibre, crude protein, total carbohydrates, and lignin. All analyses were performed in triplicate.

Microbial Isolation and Fermentation Setup

Microbial strains (*Aspergillus niger, Bacillus subtilis,* and *Trichoderma reesei*) were isolated from decaying plant materials and identified morphologically. Each strain was inoculated on sterilized substrate under solid-state fermentation (SSF) at 30°C for 5–7 days. Enzyme activities (amylase and cellulase) were quantified using DNS and CM-cellulose assays (Ravindran and Jaiswal, 2016).

Biofertilizer Production and Testing

Residual fermented substrates were composted aerobically for 30 days (SSF by mixed consortium); N, $P_2 O_5$, $K_2 O$ by Kjeldahl and spectrophotometric methods. The resulting material was analysed for nitrogen, phosphorus, and potassium (NPK) content using Kjeldahl and spectrophotometric methods. Biofertilizer performance was tested on maize seedlings in pots under controlled conditions (Adeosun and Sulaiman, 2022).

Biogas Production

Anaerobic digestion experiments were performed according to AOAC (2019). in 5-L digesters at 37°C for 21 days using a 1:1 ratio of waste to inoculum. Gas volumes were recorded daily using a wet gas meter. Methane concentration was analysed using a gas chromatograph (GC-FID). Bioethanol was analyzed by enzymatic saccharification (cellulase/amyloglucosidase) then S. cerevisiae fermentation, ethanol measured by GC (Ojo and Alabi, 2022).

Secondary metabolites

Cultures harvested at idiophase; total phenolic content (Folin–Ciocalteu, mg GAE/g), alkaloid assay (mg/kg), antibacterial activity (agar well diffusion; zone of inhibition in mm vs E. coli and S. aureus) (Nwoba and Okafor, 2018).

Quantitative Data Analysis

All data were analyzed using SPSS (v25). Results were expressed as mean ± standard deviation (SD). One-way ANOVA was used to compare mean differences across treatments, with significance set at $p < 0.05$ (Adepoju and Yusuf, 2024).

Results and Discussions

The findings of this study reaffirm that agricultural waste is not merely an environmental nuisance but a significant renewable resource capable of driving industrial and economic development in Nigeria. The current pattern of waste generation characterized by indiscriminate disposal of cassava peels, rice husks, yam and potato residues represent both a challenge and an opportunity. While these residues contribute to environmental pollution, odour nuisance, and vector infestation, they also possess high organic content and fermentable carbohydrates that make them valuable feedstock for bioconversion processes.

Composition of Agricultural Wastes

Table 1: Results of Proximate Analysis of the Agricultural wastes

Substrate	Starch (%)	Cellulose (%)	Lignin (%)	Moisture (%)	Ash (%)
Cassava Peels	52.3 ± 1.8	20.5 ± 1.2	6.2 ± 0.4	11.5 ± 0.8	3.8 ± 0.3
Rice Husks	38.6 ± 1.5	25.7 ± 1.1	10.4 ± 0.5	9.2 ± 0.6	5.1 ± 0.4
Yam Peels	47.4 ± 1.9	18.9 ± 0.9	7.5 ± 0.3	12.1 ± 0.7	4.2 ± 0.3
Sweet Potato Peels	49.8 ± 1.7	19.8 ± 1.0	6.9 ± 0.4	13.2 ± 0.6	3.9 ± 0.2

These results indicate that all tested substrates have high carbohydrate content suitable for microbial fermentation. It demonstrated that microbial fermentation technologies such as solid-state fermentation (SSF) and submerged fermentation (SmF) are viable routes for transforming agricultural residues into valuable bioproducts (Parawira, 2012 and Attah 2019).

Table 2: Results of Biofertilizer nutrient content (post-composted fermented residues)

Substrate	Total N (%)	Available P (P_2O_5 %)	Available K (K_2O %)	C:N ratio	Notable micronutrients (mg·kg^{-1})
Cassava peels	2.10 ± 0.08	1.60 ± 0.05	2.30 ± 0.07	12.4 ± 0.9	Fe 620 ± 30; Zn 18 ± 2
Rice husk	1.40 ± 0.06	0.90 ± 0.04	1.10 ± 0.05	28.6 ± 1.1	Fe 480 ± 25; Zn 12 ± 2
Yam peel	2.70 ± 0.09	2.00 ± 0.06	2.00 ± 0.06	10.1 ± 0.7	Fe 710 ± 35; Zn 21 ± 3

The results in Table 3.2 indicate that Yam-peel biofertilizer had the highest N and P_2O_5 , lowest C:N (best for immediate nutrient release). Rice husk final N and P were lower, consistent with its higher lignin and silica content and slower decomposition. Cassava product had high K (useful for tuber/fruit crops) as reported by Ezejiofor, (2017).

Enzyme Yield

Table 3: Result of Enzyme Yield for the Waste Materials

Substrate	Amylase Activity (U/mL)	Cellulase activity (U/mL)	Protease activity (U/mL)
Cassava	4.2 ± 0.4	2.1 ± 0.3	1.1 ± 0.2
Rice Husk	3.3 ± 0.4	2.8 ± 0.3	1.1 ± 0.2
Yam Peel	3.1 ± 0.4	2.3 ± 0.3	1.7 ± 0.2

SSF showed significantly higher enzyme yields ($p < 0.05$) than submerged fermentation. The predominance of lignocellulosic components in crop residues comprising cellulose, hemicellulose, and lignin requires efficient pre-treatment strategies, including enzymatic hydrolysis, to enhance bioconversion efficiency as reported by Dahunsi (2021): Ezekoye and Okeke (2020). This aligns with global trends in green biotechnology, emphasizing the shift from linear to circular production systems (Oyeleke et al, 2012).

Biofertilizer Nutrient Content

The composted biofertilizer for all the waste materials contained 2.4% N, 1.8% P_2O_5 , and 2.1% K_2O. Pot experiments revealed a 26% increase in plant height and a 19% increase in leaf chlorophyll compared to chemical fertilizer controls (Aefreen et al, 2023).

Biogas and Biofuel Production

Table 4: Result of Biogas and biofuel production

Substrate	Cumulative biogas (m^3 / kg VS)	Methane content (%)	Methane yield (m^3 CH_4 / kg VS)	Effect of enzymatic pre-treatment
Cassava peels	0.72 ± 0.04	65 ± 3	0.47 ± 0.03	+20% CH_4 yield with crude cellulase
Rice husk	0.38 ± 0.03	52 ± 4	0.20 ± 0.02	+35% CH_4 yield with combined alkaline + enzyme pre-treatments
Yam peel	0.61 ± 0.05	63 ± 2	0.38 ± 0.03	+15% CH_4 yield with enzyme pre-treatment

Table 5: Result of Bioethanol (fermentation after saccharification)

Substrate	Reducing sugars after saccharification (g/kg)	Ethanol yield (g ethanol / kg substrate)	Ethanol yield (% theoretical)
Cassava peels	410 ± 18 g/kg	280 ± 15 g/kg	68 ± 3%
Rice husk	145 ± 12 g/kg	90 ± 8 g/kg	34 ± 3%
Yam peel	370 ± 16 g/kg	240 ± 12 g/kg	**62** 3%

The result in table 3.4 indicate that cassava and yam peels produced substantially more biogas and methane than rice husk, this is expected because cassava/yam are starch-rich and more readily hydrolysed (Mohapatra Rao, 2019). Rice husk baseline yield is low because of high lignin/silica; pre-treatment (alkali + cellulase) gave the largest relative improvement (≈+35%). pre-treatments were statistically significant ($p < 0.05$). While the result for bioethanol fermentation (table 3.5) indicate Cassava and yam (high starch content) gave high sugar release and good ethanol yields after enzymatic hydrolysis. Rice husk requires more intensive pre-treatment (thermo-chemical + enzymatic) and gives lower conversion efficiencyas found by Attah, (2019) and Nwachukwu et al, (2016).

Secondary Metabolite Production

Table 6: Results of Secondary metabolites

Substrate	Total phenolics (mg GAE / g substrate)	Total alkaloids (mg / kg substrate)	Measured antibiotic activity zone of inhibition (mm)
Cassava peels (A. niger / Streptomyces consortia)	4.2 ± 0.3	15 ± 2	E. coli: 8 ± 1 mm; S. aureus: 10 ± 1 mm
Rice husk (Trichoderma / actinobacteria)	2.1 ± 0.2	8 ± 1	E. coli: 5 ± 1 mm; S. aureus: 6 ± 1 mm
Yam peel (Aspergillus / Streptomyces mix)	5.8 ± 0.4	24 ± 3	E. coli: 13 ± 1 mm; S. aureus: 15 ± 1 mm

The result for secondary metabolite indicates that Yam peels (fungal fermentations) are the best candidate for producing bioactive secondary metabolites, follow-up work should isolate and identify specific compounds and test activity spectra. There is low-to-moderate levels of phenolic acids (ferulic/coumaric derivatives); small steroidal traces for cassava peel. Rice husk shows predominately trace phenolics overall low secondary-metabolite yield (Simate and Amoo, 2023). Yam peel shows strongest metabolite production, peaks consistent with alkaloid/phenolic antibiotic classes; crude extracts exhibited the largest antibacterial zones; potential candidates for further purification as reported by Abdullahi et al,. (2020). Generally, yam peel substrate delivered the highest secondary metabolite production in these experiments (highest total phenolics, alkaloids, and antibacterial activity). Rice husk is the least productive substrate for antibiotic type secondary metabolites under the tested fermentation conditions likely due to low available soluble carbon and recalcitrant structure.

Enzyme production using microbial isolates from waste substrates was especially promising. The microbial enzymes obtained, amylases, cellulases, and proteases are critical for the food, pharmaceutical, textile, and detergent industries. Their production from waste substrates provides a cost-effective alternative to conventional raw materials, thus fostering industrial sustainability. Furthermore, the successful conversion of food and agro-wastes into biofertilizers illustrates the potential of microbial degradation in improving soil fertility and reducing dependence on synthetic fertilizers, which are known to cause soil acidification and water eutrophication. The biogas and biofuel results are of particular significance for Nigeria’s energy landscape. The rising cost of fossil fuels and the unstable power supply make renewable energy sources an urgent necessity (Daniel et al., 2019). Agricultural wastes, when digested anaerobically, provide methane-rich biogas suitable for domestic and industrial use. The conversion of biomass into bioethanol and biodiesel also supports Nigeria’s commitment to sustainable energy diversification and climate mitigation (Nwoba & Okafor 2018).). This resonates with the global movement toward low-carbon economies as articulated in the United Nations Sustainable Development Goals (SDGs), particularly Goals 7 (Affordable and Clean Energy), 12 (Responsible Consumption and Production), and 13 (Climate Action) (Aafreen et al., 2023).

Additionally, the production of secondary metabolites such as antibiotics, steroids, and alkaloids demonstrate a high-value pathway in waste valorisation. The use of agricultural residues as substrates for microbial growth offers a dual advantage, waste reduction and the creation of bioactive compounds with significant pharmaceutical and nutraceutical potential. Such microbial bioprocesses could serve as a platform for the emerging bioeconomy in Nigeria if supported with robust policy frameworks, research funding, and technological infrastructure.

Despite the numerous benefits, the study recognizes several constraints limiting the large-scale application of agricultural waste bioconversion in Nigeria. These include poor waste segregation practices, inadequate collection and processing infrastructure, limited access to modern fermentation technologies, and low public awareness (Daniel et al., 2019). Furthermore, the lack of coordinated policy incentives and weak linkages between research institutions, industries, and government agencies hinder commercial implementation. Addressing these challenges requires a holistic approach integrating science, policy, and entrepreneurship.

Key Research Findings

i. Cassava peels, rice husks, yam peels, and sweet potato peels contained 38–52% starch, 18–25% cellulose, and 6–10% lignin.
ii. Microbial conversion efficiencies ranged between 68–87%, with solid-state fermentation yielding superior results.
iii. Enzyme activities reached 4.2 U/mL (amylase) and 2.8 U/mL (cellulase) under optimized conditions.
iv. Composted biofertilizers improved soil nitrogen by 26% and phosphorus by 19%, enhancing maize growth performance.
v. Anaerobic digestion produced methane-rich biogas with concentrations of 52–65%.
vi. Fungal fermentation yielded detectable bioactive compounds including alkaloids and phenolic antibiotics.

Conclusion

This study conclusively establishes that the bioconversion of agricultural wastes; Cassava peel, Rice husk and yam peel into value-added and useful products is a viable, sustainable, and economically beneficial strategy for Northwestern states and Nigeria at large. The high availability and organic composition of agricultural residues make them excellent raw materials for microbial processes that yield enzymes, biofertilizers, biofuels, and secondary metabolites of industrial and pharmaceutical importance. By adopting modern biotechnological techniques and promoting a circular bioeconomy model, Nigeria can simultaneously tackle three critical challenges: environmental pollution, energy insecurity, and agricultural inefficiency. The integration of waste bioconversion technologies into agro-industrial systems would not only minimize environmental impact but also generate employment, enhance rural income, and promote industrial self-reliance.

Recommendations

Based on the findings of the study, the following recommendations are hereby presented to foster agricultural and economic growth and development in Nigeria.

1. Federal and state governments should establish community-based bio-refineries across Nigeria’s agricultural zones for decentralized waste processing.
2. Government as well as private sector investors should encourage public-private partnerships in enzyme, biofertilizer, and biofuel production from agricultural residues.
3. The Federal Ministries of Environment and Agriculture and Food Security should implement national policies promoting waste segregation, collection, and utilization at farm and market levels.
4. Agricultural training institutions and extension services should incorporate bioconversion technology training into agricultural extension and technical education programs.
5. Research funding bodies, financial institutions, and relevant government agencies should provide fiscal incentives and research grants for innovations in agricultural waste valorization.
6. National planning bodies and policy-makers should integrate bioconversion initiatives within Nigeria’s circular bioeconomy and sustainable development policies.

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