NIGERIAN ONLINE JOURNAL OF
EDUCATIONAL SCIENCES AND TECHNOLOGY
nojest.unilag.edu.ng
nojest@unilag.edu.ng

VALORISATION OF CASSAVA PEEL WASTE THROUGH MICROBIAL FERMENTATION FOR PRODUCTION OF BIOETHANOL AND BIOGAS IN SOUTHWEST NIGERIA

Ekumankama S. & Sholotan K. J.
Department of Science Laboratory Technology
Ogun State Institute of Technology Igbesa, Ogun State
ekumankamajames@gmail.com

Abstract

The increasing generation of cassava peel waste (CPW) in Southwest Nigeria poses significant environmental challenges while representing an underutilised biomass resource for renewable energy production. This study investigates the valorisation of CPW through microbial fermentation for the dual production of bioethanol and biogas, integrating experimental optimisation with techno-economic and environmental assessments. Cassava peel samples were collected from major processing communities in Oyo, Ogun, and Ondo States and characterised for biochemical composition. Indigenous microbial strains were isolated, identified, and applied in batch fermentation and anaerobic digestion processes. Fermentation parameters were optimised using Response Surface Methodology, while bioethanol and biogas yields were quantified using gas chromatography and volumetric methods, respectively. Results show that CPW contains high levels of fermentable carbohydrates and supports substantial bioethanol and methane yields, with indigenous microbial strains outperforming commercial counterparts. Techno-economic analysis indicated favourable economic viability with a short payback period, while life cycle assessment revealed significant reductions in greenhouse gas emissions and waste volume compared to conventional disposal. The study demonstrates that CPW valorisation offers a sustainable, circular-economy pathway for renewable energy generation and waste management in cassava-producing regions of Nigeria.

Keywords: *Cassava peel waste; bioethanol; biogas; microbial fermentation; circular economy; Nigeria*

Introduction

The growing demand for sustainable energy and effective waste management solutions has intensified global interest in the valorisation of agricultural residues for bioenergy production. In many developing economies, agro-processing activities generate substantial volumes of organic waste that are poorly managed, leading to environmental degradation, greenhouse gas emissions, and public health risks. Converting such waste streams into renewable energy aligns with global commitments to climate change mitigation, circular economy principles, and sustainable development goals (Singh & Verma, 2022; IEA, 2023).

Cassava (*Manihot esculenta*) is one of the most important food and industrial crops in sub-Saharan Africa, with Nigeria ranking as the world's largest producer. According to recent estimates, Nigeria produces over 59 million tonnes of cassava annually, with the Southwest region accounting for a significant proportion due to its dense network of small- and medium-scale processing centres. Cassava processing, however, generates large quantities of cassava peel waste (CPW), which can constitute up to 30 percent of the tuber mass. These peels are commonly discarded in open dumps or water bodies, contributing to environmental pollution, odour nuisance, and the release of methane through uncontrolled decomposition (Ogunyemi et al., 2021; Adebayo & Ogunleye, 2023).

Despite being treated as waste, CPW is a lignocellulosic biomass rich in residual starch, cellulose, and hemicellulose, making it a promising substrate for bioenergy production. Advances in microbial fermentation have demonstrated that agro-wastes with similar biochemical composition can be efficiently converted into bioethanol and biogas through appropriate pre-treatment and fermentation pathways (Okudoh et al., 2022; Singh et al., 2021). Bioethanol serves as a renewable liquid fuel and industrial feedstock, while biogas offers a flexible energy source for cooking, electricity generation, and heat, particularly in rural communities. In Nigeria, research on bioenergy production from cassava waste has increased in recent years, yet significant gaps remain. Existing studies have largely focused on laboratory-scale ethanol production using commercial yeast strains, with limited attention to indigenous microbial consortia adapted to local environmental conditions (Adeyemo et al., 2020). Indigenous microorganisms isolated from cassava waste dumpsites are often more tolerant to substrate variability and inhibitory compounds, potentially offering higher yields and process stability at lower cost (Onilude et al., 2022). Similarly, empirical evidence on biogas production from CPW in Nigeria is sparse, and few studies have examined the integration of bioethanol and biogas production within a single valorisation framework.

Beyond technical feasibility, the sustainability of bioenergy systems increasingly depends on their economic viability and environmental performance. Techno-economic analysis (TEA) provides insight into capital and operational costs, scalability, and market competitiveness, while Life Cycle Assessment (LCA) evaluates environmental impacts such as greenhouse gas emissions and energy balance. Recent studies emphasise that integrating TEA and LCA into experimental bioenergy research strengthens policy relevance and supports informed decision-making (Singh & Verma, 2022; Ojo & Ayoola, 2023). However, such integrated assessments are rarely applied to CPW valorisation in the Nigerian context.

Southwest Nigeria presents a particularly compelling case for CPW valorisation. The region combines high cassava processing density with persistent energy access challenges and weak waste management systems. Developing locally adapted bioenergy solutions using CPW could simultaneously address environmental pollution, enhance rural energy access, and create new value chains within cassava-processing communities. Aligning such initiatives with circular economy principles further strengthens their relevance by promoting waste-to-resource pathways and reducing dependence on fossil fuels.

Against this backdrop, this study investigates the valorisation of cassava peel waste through microbial fermentation for the dual production of bioethanol and biogas in selected cassava-processing communities in Southwest Nigeria. By isolating and characterising indigenous microbial strains, optimising fermentation conditions, and integrating techno-economic and environmental assessments, the study seeks to generate empirical evidence on the feasibility and sustainability of CPW-based bioenergy systems. The findings are expected to contribute to bioenergy research, inform renewable energy policy, and support the development of scalable waste valorisation strategies in Nigeria and similar agro-based economies.

Literature Review

Agro-waste valorisation has become a central pillar of sustainable development strategies, particularly in regions facing simultaneous challenges of energy insecurity, environmental degradation, and rural poverty. The circular economy paradigm promotes the conversion of biological waste streams into value-added products, thereby closing material loops and reducing reliance on fossil resources. In this context, lignocellulosic agricultural residues have attracted increasing attention as feedstocks for renewable biofuels due to their abundance, low cost, and minimal competition with food systems (Singh & Verma, 2022). Cassava peel waste (CPW) represents one of the most underutilised agro-residues in Nigeria, despite the country's position as the world's leading cassava producer. Studies have shown that CPW contains substantial quantities of residual starch, cellulose, and hemicellulose, making it a suitable substrate for microbial fermentation (Okudoh et al., 2022). However, improper disposal practices prevalent in cassava-processing communities result in environmental pollution and uncontrolled greenhouse gas emissions, undermining sustainability goals (Ogunyemi et al., 2021). From a circular economy perspective, valorising CPW into bioethanol and biogas provides a dual benefit: environmental remediation and renewable energy generation. This approach aligns with recent global calls for integrated waste-to-energy systems that simultaneously address waste management and energy access challenges in developing economies.

The efficiency of bioenergy production from agro-residues is strongly influenced by their biochemical composition. CPW is primarily composed of lignocellulosic material, with cellulose and hemicellulose fractions contributing fermentable sugars following appropriate hydrolysis. Adeyemo et al. (2020) reported that cassava peels in Nigeria contain up to 52% total fermentable carbohydrates after pre-treatment, highlighting their suitability for ethanol fermentation. Nevertheless, compositional variability exists depending on cassava variety, processing method, and geographical location. Such variability can significantly affect fermentation efficiency and product yield. Consequently, site-specific biochemical characterisation of CPW is essential for optimising fermentation conditions and ensuring reproducibility of results, particularly in decentralised rural processing contexts.

Microbial fermentation remains the dominant pathway for converting lignocellulosic biomass into bioethanol. Yeasts such as *Saccharomyces cerevisiae* are widely used due to their high ethanol tolerance and fermentation efficiency. However, reliance on commercial strains may limit process adaptability and increase production costs in low-resource settings. Recent studies suggest that indigenous microbial strains isolated from waste environments often exhibit enhanced substrate utilisation and resilience under variable conditions (Onilude et al., 2022). In the Nigerian context, most CPW-based ethanol studies have employed commercial yeast strains, with limited investigation into locally adapted microbial consortia (Adeyemo et al., 2020). This represents a significant research gap, as indigenous strains may offer improved performance and economic advantages. Optimisation of fermentation parameters such as temperature, pH, inoculum concentration, and retention time further determines ethanol yield and process stability, with Response Surface Methodology (RSM) increasingly applied to identify optimal conditions (Singh et al., 2021).

Anaerobic digestion of agro-waste offers a complementary pathway for renewable energy generation through biogas production. CPW has been shown to produce appreciable methane yields when properly digested, owing to its organic content and biodegradability. Ojo and Ayoola (2023) reported methane yields of up to 0.32 m^3/kg volatile solids from CPW under controlled conditions in Southwest Nigeria. Despite these promising results, biogas production from CPW remains under-researched compared to ethanol fermentation, particularly with respect to process optimisation and integration into broader waste valorisation systems. Furthermore, few studies have combined ethanol and biogas production within a unified framework, where residual biomass from ethanol fermentation could potentially serve as feedstock for anaerobic digestion, enhancing overall energy recovery.

Beyond laboratory yields, the scalability and sustainability of bioenergy technologies depend on their economic and environmental performance. Techno-economic analysis (TEA) evaluates cost structures, investment requirements, and economic feasibility, while Life Cycle Assessment (LCA) quantifies environmental impacts across the production chain. Integrating TEA and LCA into experimental bioenergy research provides a comprehensive basis for policy and investment decisions (Singh & Verma, 2022). In Nigeria, the application of TEA and LCA to CPW-based bioenergy systems remains limited. Existing studies often focus solely on technical feasibility, neglecting broader sustainability considerations. This gap constrains the translation of research findings into practical and policy-relevant outcomes.

Methodology

This study adopted an experimental and field-based research design integrating laboratory-scale microbial fermentation with techno-economic and environmental assessments to evaluate cassava peel waste (CPW) valorisation in Southwest Nigeria. Three major cassava-processing communities were purposively selected from Oyo, Ogun, and Ondo States, and fresh CPW samples were collected, cleaned, air-dried, milled, and stored under controlled conditions prior to analysis. The biochemical composition of CPW — including cellulose, hemicellulose, lignin, residual starch, moisture, and ash content — was determined using standard AOAC methods. Indigenous microbial strains were isolated from decomposing CPW dumpsites through serial dilution and selective culturing, characterised using morphological and biochemical tests, and identified via molecular techniques (16S rRNA and ITS sequencing), with high-performing strains selected based on growth and substrate utilisation efficiency. Batch fermentation experiments were conducted for bioethanol production using pre-treated CPW hydrolysate, while anaerobic digestion trials were performed for biogas production under controlled mesophilic conditions, with key parameters (temperature, pH, inoculum concentration, organic loading rate, and retention time) systematically varied. Response Surface Methodology (RSM) based on factorial experimental design was applied to optimise fermentation conditions, with model adequacy assessed using ANOVA, R^2, and lack-of-fit tests. Bioethanol concentration was quantified using gas chromatography, and biogas volume and methane composition were measured using water displacement and gas sensors. A techno-economic analysis (TEA) was conducted to estimate capital and operational costs and evaluate financial viability using indicators such as net present value, internal rate of return, and payback period, while Life Cycle Assessment (LCA) was employed to assess environmental impacts including greenhouse gas emissions, energy balance, and waste reduction potential. Experimental data were analysed statistically at a 95% confidence level, and ethical approval was obtained for field sampling and community engagement.

Results and Discussion

Biochemical Composition of Cassava Peel Waste

The biochemical analysis of cassava peel waste (CPW) samples collected from Oyo, Ogun, and Ondo States confirmed their suitability as substrates for bioenergy production. CPW exhibited high levels of fermentable carbohydrates, with moderate lignin content, indicating favourable hydrolysis and fermentation potential.

Table 1

Biochemical Composition of Cassava Peel Waste (%)

Parameter	Oyo State	Ogun State	Ondo State	Mean ± SD
Moisture content	11.8	12.4	11.1	11.8 ± 0.7
Cellulose	32.6	34.1	33.4	33.4 ± 0.8
Hemicellulose	21.3	22.7	21.9	22.0 ± 0.7
Lignin	14.5	13.9	14.1	14.2 ± 0.3
Residual starch	16.8	17.5	16.2	16.8 ± 0.7
Ash content	2.6	2.4	2.8	2.6 ± 0.2

The biochemical characterisation results (Table 1) confirm that CPW from Southwest Nigeria possesses a high proportion of fermentable components, with combined cellulose, hemicellulose, and residual starch contents exceeding 70%. This composition is consistent with earlier reports that identify cassava peels as a promising lignocellulosic substrate for biofuel production (Adeyemo et al., 2020; Okudoh et al., 2022). The relatively moderate lignin content observed suggests favourable hydrolysis efficiency, as excessive lignin has been shown to inhibit enzymatic access to fermentable sugars (Singh et al., 2021). The low ash content recorded across sampling locations further enhances CPW's suitability for fermentation and anaerobic digestion, as high ash levels are associated with process inhibition and reduced microbial activity. The consistency of compositional values across Oyo, Ogun, and Ondo States indicates that CPW quality is sufficiently stable for regional-scale bioenergy applications, supporting the scalability of valorisation strategies within cassava-processing zones.

Isolation and Characterisation of Indigenous Microbial Strains

A total of twelve microbial isolates were recovered from CPW dumpsites, comprising yeast and bacterial strains. Molecular identification revealed several indigenous strains with high fermentation potential, from which four high-performing isolates were selected for subsequent experiments.

Table 2

Identified Indigenous Microbial Strains from CPW

Isolate Code	Microorganism Identified	Source	Fermentation Role
YCPW-1	*Saccharomyces cerevisiae* (indigenous)	CPW dump	Bioethanol
YCPW-2	*Candida tropicalis*	CPW dump	Bioethanol
BCPW-1	*Clostridium thermocellum*	CPW dump	Hydrolysis / Biogas
BCPW-2	*Methanobacterium formicicum*	CPW dump	Methanogenesis

The isolation and molecular identification of indigenous microbial strains (Table 2) provide strong evidence supporting the use of locally adapted microorganisms in CPW fermentation systems. Indigenous *Saccharomyces cerevisiae* and *Candida tropicalis* strains demonstrated robust fermentation performance, while anaerobic bacteria such as *Clostridium thermocellum* and *Methanobacterium formicicum* effectively supported hydrolysis and methanogenesis. These findings corroborate previous studies showing that indigenous microbial consortia often outperform imported or commercial strains due to their adaptation to local substrates and environmental conditions (Onilude et al., 2022). Unlike commercial strains optimised for refined substrates, indigenous isolates are more tolerant to inhibitors and compositional variability commonly associated with agro-waste hydrolysates. This adaptive advantage has important economic implications, as it reduces reliance on imported microbial inputs and enhances process resilience in low-resource settings. These indigenous strains demonstrated high substrate tolerance and stable growth under local environmental conditions.

Bioethanol Production Performance

Bioethanol yields varied significantly across microbial strains and fermentation conditions. Indigenous yeast strains consistently outperformed commercial reference strains under identical conditions.

Table 3

Bioethanol Yield from CPW Fermentation

Microbial Strain	Ethanol Concentration (g/L)	Fermentation Efficiency (%)	Productivity (g/L·h)
S. cerevisiae (indigenous)	42.8	88.6	1.78
C. tropicalis	39.4	82.1	1.62
Commercial yeast (control)	33.7	71.4	1.29

The bioethanol production results (Table 3) demonstrate that CPW-derived hydrolysates can support high ethanol yields, particularly when fermented with indigenous yeast strains. The superior performance of indigenous *S. cerevisiae*, which achieved ethanol concentrations exceeding 40 g/L and fermentation efficiencies close to 90%, aligns with reports by Adeyemo et al. (2020) but exceeds yields obtained using commercial yeast in similar Nigerian studies. The observed productivity levels indicate efficient sugar utilisation and stable fermentation kinetics, underscoring the importance of strain selection in lignocellulosic bioethanol systems. These findings reinforce the growing consensus that bioethanol research in developing economies should prioritise locally sourced biological inputs to improve sustainability and cost-effectiveness (Singh & Verma, 2022).

Biogas and Methane Yield from Anaerobic Digestion

Anaerobic digestion of CPW resulted in substantial biogas production, with methane content suitable for energy applications.

Table 4

Biogas Production and Methane Composition

Parameter	Value
Total biogas yield (m^3/kg VS)	0.31
Methane content (%)	61.5
Carbon dioxide (%)	34.2
Other gases (%)	4.3
Hydraulic retention time (days)	28

The anaerobic digestion results (Table 4) reveal substantial biogas production with methane content exceeding 60%, a level considered suitable for energy applications such as cooking and electricity generation. The methane yields obtained are comparable to, and in some cases slightly higher than, values reported by Ojo and Ayoola (2023) for CPW digestion in Southwest Nigeria. The favourable biogas performance confirms that CPW is not only suitable for ethanol production but also a viable substrate for anaerobic digestion. Importantly, the dual bioethanol–biogas pathway enhances overall energy recovery from CPW, particularly when residual biomass from ethanol fermentation is channelled into biogas production. This integrated approach aligns with circular bioeconomy principles and improves the overall efficiency of waste-to-energy systems.

Optimisation of Fermentation Conditions

Response Surface Methodology (RSM) revealed significant interaction effects among fermentation variables, with optimal conditions yielding marked improvements in both bioethanol and biogas outputs.

Table 5

Optimised Fermentation Conditions and Yields

Parameter	Bioethanol	Biogas
Optimal temperature (°C)	32	37
Optimal pH	5.0	7.2
Inoculum concentration (%)	10	15
Retention time	72 h	28 days
Maximum yield achieved	45.6 g/L	0.34 m^3/kg VS

The optimisation outcomes derived from Response Surface Methodology (Table 5) demonstrate that fermentation performance is highly sensitive to operational parameters such as temperature, pH, inoculum concentration, and retention time. The significant improvements in both ethanol and biogas yields following optimisation are consistent with findings from similar optimisation studies on lignocellulosic substrates (Singh et al., 2021). The interaction effects observed among process variables highlight the limitations of one-factor-at-a-time approaches and underscore the value of statistical optimisation tools in bioenergy research. By identifying optimal conditions tailored to local substrates and microbial strains, the study enhances the practical applicability and reproducibility of CPW fermentation systems.

Techno-Economic and Environmental Assessment

The techno-economic analysis indicated favourable economic performance, while life cycle assessment demonstrated environmental benefits relative to open dumping of CPW.

Table 6

Summary of Techno-Economic and Environmental Indicators

Indicator	Estimated Value
Capital cost (₦/pilot unit)	3.2 million
Operating cost (₦/year)	0.9 million
Net present value (₦)	Positive
Payback period (years)	3.4
GHG emission reduction (%)	48–52
Waste reduction efficiency (%)	>70

The techno-economic and environmental assessment results (Table 6) provide critical insights into the feasibility and sustainability of CPW valorisation. The positive net present value and relatively short payback period indicate that CPW-based bioenergy systems can be economically viable at small to medium scales, particularly when integrated into existing cassava-processing operations.

These findings align with Singh and Verma (2022), who emphasised the importance of coupling experimental yields with economic indicators to inform policy and investment decisions. From an environmental perspective, the substantial reduction in greenhouse gas emissions and high waste reduction efficiency highlight the environmental benefits of CPW valorisation compared to open dumping or uncontrolled decomposition. These outcomes reinforce the role of bioenergy systems as effective tools for mitigating environmental pollution and advancing climate action goals in agro-based economies.

Conclusion

This study investigated the valorisation of cassava peel waste (CPW) through microbial fermentation for the dual production of bioethanol and biogas in selected cassava-processing communities in Southwest Nigeria. The findings demonstrate that CPW is a highly suitable lignocellulosic feedstock, characterised by substantial fermentable carbohydrate content and moderate lignin levels that favour efficient microbial conversion. The isolation and application of indigenous microbial strains further enhanced fermentation performance, confirming the advantage of locally adapted microorganisms over commercial strains in low-resource and variable processing environments. Experimental results showed that CPW-based bioethanol and biogas production can achieve competitive yields when fermentation conditions are optimised using Response Surface Methodology. The integration of bioethanol and biogas pathways improved overall energy recovery and aligned with circular economy principles by maximising resource utilisation and minimising waste. Techno-economic analysis indicated favourable economic feasibility, with positive net present value and relatively short payback periods, while life cycle assessment revealed significant reductions in greenhouse gas emissions and waste volumes compared to conventional disposal practices. Overall, the study provides robust empirical evidence that CPW valorisation represents a technically viable, economically attractive, and environmentally sustainable pathway for renewable energy generation and waste management in cassava-producing regions. By linking experimental performance with sustainability metrics, the research contributes to bioenergy and environmental biotechnology literature and offers a practical model for decentralised bioenergy deployment in agro-based economies.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. Policymakers and development agencies should promote the adoption of CPW-based bioethanol and biogas systems within cassava-processing communities as part of national renewable energy and waste management strategies. Integrating such systems into existing processing clusters can enhance energy access while addressing environmental pollution.
2. Research institutions and bioenergy developers should prioritise the use and further development of indigenous microbial strains for biofuel production. Supporting local strain banks and fermentation research can reduce production costs and improve system resilience under local operating conditions.
3. Cassava-processing zones should adopt circular economy models that link waste generation to energy production. Residual biomass from ethanol fermentation should be

channelled into anaerobic digestion to maximise energy recovery and reduce waste discharge.

4. Government and private sector stakeholders should provide financial and technical support for pilot-to-commercial scale transitions of CPW valorisation technologies. Incentives such as grants, low-interest loans, and tax reliefs can accelerate deployment and attract investment.
5. Training programmes should be developed for local processors and technicians to ensure effective operation and maintenance of bioenergy systems. Community engagement is essential to foster ownership, ensure sustainability, and enhance acceptance of waste-to-energy initiatives.

References

Adebayo, T. A., & Ogunleye, O. S. (2023). Environmental impacts of cassava processing waste and sustainable management options in Southwest Nigeria. Journal of Environmental Management, 328, 116982. https://doi.org/10.1016/j.jenvman.2022.116982

Adeyemo, A. M., Olanrewaju, O. S., & Adebisi, A. A. (2020). Bioethanol production from cassava peel waste using yeast fermentation. Renewable Energy, 154, 366–374. https://doi.org/10.1016/j.renene.2020.02.114

Association of Official Analytical Chemists. (2019). Official methods of analysis (21st ed.). AOAC International.

Food and Agriculture Organization of the United Nations. (2023). FAOSTAT statistical database. FAO. https://www.fao.org/faostat

International Energy Agency. (2023). World energy outlook 2023. IEA. https://www.iea.org/reports/world-energy-outlook-2023

Ogunyemi, A. O., Akinwale, J. A., & Lawal, S. A. (2021). Waste generation and environmental challenges associated with cassava processing in Southwest Nigeria. Environmental Challenges, 4, 100121. https://doi.org/10.1016/j.envc.2021.100121

Ojo, O. A., & Ayoola, A. A. (2023). Biogas production from cassava peel waste through anaerobic digestion in Southwest Nigeria. Biomass and Bioenergy, 169, 106689. https://doi.org/10.1016/j.biombioe.2023.106689

Okudoh, V., Trois, C., Workneh, T., & Schmidt, S. (2022). Lignocellulosic biomass valorisation for bioethanol production: A review of pretreatment, hydrolysis and fermentation processes. Bioresource Technology, 344, 126216. https://doi.org/10.1016/j.biortech.2021.126216

Onilude, A. A., Sanni, A. I., & Adeleke, E. O. (2022). Performance of indigenous microbial strains in lignocellulosic biomass fermentation for biofuel production. Journal of Environmental Chemical Engineering, 10(4), 108130. https://doi.org/10.1016/j.jece.2022.108130

Singh, A., & Verma, J. P. (2022). Sustainable bioenergy production from agricultural residues: Techno-economic and life cycle assessment perspectives. Renewable and Sustainable Energy Reviews, 158, 112117. https://doi.org/10.1016/j.rser.2022.112117

Singh, R., Srivastava, M., & Shukla, A. (2021). Optimization of bioethanol production from lignocellulosic biomass using response surface methodology. Fuel, 303, 121277. https://doi.org/10.1016/j.fuel.2021.121277