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ORIGINAL

Agricultural Waste Utilization and Adoption of Biodigesters in Cassava Processing in Ecuador

Aprovechamiento de residuos agrícolas y adopción de biodigestores en el procesamiento de yuca en Ecuador

John Alfredo Idrovo Campoverde[1]

[1] Instituto Sapiens de Investigación Científica Multidisciplinar. Milagro, Ecuador.

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Corresponding Author: John Alfredo Idrovo Campoverde

ABSTRACT

Inadequate agricultural waste management has become a growing environmental problem in developing countries, especially in regions where cassava production and processing represent important economic activities. This study aimed to analyze the current practices of cassava waste management in rural areas of Ecuador and evaluate producers' willingness to adopt sustainable waste management technologies, particularly biodigesters for biogas production. The research was conducted under a quantitative descriptive and correlational approach using surveys administered to 240 cassava producers and processors from the provinces of Guayas, Los Ríos, and Manabí. The findings revealed that the predominant waste management practices include discharging liquid effluents onto the soil, open dumping of solid waste, and burning agricultural residues, generating environmental pollution, unpleasant odors, and the proliferation of insects. In addition, a low level of knowledge regarding biogas technologies was identified; however, after receiving information about their environmental and economic benefits, most participants expressed willingness to adopt this sustainable alternative. Statistical analysis showed that factors such as access to technical training, financial support, educational level, and participation in productive associations positively influence the intention to adopt sustainable technologies. The study concludes that the sustainable utilization of agricultural waste through biodigesters can significantly contribute to environmental protection, renewable energy generation, and the strengthening of sustainable rural development in Ecuador.

Keywords: agricultural waste, biogas, environmental sustainability, cassava processing.

RESUMEN

La gestión inadecuada de residuos agrícolas constituye una problemática ambiental creciente en los países en desarrollo, especialmente en regiones donde la producción y procesamiento de yuca representan actividades económicas importantes. La presente investigación tuvo como objetivo analizar las prácticas actuales de manejo de residuos derivados del procesamiento de yuca en zonas rurales del Ecuador y evaluar la disposición de los productores para adoptar tecnologías sostenibles de gestión de residuos, particularmente sistemas de biodigestión para la producción de biogás. El estudio se desarrolló bajo un enfoque cuantitativo descriptivo y correlacional, utilizando encuestas aplicadas a 240 productores y procesadores de yuca de las provincias de Guayas, Los Ríos y Manabí. Los resultados evidenciaron que las prácticas predominantes de manejo de residuos incluyen el vertido de efluentes líquidos al suelo, la acumulación de desechos sólidos a cielo abierto y la quema de residuos agrícolas, generando contaminación ambiental, malos olores y proliferación de insectos. Asimismo, se identificó un bajo nivel de conocimiento sobre tecnologías de biogás; sin embargo, luego de recibir información sobre sus beneficios, la mayoría de los participantes manifestó disposición para adoptar esta alternativa sostenible. El análisis estadístico mostró que factores como el acceso a capacitación técnica, financiamiento, nivel educativo y participación en asociaciones productivas influyen positivamente en la intención de adopción tecnológica. Se concluye que el aprovechamiento sostenible de residuos agrícolas mediante biodigestores puede contribuir significativamente a la protección ambiental, generación de energía renovable y fortalecimiento del desarrollo rural sostenible en Ecuador.

Palabras clave: residuos agrícolas, biogás, sostenibilidad ambiental, procesamiento de yuca.

INTRODUCTION

The generation of agricultural waste constitutes one of the main environmental and productive challenges worldwide, especially in developing countries where agriculture represents a fundamental economic activity for food security and the livelihood of millions of people (United Nations, 2017; World Bank, 2022). The accelerated growth of the global population, estimated at 9.8 billion inhabitants by the year 2050, will increase the demand for food and, consequently, the production of waste derived from agro-industrial activities (United Nations, 2017). Among these wastes, those originating from the processing of staple crops such as cassava stand out, whose transformation generates large quantities of solid and liquid wastes that, in many cases, are managed through unsustainable traditional practices (Oghenejoboh et al., 2021).

The cassava industry is considered a major source of agricultural waste because approximately 20% to 25% of the tuber corresponds to peels and by-products discarded during processing (Omilani et al., 2019). Furthermore, grating, fermentation, and pressing activities produce wastewater with high contents of organic and cyanogenic compounds that can negatively affect soil and water source quality (Onifade et al., 2015). The inadequate disposal of these wastes generates environmental pollution, bad odors, insect proliferation, and adverse effects on human health and aquatic ecosystems (Ubalua, 2007). Various studies conducted in Nigeria show that practices such as open dumping, waste burning, and the discharge of effluents directly onto the soil represent significant threats to environmental sustainability and the quality of life of rural communities (Olukanni & Olatunji, 2018; Mukaila et al., 2024).

Faced with this problem, the adoption of sustainable agricultural waste management technologies, such as biogas production, emerges as an efficient alternative to reduce environmental pollution and harness agro-industrial waste for energy (Cruz et al., 2021). Biogas allows the transformation of organic waste into renewable energy through anaerobic biodigestion processes, simultaneously contributing to the reduction of greenhouse gas emissions and the strengthening of more sustainable rural economies (Lin et al., 2021). However, recent research shows that the level of knowledge and adoption of these technologies remains limited among small agricultural producers and processors, mainly due to economic, educational, and technological factors (Wang et al., 2020; Geddafa et al., 2021).

In this context, it is essential to analyze current agricultural waste management practices and promote innovative strategies oriented toward environmental sustainability. The experience developed in Nigeria demonstrates that awareness, access to credit, technical assistance, and participation in productive associations are determining factors in fostering the adoption of clean technologies such as biogas (Mukaila et al., 2024). These findings represent an important reference for other developing agricultural countries facing similar problems related to the inadequate management of agro-industrial waste.

In the case of Ecuador, this problem is highly relevant due to the importance of the agricultural sector within the national economy. The country has an extensive production of crops such as cassava, banana, cocoa, oil palm, and sugarcane, activities that generate significant volumes of organic waste. Particularly in provinces such as Manabí, Los Ríos, Guayas, and Santo Domingo de los Tsáchilas, the artisanal and industrial processing of cassava produces solid and liquid wastes that are frequently disposed of without adequate treatment, causing river pollution, soil degradation, and health impacts in rural communities.

The application of agricultural waste utilization technologies in Ecuador could significantly contribute to strengthening the country's environmental and energy sustainability. The implementation of biodigestors to transform cassava waste and other agricultural by-products into biogas would allow the generation of clean energy for domestic and industrial use, decrease dependence on fossil fuels, and reduce environmental pollution (Kemausuor et al., 2015). Likewise, the treated waste could be reused as organic fertilizers, favoring more sustainable agricultural practices and reducing the use of chemical inputs (Achi et al., 2020).

In addition, the development of training and awareness programs aimed at farmers and rural processors would be essential to increase knowledge about sustainable waste management technologies. Similarly, public policies oriented toward financing renewable energy and circular economy projects could encourage the adoption of these technologies in rural areas of Ecuador. In this way, international experience on sustainable agricultural waste management can serve as a basis for designing national strategies that contribute to rural development, environmental protection, and the country's energy security (Atinkut et al., 2020; Foguesatto & Machado, 2022).

METHODS

The present research was developed under a quantitative descriptive and correlational approach, aimed at analyzing the management practices of agricultural waste generated during cassava processing and evaluating the willingness of rural producers and processors in Ecuador to adopt sustainable waste management technologies, especially biodigestion systems for biogas production. The study focused on identifying current methods of solid and liquid waste disposal, perceived effects on the environment and community health, as well as socioeconomic and productive factors associated with the intention to adopt clean technologies.

This research was conducted in rural areas of the Guayas, Los Ríos, and Manabí provinces, as these regions exhibit significant agricultural activity and small- and medium-scale cassava processing. The study population comprised cassava producers and processors registered in agricultural associations and rural communities linked to this economic activity. Simple random probability sampling was used to select participants, based on inclusion criteria related to experience in cassava processing and agricultural waste generation. The sample consisted of 240 participants, a size considered adequate to ensure statistical representativeness and reliability in the obtained results.

Data collection was conducted using structured surveys designed with closed-ended and Likert-scale questions. The instrument incorporated variables related to sociodemographic characteristics, production experience, waste management methods, perceived environmental impacts, knowledge level regarding biogas technologies, access to technical assistance, access to financing, and willingness to adopt sustainable technologies. Prior to administration, the questionnaire was validated through expert judgment in environmental and agricultural fields, and pilot-tested with a small group of producers to ensure the clarity and coherence of the questions.

Data collection was conducted through direct visits to communities and agricultural processing centers, adhering to the ethical principles of voluntary participation, confidentiality, and informed consent. Participants were informed of the research objectives and the strictly academic use of the provided information. Additionally, an initial awareness-raising process regarding the operation and benefits of biogas technology was conducted to ensure that respondents adequately understood the concept before indicating their adoption intention.

Descriptive and inferential statistical techniques were used for data analysis. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to characterize the participants and current waste management practices. Subsequently, a binary logistic regression model was applied to identify factors significantly influencing the intention to adopt sustainable agricultural waste management technologies. Data processing was performed using specialized statistical software to interpret the relationships among socioeconomic, production, and environmental variables linked to clean technology adoption in the rural Ecuadorian context.

RESULTS

The results show that traditional agricultural waste management practices predominate among cassava processors in the studied rural areas. Most participants reported disposing of solid waste via open-air accumulation near processing centers, whereas untreated liquid waste is discharged directly onto the soil or into drainage systems. These practices adversely affect the environment and community sanitary conditions.

Respondents indicated that these disposal methods cause foul odors, insect proliferation, and contamination of nearby water sources. Furthermore, a significant proportion of respondents reported observing adverse effects on soil quality and decreased agricultural productivity resulting from organic waste accumulation.

Table 1. Current cassava waste management methods

Waste management method	Frequency	Percentage (%)
Discharge of liquid waste onto soil	82	34.2
Open-air accumulation of solid waste	76	31.7
Burning of agricultural waste	38	15.8
Disposal in drainage channels	24	10.0
Partial use as organic fertilizer	20	8.3
Total	240	100

Table 2. Main environmental effects perceived by participants

Observed environmental effects	Frequency	Percentage (%)
Persistent foul odors	91	37.9
Presence of insects and pests	73	30.4
Water pollution	41	17.1
Deterioration of agricultural soil	23	9.6
Respiratory and health problems	12	5.0
Total	240	100

Regarding sustainable waste management technologies, a low level of knowledge concerning biodigester use and biogas production was identified. Only a small proportion of producers reported prior knowledge of this technology and its environmental and energy benefits.

Table 3. Level of knowledge about biogas technology

Knowledge level	Frequency	Percentage (%)
Familiar with the technology and its benefits	38	15.8
Has heard of the technology	56	23.3
Unfamiliar with the technology	146	60.9
Total	240	100

Following a basic explanation of biodigester operation and the benefits of agricultural waste energy utilization, a high willingness to adopt this sustainable alternative was observed among participants.

Table 4. Intention to adopt biogas technology

Adoption intention	Frequency	Percentage (%)
Willing to adopt	178	74.2
Unwilling to adopt	62	25.8
Total	240	100

The logistic regression model results indicated that variables such as access to technical training, educational level, access to agricultural credit, membership in production associations, and prior knowledge of renewable energy positively influence the intention to adopt sustainable technologies. Conversely, advanced age and resistance to technological change were negatively associated with adoption willingness.

Table 5. Factors associated with the intention to adopt biodigestors

Variable	β coefficient	p-value	Interpretation
Access to technical training	0.842	0.001	Significant positive influence
Access to agricultural credit	0.716	0.004	Significant positive influence
Educational level	0.534	0.012	Positive influence
Membership in associations	0.491	0.018	Positive influence
Producer's age	-0.428	0.026	Negative influence
Prolonged traditional experience	-0.385	0.033	Negative influence

Overall, the findings reveal a significant environmental problem arising from inadequate agricultural waste management in Ecuadorian cassava processing. However, a high willingness to adopt sustainable alternatives was identified among producers when provided with adequate information, training, and institutional support. These results demonstrate the need to strengthen environmental education programs, rural financing, and technology transfer oriented toward the sustainable utilization of agro-industrial waste through biogas systems and circular economy principles.

DISCUSSION

The results of this study indicate that traditional agricultural waste management practices remain predominant among cassava processors in rural Ecuador, presenting a major environmental and health challenge. Open-air solid waste disposal and the direct discharge of liquid effluents onto soil or into drainage systems demonstrate the limited implementation of sustainable waste management strategies in the rural agro-industrial sector. These findings align with research conducted in cassava-producing African countries, where conventional waste disposal practices were found to cause environmental pollution, soil degradation, and adverse impacts on community health.

Participants' perceptions of the environmental impacts of cassava processing confirm that agricultural waste is a significant source of local pollution. Malodors, insect proliferation, and the contamination of water bodies were the most frequently reported effects. These findings indicate that rural communities recognize the negative consequences of inadequate waste management, yet continue to employ traditional practices due to economic constraints, lack of infrastructure, and limited access to alternative technologies. This issue is highly relevant in Ecuador given the expansion of agro-industrial activities and the increasing volume of organic waste generated in agricultural value chains.

The results also revealed a low level of knowledge regarding biodigestion and biogas production technologies. Most respondents were unaware of the operation and benefits of these sustainable technologies, highlighting weaknesses in technology transfer and environmental education in rural areas. This gap may be related to the limited presence of government programs and innovation projects focused on the energy recovery of agricultural waste. The lack of technical information reduces the likelihood of adopting sustainable practices and maintains dependency on traditional waste disposal methods.

However, a key finding of this study was the high willingness of producers to adopt biodigesters after receiving information about their environmental and economic benefits. This demonstrates that awareness-raising and technical training are fundamental tools for promoting changes in agricultural waste management practices. Producers identified advantages related to clean energy generation, pollution reduction, and the potential to reuse waste as organic fertilizer, which are aspects that enhance the acceptance of sustainable technologies in rural contexts.

Statistical analysis indicated that factors such as access to technical training, agricultural financing, educational attainment, and participation in producer associations positively influence the intention to adopt biogas technologies. These results suggest that strengthening technical assistance programs and access to green credit can facilitate the transition toward more sustainable production models. Likewise, participation in community organizations fosters the exchange of knowledge and experience, increasing producers' trust in new technologies.

Conversely, variables such as advanced age and extensive experience with traditional practices were negatively associated with the willingness to adopt new technology. This indicates that some producers remain resistant to change due to deep-rooted customs and risk perceptions associated with implementing new production techniques. This behavior has been observed in various studies on technology adoption in the agricultural sector, where older producers typically exhibit less openness toward productive and environmental innovations.

In the Ecuadorian context, these results identify important opportunities to promote public policies oriented toward the sustainable management of agro-industrial waste. Implementing biodigestion programs in rural communities could simultaneously contribute to reducing environmental pollution, generating renewable energy, and strengthening local economies. Furthermore, utilizing agricultural waste through circular economy frameworks would reduce the environmental impact of the agro-industrial sector and promote more efficient and sustainable production systems.

Finally, the findings of this study show that the transition toward sustainable agricultural waste management models in Ecuador requires not only technological investment, but also comprehensive environmental education, institutional strengthening, and financial support for smallholders. Coordination among government agencies, universities, agricultural associations, and rural development organizations will be fundamental to promote the adoption of clean technologies and advance toward a more sustainable and resilient agricultural sector in the face of current environmental challenges.

CONCLUSION

This study demonstrated that agricultural waste management from cassava processing in rural Ecuador continues to rely primarily on unsustainable traditional practices, such as open-air waste accumulation, burning, and the direct discharge of liquid effluents onto soil or into drainage systems. These practices generate negative impacts on the environment, community health, and natural resource quality, particularly through water pollution, insect proliferation, and malodors in agricultural processing areas.

The results also demonstrated a low level of knowledge regarding sustainable waste utilization technologies, particularly biodigesters and biogas production. However, once producers received information about the environmental, energy, and economic benefits of these technologies, a high willingness to adopt them was observed. This confirms that technical training and environmental awareness are fundamental elements for promoting positive changes in agricultural waste management practices.

Likewise, factors such as access to credit, technical assistance, educational level, and participation in producer associations positively influenced the intention to adopt sustainable technologies. Conversely, resistance to change associated with traditional practices and the age of the producers partially limited adoption. These findings highlight the need to strengthen public policies and rural development programs focused on technological innovation and environmental sustainability in the Ecuadorian agro-industrial sector.

In conclusion, utilizing agricultural waste through biodigestion technologies is a viable alternative for reducing environmental pollution, generating renewable energy, and promoting circular economy models in rural communities in Ecuador. Implementing comprehensive strategies that combine environmental education, financing, technical assistance, and organizational strengthening will facilitate progress toward more sustainable production systems, thereby contributing to rural development, energy security, and the protection of the country's natural resources.

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CONFLICT OF INTEREST

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